Aerospace Blockset™

User's Guide

MATLAB® & SIMULINK®

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Aerospace Blockset™ User's Guide

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Getting Started

Aerospace Blockset Product Description

Model, simulate, and analyze aerospace vehicle dynamics

Aerospace Blockset provides Simulink® blocks for modeling, simulating, and analyzing aerospace vehicles. You can incorporate vehicle dynamics, validated models of the flight environment, and pilot behavior, and then connect your model to the FlightGear Flight Simulator to visualize simulation results.

With Aerospace Blockset you can use aerodynamic coefficients or Data Compendium (Datcom) derivatives to model fixed-wing, rotary-wing, and multirotor vehicles. Prebuilt component libraries let you design GNC algorithms and model actuator dynamics and the propulsion subsystem. Built-in aerospace math operations and coordinate system and spatial transformations let you describe the behavior of three-degrees-of-freedom (3DOF) and six-degrees-of-freedom (6DOF) bodies.

The blockset includes validated environment models for atmosphere, gravity, wind, geoid height, and magnetic field to represent flight conditions and increase simulation fidelity. Flight control analysis tools let you analyze the dynamic response and flying qualities of aerospace vehicles. To complete your analysis, you can visualize the vehicle in flight directly from Simulink with standard cockpit instruments and using the prebuilt FlightGear Flight Simulator interface.

Key Features

- Equations of motion with fixed or variable mass, including 3DOF and 6DOF
- Built-in axis transformations for body, wind, and geodetic coordinates, including earth-centered / earth-fixed (ECEF) and earth-centered inertial (ECI)
- Validated environment models, including gravity, atmosphere, wind, geoid height, magnetic field, and planetary ephemerides
- Prebuilt aerospace vehicle components, including sensor and controller designs for GNC and propulsion, actuators, and pilot models
- Flight control analysis tools for studying a vehicle's dynamic response and flying qualities
- 3D animations and flight instruments for visualizing navigation variables
- Data Compendium (Datcom) derivatives for aerodynamic forces and moments

Code Generation Support

Use the Aerospace Blockset software with the Simulink Coder software to automatically generate code for real-time execution in rapid prototyping and for hardware-in-the-loop systems.

Support for Aerospace Toolbox Quaternion Functions

The Aerospace Blockset product supports the following Aerospace Toolbox quaternion functions in the MATLAB Function block:

```
quatconj
quatinv
quatmod
quatmultiply
quatdivide
quatnorm
quatnormalize
```

For further information on using the MATLAB Function block, see:

- “Implementing MATLAB Functions Using Blocks” (Simulink)
- `asbQuatEML` example, which illustrates quaternions and models the equations

Explore the NASA HL-20 Model

In this section...

Introduction

This section introduces a NASA HL-20 lifting body airframe model that uses blocks from the Aerospace Blockset software to simulate the airframe of a NASA HL-20 lifting body, in conjunction with other Simulink blocks.

The model simulates the NASA HL-20 lifting body airframe approach and landing flight phases using an automatic-landing controller.

For more information on this model, see "NASA HL-20 Lifting Body Airframe" on page 3-18.

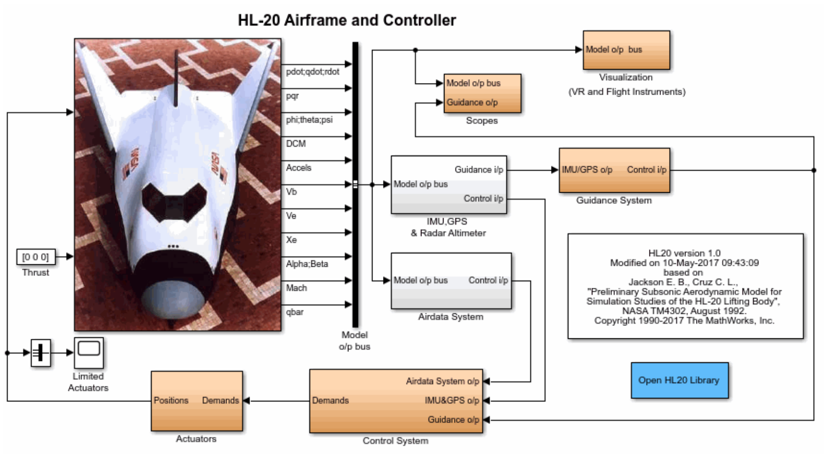
What This Example Illustrates

The NASA HL-20 lifting body airframe example illustrates the following features of the blockset:

- Representing bodies and their degrees of freedom with the Equations of Motion library blocks
- Using the Aerospace Blockset blocks with other Simulink blocks
- Feeding Simulink signals to and from Aerospace Blockset blocks with Actuator and Sensor blocks
- Encapsulating groups of blocks into subsystems
- Visualizing an aircraft with Simulink 3D Animation™ and Aerospace Blockset Flight Instrument library blocks.

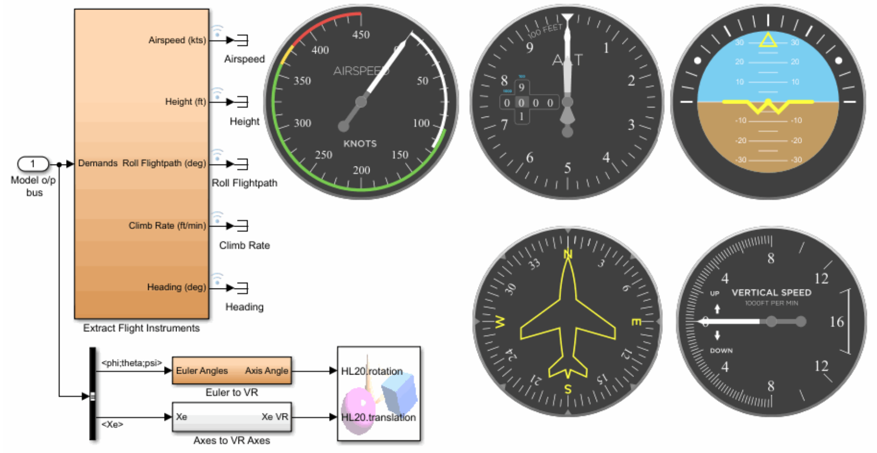
Open the Model

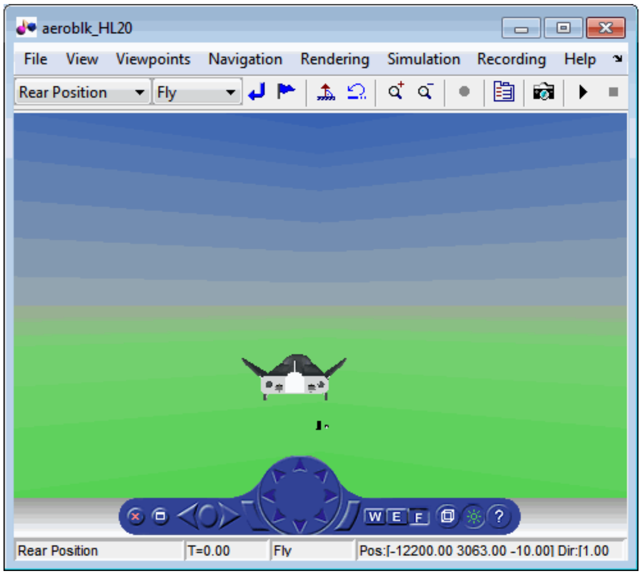
To open the NASA HL-20 airframe example, type the example name, `aeroblk_HL20`, at the MATLAB® command line. The model opens.



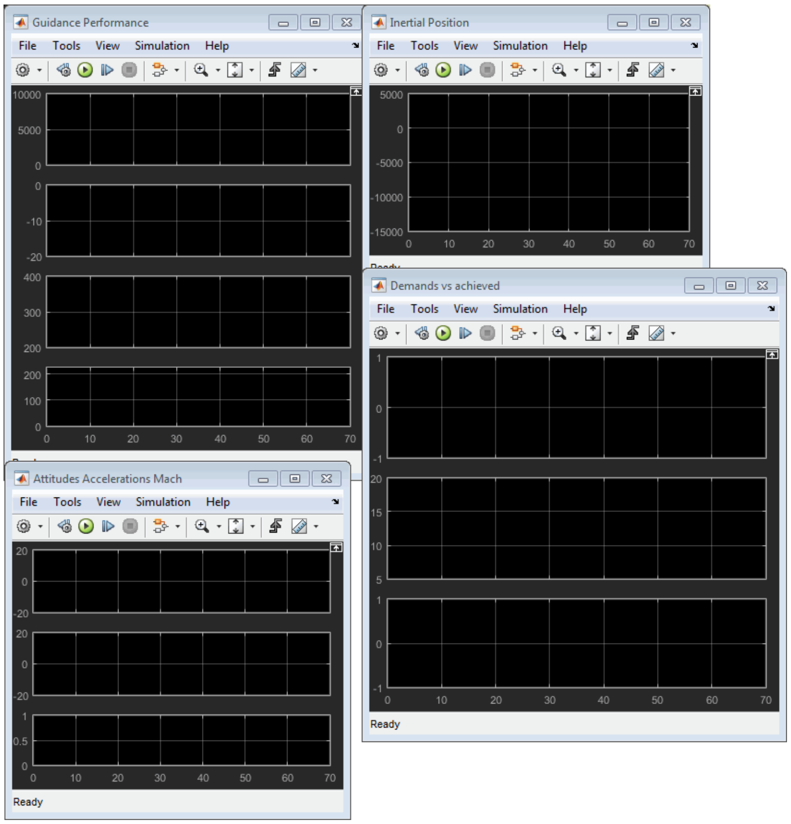
HL20 version 1.0
Modified on 10-May-2017 09:43:09
based on
Jackson E. B., Cruz C. L.,
"Preliminary Subsonic Aerodynamic Model for Simulation Studies of the HL-20 Lifting Body",
NASA TM4302, August 1992.
Copyright 1990-2017 The MathWorks, Inc.

The visualization subsystem, four scopes, and a Simulink 3D Animation viewer for the airframe might also appear.




aeroblk_HL20
File View Viewpoints Navigation Rendering Simulation Recording Help
Rear Position
Fly
W E F

Rear Position T=0.00 Fly Pos:[-12200.00 3063.00 -10.00] Dir:[1.00



Key Subsystems

The model implements the airframe using the following subsystems:

- The 6DOF (Euler Angles) subsystem implements the 6DOF (Euler Angles) block along with other Simulink blocks.
- The Environment Models subsystem implements the WGS84 Gravity Model and COESA Atmosphere Model blocks. It also contains a Wind Models subsystem that implements a number of wind blocks.
- The Alpha, Beta, Mach subsystem implements the Incidence, Sideslip & Airspeed, Mach Number, and Dynamic Pressure blocks. These blocks calculate aerodynamic coefficient values and lookup functionality.

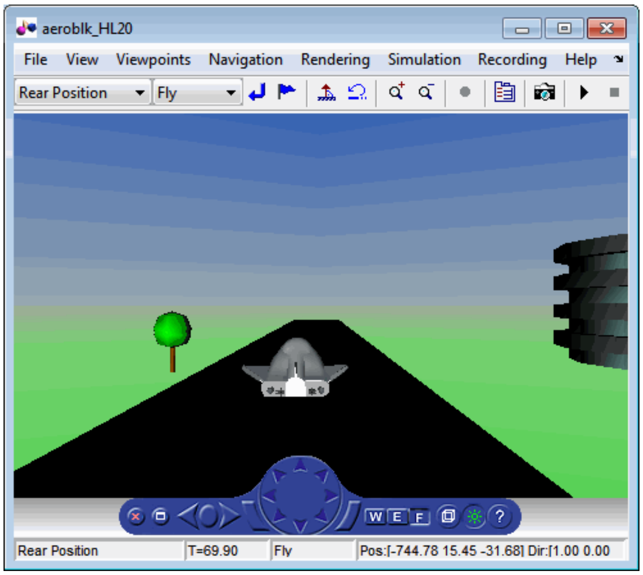
- The Forces and Moments subsystem implements the Aerodynamic Forces and Moments block. This subsystem calculates body forces and body moments.
- The Aerodynamic Coefficients subsystem implements several subsystems to calculate six aerodynamic coefficients.

NASA HL-20 Example

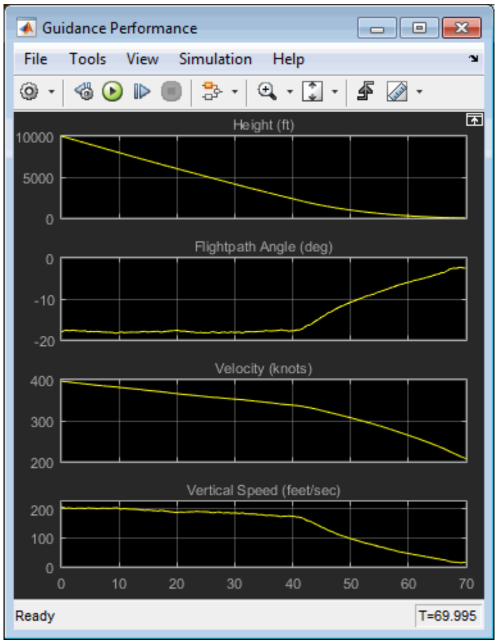
Running an example lets you observe the model simulation in real time. After you run the example, you can examine the resulting data in plots, graphs, and other visualization tools. To run this model, follow these steps:

1. If it is not already open, open the `aeroblk_HL20` example.
2. From the **Simulation** menu, select **Start**. On Microsoft® Windows® systems, you can also click the **Start** button in the model window toolbar.

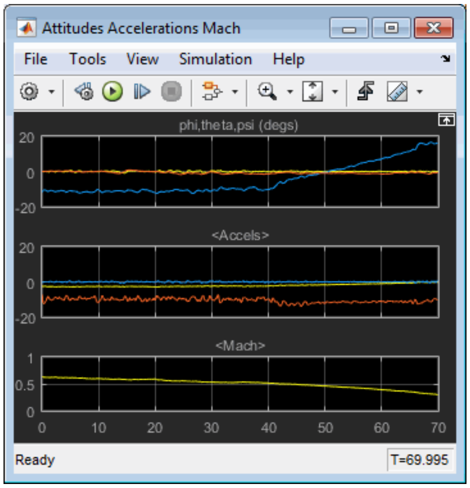
   The simulation proceeds until the aircraft lands:



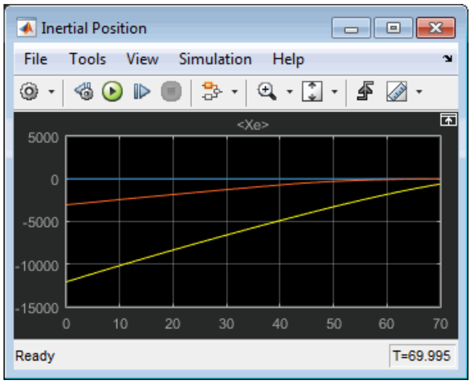
View of the landed airframe



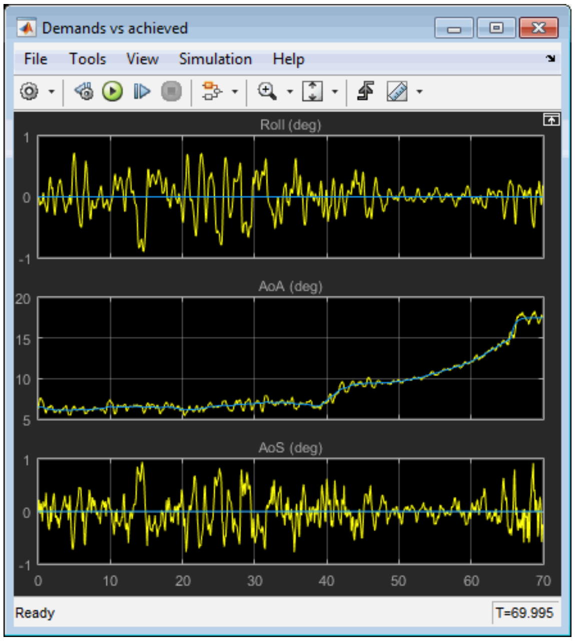
Plot that Measures Guidance Performance



Plot that Measures Altitude Accelerations Mach



Plot that Measures Inertial Position



Plot that Measures Demand Data Against Achieved Data

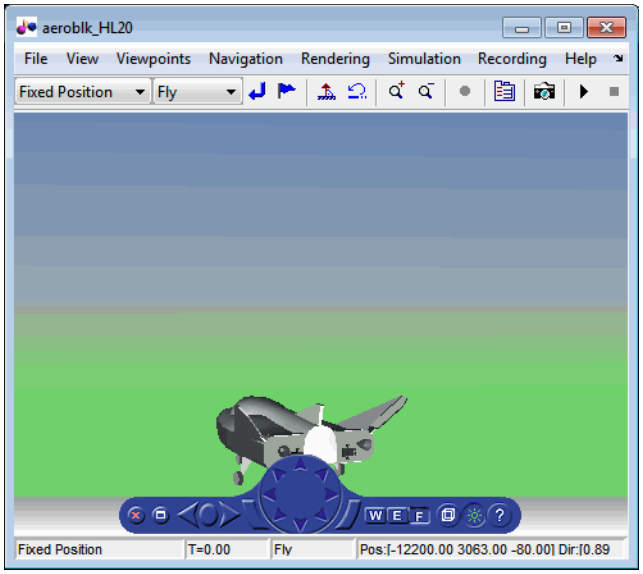
Modify the Model

You can adjust the airframe model settings and examine the effects on simulation performance. Here is one modification that you can try. It changes the camera point of view for the landing animation.

Change the Animation Point of View

By default, the airframe animation viewpoint is `Rear position`, which means the view tracks with the airframe flight path from the rear. You can change the animation point of view by selecting another viewpoint from the Simulink 3D Animation viewer:

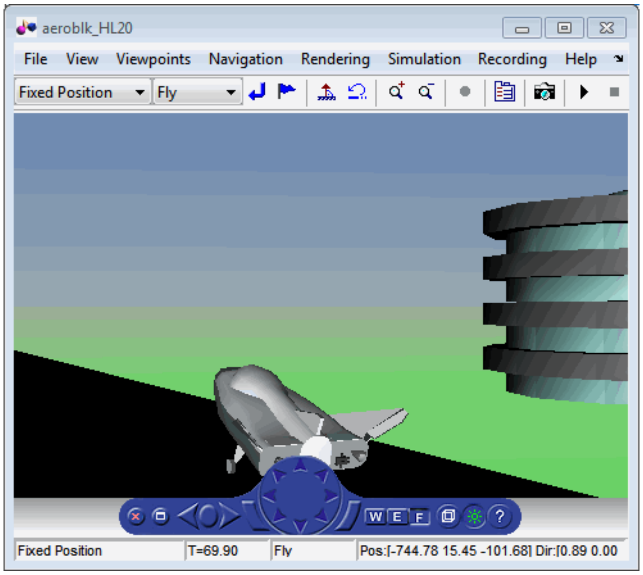
1. Open the `aeroblk_HL20` model, and click the Simulink 3D Animation viewer.
2. From the list of existing viewpoints, change the viewpoint to `Fixed Position`.


aeroblk_HL20
File View Viewpoints Navigation Rendering Simulation Recording Help
Fixed Position
Fly
W E F

Fixed Position | T=0.00 | Fly | Pos:[-12200.00 3063.00 -80.00] Dir:[0.89

The airframe view changes to a fixed position.

3. Start the model again. Notice the different airframe viewpoint when the airframe lands.


aeroblk_HL20
File View Viewpoints Navigation Rendering Simulation Recording Help
Fixed Position
Fly
W E F

Fixed Position T=69.90 Fly Pos:[-744.78 15.45 -101.68] Dir:[0.89 0.00

You can experiment with different viewpoints to watch the animation from different perspectives.

Open Aerospace Examples

To open an Aerospace Blockset example from the Help Browser:

1. Open the MATLAB Command Window.
2. Click the question mark.
3. Navigate to Aerospace Blockset and click the **Examples** tab.

For in-depth case studies of the following examples, see:

- "Ideal Airspeed Correction" on page 3-2
- "1903 Wright Flyer" on page 3-9
- "NASA HL-20 Lifting Body Airframe" on page 3-18

Aerospace Blockset Software

Create Aerospace Models

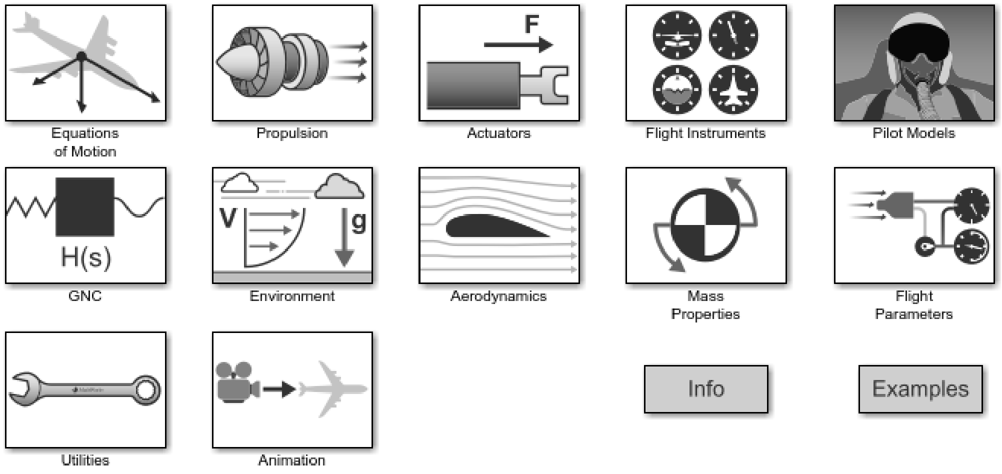
Basic Steps

Regardless of the model's complexity, you use the same essential steps for creating an aerospace model as you would for creating any other Simulink model.

1 Open the Aerospace Blockset Library. You can access this library through the Simulink Library Browser or directly open the Aerospace Blockset window from the MATLAB command line:

```
aerolib
```

Double-click any library in the window to display its contents. The following figure shows the Aerospace Blockset library window.



2 *Select and position the blocks.* You must first select the blocks that you need to build your model, and then position the blocks in the model window. For the majority of Simulink models, you select one or more blocks from each of the following categories:

a Source blocks generate or import signals into the model, such as a sine wave, a clock, or limited-band white noise.

   b. Simulation blocks can consist of almost any type of block that performs an action in the simulation. A simulation block represents a part of the model functionality to be simulated, such as an actuator block, a mathematical operation, a block from the Aerospace Blockset library, and so on.
   c. Signal Routing blocks route signals from one point in a model to another. If you need to combine or redirect two or more signals in your model, you will probably use a Simulink Signal Routing block, such as Mux and Demux.

      As an alternative to the Mux block, you can use the `Vector` option of the Concatenate block **Mode** parameter (also known as the Vector Concatenate block). This block provides a more general way for you to route signals from one point in the a model to another. The Vector mode takes as input a vector of signals of the same data type and creates a contiguous output signal. Depending on the input, this block outputs a row or column vector if any of the inputs are row or column vectors, respectively.
   d. Sink blocks display, write, or save model output. To see the results of the simulation, you must use a Sink block.
3. *Configure the blocks.* Most blocks feature configuration options that let you customize block functionality to specific simulation parameters. For example, the ISA Atmosphere Model block provides configuration options for setting the height of the troposphere, tropopause, and air density at sea level.
4. *Connect the blocks.* To create signal pathways between blocks, you connect the blocks to each other. You can do this manually by clicking and dragging, or you can connect blocks automatically.
5. *Encapsulate subsystems.* Systems made with Aerospace Blockset blocks can function as subsystems of larger, more complex models, like subsystems in any Simulink model.

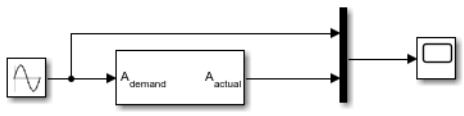
Build a Simple Actuator System

In this section...
"Build the Model" on page 2-4
"Run the Simulation" on page 2-8

Build the Model

The Simulink product is a software environment for modeling, simulating, and analyzing dynamic systems. Try building a simple model that drives an actuator with a sine wave and displays the actuator's position superimposed on the sine wave.

Note If you prefer to open the complete model shown below instead of building it, enter `aeroblktutorial` at the MATLAB command line.



The following section ("Create a Model" on page 2-5) explains how to build a model on Windows platforms. You can use this same procedure to build a model on Linux® platforms.

The section describes how to build the model. It does not describe how to set the configuration parameters for the model. See "Configuration Parameters Dialog Box Overview" (Simulink). That topic describes the Configuration Parameters Dialog Box for models. If you do not set any configuration parameters, simulating models might cause warnings like:

```
Warning: Using a default value of 0.2 for maximum step size.
The simulation step size will be equal to or less than this
value.  You can disable this diagnostic by setting
'Automatic solver parameter selection' diagnostic to 'none'
in the Diagnostics page of the configuration parameters
dialog
```

Create a Model

To create a new blank model and open the Simulink library browser:

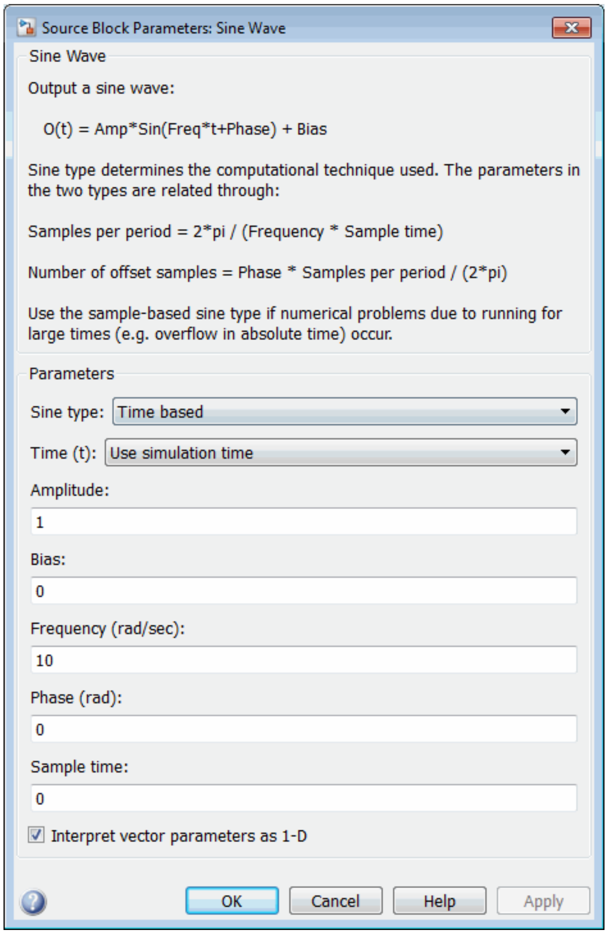
1. On the MATLAB **Home** tab, click Simulink. In the Simulink start page, click the Blank Model template, and then click Create Model.
2. To open the Library Browser, click the browser button.
3. Add a Sine Wave block to the model.
   - a. Click **Sources** in the Library Browser to view the blocks in the Simulink Sources library.
   - b. Drag the Sine Wave block from the Sources library into the new model window.
4. Add a Linear Second-Order Actuator block to the model.
   - a. Click the ▷ symbol next to **Aerospace Blockset** in the Library Browser to expand the hierarchical list of the aerospace blocks.
   - b. In the expanded list, click **Actuators** to view the blocks in the Actuator library.
   - c. Drag the Linear Second-Order Actuator block into the model window.
5. Add a Mux block to the model.
   - a. Click **Signal Routing** in the Library Browser to view the blocks in the Simulink Signals & Systems library.
   - b. Drag the Mux block from the Signal Routing library into the model window.
6. Add a Scope block to the model.
   - a. Click **Sinks** in the Library Browser to view the blocks in the Simulink Sinks library.
   - b. Drag the Scope block from the Sinks library into the model window.
7. Resize the Mux block in the model.
   - a. Click the Mux block to select the block.
   - b. Hold down the mouse button and drag a corner of the Mux block to change the size of the block.
8. Connect the blocks.
   - a. Position the pointer near the output port of the Sine Wave block. Hold down the mouse button and drag the line that appears until it touches the input port of the Linear Second-Order Actuator block. Release the mouse button.

- **b** Using the same technique, connect the output of the Linear Second-Order Actuator block to the second input port of the Mux block.
- **c** Using the same technique, connect the output of the Mux block to the input port of the Scope block.
- **d** Position the pointer near the first input port of the Mux block. Hold down the mouse button and drag the line that appears over the line from the output port of the Sine Wave block until double crosshairs appear. Release the mouse button. The lines are connected when a knot is present at their intersection.

9 Set the block parameters.

- **a** Double-click the Sine Wave block. The dialog box that appears allows you to set the block's parameters.

  For this example, configure the block to generate a 10 rad/s sine wave by entering `10` for the **Frequency** parameter. The sinusoid has the default amplitude of `1` and phase of `0` specified by the **Amplitude** and **Phase offset** parameters.
- **b** Click **OK**.



Sine Wave

Output a sine wave:

O(t) = Amp*Sin(Freq*t+Phase) + Bias

Sine type determines the computational technique used. The parameters in the two types are related through:

Samples per period = 2*pi / (Frequency * Sample time)

Number of offset samples = Phase * Samples per period / (2*pi)

Use the sample-based sine type if numerical problems due to running for large times (e.g. overflow in absolute time) occur.

Parameters

Sine type: Time based

Time (t): Use simulation time

Amplitude: 1

Bias: 0

Frequency (rad/sec): 10

Phase (rad): 0

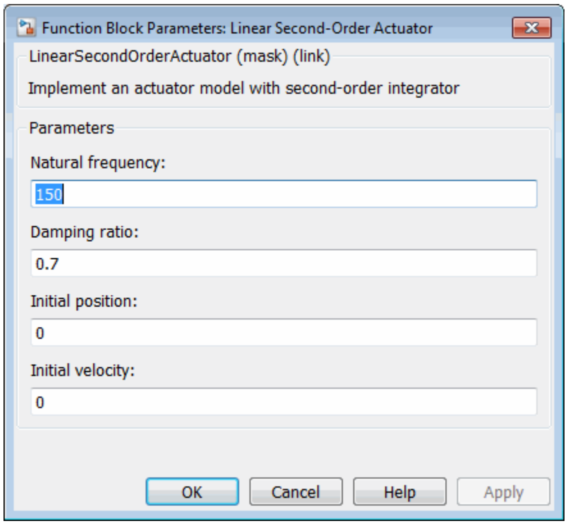
Sample time: 0

[✓] Interpret vector parameters as 1-D

c Double-click the Linear Second-Order Actuator block.

In this example, the actuator has the default natural frequency of `150` rad/s, a damping ratio of `0.7`, and an initial position of `0` radians specified by the **Natural frequency**, **Damping ratio**, and **Initial position** parameters.

d Click **OK.**


Function Block Parameters: Linear Second-Order Actuator

LinearSecondOrderActuator (mask) (link)

Implement an actuator model with second-order integrator

Parameters

Natural frequency:

150

Damping ratio:

0.7

Initial position:

0

Initial velocity:

0

Run the Simulation

You can now run the model that you built to see how the system behaves in time:

1 Double-click the Scope block if the Scope window is not already open on your screen. The Scope window appears.
2 Select **Run** from the **Simulation** menu in the model window. The signal containing the 10 rad/s sinusoid and the signal containing the actuator position are plotted on the scope.
3 Adjust the Scope block's display. While the simulation is running, right-click the *y*-axis of the scope and select **Autoscale**. The vertical range of the scope is adjusted to better fit the signal.
4 Vary the Sine Wave block parameters.
   a While the simulation is running, double-click the Sine Wave block to open its parameter dialog box.
   b You can then change the frequency of the sinusoid. Try entering `1` or `20` in the **Frequency** field. Close the Sine Wave dialog box to enter your change. You can then observe the changes on the scope.
5 Select **Stop** from the **Simulation** menu to stop the simulation.

Many parameters *cannot* be changed while a simulation is running. This is usually the case for parameters that directly or indirectly alter a signal's dimensions or sample rate. However, there are some parameters, like the Sine Wave **Frequency** parameter, that you can *tune* without stopping the simulation.

Run a Simulation from a Script

You can also modify and run a Simulink simulation from a script. By doing this, you can automate the variation of model parameters to explore a large number of simulation conditions rapidly and efficiently. For information on how to do this, see “Run Simulations Programmatically” (Simulink).

About Aerospace Coordinate Systems

In this section...

Fundamental Coordinate System Concepts

Coordinate systems allow you to keep track of an aircraft or spacecraft's position and orientation in space. The Aerospace Blockset coordinate systems are based on these underlying concepts from geodesy, astronomy, and physics.

Definitions

The blockset uses *right-handed* (RH) *Cartesian* coordinate systems. The *right-hand rule* establishes the *x*-*y*-*z* sequence of coordinate axes.

An *inertial frame* is a nonaccelerating motion reference frame. In an inertial frame, Newton's second law holds: force = mass × acceleration. Loosely speaking, acceleration is defined with respect to the distant cosmos, and an inertial frame is often said to be nonaccelerated with respect to the "fixed stars." Because the Earth and stars move so slowly with respect to one another, this assumption is a very accurate approximation.

Strictly defined, an inertial frame is a member of the set of all frames not accelerating relative to one another. A *noninertial frame* is any frame accelerating relative to an inertial frame. Its acceleration, in general, includes both translational and rotational components, resulting in *pseudoforces* (*pseudogravity,* as well as *Coriolis* and *centrifugal forces*).

The blockset models the Earth's shape (the *geoid*) as an oblate spheroid, a special type of ellipsoid with two longer axes equal (defining the *equatorial plane*) and a third, slightly shorter (*geopolar*) axis of symmetry. The equator is the intersection of the equatorial plane and the Earth's surface. The geographic poles are the intersection of the Earth's surface and the geopolar axis. In general, the Earth's geopolar and rotation axes are not identical.

Latitudes parallel the equator. Longitudes parallel the geopolar axis. The *zero longitude* or *prime meridian* passes through Greenwich, England.

Approximations

The blockset makes three standard approximations in defining coordinate systems relative to the Earth.

- The Earth's surface or geoid is an oblate spheroid, defined by its longer equatorial and shorter geopolar axes. In reality, the Earth is slightly deformed with respect to the standard geoid.
- The Earth's rotation axis and equatorial plane are perpendicular, so that the rotation and geopolar axes are identical. In reality, these axes are slightly misaligned, and the equatorial plane wobbles as the Earth rotates. This effect is negligible in most applications.
- The only noninertial effect in Earth-fixed coordinates is due to the Earth's rotation about its axis. This is a *rotating, geocentric* system. The blockset ignores the Earth's acceleration around the Sun, the Sun's acceleration in the Galaxy, and the Galaxy's acceleration through the cosmos. In most applications, only the Earth's rotation matters.

  This approximation must be changed for spacecraft sent into deep space, i.e., outside the Earth-Moon system, and a heliocentric system is preferred.

Motion with Respect to Other Planets

The blockset uses the standard WGS-84 geoid to model the Earth. You can change the equatorial axis length, the flattening, and the rotation rate.

You can represent the motion of spacecraft with respect to any celestial body that is well approximated by an oblate spheroid by changing the spheroid size, flattening, and rotation rate. If the celestial body is rotating westward (retrogradely), make the rotation rate negative.

Coordinate Systems for Modeling

Modeling aircraft and spacecraft is simplest if you use a coordinate system fixed in the body itself. In the case of aircraft, the forward direction is modified by the presence of wind, and the craft's motion through the air is not the same as its motion relative to the ground.

See “Equations of Motion” for further details on how the Aerospace Blockset product implements body and wind coordinates.

Body Coordinates

The noninertial body coordinate system is fixed in both origin and orientation to the moving craft. The craft is assumed to be rigid.

The orientation of the body coordinate axes is fixed in the shape of body.

- The *x*-axis points through the nose of the craft.
- The *y*-axis points to the right of the *x*-axis (facing in the pilot's direction of view), perpendicular to the *x*-axis.
- The *z*-axis points down through the bottom the craft, perpendicular to the *xy* plane and satisfying the RH rule.

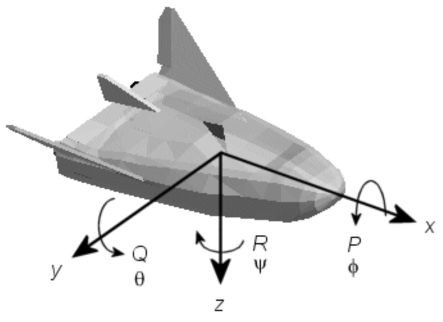
Translational Degrees of Freedom

Translations are defined by moving along these axes by distances *x*, *y*, and *z* from the origin.

Rotational Degrees of Freedom

Rotations are defined by the Euler angles *P*, *Q*, *R* or Φ, Θ, Ψ. They are:

P or Φ	Roll about the *x*-axis
Q or Θ	Pitch about the *y*-axis
R or Ψ	Yaw about the *z*-axis



Unless otherwise specified, by default the software uses ZYX rotation order for Euler angles.

Wind Coordinates

The noninertial wind coordinate system has its origin fixed in the rigid aircraft. The coordinate system orientation is defined relative to the craft's velocity ***V***.

The orientation of the wind coordinate axes is fixed by the velocity ***V***.

- The *x*-axis points in the direction of ***V***.
- The *y*-axis points to the right of the *x*-axis (facing in the direction of ***V***), perpendicular to the *x*-axis.
- The *z*-axis points perpendicular to the *xy* plane in whatever way needed to satisfy the RH rule with respect to the *x*- and *y*axes.

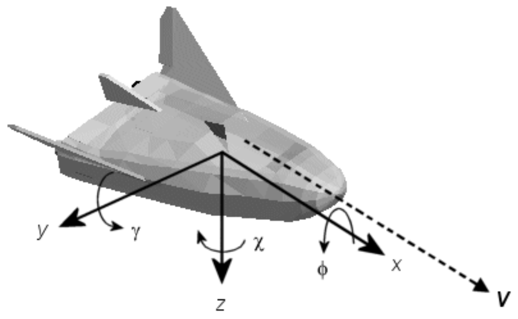
Translational Degrees of Freedom

Translations are defined by moving along these axes by distances *x*, *y*, and *z* from the origin.

Rotational Degrees of Freedom

Rotations are defined by the Euler angles Φ, γ, χ. They are:

Φ	Bank angle about the *x*-axis
γ	Flight path about the *y*-axis
χ	Heading angle about the *z*-axis



Unless otherwise specified, by default the software uses ZYX rotation order for Euler angles.

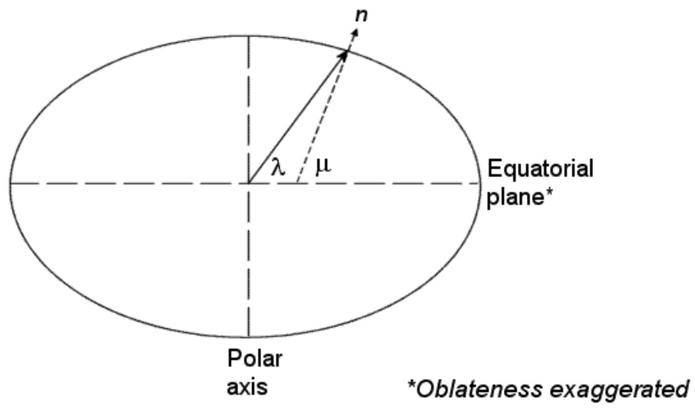
Coordinate Systems for Navigation

Modeling aerospace trajectories requires positioning and orienting the aircraft or spacecraft with respect to the rotating Earth. Navigation coordinates are defined with respect to the center and surface of the Earth.

Geocentric and Geodetic Latitudes

The *geocentric latitude* λ on the Earth's surface is defined by the angle subtended by the radius vector from the Earth's center to the surface point with the equatorial plane.

The *geodetic latitude* μ on the Earth's surface is defined by the angle subtended by the surface normal vector n and the equatorial plane.

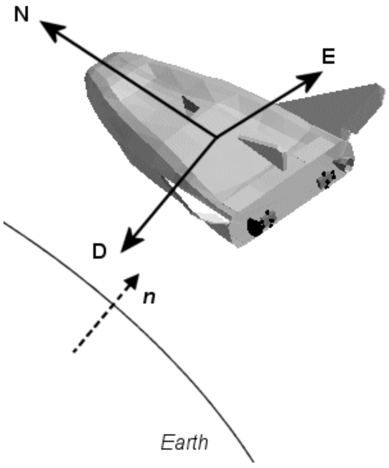


NED Coordinates

The north-east-down (NED) system is a noninertial system with its origin fixed at the aircraft or spacecraft's center of gravity. Its axes are oriented along the geodetic directions defined by the Earth's surface.

- The *x*-axis points north parallel to the geoid surface, in the polar direction.
- The *y*-axis points east parallel to the geoid surface, along a latitude curve.
- The *z*-axis points downward, toward the Earth's surface, antiparallel to the surface's outward normal ***n***.

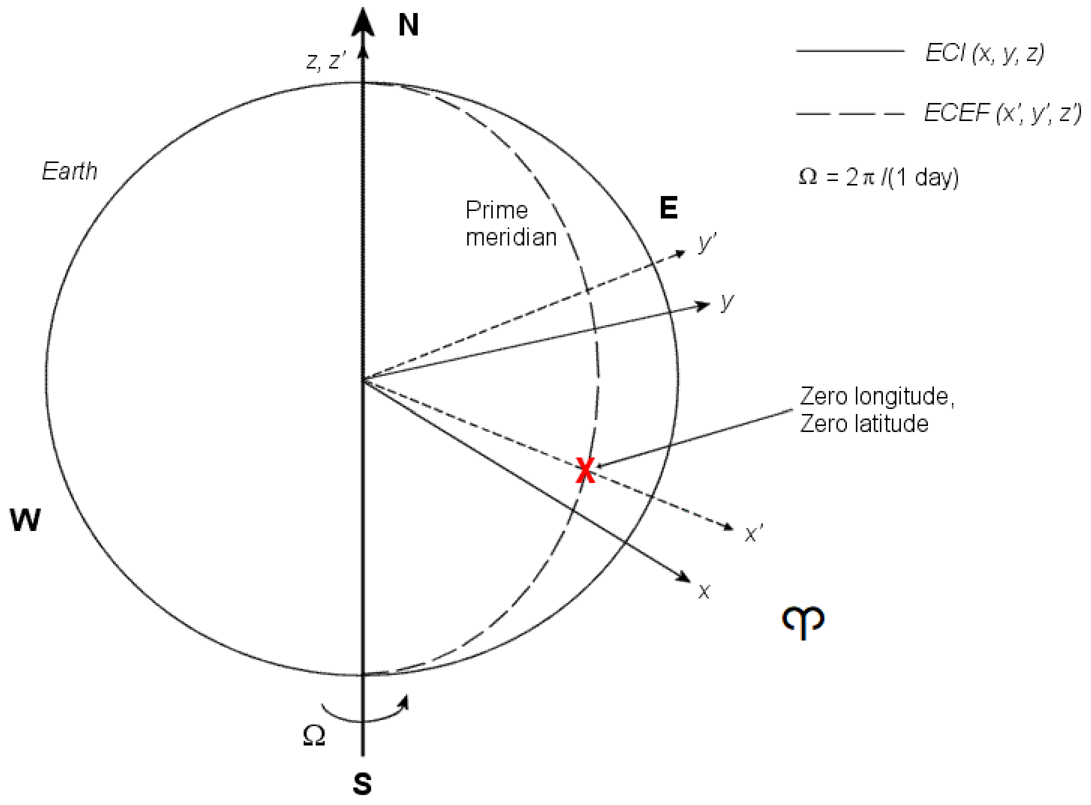
Flying at a constant altitude means flying at a constant *z* above the Earth's surface.



ECI Coordinates

The Earth-centered inertial (ECI) system is non-rotating. For most applications, assume this frame to be inertial, although the equinox and equatorial plane move very slightly over time. The ECI system is considered to be truly inertial for high-precision orbit calculations when the equator and equinox are defined at a particular epoch (e.g. J2000). Aerospace functions and blocks that use a particular realization of the ECI coordinate system provide that information in their documentation. The ECI system origin is fixed at the center of the Earth (see figure).

- The *x*-axis points towards the vernal equinox (First Point of Aries ♈).
- The *y*-axis points 90 degrees to the east of the *x*-axis in the equatorial plane.
- The *z*-axis points northward along the Earth rotation axis.



Earth-Centered Coordinates

ECEF Coordinates

The Earth-center, Earth-fixed (ECEF) system is noninertial and rotates with the Earth. Its origin is fixed at the center of the Earth (see preceding figure).

- The *x*′-axis points towards the intersection of Earth's equatorial plane and the Greenwich Meridian.
- The *y*′-axis points 90 degrees to the east of the *x*′-axis in the equatorial plane.
- The *z*′-axis points northward along the Earth's rotation axis.

Coordinate Systems for Display

Several display tools are available for use with the Aerospace Blockset product. Each has a specific coordinate system for rendering motion.

MATLAB Graphics Coordinates

See the "Axes Appearance" (MATLAB) for more information about the MATLAB Graphics coordinate axes.

MATLAB Graphics uses this default coordinate axis orientation:

- The *x*-axis points out of the screen.
- The *y*-axis points to the right.
- The *z*-axis points up.

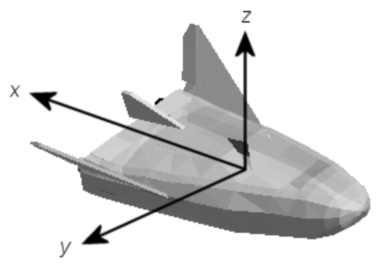
FlightGear Coordinates

FlightGear is an open-source, third-party flight simulator with an interface supported by the blockset.

- "Work with the Flight Simulator Interface" on page 2-24 discusses the blockset interface to FlightGear.
- See the FlightGear documentation at `www.flightgear.org` for complete information about this flight simulator.

The FlightGear coordinates form a special body-fixed system, rotated from the standard body coordinate system about the *y*-axis by -180 degrees:

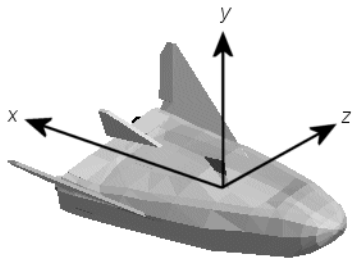
- The *x*-axis is positive toward the back of the vehicle.
- The *y*-axis is positive toward the right of the vehicle.
- The *z*-axis is positive upward, e.g., wheels typically have the lowest *z* values.



AC3D Coordinates

AC3D is a low-cost, widely used, geometry editor available from `www.ac3d.org`. Its body-fixed coordinates are formed by inverting the three standard body coordinate axes:

- The *x*-axis is positive toward the back of the vehicle.
- The *y*-axis is positive upward, e.g., wheels typically have the lowest *y* values.
- The *z*-axis is positive to the left of the vehicle.



References

Recommended Practice for Atmospheric and Space Flight Vehicle Coordinate Systems, R-004-1992, ANSI/AIAA, February 1992.

Mapping Toolbox documentation, The MathWorks, Inc., Natick, Massachusetts. “Mapping Toolbox”.

Rogers, R. M., *Applied Mathematics in Integrated Navigation Systems,* AIAA, Reston, Virginia, 2000.

Sobel, D., *Longitude*, Walker & Company, New York, 1995.

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation,* 2nd ed., *Aircraft Control and Simulation,* Wiley-Interscience, New York, 2003.

Thomson, W. T., *Introduction to Space Dynamics,* John Wiley & Sons, New York, 1961/ Dover Publications, Mineola, New York, 1986.

World Geodetic System 1984 (WGS 84), `http://earth-info.nga.mil/GandG/wgs84/`.

Flight Simulator Interface

In this section...

About the FlightGear Interface

The Aerospace Blockset product supports an interface to the third-party FlightGear flight simulator, open-source software available through a GNU General Public License (GPL). The FlightGear flight simulator interface included with the blockset is a unidirectional transmission link from the Simulink interface to FlightGear using the FlightGear published `net_fdm` binary data exchange protocol. Data is transmitted via UDP network packets to a running instance of FlightGear. The blockset supports multiple standard binary distributions of FlightGear. See “Run FlightGear with Simulink Models” on page 2-29 for interface details.

FlightGear is a separate software entity not created, owned, or maintained by MathWorks.

- To report bugs in or request enhancements to the Aerospace Blockset FlightGear interface, use the `form`.
- To report bugs or request enhancements to FlightGear itself, visit `FlightGear website`.

Supported FlightGear Versions

The Aerospace Blockset product supports these FlightGear versions:

- `v2018.2`
- `v2018.1`

- `v2017.3`
- `v2017.1`
- `v2016.3`
- `v2016.1`
- `v3.4`
- `v3.2`
- `v3.0`
- `v2.12`
- `v2.10`
- `v2.8`
- `v2.6`
- `v2.4`
- `v2.0`

If you are using a FlightGear version older than 2.0, update your FlightGear installation to a supported version. When you open the model, the software returns a warning or error. Obtain updated FlightGear software from `www.flightgear.org` in the download area.

Obtain FlightGear

You can obtain FlightGear from the FlightGear website in the download area or by ordering CDs from FlightGear. The download area contains extensive documentation for installation and configuration. Because FlightGear is an open-source project, source downloads are also available for customizing and porting to custom environments.

Configure Your Computer for FlightGear

To use FlightGear, you must have a high-performance graphics card with stable drivers For more information, see the FlightGear CD distribution or the hardware requirements and documentation areas of the FlightGear website.

FlightGear performance and stability can be sensitive to computer video cards, driver versions, and driver settings. You need OpenGL® support with hardware acceleration activated. Without proper setup, performance can drop from about a 30 frames-per-second (fps) update rate to less than 1 fps. If your system allows you to update OpenGL settings, modify them to improve performance.

Graphics Recommendations for Windows

For Windows systems, use the following graphics recommendations:

- A graphics card with acceptable OpenGL performance (as outlined at the FlightGear website).
- The latest tested and stable driver release for your video card. Test the driver thoroughly on a few computers before deploying to others.

For more information, see `FlightGear Hardware Recommendations`.

Setup on Linux, Macintosh, and Other Platforms

FlightGear distributions are available for Linux, Macintosh, and other platforms from the FlightGear website, `www.flightgear.org`. Installation on these platforms, like Windows, requires careful configuration of graphics cards and drivers. Consult the documentation and hardware requirements sections at the FlightGear website.

FlightGear and Video Cards in Windows Systems

Your computer built-in video card, such as NVIDIA® cards, can conflict with FlightGear shaders. Consider this workaround:

- Disable the FlightGear shaders by selecting the Generate Run Script block **Disable FlightGear shader options** check box.

Install and Start FlightGear

The extensive FlightGear documentation guides you through the installation in detail. Consult the following:

- Documentation section of the FlightGear website for installation instructions: `www.flightgear.org`.
- Hardware recommendations section of the FlightGear website.
- MATLAB system requirements.

Keep the following points in mind:

- Configure your computer graphics card before you install FlightGear. See the preceding section, “Configure Your Computer for FlightGear” on page 2-20.
- Shut down all running applications (including the MATLAB interface) before installing FlightGear.
- Install FlightGear in a folder path name composed of ASCII characters.
- MathWorks tests indicate that the operational stability of FlightGear is especially sensitive during startup. It is best not to move, resize, mouse over, overlap, or cover up the FlightGear window until the initial simulation scene appears after the startup splash screen fades out.

Aerospace Blockset supports FlightGear on several platforms. This table lists the properties to consider before you start to use FlightGear.

FlightGear Property	Folder Description	Platforms	Typical Location
`FlightGearBase-Directory`	FlightGear installation folder.	Windows 64-bit	`C:\Program Files\FlightGear` (default)
		Linux	Folder into which you installed FlightGear
		Mac	`/Applications` (folder to which you dragged the FlightGear icon)
`GeometryModelName`	Model geometry folder	Windows 64-bit	`C:\Program Files\FlightGear\data\Aircraft\HL20` (default)
		Linux	`$FlightGearBaseDirectory/-data/Aircraft/HL20`
		Mac	`$FlightGearBaseDirectory/-FlightGear.app/Contents/-Resources/data/Aircraft/-HL20`

Install Additional FlightGear Scenery

When you install the FlightGear software, the installation provides a basic level of scenery files. The FlightGear documentation guides you through installing scenery as part the general FlightGear installation.

If you need to install more FlightGear scenery files, see the instructions at `http://www.flightgear.org`. The instructions describe how to install the additional scenery in a default location. MathWorks® recommends that you follow those instructions.

If you must install additional scenery in a nonstandard location, try setting the `FG_SCENERY` environment variable in the script output from the Generate Run Script block. See the documentation at `http://www.flightgear.org` for a description of the `FG_SCENERY` variable.

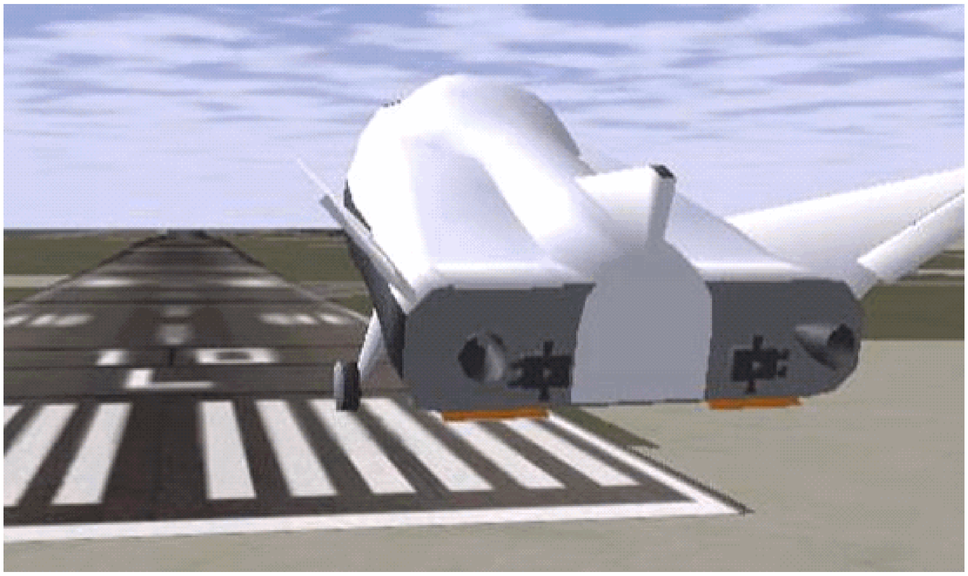
If you do not download scenery, you can direct FlightGear to download it automatically during simulation by selecting the Generate Run Script block **Install FlightGear scenery during simulation (requires Internet connection)** check box.

Work with the Flight Simulator Interface

In this section...

Introduction

Use this section to learn how to use the FlightGear flight simulator and the Aerospace Blockset software to visualize your Simulink aircraft models. If you have not yet installed FlightGear, see "Flight Simulator Interface" on page 2-19 first.



Simulink Driven HL-20 Model in a Landing Flare at KSFC

About Aircraft Geometry Models

Before you can visualize your aircraft's dynamics, you need to create or obtain an aircraft model file compatible with FlightGear. This section explains how to do this.

Aircraft Geometry Editors and Formats

You have a competitive choice of over twelve 3-D geometry file formats supported by FlightGear.

Currently, the most popular 3-D geometry file format is the AC3D format, which has the suffix `*.ac`. AC3D is a low-cost geometry editor available from `www.ac3d.org`. Another popular 3-D editor for aircraft models is Flight Sim Design Studio, distributed by Abacus Publications at `www.abacuspub.com`.

Aircraft Model Structure and Requirements

Aircraft models are contained in the *`FlightGearRoot`*`/data/Aircraft/` folder and subfolders. A complete aircraft model must contain a folder linked through the required aircraft master file named *`model`*`-set.xml`.

All other model elements are optional. This is a partial list of the optional elements you can put in an aircraft data folder:

- Vehicle objects and their shapes and colors
- Vehicle objects' surface bitmaps
- Variable geometry descriptions
- Cockpit instrument 3-D models
- Vehicle sounds to tie to events (e.g., engine, gear, wind noise)
- Flight dynamics model
- Simulator views
- Submodels (independently movable items) associated with the vehicle

Model behavior reverts to defaults when these elements are not used. For example,

- Default sound: no vehicle-related sounds are emitted.
- Default instrument panel: no instruments are shown.

Models can contain some, all, or even none of the above elements. If you always run FlightGear from the cockpit view, the aircraft geometry is often secondary to the instrument geometries.

A how-to document for including optional elements is included in the FlightGear documentation at:

```
http://www.flightgear.org/Docs/fgfs-model-howto.html
```

Required Flight Dynamics Model Specification

The flight dynamics model (FDM) specification is a required element for an aircraft model. To set the Simulink software as the source of the flight dynamics model data stream for a given geometry model, you put this line in `data/Aircraft/`*`model`*`/`*`model`*`-set.xml`:

```
<flight-model>network</flight-model>
```

Obtain and Modify Existing Aircraft Models

You can quickly build models from scratch by referencing instruments, sounds, and other optional elements from existing FlightGear models. Such models provide examples of geometry, dynamics, instruments, views, and sounds. It is simple to copy an aircraft folder to a new name, rename the *`model`*`-set.xml file`, modify it for network flight dynamics, and then run FlightGear with the `—aircraft` flag set to the name in *`model`*`-set.xml`.

Many existing 3-D aircraft geometry models are available for use with FlightGear. Visit the download area of `www.flightgear.org` to see some of the aircraft models available. Additional models can be obtained via Web search. Search key words such as “flight gear aircraft model” are a good starting point. Be sure to comply with copyrights when distributing these files.

Hardware Requirements for Aircraft Geometry Rendering

When creating your own geometry files, keep in mind that your graphics card can efficiently render a limited number of surfaces. Some cards can efficiently render fewer than 1000 surfaces with bitmaps and specular reflections at the nominal rate of 30 frames per second. Other cards can easily render on the order of 10,000 surfaces.

If your performance slows while using a particular geometry, gauge the effect of geometric complexity on graphics performance by varying the number of aircraft model surfaces. An easy way to check this is to replace the full aircraft geometry file with a simple shape, such as a single triangle, then test FlightGear with this simpler geometry. If a geometry file is too complex for smooth display, use a 3-D geometry editor to simplify your model by reducing the number of surfaces in the geometry.

Work with Aircraft Geometry Models

Once you have obtained, modified, or created an aircraft data file, you need to put it in the correct folder for FlightGear to access it.

Import Aircraft Models into FlightGear

To install a compatible model into FlightGear, use one of the following procedures. Choose the one appropriate for your platform. This section assumes that you have read "Install and Start FlightGear" on page 2-21.

If your platform is Windows:

1. Go to your installed FlightGear folder. Open the `data` folder, then the `Aircraft` folder: `\FlightGear\data\Aircraft\`.
2. Make a subfolder *`model`*`\` here for your aircraft data.
3. Put *`model`*`-set.xml` in that subfolder, plus any other files needed.

   It is common practice to make subdirectories for the vehicle geometry files (`\model\`), instruments (`\instruments\`), and sounds (`\sounds\`).

If your platform is Linux:

1. Go to your installed FlightGear directory. Open the `data` directory, then the `Aircraft` directory: *`$FlightGearBaseDirectory`*`/data/Aircraft/`.
2. Make a subdirectory *`model`*`/` here for your aircraft data.
3. Put *`model`*`-set.xml` in that subdirectory, plus any other files needed.

   It is common practice to make subdirectories for the vehicle geometry files (`/model/`), instruments (`/instruments/`), and sounds (`/sounds/`).

If your platform is Mac:

1. Open a terminal.
2. Go to your installed FlightGear folder. Open the `data` folder, then the `Aircraft` folder:

`$FlightGearBaseDirectory/FlightGear.app/Contents/Resources/data/Aircraft/`

3 Make a subfolder *`model`*`/` here for your aircraft data.

4 Put *`model`*`-set.xml` in that subfolder, plus any other files needed.

   It is common practice to make subdirectories for the vehicle geometry files (`/model/`), instruments (`/instruments/`), and sounds (`/sounds/`).

Example: Animate Vehicle Geometries

This example illustrates how to prepare hinge line definitions for animated elements such as vehicle control surfaces and landing gear. To enable animation, each element must be a named entity in a geometry file. The resulting code forms part of the HL20 lifting body model presented in “Run the HL-20 Example with FlightGear” on page 2-36.

1 The standard body coordinates used in FlightGear geometry models form a right-handed system, rotated from the standard body coordinate system in *Y* by -180 degrees:

   - *X* = positive toward the back of the vehicle
   - *Y* = positive toward the right of the vehicle
   - *Z* = positive is up, e.g., wheels typically have the lowest *Z* values.

   See “About Aerospace Coordinate Systems” on page 2-10 for more details.

2 Find two points that lie on the desired named-object hinge line in body coordinates and write them down as *XYZ* triplets or put them into a MATLAB calculation like this:

```
a = [2.98, 1.89, 0.53];
b = [3.54, 2.75, 1.46];
```

3 Calculate the difference between the points:

```
pdiff = b - a
pdiff =
    0.5600    0.8600    0.9300
```

4 The hinge point is either of the points in step 2 (or the midpoint as shown here):

```
mid = a + pdiff/2
mid =
    3.2600    2.3200    0.9950
```

5 Put the hinge point into the animation scope in *`model`*`-set.xml`:

```
<center>
    <x-m>3.26</x-m>
    <y-m>2.32</y-m>
    <z-m>1.00</z-m>
</center>
```

6 Use the difference from step 3 to define the relative motion vector in the animation axis:

```
<axis>
    <x>0.56</x>
    <y>0.86</y>
    <z>0.93</z>
</axis>
```

7 Put these steps together to obtain the complete hinge line animation used in the HL20 example model:

```
<animation>
    <type>rotate</type>
    <object-name>RightAileron</object-name>
    <property>/surface-positions/right-aileron-pos-norm</property>
    <factor>30</factor>
    <offset-deg>0</offset-deg>
    <center>
        <x-m>3.26</x-m>
        <y-m>2.32</y-m>
        <z-m>1.00</z-m>
    </center>
    <axis>
        <x>0.56</x>
        <y>0.86</y>
        <z>0.93</z>
    </axis>
</animation>
```

Run FlightGear with Simulink Models

To run a Simulink model of your aircraft and simultaneously animate it in FlightGear with an aircraft data file `model-set.xml`, you need to configure the aircraft data file and modify your Simulink model with some new blocks.

These are the main steps to connecting and using FlightGear with the Simulink software:

- “Set the Flight Dynamics Model to Network in the Aircraft Data File” on page 2-30 explains how to create the network connection you need.
- “Obtain the Destination IP Address” on page 2-30 starts by determining the IP address of the computer running FlightGear.
- “Send Simulink Data to FlightGear” on page 2-38 shows how to add and connect interface and pace blocks to your Simulink model.

- “Create a FlightGear Run Script” on page 2-31 shows how to write a FlightGear run script compatible with your Simulink model.
- “Start FlightGear” on page 2-33 guides you through the final steps to making the Simulink software work with FlightGear.
- “Improve Performance” on page 2-35 helps you speed your model up.
- “Run FlightGear and Simulink Software on Different Computers” on page 2-35 explains how to connect a simulation from the Simulink software running on one computer to FlightGear running on another computer.

Set the Flight Dynamics Model to Network in the Aircraft Data File

Be sure to:

- Remove any pre-existing flight dynamics model (FDM) data from the aircraft data file.
- Indicate in the aircraft data file that its FDM is streaming from the network by adding this line:

```
<flight-model>network</flight-model>
```

Obtain the Destination IP Address

You need the destination IP address for your Simulink model to stream its flight data to FlightGear.

- If you know your computer's name, enter at the MATLAB command line:

```
java.net.InetAddress.getByName('www.mathworks.com')
```

- If you are running FlightGear and the Simulink software on the same computer, get your computer's name by entering at the MATLAB command line:

```
java.net.InetAddress.getLocalHost
```

- If you are working in Windows, get your computer's IP address by entering at the DOS prompt:

```
ipconfig /all
```

  Examine the IP address entry in the resulting output. There is one entry per Ethernet device.

Create a FlightGear Run Script

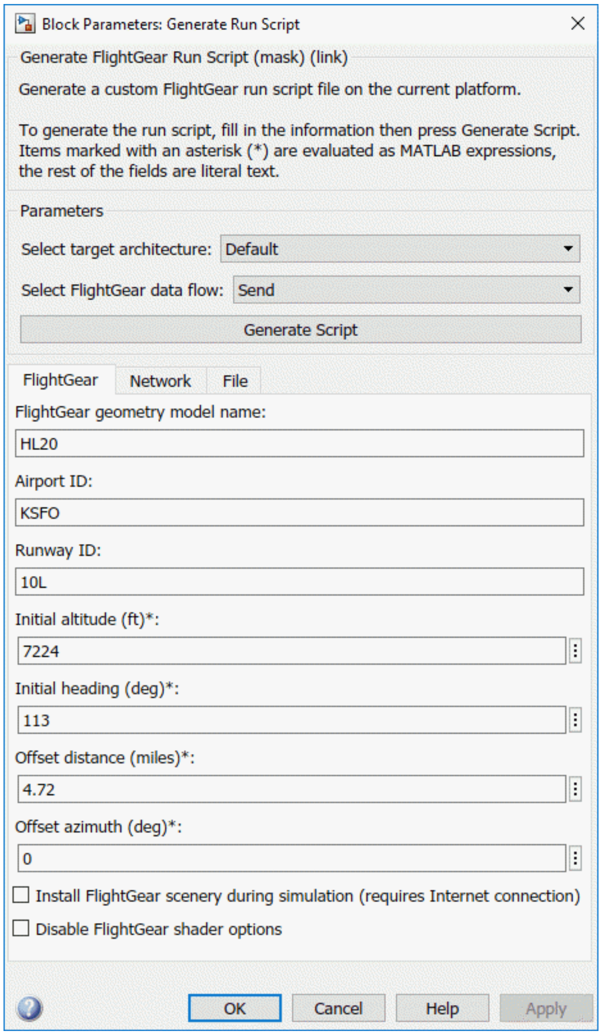
To start FlightGear with the desired initial conditions (location, date, time, weather, operating modes), it is best to create a run script by “Use the Generate Run Script Block” on page 2-31 or “Use the Interface Provided with FlightGear” on page 2-33.

If you make separate run scripts for each model you intend to link to FlightGear and place them in separate directories, run the appropriate script from the MATLAB interface just before starting your Simulink model.

Use the Generate Run Script Block

The easiest way to create a run script is by using the Generate Run Script block. Use the following procedure:

1. Open the Flight Simulator Interfaces sublibrary.
2. Create a new Simulink model or open an existing model.
3. Drag a Generate Run Script block into the Simulink diagram.
4. Double-click the Generate Run Script block. Its dialog opens. Observe the three panes, **FlightGear**, **Network**, and **File**.



Block Parameters: Generate Run Script

Generate FlightGear Run Script (mask) (link)

Generate a custom FlightGear run script file on the current platform.

To generate the run script, fill in the information then press Generate Script. Items marked with an asterisk (*) are evaluated as MATLAB expressions, the rest of the fields are literal text.

Parameters

Select target architecture: Default

Select FlightGear data flow: Send

FlightGear geometry model name: HL20

Airport ID: KSFO

Runway ID: 10L

Initial altitude (ft)*: 7224

Initial heading (deg)*: 113

Offset distance (miles)*: 4.72

Offset azimuth (deg)*: 0

☐ Install FlightGear scenery during simulation (requires Internet connection)

☐ Disable FlightGear shader options

5 In the **File > Output file name** field, type the name of the output file. This name should be the name of the command you want to use to start FlightGear with these initial parameters. Use the appropriate file extension:

Platform	Extension
Windows	`.bat`

Platform	**Extension**
Linux and macOS	`.sh`

For example, if your file name is `runfg.bat`, use the `runfg` command to execute the run script and start FlightGear.

6. In the **File > FlightGear base directory** field, specify the name of your FlightGear installation folder.
7. In the **File > FlightGear geometry model name** field, specify the name of the subfolder, in the *`FlightGear`*`/data/Aircraft` folder, containing the desired model geometry.
8. Specify the initial conditions as needed.
9. Click the **Generate Script** button at the top of the **Parameters** area.

   The Aerospace Blockset software generates the run script, and saves it in your MATLAB working folder under the file name that you specified in the **File > Output file name** field.
10. Repeat steps 5 through 9 to generate other run scripts, if needed.
11. Click **OK** to close the dialog box. You do not need to save the Generate Run Script block with the Simulink model.

The Generate Run Script block saves the run script as a text file in your working folder. This is an example of the contents of a run script file:

```
>> cd C:\Applications\FlightGear-2018.2
>> SET FG_ROOT=C:\Applications\FlightGear-2018.2\data
>> cd \bin\
>> fgfs --aircraft=HL20 --fdm=network,localhost,5501,5502,5503
  --fog-fastest --disable-clouds --start-date-lat=2004:06:01:09:00:00
  --disable-sound --in-air --enable-freeze --airport=KSFO --runway=10L
  --altitude=7224 --heading=113 --offset-distance=4.72 --offset-azimuth=0
```

Use the Interface Provided with FlightGear

The FlightGear launcher GUI (part of FlightGear, not the Aerospace Blockset product) lets you build simple and advanced options into a visible FlightGear run command.

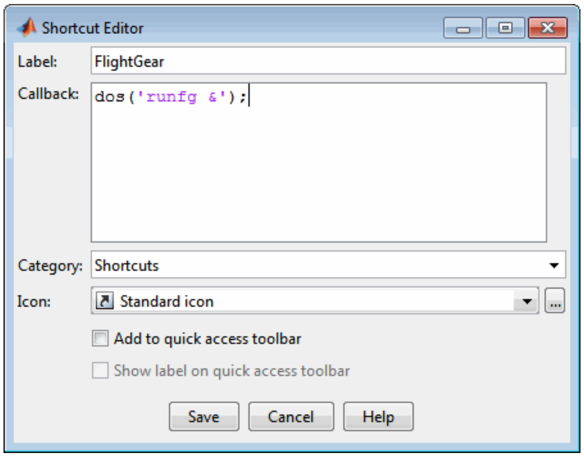
Start FlightGear

If your computer has enough computational power to run both the Simulink software and FlightGear at the same time, a simple way to start FlightGear on a Windows system is to create a MATLAB desktop button containing the following command to execute a run script like the one created above:

```
system('runfg &')
```

To create a desktop button:

1. In the MATLAB Command Window, select **Shortcuts** and click **New Shortcut**. The **Shortcut Editor** dialog opens.
2. Set the **Label**, **Callback**, **Category**, and **Icon** fields as shown in the following figure.



Label: FlightGear

Callback:

```
dos('runfg &');
```

Category: Shortcuts

Icon: Standard icon

Add to quick access toolbar
Show label on quick access toolbar
Save
Cancel
Help

3. Click **Save**.

   The **FlightGear** button appears in your MATLAB desktop. If you click it, the output file, for example `runfg.bat`, runs in the current folder.

Once you have completed the setup, start FlightGear and run your model:

1. Make sure your model is in a writable folder. Open the model, and update the diagram. This step ensures that any referenced block code is compiled and that the block diagram is compiled before running. Once you start FlightGear, it uses all available processor power while it is running.
2. Click the **FlightGear** button or run the FlightGear run script manually.
3. When FlightGear starts, it displays the initial view at the initial coordinates specified in the run script. If you are running the Simulink software and FlightGear on different computers, arrange to view the two displays at the same time.
4. Now begin the simulation and view the animation in FlightGear.

Improve Performance

If your Simulink model is complex and cannot run at the aggregate rate needed for the visualization, you might need to

- Use the Accelerator mode in Simulink ("Perform Acceleration" (Simulink).)
- Free up processor power by running the Simulink model on one computer and FlightGear on another computer. Use the **Destination IP Address** parameter of the Send net_fdm Packet to FlightGear block to specify the network address of the computer where FlightGear is running.
- Simulate the Simulink model first, then save the resulting translations (*x*-axis, *y*-axis, *z*-axis) and positions (latitude, longitude, altitude), and use the FlightGear Animation object in Aerospace Toolbox to visualize this data.

Tip If FlightGear uses more computer resources than you want, you can change its scheduling priority to a lesser one. For example, see commands like Windows `start` and Linux `nice` or their equivalents.

Run FlightGear and Simulink Software on Different Computers

It is possible to simulate an aerospace system in the Simulink environment on one computer (the source) and use its simulation output to animate FlightGear on another computer (the target). The steps are similar to those already explained, with certain modifications.

1. Obtain the IP address of the computer running FlightGear. See "Obtain the Destination IP Address" on page 2-30.
2. Enter this target computer's IP address in the Send net_fdm Packet to FlightGear block. See "Send Simulink Data to FlightGear" on page 2-38.
3. Update the Generate Run Script block in your model with the target computer's FlightGear base folder. Regenerate the run script to reflect the target computer's separate identity.

   See "Create a FlightGear Run Script" on page 2-31.
4. Copy the generated run script to the target computer. Start FlightGear there. See "Start FlightGear" on page 2-33.

5. If you want to also receive data from FlightGear, use the Receive net_ctrl Packet from FlightGear block. Enter the IP address of the computer running FlightGear in the **Origin IP address** parameter.
6. Update the run script for the receive data. Use the Generate Run Script block to regenerate the run script.
7. Start your Simulink model on the source computer. FlightGear running on the target displays the simulation motion.

Run the HL-20 Example with FlightGear

The Aerospace Blockset software contains an example model of the HL-20 lifting body that uses the FlightGear interface and projects. This example illustrates many features of the Aerospace Blockset software. It also contains a Variant Subsystem block that you can use to specify the data source for the simulation. You might want to use the Variant Subsystem block to change the terrain data source or if you do not want to use FlightGear but still want to simulate the model.

To install and configure FlightGear before attempting to simulate this model, see “Flight Simulator Interface” on page 2-19. Also, before attempting to simulate this model, read “Install and Start FlightGear” on page 2-21.

Note Step 2 of this example copies the preconfigured geometries for the HL-20 simulation from `*projectroot*\support` to `*FlightGear*\data\Aircraft\`. It requires that you have system administrator privileges for your machine. If you do not have these privileges, manually copy these files, depending on your platform.

Windows

> Copy the `HL20` folder from *`projectroot`*`\support` folder to *`FlightGear`*`\data\Aircraft\` folder. This folder contains the preconfigured geometries for the HL-20 simulation and `HL20-set.xml`. The file *`projectroot`*`\support\HL20\Models\HL20.xml` defines the geometry.
>
> For Windows platforms, start the MATLAB app with administrator privileges. For example, in the Start menu, right click the MATLAB app, then select **Run as administrator**.
>
> For more information, see “Import Aircraft Models into FlightGear” on page 2-27.

Linux

Copy the `HL20` directory from *`projectroot`*`/support` directory to *`$FlightGearBaseDirectory`*`/data/Aircraft/` directory. This directory contains the preconfigured geometries for the HL-20 simulation and `HL20-set.xml`. The file *`projectroot`*`/support/HL20/Models/HL20.xml` defines the geometry.

For more about this step, see "Import Aircraft Models into FlightGear" on page 2-27.

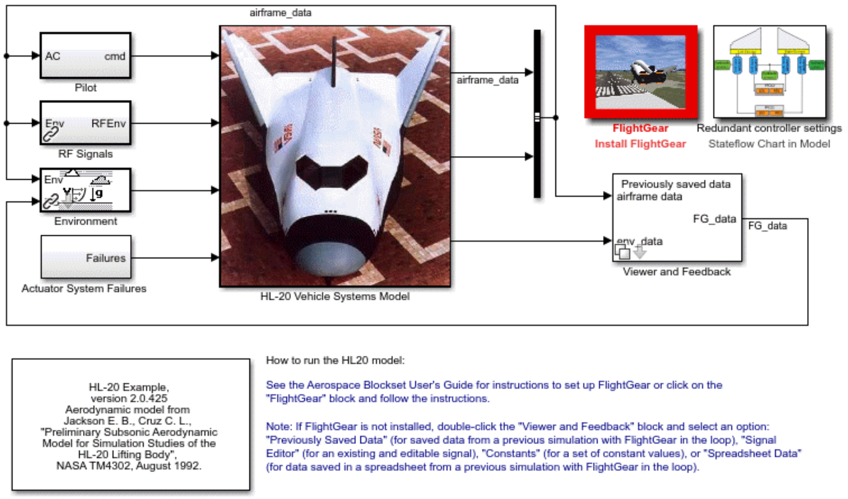
Mac

Copy the `HL20` folder from *`projectroot`*`/support` folder to *`$FlightGearBaseDirectory`*`/FlightGear.app/Contents/Resources/data/Aircraft/` folder. This folder contains the preconfigured geometries for the HL-20 simulation and `HL20-set.xml`. The file *`projectroot`*`/support/HL20/Models/HL20.xml` defines the geometry.

For more about this step, see "Import Aircraft Models into FlightGear" on page 2-27.

---

1 Start the MATLAB interface. Open the example either by entering `asbhl20` in the MATLAB Command Window or by finding the example entry (HL-20 with FlightGear Interface) in the Aerospace Blockset Examples page. The project for the model starts and the model opens.



HL-20 Example,
version 2.0.425
Aerodynamic model from
Jackson E. B., Cruz C. L.,
"Preliminary Subsonic Aerodynamic
Model for Simulation Studies of the
HL-20 Lifting Body",
NASA TM4302, August 1992.

How to run the HL20 model:

See the Aerospace Blockset User's Guide for instructions to set up FlightGear or click on the "FlightGear" block and follow the instructions.

Note: If FlightGear is not installed, double-click the "Viewer and Feedback" block and select an option: "Previously Saved Data" (for saved data from a previous simulation with FlightGear in the loop), "Signal Editor" (for an existing and editable signal), "Constants" (for a set of constant values), or "Spreadsheet Data" (for data saved in a spreadsheet from a previous simulation with FlightGear in the loop).

2 If this is your first time running FlightGear for this model, you need to create and run a customized FlightGear run script. You can do this with one of the following:

   - In the model, double-click the Install FlightGear block and follow the steps in the block. Initially, this block is red. As you follow the steps outlined in the block, the block mask changes.

     To start FlightGear for the model, click **Launch HL20 in FlightGear**.

3 Now start the simulation and view the animation in FlightGear.

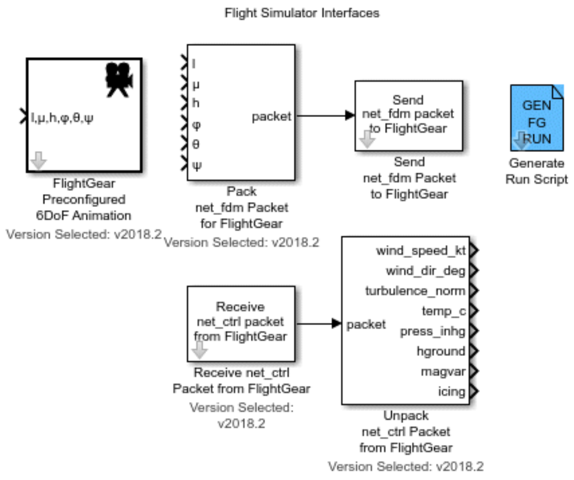
Note With the FlightGear window in focus, press the **V** key to alternate between the different aircraft views: cockpit view, helicopter view, chase view, and so on.

Send and Receive Data

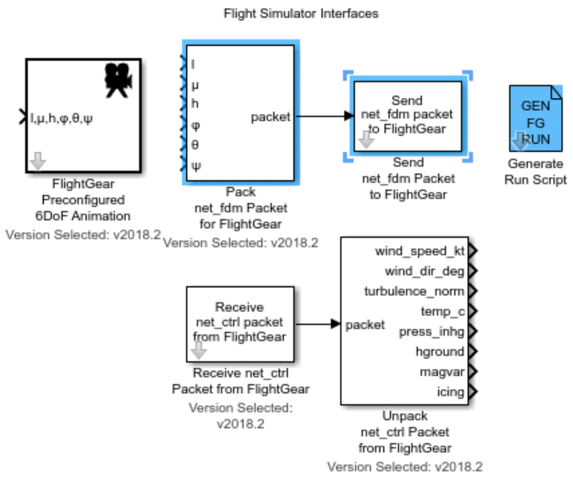
You can send and receive data between a Simulink model and a running FlightGear Flight Simulator.

Send Simulink Data to FlightGear

The easiest way to connect your model to FlightGear with the blockset is to use the FlightGear Preconfigured 6DoF Animation block:

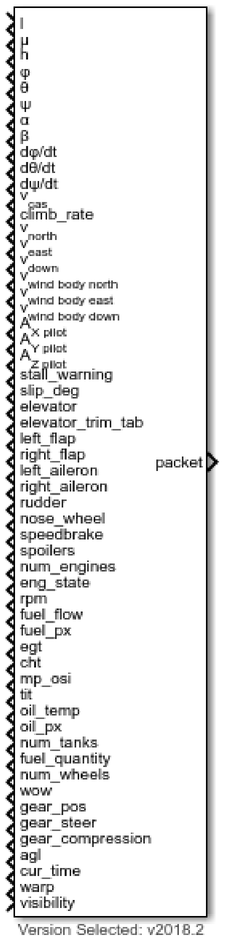

Flight Simulator Interfaces
l,μ,h,φ,θ,ψ
FlightGear Preconfigured 6DoF Animation
Version Selected: v2018.2
l
μ
h
φ
θ
ψ
packet
Pack net_fdm Packet for FlightGear
Version Selected: v2018.2
Send net_fdm packet to FlightGear
Send net_fdm Packet to FlightGear
GEN FG RUN
Generate Run Script
Receive net_ctrl packet from FlightGear
Receive net_ctrl Packet from FlightGear
Version Selected: v2018.2
packet
wind_speed_kt
wind_dir_deg
turbulence_norm
temp_c
press_inhg
hground
magvar
icing
Unpack net_ctrl Packet from FlightGear
Version Selected: v2018.2

The FlightGear Preconfigured 6DoF Animation block is a subsystem containing the Pack net_fdm Packet for FlightGear and Send net_fdm Packet to FlightGear blocks:


Flight Simulator Interfaces
l,μ,h,φ,θ,ψ
FlightGear Preconfigured 6DoF Animation
Version Selected: v2018.2
l
μ
h
φ
θ
ψ
packet
Pack net_fdm Packet for FlightGear
Version Selected: v2018.2
Send net_fdm packet to FlightGear
Send net_fdm Packet to FlightGear
GEN FG RUN
Generate Run Script
Receive net_ctrl packet from FlightGear
Receive net_ctrl Packet from FlightGear
Version Selected: v2018.2
packet
wind_speed_kt
wind_dir_deg
turbulence_norm
temp_c
press_inhg
hground
magvar
icing
Unpack net_ctrl Packet from FlightGear
Version Selected: v2018.2

These blocks transmit data from a model to a FlightGear session. The blocks are separate for maximum flexibility and compatibility.

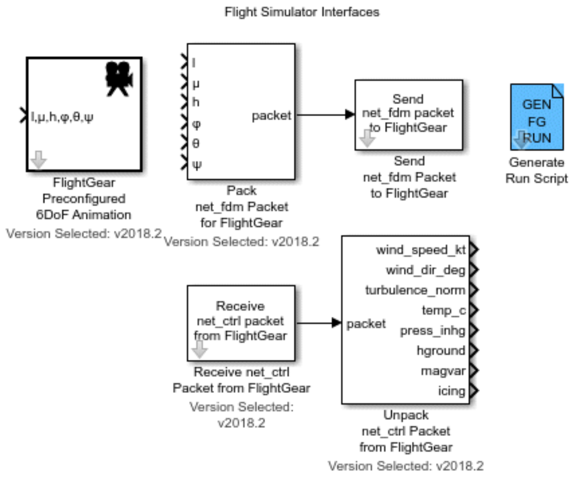
- The Pack net_fdm Packet for FlightGear block formats a binary structure compatible with FlightGear from model inputs. In the default configuration, the block displays only the 6DoF ports, but you can configure the full FlightGear interface supporting more than 50 distinct signals from the block dialog box:



- The Send net_fdm Packet to FlightGear block transmits this packet via UDP to the specified IP address and port where a FlightGear session awaits an incoming datastream. Use the IP address you found in “Obtain the Destination IP Address” on page 2-30.
- The Simulation Pace block slows the simulation so that its aggregate run rate is 1 second of simulation time per second of clock time. You can also use it to specify other ratios of simulation time to clock time.

Send FlightGear Data to Model

To increase the accuracy of your model simulation, you might want to send FlightGear environment variables to the Simulink model. Use the following blocks:


Flight Simulator Interfaces
l,μ,h,φ,θ,ψ
FlightGear Preconfigured 6DoF Animation
Version Selected: v2018.2
l
μ
h
φ
θ
ψ
packet
Pack net_fdm Packet for FlightGear
Version Selected: v2018.2
Send net_fdm packet to FlightGear
Send net_fdm Packet to FlightGear
GEN FG RUN
Generate Run Script
Receive net_ctrl packet from FlightGear
Receive net_ctrl Packet from FlightGear
Version Selected: v2018.2
packet
wind_speed_kt
wind_dir_deg
turbulence_norm
temp_c
press_inhg
hground
magvar
icing
Unpack net_ctrl Packet from FlightGear
Version Selected: v2018.2

- Receive net_ctrl Packet from FlightGear — Receives a network control and environment data packet `net_ctrl` from either the simulation of a Simulink model in the FlightGear simulator, or from a FlightGear session.
- Unpack net_ctrl Packet from FlightGear — Unpacks net_ctrl variable packets received from FlightGear and makes them available for the Simulink environment.
- Generate Run Script — Generates a customized FlightGear run script on the current platform.

For an example of how to use these blocks to send data to a Simulink model, see `HL-20 with FlightGear Interface`.

These blocks use UDP to transfer data from FlightGear to the Simulink environment. Note the following:

- When a host and target are Windows or Linux platforms, you can use any combination of Windows or Linux platforms for the host and target.
- When a host or target is a Mac platform, use only Mac platforms for both the host and target.

Macintosh Platform and FlightGear Version 2.6 or Later

On a Macintosh system with FlightGear v2.6 or later, you might see unexpected results (for example, very large or very small data values) if your model uses the following blocks:

- Receive net_ctrl Packet from FlightGear
- Unpack net_ctrl Packet from FlightGear

To work around this issue:

1. In the model, change the **FlightGear version** parameter to `v2.4` for both blocks.
2. Save and rerun the model.

   The results should now be as expected.

Projects Template for Flight Simulation Applications

Flight Simulation Applications

Use projects (Simulink) to help organize large flight simulation modeling projects and makes it easier to share projects with others. This template provides a framework for the collaborative development of a flight simulation application. You can customize this project structure for specific applications.

Note To successfully run this example, install a C/C++ compiler.

The Aerospace Blockset software supplies a projects template that you can use to create your own flight simulation application. This template uses variant subsystems, model variants, and referenced models to implement flight simulation application components such as:

- An airframe that contains a 6DOF equation of motion environment model and actuator dynamics
- An inertial measurement unit (IMU) sensor model
- A visualization subsystem oriented for FlightGear
- A model of the nonlinear dynamics of the airframe
- A model of the linear dynamics of the airframe

Download the Flight Simulation Template

1. From the Simulink Start Page, select **Flight Simulation**.
2. In the Create Project window, in **Name**, enter a project name, for example `FlightSimProj`.
3. In **Folder**, enter a project folder or browse to the folder to contain the project, for example `FlightSimFolder`.
4. Click **OK**.

   If the folder does not exist, the dialog prompts you to create it. Click **Yes**.

   The software compiles the project, populates the project folders, and opens the main model, `flightSimulation`. All models and supporting files are in place for you to customize for your flight simulation application.

Contents of the Project Template

The flight simulation project template contains the following folders

- **mainModels**

  Contains the top-level simulation model, `flightSimulation`.This model opens on startup. This file contains the top-level blocks for the flight simulation environment. Simulink uses the Variant Subsystem, Model Variants, and Model blocks at this level to adapt to the different simulation conditions.

  - The aircraft airframe can vary between a nonlinear an linear approach.
  - The commands to the aircraft can vary between a Signal Editor block, a joystick or a variable from the workspace.
  - Sensors can vary between models that include sensor dynamics or feedthrough (no associated dynamics).
  - Environment values can vary between state-dependent values (the values of temperature, pressure and so on depend on local position, latitude, etc.) or constant values that do not depend on state values.
  - The Visualization subsystem provides hooks that let you work with the states. For example, you can visualize the states using FlightGear or they can be recorded in a variable in the workspace for further analysis. States can also be visualized using the Simulation Data Inspector.
- **libraries**
- Contains the libraries used by the models.
- **nonlinearAirframe**

  Contains a model of the nonlinear dynamics of the airframe.

  - A specific subsystem (AC model) that contains a placeholder for the dynamics of your aircraft model . The characteristics of this subsystem are:

    - Actuators and environment inputs. Actuators refer to generic signals that may affect the behavior of the aircraft (for example an electric signal in voltage that will change the position of the hydraulic actuator connected to a control surface such as an aileron).
    - Forces and moments outputs. Effective in the center of gravity of the aircraft in body axis.

  - A 6DOF Body Quaternion block that solves the differential equations of forces and moments to obtain the aircraft states.
- **linearAirframe**

  Contains the linear dynamics of the airframe and the model to obtain these linear dynamics. The example obtains these dynamics by linearizing the nonlinear model using the `trimLinearizeOpPoint` function and `trimNonlinearAirframe` model. This function uses “Simulink Control Design” software to perform the linearization. It performs linearization of the nonlinear model for a given set of known inputs and conditions. For further information regarding trim and linearization, see the Simulink Control Design™ documentation). The `trimLinearizeOpPoint` function stores the output in a MAT-file.
- **controller**

  Contains the models for the Flight Control System (FCS) and its design. These models contain referenced models for different controller architectures needed for the design of aircraft simulation.
- **src**

  Contains source code such as C code. For simulation, it also has two folders that contain S-functions for simulation. These S-functions map buses to vectors and vice versa for the linear airframe model. This mapping can be changed depending on the linearization scheme, and the set of inputs and outputs for the model. To edit the indices for the different signals, you can use the S-Function Builder block
- **tasks**

  Contains scripts to run the model. These scripts do not run continuously during the simulation process.

  The folder also contains the non-virtual bus definitions for the states, environment, and sensor buses. These definitions, set the signals and characteristics that different elements in the simulation environment use. This folder also contains the definitions for the variables used in the mask workspace for the Sensors, FlightGear, linearAirframe and nonlinearAirframe blocks. These utilities store parameter values in data structures. For example, if the nonlinear model uses a parameter for a Gain block, the stored variable in the structure is `Vehicle.Nonlinear.Gain.gainValue`, which points to the parameter.
- **tests**

  Contains a sample test harness:

    - The `linearTest` file contains the actual test point. This file compares a subset of the outputs of the linearized airframe model to the outputs of the nonlinear airframe for the specific trim condition.
    - The `runProjectTests` file runs all the available files classified as "Tests" in the project.
- **utilities**

  Contains project-specific maintenance task utilities, such as:

  - `projectPaths` - Lists the location of folders to be added to the MATLAB path.
  - `rebuildSFunction` - Rebuilds S-functions for `linearInputBus` and `linearOutputBus`.
  - `startVars` - Defines the variables that the simulation environment requires to be in the base workspace. This utility also controls variants using the `Variants` structure. This structure lets the example switch between the nonlinear and linear airframefrom the workspace by changing `VSS_VEHICLE` from `1` (for the nonlinear model) to `0` (for the linear model). For more information on subsystem variants see Model.
- **work**

  Contains files generated from every run. These files derive from source files, such as the MEX-file that you build from S-function C code.

In Shortcuts, projects creates shortcuts for common tasks:

- **Initialize Variables** — Runs the `startVars` script, which initializes the variables to the base workspace.
- **Rebuild S-functions** —Rebuilds the S-functions in the `src` folder.
- **Run Project Tests** —Runs the test points, labeled **Tests**, for test files in the project.
- **Top Level Simulation Model** — Opens the `flightSimulation` model. It runs on project startup.

Template Labels

Provides file classification labels for automatic and componentization sorting. This utility adds template labels such as **Tests**, **Airframe Design**, **Flight Controller Design**, and **Calibration Data**.

Add Airframe Dynamics and Controller Algorithm to the Project

1. To open the `linearAirframe` model, in `flightSimulation` double-click the Airframe subsystem.
2. Double-click the Nonlinear subsystem.
3. In the AC model, add your airframe dynamics.
4. Save the model.

Add Controller Algorithm to the Project

1. To open the `flightControlSystem` model, in `flightSimulation`, double-click the FCS subsystem.
2. In the Controller subsystem, add your controller algorithm.
3. Save the model.

Other things to try:

- Simulate your model.
- Explore the **tests** folder for sample tests for your application.

See Also

Related Examples

- “Create a New Project Using Templates” (Simulink)
- “Quadcopter Project” on page 6-72

Flight Instrument Gauges

Use the blocks for flight instrument gauges to visualize navigation variables, such as altitude and heading. These blocks, located in the Flight Instruments library, represent standard cockpit instruments:

- Airspeed Indicator
- Altimeter
- Artificial Horizon
- Climb Rate Indicator
- Exhaust Gas Temperature (EGT) Indicator
- Heading Indicator
- Revolutions Per Minute (RPM) Indicator
- Turn Coordinator

See Also

Airspeed Indicator | Altimeter | Artificial Horizon | Climb Rate Indicator | Exhaust Gas Temperature (EGT) Indicator | Heading Indicator | Revolutions Per Minute (RPM) Indicator | Turn Coordinator

Related Examples

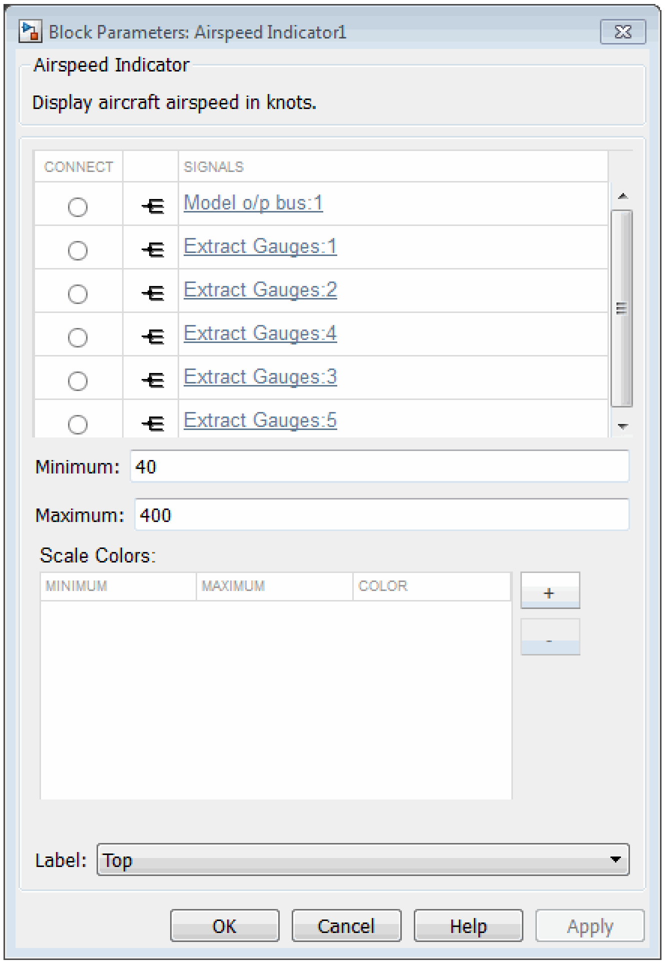
- “Display Measurements with Cockpit Instruments” on page 2-49
- “Programmatically Interact with Gauge Band Colors” on page 2-52

Display Measurements with Cockpit Instruments

You can view signal data using any of the flight instrument blocks. This example uses the "HL-20 with Flight Instrumentation Blocks" on page 6-31 model. In this example, connect a gauge so that you can view the aircraft heading.

1. To open the model, at the MATLAB command window, enter `aeroblk_HL20_Gauges`.
2. Open the Visualization subsystem.

   There is an existing Airspeed Indicator block in the model.
3. Add a second Airspeed Indicator block from the Flight Instruments library to the subsystem.
4. Open the new Airspeed Indicator block.
5. Select the Extract Flight Instruments block.
6. In the new Airspeed Indicator block, observe that the block connection table is filled with signals from the Extract Flight Instruments block that you can observe.



Block Parameters: Airspeed Indicator1

Airspeed Indicator

Display aircraft airspeed in knots.

CONNECT		SIGNALS
○	⋲	Model o/p bus:1
○	⋲	Extract Gauges:1
○	⋲	Extract Gauges:2
○	⋲	Extract Gauges:4
○	⋲	Extract Gauges:3
○	⋲	Extract Gauges:5

Minimum: 40

Maximum: 400

Scale Colors:

MINIMUM	MAXIMUM	COLOR

Label: Top

7 Select the option button next to `Extract_Gauges:2` in the connection table.

8 To connect the `Extract_Gauges:2` signal to the Airspeed Indicator block, click **OK**.

Tip To directly select the signal to connect, on the Extract Flight Instruments block, select the third output port (Roll Flightpath).

9 Simulate the model and observe the gauge as it registers the data.

10 To change the signal to connect to, you can:

- Select the same or another block and then select another signal in the updated block connection table.
- Select another output port for the same or a different block.

11 Close the model without saving it.

To create a Simulink model with prewired connections to flight instrument blocks, see flightControl3DOFAirframeTemplate.

See Also

Airspeed Indicator | Altimeter | Artificial Horizon | Climb Rate Indicator | Exhaust Gas Temperature (EGT) Indicator | Heading Indicator | Revolutions Per Minute (RPM) Indicator | Turn Coordinator

More About

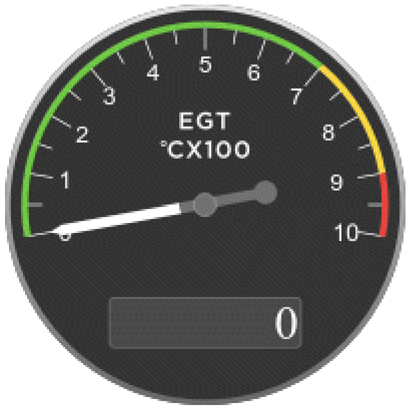
- “Flight Instrument Gauges” on page 2-48
- “Programmatically Interact with Gauge Band Colors” on page 2-52

Programmatically Interact with Gauge Band Colors

Programatically interact with Airspeed Indicator, EGT Indicator, and RPM Indicator gauge band colors using the `ScaleColors` property. When used with `get_param`, this property returns an *n*-by-1 structure containing these elements, where *n* is the number of colored bands on the gauge:

- Min — Minimum value range for a color band
- Max — Maximum value range for a color band
- Color — RGB color triplet for a band (range from 0 to 1)

This example describes how to change a color band of the EGT Indicator gauge. By default, the EGT Indicator gauge looks like this:



This gauge has three bands, clockwise 1, 2, and 3.

1 To change the color bands, get the handle of the scale color objects.

```
sc=get_param(gcb,'ScaleColors')
```

```
sc =

  3×1 struct array with fields:

    Min
    Max
    Color
```

2 To see the values of the `Min`, `Max`, and `Color` values, use the `sc` handle. For example, to see the values of the first band, `sc(1)`, type:

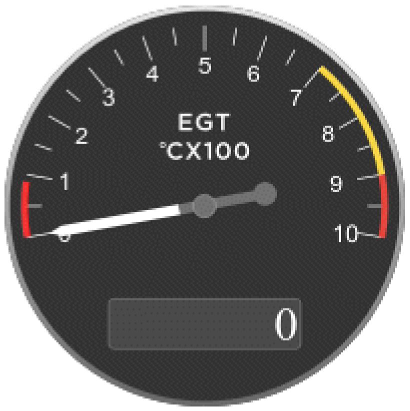
```
sc(1)
```

```
sc(1)

ans = 

  struct with fields:

      Min: 0
      Max: 700
    Color: [0.2980 0.7333 0.0902]
```

3 To change the color and size of this band, define a structure with different `Min`, `Max`, and `Color` values and set `ScaleColors` to that new structure. For example, to change the band range to 1 to 89 and the color to red:

```
sc(1) = struct('Min',1,'Max',89,'Color',[1 0 0]);
set_param(gcb,'ScaleColors',sc)
```

4 Observe the change in the EGT Indicator gauge.



5 You can add and change as many color bands as you need. For example, to add a fourth band and set up the gauge with that band:

```
sc(4) = struct('Min',200,'Max',300,'Color',[0 1 .6]);
set_param(gcb,'ScaleColors',sc)
```

EGT
°CX100
0
1
2
3
4
5
6
7
8
9
10
0

See Also

Airspeed Indicator | Exhaust Gas Temperature (EGT) Indicator | Revolutions Per Minute (RPM) Indicator

More About

- “Flight Instrument Gauges” on page 2-48
- “Display Measurements with Cockpit Instruments” on page 2-49

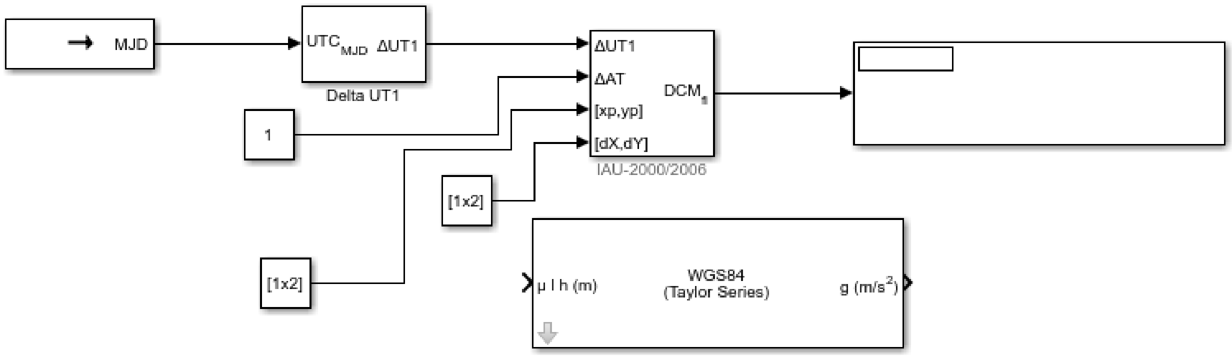
Calculate UT1 to UTC Values

Calculate the difference between principal Universal Time (UT1) and Coordinated Universal Time (UTC) according to International Earth Rotation Service (IERS) by using the Delta UT1 block. Use the Delta UT1 block with these axes transformation blocks:

- LLA to ECI Position
- ECI Position to LLA
- Direction Cosine Matrix ECI to ECEF
- ECI Position to AER

To calculate the difference between UT1 and UTC, the Delta UT1 block requires the modified Julian date. This example uses the Julian Date Conversion block. However, you can calculate the modified Julian data with other methods. For example, you can use the mjuliandate`mjuliandate` function from the Aerospace Toolbox software to calculate the date and input the result to the Delta UT1 block.

Use the Delta UT1 Block to Create Difference Values for the Direction Cosine Matrix ECI to ECEF Block



This model shows how a Direction Cosine Matrix ECI to ECEF block uses the output from the Delta UT1 and Julian Data Conversion blocks to obtain the difference between UTC and Universal Time (UT1).

1. Drag these blocks into a new model and connect them as shown:

- Julian Date Conversion
- Delta UT1
- Direction Cosine Matrix ECI to ECEF
- Display
- Three Constant blocks

2. Set up the Julian Date Conversion to convert the date December 28, 2015 to its modified Julian date equivalent. This date must match the one specified in the Direction Cosine Matrix ECI to ECEF.

   - For **Year**, enter `2015`.
   - For **Month**, enter `12`.
   - For **Day**, enter `28`.
   - To calculate the modified Julian date for December 28, 2015, select the **Calculate modified Julian date** check box.
   - For **Time increment**, select `None`.

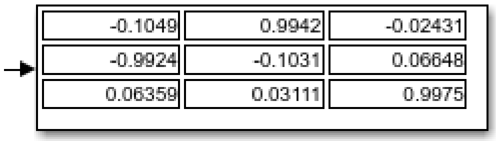
3. Leave the default settings for Delta UT1. By default, the block calculates the difference between Universal Time (UT1) and Universal Coordinated Time (UTC) to using the `aeroiersdata.mat` file supplied with the Aerospace Blocksetsoftware.
4. Set up the Direction Cosine Matrix ECI to ECEF block to work with the Universal Coordinated Time (UTC) December 28, 2015. This date must match the one specified in the Julian Date Conversion block:

   - For **Year**, enter `2015`.
   - For **Month**, enter `12`.
   - For **Day**, enter `28`.
   - For **Time increment**, select `None`.

5. Set up the Δ*UT1*, Δ*AT*, and polar displacement of the Earth inputs for the Direction Cosine Matrix ECI to ECEF.

   - Constant — Set **Constant value** to `1`.
   - Constant1 — Set **Constant value** to `l`.
   - Constant2 — Set **Constant value** to `[.05 .05]`.

6. Save and run the model. Observe the resulting direction cosine matrix in the Display block.



-0.1049	0.9942	-0.02431
-0.9924	-0.1031	0.06648
0.06359	0.03111	0.9975

See Also

Delta UT1 | Direction Cosine Matrix ECI to ECEF | Julian Date Conversion

Analyze Dynamic Response and Flying Qualities of Aerospace Vehicles

Aerospace Blockset provides flight control analysis tools that you can use to analyze the dynamic response and flying qualities of aerospace vehicles.

- "Flight Control Analysis Live Scripts" on page 2-58 — MATLAB live scripts demonstrate dynamic response and flying quality analysis of Sky Hogg and de Havilland Beaver airframes.
- "Modify Flight Control Analysis Templates" on page 2-61 — You can use templates to analyze the flying qualities of 3 degree-of-freedom and 6 degree-of-freedom airframe models. When you are comfortable running the analysis on the default airframes, you can replace them with your own airframe and analyze it.

Note Analyzing dynamic response and flying qualities of airframes requires a Simulink Control Design license.

Flight Control Analysis Live Scripts

Each flight control analysis template has an associated MATLAB live script that guides you through a flying quality analysis workflow for the default airframe. You can interact with the script and explore the analysis workflow.

- DehavillandBeaverFlyingQualityAnalysis — Compute longitudinal and lateral-directional flying qualities for a Dehavilland Beaver airframe.
- SkyHoggLongitudinalFlyingQualityAnalysis — Compute longitudinal flying qualities for a Sky Hogg airframe.

For more information on running live scripts, see "Run Sections in Live Scripts" (MATLAB).

1 Open one of the templates, for example:

  ```
  asbFlightControlAnalysis('6DOF')
  ```

  Navigate to the **Getting Started** section and click the first link.

  Alternatively, in the Command Window, type:

```
open('DehavillandBeaverFlyingQualityAnalysis')
```

2. The script describes how to use eigenvalue analysis to determine the longitudinal flying qualities (long-period phugoid mode and short-period mode) and lateral-directional flying qualities (Dutch roll mode, roll mode, and spiral mode) for an aircraft modeled in Simulink.

   As you run the script, when applicable, the results of the runs display inline.

Modify Flight Analysis Templates

Aerospace Blockset provides these templates:

- flightControl6DOFAirframeTemplate — This template uses a six degree-of-freedom airframe configured for linearization and quality analysis. For initialization, the template uses the de Havilland Beaver airframe parameters.
- flightControl3DOFAirframeTemplate — This template uses a 3 degree-of-freedom longitudinal airframe configured for linearization and quality analysis. For initialization, the template uses Sky Hogg airframe parameters.

When you are comfortable navigating the flight control analysis templates with the default airframes, consider customizing the templates for your own airframe model.

Flight Control Analysis Templates

To familiarize yourself with Aerospace Blockset flight control analysis templates:

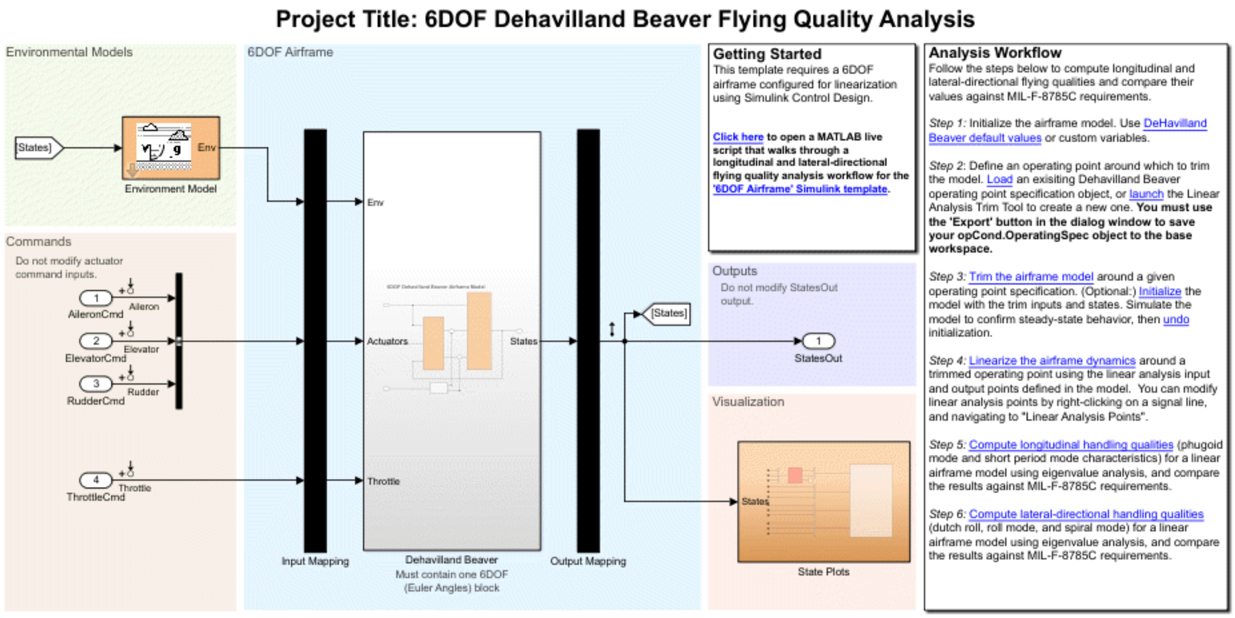
1. Open one of the templates. For example, to start a 3DOF template:

   ```
   asbFlightControlAnalysis('3DOF')
   ```

   To open a 6DOF template:

   ```
   asbFlightControlAnalysis('6DOF')
   ```

   The flight control analysis model opens.



Getting Started

This template requires a 6DOF airframe configured for linearization using Simulink Control Design.

Click here to open a MATLAB live script that walks through a longitudinal and lateral-directional flying quality analysis workflow for the '6DOF Airframe' Simulink template.

Analysis Workflow

Follow the steps below to compute longitudinal and lateral-directional flying qualities and compare their values against MIL-F-8785C requirements.

Step 1: Initialize the airframe model. Use DeHavilland Beaver default values or custom variables.

Step 2: Define an operating point around which to trim the model. Load an exisiting Dehavilland Beaver operating point specification object, or launch the Linear Analysis Trim Tool to create a new one. **You must use the 'Export' button in the dialog window to save your opCond.OperatingSpec object to the base workspace.**

Step 3: Trim the airframe model around a given operating point specification. (Optional:) Initialize the model with the trim inputs and states. Simulate the model to confirm steady-state behavior, then undo initialization.

Step 4: Linearize the airframe dynamics around a trimmed operating point using the linear analysis input and output points defined in the model. You can modify linear analysis points by right-clicking on a signal line, and navigating to "Linear Analysis Points".

Step 5: Compute longitudinal handling qualities (phugoid mode and short period mode characteristics) for a linear airframe model using eigenvalue analysis, and compare the results against MIL-F-8785C requirements.

Step 6: Compute lateral-directional handling qualities (dutch roll, roll mode, and spiral mode) for a linear airframe model using eigenvalue analysis, and compare the results against MIL-F-8785C requirements.

2 The **Analysis Workflow** section contains a clickable guided workflow to compute longitudinal and lateral-directional flying qualities and compare their values against MIL-F-8785C requirements. Each step creates the necessary variables for the following step. To perform the flying quality analysis, sequentially click the links in the steps.

   a Create an operating point specification object in the base workspace for the airframe model using the Linear Analysis Trim Tool. Alternatively, load the default object provided in step 2.

   b To trim the airframe, click **Trim the airframe** in step 3. This action calls the `trimAirframe` function.

   c To linearize the airframe around a trimmed operating point, click **Linearize the airframe** in step 4. This action calls the `linearizeAirframe` function.

   d To compute the longitudinal flying qualities, click **Compute longitudinal handling qualities**. This action calls the `computeLongitudinalFlyingQualities` function.

   e To compute the lateral-directional handling qualities, click **Compute lateral-directional handling qualities** in step 6. This action calls the `computeLateralDirectionalFlyingQualities` function.

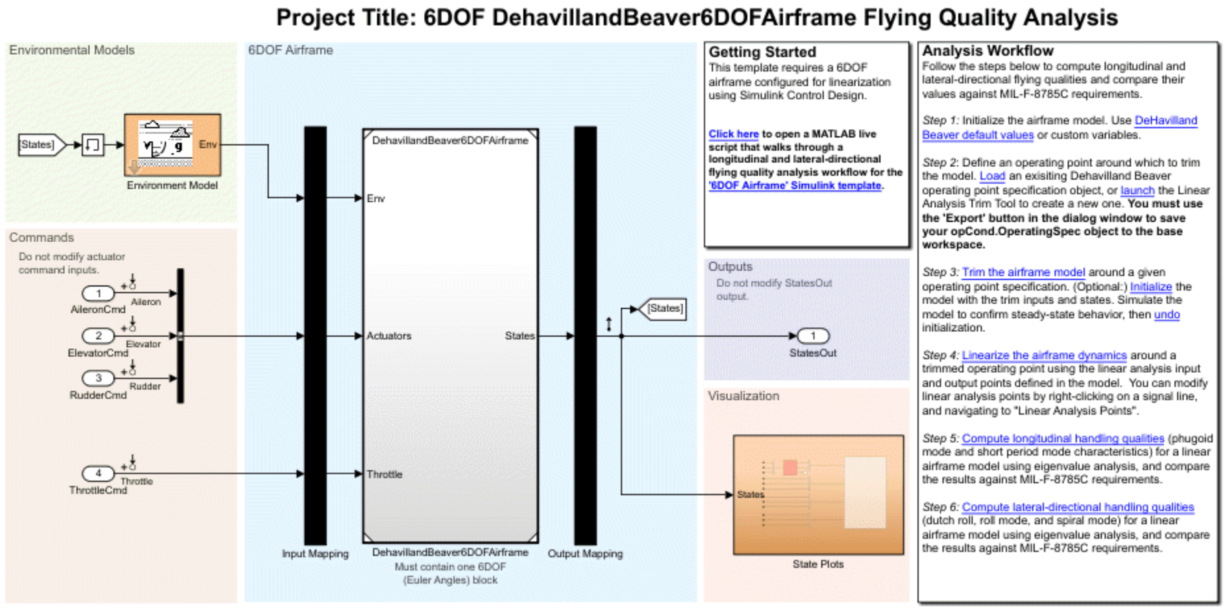
Modify Flight Control Analysis Templates

When you are comfortable using the 3DOF and/or 6DOF flight control analysis templates on page 2-59 to trim, linearize, and compute the longitudinal and lateral-directional handling qualities for the default airframes, consider customizing the templates to include your own airframe.

1 Open a 3DOF or 6DOF template and change the airframe to one of your own. For example, to change the template airframe to an external model:

```
asbFlightControlAnalysis('6DOF', 'sixDOFAirframeExample','DehavillandBeaver6DOFAirframe')
```

This command replaces the de Havilland Beaver subsystem with the `DehavillandBeaver6DOFAirframe` model and includes it as a referenced model.



Getting Started
This template requires a 6DOF airframe configured for linearization using Simulink Control Design.

Click here to open a MATLAB live script that walks through a longitudinal and lateral-directional flying quality analysis workflow for the '6DOF Airframe' Simulink template.

Analysis Workflow
Follow the steps below to compute longitudinal and lateral-directional flying qualities and compare their values against MIL-F-8785C requirements.

Step 1: Initialize the airframe model. Use DeHavilland Beaver default values or custom variables.

Step 2: Define an operating point around which to trim the model. Load an exisiting Dehavilland Beaver operating point specification object, or launch the Linear Analysis Trim Tool to create a new one. **You must use the 'Export' button in the dialog window to save your opCond.OperatingSpec object to the base workspace.**

Step 3: Trim the airframe model around a given operating point specification. (Optional:) Initialize the model with the trim inputs and states. Simulate the model to confirm steady-state behavior, then undo initialization.

Step 4: Linearize the airframe dynamics around a trimmed operating point using the linear analysis input and output points defined in the model. You can modify linear analysis points by right-clicking on a signal line, and navigating to "Linear Analysis Points".

Step 5: Compute longitudinal handling qualities (phugoid mode and short period mode characteristics) for a linear airframe model using eigenvalue analysis, and compare the results against MIL-F-8785C requirements.

Step 6: Compute lateral-directional handling qualities (dutch roll, roll mode, and spiral mode) for a linear airframe model using eigenvalue analysis, and compare the results against MIL-F-8785C requirements.

Alternatively, in the corresponding canvas, manually replace the default model airframe in the blue area with your own airframe.

2 On the canvas, align the inputs and outputs of the airframe using the Input Mapping and Output Mapping subsystems.

3 Create a new operating point specification object. In the **Analysis Workflow** section, go to step 2 and click the **Launch** link to start the Linear Analysis Trim Tool.

4 To save your `opCond.OperatingSpec` object to the base workspace, click the **Export** button in the dialog window.

5 To trim, linearize, and compute the longitudinal and lateral-directional handling qualities for the airframe model, click the links in workflow steps 3, 4, 5, and 6.

Explore Flight Control Analysis Functions

The flight control analysis live scripts and template workflows use these functions:

- `asbFlightControlAnalysis`
- `trimAirframe`
- `linearizeAirframe`
- `computeLongitudinalFlyingQualities`
- `computeLateralDirectionalFlyingQualities`

To customize your own scripts to trim airframes around operating points, linearize airframes, and calculate longitudinal and lateral-directional handling qualities, you can use these functions in a workflow as follows:

1 Create a flight control analysis template using the `asbFlightControlAnalysis` function.

2 Trim the airframe model around an operating point using the `trimAirframe` function.

   This step creates a trimmed operating point, required by the `linearizeAirframe` function.

3 Linearize the airframe model around the trimmed operating point using the `linearizeAirframe` function.

   This step creates a state space model that describes the linearized dynamics of the airframe model at a trimmed operating point.

4 Compute the flying qualities for the airframe, including short- and long-period (phugoid) mode characteristics of the specified state space model, using `computeLongitudinalFlyingQualities`, and lateral-directional (Dutch roll, roll, and spiral) mode characteristics, using `computeLateralDirectionalFlyingQualities`.

For example:

```
asbFlightControlAnalysis('6DOF', 'DehavillandBeaverAnalysisModel');
opSpecDefault = DehavillandBeaver6DOFOpSpec('DehavillandBeaverAnalysisModel');
opTrim = trimAirframe('DehavillandBeaverAnalysisModel', opSpecDefault);
linSys = linearizeAirframe('DehavillandBeaverAnalysisModel', opTrim);
lonFlyingQual = computeLongitudinalFlyingQualities('DehavillandBeaverAnalysisModel', linSys)
latFlyingQual = computeLateralDirectionalFlyingQualities('DehavillandBeaverAnalysisModel', linSys)
```

See Also

Linear Analysis Tool | `asbFlightControlAnalysis` | `computeLateralDirectionalFlyingQualities` | `computeLongitudinalFlyingQualities` | `linearizeAirframe` | `trimAirframe`

Case Studies

Ideal Airspeed Correction

In this section...

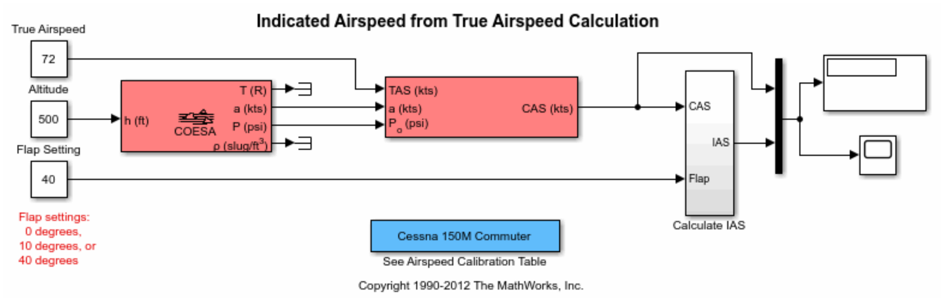
Introduction

This case study simulates indicated and true airspeed. It constitutes a fragment of a complete aerodynamics problem, including only measurement and calibration.

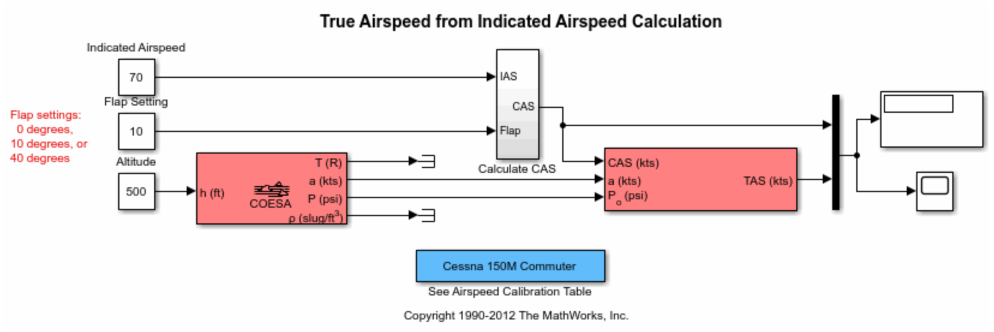
Airspeed Correction Models

To view the airspeed correction models, enter the following at the MATLAB command line:

```
aeroblk_indicated
aeroblk_calibrated
```


Indicated Airspeed from True Airspeed Calculation
True Airspeed
72
Altitude
500
Flap Setting
40
Flap settings: 0 degrees, 10 degrees, or 40 degrees
h (ft)
COESA
T (R)
a (kts)
P (psi)
ρ (slug/ft³)
TAS (kts)
a (kts)
P_o (psi)
CAS (kts)
CAS
IAS
Flap
Calculate IAS
Cessna 150M Commuter
See Airspeed Calibration Table
Copyright 1990-2012 The MathWorks, Inc.

aeroblk_indicated Model


True Airspeed from Indicated Airspeed Calculation
Indicated Airspeed
70
Flap Setting
10
Flap settings: 0 degrees, 10 degrees, or 40 degrees
Altitude
500
h (ft)
COESA
T (R)
a (kts)
P (psi)
ρ (slug/ft³)
IAS
CAS
Flap
Calculate CAS
CAS (kts)
a (kts)
Po (psi)
TAS (kts)
Cessna 150M Commuter
See Airspeed Calibration Table
Copyright 1990-2012 The MathWorks, Inc.

aeroblk_calibrated Model

Measure Airspeed

To measure airspeed, most light aircraft designs implement pitot-static airspeed indicators based on Bernoulli's principle. Pitot-static airspeed indicators measure airspeed by an expandable capsule that expands and contracts with increasing and decreasing dynamic pressure. This is known as *calibrated airspeed* (CAS). It is what a pilot sees in the cockpit of an aircraft.

To compensate for measurement errors, it helps to distinguish three types of airspeed. These types are explained more completely in the following.

Airspeed Type	Description
Calibrated	Indicated airspeed corrected for calibration error
Equivalent	Calibrated airspeed corrected for compressibility error
True	Equivalent airspeed corrected for density error

Calibration Error

An airspeed sensor features a static vent to maintain its internal pressure equal to atmospheric pressure. Position and placement of the static vent with respect to the angle of attack and velocity of the aircraft determines the pressure inside the airspeed sensor and therefore the calibration error. Thus, a calibration error is specific to an aircraft's design.

An airspeed calibration table, which is usually included in the pilot operating handbook or other aircraft documentation, helps pilots convert the indicated airspeed to the calibrated airspeed.

Compressibility Error

The density of air is not constant, and the compressibility of air increases with altitude and airspeed, or when contained in a restricted volume. A pitot-static airspeed sensor contains a restricted volume of air. At high altitudes and high airspeeds, calibrated airspeed is always higher than equivalent airspeed. Equivalent airspeed can be derived by adjusting the calibrated airspeed for compressibility error.

Density Error

At high altitudes, airspeed indicators read lower than true airspeed because the air density is lower. True airspeed represents the compensation of equivalent airspeed for the density error, the difference in air density at altitude from the air density at sea level, in a standard atmosphere.

Model Airspeed Correction

The `aeroblk_indicated` and `aeroblk_calibrated` models show how to take true airspeed and correct it to indicated airspeed for instrument display in a Cessna 150M Commuter light aircraft. The `aeroblk_indicated` model implements a conversion to indicated airspeed. The `aeroblk_calibrated` model implements a conversion to true airspeed.

Each model consists of two main components:

- “COESA Atmosphere Model Block” on page 3-4 calculates the change in atmospheric conditions with changing altitude.
- “Ideal Airspeed Correction Block” on page 3-5 transforms true airspeed to calibrated airspeed and vice versa.

COESA Atmosphere Model Block

The COESA Atmosphere Model block is a mathematical representation of the U.S. 1976 COESA (Committee on Extension to the Standard Atmosphere) standard lower atmospheric values for absolute temperature, pressure, density, and speed of sound for input geopotential altitude. Below 32,000 meters (104,987 feet), the U.S. Standard

Atmosphere is identical with the Standard Atmosphere of the ICAO (International Civil Aviation Organization).

The `aeroblk_indicated` and `aeroblk_calibrated` models use the COESA Atmosphere Model block to supply the speed of sound and air pressure inputs for the Ideal Airspeed Correction block in each model.

Ideal Airspeed Correction Block

The Ideal Airspeed Correction block compensates for airspeed measurement errors to convert airspeed from one type to another type. The following table contains the Ideal Airspeed Correction block's inputs and outputs.

Airspeed Input	Airspeed Output
True Airspeed	Equivalent airspeed
	Calibrated airspeed
Equivalent Airspeed	True airspeed
	Calibrated airspeed
Calibrated Airspeed	True airspeed
	Equivalent airspeed

In the `aeroblk_indicated` model, the Ideal Airspeed Correction block transforms true to calibrated airspeed. In the `aeroblk_calibrated` model, the Ideal Airspeed Correction block transforms calibrated to true airspeed.

The following sections explain how the Ideal Airspeed Correction block mathematically represents airspeed transformations:

- "True Airspeed Implementation" on page 3-5
- "Calibrated Airspeed Implementation" on page 3-6
- "Equivalent Airspeed Implementation" on page 3-6

True Airspeed Implementation

True airspeed (TAS) is implemented as an input and as a function of equivalent airspeed (EAS), expressible as

$$TAS = \frac{EAS \times a}{a_0\sqrt{\delta}}$$

where

α	Speed of sound at altitude in m/s
δ	Relative pressure ratio at altitude
a_0	Speed of sound at mean sea level in m/s

Calibrated Airspeed Implementation

Calibrated airspeed (CAS), derived using the compressible form of Bernoulli's equation and assuming isentropic conditions, can be expressed as

$$CAS = \sqrt{\frac{2\gamma P_0}{(\gamma - 1)\rho_0}\left[\left(\frac{q}{P_0} + 1\right)^{(\gamma - 1)/\gamma} - 1\right]}$$

where

ρ_0	Air density at mean sea level in kg/m^3
P_0	Static pressure at mean sea level in N/m^2
γ	Ratio of specific heats
q	Dynamic pressure at mean sea level in N/m^2

Equivalent Airspeed Implementation

Equivalent airspeed (EAS) is the same as CAS, except static pressure at sea level is replaced by static pressure at altitude.

$$EAS = \sqrt{\frac{2\gamma P}{(\gamma - 1)\rho_0}\left[\left(\frac{q}{P} + 1\right)^{(\gamma - 1)/\gamma} - 1\right]}$$

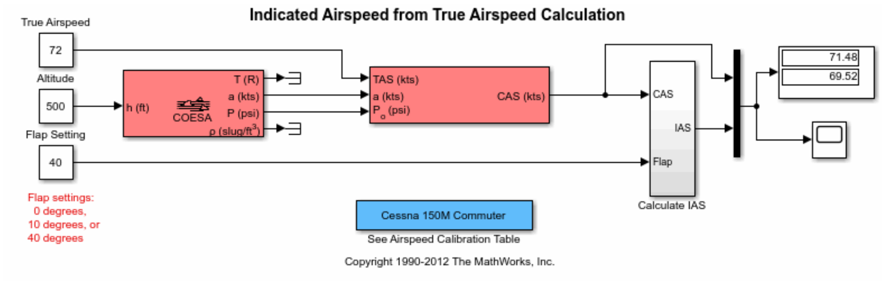
The symbols are defined as follows:

ρ_0	Air density at mean sea level in kg/m^3
P	Static pressure at altitude in N/m^2
γ	Ratio of specific heats
q	Dynamic pressure at mean sea level in N/m^2

Simulate Airspeed Correction

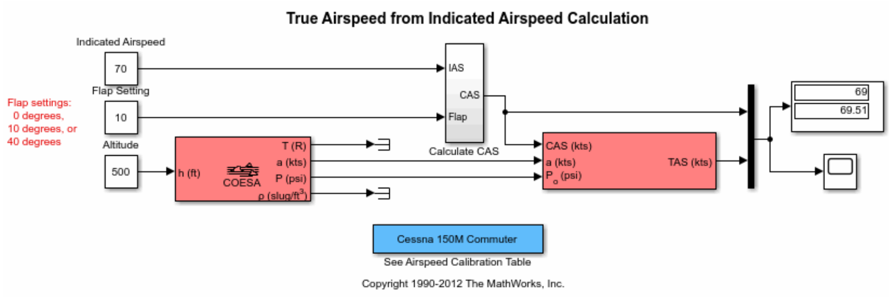
In the `aeroblk_indicated` model, the aircraft is defined to be traveling at a constant speed of 72 knots (true airspeed) and altitude of 500 feet. The flaps are set to 40 degrees. The COESA Atmosphere Model block takes the altitude as input and outputs the speed of sound and air pressure. Taking the speed of sound, air pressure, and airspeed as inputs, the Ideal Airspeed Correction block converts true airspeed to calibrated airspeed. Finally, the Calculate IAS subsystem uses the flap setting and calibrated airspeed to calculate indicated airspeed.

The model's Display block shows both indicated and calibrated airspeeds.



In the `aeroblk_calibrated` model, the aircraft is defined to be traveling at a constant speed of 70 knots (indicated airspeed) and altitude of 500 feet. The flaps are set to 10 degrees. The COESA Atmosphere Model block takes the altitude as input and outputs the speed of sound and air pressure. The `Calculate CAS` subsystem uses the flap setting and indicated airspeed to calculate the calibrated airspeed. Finally, using the speed of sound, air pressure, and true calibrated airspeed as inputs, the Ideal Airspeed Correction block converts calibrated airspeed back to true airspeed.

The model's Display block shows both calibrated and true airspeeds.


True Airspeed from Indicated Airspeed Calculation
Indicated Airspeed
70
Flap Setting
10
Flap settings:
0 degrees,
10 degrees, or
40 degrees
Altitude
500
h (ft)
COESA
T (R)
a (kts)
P (psi)
ρ (slug/ft³)
IAS
CAS
Flap
Calculate CAS
CAS (kts)
a (kts)
Po (psi)
TAS (kts)
69
69.51
Cessna 150M Commuter
See Airspeed Calibration Table
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1903 Wright Flyer

In this section...

Introduction

Note The final section of this study requires the Simulink 3D Animation software.

This case study describes a model of the 1903 Wright Flyer. Built by Orville and Wilbur Wright, the Wright Flyer took to the skies in December 1903 and opened the age of controlled flight. The Wright brothers' flying machine achieved the following goals:

- Left the ground under its own power
- Moved forward and maintained its speed
- Landed at an elevation no lower than where it started

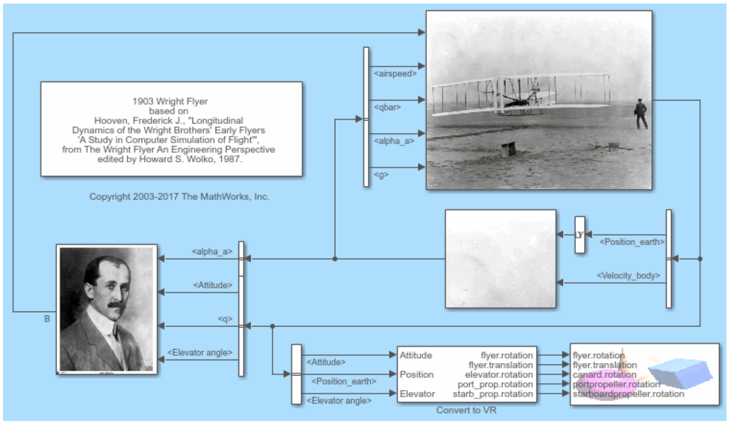
This model is based on an earlier simulation [1] that explored the longitudinal stability of the Wright Flyer and therefore modeled only forward and vertical motion along with the pitch angle. The Wright Flyer suffered from numerous engineering challenges, including dynamic and static instability. Laterally, the Flyer tended to overturn in crosswinds and gusts, and longitudinally, its pitch angle would undulate [2].

Under these constraints, the model recreates the longitudinal flight dynamics that pilots of the Wright Flyer would have experienced. Because they were able to control lateral motion, Orville and Wilbur Wright were able to maintain a relatively straight flight path.

Note, running this model generates information messages in the MATLAB Command Window and assertion warning messages in the Diagnostic Viewer. This is because the model illustrates the use of the Assertion block to indicate that the flyer is hitting the ground when landing.

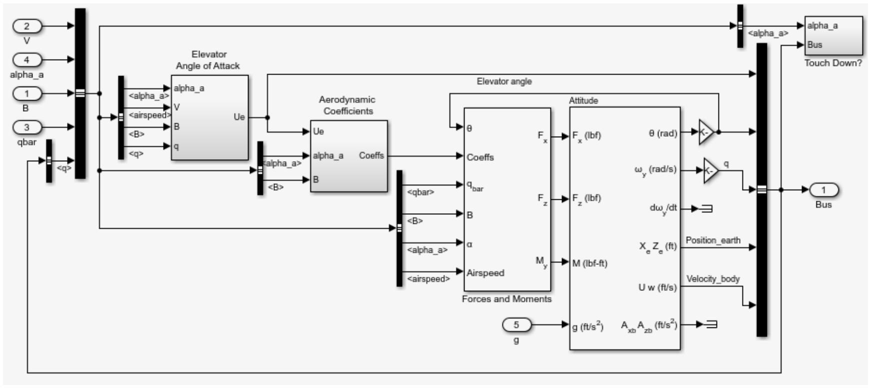
Wright Flyer Model

Open the Wright Flyer model by entering `aeroblk_wf_3dof` at the MATLAB command line.



Airframe Subsystem

The Airframe subsystem simulates the rigid body dynamics of the Wright Flyer airframe, including elevator angle of attack, aerodynamic coefficients, forces and moments, and three-degrees-of-freedom equations of motion.

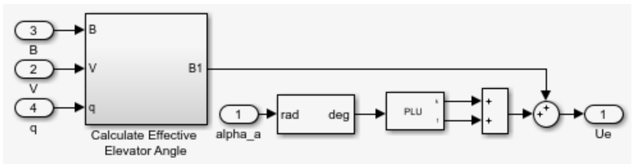


The Airframe subsystem consists of the following parts:

- "Elevator Angle of Attack Subsystem" on page 3-11
- "Aerodynamic Coefficients Subsystem" on page 3-11
- "Forces and Moments Subsystem" on page 3-11
- "3DOF (Body Axes) Block" on page 3-12

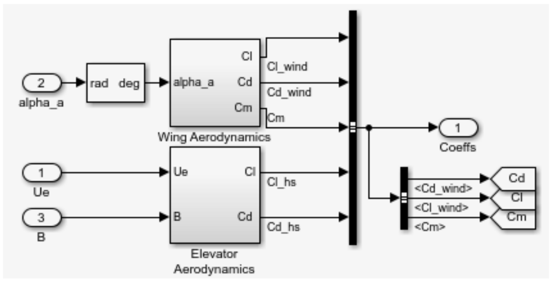
Elevator Angle of Attack Subsystem

The Elevator Angle of Attack subsystem calculates the effective elevator angle for the Wright Flyer airframe and feeds its output to the Pilot subsystem.



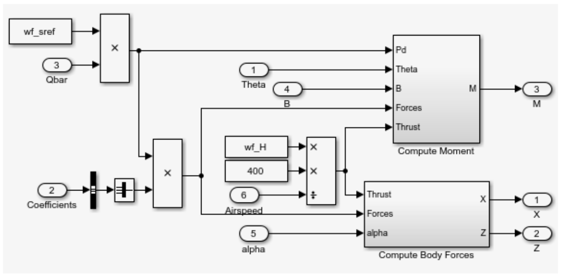
Aerodynamic Coefficients Subsystem

The Aerodynamic Coefficients subsystem contains aerodynamic data and equations for calculating the aerodynamic coefficients, which are summed and passed to the Forces and Moments subsystem. Stored in data sets, the aerodynamic coefficients are determined by interpolation using Prelookup blocks.



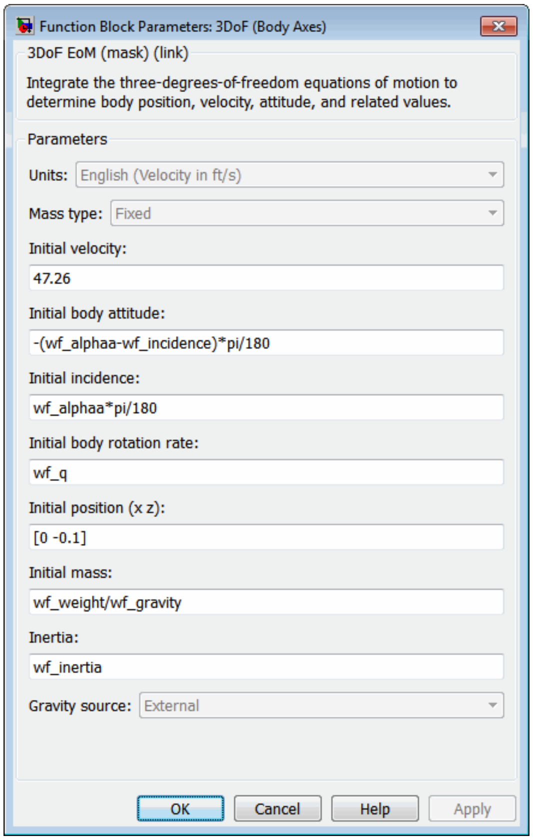
Forces and Moments Subsystem

The aerodynamic forces and moments acting on the airframe are generated from aerodynamic coefficients. The Forces and Moments subsystem calculates the body forces and body moments acting on the airframe about the center of gravity. These forces and moments depend on the aerodynamic coefficients, thrust, dynamic pressure, and reference airframe parameters.



3DOF (Body Axes) Block

The 3DOF (Body Axes) block use equations of motion to define the linear and angular motion of the Wright Flyer airframe. It also performs conversions from the original model's axis system and the body axes.


Function Block Parameters: 3DoF (Body Axes)

3DoF EoM (mask) (link)

Integrate the three-degrees-of-freedom equations of motion to determine body position, velocity, attitude, and related values.

Parameters

Units: English (Velocity in ft/s)

Mass type: Fixed

Initial velocity:
47.26

Initial body attitude:
-(wf_alphaa-wf_incidence)*pi/180

Initial incidence:
wf_alphaa*pi/180

Initial body rotation rate:
wf_q

Initial position (x z):
[0 -0.1]

Initial mass:
wf_weight/wf_gravity

Inertia:
wf_inertia

Gravity source: External

3DOF (Body Axes) Block Parameters

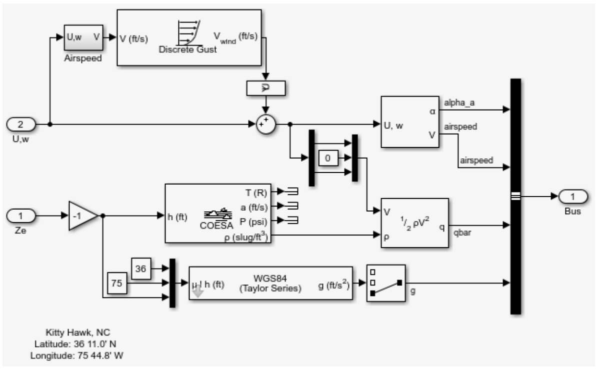
Environment Subsystem

The first and final flights of the Wright Flyer occurred on December 17, 1903. Orville and Wilbur Wright chose an area near Kitty Hawk, North Carolina, situated near the Atlantic coast. Wind gusts of more than 25 miles per hour were recorded that day. After the final flight on that blustery December day, a wind gust caught and overturned the Wright Flyer, damaging it beyond repair.

The Environment subsystem of the Wright Flyer model contains a variety of blocks from the Environment sublibrary of the Aerospace Blockset software, including wind, atmosphere, and gravity, and calculates airspeed and dynamic pressure. The Discrete

Wind Gust Model block provides wind gusts to the simulated environment. The other blocks are

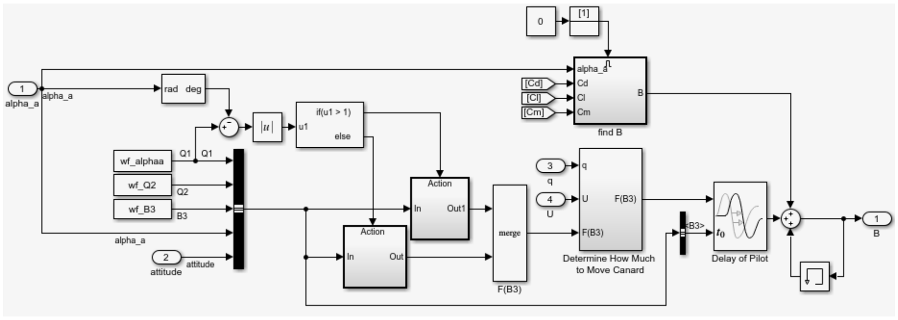
- The Incidence & Airspeed block calculates the angle of attack and airspeed.
- The COESA Atmosphere Model block calculates the air density.
- The Dynamic Pressure block computes the dynamic pressure from the air density and velocity.
- The WGS84 Gravity Model block produces the gravity at the Wright Flyer's latitude, longitude, and height.



Pilot Subsystem

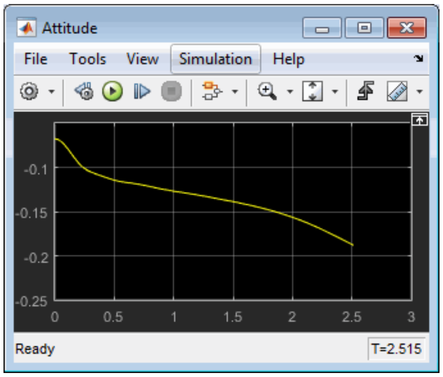
The Pilot subsystem controls the aircraft by responding to both pitch angle (attitude) and angle of attack. If the angle of attack differs from the set angle of attack by more than one degree, the Pilot subsystem responds with a correction of the elevator (canard) angle. When the angular velocity exceeds +/- 0.02 rad/s, angular velocity and angular acceleration are also taken into consideration with additional corrections to the elevator angle.

Pilot reaction time largely determined the success of the flights [1]. Without an automatic controller, a reaction time of 0.06 seconds is optimal for successful flight. The Delay of Pilot (Variable Time Delay) block recreates this effect by producing a delay of no more than 0.08 second.



Run the Simulation

The default values for this simulation allow the Wright Flyer model to take off and land successfully. The pilot reaction time (`wf_B3`) is set to 0.06 seconds, the desired angle of attack (`wf_alphaa`) is constant, and the altitude attained is low. The Wright Flyer model reacts similarly to the actual Wright Flyer. It leaves the ground, moves forward, and lands on a point as high as that from which it started. This model exhibits the longitudinal undulation in attitude of the original aircraft.



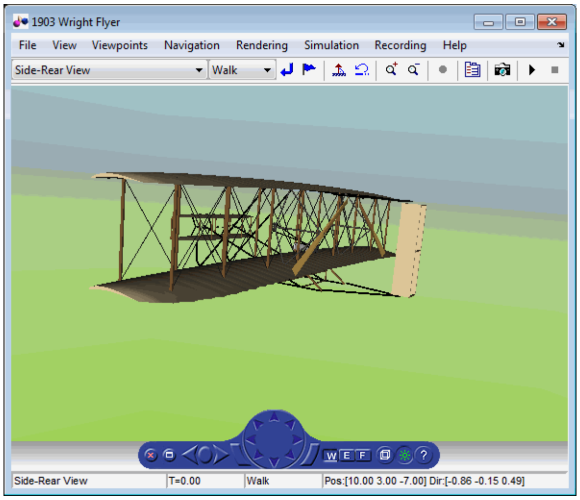
Attitude Scope (Measured in Radians)

A pilot with quick reaction times and ideal flight conditions makes it possible to fly the Wright Flyer successfully. The Wright Flyer model confirms that controlling its longitudinal motion was a serious challenge. The longest recorded flight on that day lasted a mere 59 seconds and covered 852 feet.

Virtual Reality Visualization of the Wright Flyer

Note This section requires the Simulink 3D Animation.

The Wright Flyer model also provides a virtual world visualization, coded in Virtual Reality Modeling Language (VRML) [3]. The VR Sink block in the main model allows you to view the flight motion in three dimensions.


1903 Wright Flyer
File View Viewpoints Navigation Rendering Simulation Recording Help
Side-Rear View
Walk
W E F
Side-Rear View
T=0.00
Walk
Pos:[10.00 3.00 -7.00] Dir:[-0.86 -0.15 0.49]

1903 Wright Flyer Virtual Reality World

References

[1] Hooven, Frederick J., “Longitudinal Dynamics of the Wright Brothers' Early Flyers: A Study in Computer Simulation of Flight,” from *The Wright Flyer: An Engineering Perspective*, ed. Howard S. Wolko, Smithsonian Institution Press, 1987.

[2] Culick, F. E. C. and H. R. Jex, “Aerodynamics, Stability, and Control of the 1903 Wright Flyer,” from *The Wright Flyer: An Engineering Perspective,* ed. Howard S. Wolko, Smithsonian Institution Press, 1987.

[3] Thaddeus Beier created the initial Wright Flyer model in Inventor format, and Timothy Rohaly converted it to VRML.

Additional Information About the 1903 Wright Flyer

- `http://www.wrightexperience.com`
- `https://wright.nasa.gov`

NASA HL-20 Lifting Body Airframe

In this section...

Introduction

This case study models the airframe of a NASA HL-20 lifting body, a low-cost complement to the Space Shuttle orbiter. The HL-20 is unpowered, but the model includes both airframe and controller.

For most flight control designs, the airframe, or plant model, needs to be modeled, simulated, and analyzed. Ideally, this airframe should be modeled quickly, reusing blocks or model structure to reduce validation time and leave more time available for control design. In this study, the Aerospace Blockset software efficiently models portions of the HL-20 airframe. The remaining portions, including calculation of the aerodynamic coefficients, are modeled with the Simulink software. This case study examines the HL-20 airframe model and touches on how the aerodynamic data are used in the model.

NASA HL-20 Lifting Body

The HL-20, also known as the Personnel Launch System (PLS), is a lifting body reentry vehicle designed to complement the Space Shuttle orbiter. It was developed originally as a low-cost solution for getting to and from low Earth orbit. It can carry up to 10 people and a limited cargo [1].

The HL-20 lifting body can be placed in orbit either by launching it vertically with booster rockets or by transporting it in the payload bay of the Space Shuttle orbiter. The HL-20 lifting body deorbits using a small onboard propulsion system. Its reentry profile is nose first, horizontal, and unpowered.

Top-Front View of the HL-20 Lifting Body (Photo: NASA Langley)

The HL-20 design has a number of benefits:

- Rapid turnaround between landing and launch reduces operating costs.
- The HL-20 has exceptional flight safety.
- It can land conventionally on aircraft runways.

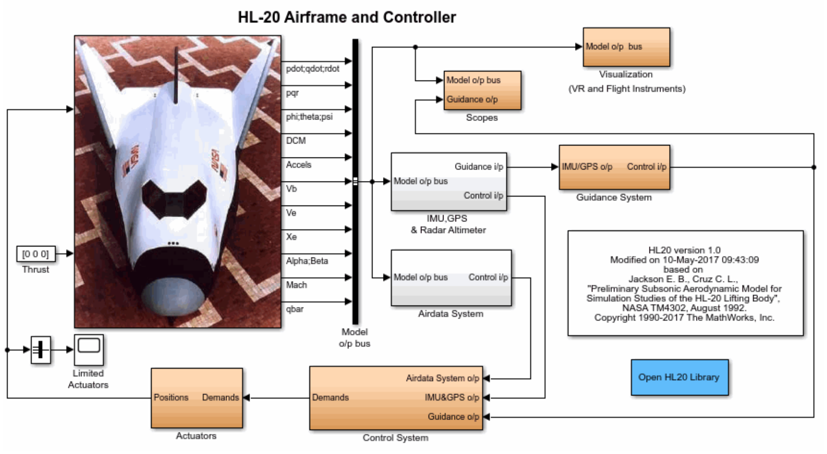
Potential uses for the HL-20 include

- Orbital rescue of stranded astronauts
- International Space Station crew exchanges
- Observation missions
- Satellite servicing missions

Although the HL-20 program is not currently active, the aerodynamic data from HL-20 tests are being used in current NASA projects [2].

The HL-20 Airframe and Controller Model

You can open the HL-20 airframe and controller model by entering `aeroblk_HL20` at the MATLAB command line.



Modeling Assumptions and Limitations

Preliminary aerodynamic data for the HL-20 lifting body are taken from NASA document TM4302 [1].

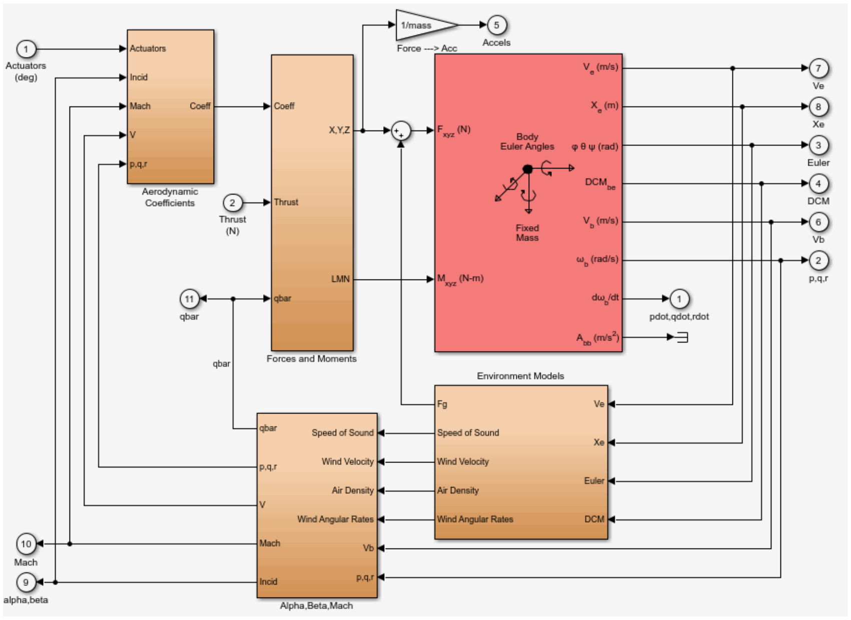
The airframe model incorporates several key assumptions and limitations:

- The airframe is assumed to be rigid and have constant mass, center of gravity, and inertia, since the model represents only the unpowered reentry portion of a mission.
- HL-20 is assumed to be a laterally symmetric vehicle.
- Compressibility (Mach) effects are assumed to be negligible.
- Control effectiveness is assumed to vary nonlinearly with angle of attack and linearly with angle of deflection. Control effectiveness is not dependent on sideslip angle.
- The nonlinear six-degrees-of-freedom aerodynamic model is a representation of an early version of the HL-20. Therefore, the model is not intended for realistic performance simulation of later versions of the HL-20.

The typical airframe model consists of a number of components, such as

- Equations of motion
- Environmental models
- Calculation of aerodynamic coefficients, forces, and moments

The airframe subsystem of the HL-20 model contains five subsystems, which model the typical airframe components:



HL-20 Airframe Subsystem

6DOF (Euler Angles) Subsystem

The 6DOF (Euler Angles) subsystem contains the six-degrees-of-freedom equations of motion for the airframe. In the 6DOF (Euler Angles) subsystem, the body attitude is propagated in time using an Euler angle representation. This subsystem is one of the equations of motion blocks from the Aerospace Blockset library. A quaternion representation is also available. See the 6DOF (Euler Angles) and 6DOF (Quaternion) block reference pages for more information on these blocks.

Environmental Models Subsystem

The Environmental Models subsystem contains the following subsystems and blocks:

- The WGS84 Gravity Model block implements the mathematical representation of the geocentric equipotential ellipsoid of the World Geodetic System (WGS84).

  See the WGS84 Gravity Model block reference page for more information on this block.
- The COESA Atmosphere Model block implements the mathematical representation of the 1976 Committee on Extension to the Standard Atmosphere (COESA) standard lower atmospheric values for absolute temperature, pressure, density, and speed of sound, given the input geopotential altitude.

  See the COESA Atmosphere Model block reference page for more information on this block.
- The Wind Models subsystem contains the following blocks:

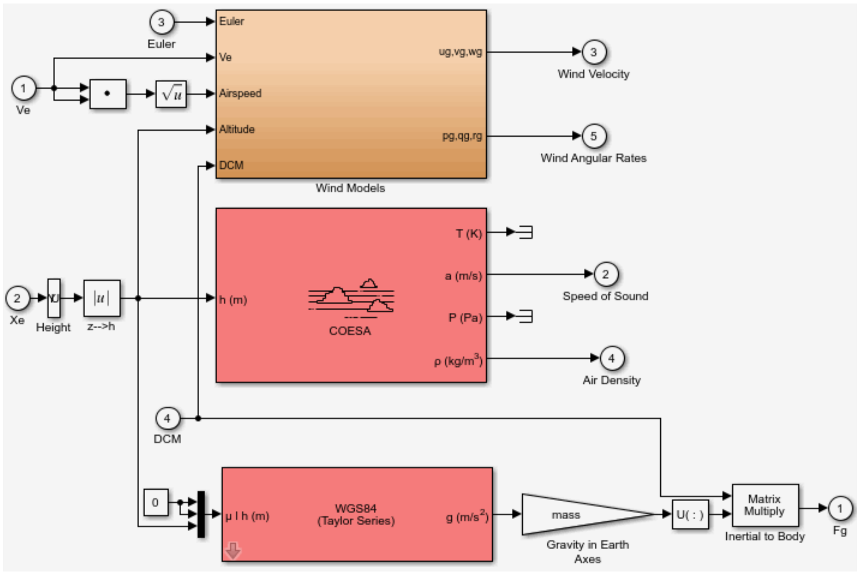
  - The Wind Shear Model block adds wind shear to the model.

    See the Wind Shear Model block reference page for more information on this block.
  - The Discrete Wind Gust Model block implements a wind gust of the standard “1 - cosine” shape.

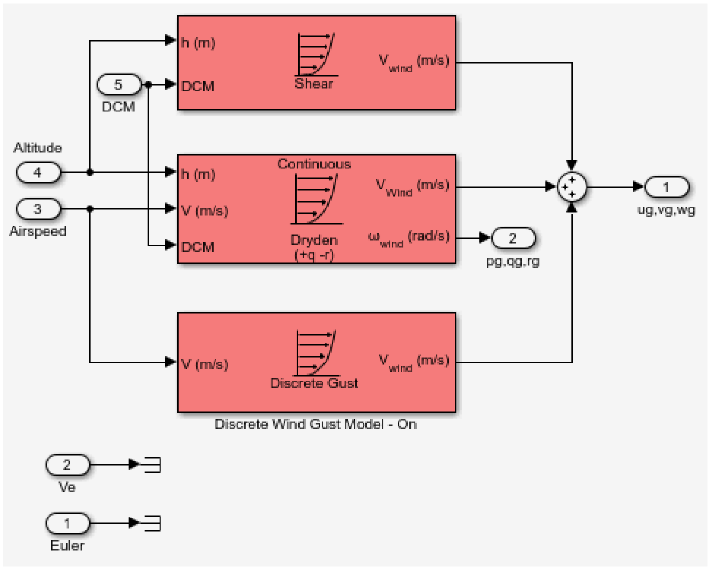
    See the Discrete Wind Gust Model block reference page for more information on this block.
  - The Dryden Wind Turbulence Model (Continuous) block uses the Dryden spectral representation to add turbulence to the aerospace model by passing band-limited white noise through appropriate forming filters.

    See the Dryden Wind Turbulence Model (Continuous) block reference page for more information on this block.

The environmental models implement mathematical representations within standard references, such as U.S. Standard Atmosphere, 1976.



Environmental Models in HL-20 Airframe Model



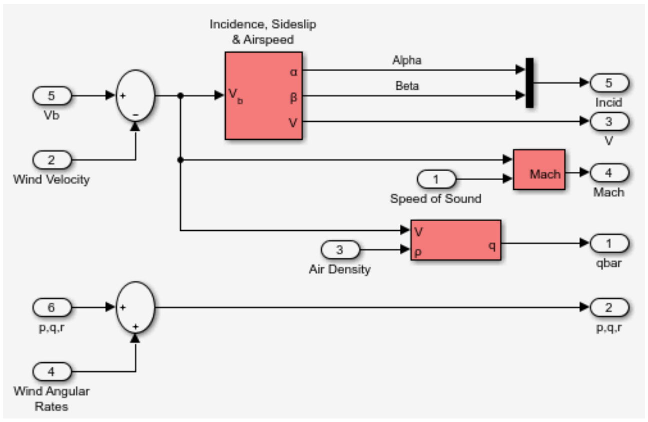
Wind Models in HL-20 Airframe Model

Alpha, Beta, Mach Subsystem

The Alpha, Beta, Mach subsystem calculates additional parameters needed for the aerodynamic coefficient computation and lookup. These additional parameters include

- Mach number
- Incidence angles (α, β)
- Airspeed
- Dynamic pressure

The Alpha, Beta, Mach subsystem corrects the body velocity for wind velocity and corrects the body rates for wind angular acceleration.



Additional Computed Parameters for HL-20 Airframe Model (Alpha, Beta, Mach Subsystem)

Aerodynamic Coefficients Subsystem

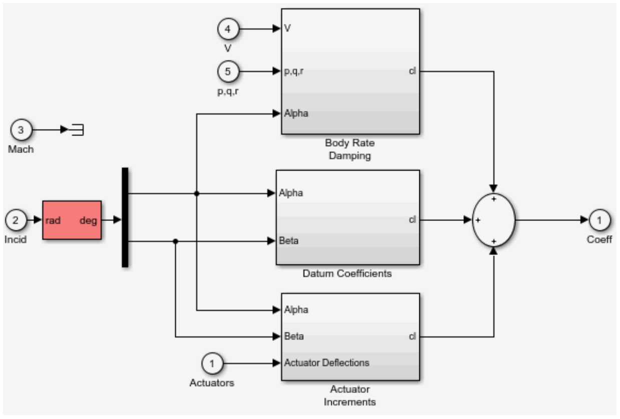
The Aerodynamic Coefficients subsystem contains aerodynamic data and equations for calculating the six aerodynamic coefficients, which are implemented as in reference [1]. The six aerodynamic coefficients follow.

C_x	Axial-force coefficient
C_y	Side-force coefficient
C_z	Normal-force coefficient

C_l	Rolling-moment coefficient
C_m	Pitching-moment coefficient
C_n	Yawing-moment coefficient

Ground and landing gear effects are not included in this model.

The contribution of each of these coefficients is calculated in the subsystems (body rate, actuator increment, and datum), and then summed and passed to the Forces and Moments subsystem.



Aerodynamic Coefficients in HL-20 Airframe Model

The aerodynamic data was gathered from wind tunnel tests, mainly on scaled models of a preliminary subsonic aerodynamic model of the HL-20. The data was curve fitted, and most of the aerodynamic coefficients are described by polynomial functions of angle of attack and sideslip angle. In-depth details about the aerodynamic data and the data reduction can be found in reference [1].

The polynomial functions contained in the `aeroblk_init_hl20.m` file are used to calculate lookup tables used by the model's preload function. Lookup tables substitute for polynomial functions. Depending on the order and implementation of the function, using lookup tables can be more efficient than recalculating values at each time step with functions. To further improve efficiency, most tables are implemented as PreLook-up Index Search and Interpolation (n-D) using PreLook-up blocks. These blocks improve performance most when the model has a number of tables with identical breakpoints. These blocks reduce the number of times the model has to search for a breakpoint in a given time step. Once the tables are populated by the preload function, the aerodynamic coefficient can be computed.

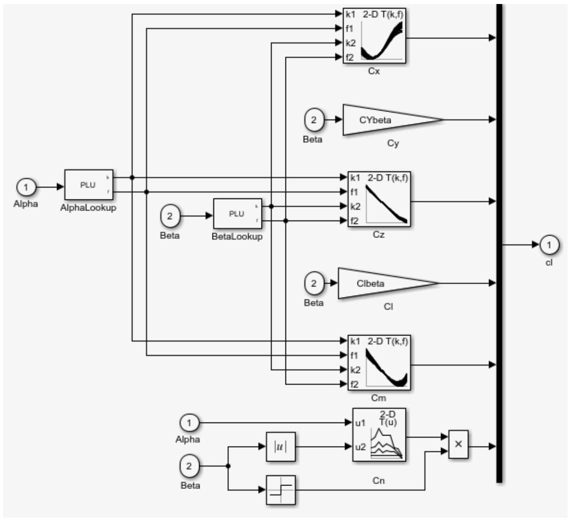
The equations for calculating the six aerodynamic coefficients are divided among three subsystems:

- "Datum Coefficients Subsystem" on page 3-26
- "Body Rate Damping Subsystem" on page 3-26
- "Actuator Increment Subsystem" on page 3-27

Summing the Datum Coefficients, Body Rate Damping, and Actuator Increments subsystem outputs generates the six aerodynamic coefficients used to calculate the airframe forces and moments [1].

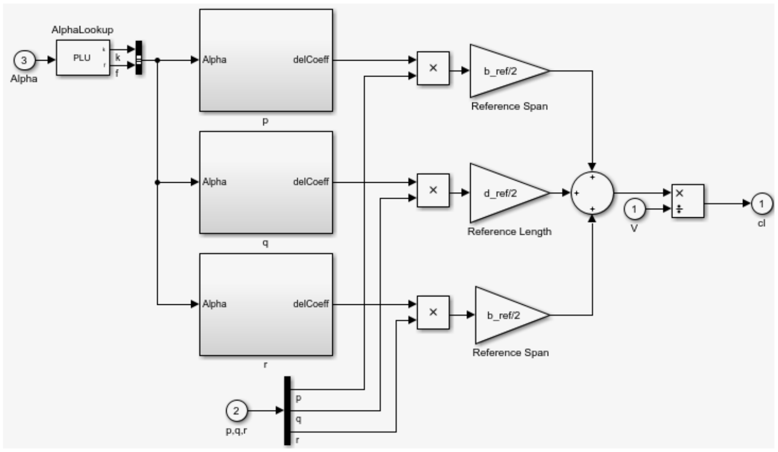
Datum Coefficients Subsystem

The Datum Coefficients subsystem calculates coefficients for the basic configuration without control surface deflection. These datum coefficients depend only on the incidence angles of the body.



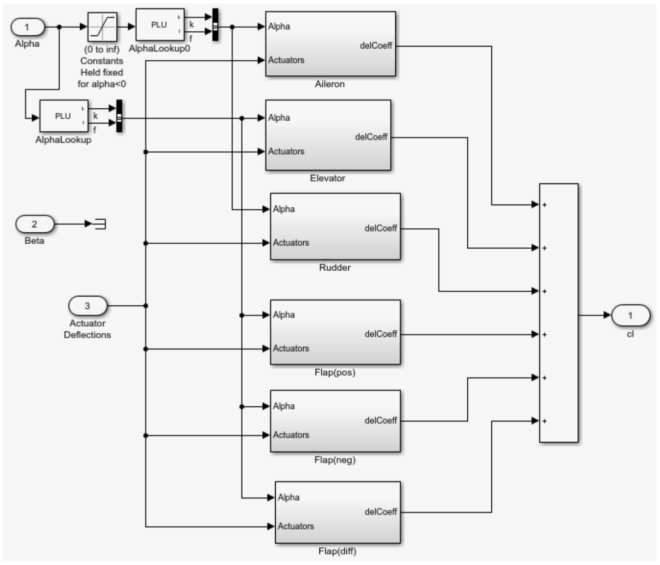
Body Rate Damping Subsystem

Dynamic motion derivatives are computed in the Body Rate Damping subsystem.



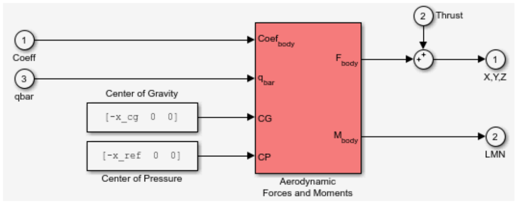
Actuator Increment Subsystem

Lookup tables determine the incremental changes to the coefficients due to the control surface deflections in the Actuator Increment subsystem. Available control surfaces include symmetric wing flaps (elevator), differential wing flaps (ailerons), positive body flaps, negative body flaps, differential body flaps, and an all-movable rudder.



Forces and Moments Subsystem

The Forces and Moments subsystem calculates the body forces and body moments acting on the airframe about the center of gravity. These forces and moments depend on the aerodynamic coefficients, thrust, dynamic pressure, and reference airframe parameters.



Complete the Model

These subsystems that you have examined complete the HL-20 airframe. The next step in the flight control design process is to analyze, trim, and linearize the HL-20 airframe so that a flight control system can be designed for it. You can see an example of an auto-land flight control for the HL-20 airframe in the `aeroblk_HL20` example.

References

[1] Jackson, E. B., and C. L. Cruz, “Preliminary Subsonic Aerodynamic Model for Simulation Studies of the HL-20 Lifting Body,” NASA TM4302 (August 1992).This document is included in the HL-20 Lifting Body `.zip` file available from MATLAB Central.

[2] Morring, F., Jr., “ISS `Lifeboat' Study Includes ELVs,” *Aviation Week & Space Technology* (May 20, 2002).

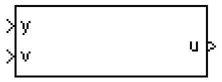
Additional Information About the HL-20 Lifting Body

http://www.astronautix.com/h/hl-20.html

Blocks — Alphabetical List

1D Controller [A(v),B(v),C(v),D(v)]

Implement gain-scheduled state-space controller depending on one scheduling parameter
Library: Aerospace Blockset / GNC / Control



Description

The 1D Controller [A(v),B(v),C(v),D(v)] block implements a gain-scheduled state-space controller, as described in “Algorithms” on page 4-5.

The output from this block is the actuator demand, which you can input to an actuator block.

Limitations

If the scheduling parameter inputs to the block go out of range, they are clipped. The state-space matrices are not interpolated out of range.

Ports

Input

y — Aircraft measurements
vector

Aircraft measurements, specified as a vector.

Data Types: `double`

v — Scheduling variable
vector

Scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

Output

u — Actuator demands
vector

Actuator demands, specified as a vector.

Data Types: `double`

Parameters

`A-matrix(v)` — *A* matrix of the state-space implementation
`A1` (default) | array

A-matrix of the state-space implementation, specified as a array. In the case of 1-D scheduling, the *A*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *A*-matrix corresponding to the first entry of *v* is the identity matrix, then `A(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `A`
Type: character vector
Values: vector
Default: `'A1'`

`B-matrix(v)` — *B* matrix of the state-space implementation
`B1` (default) | array

B-matrix of the state-space implementation, specified as a array. In the case of 1-D scheduling, the *B*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *B*-matrix corresponding to the first entry of *v* is the identity matrix, then `B(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `B`
Type: character vector
Values: vector
Default: `'B1'`

`C-matrix(v)` — *C* matrix of the state-space implementation

`C1` (default) | array

C-matrix of the state-space implementation, specified as a vector. In the case of 1-D scheduling, the *C*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *C*-matrix corresponding to the first entry of *v* is the identity matrix, then `C(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `C`
Type: character vector
Values: vector
Default: `'C1'`

`D-matrix(v)` — *D*

`D1` (default) | array

D-matrix of the state-space implementation, specified as a array. In the case of 1-D scheduling, the *D*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *D*-matrix corresponding to the first entry of *v* is the identity matrix, then `D(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `D`
Type: character vector
Values: vector
Default: `'D1'`

`Scheduling variable breakpoints` — Breakpoints for scheduling variable

`v_vec` (default) | vector

Breakpoints for the scheduling variable, specified as a vector. The length of *v* must be the same as the size of the third dimension of *A*, *B*, *C*, and *D*.

Programmatic Use
Block Parameter: `AoA_vec`
Type: character vector
Values: vector
Default: `'v_vec'`

`Initial state, x_initial` — Initial states

`0` (default) | vector

Initial states for the controller, such as initial values for the state vector, x, specified as a vector. The length of the vector must equal the size of the first dimension of A.

Programmatic Use
Block Parameter: `x_initial`
Type: character vector
Values: vector
Default: `'0'`

Algorithms

The block implements a gain-scheduled state-space controller as defined by this equation:

$$\dot{x} = A(v)x + B(v)y$$
$$u = C(v)x + D(v)y$$

where v is a parameter over which A, B, C, and D are defined. This type of controller scheduling assumes that the matrices A, B, C, and D vary smoothly as a function of v, which is often the case in aerospace applications.

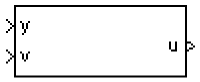
See Also

1D Controller [A(v),B(v),C(v),D(v)] | 1D Observer Form [A(v),B(v),C(v),F(v),H(v)] | 1D Self-Conditioned [A(v),B(v),C(v),D(v)] | 2D Controller [A(v),B(v),C(v),D(v)] | 3D Controller [A(v),B(v),C(v),D(v)] | Linear Second-Order Actuator | Nonlinear Second-Order Actuator

Introduced before R2006a

1D Controller Blend: u=(1-L).K1.y+L.K2.y

Implement 1-D vector of state-space controllers by linear interpolation of their outputs
Library: Aerospace Blockset / GNC / Control



Description

The 1D Controller Blend u=(1-L).K1.y+L.K2.y block implements an array of state-space controller designs. The model runs the controllers in parallel and interpolates their outputs according to the current flight condition or operating point. The advantage of this implementation approach is that the state-space matrices *A*, *B*, *C*, and *D* for the individual controller designs do not need to vary smoothly from one design point to the next. The output from this block is the actuator demand, which you can input to an actuator block.

Limitations

This block requires the Control System Toolbox™ license.

Ports

Input

y — Aircraft measurements
vector

Aircraft measurements, specified as a vector.

Data Types: `double`

v — Scheduling variable
vector

Scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

Output

u — Actuator demands
vector

Actuator demands, specified as a vector.

Data Types: `double`

Parameters

`A-matrix(v)` — *A*-matrix of the state-space implementation
`A1` (default) | array

A-matrix of the state-space implementation, specified as a array. In the case of 1-D blending, the *A*-matrix should have three dimensions, the last one corresponding to scheduling variable *v*. For example, if the *A*-matrix corresponding to the first entry of *v* is the identity matrix, then `A(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `A`
Type: character vector
Values: vector
Default: `'A1'`

`B-matrix(v)` — *B*-matrix of the state-space implementation
`B1` (default) | array

B-matrix of the state-space implementation, specified as a array. In the case of 1-D scheduling, the *B*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *B*-matrix corresponding to the first entry of *v* is the identity matrix, then `B(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `B`
Type: character vector

Values: vector
Default: `'B1'`

`C-matrix(v)` — *C*-matrix of the state-space implementation

`C1` (default) | array

C-matrix of the state-space implementation, specified as a array. In the case of 1-D scheduling, the *C*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *C*-matrix corresponding to the first entry of *v* is the identity matrix, then `C(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `C`
Type: character vector
Values: vector
Default: `'C1'`

`D-matrix(v)` — *D*-matrix of the state-space implementation

`D1` (default) | array

D-matrix of the state-space implementation, specified as a array. In the case of 1-D scheduling, the *D*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *D*-matrix corresponding to the first entry of *v* is the identity matrix, then `D(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `D`
Type: character vector
Values: vector
Default: `'D1'`

`Scheduling variable breakpoints` — Breakpoints for scheduling variable

`[1 1.5 2]` (default) | vector

Breakpoints for the scheduling variable, specified as a vector. The length of *v* must be same as the size of the third dimension of *A*, *B*, *C*, and *D*.

Programmatic Use
Block Parameter: `breakpoints_v`
Type: character vector
Values: vector
Default: `'[1 1.5 2]'`

`Initial state, x_initial` — Initial states
`0` (default) | vector

Initial states for the controller, such as initial values for the state vector, x, specified as a vector. The length must equal the size of the first dimension of A.

Programmatic Use
Block Parameter: `x_initial`
Type: character vector
Values: vector
Default: `'0'`

`Poles of A(v)-H(v)*C(v) = [w1 ... wn])` — Poles of observer
`[-5 -2]` (default) | vector

Poles of observer, specified as a vector. For incoming controllers, the block uses an observer-like structure to ensure that the controller output tracks the current block output, u. The number of poles must equal the dimension of the A-matrix. Poles that are too fast result in sensor noise propagation; poles that are too slow result in the failure of the controller output to track u.

Programmatic Use
Block Parameter: `vec_w`
Type: character vector
Values: vector
Default: `'[-5 -2]'`

Algorithms

The block implements

$$\dot{x}_1 = A_1 x_1 + B_1 y$$
$$u_1 = C_1 x_1 + D_1 y$$
$$\dot{x}_2 = A_2 x_2 + B_2 y$$
$$u_2 = C_2 x_2 + D_2 y$$
$$u = (1 - \lambda) u_1 + \lambda u_2$$
$$\lambda = \begin{cases} 0 & v < v_{\min} \\ \dfrac{v - v_{\min}}{v_{\max} - v_{\min}} & v_{\min} \le v \le v_{\max} \\ 1 & v > v_{\max} \end{cases}$$

For example, suppose two controllers are designed at two operating points v=$v_{\min}$ and v=$v_{\max}$. For longer arrays of design points, the block only implements nearest neighbor designs. At any given instant in time, the block updates three controller designs, reducing computational requirements.

As the value of the scheduling parameter varies and the index of the controllers that need to be run changes, the block initializes the states of the oncoming controller using the self-conditioned form as defined for the Self-Conditioned [A,B,C,D] block.

References

[1] Hyde, R. A., "H-infinity Aerospace Control Design — A VSTOL Flight Application." , *Advances in Industrial Control Series*, Springer Verlag, 1995.

See Also

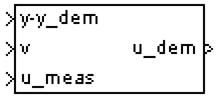
1D Controller [A(v),B(v),C(v),D(v)] | 1D Observer Form [A(v),B(v),C(v),F(v),H(v)] | 1D Self-Conditioned [A(v),B(v),C(v),D(v)] | 2D Controller Blend | Self-Conditioned [A,B,C,D] | Linear Second-Order Actuator | Nonlinear Second-Order Actuator

Introduced before R2006a

1D Observer Form [A(v),B(v),C(v),F(v),H(v)]

Implement gain-scheduled state-space controller in observer form depending on one scheduling parameter

Library: Aerospace Blockset / GNC / Control



Description

The 1D Observer Form [A(v),B(v),C(v),F(v),H(v)] block implements a gain-scheduled state-space controller as defined in “Algorithms” on page 4-14.

The output from this block is the actuator demand, which you can input to an actuator block. Use this block to implement a controller designed using *H*-infinity loop-shaping, one of the design methods supported by Robust Control Toolbox.

Limitations

If the scheduling parameter inputs to the block go out of range, they are clipped. The state-space matrices are not interpolated out of range.

Ports

Input

y-y_dem — Set-point error
vector

Set-point error, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

v — Scheduling variable
vector

Scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

`u_meas` — Measured actuator position
vector

Measured actuator position, specified as a vector.

Data Types: `double`

Output

`u_dem` — Actuator demands
vector

Actuator demands, specified as a vector.

Data Types: `double`

Parameters

`A-matrix(v)` — *A*-matrix of the state-space implementation
A (default) | array

A-matrix of the state-space implementation. The *A*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *A*-matrix corresponding to the first entry of *v* is the identity matrix, then `A(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `A`
Type: character vector
Values: vector
Default: `'A'`

`B-matrix(v)` — *B*-matrix of the state-space implementation
B (default) | array

B-matrix of the state-space implementation. The *B*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *B*-matrix corresponding to the first entry of *v* is the identity matrix, then `B(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `B`
Type: character vector
Values: vector
Default: `'B'`

`C-matrix(v)` — *C*-matrix of the state-space implementation

`C` (default) | array

C-matrix of the state-space implementation. The *C*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. Hence, for example, if the *C*-matrix corresponding to the first entry of *v* is the identity matrix, then `C(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `C`
Type: character vector
Values: vector
Default: `'C'`

`F-matrix(v)` — *F*-matrix of the state-space implementation

`F` (default) | array

State-feedback matrix. The *F*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. Hence, for example, if the *F*-matrix corresponding to the first entry of *v* is the identity matrix, then `F(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `F`
Type: character vector
Values: vector
Default: `'F'`

`H-matrix(v)` — *H*-matrix of the state-space implementation

`H` (default) | array

Observer (output injection) matrix. The *H*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. Hence, for example, if the *H*-matrix corresponding to the first entry of v is the identity matrix, then `H(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `H`
Type: character vector
Values: vector
Default: `'H'`

`Scheduling variable breakpoints` — Breakpoints for scheduling variable
`v_vec` (default) | vector

Breakpoints for the scheduling variable, specified as a vector. The length of v should be same as the size of the third dimension of A, B, C, F, and H.

Programmatic Use
Block Parameter: `AoA_vec`
Type: character vector
Values: vector
Default: `'v_vec'`

`Initial state, x_initial` — Initial states
`0` (default) | vector

Initial states for the controller, i.e., initial values for the state vector, x, specified as a vector. It should have length equal to the size of the first dimension of A.

Programmatic Use
Block Parameter: `x_initial`
Type: character vector
Values: vector
Default: `'0'`

Algorithms

The block implements a gain-scheduled state-space controller defined in the following observer form:

$$\dot{x} = (A(v) + H(v)C(v))x + B(v)u_{meas} + H(v)(y - y_{dem})$$

$$u_{dem} = F(v)x$$

References

[1] Hyde, R. A., "H-infinity Aerospace Control Design — A VSTOL Flight Application," Springer Verlag, *Advances in Industrial Control Series*, 1995.

See Also

1D Controller [A(v),B(v),C(v),D(v)] | 1D Controller Blend: u=(1-L).K1.y+L.K2.y | 1D Self-Conditioned [A(v),B(v),C(v),D(v)] | 2D Observer Form [A(v),B(v),C(v),F(v),H(v)] | 3D Observer Form [A(v),B(v),C(v),F(v),H(v)] | Linear Second-Order Actuator | Nonlinear Second-Order Actuator

Introduced before R2006a

1D Self-Conditioned [A(v),B(v),C(v),D(v)]

Implement gain-scheduled state-space controller in self-conditioned form depending on one scheduling parameter

Library: Aerospace Blockset / GNC / Control

y
v
u_meas
u_dem

Description

The 1D Self-Conditioned [A(v),B(v),C(v),D(v)] block implements a gain-scheduled state-space controller as defined in “Algorithms” on page 4-19.

The output from this block is the actuator demand, which you can input to an actuator block.

Limitations

- If the scheduling parameter inputs to the block go out of range, they are clipped. The state-space matrices are not interpolated out of range.
- This block requires the Control System Toolbox license.

Ports

Input

y — Aircraft measurements
vector

Aircraft measurements, specified as a vector.

Data Types: `double`

v — Scheduling variable
vector

Scheduling variable, specified as a vector, ordered according to the dimensions of the state-space matrices.

Data Types: `double`

`u_meas` — Measured actuator position
vector

Measured actuator position, specified as a vector.

Data Types: `double`

Output

`u_dem` — Actuator demands
vector

Actuator demands, specified as a vector.

Data Types: `double`

Parameters

`A-matrix(v)` — *A*-matrix of the state-space implementation
A (default) | array

A-matrix of the state-space implementation. The *A*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *A*-matrix corresponding to the first entry of *v* is the identity matrix, then `A(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `A`
Type: character vector
Values: vector
Default: `'A'`

`B-matrix(v)` — *B*-matrix of the state-space implementation
B (default) | array

B-matrix of the state-space implementation. The *B*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *B*-matrix corresponding to the first entry of *v* is the identity matrix, then `B(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `B`
Type: character vector
Values: vector
Default: `'B'`

`C-matrix(v)` — *C*-matrix of the state-space implementation

`C` (default) | array

C-matrix of the state-space implementation. The *C*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *C*-matrix corresponding to the first entry of *v* is the identity matrix, then `C(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `C`
Type: character vector
Values: vector
Default: `'C'`

`D-matrix(v)` — *D*-matrix of the state-space implementation

`D` (default) | array

D-matrix of the state-space implementation. The *D*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *D*-matrix corresponding to the first entry of *v* is the identity matrix, then `D(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `D`
Type: character vector
Values: vector
Default: `'D'`

`Scheduling variable breakpoints` — Breakpoints for scheduling variable

`v_vec` (default) | vector

Vector of the breakpoints for the first scheduling variable. The length of *v* should be same as the size of the third dimension of *A*, *B*, *C*, and *D*.

Programmatic Use
Block Parameter: `breakpoints_v`
Type: character vector
Values: vector
Default: `'v_vec'`

`Initial state, x_initial` — Initial states

`0` (default) | vector

Vector of initial states for the controller, that is, initial values for the state vector, *x*. It should have length equal to the size of the first dimension of *A*.

Programmatic Use
Block Parameter: `x_initial`
Type: character vector
Values: vector
Default: `'0'`

`Poles of A(v)-H(v)*C(v)` — Desired poles

`[-5 -2]` (default) | vector

Desired poles of *A*-*HC*, specified as a vector. The poles are assigned to the same locations for all values of the scheduling parameter *v*. Hence, the number of pole locations defined should be equal to the length of the first dimension of the *A*-matrix.

Programmatic Use
Block Parameter: `vec_w`
Type: character vector
Values: vector
Default: `'[-5 -2]'`

Algorithms

The block implements a gain-scheduled state-space controller as defined by the equations:

$$\dot{x} = A(v)x + B(v)y$$
$$u = C(v)x + D(v)y$$

in the self-conditioned form

$$\dot{z} = (A(v) - H(v)C(v))z + (B(v) - H(v)D(V))e + H(v)u_{meas}$$
$$u_{dem} = C(v)z + D(v)e$$

This block implements a gain-scheduled version of the Self-Conditioned [A,B,C,D] block, where v is the parameter over which A, B, C, and D are defined. This type of controller scheduling assumes that the matrices A, B, C, and D vary smoothly as a function of v, which is often the case in aerospace applications.

References

[1] Kautsky, Nichols, and Van Dooren. "Robust Pole Assignment in Linear State Feedback." *International Journal of Control*, Vol. 41, Number 5, 1985, pp. 1129-1155.

See Also

1D Controller [A(v),B(v),C(v),D(v)] | 1D Controller Blend: u=(1-L).K1.y+L.K2.y | 1D Observer Form [A(v),B(v),C(v),F(v),H(v)] | 2D Self-Conditioned [A(v),B(v),C(v),D(v)] | 3D Self-Conditioned [A(v),B(v),C(v),D(v)] | Self-Conditioned [A,B,C,D] | Linear Second-Order Actuator | Nonlinear Second-Order Actuator | Self-Conditioned [A,B,C,D]

Introduced before R2006a

2D Controller [A(v),B(v),C(v),D(v)]

Implement gain-scheduled state-space controller depending on two scheduling parameters

Library: Aerospace Blockset / GNC / Control

Description

The 2D Controller [A(v),B(v),C(v),D(v)] block implements a gain-scheduled state-space controller, as described in “Algorithms” on page 4-24.

The output from this block is the actuator demand, which you can input to an actuator block.

Limitations

If the scheduling parameter inputs to the block go out of range, they are clipped. The state-space matrices are not interpolated out of range.

Ports

Input

y — Aircraft measurements
vector

Aircraft measurements, specified as a vector.

Data Types: `double`

v1 — Scheduling variable
vector

Scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

v2 — Scheduling variable
vector

Scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

Output

u — Actuator demands
vector

Actuator demands, specified as a vector.

Data Types: `double`

Parameters

`A-matrix(v1,v2)` — *A*-matrix of the state-space implementation
A (default) | array

A-matrix of the state-space implementation. In the case of 2-D scheduling, the *A*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *A*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `A(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `A`
Type: character vector
Values: vector
Default: `'A'`

`B-matrix(v1,v2)` — *B*-matrix of the state-space implementation
B (default) | array

B-matrix of the state-space implementation. In the case of 2-D scheduling, the *B*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *B*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `B(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `B`
Type: character vector
Values: vector
Default: `'B'`

`C-matrix(v1,v2)` — -matrix of the state-space implementation

C (default) | array

C-matrix of the state-space implementation. In the case of 2-D scheduling, the *C*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *C*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `C(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `C`
Type: character vector
Values: vector
Default: `'C'`

`D-matrix(v1,v2)` — *D*-matrix of the state-space implementation

D (default) | array

D-matrix of the state-space implementation. In the case of 2-D scheduling, the *D*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *D*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `D(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `D`
Type: character vector
Values: vector
Default: `'D'`

`First scheduling variable (v1) breakpoints` — Breakpoints for first scheduling variable

`v1_vec` (default) | vector

Vector of the breakpoints for the first scheduling variable. The length of $v1$ should be same as the size of the third dimension of A, B, C, and D.

Programmatic Use
Block Parameter: `AoA_vec`
Type: character vector
Values: vector
Default: `'v1_vec'`

`Second scheduling variable (v2) breakpoints` — Breakpoints for second scheduling variable

`v2_vec` (default) | vector

Vector of the breakpoints for the second scheduling variable. The length of $v2$ should be same as the size of the fourth dimension of A, B, C, and D.

Programmatic Use
Block Parameter: `Mach_vec`
Type: character vector
Values: vector
Default: `'v2_vec'`

`Initial state, x_initial` — Initial states

`0` (default) | vector

Vector of initial states for the controller, that is, initial values for the state vector, x. It should have length equal to the size of the first dimension of A.

Programmatic Use
Block Parameter: `x_initial`
Type: character vector
Values: vector
Default: `'0'`

Algorithms

The block implements a gain-scheduled state-space controller as defined by this equation:

$$\begin{aligned}\dot{x} &= A(v)x + B(v)y \\ u &= C(v)x + D(v)y\end{aligned}$$

where *v* is a vector of parameters over which *A*, *B*, *C*, and *D* are defined. This type of controller scheduling assumes that the matrices *A*, *B*, *C*, and *D* vary smoothly as a function of *v*, which is often the case in aerospace applications.

See Also

1D Controller [A(v),B(v),C(v),D(v)] | 2D Controller Blend | 2D Observer Form [A(v),B(v),C(v),F(v),H(v)] | 2D Self-Conditioned [A(v),B(v),C(v),D(v)] | 3D Controller [A(v),B(v),C(v),D(v)] | Linear Second-Order Actuator | Nonlinear Second-Order Actuator

Introduced before R2006a

2D Controller Blend

Implement 2-D vector of state-space controllers by linear interpolation of their outputs
Library: Aerospace Blockset / GNC / Control

Description

The 2D Controller Blend block implements an array of state-space controller designs. The controllers are run in parallel, and their outputs interpolated according to the current flight condition or operating point. The advantage of this implementation approach is that the state-space matrices *A*, *B*, *C*, and *D* for the individual controller designs do not need to vary smoothly from one design point to the next. The output from this block is the actuator demand, which you can input to an actuator block.

For the 2D Controller Blend block, at any given instant in time, nine controller designs are updated.

As the value of the scheduling parameter varies and the index of the controllers that need to be run changes, the states of the oncoming controller are initialized by using the self-conditioned form as defined for the Self-Conditioned [A,B,C,D] block.

Limitations

This block requires the Control System Toolbox license.

Ports

Input

y — Aircraft measurements
vector

Aircraft measurements, specified as a vector.

Data Types: `double`

v1 — Scheduling variable
vector

Scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

v2 — Scheduling variable
vector

Scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

Output

u — Actuator demands
vector

Actuator demands, specified as a vector.

Data Types: `double`

Parameters

`A-matrix(v1,v2)` — *A*-matrix of the state-space implementation
A (default) | array

A-matrix of the state-space implementation. In the case of 2-D blending, the *A*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *A*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `A(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `A`
Type: character vector
Values: vector

Default: `'A'`

`B-matrix(v1,v2)` — *B*-matrix of the state-space implementation
A (default) | array

B-matrix of the state-space implementation. The *B*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *B*-matrix corresponding to the first entry of *v* is the identity matrix, then `B(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `B`
Type: character vector
Values: vector
Default: `'B'`

`C-matrix(v1,v2)` — *C*-matrix of the state-space implementation
C (default) | array

C-matrix of the state-space implementation. The *C*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *C*-matrix corresponding to the first entry of *v* is the identity matrix, then `C(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `C`
Type: character vector
Values: vector
Default: `'C'`

`D-matrix(v1,v2)` — *D*-matrix of the state-space implementation
C (default) | array

D-matrix of the state-space implementation. The *D*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *D*-matrix corresponding to the first entry of *v* is the identity matrix, then `D(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `D`
Type: character vector
Values: vector

Default: `'D'`

`First scheduling variable (v1) breakpoints` — Breakpoints for first scheduling variable

`v1_vec` (default) | vector

Breakpoints for the first scheduling variable, specified as a vector. The length of *v*1 should be same as the size of the third dimension of *A*, *B*, *C*, and *D*.

Programmatic Use
Block Parameter: `breakpoints_v1`
Type: character vector
Values: vector
Default: `'v1_vec'`

`Second scheduling variable (v2) breakpoints` — Breakpoints for second scheduling variable

`v2_vec` (default) | vector

Breakpoints for the second scheduling variable, specified as a vector. The length of *v*2 should be same as the size of the fourth dimension of *A*, *B*, *C*, and *D*.

Programmatic Use
Block Parameter: `breakpoints_v2`
Type: character vector
Values: vector
Default: `'v2_vec'`

`Initial state, x_initial` — Initial states

`0` (default) | vector

Vector of initial states for the controller, that is, initial values for the state vector, *x*. It should have length equal to the size of the first dimension of *A*.

Programmatic Use
Block Parameter: `x_initial`
Type: character vector
Values: vector
Default: `'0'`

`Poles of A(v)-H(v)*C(v)` — Desired poles

`[-5 -2]` (default)

For oncoming controllers, an observer-like structure is used to ensure that the controller output tracks the current block output, *u*. The poles of the observer are defined in this dialog box as a vector, the number of poles being equal to the dimension of the *A*-matrix. Poles that are too fast result in sensor noise propagation, and poles that are too slow result in the failure of the controller output to track *u*.

Programmatic Use
Block Parameter: `vec_w`
Type: character vector
Values: vector
Default: `'[-5 -2]'`

References

[1] Hyde, R. A. "H-infinity Aerospace Control Design - A VSTOL Flight Application." Springer Verlag: *Advances in Industrial Control Series*, 1995.

See Also

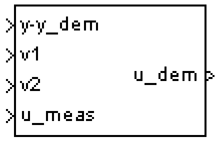
1D Controller Blend: u=(1-L).K1.y+L.K2.y | 2D Controller [A(v),B(v),C(v),D(v)] | 2D Observer Form [A(v),B(v),C(v),F(v),H(v)] | 2D Self-Conditioned [A(v),B(v),C(v),D(v)] | Linear Second-Order Actuator | Nonlinear Second-Order Actuator | Self-Conditioned [A,B,C,D]

Introduced before R2006a

2D Observer Form [A(v),B(v),C(v),F(v),H(v)]

Implement gain-scheduled state-space controller in observer form depending on two scheduling parameters

Library: Aerospace Blockset / GNC / Control



Description

The 2D Observer Form [A(v),B(v),C(v),F(v),H(v)] block implements a gain-scheduled state-space controller as defined in “Algorithms” on page 4-35.

The output from this block is the actuator demand, which you can input to an actuator block. Use this block to implement a controller designed using *H*-infinity loop-shaping, one of the design methods supported by Robust Control Toolbox.

Limitations

If the scheduling parameter inputs to the block go out of range, they are clipped. The state-space matrices are not interpolated out of range.

Ports

Input

`y-y_dem` — Set-point error
vector

Set-point error, specified as a vector.

Data Types: `double`

v1 — First scheduling variable
vector

First scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

v2 — Second scheduling variable
vector

Second scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

`u_meas` — Measured actuator position
vector

Measured actuator position, specified as a vector.

Data Types: `double`

Output

`u_dem` — Actuator demands
vector

Actuator demands, specified as a vector.

Data Types: `double`

Parameters

`A-matrix(v1,v2)` — *A*-matrix of the state-space implementation
A (default) | array

A-matrix of the state-space implementation. In the case of 2-D scheduling, the *A*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *A*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `A(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `A`
Type: character vector
Values: vector
Default: `'A'`

`B-matrix(v1,v2)` — *B*-matrix of the state-space implementation

`B` (default) | array

B-matrix of the state-space implementation. In the case of 2-D scheduling, the *B*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *B*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `B(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `B`
Type: character vector
Values: vector
Default: `'B'`

`C-matrix(v1,v2)` — *C*-matrix of the state-space implementation

`C` (default) | array

C-matrix of the state-space implementation. In the case of 2-D scheduling, the *C*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *C*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `C(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `C`
Type: character vector
Values: vector
Default: `'C'`

`F-matrix(v1,v2)` — *F*-matrix of the state-space implementation

`F` (default) | array

State-feedback matrix. In the case of 2-D scheduling, the *F*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *F*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `F(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `F`
Type: character vector
Values: vector
Default: `'F'`

`H-matrix(v1,v2)` — *H*-matrix of the state-space implementation

`H` (default) | array

Observer (output injection) matrix. In the case of 2-D scheduling, the *H*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *H*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `H(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `H`
Type: character vector
Values: vector
Default: `'H'`

`First scheduling variable (v1) breakpoints` — Breakpoints for first scheduling variable

`v1_vec` (default)

Vector of the breakpoints for the first scheduling variable. The length of *v*1 should be same as the size of the third dimension of *A*, *B*, *C*, *F*, and *H*.

Programmatic Use
Block Parameter: `AoA_vec`
Type: character vector
Values: vector
Default: `'v1_vec'`

`Second scheduling variable (v2) breakpoints` — Breakpoints for second scheduling variable

`v2_vec` (default)

Vector of the breakpoints for the second scheduling variable. The length of *v*2 should be same as the size of the fourth dimension of *A*, *B*, *C*, *F*, and *H*.

Programmatic Use
Block Parameter: `Mach_vec`

Type: character vector
Values: vector
Default: `'v2_vec'`

`Initial state, x_initial` — Initial states
`0` (default)

Vector of initial states for the controller,that is, initial values for the state vector, x. It should have length equal to the size of the first dimension of A.

Programmatic Use
Block Parameter: `x_initial`
Type: character vector
Values: vector
Default: `'0'`

Algorithms

The block implements a gain-scheduled state-space controller defined in the following observer form:

$$\dot{x} = (A(v) + H(v)C(v))x + B(v)u_{meas} + H(v)(y - y_{dem})$$
$$u_{dem} = F(v)x$$

References

[1] Hyde, R. A.. "H-infinity Aerospace Control Design — A VSTOL Flight Application." *Advances in Industrial Control Series*, Springer Verlag, 1995.

See Also

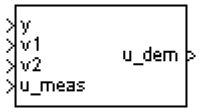
1D Controller [A(v),B(v),C(v),D(v)] | 2D Controller [A(v),B(v),C(v),D(v)] | 2D Controller Blend | 2D Self-Conditioned [A(v),B(v),C(v),D(v)] | 3D Observer Form [A(v),B(v),C(v),F(v),H(v)] | Linear Second-Order Actuator | Nonlinear Second-Order Actuator

Introduced before R2006a

2D Self-Conditioned [A(v),B(v),C(v),D(v)]

Implement gain-scheduled state-space controller in self-conditioned form depending on two scheduling parameters

Library: Aerospace Blockset / GNC / Control



Description

The 2D Self-Conditioned [A(v),B(v),C(v),D(v)] block implements a gain-scheduled state-space controller as defined in “Algorithms” on page 4-40.

The output from this block is the actuator demand, which you can input to an actuator block.

Limitations

- If the scheduling parameter inputs to the block go out of range, they are clipped. The state-space matrices are not interpolated out of range.
- This block requires the Control System Toolbox license.

Ports

Input

y — Aircraft measurements
vector

Aircraft measurements, specified as a vector.

Data Types: `double`

v1 — First scheduling variable

vector

First scheduling variable, specified as a vector, ordered according to the dimensions of the state-space matrices.

Data Types: `double`

v2 — Second scheduling variable

vector

Second scheduling variable, specified as a vector, ordered according to the dimensions of the state-space matrices.

Data Types: `double`

`u_meas` — Measured actuator position

vector

Measured actuator position, specified as a vector.

Data Types: `double`

Output

`u_dem` — Actuator demands

vector

Actuator demands, specified as a vector.

Data Types: `double`

Parameters

`A-matrix(v1,v2)` — *A*-matrix of the state-space implementation

A (default) | array

A-matrix of the state-space implementation. In the case of 2-D scheduling, the *A*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *A*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `A(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `A`
Type: character vector
Values: vector
Default: `'A'`

`B-matrix(v1,v2)` — *B*-matrix of the state-space implementation
`B` (default) | array

B-matrix of the state-space implementation. In the case of 2-D scheduling, the *B*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *B*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `B(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `B`
Type: character vector
Values: vector
Default: `'B'`

`C-matrix(v1,v2)` — *C*-matrix of the state-space implementation
`C` (default) | array

C-matrix of the state-space implementation. In the case of 2-D scheduling, the *C*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *C*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `C(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `C`
Type: character vector
Values: vector
Default: `'C'`

`D-matrix(v1,v2)` — *D*-matrix of the state-space implementation
`D` (default) | array

D-matrix of the state-space implementation. In the case of 2-D scheduling, the *D*-matrix should have four dimensions, the last two corresponding to scheduling variables *v*1 and *v*2. For example, if the *D*-matrix corresponding to the first entry of *v*1 and first entry of *v*2 is the identity matrix, then `D(:,:,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `D`
Type: character vector
Values: vector
Default: `'D'`

`First scheduling variable (v1) breakpoints` — Breakpoints for first scheduling variable

v1_vec (default) | vector

Vector of the breakpoints for the first scheduling variable. The length of *v*1 should be same as the size of the third dimension of *A*, *B*, *C*, and *D*.

Programmatic Use
Block Parameter: `breakpoints_v1`
Type: character vector
Values: vector
Default: `'v1_vec'`

`Second scheduling variable (v2) breakpoints` — Breakpoints for second scheduling variable

v2_vec (default) | vector

Vector of the breakpoints for the second scheduling variable. The length of *v*2 should be same as the size of the fourth dimension of *A*, *B*, *C*, and *D*.

Programmatic Use
Block Parameter: `breakpoints_v2`
Type: character vector
Values: vector
Default: `'v2_vec'`

`Initial state, x_initial` — Initial states

`0` (default) | vector

Vector of initial states for the controller, that is, initial values for the state vector, *x*. It should have length equal to the size of the first dimension of *A*.

Programmatic Use
Block Parameter: `x_initial`
Type: character vector
Values: vector

Default: `'0'`

`Poles of A(v)-H(v)*C(v)` — Desired poles
`[-5 -2]` (default) | vector

Vector of the desired poles of *A*-*HC*. Note that the poles are assigned to the same locations for all values of the scheduling parameter, *v*. Hence, the number of pole locations defined should be equal to the length of the first dimension of the *A*-matrix.

Programmatic Use
Block Parameter: `vec_w`
Type: character vector
Values: vector
Default: `'[-5 -2]'`

Algorithms

The block implements a gain-scheduled state-space controller as defined by the equations:

$$\dot{x} = A(v)x + B(v)y$$
$$u = C(v)x + D(v)y$$

in the self-conditioned form

$$\dot{z} = (A(v) - H(v)C(v))z + (B(v) - H(v)D(v))e + H(v)u_{meas}$$
$$u_{dem} = C(v)z + D(v)e$$

For the rationale behind this self-conditioned implementation, refer to the Self-Conditioned [A,B,C,D] block reference. This block implements a gain-scheduled version of the Self-Conditioned [A,B,C,D] block, *v* being the vector of parameters over which *A*, *B*, *C*, and *D* are defined. This type of controller scheduling assumes that the matrices *A*, *B*, *C*, and *D* vary smoothly as a function of *v*, which is often the case in aerospace applications.

References

[1] Kautsky, Nichols, and Van Dooren. "Robust Pole Assignment in Linear State Feedback," *International Journal of Control*, Vol. 41, Number 5, 1985, pp 1129-1155.

See Also

1D Self-Conditioned [A(v),B(v),C(v),D(v)] | 2D Controller [A(v),B(v),C(v),D(v)] | 2D Controller Blend | 2D Observer Form [A(v),B(v),C(v),F(v),H(v)] | 3D Self-Conditioned [A(v),B(v),C(v),D(v)] | Linear Second-Order Actuator | Nonlinear Second-Order Actuator

Introduced before R2006a

3D Controller [A(v),B(v),C(v),D(v)]

Implement gain-scheduled state-space controller depending on three scheduling parameters

Library: Aerospace Blockset / GNC / Control

Description

The 3D Controller [A(v),B(v),C(v),D(v)] block implements a gain-scheduled state-space controller as described in “Algorithms” on page 4-46.

The output from this block is the actuator demand, which you can input to an actuator block.

Limitations

If the scheduling parameter inputs to the block go out of range, they are clipped. The state-space matrices are not interpolated out of range.

Ports

Input

y — Aircraft measurements
vector

Aircraft measurements, specified as a vector.

Data Types: `double`

v1 — First scheduling variable
vector

First scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

v2 — Second scheduling variable
vector

Second scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

v3 — Third scheduling variable
vector

Second scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

Output

u — Actuator demands
vector

Actuator demands, specified as a vector.

Data Types: `double`

Parameters

`A-matrix(v1,v2,v3)` — *A* matrix of the state-space implementation
A (default) | array

A-matrix of the state-space implementation. In the case of 3-D scheduling, the *A*-matrix should have five dimensions, the last three corresponding to scheduling variables *v*1, *v*2, and *v*3. For example, if the *A*-matrix corresponding to the first entry of *v*1, the first entry of *v*2, and the first entry of *v*3 is the identity matrix, then `A(:,:,1,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `A`
Type: character vector
Values: vector
Default: `'A'`

`B-matrix(v1,v2,v3)` — *B* matrix of the state-space implementation

`B` (default) | array

B-matrix of the state-space implementation. In the case of 3-D scheduling, the *B*-matrix should have five dimensions, the last three corresponding to scheduling variables *v*1, *v*2, and *v*3. For example, if the *B*-matrix corresponding to the first entry of *v*1, the first entry of *v*2, and the first entry of *v*3 is the identity matrix, then `B(:,:,1,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `B`
Type: character vector
Values: vector
Default: `'B'`

`C-matrix(v1,v2,v3)` — *C* matrix of the state-space implementation

`C` (default) | array

C-matrix of the state-space implementation. In the case of 3-D scheduling, the *C*-matrix should have five dimensions, the last three corresponding to scheduling variables *v*1, *v*2, and *v*3. For example, if the *C*-matrix corresponding to the first entry of *v*1, the first entry of *v*2, and the first entry of *v*3 is the identity matrix, then `C(:,:,1,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `C`
Type: character vector
Values: vector
Default: `'C'`

`D-matrix(v1,v2,v3)` — *D* matrix of the state-space implementation

`D` (default) | array

D-matrix of the state-space implementation. In the case of 3-D scheduling, the *D*-matrix should have five dimensions, the last three corresponding to scheduling variables *v*1, *v*2, and *v*3. For example, if the *D*-matrix corresponding to the first entry of *v*1, the first entry of *v*2, and the first entry of *v*3 is the identity matrix, then `D(:,:,1,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `D`
Type: character vector
Values: vector
Default: `'D'`

`First scheduling variable (v1) breakpoints` — Breakpoints for first scheduling variable

v1_vec (default) | vector

Vector of the breakpoints for the first scheduling variable. The length of *v*1 should be same as the size of the third dimension of *A*, *B*, *C*, and *D*.

Programmatic Use
Block Parameter: `AoA_vec`
Type: character vector
Values: vector
Default: `'v1_vec'`

`Second scheduling variable (v2) breakpoints` — Breakpoints for second scheduling variable

v2_vec (default) | vector

Vector of the breakpoints for the second scheduling variable. The length of *v*2 should be same as the size of the fourth dimension of *A*, *B*, *C*, and *D*.

Programmatic Use
Block Parameter: `AoS_vec`
Type: character vector
Values: vector
Default: `'v2_vec'`

`Third scheduling variable (v3) breakpoints` — Breakpoints for third scheduling variable

v3_vec (default) | vector

Vector of the breakpoints for the third scheduling variable. The length of *v*3 should be same as the size of the fifth dimension of *A*, *B*, *C*, and *D*.

Programmatic Use
Block Parameter: `Mach_vec`
Type: character vector
Values: vector
Default: `'v3_vec'`

`Initial state, x_initial` — Initial states
`0` (default) | vector

Vector of initial states for the controller, i.e., initial values for the state vector, x. It should have length equal to the size of the first dimension of A.

Programmatic Use
Block Parameter: `x_initial`
Type: character vector
Values: vector
Default: `'0'`

Algorithms

The block implements a gain-scheduled state-space controller as defined by this equation:

$$\dot{x} = A(v)x + B(v)y$$
$$u = C(v)x + D(v)y$$

where v is a vector of parameters over which A, B, C, and D are defined. This type of controller scheduling assumes that the matrices A, B, C, and D vary smoothly as a function of v, which is often the case in aerospace applications.

See Also

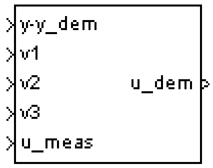
1D Controller [A(v),B(v),C(v),D(v)] | 2D Controller [A(v),B(v),C(v),D(v)] | 3D Observer Form [A(v),B(v),C(v),F(v),H(v)] | 3D Self-Conditioned [A(v),B(v),C(v),D(v)] | Linear Second-Order Actuator | Nonlinear Second-Order Actuator

Introduced before R2006a

3D Observer Form [A(v),B(v),C(v),F(v),H(v)]

Implement gain-scheduled state-space controller in observer form depending on three scheduling parameters

Library: Aerospace Blockset / GNC / Control



Description

The 3D Observer Form [A(v),B(v),C(v),F(v),H(v)] block implements a gain-scheduled state-space controller defined in “Algorithms” on page 4-35.

The main application of this block is to implement a controller designed using H-infinity loop-shaping. Use this block to implement a controller designed using *H*-infinity loop-shaping, one of the design methods supported by Robust Control Toolbox.

Limitations

If the scheduling parameter inputs to the block go out of range, they are clipped. The state-space matrices are not interpolated out of range.

Ports

Input

`y-y_dem` — Set-point error
vector

Set-point error, specified as a vector.

Data Types: `double`

v1 — First scheduling variable
vector

First scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

v2 — Second scheduling variable
vector

Second scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

v3 — Third scheduling variable
vector

Third scheduling variable, specified as a vector, that conforms to the dimensions of the state-space matrices.

Data Types: `double`

`u_meas` — Measured actuator position
vector

Measured actuator position, specified as a vector.

Data Types: `double`

Output

`u_dem` — Actuator demands
vector

Actuator demands, specified as a vector.

Data Types: `double`

Parameters

`A-matrix(v1,v2,v3)` — *A*-matrix of the state-space implementation

A (default) | array

A-matrix of the state-space implementation. In the case of 3-D scheduling, the *A*-matrix should have five dimensions, the last three corresponding to scheduling variables *v*1, *v*2, and *v*3. For example, if the *A*-matrix corresponding to the first entry of *v*1, the first entry of *v*2, and the first entry of *v*3 is the identity matrix, then `A(:,:,1,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `A`
Type: character vector
Values: vector
Default: `'A'`

`B-matrix(v1,v2,v3)` — *B*-matrix of the state-space implementation

B (default) | array

B-matrix of the state-space implementation. In the case of 3-D scheduling, the *B*-matrix should have five dimensions, the last three corresponding to scheduling variables *v*1, *v*2, and *v*3. For example, if the *B*-matrix corresponding to the first entry of *v*1, the first entry of *v*2, and the first entry of *v*3 is the identity matrix, then `B(:,:,1,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `B`
Type: character vector
Values: vector
Default: `'B'`

`C-matrix(v1,v2,v3)` — *C*-matrix of the state-space implementation

C (default) | array

C-matrix of the state-space implementation. In the case of 3-D scheduling, the *C*-matrix should have five dimensions, the last three corresponding to scheduling variables *v*1, *v*2, and *v*3. For example, if the *C*-matrix corresponding to the first entry of *v*1, the first entry of *v*2, and the first entry of *v*3 is the identity matrix, then `C(:,:,1,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `C`
Type: character vector
Values: vector
Default: `'C'`

`F-matrix(v1,v2,v3)` — *F*-matrix of the state-space implementation

`F` (default) | array

State-feedback matrix. In the case of 3-D scheduling, the *F*-matrix should have five dimensions, the last three corresponding to scheduling variables *v*1, *v*2, and *v*3. For example, if the *F*-matrix corresponding to the first entry of *v*1, the first entry of *v*2, and the first entry of *v*3 is the identity matrix, then `F(:,:,1,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `F`
Type: character vector
Values: vector
Default: `'F'`

`H-matrix(v1,v2,v3)` — *H*-matrix of the state-space implementation

`H` (default) | array

Observer (output injection) matrix. In the case of 3-D scheduling, the *H*-matrix should have five dimensions, the last three corresponding to scheduling variables *v*1, *v*2, and *v*3. For example, if the *H*-matrix corresponding to the first entry of *v*1, the first entry of *v*2, and the first entry of *v*3 is the identity matrix, then `H(:,:,1,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `H`
Type: character vector
Values: vector
Default: `'H'`

`First scheduling variable (v1) breakpoints` — Breakpoints for first scheduling variable

`v1_vec` (default)

Vector of the breakpoints for the first scheduling variable. The length of *v*1 should be same as the size of the third dimension of *A*, *B*, *C*, *F*, and *H*.

Programmatic Use
Block Parameter: `AoA_vec`
Type: character vector
Values: vector
Default: `'v1_vec'`

`Second scheduling variable (v2) breakpoints` — Breakpoints for second scheduling variable

`v2_vec` (default)

Vector of the breakpoints for the second scheduling variable. The length of *v*2 should be same as the size of the fourth dimension of *A*, *B*, *C*, *F*, and *H*.

Programmatic Use
Block Parameter: `AoS_vec`
Type: character vector
Values: vector
Default: `'v2_vec'`

`Third scheduling variable (v3) breakpoints` — Breakpoints for third scheduling variable

`v3_vec` (default)

Vector of the breakpoints for the third scheduling variable. The length of *v*3 should be same as the size of the fifth dimension of *A*, *B*, *C*, *F*, and *H*.

Programmatic Use
Block Parameter: `Mach_vec`
Type: character vector
Values: vector
Default: `'v3_vec'`

`Initial state, x_initial` — Initial states

`0` (default)

Vector of initial states for the controller, that is, initial values for the state vector, *x*. It should have length equal to the size of the first dimension of *A*.

Programmatic Use
Block Parameter: `x_initial`
Type: character vector
Values: vector

Default: `'0'`

Algorithms

The block implements gain-scheduled state-space controller as defined by these equations:

$$\dot{x} = (A(v) + H(v)C(v))x + B(v)u_{meas} + H(v)(y - y_{dem})$$
$$u_{dem} = F(v)x$$

References

[1] Hyde, R. A. "H-infinity Aerospace Control Design — A VSTOL Flight Application." *Advances in Industrial Control Series*, Springer Verlag, 1995.

See Also

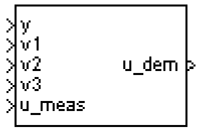
1D Controller [A(v),B(v),C(v),D(v)] | 2D Observer Form [A(v),B(v),C(v),F(v),H(v)] | 3D Controller [A(v),B(v),C(v),D(v)] | 3D Self-Conditioned [A(v),B(v),C(v),D(v)] | Linear Second-Order Actuator | Nonlinear Second-Order Actuator

Introduced before R2006a

3D Self-Conditioned [A(v),B(v),C(v),D(v)]

Implement gain-scheduled state-space controller in self-conditioned form depending on two scheduling parameters

Library: Aerospace Blockset / GNC / Control



Description

The 3D Self-Conditioned [A(v),B(v),C(v),D(v)] block implements a gain-scheduled state-space controller as defined in “Algorithms” on page 4-58.

If the scheduling parameter inputs to the block go out of range, then they are clipped. The state-space matrices are not interpolated out of range.

The output from this block is the actuator demand, which you can input to an actuator block.

Limitations

This block requires the Control System Toolbox license.

Ports

Input

y — Aircraft measurements
vector

Aircraft measurements, specified as a vector.

Data Types: `double`

`v1` — First scheduling variable
vector

First scheduling variable, specified as a vector, ordered according to the dimensions of the state-space matrices.

Data Types: `double`

`v2` — Second scheduling variable
vector

Second scheduling variable, specified as a vector, ordered according to the dimensions of the state-space matrices.

Data Types: `double`

`v3` — Third scheduling variable
vector

Third scheduling variable, specified as a vector, ordered according to the dimensions of the state-space matrices.

Data Types: `double`

`u_meas` — Measured actuator position
vector

Measured actuator position, specified as a vector.

Data Types: `double`

Output

`Output 1` — Actuator demands
vector

Actuator demands, specified as a vector.

Data Types: `double`

Parameters

`A-matrix(v1,v2,v3)` — *A*-matrix of the state-space implementation

`A` (default) | array

A-matrix of the state-space implementation. In the case of 3-D scheduling, the *A*-matrix should have five dimensions, the last three corresponding to scheduling variables *v*1, *v*2, and *v*3. For example, if the *A*-matrix corresponding to the first entry of *v*1, the first entry of *v*2, and the first entry of *v*3 is the identity matrix, then `A(:,:,1,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `A`
Type: character vector
Values: vector
Default: `'A'`

`B-matrix(v1,v2,v3)` — *B*-matrix of the state-space implementation

`B` (default) | array

B-matrix of the state-space implementation. In the case of 3-D scheduling, the *B*-matrix should have five dimensions, the last three corresponding to scheduling variables *v*1, *v*2, and *v*3. For example, if the *B*-matrix corresponding to the first entry of *v*1, the first entry of *v*2, and the first entry of *v*3 is the identity matrix, then `B(:,:,1,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `B`
Type: character vector
Values: vector
Default: `'B'`

`C-matrix(v1,v2,v3)` — *C*-matrix of the state-space implementation

`C` (default) | array

C-matrix of the state-space implementation. In the case of 3-D scheduling, the *C*-matrix should have five dimensions, the last three corresponding to scheduling variables *v*1, *v*2, and *v*3. For example, if the *C*-matrix corresponding to the first entry of *v*1, the first entry of *v*2, and the first entry of *v*3 is the identity matrix, then `C(:,:,1,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `C`
Type: character vector
Values: vector
Default: `'C'`

`D-matrix(v1,v2,v3)` — *D*-matrix of the state-space implementation

`D` (default) | array

D-matrix of the state-space implementation. In the case of 3-D scheduling, the *D*-matrix should have five dimensions, the last three corresponding to scheduling variables *v*1, *v*2, and *v*3. For example, if the *D*-matrix corresponding to the first entry of *v*1, the first entry of *v*2, and the first entry of *v*3 is the identity matrix, then `D(:,:,1,1,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `D`
Type: character vector
Values: vector
Default: `'D'`

`First scheduling variable (v1) breakpoints` — Breakpoints for first scheduling variable

v1_vec (default) | vector

Vector of the breakpoints for the first scheduling variable. The length of *v*1 should be same as the size of the third dimension of *A*, *B*, *C*, and *D*.

Programmatic Use
Block Parameter: `breakpoints_v1`
Type: character vector
Values: vector
Default: `'v1_vec'`

`Second scheduling variable (v2) breakpoints` — Breakpoints for second scheduling variable

v2_vec (default) | vector

Vector of the breakpoints for the second scheduling variable. The length of *v*2 should be same as the size of the fourth dimension of *A*, *B*, *C*, and *D*.

Programmatic Use
Block Parameter: `breakpoints_v2`
Type: character vector
Values: vector
Default: `'v2_vec'`

`Third scheduling variable (v3) breakpoints` — Breakpoints for third scheduling variable

v3_vec (default) | vector

Vector of the breakpoints for the third scheduling variable. The length of *v*3 should be same as the size of the fifth dimension of *A*, *B*, *C*, and *D*.

Programmatic Use
Block Parameter: `breakpoints_v3`
Type: character vector
Values: vector
Default: `'v3_vec'`

`Initial state, x_initial` — Initial states

`0` (default) | vector

Vector of initial states for the controller, that is, initial values for the state vector, *x*. It should have length equal to the size of the first dimension of *A*.

Programmatic Use
Block Parameter: `x_initial`
Type: character vector
Values: vector
Default: `'0'`

`Poles of A(v)-H(v)*C(v)` — Desired poles

`[-5 -2]` (default) | vector

Vector of the desired poles of *A*-*HC*. Note that the poles are assigned to the same locations for all values of the scheduling parameter *v*. Hence the number of pole locations defined should be equal to the length of the first dimension of the *A*-matrix.

Programmatic Use
Block Parameter: `vec_w`
Type: character vector
Values: vector

Default: `'[-5 -2]'`

Algorithms

The block implements a gain-scheduled state-space controller as defined by the equations:

$$\dot{x} = A(v)x + B(v)y$$
$$u = C(v)x + D(v)y$$

in the self-conditioned form

$$\dot{z} = (A(v) - H(v)C(v))z + (B(v) - H(v)D(v))e + H(v)u_{meas}$$
$$u_{dem} = C(v)z + D(v)e$$

For the rationale behind this self-conditioned implementation, refer to the Self-Conditioned [A,B,C,D] block reference. These blocks implement a gain-scheduled version of the Self-Conditioned [A,B,C,D] block, v being the vector of parameters over which A, B, C, and D are defined. This type of controller scheduling assumes that the matrices A, B, C, and D vary smoothly as a function of v, which is often the case in aerospace applications.

References

[1] Kautsky, Nichols, and Van Dooren. "Robust Pole Assignment in Linear State Feedback." *International Journal of Control*, Vol. 41, Number 5, 1985, pp. 1129-1155.

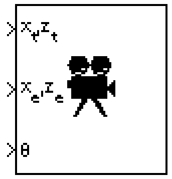
See Also

1D Self-Conditioned [A(v),B(v),C(v),D(v)] | 2D Self-Conditioned [A(v),B(v),C(v),D(v)] | 3D Controller [A(v),B(v),C(v),D(v)] | 3D Observer Form [A(v),B(v),C(v),F(v),H(v)] | Linear Second-Order Actuator | Nonlinear Second-Order Actuator

Introduced before R2006a

3DoF Animation

Create 3-D MATLAB Graphics animation of three-degrees-of-freedom object



Library

Animation

Description

The 3DoF Animation block displays a 3-D animated view of a three-degrees-of-freedom (3DoF) craft, its trajectory, and its target using MATLAB Graphics.

The 3DoF Animation block uses the input values and the dialog parameters to create and display the animation.

This block does not produce deployable code, but can be used with Simulink Coder external mode as a SimViewingDevice.

Parameters

Axes limits [xmin xmax ymin ymax zmin zmax]

Specifies the three-dimensional space to be viewed.

Time interval between updates

Specifies the time interval at which the animation is redrawn.

Size of craft displayed

Scale factor to adjust the size of the craft and target.

Enter view

Selects preset MATLAB Graphics parameters **CameraTarget** and **CameraUpVector** for the figure axes. The dialog parameters **Position of camera** and **View angle** are used to customize the position and field of view for the selected view. Possible views are

- Fixed position
- Cockpit
- Fly alongside

Position of camera [xc yc zc]

Specifies the MATLAB Graphics parameter CameraPosition for the figure axes. Used in all cases except for the Cockpit view.

View angle

Specifies the MATLAB Graphics parameter CameraViewAngle for the figure axes in degrees.

Enable animation

When selected, the animation is displayed during the simulation. If not selected, the animation is not displayed.

Inputs

Input	Dimension Type	Description
First	Vector	Contains the altitude and the downrange position of the target in Earth coordinates.
Second	Vector	Contains the altitude and the downrange position of the craft in Earth coordinates.
Third	1-by-1 scalar	Contains the attitude of the craft in radians.

Examples

See `aero_guidance` for an example of this block.

See Also

6DoF Animation

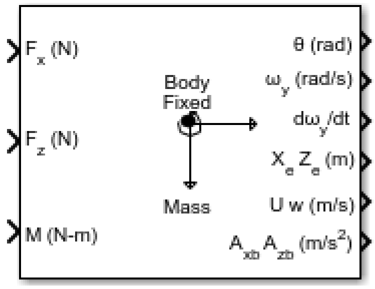
FlightGear Preconfigured 6DoF Animation

The figure axes properties CameraPosition and CameraViewAngle

Introduced before R2006a

3DOF (Body Axes)

Implement three-degrees-of-freedom equations of motion with respect to body axes

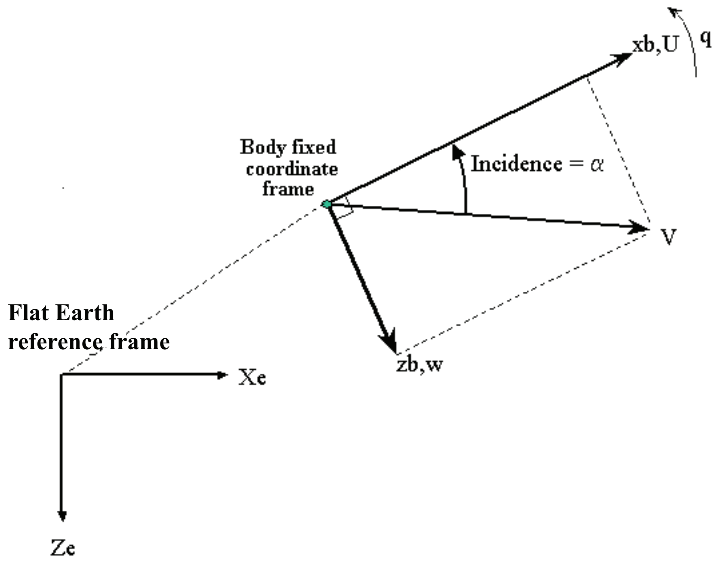


Library

Equations of Motion/3DOF

Description

The 3DOF (Body Axes) block considers the rotation in the vertical plane of a body-fixed coordinate frame about a flat Earth reference frame.



The equations of motion are

$$A_{xb} = \dot{u} = \frac{F_x}{m} - qw - g\sin\theta, A_{xe} = \frac{F_x}{m} - \varepsilon\sin\theta$$

$$A_{zb} = \dot{w} = \frac{F_z}{m} + qu + g\cos\theta, A_{ze} = \frac{F_z}{m} + \varepsilon\cos\theta$$

$$\dot{q} = \frac{M}{I_{yy}}$$

$$\dot{\theta} = q$$

where the applied forces are assumed to act at the center of gravity of the body.

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton-meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot-pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot-pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Fixed` selection conforms to the previously described equations of motion.

Initial velocity

A scalar value for the initial velocity of the body, (V_0).

Initial body attitude

A scalar value for the initial pitch attitude of the body, (θ_0).

Initial incidence

A scalar value for the initial angle between the velocity vector and the body, (α_0).

Initial body rotation rate

A scalar value for the initial body rotation rate, (q_0).

Initial position (x,z)

A two-element vector containing the initial location of the body in the flat Earth reference frame.

Initial Mass

A scalar value for the mass of the body.

Inertia

A scalar value for the inertia of the body.

Gravity Source

Specify source of gravity:

`External`	Variable gravity input to block
`Internal`	Constant gravity specified in mask

Acceleration due to gravity

A scalar value for the acceleration due to gravity used if internal gravity source is selected. If gravity is to be neglected in the simulation, this value can be set to 0.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.

- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Velocity: e.g., {'u', 'w'}

Specify velocity state names.

Default value is `''`.

Pitch attitude: e.g., 'theta'

Specify pitch attitude state name.

Default value is `''`.

Position: e.g., {'Xe', 'Ze'}

Specify position state names.

Default value is `''`.

Pitch angular rate: e.g., 'q'

Specify pitch angular rate state name.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the force acting along the body *x*-axis, (F_x).
Second		Contains the force acting along the body *z*-axis, (F_z).
Third		Contains the applied pitch moment, (M).
Fourth (Optional)		Contains the block is gravity in the selected units.

Output	Dimension Type	Description
First		Contains the pitch attitude, within ±pi, in radians (θ).

Output	Dimension Type	Description
Second		Contains the pitch angular rate, in radians per second (q).
Third		Contains the pitch angular acceleration, in radians per second squared ($\dot{q}$).
Fourth	Two-element vector	Contains the location of the body, in the flat Earth reference frame, (Xe, Ze).
Fifth	Two-element vector	Contains the velocity of the body resolved into the body-fixed coordinate frame, (u, w).
Sixth	Two-element vector	Contains the acceleration of the body resolved into the body-fixed coordinate frame, (Ax, Az).
Seventh	Two-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Examples

See `aero_guidance` for an example of this block.

See Also

3DOF (Wind Axes)

4th Order Point Mass (Longitudinal)

Custom Variable Mass 3DOF (Body Axes)

Custom Variable Mass 3DOF (Wind Axes)

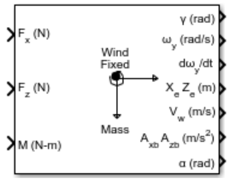
Simple Variable Mass 3DOF (Body Axes)

Simple Variable Mass 3DOF (Wind Axes)

Introduced in R2006a

3DOF (Wind Axes)

Implement three-degrees-of-freedom equations of motion with respect to wind axes

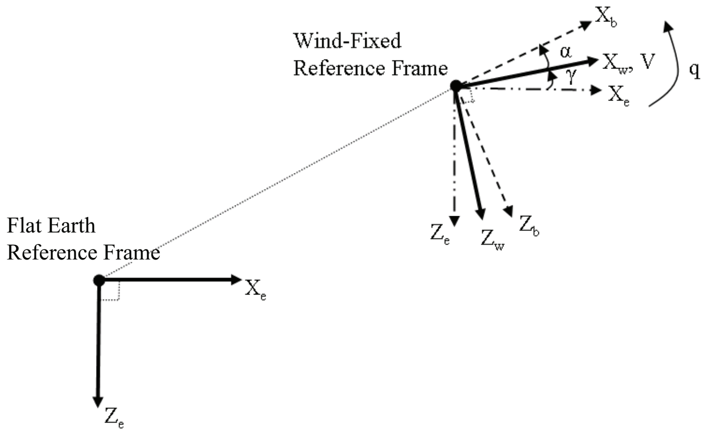


Library

Equations of Motion/3DOF

Description

The 3DOF (Wind Axes) block considers the rotation in the vertical plane of a wind-fixed coordinate frame about a flat Earth reference frame.



The equations of motion are

$$\dot{V} = \frac{F_{x_{wind}}}{m} - g\sin\gamma$$

$$\dot{\alpha} = \frac{F_{z_{wind}}}{mV\cos\beta} + q + \frac{g}{V\cos\beta}\cos\gamma$$

$$\dot{q} = \ddot{\theta} = \frac{M_{y_{body}}}{I_{yy}}$$

$$\dot{\gamma} = q - \dot{\alpha}$$

$$A_{be} = \begin{bmatrix} A_{xe} \\ A_{ze} \end{bmatrix} = DCM_{wb}\left[\frac{F_w}{m} - g\sin\gamma\right]$$

$$A_{bb} = \begin{bmatrix} \dot{u}_b \\ \dot{w}_b \end{bmatrix} = DCM_{wb}\left[\frac{F_w}{m} - g\sin\gamma - \bar{\omega}_w \times \bar{V}_w\right]$$

$$\bar{F}_w = \begin{bmatrix} F_{x_{wind}} \\ F_{z_{wind}} \end{bmatrix}, \bar{V}_w = \begin{bmatrix} V_{x_{wind}} \\ V_{z_{wind}} \end{bmatrix}, \bar{\omega}_w = q$$

where the applied forces are assumed to act at the center of gravity of the body.

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Fixed` selection conforms to the previously described equations of motion.

Initial airspeed

A scalar value for the initial velocity of the body, (V_0).

Initial flight path angle

A scalar value for the initial flight path angle of the body, (γ_0).

Initial incidence

A scalar value for the initial angle between the velocity vector and the body, (α_0).

Initial body rotation rate

A scalar value for the initial body rotation rate, (q_0).

Initial position (x,z)

A two-element vector containing the initial location of the body in the flat Earth reference frame.

Initial Mass

A scalar value for the mass of the body.

Inertia body axes

A scalar value for the inertia of the body.

Gravity Source

Specify source of gravity:

`External`	Variable gravity input to block

`Internal`	Constant gravity specified in mask

Acceleration due to gravity

A scalar value for the acceleration due to gravity used if internal gravity source is selected. If gravity is to be neglected in the simulation, this value can be set to 0.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. Use state names instead of block paths throughout the linearization process.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Velocity: e.g., 'V'

Specify velocity name for the state.

Default value is `' '`.

Incidence angle: e.g., 'alpha'

Specify incidence angle name for the state.

Default value is `' '`.

Flight path angle: e.g., 'gamma'

Specify flight path angle name for the state.

Default value is `' '`.

Body rotation rates: e.g., 'q'

Specify body rotation rates name for the state.

Default value is `' '`.

Position: e.g., {'Xe', 'Ze'}

Specify position name for the state.

Default value is `' '`.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the force acting along the wind *x*-axis, (F_x).
Second		Contains the force acting along the wind *z*-axis, (F_z).
Third		Contains the applied pitch moment in body axes, (M).
Fourth (Optional)		Contains the block is gravity in the selected units.

Output	Dimension Type	Description
First		Contains the flight path angle, within ±pi, in radians (γ).
Second		Contains the pitch angular rate, in radians per second (ω_y).
Third		Contains the pitch angular acceleration, in radians per second squared ($d\omega_y/dt$).

Output	Dimension Type	Description
Fourth	Two-element vector	Contains the location of the body, in the flat Earth reference frame, (*Xe, Ze*).
Fifth	Two-element vector	Contains the velocity of the body resolved into the wind-fixed coordinate frame, (*V*, 0).
Sixth	Two-element vector	Contains the acceleration of the body resolved into the body-fixed coordinate frame, (*Ax, Az*).
Seventh	Scalar	Contains the angle of attack, (α).
Eighth	Two-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body, and that the mass and inertia are constant.

Reference

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

See Also

3DOF (Body Axes)

4th Order Point Mass (Longitudinal)

Custom Variable Mass 3DOF (Body Axes)

Custom Variable Mass 3DOF (Wind Axes)

Simple Variable Mass 3DOF (Body Axes)

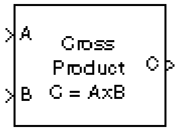
Simple Variable Mass 3DOF (Wind Axes)

Introduced in R2006a

3x3 Cross Product

Calculate cross product of two 3-by-1 vectors

Library: Aerospace Blockset / Utilities / Math Operations



Description

The 3x3 Cross Product block computes cross (or vector) product of two vectors, *A* and *B*. The block generates a third vector, *C*, in a direction normal to the plane containing *A* and *B*, with magnitude equal to the product of the lengths of *A* and *B* multiplied by the sine of the angle between them. The direction of *C* follows the right-hand rule in turning from *A* to *B*.

$$A = a_1\mathbf{i} + a_2\mathbf{j} + a_3\mathbf{k}$$

$$B = b_1\mathbf{i} + b_2\mathbf{j} + b_3\mathbf{k}$$

$$C = A \times B = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{vmatrix}$$

$$= (a_2b_3 - a_3b_2)\mathbf{i} + (a_3b_1 - a_1b_3)\mathbf{j} + (a_1b_2 - a_2b_1)\mathbf{k}$$

Ports

Input

`Input 1` — First cross product input

3-by-1 vector

First cross product input, specified as a vector.

Example: `[10 2 3]`

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32` | `Boolean` | `fixed point`

`Input 2` — Second cross product input
3-by-1 vector

Second cross product input, specified as a vector.

Example: `[10 2 3]`

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32` | `fixed point`

Output

`Output 1` — Cross product
3-by-1 vector

Cross product, output as a vector.

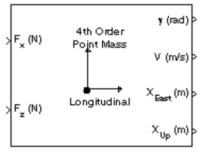
Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32` | `fixed point`

See Also

Introduced before R2006a

4th Order Point Mass (Longitudinal)

Calculate fourth-order point mass

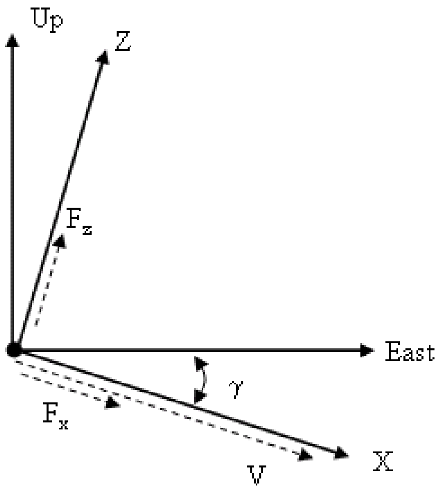


Library

Equations of Motion/Point Mass

Description

The 4th Order Point Mass (Longitudinal) block performs the calculations for the translational motion of a single point mass or multiple point masses.



The translational motions of the point mass $[X_{\text{East}}\ X_{\text{Up}}]^T$ are functions of airspeed (V) and flight path angle (γ),

$$F_x = m\dot{V}$$

$$F_z = mV\dot{\gamma}$$

$$\dot{X}_{East} = V\cos\gamma$$

$$\dot{X}_{Up} = V\sin\gamma$$

where the applied forces $[F_x\ F_z]^T$ are in a system defined as follows: x-axis is in the direction of vehicle velocity relative to air, z-axis is upward, and y-axis completes the right-handed frame. The mass of the body m is assumed constant.

Parameters

Units

Specifies the input and output units:

Units	Forces	Velocity	Position
`Metric (MKS)`	Newton	Meters per second	Meters
`English (Velocity in ft/s)`	Pound	Feet per second	Feet
`English (Velocity in kts)`	Pound	Knots	Feet

Initial flight path angle

The scalar or vector containing the initial flight path angle of the point mass(es).

Initial airspeed

The scalar or vector containing the initial airspeed of the point mass(es).

Initial downrange

The scalar or vector containing the initial downrange of the point mass(es).

Initial altitude

The scalar or vector containing the initial altitude of the point mass(es).

Initial mass

The scalar or vector containing the mass of the point mass(es).

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the force in *x*-axis in selected units.
Second		Contains the force in *z*-axis in selected units.

Output	Dimension Type	Description
First		Contains the flight path angle in radians.
Second		Contains the airspeed in selected units.
Third		Contains the downrange or amount traveled East in selected units.
Fourth		Contains the altitude or amount traveled Up in selected units.

Assumptions and Limitations

The flat Earth reference frame is considered inertial, an excellent approximation that allows the forces due to the Earth's motion relative to the “fixed stars” to be neglected.

See Also

4th Order Point Mass Forces (Longitudinal)

3DOF (Body Axes)

3DOF (Wind Axes)

6th Order Point Mass (Coordinated Flight)

6th Order Point Mass Forces (Coordinated Flight)

Custom Variable Mass 3DOF (Body Axes)

Custom Variable Mass 3DOF (Wind Axes)

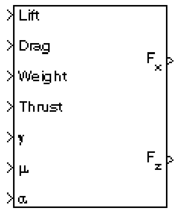
Simple Variable Mass 3DOF (Body Axes)

Simple Variable Mass 3DOF (Wind Axes)

Introduced before R2006a

4th Order Point Mass Forces (Longitudinal)

Calculate forces used by fourth-order point mass

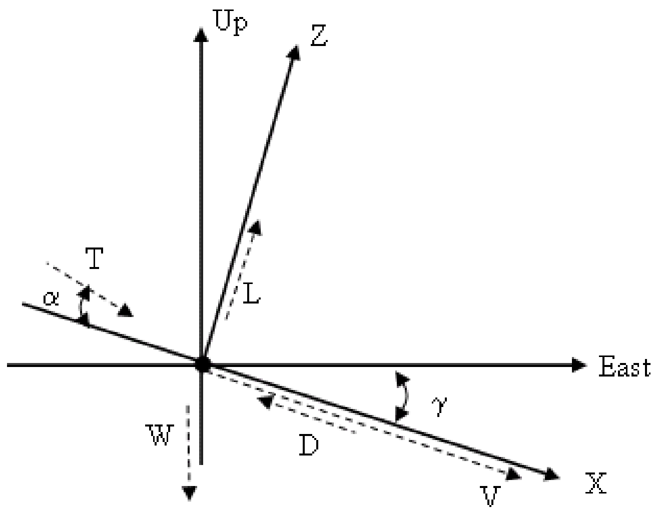


Library

Equations of Motion/Point Mass

Description

The 4th Order Point Mass Forces (Longitudinal) block calculates the applied forces for a single point mass or multiple point masses.



The applied forces $[F_x\ F_z]^T$ are in a system defined as follows: *x*-axis is in the direction of vehicle velocity relative to air, *z*-axis is upward, and *y*-axis completes the right-handed frame. They are functions of lift (*L*), drag (*D*), thrust (*T*), weight (*W*), flight path angle (*γ*), angle of attack (*α*), and bank angle (*μ*).

$$F_z = (L + T\sin\alpha)\cos\mu - W\cos\gamma$$
$$F_x = T\cos\alpha - D - W\sin\gamma$$

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the lift in units of force.
Second		Contains the drag in units of force.
Third		Contains the weight in units of force.
Fourth		Contains the thrust in units of force.
Fifth		Contains the flight path angle in radians.

Input	Dimension Type	Description
Sixth		Contains the bank angle in radians.
Seventh		Contains the angle of attack in radians.

Output	Dimension Type	Description
First		Contains the force in *x*-axis in units of force.
Second		Contains the force in *z*-axis in units of force.

Assumptions and Limitations

The flat Earth reference frame is considered inertial, an excellent approximation that allows the forces due to the Earth's motion relative to the “fixed stars” to be neglected.

See Also

4th Order Point Mass (Longitudinal)

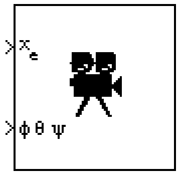
6th Order Point Mass (Coordinated Flight)

6th Order Point Mass Forces (Coordinated Flight)

Introduced before R2006a

6DoF Animation

Create 3-D MATLAB Graphics animation of six-degrees-of-freedom object



Library

Animation

Description

The 6DoF Animation block displays a 3-D animated view of a six-degrees-of-freedom (6DoF) craft, its trajectory, and its target using MATLAB Graphics.

The 6DoF Animation block uses the input values and the dialog parameters to create and display the animation.

This block does not produce deployable code, but can be used with Simulink Coder external mode as a SimViewingDevice.

Parameters

Axes limits [xmin xmax ymin ymax zmin zmax]

Specifies the three-dimensional space to be viewed.

Time interval between updates

Specifies the time interval at which the animation is redrawn.

Size of craft displayed

Scale factor to adjust the size of the craft and target.

Static object position

Specifies the altitude, the crossrange position, and the downrange position of the target.

Enter view

Selects preset MATLAB Graphics parameters **CameraTarget** and **CameraUpVector** for the figure axes. The dialog parameters **Position of camera** and **View angle** are used to customize the position and field of view for the selected view. Possible views are

- `Fixed position`
- `Cockpit`
- `Fly alongside`

Position of camera [xc yc zc]

Specifies the MATLAB Graphics parameter CameraPosition for the figure axes. Used in all cases except for the Cockpit view.

View angle

Specifies the MATLAB Graphics parameter CameraViewAngle for the figure axes in degrees.

Enable animation

When selected, the animation is displayed during the simulation. If not selected, the animation is not displayed.

Inputs

Input	Dimension Type	Description
First	Vector	Contains the altitude, the crossrange position, and the downrange position of the craft in Earth coordinates.
Second	Vector	Contains the Euler angles of the craft.

See Also

3DoF Animation

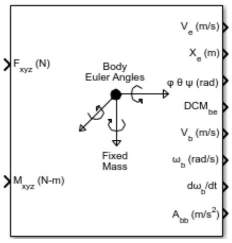
FlightGear Preconfigured 6DoF Animation

The figure axes properties CameraPosition and CameraViewAngle

Introduced before R2006a

6DOF (Euler Angles)

Implement Euler angle representation of six-degrees-of-freedom equations of motion

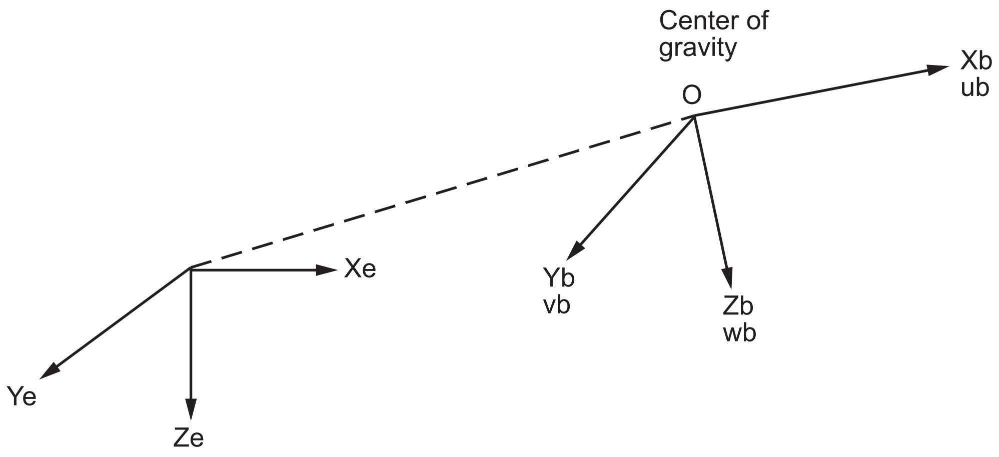


Library

Equations of Motion/6DOF

Description

The 6DOF (Euler Angles) block considers the rotation of a body-fixed coordinate frame (X_b, Y_b, Z_b) about a flat Earth reference frame (X_e, Y_e, Z_e). The origin of the body-fixed coordinate frame is the center of gravity of the body, and the body is assumed to be rigid, an assumption that eliminates the need to consider the forces acting between individual elements of mass. The flat Earth reference frame is considered inertial, an excellent approximation that allows the forces due to the Earth's motion relative to the “fixed stars” to be neglected.



Flat Earth reference frame

The translational motion of the body-fixed coordinate frame is given below, where the applied forces $[F_x\ F_y\ F_z]^T$ are in the body-fixed frame, and the mass of the body *m* is assumed constant.

$$\bar{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m\left(\dot{\bar{V}}_b + \bar{\omega} \times \bar{V}_b\right)$$

$$A_{bb} = \begin{bmatrix} \dot{u}_b \\ \dot{v}_b \\ \dot{w}_b \end{bmatrix} = \frac{1}{m}\bar{F}_b - \bar{\omega} \times \bar{V}_b$$

$$A_{be} = \frac{1}{m}F_b$$

$$\bar{V}_b = \begin{bmatrix} u_b \\ v_b \\ w_b \end{bmatrix}, \bar{\omega} = \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

A_{bb} is the acceleration of the body with respect to the body reference frame. A_{bi} is the acceleration of the body with respect to an inertial reference frame.

The rotational dynamics of the body-fixed frame are given below, where the applied moments are $[L\ M\ N]^T$, and the inertia tensor I is with respect to the origin O.

$$\bar{M}_B = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I\dot{\bar{\omega}} + \bar{\omega} \times (I\bar{\omega})$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

The relationship between the body-fixed angular velocity vector, $[p\ q\ r]^T$, and the rate of change of the Euler angles, $\begin{bmatrix}\dot{\phi} & \dot{\theta} & \dot{\psi}\end{bmatrix}^T$, can be determined by resolving the Euler rates into the body-fixed coordinate frame.

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} \dot{\phi} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix} \equiv J^{-1} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

Inverting J then gives the required relationship to determine the Euler rate vector.

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = J \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & (\sin\phi\tan\theta) & (\cos\phi\tan\theta) \\ 0 & \cos\phi & -\sin\phi \\ 0 & \dfrac{\sin\phi}{\cos\theta} & \dfrac{\cos\phi}{\cos\theta} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Fixed` selection conforms to the previously described equations of motion.

Representation

Select the representation to use:

`Euler Angles`	Use Euler angles within equations of motion.
`Quaternion`	Use quaternions within equations of motion.

The `Euler Angles` selection conforms to the previously described equations of motion.

Initial position in inertial axes

The three-element vector for the initial location of the body in the flat Earth reference frame.

Initial velocity in body axes

The three-element vector for the initial velocity in the body-fixed coordinate frame.

Initial Euler rotation

The three-element vector for the initial Euler rotation angles [roll, pitch, yaw], in radians.

Initial body rotation rates

The three-element vector for the initial body-fixed angular rates, in radians per second.

Initial Mass

The mass of the rigid body.

Inertia

The 3-by-3 inertia tensor matrix *I*.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Position: e.g., {'Xe', 'Ye', 'Ze'}

Specify position state names.

Default value is `''`.

Velocity: e.g., {'U', 'v', 'w'}

Specify velocity state names.

Default value is `''`.

Euler rotation angles: e.g., {'phi', 'theta', 'psi'}

Specify Euler rotation angle state names. This parameter appears if the **Representation** parameter is set to `Euler Angles`.

Default value is `''`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rate state names.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces in body-fixed coordinate frame.
Second	Vector	Contains the three applied moments in body-fixed coordinate frame.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity in the flat Earth reference frame.
Second	Three-element vector	Contains the position in the flat Earth reference frame.
Third	Three-element vector	Contains the Euler rotation angles [roll, pitch, yaw], within ±pi, in radians.

Output	Dimension Type	Description
Fourth	3-by-3 matrix	Contains the coordinate transformation from flat Earth axes to body-fixed axes.
Fifth	Three-element vector	Contains the velocity in the body-fixed frame.
Sixth	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Seventh	Three-element vector	Contains the angular accelerations in body-fixed axes, in radians per second squared.
Eighth	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Ninth (Optional)	Three-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body, and that the mass and inertia are constant.

Examples

See the `aeroblk_six_dof` airframe in `aeroblk_HL20` and `asbhl20` for examples of this block.

Reference

Stevens, Brian, and Frank Lewis, *Aircraft Control and Simulation*, Second Edition, John Wiley & Sons, 2003.

Zipfel, Peter H., *Modeling and Simulation of Aerospace Vehicle Dynamics*. Second Edition, AIAA Education Series, 2007.

See Also

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

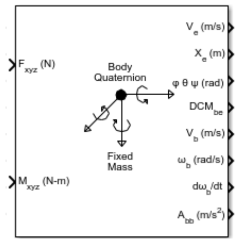
Simple Variable Mass 6DOF Wind (Wind Angles)

"About Aerospace Coordinate Systems" on page 2-10

Introduced in R2006a

6DOF (Quaternion)

Implement quaternion representation of six-degrees-of-freedom equations of motion with respect to body axes



Library

Equations of Motion/6DOF

Description

For a description of the coordinate system and the translational dynamics, see the block description for the 6DOF (Euler Angles) block.

The integration of the rate of change of the quaternion vector is given below. The gain *K* drives the norm of the quaternion state vector to 1.0 should *ε*become nonzero. You must choose the value of this gain with care, because a large value improves the decay rate of the error in the norm, but also slows the simulation because fast dynamics are introduced. An error in the magnitude in one element of the quaternion vector is spread equally among all the elements, potentially increasing the error in the state vector.

$$\begin{bmatrix}\dot{q}_0\\\dot{q}_1\\\dot{q}_2\\\dot{q}_3\end{bmatrix} = {}^1\!/_2\begin{bmatrix}0 & -p & -q & -r\\ p & 0 & r & -q\\ q & -r & 0 & p\\ r & q & -p & 0\end{bmatrix}\begin{bmatrix}q_0\\q_1\\q_2\\q_3\end{bmatrix} + K\varepsilon\begin{bmatrix}q_0\\q_1\\q_2\\q_3\end{bmatrix}$$

$$\varepsilon = 1 - \left(q_0^2 + q_1^2 + q_2^2 + q_3^2\right)$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Fixed` selection conforms to the previously described equations of motion.

Representation

Select the representation to use:

`Euler Angles`	Use Euler angles within equations of motion.
`Quaternion`	Use quaternions within equations of motion.

The `Quaternion` selection conforms to the previously described equations of motion.

Initial position in inertial axes

The three-element vector for the initial location of the body in the flat Earth reference frame.

Initial velocity in body axes

The three-element vector for the initial velocity in the body-fixed coordinate frame.

Initial Euler rotation

The three-element vector for the initial Euler rotation angles [roll, pitch, yaw], in radians.

Initial body rotation rates

The three-element vector for the initial body-fixed angular rates, in radians per second.

Initial Mass

The mass of the rigid body.

Inertia matrix

The 3-by-3 inertia tensor matrix *I*.

Gain for quaternion normalization

The gain to maintain the norm of the quaternion vector equal to 1.0.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.

- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Position: e.g., {'Xe', 'Ye', 'Ze'}

Specify position state names.

Default value is `''`.

Velocity: e.g., {'U', 'v', 'w'}

Specify velocity state names.

Default value is `''`.

Quaternion vector: e.g., {'qr', 'qi', 'qj', 'qk'}

Specify quaternion vector state names.

Default value is `''`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rate state names.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces.
Second	Vector	Contains the three applied moments.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity in the flat Earth reference frame.

Output	Dimension Type	Description
Second	Three-element vector	Contains the position in the flat Earth reference frame.
Third	Three-element vector	Contains the Euler rotation angles [roll, pitch, yaw], in radians.
Fourth	3-by-3 matrix	Contains the coordinate transformation from flat Earth axes to body-fixed axes.
Fifth	Three-element vector	Contains the velocity in the body-fixed frame.
Sixth	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Seventh	Three-element vector	Contains the angular accelerations in body-fixed axes, in radians per second squared.
Eight	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Ninth (Optional)	Three-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body, and that the mass and inertia are constant.

Reference

Stevens, Brian, and Frank Lewis, *Aircraft Control and Simulation*, Second Edition, John Wiley & Sons, 2003.

Zipfel, Peter H., *Modeling and Simulation of Aerospace Vehicle Dynamics*. Second Edition, AIAA Education Series, 2007.

See Also

6DOF (Euler Angles)

6DOF ECEF (Quaternion)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

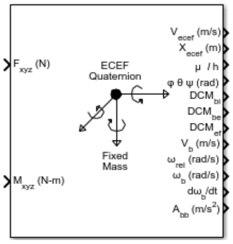
Simple Variable Mass 6DOF Wind (Wind Angles)

“About Aerospace Coordinate Systems” on page 2-10

Introduced in R2006a

6DOF ECEF (Quaternion)

Implement quaternion representation of six-degrees-of-freedom equations of motion in Earth-centered Earth-fixed (ECEF) coordinates

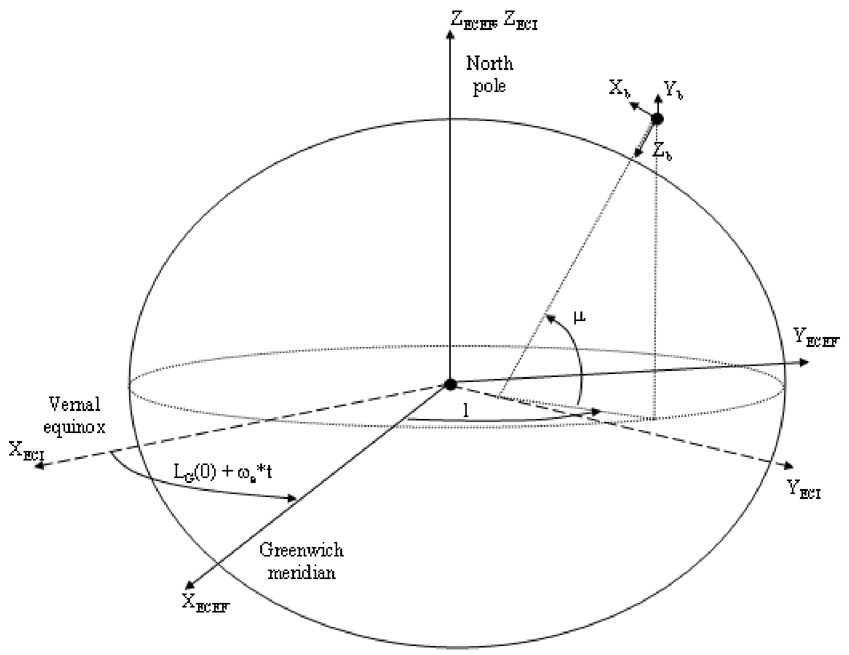


Library

Equations of Motion/6DOF

Description

The 6DOF ECEF (Quaternion) block considers the rotation of a Earth-centered Earth-fixed (ECEF) coordinate frame (X_{ECEF}, Y_{ECEF}, Z_{ECEF}) about an Earth-centered inertial (ECI) reference frame (X_{ECI}, Y_{ECI}, Z_{ECI}). The origin of the ECEF coordinate frame is the center of the Earth, additionally the body of interest is assumed to be rigid, an assumption that eliminates the need to consider the forces acting between individual elements of mass. The representation of the rotation of ECEF frame from ECI frame is simplified to consider only the constant rotation of the ellipsoid Earth (ω_e) including an initial celestial longitude ($L_G(0)$). This excellent approximation allows the forces due to the Earth's complex motion relative to the “fixed stars” to be neglected.



The translational motion of the ECEF coordinate frame is given below, where the applied forces $[F_x\ F_y\ F_z]^T$ are in the body frame, and the mass of the body m is assumed constant.

$$\bar{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m\left(\dot{\bar{V}}_b + \bar{\omega}_b \times \bar{V}_b + DCM_{bf}\bar{\omega}_e \times \bar{V}_b + DCM_{bf}\left(\bar{\omega}_e \times \left(\bar{\omega}_e \times \bar{X}_f\right)\right)\right)$$

where the change of position in ECEF $\dot{x}_f$ is calculated by

$$\dot{x}_f = DCM_{fb}\bar{V}_b$$

and the velocity of the body with respect to ECEF frame, expressed in body frame $(\bar{V}_b)$, angular rates of the body with respect to ECI frame, expressed in body frame $(\bar{\omega}_b)$. Earth rotation rate $(\bar{\omega}_e)$, and relative angular rates of the body with respect to north-east-down (NED) frame, expressed in body frame $(\bar{\omega}_{rel})$ are defined as

$$\bar{V}_b = \begin{bmatrix} u \\ v \\ w \end{bmatrix}, \bar{\omega}_{rel} = \begin{bmatrix} p \\ q \\ r \end{bmatrix}, \bar{\omega}_e = \begin{bmatrix} 0 \\ 0 \\ \omega_e \end{bmatrix}, \bar{\omega}_b = \bar{\omega}_{rel} + DCM_{bf}\bar{\omega}_e + DCM_{be}\bar{\omega}_{ned}$$

$$\bar{\omega}_{ned} = \begin{bmatrix} \dot{l}\cos\mu \\ -\dot{\mu} \\ -\dot{l}\sin\mu \end{bmatrix} = \begin{bmatrix} V_E/(N+h) \\ -V_N/(M+h) \\ V_E \bullet \tan\mu/(N+h) \end{bmatrix}$$

The rotational dynamics of the body defined in body-fixed frame are given below, where the applied moments are $[L\ M\ N]^T$, and the inertia tensor I is with respect to the origin O.

$$A_{bb} = \begin{bmatrix} \dot{u}_b \\ \dot{v}_b \\ \dot{\omega}_b \end{bmatrix} = \frac{1}{m}\bar{F}_b - \left[\bar{\omega}_b \times \bar{V}_b + DCM_{bf}\bar{\omega}_e \times \bar{V}_b + DCM_{bf}\left(\bar{\omega}_e \times \left(\bar{\omega}_e \times \bar{X}_f\right)\right)\right]$$

$$A_{becef} = \frac{F_b}{m}$$

$$\bar{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I\dot{\bar{\omega}}_b + \bar{\omega}_b \times (I\bar{\omega}_b)$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

The integration of the rate of change of the quaternion vector is given below.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = -\,{}^1\!/_2 \begin{bmatrix} 0 & \omega_b(1) & \omega_b(2) & \omega_b(3) \\ -\omega_b(1) & 0 & -\omega_b(3) & \omega_b(2) \\ -\omega_b(2) & \omega_b(3) & 0 & -\omega_b(1) \\ -\omega_b(3) & -\omega_b(2) & \omega_b(1) & 0 \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Fixed` selection conforms to the previously described equations of motion.

Initial position in geodetic latitude, longitude and altitude

The three-element vector for the initial location of the body in the geodetic reference frame, with latitude, longitude, and altitude. The altitude value depends on the selected units (meters (MKS) or feet (English)). Latitude and longitude values are in degrees and can be any value. However, latitude values of +90 and -90 may return unexpected values because of singularity at the poles.

Initial velocity in body axes

The three-element vector containing the initial velocity of the body with respect to ECEF frame, expressed in body frame.

Initial Euler orientation

The three-element vector containing the initial Euler rotation angles [roll, pitch, yaw], in radians. Euler rotation angles are those between the body and north-east-down (NED) coordinate systems.

Initial body rotation rates

The three-element vector for the initial angular rates of the body with respect to NED frame, expressed in body frame, in radians per second.

Initial mass

The mass of the rigid body.

Inertia

The 3-by-3 inertia tensor matrix *I*, in body-fixed axes.

Planet model

Specifies the planet model to use: `Custom` or `Earth (WGS84)`.

Flattening

Specifies the flattening of the planet. This option is only available when **Planet model** is set to `Custom`.

Equatorial radius of planet

Specifies the radius of the planet at its equator. The units of the equatorial radius parameter should be the same as the units for ECEF position. This option is only available when **Planet model** is set to `Custom`.

Rotational rate

Specifies the scalar rotational rate of the planet in rad/s. This option is only available when **Planet model** is set to `Custom`.

Celestial longitude of Greenwich source

Specifies the source of Greenwich meridian's initial celestial longitude:

`Internal`	Use celestial longitude value from mask dialog.
`External`	Use external input for celestial longitude value.

Celestial longitude of Greenwich

The initial angle between Greenwich meridian and the *x*-axis of the ECI frame.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Quaternion vector: e.g., {'qr', 'qi', 'qj', 'qk'}

Specify quaternion vector state names.

Default value is `''`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rate state names.

Default value is `''`.

Velocity: e.g., {'U', 'v', 'w'}

Specify velocity state names.

Default value is `''`.

ECEF position: e.g., {'Xecef', 'Yecef', 'Zecef'}

Specify the ECEF position state names.

Default value is `''`.

Inertial position: e.g., {'Xeci', 'Yeci', 'Zeci'}

Specify the inertial position state names.

Default value is `''`.

Celestial longitude of Greenwich: e.g., 'LG'

Specify the Celestial longitude of Greenwich state name.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces in body-fixed axes.
Second	Vector	Contains the three applied moments in body-fixed axes.

Output	Dimension Type	Description
First	Vector	Contains the velocity of the body with respect to ECEF frame, expressed in ECEF frame.
Second	Three-element vector	Contains the position in ECEF reference frame.
Third	Three-element vector	Contains the position in geodetic latitude, longitude and altitude, in degrees, degrees and selected units of length respectively.
Fourth	Three-element vector	Contains the body rotation angles [roll, pitch, yaw], in radians. Euler rotation angles are those between the body and north-east-down (NED) coordinate systems.
Fifth	3-by-3 matrix	Applies to the coordinate transformation from ECI axes to body-fixed axes

Output	Dimension Type	Description
Sixth	3-by-3 matrix	Applies to the coordinate transformation from NED axes to body-fixed axes.
Seventh	3-by-3 matrix	Applies to the coordinate transformation from ECEF axes to NED axes.
Eighth	Three-element vector	Contains the velocity of the body with respect to ECEF frame, expressed in the body frame.
Ninth	Three-element vector	Contains the relative angular rates of the body with respect to NED frame, expressed in the body frame, in radians per second.
Tenth	Three-element vector	Contains the angular rates of the body with respect to the ECI frame, expressed in body frame, in radians per second.
Eleventh	Three-element vector	Contains the angular accelerations of the body with respect to ECI frame, expressed in the body frame, in radians per second squared.
Twelfth	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Thirteenth (Optional)	Three-element vector	Contains the accelerations in body-fixed axes with respect to ECEF frame.

Assumptions and Limitations

This implementation assumes that the applied forces are acting at the center of gravity of the body, and that the mass and inertia are constant.

This implementation generates a geodetic latitude that lies between ±90 degrees, and longitude that lies between ±180 degrees. Additionally, the MSL altitude is approximate.

The Earth is assumed to be ellipsoidal. By setting flattening to 0.0, a spherical planet can be achieved. The Earth's precession, nutation, and polar motion are neglected. The celestial longitude of Greenwich is Greenwich Mean Sidereal Time (GMST) and provides a rough approximation to the sidereal time.

The implementation of the ECEF coordinate system assumes that the origin is at the center of the planet, the *x*-axis intersects the Greenwich meridian and the equator, the *z*-

axis is the mean spin axis of the planet, positive to the north, and the *y*-axis completes the right-handed system.

The implementation of the ECI coordinate system assumes that the origin is at the center of the planet, the *x*-axis is the continuation of the line from the center of the Earth toward the vernal equinox, the *z*-axis points in the direction of the mean equatorial plane's north pole, positive to the north, and the *y*-axis completes the right-handed system.

References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation, Second Edition*, John Wiley & Sons, New York, 2003.

McFarland, Richard E., *A Standard Kinematic Model for Flight simulation at NASA-Ames*, NASA CR-2497.

“Supplement to Department of Defense World Geodetic System 1984 Technical Report: Part I - Methods, Techniques and Data Used in WGS84 Development,” DMA TR8350.2-A.

See Also

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

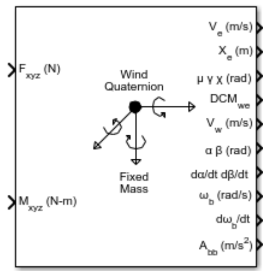
Simple Variable Mass 6DOF Wind (Wind Angles)

“About Aerospace Coordinate Systems” on page 2-10

Introduced in R2006a

6DOF Wind (Quaternion)

Implement quaternion representation of six-degrees-of-freedom equations of motion with respect to wind axes

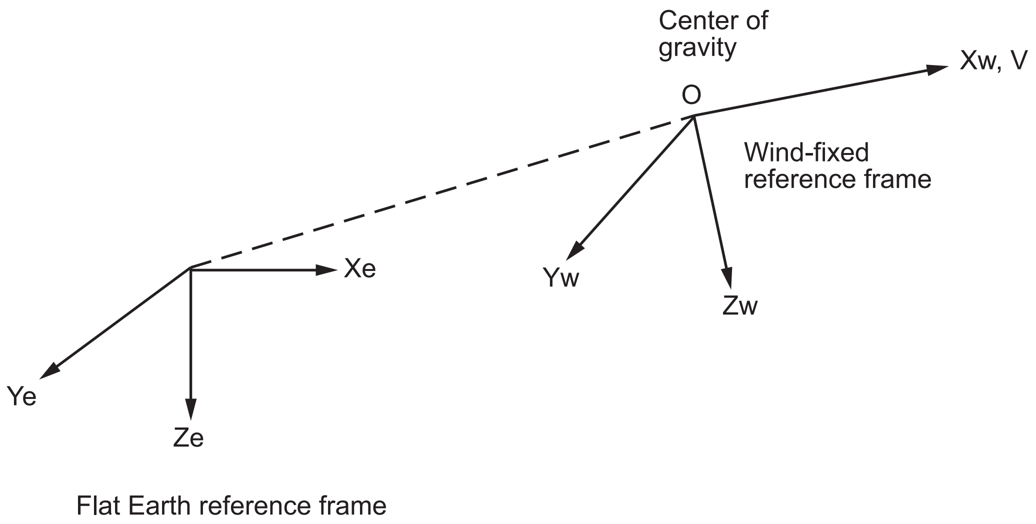


Library

Equations of Motion/6DOF

Description

The 6DOF Wind (Quaternion) block considers the rotation of a wind-fixed coordinate frame (X_w, Y_w, Z_w) about an flat Earth reference frame (X_e, Y_e, Z_e). The origin of the wind-fixed coordinate frame is the center of gravity of the body, and the body is assumed to be rigid, an assumption that eliminates the need to consider the forces acting between individual elements of mass. The flat Earth reference frame is considered inertial, an excellent approximation that allows the forces due to the Earth's motion relative to the "fixed stars" to be neglected.



The translational motion of the wind-fixed coordinate frame is given below, where the applied forces $[F_x\ F_y\ F_z]^T$ are in the wind-fixed frame, and the mass of the body m is assumed constant.

$$\bar{F}_w = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\bar{V}}_w + \bar{\omega}_w \times \bar{V}_w)$$

$$A_{be} = DCM_{wb}\frac{\bar{F}_w}{m}$$

$$\bar{V}_w = \begin{bmatrix} V \\ 0 \\ 0 \end{bmatrix}, \bar{\omega}_w = \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = DMC_{wb}\begin{bmatrix} p_b - \dot{\beta}\sin\alpha \\ q_b - \dot{\alpha} \\ r_b + \dot{\beta}\cos\alpha \end{bmatrix}, \bar{\omega}_b = \begin{bmatrix} p_b \\ q_b \\ r_b \end{bmatrix}$$

$$A_{bb} = \begin{bmatrix} \dot{u}_b \\ \dot{v}_b \\ \dot{w}_b \end{bmatrix} = DCM_{wb}\left[\frac{\bar{F}_w}{m} - \bar{\omega}_w \times \bar{V}_w\right]$$

The rotational dynamics of the body-fixed frame are given below, where the applied moments are $[L\ M\ N]^T$, and the inertia tensor I is with respect to the origin O. Inertia tensor I is much easier to define in body-fixed frame.

$$\bar{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I\dot{\bar{\omega}}_b + \bar{\omega}_b \times (I\bar{\omega}_b)$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

The integration of the rate of change of the quaternion vector is given below.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = -\tfrac{1}{2} \begin{bmatrix} 0 & p & q & r \\ -p & 0 & -r & q \\ -q & r & 0 & -p \\ -r & -q & p & 0 \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Fixed` selection conforms to the previously described equations of motion.

Representation

Select the representation to use:

`Wind Angles`	Use wind angles within equations of motion.
`Quaternion`	Use quaternions within equations of motion.

The `Quaternion` selection conforms to the previously described equations of motion.

Initial position in inertial axes

The three-element vector for the initial location of the body in the flat Earth reference frame.

Initial airspeed, angle of attack, and sideslip angle

The three-element vector containing the initial airspeed, initial angle of attack and initial sideslip angle.

Initial wind orientation

The three-element vector containing the initial wind angles [bank, flight path, and heading], in radians.

Initial body rotation rates

The three-element vector for the initial body-fixed angular rates, in radians per second.

Initial mass

The mass of the rigid body.

Inertia matrix

The 3-by-3 inertia tensor matrix *I*, in body-fixed axes.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Position: e.g., {'Xe', 'Ye', 'Ze'}

Specify position state names.

Default value is `''`.

Velocity: e.g., 'V'

Specify velocity state name.

Default value is `''`.

Incidence angle: e.g., 'alpha'

Specify incidence angle state name.

Default value is `''`.

Sideslip angle: e.g., 'beta'

Specify sideslip angle state name.

Default value is `''`.

Quaternion vector: e.g., {'qr', 'qi', 'qj', 'qk'}

Specify quaternion vector state names.

Default value is `''`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rate state names.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces in wind-fixed axes.
Second	Vector	Contains the three applied moments in body-fixed axes.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity in the flat Earth reference frame.
Second	Three-element vector	Contains the position in the flat Earth reference frame.
Third	Three-element vector	Contains the wind rotation angles [bank, flight path, heading], in radians.
Fourth	3-by-3 matrix	Contains the coordinate transformation from flat Earth axes to wind-fixed axes.
Fifth	Three-element vector	Contains the velocity in the wind-fixed frame.
Sixth	Two-element vector	Contains the angle of attack and sideslip angle, in radians.

Output	Dimension Type	Description
Seventh	Two-element vector	Contains the rate of change of angle of attack and rate of change of sideslip angle, in radians per second.
Eight	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Ninth	Three-element vector	Contains the angular accelerations in body-fixed axes, in radians per second squared.
Tenth	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Eleventh (Optional)	Three-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body, and that the mass and inertia are constant.

Reference

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

See Also

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

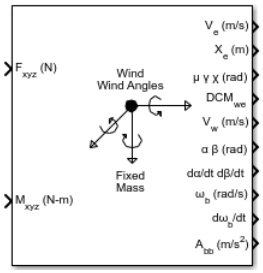
Simple Variable Mass 6DOF Wind (Wind Angles)

“About Aerospace Coordinate Systems” on page 2-10

Introduced in R2006a

6DOF Wind (Wind Angles)

Implement wind angle representation of six-degrees-of-freedom equations of motion



Library

Equations of Motion/6DOF

Description

For a description of the coordinate system employed and the translational dynamics, see the block description for the 6DOF Wind (Quaternion) block.

The relationship between the wind angles, $[\mu\gamma\chi]^T$, can be determined by resolving the wind rates into the wind-fixed coordinate frame.

$$\begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} \dot{\mu} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\mu & \sin\mu \\ 0 & -\sin\mu & \cos\mu \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\gamma} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\mu & \sin\mu \\ 0 & -\sin\mu & \cos\mu \end{bmatrix} \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\chi} \end{bmatrix} \equiv J^{-1} \begin{bmatrix} \dot{\mu} \\ \dot{\gamma} \\ \dot{\chi} \end{bmatrix}$$

Inverting *J* then gives the required relationship to determine the wind rate vector.

$$\begin{bmatrix} \dot{\mu} \\ \dot{\gamma} \\ \dot{\chi} \end{bmatrix} = J \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} 1 & (\sin\mu\tan\gamma) & (\cos\mu\tan\gamma) \\ 0 & \cos\mu & -\sin\mu \\ 0 & \dfrac{\sin\mu}{\cos\gamma} & \dfrac{\cos\mu}{\cos\gamma} \end{bmatrix} \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix}$$

The body-fixed angular rates are related to the wind-fixed angular rate by the following equation.

$$\begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = DMC_{wb} \begin{bmatrix} p_b - \dot{\beta}\sin\alpha \\ q_b - \dot{\alpha} \\ r_b + \dot{\beta}\cos\alpha \end{bmatrix}$$

Using this relationship in the wind rate vector equations, gives the relationship between the wind rate vector and the body-fixed angular rates.

$$\begin{bmatrix} \dot{\mu} \\ \dot{\gamma} \\ \dot{\chi} \end{bmatrix} = J \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} 1 & (\sin\mu\tan\gamma) & (\cos\mu\tan\gamma) \\ 0 & \cos\mu & -\sin\mu \\ 0 & \dfrac{\sin\mu}{\cos\gamma} & \dfrac{\cos\mu}{\cos\gamma} \end{bmatrix} DMC_{wb} \begin{bmatrix} p_b - \dot{\beta}\sin\alpha \\ q_b - \dot{\alpha} \\ r_b + \dot{\beta}\cos\alpha \end{bmatrix}$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Fixed` selection conforms to the previously described equations of motion.

Representation

Select the representation to use:

`Wind Angles`	Use wind angles within equations of motion.
`Quaternion`	Use quaternions within equations of motion.

The `Wind Angles` selection conforms to the previously described equations of motion.

Initial position in inertial axes

The three-element vector for the initial location of the body in the flat Earth reference frame.

Initial airspeed, angle of attack, and sideslip angle

The three-element vector containing the initial airspeed, initial angle of attack and initial sideslip angle.

Initial wind orientation

The three-element vector containing the initial wind angles [bank, flight path, and heading], in radians.

Initial body rotation rates

The three-element vector for the initial body-fixed angular rates, in radians per second.

Initial mass

The mass of the rigid body.

Inertia

The 3-by-3 inertia tensor matrix I, in body-fixed axes.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Position: e.g., {'Xe', 'Ye', 'Ze'}

Specify position state names.

Default value is `''`.

Velocity: e.g., 'V'

Specify velocity state name.

Default value is `''`.

Incidence angle: e.g., 'alpha'

Specify incidence angle state name.

Default value is `''`.

Sideslip angle: e.g., 'beta'

Specify sideslip angle state name.

Default value is `''`.

Wind orientation: e.g., {'mu', 'gamma', 'chi'}

Specify wind orientation state names. This parameter appears if the **Representation** parameter is set to `Wind Angles`.

Default value is `''`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rate state names.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces in wind-fixed axes.
Second	Vector	Contains the three applied moments in body-fixed axes.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity in the flat Earth reference frame.
Second	Three-element vector	Contains the position in the flat Earth reference frame.
Third	Three-element vector	Contains the wind rotation angles [bank, flight path, heading], within ±pi, in radians.
Fourth	3-by-3 matrix	Contains the coordinate transformation from flat Earth axes to wind-fixed axes.
Fifth	Three-element vector	Contains the velocity in the wind-fixed frame.
Sixth	Two-element vector	Contains the angle of attack and sideslip angle, in radians.

Output	Dimension Type	Description
Seventh	Two-element vector	Contains the rate of change of angle of attack and rate of change of sideslip angle, in radians per second.
Eighth	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Ninth	Three-element vector	Contains the angular accelerations in body-fixed axes, in radians per second squared.
Tenth	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Eleventh (Optional)	Three-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body, and that the mass and inertia are constant.

Reference

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

See Also

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Quaternion)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

Simple Variable Mass 6DOF Wind (Wind Angles)

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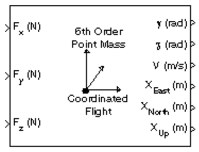
Introduced in R2006a

6th Order Point Mass (Coordinated Flight)

Calculate sixth-order point mass in coordinated flight

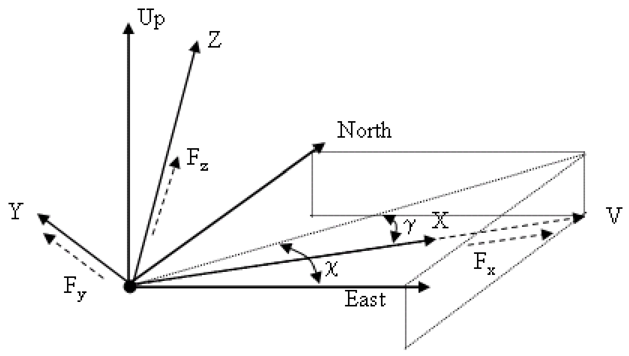


Library

Equations of Motion/Point Mass

Description

The 6th Order Point Mass (Coordinated Flight) block performs the calculations for the translational motion of a single point mass or multiple point masses.



The translational motion of the point mass $[X_{East}\ X_{North}\ X_{Up}]^T$ are functions of airspeed (V), flight path angle (γ), and heading angle (χ),

$$F_x = mV$$
$$F_y = (mV\cos\gamma)\dot{\chi}$$
$$F_z = mV\dot{\gamma}$$
$$\dot{X}_{East} = V\cos\chi\cos\gamma$$
$$\dot{X}_{North} = V\sin\chi\cos\gamma$$
$$\dot{X}_{Up} = V\sin\gamma$$

where the applied forces $[F_x\ F_y\ F_h]^T$ are in a system is defined by x-axis in the direction of vehicle velocity relative to air, z-axis is upward, and y-axis completes the right-handed frame, and the mass of the body m is assumed constant.

Parameters

Units

Specifies the input and output units:

Units	Forces	Velocity	Position
`Metric (MKS)`	Newton	Meters per second	Meters
`English (Velocity in ft/s)`	Pound	Feet per second	Feet
`English (Velocity in kts)`	Pound	Knots	Feet

Initial flight path angle

The scalar or vector containing initial flight path angle of the point mass(es).

Initial heading angle

The scalar or vector containing initial heading angle of the point mass(es).

Initial airspeed

The scalar or vector containing initial airspeed of the point mass(es).

Initial downrange [East]

The scalar or vector containing initial downrange of the point mass(es).

Initial crossrange [North]

The scalar or vector containing initial crossrange of the point mass(es).

Initial altitude [Up]

The scalar or vector containing initial altitude of the point mass(es).

Initial mass

The scalar or vector containing mass of the point mass(es).

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the force in *x*-axis in selected units.
Second		Contains the force in *y*-axis in selected units.
Third		Contains the force in *z*-axis in selected units.

Output	Dimension Type	Description
First		Contains the flight path angle in radians.
Second		Contains the heading angle in radians.
Third		Contains the airspeed in selected units.
Fourth		Contains the downrange or amount traveled East in selected units.
Fifth		Contains the crossrange or amount traveled North in selected units.
Sixth		Contains the altitude or amount traveled Up in selected units.

Assumptions and Limitations

The block assumes that there is fully coordinated flight, i.e., there is no side force (wind axes) and sideslip is always zero.

The flat flat Earth reference frame is considered inertial, an excellent approximation that allows the forces due to the Earth's motion relative to the “fixed stars” to be neglected.

See Also

4th Order Point Mass (Longitudinal)

4th Order Point Mass Forces (Longitudinal)

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass Forces (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

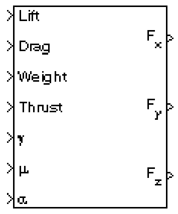
Simple Variable Mass 6DOF Wind (Quaternion)

Simple Variable Mass 6DOF Wind (Wind Angles)

Introduced before R2006a

6th Order Point Mass Forces (Coordinated Flight)

Calculate forces used by sixth-order point mass in coordinated flight

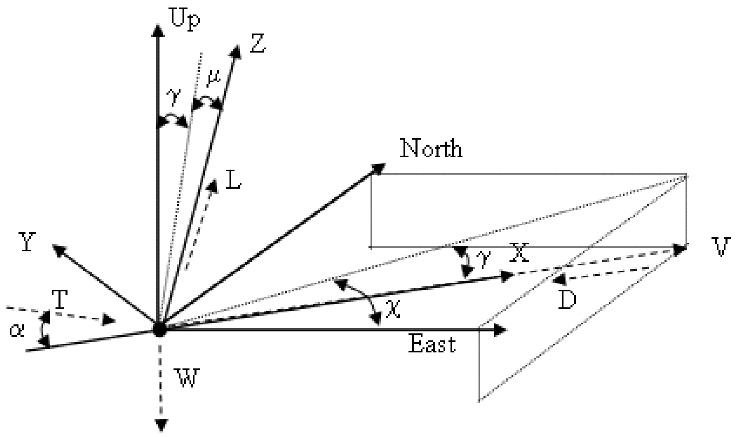


Library

Equations of Motion/Point Mass

Description

The 6th Order Point Mass Forces (Coordinated Flight) block calculates the applied forces for a single point mass or multiple point masses.



The applied forces $[F_x\ F_y\ F_h]^T$ are in a system is defined by *x*-axis in the direction of vehicle velocity relative to air, *z*-axis is upwards and *y*-axis completes the right-handed frame and are functions of lift (*L*), drag (*D*), thrust (*T*), weight (*W*), flight path angle (*γ*), angle of attack (*α*), and bank angle (*μ*).

$$F_x = T\cos\alpha - D - W\sin\gamma$$

$$F\gamma = (L + T\sin\alpha)\sin\mu$$

$$F_z = (L + T\sin\alpha)\cos\mu - W\cos\gamma$$

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the lift in units of force.
Second		Contains the drag in units of force.
Third		Contains the weight in units of force.
Fourth		Contains the thrust in units of force.
Fifth		Contains the flight path angle in radians.
Sixth		Contains the bank angle in radians.
Seventh		Contains the angle of attack in radians.

Output	Dimension Type	Description
First		Contains the force in *x*-axis in units of force.
Second		Contains the force in *y*-axis in units of force.
Third		Contains the force in *z*-axis in units of force.

Assumptions and Limitations

The block assumes that there is fully coordinated flight, i.e., there is no side force (wind axes) and sideslip is always zero.

The flat Earth reference frame is considered inertial, an excellent approximation that allows the forces due to the Earth's motion relative to the “fixed stars” to be neglected.

See Also

4th Order Point Mass (Longitudinal)

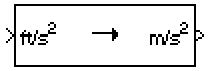
4th Order Point Mass Forces (Longitudinal)

6th Order Point Mass (Coordinated Flight)

Introduced before R2006a

Acceleration Conversion

Convert from acceleration units to desired acceleration units



Library

Utilities/Unit Conversions

Description

The Acceleration Conversion block computes the conversion factor from specified input acceleration units to specified output acceleration units and applies the conversion factor to the input signal.

The Acceleration Conversion block icon displays the input and output units selected from the **Initial unit** and **Final unit** lists.

Parameters

Initial unit

Specifies the input units.

Final unit

Specifies the output units.

The following conversion units are available:

`m/s`^{2}	Meters per second squared
`ft/s`^{2}	Feet per second squared
`km/s`^{2}	Kilometers per second squared
`in/s`^{2}	Inches per second squared

`km/h-s`	Kilometers per hour per second
`mph-s`	Miles per hour per second
`G's`	g-units

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the acceleration in initial acceleration units.

Output	Dimension Type	Description
First		Contains the acceleration in final acceleration units.

See Also

Angle Conversion

Angular Acceleration Conversion

Angular Velocity Conversion

Density Conversion

Force Conversion

Length Conversion

Mass Conversion

Pressure Conversion

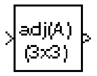
Temperature Conversion

Velocity Conversion

Introduced before R2006a

Adjoint of 3x3 Matrix

Compute adjoint of matrix



Library

Utilities/Math Operations

Description

The Adjoint of 3x3 Matrix block computes the adjoint matrix for the input matrix.

The input matrix has the form of

$$A = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

The adjoint of the matrix has the form of

$$adj(A) = \begin{pmatrix} +\begin{vmatrix} A_{22} & A_{23} \\ A_{32} & A_{33} \end{vmatrix} & -\begin{vmatrix} A_{12} & A_{13} \\ A_{32} & A_{33} \end{vmatrix} & +\begin{vmatrix} A_{12} & A_{13} \\ A_{22} & A_{23} \end{vmatrix} \\ -\begin{vmatrix} A_{21} & A_{23} \\ A_{31} & A_{33} \end{vmatrix} & +\begin{vmatrix} A_{11} & A_{13} \\ A_{31} & A_{33} \end{vmatrix} & -\begin{vmatrix} A_{11} & A_{13} \\ A_{21} & A_{23} \end{vmatrix} \\ +\begin{vmatrix} A_{21} & A_{22} \\ A_{31} & A_{32} \end{vmatrix} & -\begin{vmatrix} A_{11} & A_{12} \\ A_{31} & A_{32} \end{vmatrix} & +\begin{vmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{vmatrix} \end{pmatrix}$$

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the acceleration in initial acceleration units.

Output	Dimension Type	Description
First		Contains the acceleration in final acceleration units.

See Also

Create 3x3 Matrix

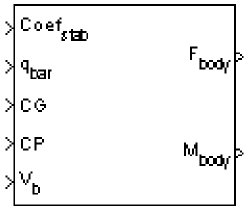
Determinant of 3x3 Matrix

Invert 3x3 Matrix

Introduced before R2006a

Aerodynamic Forces and Moments

Compute aerodynamic forces and moments using aerodynamic coefficients, dynamic pressure, center of gravity, center of pressure, and velocity



Library

Aerodynamics

Description

The Aerodynamic Forces and Moments block computes the aerodynamic forces and moments about the center of gravity. By default, the inputs and outputs are represented in the body axes.

Let α be the angle of attack and β the sideslip. The rotation from body to stability axes:

$$C_{s \leftarrow b} = \begin{bmatrix} \cos(\alpha) & 0 & \sin(\alpha) \\ 0 & 1 & 0 \\ -\sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix}$$

can be combined with the rotation from stability to wind axes:

$$C_{w \leftarrow s} = \begin{bmatrix} \cos(\beta) & \sin(\beta) & 0 \\ -\sin(\beta) & \cos(\beta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

to yield the net rotation from body to wind axes:

$$C_{w \leftarrow b} = \begin{bmatrix} \cos(\alpha)\cos(\beta) & \sin(\beta) & \sin(\alpha)\cos(\beta) \\ -\cos(\alpha)\sin(\beta) & \cos(\beta) & -\sin(\alpha)\sin(\beta) \\ -\sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix}$$

Moment coefficients have the same notation in all systems. Force coefficients are given below. Note there are no specific symbols for stability-axes force components. However, the stability axes have two components that are unchanged from the other axes.

$$\mathbf{F}_A^w \equiv \begin{bmatrix} -D \\ -C \\ -L \end{bmatrix} = C_{w \leftarrow b} \cdot \begin{bmatrix} X_A \\ Y_A \\ Z_A \end{bmatrix} \equiv C_{w \leftarrow b} \cdot \mathbf{F}_A^b$$

Components/Axes	***x***	***y***	***z***
Wind	C_D	C_C	C_L
Stability	—	C_Y	C_L
Body	C_X	C_Y	C_Z ($-C_N$)

Given these definitions, to account for the standard definitions of D, C, Y (where $Y = -C$), and L, force coefficients in the wind axes are multiplied by the negative identity *diag*(-1, -1, -1). Forces coefficients in the stability axes are multiplied by *diag*(-1, 1, -1). C_N and C_X are, respectively, the normal and axial force coefficients ($C_N = -C_Z$).

Parameters

Input Axes

Specifies coordinate system for input coefficients: `Body` (default), `Stability`, or `Wind`.

Force Axes

Specifies coordinate system for aerodynamic force: `Body` (default), `Stability`, or `Wind`.

Moment Axes

Specifies coordinate system for aerodynamic moment: `Body` (default), `Stability`, or `Wind`.

Reference area

Specifies the reference area for calculating aerodynamic forces and moments.

Reference span

Specifies the reference span for calculating aerodynamic moments in *x*-axes and *z*-axes.

Reference length

Specifies the reference length for calculating aerodynamic moment in the *y*-axes.

Inputs and Outputs

The first input consists of aerodynamic coefficients (in the chosen input axes) for forces and moments. These coefficients are ordered into a vector depending on the choice of axes:

Input Axes	Input Vector
Body	(axial force C_x, side force C_y, normal force C_z, rolling moment C_l, pitching moment C_m, yawing moment C_n)
Stability	(drag force $C_{D(\beta=0)}$, side force C_y, lift force C_L, rolling moment C_l, pitching moment C_m, yawing moment C_n)
Wind	(drag force C_D, cross-wind force C_c, lift force C_L, rolling moment C_l, pitching moment C_m, yawing moment C_n)

Input	Dimension Type	Description
Second		Contains the dynamic pressure.
Third		Contains the center of gravity.
Fourth		Contains the center of pressure. This can also be taken as any general moment reference point as long as the rest of the model reflects the use of the moment reference point.
Fifth (For inputs or outputs in stability or wind axes)	Three-element vector	Contains the velocity in the body axes.

Output	Dimension Type	Description
First		Contains the aerodynamic forces (in the chosen output axes) at the center of gravity in *x*-, *y*-, and *z*-axes.
Second		Contains the aerodynamic moments (in the chosen output axes) at the center of gravity in *x*-, *y*-, and *z*-axes.

Assumptions and Limitations

The default state of the block hides the V_b input port and assumes that the transformation is body-body.

The center of gravity and the center of pressure are assumed to be in body axes.

While this block has the ability to output forces and/or moments in the stability axes, the blocks in the Equations of Motion library are currently designed to accept forces and moments in either the body or wind axes only.

Examples

See Airframe in `aeroblk_HL20` for an example of this block.

Reference

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation,* John Wiley & Sons, New York, 1992

See Also

Digital DATCOM Forces and Moments

Dynamic Pressure

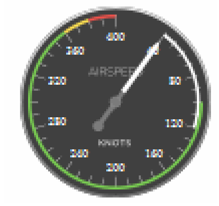
Estimate Center of Gravity

Moments About CG Due to Forces

Introduced before R2006a

Airspeed Indicator

Display measurements for aircraft airspeed
Library: Aerospace Blockset / Flight Instruments



Description

The Airspeed Indicator block displays measurements for aircraft airspeed in knots.

By default, minor ticks represent 10-knot increments and major ticks represent 40-knot increments. The parameters **Minimum** and **Maximum** determine the minimum and maximum values on the gauge. The number and distribution of ticks is fixed, which means that the first and last tick display the minimum and maximum values. The ticks in between distribute evenly between the minimum and maximum values. For major ticks, the distribution of ticks is (**Maximum-Minimum**)/9. For minor ticks, the distribution of ticks is (**Maximum-Minimum**)/36.

The airspeed indicator has scale color bars that allow for overlapping for the first bar, displayed at a different radius. This different radius lets the block represent maximum speed with flap extended (V_{FE}) and stall speed with flap extended (V_{SO}) accurately for aircraft airspeed and stall speed.

Parameters

`Connection` — Connect to signal
signal name

Connect to signal for display, selected from list of signal names.

To view the data from a signal, select a signal in the model. The signal appears in the **Connection** table. Select the option button next to the signal you want to display. Click **Apply** to connect the signal.

The table has a row for the signal connected to the block. If there are no signals selected in the model, or the block is not connected to any signals, the table is empty.

`Minimum` — Minimum tick mark value

40 (default) | finite | real | double | scalar

Minimum tick mark value, specified as a finite, real, double, or scalar value, in ft/min.

Dependencies

The **Minimum** tick value must be less than the **Maximum** tick value.

Programmatic Use
Block Parameter: `Limits`
Type: double
Values: vector
Default: `[40 400]`, where `40` is the minimum value

`Maximum` — Maximum tick mark value

400 (default) | finite | real | double | scalar

Specify the maximum tick mark value, specified as a finite, real, double, or scalar value, in ft/min..

Dependencies

The **Maximum** tick value must be greater than the **Minimum** tick value.

Programmatic Use
Block Parameter: `Limits`
Type: double
Values: vector
Default: `[40 400]`, where `400` is the maximum value

`Scale Colors` — Ranges of color bands

0 (default) | real | double | scalar

Ranges of color bands outside the scale, specified as a finite, real, double, or scalar value. Specify the minimum and maximum color range to display on the gauge.

To add a new color, click `+`. To remove a color, click `-`.

Programmatic Use
Block Parameter: `ScaleColors`
Type: *n*-by-1 struct array
Values: struct array with elements `Min`, `Max`, and `Color`

Label — Name of connected signal
`Top` (default) | `Bottom` | `Hide`

Name of connected signal.

- `Top`

  Show label at the top of the block.
- `Bottom`

  Show label at the bottom of the block.
- `Hide`

  Do not show the label or instructional text when the block is not connected.

Programmatic Use
Block Parameter: `LabelPosition`
Type: character vector
Values: `'Top'` | `'Bottom'` | `'Hide'`
Default: `'Top'`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

This block is ignored for code generation.

See Also

Indicator | Altimeter | Artificial Horizon | Climb Rate Indicator | Exhaust Gas Temperature (EGT) Indicator | Heading Indicator | Revolutions Per Minute (RPM) Indicator | Turn Coordinator

Topics

“Display Measurements with Cockpit Instruments” on page 2-49
“Programmatically Interact with Gauge Band Colors” on page 2-52
“Flight Instrument Gauges” on page 2-48

Introduced in R2016a

Altimeter

Display measurements for aircraft altitude
Library: Aerospace Blockset / Flight Instruments

Description

The Altimeter Indicator block displays the altitude above sea level in feet, also known as the pressure altitude. The block displays the altitude value with needles on a gauge and a numeric indicator.

- The gauge has 10 major ticks. Within each major tick are five minor ticks. This gauge has three needles. Using the needles, the altimeter can display accurately only altitudes between 0 and 100,000 feet.
  - For the longest needle, an increment of a small tick represents 20 feet and a major tick represents 100 feet.
  - For the second longest needle, a minor tick represents 200 feet and a major tick represents 1,000 feet.
  - For the shortest needle a minor tick represents 2,000 feet and a major tick represents 10,000 feet.
- For the numeric display, the block shows values as numeric characters between 0 and 9,999 feet. When the numeric display value reaches 10,000 feet, the gauge displays the value as the remaining values below 10,000 feet. For example, 12,345 feet displays as 2,345 feet. When a value is less than 0 (below sea level), the block displays `0`. The needles show the appropriate value except for when the value is below sea level or over 100000 feet. Below sea level, the needles set to `0`, over 100,000, the needles stay set at 100,000.

Parameters

`Connection` — Connect to signal
signal name

Connect to signal for display, selected from list of signal names.

To view the data from a signal, select a signal in the model. The signal appears in the **Connection** table. Select the option button next to the signal you want to display. Click **Apply** to connect the signal.

The table has a row for the signal connected to the block. If there are no signals selected in the model, or the block is not connected to any signals, the table is empty.

`Label` — Block label location
`Top` (default) | `Bottom` | `Hide`

Block label, displayed at the top or bottom of the block, or hidden.

- `Top`

  Show label at the top of the block.
- `Bottom`

  Show label at the bottom of the block.
- `Hide`

  Do not show the label or instructional text when the block is not connected.

Programmatic Use
Block Parameter: `LabelPosition`
Type: character vector
Values: `'Top'` | `'Bottom'` | `'Hide'`
Default: `'Top'`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

This block is ignored for code generation.

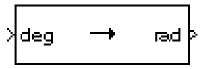
See Also
Airspeed Indicator | Artificial Horizon | Climb Rate Indicator | Exhaust Gas Temperature (EGT) Indicator | Heading Indicator | Revolutions Per Minute (RPM) Indicator | Turn Coordinator

Topics
“Display Measurements with Cockpit Instruments” on page 2-49
“Flight Instrument Gauges” on page 2-48

Introduced in R2016a

Angle Conversion

Convert from angle units to desired angle units



Library

Utilities/Unit Conversions

Description

The Angle Conversion block computes the conversion factor from specified input angle units to specified output angle units and applies the conversion factor to the input signal.

The Angle Conversion block icon displays the input and output units selected from the **Initial unit** and the **Final unit** lists.

Parameters

Initial unit

Specifies the input units.

Final unit

Specifies the output units.

The following conversion units are available:

`deg`	Degrees
`rad`	Radians
`rev`	Revolutions

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the angle in initial angle units.

Output	Dimension Type	Description
First		Contains the angle in final angle units.

See Also

Acceleration Conversion

Angular Acceleration Conversion

Angular Velocity Conversion

Density Conversion

Force Conversion

Length Conversion

Mass Conversion

Pressure Conversion

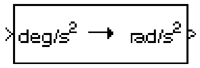
Temperature Conversion

Velocity Conversion

Introduced before R2006a

Angular Acceleration Conversion

Convert from angular acceleration units to desired angular acceleration units



Library

Utilities/Unit Conversions

Description

The Angular Acceleration Conversion block computes the conversion factor from specified input angular acceleration units to specified output angular acceleration units and applies the conversion factor to the input signal.

The Angular Acceleration Conversion block icon displays the input and output units selected from the **Initial unit** and the **Final unit** lists.

Parameters

Initial unit

Specifies the input units.

Final unit

Specifies the output units.

The following conversion units are available:

`deg/s`^{2}	Degrees per second squared
`rad/s`^{2}	Radians per second squared
`rpm/s`	Revolutions per minute per second

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the angular acceleration in initial angular acceleration units.

Output	Dimension Type	Description
First		Contains the angular acceleration in final angular acceleration units.

See Also

Acceleration Conversion

Angle Conversion

Angular Velocity Conversion

Density Conversion

Force Conversion

Length Conversion

Mass Conversion

Pressure Conversion

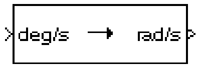
Temperature Conversion

Velocity Conversion

Introduced before R2006a

Angular Velocity Conversion

Convert from angular velocity units to desired angular velocity units



Library

Utilities/Unit Conversions

Description

The Angular Velocity Conversion block computes the conversion factor from specified input angular velocity units to specified output angular velocity units and applies the conversion factor to the input signal.

The Angular Velocity Conversion block icon displays the input and output units selected from the **Initial unit** and the **Final unit** lists.

Parameters

Initial unit

Specifies the input units.

Final unit

Specifies the output units.

The following conversion units are available:

`deg/s`	Degrees per second
`rad/s`	Radians per second
`rpm`	Revolutions per minute

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the angular acceleration in initial angular acceleration units.

Output	Dimension Type	Description
First		Contains the angular acceleration in final angular acceleration units.

See Also

Acceleration Conversion

Angle Conversion

Angular Acceleration Conversion

Density Conversion

Force Conversion

Length Conversion

Mass Conversion

Pressure Conversion

Temperature Conversion

Velocity Conversion

Introduced before R2006a

Artificial Horizon

Represent aircraft attitude relative to horizon
Library: Aerospace Blockset / Flight Instruments

Description

The Artificial Horizon block represents aircraft attitude relative to horizon and displays roll and pitch in degrees:

- Values for roll cannot exceed +/– 90 degrees.
- Values for pitch cannot exceed +/– 30 degrees.

If the values exceed the maximum values, the gauge maximum and minimum values do not change.

Changes in roll value affect the gauge semicircles and the ticks located on the black arc turn accordingly. Changes in pitch value affect the scales and the distribution of the semicircles.

Combine the roll and pitch signals in a Mux block in the order:

1. Roll
2. Pitch

Parameters

`Connection` — Connect to signal
signal name | 2-element signal

Connect to 2-element signal for display, selected from list of signal names. The 2-element signal consists of turn indicator and inclinometer signals combined together in a Mux block, in degrees. You connect and display this combined signal. This input cannot be a bus signal.

To view the data from a signal, select a signal in the model. The signal appears in the **Connection** table. Select the option button next to the signal you want to display. Click **Apply** to connect the signal.

The table has a row for the signal connected to the block. If there are no signals selected in the model, or the block is not connected to any signals, the table is empty.

To view the data from a signal, select a signal in the model. The signal appears in the **Connection** table. Select the option button next to the signal you want to display. Click **Apply** to connect the signal.

The table has a row for the signal connected to the block. If there are no signals selected in the model, or the block is not connected to any signals, the table is empty.

`Label` — Block label location
`Top` (default) | `Bottom` | `Hide`

Block label, displayed at the top or bottom of the block, or hidden.

- `Top`

  Show label at the top of the block.
- `Bottom`

  Show label at the bottom of the block.
- `Hide`

  Do not show the label or instructional text when the block is not connected.

Programmatic Use
Block Parameter: `LabelPosition`
Type: character vector
Values: `'Top'` | `'Bottom'` | `'Hide'`
Default: `'Top'`

See Also

Airspeed Indicator | Altimeter | Artificial Horizon | Climb Rate Indicator | Exhaust Gas Temperature (EGT) Indicator | Revolutions Per Minute (RPM) Indicator | Turn Coordinator

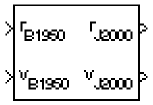
Topics

“Display Measurements with Cockpit Instruments” on page 2-49
“Flight Instrument Gauges” on page 2-48

Introduced in R2016a

Besselian Epoch to Julian Epoch

Transform position and velocity components from discontinued Standard Besselian Epoch (B1950) to Standard Julian Epoch (J2000)



Library

Utilities/Axes Transformations

Description

The Besselian Epoch to Julian Epoch block transforms two 3-by-1 vectors of Besselian Epoch position ($\bar{r}_{B1950}$), and Besselian Epoch velocity ($\bar{v}_{B1950}$) into Julian Epoch position ($\bar{r}_{J2000}$), and Julian Epoch velocity ($\bar{v}_{J2000}$). The transformation is calculated using:

$$\begin{bmatrix} \bar{r}_{J2000} \\ \bar{v}_{J2000} \end{bmatrix} = \begin{bmatrix} \bar{M}_{rr} & \bar{M}_{vr} \\ \bar{M}_{rv} & \bar{M}_{vv} \end{bmatrix} \begin{bmatrix} \bar{r}_{B1950} \\ \bar{v}_{B1950} \end{bmatrix}$$

where ($\bar{M}_{rr}, \bar{M}_{vr}, \bar{M}_{rv}, M_{vv}$) are defined as:

$$\bar{M}_{rr} \begin{bmatrix} 0.9999256782 & -0.0111820611 & -0.0048579477 \\ 0.0111820610 & 0.9999374784 & -0.0000271765 \\ 0.0048579479 & -0.0000271474 & 0.9999881997 \end{bmatrix}$$

$$\bar{M}_{vr} = \begin{bmatrix} 0.00000242395018 & -0.00000002710663 & -0.00000001177656 \\ 0.00000002710663 & 0.00000242397878 & -0.00000000006587 \\ 0.00000001177656 & -0.00000000006582 & 0.00000242410173 \end{bmatrix}$$

$$\bar{M}_{rv} = \begin{bmatrix} -0.000551 & -0.238565 & 0.435739 \\ 0.238514 & -0.002667 & -0.008541 \\ -0.435623 & 0.012254 & 0.002117 \end{bmatrix}$$

$$\overline{M}_{vv} = \begin{bmatrix} 0.99994704 & -0.01118251 & -0.00485767 \\ 0.01118251 & 0.99995883 & -0.00002718 \\ 0.00485767 & -0.00002714 & 1.00000956 \end{bmatrix}$$

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-1 vector	Contains the position in Standard Besselian Epoch (B1950).
Second	3-by-1 vector	Contains the velocity in Standard Besselian Epoch (B1950).

Output	Dimension Type	Description
First	3-by-1 vector	Contains the position in Standard Julian Epoch (J2000).
Second	3-by-1 vector	Contains the velocity in Standard Julian Epoch (J2000).

Reference

“Supplement to Department of Defense World Geodetic System 1984 Technical Report: Part I - Methods, Techniques and Data Used in WGS84 Development,” DMA TR8350.2-A.

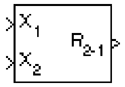
See Also

Julian Epoch to Besselian Epoch

Introduced before R2006a

Calculate Range

Calculate range between two crafts given their respective positions



Library

GNC/Guidance

Description

The Calculate Range block computes the range between two crafts. The equation used for the range calculation is

$$Range = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the (x, y and z) position of craft 1.
Second		Contains the (x, y and z) position of craft 2.

Output	Dimension Type	Description
First		Contains the range from craft 2 and craft 1.

Limitation

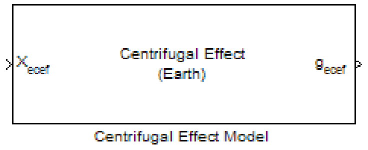
The calculated range is the magnitude of the distance, but not the direction. Therefore it is always positive or zero.

Craft positions are real values.

Introduced before R2006a

Centrifugal Effect Model

Implement mathematical representation of centrifugal effect for planetary gravity



Library

Environment/Gravity

Description

The Centrifugal Effect Model block implements the mathematical representation of centrifugal effect for planetary gravity. The gravity centrifugal effect is the acceleration portion of centrifugal force effects due to the rotation of a planet. This block implements this representation using planetary rotation rates. You use centrifugal force values in rotating or non-inertial coordinate systems.

Parameters

Planet model

Specify the planetary model. From the list, select `Mercury`, `Venus`, `Earth`, `Moon`, `Mars`, `Jupiter`, `Saturn`, `Uranus`, `Neptune`, or `Custom`. The block uses the rotation of the selected planet to implement the mathematical representation of the centrifugal effect.

Selecting Custom enables you to specify your own planetary model. This option enables the **Planetary rotational rate (rad/sec)** and **Input planetary rotation rate** parameters.

Planetary rotational rate (rad/sec)

Specify the planetary rotational rate in radians per second.

If you want to specify the planetary rotational rate as an input to the block, see the **Input planetary rotation rate** parameter.

Selecting the **Input planetary rotation rate** check box disables the **Planetary rotational rate (rad/sec)** parameter.

Input planetary rotation rate

Select this check box to enable a block input. You can then input a planetary rotation rate as a block input. When you select this check box, the block mask updates to display an input port for the rotation rate.

Selecting the **Input planetary rotation rate** check box disables the **Planetary rotational rate (rad/sec)** parameter.

Inputs and Outputs

This block accepts only scalar inputs (m=1).

Input	Dimension Type	Description
First	m-by-3 matrix	Contains planet-centered planet-fixed coordinates from the center of the planet. If **Planet model** has a value of `Earth`, this matrix contains Earth-centered Earth-fixed (ECEF) coordinates. The block does not use explicit units.

Output	Dimension Type	Description
First	m-by-3 array	Contains gravity values in the *x*-axis, *y*-axis and *z*-axis of the planet-centered planet-fixed coordinates in input distance units per second squared.

References

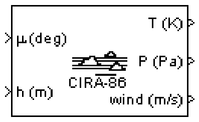
Vallado, D. A., *Fundamentals of Astrodynamics and Applications*, McGraw-Hill, New York, 1997.

NIMA TR8350.2: *Department of Defense World Geodetic System 1984, Its Definition and Relationship with Local Geodetic Systems*.

Introduced in R2010a

CIRA-86 Atmosphere Model

Implement mathematical representation of 1986 CIRA atmosphere



Library

Environment/Atmosphere

Description

The CIRA-86 Atmosphere Model block implements the mathematical representation of the 1986 Committee on Space Research (COSPAR) International Reference Atmosphere (CIRA). The block provides values for absolute temperature, pressure, density, and speed of sound for the input geopotential altitude.

The CIRA-86 Atmosphere Model block icon displays the input and output units selected from the **Units** list.

Parameters

Units

Specifies the input and output units:

Units	Height	Temperature	Speed of Sound	Air Pressure	Air Density
`Metric (MKS)`	Meters	Kelvin	Meters per second	Pascal	Kilograms per cubic meter

Units	Height	Temperature	Speed of Sound	Air Pressure	Air Density
`English (Velocity in ft/s)`	Feet	Degrees Rankine	Feet per second	Pound-force per square inch	Slug per cubic foot
`English (Velocity in kts)`	Feet	Degrees Rankine	Knots	Pound-force per square inch	Slug per cubic foot

Coordinate type

Specify the representation of the coordinate type. The default is `GPHeight`.

- `Pressure`

  Indicates pressure in pascal.
- `GPHeight`

  Indicates geopotential height in meters.

Mean value type

Specify mean value types. The default is `Monthly`.

- `Monthly`

  Indicates monthly values. If you select `Monthly`, you must also set the **Month** parameter.
- `Annual`

  Indicates annual values. Valid when **Coordinate type** has a value of `Pressure`.

Month

Indicates the month in which the mean values are taken. From the list, select the desired month. This parameter applies only when **Mean value type** has a value of `Monthly`.

Action for out-of-range input

Specify if out-of-range input invokes a warning, error, or no action.

Inputs and Outputs

Input	Dimension Type	Description
First	Array	Contains the latitude in degrees (limited to +/-80 degrees).
Second	Array	Contains an `m` array of either: • Geopotential heights in selected length units (**Coordinate type** is `GPHeight`) • Pressures in selected pressure units (**Coordinate type** is `Pressure`)

Output	Dimension Type	Description
First	Array	Contains mean temperature in selected units.
Second	Array	Contains an `m` array of either: • Pressures in selected pressure units (**Coordinate type** is `GPHeight`) • Geopotential heights in selected length units (**Coordinate type** is `Pressure`)
Third	Array	Contains mean zonal winds in selected units.

Assumptions and Limitations

This function uses a corrected version of the CIRA data files provided by J. Barnett in July 1990 in ASCII format.

This function has the limitations of the CIRA 1986 model. The values for the CIRA 1986 model are limited to the regions of 80 degrees S to 80 degrees N on the Earth and geopotential heights of 0 to 120 kilometers. In each monthly mean data set, values at 80 degrees S for 101,300 pascal or 0 meters were omitted because these levels are within the Antarctic land mass. For zonal mean pressure in constant altitude coordinates, pressure data is not available below 20 kilometers. Therefore, this is the bottom level of the CIRA climatology.

Reference

Fleming, E. L., Chandra, S., Shoeberl, M. R., Barnett, J. J., *Monthly Mean Global Climatology of Temperature, Wind, Geopotential Height and Pressure for 0-120 km*, NASA TM100697, February 1988

`https://ccmc.gsfc.nasa.gov/modelweb/atmos/cospar1.html`

See Also

COESA Atmosphere Model

ISA Atmosphere Model

Introduced in R2007b

Climb Rate Indicator

Display measurements for aircraft climb rate
Library: Aerospace Blockset / Flight Instruments

2
1
3
VERTICAL SPEED
0
4
1
3
2

Description

The Climb Rate Indicator block displays measurements for an aircraft climb rate in ft/min.

The needle covers the top semicircle, if the velocity is positive, and the lower semicircle, if the climb rate is negative. The range of the indicator is from –**Maximum** feet per minute to **Maximum** feet per minute. Major ticks indicate **Maximum**/4. Minor ticks indicate **Maximum**/8 and **Maximum**/80.

Parameters

`Connection` — Connect to signal

signal name

Connect to signal for display, selected from list of signal names.

To view the data from a signal, select a signal in the model. The signal appears in the **Connection** table. Select the option button next to the signal you want to display. Click **Apply** to connect the signal.

The table has a row for the signal connected to the block. If there are no signals selected in the model, or the block is not connected to any signals, the table is empty.

`Maximum` — Maximum tick mark value

4000 (default) | finite | real | double | scalar

Maximum tick mark value, specified as a finite, real, double, or scalar value, in ft/min.

The minimum tick value is always `0`.

Programmatic Use
Block Parameter: `MaximumRate`
Type: character vector
Values: scalar
Default: `'4000'`

`Label` — Block label location
`Top` (default) | `Bottom` | `Hide`

Block label, displayed at the top or bottom of the block, or hidden.

- `Top`

  Show label at the top of the block.
- `Bottom`

  Show label at the bottom of the block.
- `Hide`

  Do not show the label or instructional text when the block is not connected.

Programmatic Use
Block Parameter: `LabelPosition`
Type: character vector
Values: `'Top'` | `'Bottom'` | `'Hide'`
Default: `'Top'`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

This block is ignored for code generation.

See Also

Indicator | Airspeed Indicator | Altimeter | Artificial Horizon | Exhaust Gas Temperature (EGT) | Heading Indicator | Revolutions Per Minute (RPM) Indicator | Turn Coordinator

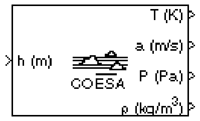
Topics

“Display Measurements with Cockpit Instruments” on page 2-49
“Programmatically Interact with Gauge Band Colors” on page 2-52
“Flight Instrument Gauges” on page 2-48

Introduced in R2016a

COESA Atmosphere Model

Implement 1976 COESA lower atmosphere



Library

Environment/Atmosphere

Description

The COESA Atmosphere Model block implements the mathematical representation of the 1976 Committee on Extension to the Standard Atmosphere (COESA) United States standard lower atmospheric values for absolute temperature, pressure, density, and speed of sound for the input geopotential altitude.

Below 32,000 meters (approximately 104,987 feet), the U.S. Standard Atmosphere is identical with the Standard Atmosphere of the International Civil Aviation Organization (ICAO).

The COESA Atmosphere Model block icon displays the input and output units selected from the **Units** list.

Parameters

Units

Specifies the input and output units:

Units	Height	Temperature	Speed of Sound	Air Pressure	Air Density
`Metric (MKS)`	Meters	Kelvin	Meters per second	Pascal	Kilograms per cubic meter
`English (Velocity in ft/s)`	Feet	Degrees Rankine	Feet per second	Pound-force per square inch	Slug per cubic foot
`English (Velocity in kts)`	Feet	Degrees Rankine	Knots	Pound-force per square inch	Slug per cubic foot

Specification

Specify the atmosphere model type from one of the following atmosphere models. The default is `1976 COESA-extended U.S. Standard Atmosphere`.

`MIL-HDBK-310` This selection is linked to the Non-Standard Day 310 block. See the block reference for more information. Selecting `MIL-HDBK-310` enables the parameters **Atmospheric model type**, **Extreme parameter**, **Frequency of occurrence**, and **Altitude of extreme value**.
`MIL-STD-210C` This selection is linked to the Non-Standard Day 210C block. See the block reference for more information. Selecting `MIL-HDBK-310` enables the parameters **Atmospheric model type**, **Extreme parameter**, **Frequency of occurrence**, and **Altitude of extreme value**.

Atmospheric model type

Select the representation of the atmospheric data.

`Profile`	Realistic atmospheric profiles associated with extremes at specified altitudes. Recommended for simulation of vehicles vertically traversing the atmosphere or when the total influence of the atmosphere is needed.

`Envelope`	Uses extreme atmospheric values at each altitude. Recommended for vehicles only horizontally traversing the atmosphere without much change in altitude.

Selecting **Specification** > **MIL-HDBK-310** or **Specification** > **MIL-STD-210C** enables this parameter.

Extreme parameter

Select the atmospheric parameter that is the extreme value.

`High temperature`	Option always available
`Low temperature`	Option always available
`High density`	Option always available
`Low density`	Option always available
`High pressure`	This option is available only when `Envelope` is selected for **Atmospheric model type**
`Low pressure`	This option is available only when `Envelope` is selected for **Atmospheric model type**

Selecting **Specification** > **MIL-HDBK-310** or **Specification** > **MIL-STD-210C** enables this parameter.

Frequency of occurrence

Select percent of time the values would occur.

`Extreme values`	This option is available only when `Envelope` is selected for **Atmospheric model type**.
`1%`	Option always available
`5%`	This option is available only when `Envelope` is selected for **Atmospheric model type**.
`10%`	Option always available
`20%`	This option is available only when `Envelope` is selected for **Atmospheric model type**.

Selecting **Specification** > **MIL-HDBK-310** or **Specification** > **MIL-STD-210C** enables this parameter.

Altitude of extreme value

Select geometric altitude at which the extreme values occur. Applies to the profile atmospheric model only.

`5 km (16404 ft)`
`10 km (32808 ft)`
`20 km (65617 ft)`
`30 km (98425 ft)`
`40 km (131234 ft)`

Selecting **Specification** > **MIL-HDBK-310** or **Specification** > **MIL-STD-210C** enables this parameter.

Action for out-of-range input

Specify if out-of-range input invokes a warning, error, or no action.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the geopotential height.

Output	Dimension Type	Description
First		Contains the temperature.
Second		Contains the speed of sound.
Third		Contains the air pressure.
Fourth		Contains the air density.

Assumptions and Limitations

Below the geopotential altitude of 0 m (0 feet) and above the geopotential altitude of 84,852 m (approximately 278,386 feet), temperature values are extrapolated linearly and pressure values are extrapolated logarithmically. Density and speed of sound are calculated using a perfect gas relationship.

Examples

See the `aeroblk_calibrated` model, the `aeroblk_indicated` model, and the airframe in `aeroblk_HL20` for examples of this block.

Reference

U.S. Standard Atmosphere, 1976, U.S. Government Printing Office, Washington, D.C.

See Also

CIRA-86 Atmosphere Model, ISA Atmosphere Model

Non-Standard Day 210C

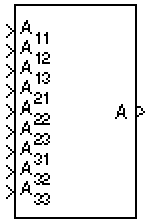
Non-Standard Day 310

Introduced before R2006a

Create 3x3 Matrix

Create 3-by-3 matrix from nine input values

Library: Aerospace Blockset / Utilities / Math Operations



Description

The Create 3x3 Matrix block creates a 3-by-3 matrix from nine input values where each input corresponds to an element of the matrix.

The output matrix has the form of

$$A = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

Ports

Input

A_{11} — First row, first column of matrix
matrix element

First row, first column of the matrix, specified as a matrix element.

Example: 1

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `Boolean` | `fixed point`

A_{12} — First row, second column of matrix
matrix element

First row, second column of the matrix, specified as a matrix element.

Example: 2

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `Boolean` | `fixed point`

A_{13} — First row, third column of matrix
matrix element

First row, third column of the matrix, specified as a matrix element.

Example: 3

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `Boolean` | `fixed point`

A_{21} — Second row, first column of matrix
matrix element

Second row, first column of the matrix, specified as a matrix element.

Example: 4

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `Boolean` | `fixed point`

A_{22} — Second row, second column of matrix
matrix element

Second row, second column of the matrix, specified as a matrix element.

Example: 5

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `Boolean` | `fixed point`

A_{23} — Second row, third column of matrix
matrix element

Second row, third column of the matrix, specified as a matrix element.

Example: 6

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `Boolean` | `fixed point`

A_{31} — Third row, first column of matrix
matrix element

Third row, first column of the matrix, specified as a matrix element.

Example: 7

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `Boolean` | `fixed point`

A_{32} — Third row, second column of matrix
matrix element

Third row, second column of the matrix, specified as a matrix element.

Example: 8

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `Boolean` | `fixed point`

A_{33} — Third row, third column of matrix
matrix element

Third row, third column of the matrix, specified as a matrix element.

Example: 9

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `Boolean` | `fixed point`

Output

A — Matrix
3-by-3 matrix

Matrix, output as a 3-by-3 matrix.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `Boolean` | `fixed point`

See Also

Adjoint of 3x3 Matrix | Determinant of 3x3 Matrix | Invert 3x3 Matrix | Symmetric Inertia Tensor

Introduced before R2006a

Crossover Pilot Model

Represent crossover pilot model

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x

Crossover Pilot Model

Library

Pilot Models

Description

The Crossover Pilot Model block represents the pilot model described in *Mathematical Models of Human Pilot Behavior*. (For more information, see [1 on page 4-186]). This pilot model is a single input, single output (SISO) model that represents some aspects of human behavior when controlling aircraft. When modeling human pilot models, use this block for more accuracy than that provided by the Tustin Pilot Model block. This block is also less accurate than the Precision Pilot Model block.

The Crossover Model takes into account the combined dynamics of the human pilot and the aircraft, using the following form around the crossover frequency:

$$Y_pY_c = \frac{\omega_c e^{-\tau s}}{s}.$$

In this equation:

Variable	Description
Y_p	Pilot transfer function.
Y_c	Aircraft transfer function.
ω_c	Crossover frequency.

Variable	Description
τ	Transport delay time caused by the pilot neuromuscular system.

If the dynamics of the aircraft (Y_c) change, Y_p changes correspondingly. From the options provided in the **Type of control** parameter, specify the dynamics of the aircraft. The preceding table lists the possible types of control that you can select for the aircraft.

Note This block is valid only around the crossover frequency. It is not valid for discrete inputs such as a step.

This block has non-linear behavior. If you want to linearize the block (for example, with one of the Simulink `linmod` functions), you might need to change the Pade approximation order. The Crossover Pilot Model block implementation incorporates the Simulink Transport Delay block with the **Pade order (for linearization)** parameter set to `2` by default. To change this value, use the `set_param` function, for example:

```
set_param(gcb,'pade','3')
```

Parameters

Type of control

From the list, select one of the following options to specify the type of dynamics control that you want the pilot to have over for the aircraft.

Option (Controlled Element Transfer Function)	Transfer Function of Controlled Element (Y_c)	Transfer Function of Pilot (Y_p)	Y_cY_p	Notes
`Proportional`	K_c	$\frac{K_p e^{-\tau s}}{s}$	$\frac{K_c K_p e^{-\tau s}}{s}$	
`Rate or velocity`	$\frac{K_c}{s}$	$K_p e^{-\tau s}$	$\frac{K_c K_p e^{-\tau s}}{s}$	

Option (Controlled Element Transfer Function)	Transfer Function of Controlled Element (Y_c)	Transfer Function of Pilot (Y_p)	Y_cY_p	Notes
Spiral divergence	$\frac{K_c}{T_I s - 1}$	$K_p e^{-\tau s}$	$\frac{K_c K_p e^{-\tau s}}{(T_I s - 1)}$	
Second order - Short period	$\frac{K_c \omega_n{}^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$	$\frac{K_p e^{-\tau s}}{T_I s + 1}$	$\frac{K_c \omega_n{}^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \times \frac{K_p e^{-\tau s}}{T_I s + 1}$	Short period, with $\omega_n > 1/\tau$
Accelera- tion (*)	$\frac{K_c}{s^2}$	$K_p s e^{-\tau s}$	$\frac{K_c K_p e^{-\tau s}}{s}$	
Roll attitude (*)	$\frac{K_c}{s(T_I s + 1)}$	$K_p(T_L s + 1)e^{-\tau s}$	$\frac{K_c K_p e^{-\tau s}}{s}$	With $T_L \approx T_I$
Unstable short period(*)	$\frac{K_c}{(T_{I1} s + 1)(T_{I2} s - 1)}$	$K_p(T_L s + 1)e^{-\tau s}$	$\frac{K_c K_p e^{-\tau s}}{(T_{I2} s - 1)}$	With $T_L \approx T_{I1}$
Second order - Phugoid(*)	$\frac{K_c \omega_n{}^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$	$K_p(T_L s + 1)e^{-\tau s}$	$\frac{K_c K_p \omega_n^2 e^{-\tau s}}{s}$	Phugoid, with $\omega_n \ll 1/\tau$, $1/T_L \approx \zeta\omega_n$

* Indicates that the pilot model includes a Derivative block, which produces a numerical derivative. For this reason, do not send discontinuous (such as a step) or noisy input to the Crossover Pilot Model block. Such inputs can cause large outputs that might render the system unstable.

Variable	Description
K_c	Aircraft gain.
K_p	Pilot gain.
τ	Pilot time delay.

Variable	Description
T_I	Lag constant.
T_L	Lead constant.
ζ	Damping ratio for the aircraft.
ω_n	Natural frequency of the aircraft.

Calculated value

From the list, select one of the following options to specify which value the block is to calculate:

- `Crossover frequency` — The block calculates the crossover frequency value. Selecting this option disables the **Crossover frequency (rad/s)** parameter.
- `Pilot gain` — The block calculates the pilot gain value. Selecting this option disables the **Pilot gain** parameter.

Controlled element gain

Specifies the gain of the aircraft controlled dynamics.

Pilot gain

Specifies the pilot gain.

Crossover frequency (rad/s)

Specifies a crossover frequency value, rad/s. This value ranges from 1 to 10 rad/s.

Pilot time delay(s)

Specifies the total pilot time delay, in seconds. This value typically ranges from 0.1 s to 0.2 s.

Pilot lag constant

Specifies the pilot lag constant.

Pilot lead constant

Specifies the pilot lead constant.

Inputs and Outputs

Input	Dimension Type	Description
First	1-by-1	Contains the command for the signal that the pilot model controls.
Second	1-by-1	Contains the signal that the pilot model controls.

Output	Dimension Type	Description
First	1-by-1	Contains the command for the aircraft.

References

[1] McRuer, D. T., Krendel, E., *Mathematical Models of Human Pilot Behavior*. Advisory Group on Aerospace Research and Development AGARDograph 188, Jan. 1974.

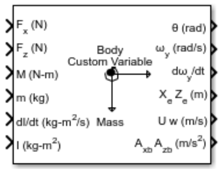
See Also

Precision Pilot Model | Tustin Pilot Model

Introduced in R2012b

Custom Variable Mass 3DOF (Body Axes)

Implement three-degrees-of-freedom equations of motion of custom variable mass with respect to body axes

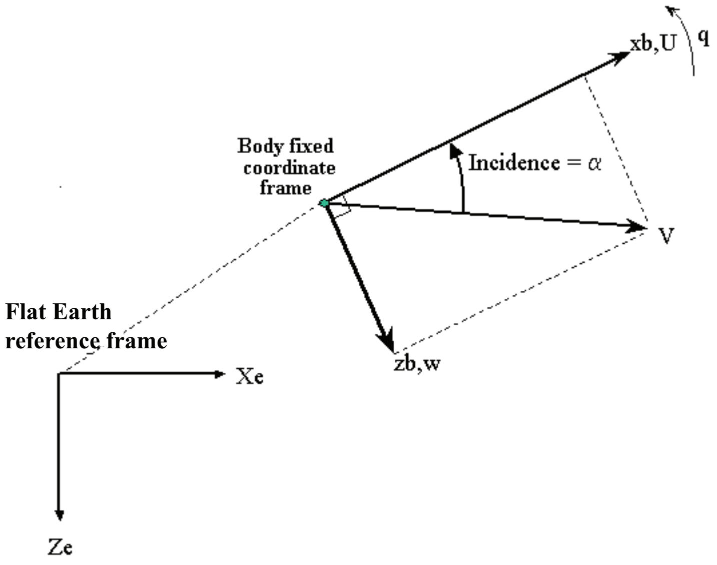


Library

Equations of Motion/3DOF

Description

The Custom Variable Mass 3DOF (Body Axes) block considers the rotation in the vertical plane of a body-fixed coordinate frame about a flat Earth reference frame.



The equations of motion are

$$A_{xb} = \dot{u} = \frac{F_x}{m} - \frac{\dot{m}Ure_b}{m} - qw - g\sin\theta$$

$$Vre_b = [Ure\ \ Wre]_b$$

$$A_{yb} = \dot{w} = \frac{F_z}{m} - \frac{\dot{m}Wre_b}{m} + qu + g\cos\theta$$

$$\dot{q} = \frac{M - \dot{I}_{yy}q}{I_{yy}}$$

$$\dot{\theta} = q$$

$$A_{be} = \begin{bmatrix} A_{xe} \\ A_{ze} \end{bmatrix} = \frac{F_b - \dot{m}Ure_b}{m} - \bar{g}$$

$$A_{bb} = \begin{bmatrix} A_{xb} \\ A_{yb} \end{bmatrix}$$

where the applied forces are assumed to act at the center of gravity of the body. Ure_b and Wre_b are the relative velocities of the mass flow ($\dot{m}$) being added to or ejected from the body in body-fixed axes.

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Custom Variable` selection conforms to the previously described equations of motion.

Initial velocity

A scalar value for the initial velocity of the body, (V_0).

Initial body attitude

A scalar value for the initial pitch attitude of the body, (θ_0).

Initial incidence

A scalar value for the initial angle between the velocity vector and the body, (α_0).

Initial body rotation rate

A scalar value for the initial body rotation rate, (q_0).

Initial position (x,z)

A two-element vector containing the initial location of the body in the flat Earth reference frame.

Gravity Source

Specify source of gravity:

`External`	Variable gravity input to block
`Internal`	Constant gravity specified in **Acceleration due to gravity**

Acceleration due to gravity

A scalar value for the acceleration due to gravity used if internal gravity source is selected. If gravity is to be neglected in the simulation, this value can be set to `0`. This parameter appears if you set **Gravity source** to `Internal`.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.

- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Velocity: e.g., {'u', 'w'}

Specify velocity state names.

Default value is `''`.

Pitch attitude: e.g., 'theta'

Specify pitch attitude state name.

Default value is `''`.

Position: e.g., {'Xe', 'Ze'}

Specify position state names.

Default value is `''`.

Pitch angular rate: e.g., 'q'

Specify pitch angular rate state name.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First	Scalar	Contains the force acting along the body *x*-axis, (F_x).
Second	Scalar	Contains the force acting along the body *z*-axis, (F_z).
Third	Scalar	Contains the applied pitch moment, (M).

Input	Dimension Type	Description
Fourth (Optional)	Vector	Contains the rate of change of mass, ($\dot{m}$) (positive if accreted, negative if ablated).
Fifth	Scalar	Contains the mass, (m).
Sixth	Scalar	Contains the rate of change of inertia tensor matrix, ($\dot{I}_{yy}$).
Seventh	Scalar	Contains the inertia tensor matrix, (I_{yy}).
Eighth (Optional)	Scalar	Contains the gravity in the selected units.
Ninth (Optional)	Two-element vector	Contains one or more relative velocities at which the mass is accreted to or ablated from the body in body axes.

Output	Dimension Type	Description
First	Scalar	Contains the pitch attitude, within ±pi, in radians (θ).
Second	Scalar	Contains the pitch angular rate, in radians per second (q).
Third	Scalar	Contains the pitch angular acceleration, in radians per second squared ($\dot{q}$).
Fourth	Two-element vector	Contains the location of the body, in the flat Earth reference frame, (Xe, Ze).
Fifth	Two-element vector	Contains the velocity of the body resolved into the body-fixed coordinate frame, (u, w).
Sixth	Two-element vector	Contains the acceleration of the body resolved into the body-fixed coordinate frame, (Ax, Az).
Seventh (Optional)	Two-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

See Also

3DOF (Body Axes)

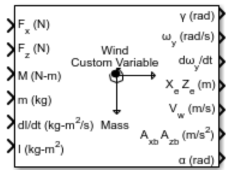
Incidence & Airspeed

Simple Variable Mass 3DOF (Body Axes)

Introduced in R2006a

Custom Variable Mass 3DOF (Wind Axes)

Implement three-degrees-of-freedom equations of motion of custom variable mass with respect to wind axes

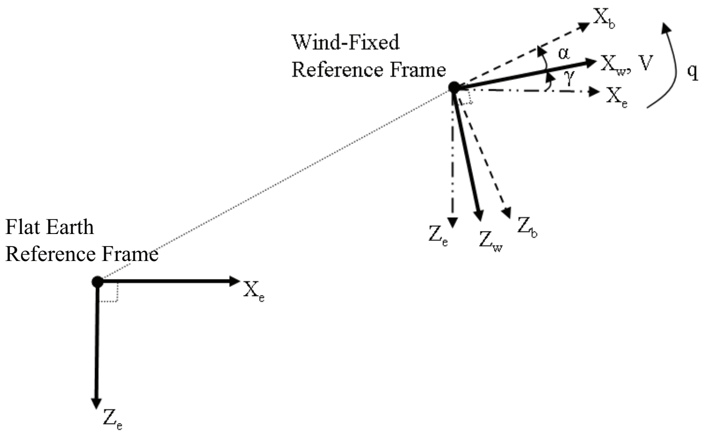


Library

Equations of Motion/3DOF

Description

The Custom Variable Mass 3DOF (Wind Axes) block considers the rotation in the vertical plane of a wind-fixed coordinate frame about a flat Earth reference frame.



The equations of motion are

$$\dot{V} = \frac{F_{x_{wind}}}{m} - \frac{\dot{m}Vre_{x_{wind}}}{m} - g\sin\gamma$$

$$A_{be} = \begin{bmatrix} A_{x_c} \\ A_{z_c} \end{bmatrix} = DCM_{wb}\left[\frac{F_w - \dot{m}V_{rew}}{m} - \bar{g}\right]$$

$$A_{bb} = \begin{bmatrix} A_{xb} \\ A_{zb} \end{bmatrix} = DCM_{wb}\left[\frac{F_w - \dot{m}V_{rew}}{m} - g - \bar{\omega}_w \times \bar{V}_w\right]$$

$$\dot{\alpha} = \frac{F_{z_{wind}}}{mV} + q + \frac{g}{V}\cos\gamma - \frac{\dot{m}Vre_{z_{wind}}}{mV}$$

$$\dot{q} = \dot{\theta} = \frac{M_{y_{body}} - \dot{I}_{yy}q}{I_{yy}}$$

$$\dot{\gamma} = q - \dot{\alpha}$$

where the applied forces are assumed to act at the center of gravity of the body. Vre_{w} is the relative velocity in the wind axes at which the mass flow ($\dot{m}$) is ejected or added to the body in wind axes.

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Custom Variable` selection conforms to the previously described equations of motion.

Initial airspeed

A scalar value for the initial velocity of the body, (V_0).

Initial flight path angle

A scalar value for the initial pitch attitude of the body, (γ_0).

Initial incidence

A scalar value for the initial angle between the velocity vector and the body, (α_0).

Initial body rotation rate

A scalar value for the initial body rotation rate, (q_0).

Initial position (x,z)

A two-element vector containing the initial location of the body in the flat Earth reference frame.

Gravity Source

Specify source of gravity:

`External`	Variable gravity input to block
`Internal`	Constant gravity specified in **Acceleration due to gravity**

Acceleration due to gravity

A scalar value for the acceleration due to gravity used if internal gravity source is selected. If gravity is to be neglected in the simulation, this value can be set to `0`. This parameter appears if you set **Gravity source** to `Internal`.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Velocity: e.g., 'V'

Specify velocity state name.

Default value is `''`.

Incidence angle: e.g., 'alpha'

Specify incidence angle state name.

Default value is `''`.

Flight path angle: e.g., 'gamma'

Specify flight path angle state name.

Default value is `''`.

Body rotation rate: e.g., 'q'

Specify body rotation rates state name.

Default value is `''`.

Position: e.g., {'Xe', 'Ze'}

Specify position state names.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the force acting along the wind *x*-axis, (F_x).
Second		Contains the force acting along the wind *z*-axis, (F_z).
Third		Contains the applied pitch moment in body axes, (M).
Fourth (Optional)	Vector	Contains one or more rates of change of mass, ($\dot{m}$) (positive if accreted, negative if ablated).
Fifth		Contains the mass, (m).
Sixth		Contains the rate of change of inertia tensor matrix, ($\dot{I}_{yy}$).
Seventh		Contains the inertia tensor matrix, (I_{yy}).
Eighth (Optional)		Contains the gravity in the selected units.

Input	Dimension Type	Description
Ninth (Optional)	Two-element vector	Contains one or more relative velocities at which the mass is accreted to or ablated from the body in wind axes.

Output	Dimension Type	Description
First		Contains the flight path angle, within ±pi, in radians (γ).
Second		Contains the pitch angular rate, in radians per second (ω_y).
Third		Contains the pitch angular acceleration, in radians per second squared ($d\omega_y/dt$).
Fourth	Two-element vector	Contains the location of the body, in the flat Earth reference frame, (Xe, Ze).
Fifth	Two-element vector	Contains the velocity of the body resolved into the wind-fixed coordinate frame, (V, 0).
Sixth	Two-element vector	Contains the acceleration of the body resolved into the body-fixed coordinate frame, (Ax, Az).
Seventh	Scalar	Contains the angle of attack, (α).
Eight (Optional)	Two-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Reference

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

See Also

3DOF (Body Axes)

3DOF (Wind Axes)

4th Order Point Mass (Longitudinal)

Custom Variable Mass 3DOF (Body Axes)

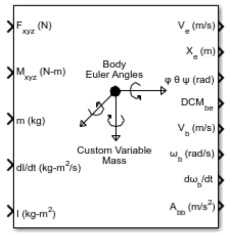
Simple Variable Mass 3DOF (Body Axes)

Simple Variable Mass 3DOF (Wind Axes)

Introduced in R2006a

Custom Variable Mass 6DOF (Euler Angles)

Implement Euler angle representation of six-degrees-of-freedom equations of motion of custom variable mass

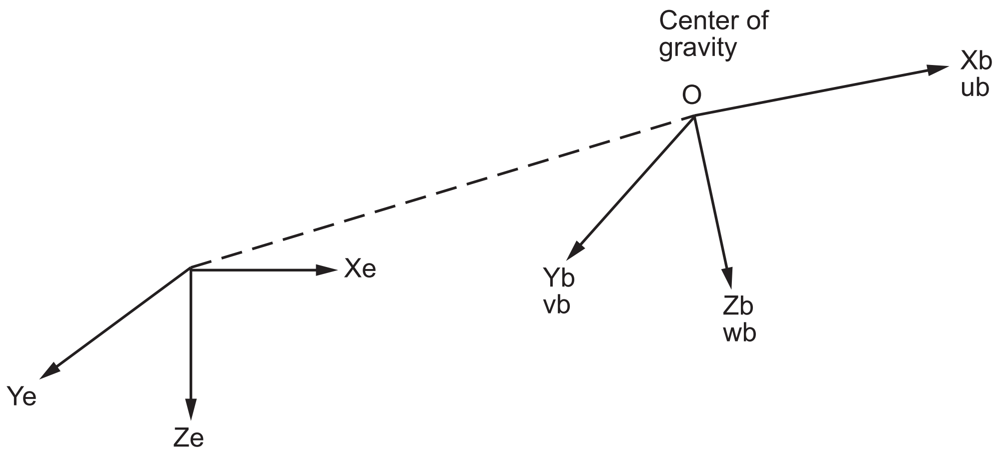


Library

Equations of Motion/6DOF

Description

The Custom Variable Mass 6DOF (Euler Angles) block considers the rotation of a body-fixed coordinate frame (X_b, Y_b, Z_b) about a flat Earth reference frame (X_e, Y_e, Z_e). The origin of the body-fixed coordinate frame is the center of gravity of the body, and the body is assumed to be rigid, an assumption that eliminates the need to consider the forces acting between individual elements of mass. The flat Earth reference frame is considered inertial, an excellent approximation that allows the forces due to the Earth's motion relative to the “fixed stars” to be neglected.



Flat Earth reference frame

The translational motion of the body-fixed coordinate frame is given below, where the applied forces $[F_x\ F_y\ F_z]^T$ are in the body-fixed frame. Vre_b is the relative velocity in the body axes at which the mass flow ($\dot{m}$) is ejected or added to the body-fixed axes.

$$\bar{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\bar{V}}_b + \bar{\omega} \times \bar{V}_b) + \dot{m}\bar{V}re_b$$

$$A_{be} = \frac{\bar{F}_b - \dot{m}\bar{V}_{re_b}}{m}$$

$$A_{bb} = \begin{bmatrix} \dot{u}_b \\ \dot{v}_b \\ \dot{w}_b \end{bmatrix} = \frac{\bar{F}_b - \dot{m}\bar{V}_{re_b}}{m} - \bar{\omega} \times \bar{V}_b$$

$$\bar{V}_b = \begin{bmatrix} u_b \\ v_b \\ w_b \end{bmatrix}, \bar{\omega} = \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

The rotational dynamics of the body-fixed frame are given below, where the applied moments are $[L\ M\ N]^T$, and the inertia tensor I is with respect to the origin O.

$$\overline{M}_B = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I\dot{\overline{\omega}} + \overline{\omega} \times (I\overline{\omega}) + \dot{I}\,\overline{\omega}$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

$$\dot{I} = \begin{bmatrix} \dot{I}_{xx} & -\dot{I}_{xy} & -\dot{I}_{xz} \\ -\dot{I}_{yx} & \dot{I}_{yy} & -\dot{I}_{yz} \\ -\dot{I}_{zx} & -\dot{I}_{zy} & \dot{I}_{zz} \end{bmatrix}$$

The relationship between the body-fixed angular velocity vector, $[p\ q\ r]^{\mathrm{T}}$, and the rate of change of the Euler angles, $[\dot{\phi}\dot{\theta}\dot{\psi}]^{\mathrm{T}}$, can be determined by resolving the Euler rates into the body-fixed coordinate frame.

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} \dot{\phi} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix}\begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix}\begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix} = J^{-1}\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

Inverting J then gives the required relationship to determine the Euler rate vector.

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = J\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & (\sin\phi\tan\theta) & (\cos\phi\tan\theta) \\ 0 & \cos\phi & -\sin\phi \\ 0 & \dfrac{\sin\phi}{\cos\theta} & \dfrac{\cos\phi}{\cos\theta} \end{bmatrix}\begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

For more information on aerospace coordinate systems, see “About Aerospace Coordinate Systems” on page 2-10.

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Custom Variable` selection conforms to the previously described equations of motion.

Representation

Select the representation to use:

`Euler Angles`	Use Euler angles within equations of motion.
`Quaternion`	Use quaternions within equations of motion.

The `Euler Angles` selection conforms to the previously described equations of motion.

Initial position in inertial axes

The three-element vector for the initial location of the body in the flat Earth reference frame.

Initial velocity in body axes

The three-element vector for the initial velocity in the body-fixed coordinate frame.

Initial Euler rotation

The three-element vector for the initial Euler rotation angles [roll, pitch, yaw], in radians.

Initial body rotation rates

The three-element vector for the initial body-fixed angular rates, in radians per second.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.

- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Position: e.g., {'Xe', 'Ye', 'Ze'}

Specify position state names.

Default value is `''`.

Velocity: e.g., {'U', 'v', 'w'}

Specify velocity state names.

Default value is `''`.

Euler rotation angles: e.g., {'phi', 'theta', 'psi'}

Specify Euler rotation angles state names. This parameter appears if the **Representation** parameter is set to `Euler Angles`.

Default value is `''`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rate state names.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces.
Second	Vector	Contains the three applied moments.
Third (Optional)	Vector	Contains one or more rates of change of mass (positive if accreted, negative if ablated).
Fourth	Scalar	Contains the mass.
Fifth	3-by-3 matrix	Contains the rate of change of inertia tensor matrix.
Sixth	3-by-3 matrix	Contains the inertia tensor matrix.

Input	Dimension Type	Description
Seventh (Optional)	Three-element vector	Contains one or more relative velocities at which the mass is accreted to or ablated from the body in body-fixed axes.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity in the flat Earth reference frame.
Second	Three-element vector	Contains the position in the flat Earth reference frame.
Third	Three-element vector	Contains the Euler rotation angles [roll, pitch, yaw], within ±pi, in radians.
Fourth	3–by-3 matrix	Contains the coordinate transformation from flat Earth axes to body-fixed axes.
Fifth	Three-element vector	Contains the velocity in the body-fixed frame.
Sixth	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Seventh	Three-element vector	Contains the angular accelerations in body-fixed axes, in radians per second squared.
Eight	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Ninth (Optional)	Three-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

Reference

Stevens, Brian, and Frank Lewis, *Aircraft Control and Simulation*, Second Edition, John Wiley & Sons, 2003.

Zipfel, Peter H., *Modeling and Simulation of Aerospace Vehicle Dynamics*. Second Edition, AIAA Education Series, 2007.

See Also

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

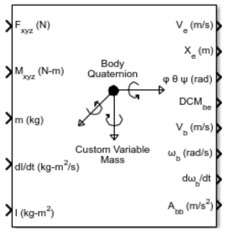
Simple Variable Mass 6DOF Wind (Wind Angles)

"About Aerospace Coordinate Systems" on page 2-10

Introduced in R2006a

Custom Variable Mass 6DOF (Quaternion)

Implement quaternion representation of six-degrees-of-freedom equations of motion of custom variable mass with respect to body axes



Library

Equations of Motion/6DOF

Description

For a description of the coordinate system and the translational dynamics, see the block description for the Custom Variable Mass 6DOF (Euler Angles) block.

The integration of the rate of change of the quaternion vector is given below. The gain K drives the norm of the quaternion state vector to 1.0 should ε become nonzero. You must choose the value of this gain with care, because a large value improves the decay rate of the error in the norm, but also slows the simulation because fast dynamics are introduced. An error in the magnitude in one element of the quaternion vector is spread equally among all the elements, potentially increasing the error in the state vector.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = {}^1\!/_2 \begin{bmatrix} 0 & -p & -q & -r \\ p & 0 & r & -q \\ q & -r & 0 & p \\ r & q & -p & 0 \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix} + K\varepsilon \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

$$\varepsilon = 1 - (q_0^2 + q_1^2 + q_2^2 + q_3^2) \,.$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Custom Variable` selection conforms to the previously described equations of motion.

Representation

Select the representation to use:

`Euler Angles`	Use Euler angles within equations of motion.

`Quaternion`	Use quaternions within equations of motion.

The `Quaternion` selection conforms to the previously described equations of motion.

Initial position in inertial axes

The three-element vector for the initial location of the body in the flat Earth reference frame.

Initial velocity in body axes

The three-element vector for the initial velocity in the body-fixed coordinate frame.

Initial Euler rotation

The three-element vector for the initial Euler rotation angles [roll, pitch, yaw], in radians.

Initial body rotation rates

The three-element vector for the initial body-fixed angular rates, in radians per second.

Gain for quaternion normalization

The gain to maintain the norm of the quaternion vector equal to 1.0.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.

- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Position: e.g., {'Xe', 'Ye', 'Ze'}

Specify position state names.

Default value is `''`.

Velocity: e.g., {'U', 'v', 'w'}

Specify velocity state names.

Default value is `''`.

Quaternion vector: e.g., {'qr', 'qi', 'qj', 'qk'}

Specify quaternion vector state names. This parameter appears if the **Representation** parameter is set to `Quaternion`.

Default value is `''`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rate state names.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces.
Second	Vector	Contains the three applied moments.
Third (Optional)	Vector	Contains one or more rates of change of mass (positive if accreted, negative if ablated).

Input	Dimension Type	Description
Fourth	Scalar	Contains the mass.
Fifth	3-by-3 matrix	Contains rate of change of inertia tensor matrix.
Sixth	3-by-3 matrix	Contains the inertia tensor matrix.
Seventh (Optional)	Three-element vector	Contains one or more relative velocities at which the mass is accreted to or ablated from the body in body-fixed axes.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity in the flat Earth reference frame.
Second	Three-element vector	Contains the position in the flat Earth reference frame.
Third	Three-element vector	Contains the Euler rotation angles [roll, pitch, yaw], in radians.
Fourth	3-by-3 matrix	Contains the coordinate transformation from flat Earth axes to body-fixed axes.
Fifth	Three-element vector	Contains the velocity in the body-fixed frame.
Sixth	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Seventh	Three-element vector	Contains the angular accelerations in body-fixed axes, in radians per second squared.
Eighth	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Ninth (Optional)	Three-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

Reference

Stevens, Brian, and Frank Lewis, *Aircraft Control and Simulation*, Second Edition, John Wiley & Sons, 2003.

Zipfel, Peter H., *Modeling and Simulation of Aerospace Vehicle Dynamics*. Second Edition, AIAA Education Series, 2007.

See Also

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

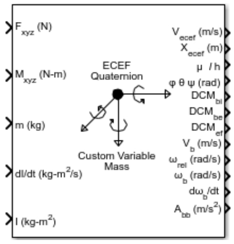
Simple Variable Mass 6DOF Wind (Wind Angles)

"About Aerospace Coordinate Systems" on page 2-10

Introduced in R2006a

Custom Variable Mass 6DOF ECEF (Quaternion)

Implement quaternion representation of six-degrees-of-freedom equations of motion of custom variable mass in Earth-centered Earth-fixed (ECEF) coordinates

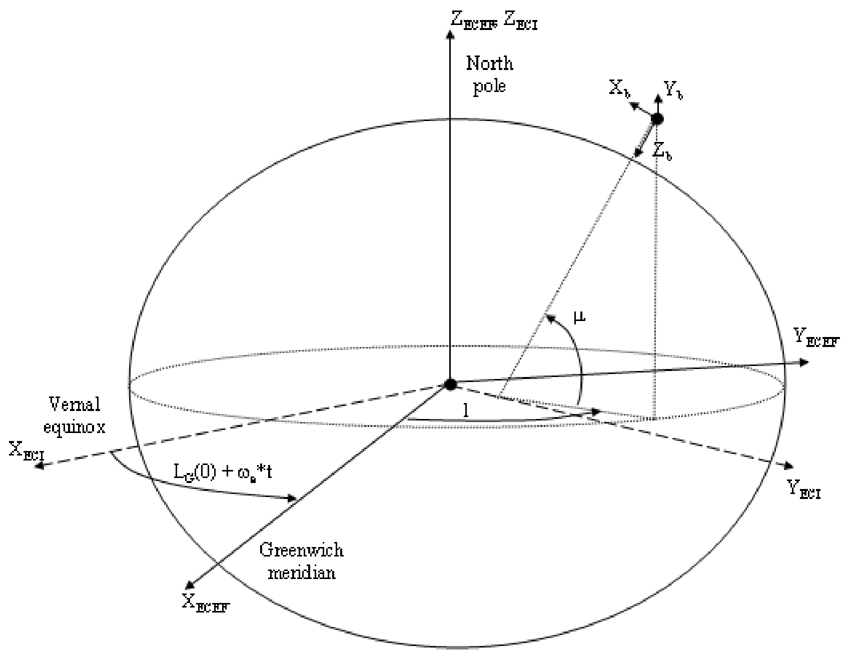


Library

Equations of Motion/6DOF

Description

The Custom Variable Mass 6DOF ECEF (Quaternion) block considers the rotation of a Earth-centered Earth-fixed (ECEF) coordinate frame (X_{ECEF}, Y_{ECEF}, Z_{ECEF}) about an Earth-centered inertial (ECI) reference frame (X_{ECI}, Y_{ECI}, Z_{ECI}). The origin of the ECEF coordinate frame is the center of the Earth, additionally the body of interest is assumed to be rigid, an assumption that eliminates the need to consider the forces acting between individual elements of mass. The representation of the rotation of ECEF frame from ECI frame is simplified to consider only the constant rotation of the ellipsoid Earth (ω_e) including an initial celestial longitude ($L_G(0)$). This excellent approximation allows the forces due to the Earth's complex motion relative to the “fixed stars” to be neglected.



The translational motion of the ECEF coordinate frame is given below, where the applied forces $[F_x\ F_y\ F_z]^T$ are in the body frame. Vre_b is the relative velocity in the wind axes at which the mass flow ($\dot{m}$) is ejected or added to the body in body-fixed axes.

$$\bar{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m\left(\dot{\bar{V}}_b + \bar{\omega}_b \times \bar{V}_b + DCM_{bf}\bar{\omega}_e \times \bar{V}_b + DCM_{bf}\left(\bar{\omega}_e \times \left(\bar{\omega}_e \times \bar{X}_f\right)\right)\right)$$
$$+\dot{m}\left(\bar{V}re_b + DCM_{bf}\left(\bar{\omega}_e \times \bar{X}_f\right)\right)$$

$$A_{bb} = \begin{bmatrix} \dot{u}_b \\ \dot{v}_b \\ \dot{w}_b \end{bmatrix} = \frac{\bar{F}_b - \dot{m}\left(\bar{V}_{re_b} + DCM_{bf}\left(w_e \times X_f\right)\right)}{m}$$
$$-\left[\bar{\omega}_b \times \bar{V}_b + DCM\bar{\omega}_e \times \bar{V}_b + DCM_{bf}\left(\bar{\omega}_e\left(\bar{\omega}_e \times X_f\right)\right)\right]$$

$$A_{becef} = \frac{\bar{F}_b - \dot{m}\left(\bar{V}_{re_b} + DCM_{bf}\left(\omega_e \times X_f\right)\right)}{m}$$

where the change of position in ECEF $\dot{\bar{x}}_f$ is calculated by

$$\dot{\bar{x}}_f = DCM_{fb}\bar{V}_b$$

and the velocity of the body with respect to ECEF frame, expressed in body frame ($\bar{V}_b$), angular rates of the body with respect to ECI frame, expressed in body frame ($\bar{\omega}_b$). Earth rotation rate ($\bar{\omega}_e$), and relative angular rates of the body with respect to north-east-down (NED) frame, expressed in body frame ($\bar{\omega}_{rel}$) are defined as

$$\bar{V}_b = \begin{bmatrix} u \\ v \\ w \end{bmatrix}, \bar{\omega}_{rel} = \begin{bmatrix} p \\ q \\ r \end{bmatrix}, \bar{\omega}_e = \begin{bmatrix} 0 \\ 0 \\ \omega_e \end{bmatrix}, \bar{\omega}_b = \bar{\omega}_{rel} + DCM_{bf}\bar{\omega}_e + DCM_{be}\bar{\omega}_{ned}$$

$$\bar{\omega}_{ned} = \begin{bmatrix} \dot{l}\cos\mu \\ -\dot{\mu} \\ -\dot{l}\sin\mu \end{bmatrix} = \begin{bmatrix} V_E/(N+h) \\ -V_N/(M+h) \\ V_E \bullet \tan\mu/(N+h) \end{bmatrix}$$

The rotational dynamics of the body defined in body-fixed frame are given below, where the applied moments are $[L\ M\ N]^{\mathrm{T}}$, and the inertia tensor I is with respect to the origin O.

$$\bar{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = \bar{I}\dot{\bar{\omega}}_b + \bar{\omega}_b \times (\bar{I}\bar{\omega}_b) + \dot{I}\bar{\omega}_b$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

The rate of change of the inertia tensor is defined by the following equation.

$$\dot{I} = \begin{bmatrix} \dot{I}_{xx} & -\dot{I}_{xy} & -\dot{I}_{xz} \\ -\dot{I}_{yx} & \dot{I}_{yy} & -\dot{I}_{yz} \\ -\dot{I}_{zx} & -\dot{I}_{zy} & \dot{I}_{zz} \end{bmatrix}$$

The integration of the rate of change of the quaternion vector is given below.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = -\,{}^1\!/_2 \begin{bmatrix} 0 & \omega_b(1) & \omega_b(2) & \omega_b(3) \\ -\omega_b(1) & 0 & -\omega_b(3) & \omega_b(2) \\ -\omega_b(2) & \omega_b(3) & 0 & -\omega_b(1) \\ -\omega_b(3) & -\omega_b(2) & \omega_b(1) & 0 \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation (see 6DOF ECEF (Quaternion)).
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate (see Simple Variable Mass 6DOF ECEF (Quaternion)).
`Custom Variable`	Mass and inertia variations are customizable.

The `Simple Variable` selection conforms to the previously described equations of motion.

Initial position in geodetic latitude, longitude and altitude

The three-element vector for the initial location of the body in the geodetic reference frame. Latitude and longitude values can be any value. However, latitude values of +90 and -90 may return unexpected values because of singularity at the poles.

Initial velocity in body-axis

The three-element vector containing the initial velocity of the body with respect to ECEF frame, expressed in body frame.

Initial Euler orientation

The three-element vector containing the initial Euler rotation angles [roll, pitch, yaw], in radians. Euler rotation angles are those between the body and north-east-down (NED) coordinate systems.

Initial body rotation rates

The three-element vector for the initial angular rates of the body with respect to NED frame, expressed in body frame, in radians per second.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

Planet model

Specifies the planet model to use, `Custom` or `Earth (WGS84)`.

Equatorial radius of planet

Specifies the radius of the planet at its equator. The units of the equatorial radius parameter should be the same as the units for ECEF position. This option is only available when **Planet model** is set to `Custom`.

Flattening

Specifies the flattening of the planet. This option is only available when **Planet model** is set to `Custom`.

Rotational rate

Specifies the scalar rotational rate of the planet in rad/s. This option is only available when **Planet model** is set to `Custom`.

Celestial longitude of Greenwich source

Specifies the source of Greenwich meridian's initial celestial longitude:

`Internal`	Use celestial longitude value from mask dialog.
`External`	Use external input for celestial longitude value.

Celestial longitude of Greenwich

The initial angle between Greenwich meridian and the *x*-axis of the ECI frame.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. Use state names instead of block paths throughout the linearization process.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.

- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Quaternion vector: e.g., {'qr', 'qi', 'qj', 'qk'}

Specify quaternion vector name for the state.

Default value is `' '`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rate name for the state.

Default value is `' '`.

Velocity: e.g., {'U', 'v', 'w'}

Specify velocity name for the state.

Default value is `' '`.

ECEF position: e.g., {'Xecef', 'Yecef', 'Zecef'}

Specify the ECEF position name for the state.

Default value is `' '`.

Inertial position: e.g., {'Xeci', 'Yeci', 'Zeci'}

Specify the inertial position name for the state.

Default value is `' '`.

Celestial longitude of Greenwich: e.g., 'LG'

Specify the Celestial longitude of Greenwich name for the state.

Default value is `' '`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces in body-fixed axes.
Second	Vector	Contains the three applied moments in body-fixed axes.
Third (Optional)	Vector	Contains one or more rates of change of mass (positive if accreted, negative if ablated).
Fourth	Scalar	Contains the mass.
Sixth	3-by-3 matrix	Applies to the inertia tensor matrix.
Seventh (Optional)	1-by-1-by-*m* array	Contains one or more relative velocities at which the mass is accreted to or ablated from the body in body-fixed axes. *m* is three times the size of the third input vector.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity of the body with respect to ECEF frame, expressed in ECEF frame.
Second	Three-element vector	Contains the position in the ECEF reference frame.
Third	Three-element vector	Contains the position in geodetic latitude, longitude and altitude, in degrees, degrees and selected units of length respectively.
Fourth	Three-element vector	Contains the body rotation angles [roll, pitch, yaw], in radians. Euler rotation angles are those between the body and NED coordinate systems.
Fifth	3-by-3 matrix	Applies to the coordinate transformation from ECI axes to body-fixed axes.
Sixth	3-by-3 matrix	Applies to the coordinate transformation from NED axes to body-fixed axes.
Seventh	3-by-3 matrix	Applies to the coordinate transformation from ECEF axes to NED axes.

Output	Dimension Type	Description
Eighth	Three-element vector	Contains the velocity of the body with respect to ECEF frame, expressed in body frame.
Ninth	Three-element vector	Contains the relative angular rates of the body with respect to NED frame, expressed in body frame, in radians per second.
Tenth	Three-element vector	Contains the angular rates of the body with respect to ECI frame, expressed in body frame, in radians per second.
Eleventh	Three-element vector	Contains the angular accelerations of the body with respect to ECI frame, expressed in body frame, in radians per second squared.
Twelfth	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Thirteenth (Optional)	Three-element vector	Contains the accelerations in body-fixed axes with respect to ECEF frame.

Assumptions and Limitations

This implementation assumes that the applied forces are acting at the center of gravity of the body.

This implementation generates a geodetic latitude that lies between ±90 degrees, and longitude that lies between ±180 degrees. Additionally, the MSL altitude is approximate.

The Earth is assumed to be ellipsoidal. By setting flattening to 0.0, a spherical planet can be achieved. The Earth's precession, nutation, and polar motion are neglected. The celestial longitude of Greenwich is Greenwich Mean Sidereal Time (GMST) and provides a rough approximation to the sidereal time.

The implementation of the ECEF coordinate system assumes that the origin is at the center of the planet, the *x*-axis intersects the Greenwich meridian and the equator, the *z*-axis is the mean spin axis of the planet, positive to the north, and the *y*-axis completes the right-handed system.

The implementation of the ECI coordinate system assumes that the origin is at the center of the planet, the *x*-axis is the continuation of the line from the center of the Earth toward the vernal equinox, the *z*-axis points in the direction of the mean equatorial plane's north pole, positive to the north, and the *y*-axis completes the right-handed system.

References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation, Second Edition*, John Wiley & Sons, New York, 2003.

McFarland, Richard E., *A Standard Kinematic Model for Flight simulation at NASA-Ames*, NASA CR-2497.

“Supplement to Department of Defense World Geodetic System 1984 Technical Report: Part I - Methods, Techniques and Data Used in WGS84 Development,” DMA TR8350.2-A.

See Also

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

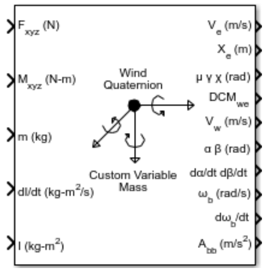
Simple Variable Mass 6DOF Wind (Wind Angles)

“About Aerospace Coordinate Systems” on page 2-10

Introduced in R2006a

Custom Variable Mass 6DOF Wind (Quaternion)

Implement quaternion representation of six-degrees-of-freedom equations of motion of custom variable mass with respect to wind axes

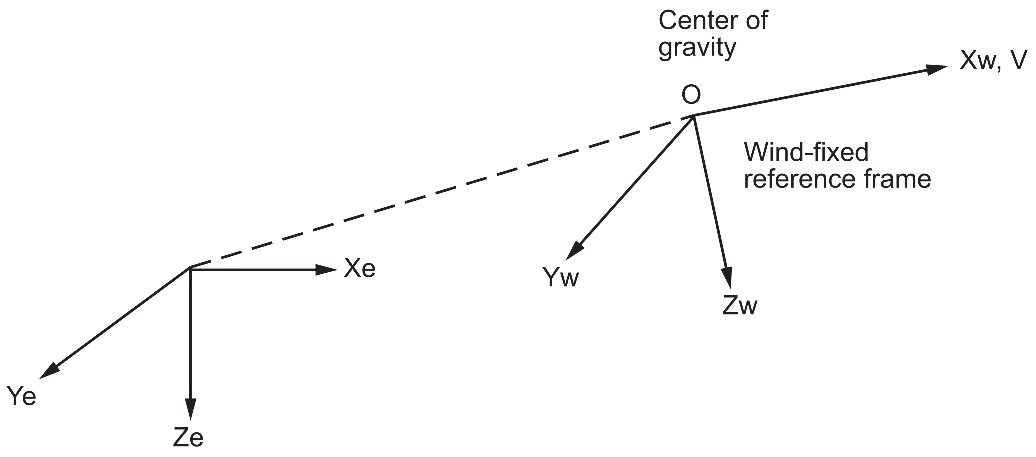


Library

Equations of Motion/6DOF

Description

The Custom Variable Mass 6DOF Wind (Quaternion) block considers the rotation of a wind-fixed coordinate frame (X_w,Y_w, Z_w) about an flat Earth reference frame (X_e,Y_e, Z_e). The origin of the wind-fixed coordinate frame is the center of gravity of the body, and the body is assumed to be rigid, an assumption that eliminates the need to consider the forces acting between individual elements of mass. The flat Earth reference frame is considered inertial, an excellent approximation that allows the forces due to the Earth's motion relative to the “fixed stars” to be neglected.



Flat Earth reference frame

The translational motion of the wind-fixed coordinate frame is given below, where the applied forces $[F_x, F_y, F_z]^T$ are in the wind-fixed frame. Vre_w is the relative velocity in the wind axes at which the mass flow ($\dot{m}$) is ejected or added to the body.

$$\bar{F}_w = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\bar{V}}_w + \bar{\omega}_w \times \bar{V}_w) + \dot{m}\bar{V}re_w$$

$$A_{be} = DCM_{wb}\frac{\left[\bar{F}_w - \dot{m}V_{re}\right]}{m}$$

$$\bar{V}_w = \begin{bmatrix} V \\ 0 \\ 0 \end{bmatrix}, \bar{\omega}_w = \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = DMC_{wb}\begin{bmatrix} p_b - \dot{\beta}\sin\alpha \\ q_b - \dot{\alpha} \\ r_b + \dot{\beta}\cos\alpha \end{bmatrix}, \bar{w}_b = \begin{bmatrix} p_b \\ q_b \\ r_b \end{bmatrix}$$

$$A_{bb} = DCM_{wb}\left[\frac{\bar{F}w - \dot{m}V_{re}}{m} - \bar{\omega}_w \times \bar{V}_w\right]$$

The rotational dynamics of the body-fixed frame are given below, where the applied moments are $[L\ M\ N]^T$, and the inertia tensor I is with respect to the origin O. Inertia tensor I is much easier to define in body-fixed frame.

$$\bar{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I\dot{\bar{\omega}}_b + \bar{\omega}_b \times (I\bar{\omega}_b) + \dot{I}\,\bar{\omega}_b$$

$$A_{bb} = \begin{bmatrix} \dot{U}_b \\ \dot{V}_b \\ \dot{W}_b \end{bmatrix} = DCM_{wb}\left[\frac{\bar{F}w - \dot{m}V_{re}}{m} - \bar{\omega}_w \times \bar{V}_w\right]$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

The integration of the rate of change of the quaternion vector is given below.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = -\frac{1}{2}\begin{bmatrix} 0 & p & q & r \\ -p & 0 & -r & q \\ -q & r & 0 & -p \\ -r & -q & p & 0 \end{bmatrix}\begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Custom Variable` selection conforms to the previously described equations of motion.

Representation

Select the representation to use:

`Wind Angles`	Use wind angles within equations of motion.
`Quaternion`	Use quaternions within equations of motion.

The `Quaternion` selection conforms to the previously described equations of motion.

Initial position in inertial axes

The three-element vector for the initial location of the body in the flat Earth reference frame.

Initial airspeed, sideslip angle, and angle of attack

The three-element vector containing the initial airspeed, initial sideslip angle and initial angle of attack.

Initial wind orientation

The three-element vector containing the initial wind angles [bank, flight path, and heading], in radians.

Initial body rotation rates

The three-element vector for the initial body-fixed angular rates, in radians per second.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. Use state names instead of block paths throughout the linearization process.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Position: e.g., {'Xe', 'Ye', 'Ze'}

Specify position name for the state.

Default value is `' '`.

Velocity: e.g., 'V'

Specify velocity name for the state.

Default value is `' '`.

Incidence angle: e.g., 'alpha'

Specify incidence angle name for the state.

Default value is `' '`.

Sideslip angle: e.g., 'beta'

Specify sideslip angle name for the state.

Default value is `' '`.

Quaternion vector: e.g., {'qr', 'qi', 'qj', 'qk'}

Specify quaternion vector name for the state.

Default value is `' '`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rates name for the state.

Default value is `' '`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces in wind-fixed axes.
Second	Vector	Contains the three applied moments in body-fixed axes.
Third (Optional)	Vector	Contains one or more rates of change of mass, positive if accreted, negative if ablated.
Fourth	Scalar	Contains the mass of the body
Fifth	3-by-3 matrix	Applies to the rate of change of inertia tensor matrix in body-fixed axes.
Sixth	3-by-3 matrix	Applies to the inertia tensor matrix in body-fixed axes.
Seventh (Optional)	Three-element vector	Contains one or more relative velocities at which the mass is accreted to or ablated from the body in wind axes.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity in the flat Earth reference frame
Second	Three-element vector	Contains the position in the flat Earth reference frame.
Third	Three-element vector	Contains the wind rotation angles [bank, flight path, heading], in radians.
Fourth	3-by-3 matrix	Applies to the coordinate transformation from flat Earth axes to wind-fixed axes.
Fifth	Three-element vector	Contains to the velocity in the wind-fixed frame.
Sixth	Two-element vector	Contains the angle of attack and sideslip angle, in radians.
Seventh	Two-element vector	Contains the rate of change of angle of attack and rate of change of sideslip angle, in radians per second.
Eighth	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Ninth	Three-element vector	Contains the angular accelerations in body-fixed axes, in radians per second squared.
Tenth	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Eleventh (Optional)	Three-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

References

Stevens, Brian, and Frank Lewis, *Aircraft Control and Simulation*, Second Edition, John Wiley & Sons, 2003.

Zipfel, Peter H., *Modeling and Simulation of Aerospace Vehicle Dynamics*. Second Edition, AIAA Education Series, 2007.

See Also

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

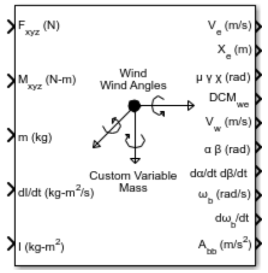
Simple Variable Mass 6DOF Wind (Wind Angles)

"About Aerospace Coordinate Systems" on page 2-10

Introduced in R2006a

Custom Variable Mass 6DOF Wind (Wind Angles)

Implement wind angle representation of six-degrees-of-freedom equations of motion of custom variable mass



Library

Equations of Motion/6DOF

Description

For a description of the coordinate system employed and the translational dynamics, see the block description for the Custom Variable Mass 6DOF Wind (Quaternion) block.

The relationship between the wind angles, $[\mu\ \gamma\ \chi]^T$, can be determined by resolving the wind rates into the wind-fixed coordinate frame.

$$\begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} \dot{\mu} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\mu & \sin\mu \\ 0 & -\sin\mu & \cos\mu \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\gamma} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\mu & \sin\mu \\ 0 & -\sin\mu & \cos\mu \end{bmatrix} \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\chi} \end{bmatrix} \equiv J^{-1} \begin{bmatrix} \dot{\mu} \\ \dot{\gamma} \\ \dot{\chi} \end{bmatrix}$$

Inverting J then gives the required relationship to determine the wind rate vector.

$$\begin{bmatrix}\dot{\mu}\\\dot{\gamma}\\\dot{\chi}\end{bmatrix} = J\begin{bmatrix}p_w\\q_w\\r_w\end{bmatrix} = \begin{bmatrix}1 & (\sin\mu\tan\gamma) & (\cos\mu\tan\gamma)\\0 & \cos\mu & -\sin\mu\\0 & \dfrac{\sin\mu}{\cos\gamma} & \dfrac{\cos\mu}{\cos\gamma}\end{bmatrix}\begin{bmatrix}p_w\\q_w\\r_w\end{bmatrix}$$

The body-fixed angular rates are related to the wind-fixed angular rate by the following equation.

$$\begin{bmatrix}p_w\\q_w\\r_w\end{bmatrix} = DMC_{wb}\begin{bmatrix}p_b - \dot{\beta}\sin\alpha\\q_b - \dot{\alpha}\\r_b + \dot{\beta}\cos\alpha\end{bmatrix}$$

Using this relationship in the wind rate vector equations, gives the relationship between the wind rate vector and the body-fixed angular rates.

$$\begin{bmatrix}\dot{\mu}\\\dot{\gamma}\\\dot{\chi}\end{bmatrix} = J\begin{bmatrix}p_w\\q_w\\r_w\end{bmatrix} = \begin{bmatrix}1 & (\sin\mu\tan\gamma) & (\cos\mu\tan\gamma)\\0 & \cos\mu & -\sin\mu\\0 & \dfrac{\sin\mu}{\cos\gamma} & \dfrac{\cos\mu}{\cos\gamma}\end{bmatrix}DMC_{wb}\begin{bmatrix}p_b - \dot{\beta}\sin\alpha\\q_b - \dot{\alpha}\\r_b + \dot{\beta}\cos\alpha\end{bmatrix}$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Custom Variable` selection conforms to the previously described equations of motion.

Representation

Select the representation to use:

`Wind Angles`	Use wind angles within equations of motion.
`Quaternion`	Use quaternions within equations of motion.

The `Wind Angles` selection conforms to the previously described equations of motion.

Initial position in inertial axes

The three-element vector for the initial location of the body in the flat Earth reference frame.

Initial airspeed, sideslip angle, and angle of attack

The three-element vector containing the initial airspeed, initial sideslip angle and initial angle of attack.

Initial wind orientation

The three-element vector containing the initial wind angles [bank, flight path, and heading], in radians.

Initial body rotation rates

The three-element vector for the initial body-fixed angular rates, in radians per second.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. Use state names instead of block paths throughout the linearization process.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Position: e.g., {'Xe', 'Ye', 'Ze'}

Specify position name for the state.

Default value is `' '`.

Velocity: e.g., 'V'

Specify velocity name for the state.

Default value is `' '`.

Incidence angle: e.g., 'alpha'

Specify incidence angle name for the state.

Default value is `' '`.

Sideslip angle: e.g., 'beta'

Specify sideslip angle name for the state.

Default value is `' '`.

Wind orientation: e.g., {'mu', 'gamma', 'chi'}

Specify wind orientation name for the state. This parameter appears if the **Representation** parameter is set to `Wind Angles`.

Default value is `' '`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rates name for the state.

Default value is `' '`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces in wind-fixed axes.
Second	Vector	Contains the three applied moments in body-fixed axes (+/-).
Third (Optional)	Vector	Contains one or more rates of change of mass (positive if accreted, negative if ablated).
Fourth	Scalar	Contains the mass.
Fifth	3-by-3 matrix	Applies to the rate of change of inertia tensor matrix in body-fixed axes.

Input	Dimension Type	Description
Sixth	3-by-3 matrix	Applies to the inertia tensor matrix in body-fixed axes.
Seventh (Optional)	1-by-1-by-*m* array	Contains one or more relative velocities at which the mass is accreted to or ablated from the body in wind axes. *m* is three times the size of the third input vector.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity in the flat Earth reference frame.
Second	Three-element vector	Contains the position in the flat Earth reference frame.
Third	Three-element vector	Contains the wind rotation angles [bank, flight path, heading], within ±pi, in radians.
Fourth	3-by-3 matrix	Applies to the coordinate transformation from flat Earth axes to wind-fixed axes.
Fifth	Three-element vector	Contains the velocity in the wind-fixed frame.
Sixth	Two-element vector	Contains the angle of attack and sideslip angle, in radians.
Seventh	Two-element vector	Contains the rate of change of angle of attack and rate of change of sideslip angle, in radians per second.
Eighth	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Ninth	Three-element vector	Contains the angular accelerations in body-fixed axes, in radians per second squared.
Tenth	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Eleventh (Optional)	Three-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

References

Stevens, Brian, and Frank Lewis, *Aircraft Control and Simulation*, Second Edition, John Wiley & Sons, 2003.

Zipfel, Peter H., *Modeling and Simulation of Aerospace Vehicle Dynamics*. Second Edition, AIAA Education Series, 2007.

See Also

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

Simple Variable Mass 6DOF Wind (Wind Angles)

“About Aerospace Coordinate Systems” on page 2-10

Introduced in R2006a

Delta UT1

Calculate difference between principal Universal Time (UT1) and Coordinated Universal Time (UTC) according to International Astronomical Union (IAU) 2000A reference system

Library: Aerospace Blockset / Environment / Celestial Phenomena
Aerospace Blockset / Utilities / Axes Transformations

UTC MJD
ΔUT1

Description

The Delta UT1 block calculates the difference between principal UT1 and UTC according to the IAU 2000A reference system and Earth orientation data. By default, this block uses a prepopulated list of International Earth Rotation and Reference Systems Service (IERS) data. This list contains measured and calculated (predicted) data supplied by the IERS. The IERS measures and calculates this data for a set of predetermined dates. For dates after those listed in the prepopulated list, Delta UT1 calculates the data using this equation, limiting the values to +/- .9s:

```
UT1-UTC=0.5309-0.00123(MJD-57808)-(UT2-UT1)
```

Ports

Input

UTC — UT1 for UTC
modified Julian date

UT1 for UTC, specified as a modified Julian date. Use the `mjuliandate` function to convert the UTC date to a modified Julian date.

Data Types: `double`

Output Arguments

ΔUT1 — Difference between UT1 and UTC
double

Difference between UT1 and UTC.

Data Types: `double`

Parameters

`IERS data file` — Earth orientation data
`aeroiersdata.mat` (default) | MAT-file

Custom list of Earth orientation data, specified in a MAT-file.

`Action for out-of-range input` — Out-of-range action
Warning (default) | Error | None

Out-of-range action, specified as a string.

Action to take in case of out-of-range or predicted value dates, specified as a string:

- Warning — Displays warning and indicates that the dates were out-of-range or predicted values.
- Error — Displays error and indicates that the dates were out-of-range or predicted values.
- None — Does not display warning or error.

`IERS data URL` — Website or Earth orientation data file
`http://maia.usno.navy.mil/ser7/finals2000A.data` (default) | website address | file name

Website or Earth orientation data file containing the Earth orientation data according to the IAU 2000A, specified as a website address or file name.

`Destination folder` — Folder for IERS data file
Current Folder (default)

Folder for IERS data file, specified as a character array or string. Before running this function, create *foldername* with write permission.

To create the IERS data file in the destination folder, click the **Create** button.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also
Direction Cosine Matrix ECI to ECEF | Earth Orientation Parameters | `aeroReadIERSData`

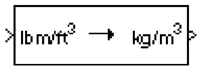
Topics
“Calculate UT1 to UTC Values” on page 2-55

External Websites
http://maia.usno.navy.mil/ser7/finals2000A.data

Introduced in R2017b

Density Conversion

Convert from density units to desired density units



Library

Utilities/Unit Conversions

Description

The Density Conversion block computes the conversion factor from specified input density units to specified output density units and applies the conversion factor to the input signal.

The Density Conversion block icon displays the input and output units selected from the **Initial unit** and the **Final unit** lists.

Parameters

Initial unit

Specifies the input units.

Final unit

Specifies the output units.

The following conversion units are available:

`lbm/ft`^{3}	Pound mass per cubic foot
`kg/m`^{3}	Kilograms per cubic meter
`slug/ft`^{3}	Slugs per cubic foot
`lbm/in`^{3}	Pound mass per cubic inch

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the density, in initial density units.

Output	Dimension Type	Description
First		Contains the density, in final density units.

See Also

Acceleration Conversion

Angle Conversion

Angular Acceleration Conversion

Angular Velocity Conversion

Force Conversion

Length Conversion

Mass Conversion

Pressure Conversion

Temperature Conversion

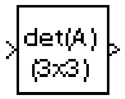
Velocity Conversion

Introduced before R2006a

Determinant of 3x3 Matrix

Compute determinant of matrix

Library: Aerospace Blockset / Utilities / Math Operations



Description

The Determinant of 3x3 Matrix block computes the determinant for the input matrix.

The input matrix has the form of

$$A = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

The determinant of the matrix has the form of

$$det(A) = A_{11}(A_{22}A_{33} - A_{23}A_{32}) - A_{12}(A_{21}A_{33} - A_{23}A_{31}) + A_{13}(A_{21}A_{32} - A_{22}A_{31})$$

Ports

Input

`Input 1` — Input matrix
3-by-3 matrix

Input matrix, specified as a 3-by-3 matrix.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `fixed point`

Output

`Output 1` — Determinant
scalar

Determinant, output as a scalar.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `fixed point`

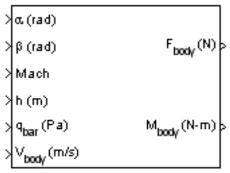
See Also

Adjoint of 3x3 Matrix | Create 3x3 Matrix | Invert 3x3 Matrix

Introduced before R2006a

Digital DATCOM Forces and Moments

Compute aerodynamic forces and moments using Digital DATCOM static and dynamic stability derivatives



Library

Aerodynamics

Description

The Digital DATCOM Forces and Moments block computes the aerodynamic forces and moments about the center of gravity using aerodynamic coefficients from Digital DATCOM.

Algorithms for calculating forces and moments build up the overall aerodynamic forces and moments (***F*** and ***M***) from data contained in the **Digital DATCOM structure** parameter:

$$\boldsymbol{F} = \boldsymbol{F}_{\text{static}} + \boldsymbol{F}_{\text{dyn}}$$

$$\boldsymbol{M} = \boldsymbol{M}_{\text{static}} + \boldsymbol{M}_{\text{dyn}}$$

$\boldsymbol{F}_{\text{static}}$ and $\boldsymbol{M}_{\text{static}}$ are the static contribution, and $\boldsymbol{F}_{\text{dyn}}$ and $\boldsymbol{M}_{\text{dyn}}$ the dynamic contribution, to the aerodynamic coefficients. If the dynamic characteristics are not contained in the **Digital DATCOM structure** parameter, their contribution is set to zero.

Static Stability Characteristics

Static stability characteristics include the following.

Coefficient	Meaning
C_D	Matrix of drag coefficients. These coefficients are defined positive for an aft-acting load.
C_L	Matrix of lift coefficients. These coefficients are defined positive for an up-acting load.
C_m	Matrix of pitching-moment coefficients. These coefficients are defined positive for a nose-up rotation.
$C_{Y\beta}$	Matrix of derivatives of side-force coefficients with respect to sideslip angle
$C_{n\beta}$	Matrix of derivatives of yawing-moment coefficients with respect to sideslip angle
$C_{l\beta}$	Matrix of derivatives of rolling-moment coefficients with respect to sideslip angle

These are the static contributions to the aerodynamic coefficients in stability axes.

$$C_{D\,\text{static}} = C_D$$

$$C_{y\,\text{static}} = C_{Y\beta}\beta$$

$$C_{L\,\text{static}} = C_L$$

$$C_{l\,\text{static}} = C_{l\beta}\beta$$

$$C_{m\,\text{static}} = C_M$$

$$C_{n\,\text{static}} = C_{n\beta}\beta$$

Dynamic Stability Characteristics

Dynamic stability characteristics include the following.

Coefficient	Meaning
C_{Lq}	Matrix of lift force derivatives due to pitch rate
C_{mq}	Matrix of pitching-moment derivatives due to pitch rate
$C_{Ld\alpha/dt}$	Matrix of lift force derivatives due to rate of angle of attack
$C_{md\alpha/dt}$	Matrix of pitching-moment derivatives due to rate of angle of attack

Coefficient	Meaning
C_{lp}	Matrix of rolling-moment derivatives due to roll rate
C_{Yp}	Matrix of lateral force derivatives due to roll rate
C_{np}	Matrix of yawing-moment derivatives due to roll rate
C_{nr}	Matrix of yawing-moment derivatives due to yaw rate
C_{lr}	Matrix of rolling-moment derivatives due to yaw rate

These are the dynamic contributions to the aerodynamic coefficients in stability axes.

$$C_{\mathrm{D\ dyn}} = 0$$
$$C_{\mathrm{y\ dyn}} = C_{\mathrm{yp}}p(b_{\mathrm{ref}}/2V)$$
$$C_{\mathrm{L\ dyn}} = (C_{\mathrm{L}q}q + C_{L\dot{\alpha}}\dot{\alpha})(c_{\mathrm{bar}}/2V)$$
$$C_{\mathrm{l\ dyn}} = (C_{\mathrm{lp}}p + C_{\mathrm{lr}}r)(b_{\mathrm{ref}}/2V)$$
$$C_{\mathrm{m\ dyn}} = (C_{\mathrm{mq}}q + C_{\mathrm{m}\dot{\alpha}}\dot{\alpha})(c_{\mathrm{bar}}/2V)$$
$$C_{\mathrm{n\ dyn}} = (C_{\mathrm{np}}p + C_{\mathrm{nr}}r)(b_{\mathrm{ref}}/2V)$$

Parameters

Units

Specifies the input and output units:

Units	Force	Moment	Length	Velocity	Pressure
`Metric (MKS)`	Newton	Newton-meter	Meters	Meters per second	Pascal
`English (Velocity in ft/s)`	Pound	Foot-pound	Feet	Feet per second	Pound per square inch
`English (Velocity in kts)`	Pound	Foot-pound	Feet	Knots	Pound per square inch

Digital DATCOM structure

Specifies the MATLAB structure containing the digital DATCOM data. This structure is generated by the Aerospace Toolbox function `datcomimport`. To include dynamic derivatives in the generated output file, call the `datomimport` function with the damp keyword. The Digital DATCOM Forces and Moments block supports only Digital DATCOM, which is the 1976 version of DATCOM.

For more information on creating the digital DATCOM structure, see “Importing from USAF Digital DATCOM Files” (Aerospace Toolbox). This example shows how to bring United States Air Force (USAF) Digital DATCOM files into the MATLAB environment using the Aerospace Toolbox software.

Force axes

Specifies coordinate system for aerodynamic force: `Body` or `Wind`.

Interpolation method

`None (flat)` or `Linear`

Extrapolation method

`None (clip)` or `Linear`

Process out of range input

Specifies how to handle out-of-range input: `Linear Extrapolation` or `Clip to Range`.

Action for out-of-range input

Specifies if out-of-range input invokes a warning, an error, or no action.

Inputs and Outputs

Input	Dimension Type	Description
First	Scalar	Contains the angle of attack.
Second	Scalar	Contains the sideslip angle, in radians.
Third	Scalar	Contains the Mach number.
Fourth	Scalar	Contains the altitude, in selected length units.
Fifth	Scalar	Contains the dynamic pressure, in selected pressure units.
Sixth	Three-element vector	Contains the velocity, in selected velocity units and selected force axes.

Input	Dimension Type	Description
Seventh (Optional)	Scalar	Contains the angle of attack rate, in radians per second. Appears when DAMP Control Card is used in input to Digital DATCOM.
Eight (Optional)	Three-element vector	Contains the body angular rates, in radians per second. Appears when DAMP Control Card is used in input to Digital DATCOM.
Ninth (Optional)	Scalar	Contains the ground height, in select units of length. Appears when GRNDEF Namelist is used in input to Digital DATCOM.
Tenth (Optional)		Contains the control surface deflections, radians. Appears when ASYFLP or SYMFLP and GRNDEF namelists are used in input to Digital DATCOM.

Output	Dimension Type	Description
First	Three-element vector	Contains the aerodynamic forces at the center of gravity in selected coordinate system: Body (F_x, F_y, and F_z), or Wind (F_D, F_y, and F_L).
Second	Three-element vector	Contains the aerodynamic moments at the center of gravity in body coordinates (M_x, M_y, and M_z).

Assumptions and Limitations

The operational limitations of Digital DATCOM apply to the data contained in the **Digital DATCOM structure** parameter. For more information on Digital DATCOM limitations, see Section 2.4.5 of reference [1].

The **Digital DATCOM structure** parameters `alpha`, `mach`, `alt`, `grndht`, and `delta` must be strictly monotonically increasing to be used with the Digital DATCOM Forces and Moments block.

The **Digital DATCOM structure** coefficients must correspond to the dimensions of the breakpoints (`alpha`, `mach`, `alt`, `grndht`, and `delta`) to be used with the Digital DATCOM Forces and Moments block.

References

[1] *The USAF Stability and Control Digital Datcom*, AFFDL-TR-79-3032, 1979.

[2] Etkin, B., and L. D. Reid, *Dynamics of Flight Stability and Control,* John Wiley & Sons, New York, 1996.

[3] Roskam, J., "Airplane Design Part VI: Preliminary Calculation of Aerodynamic, Thrust and Power Characteristics," Roskam Aviation and Engineering Corporation, Ottawa, Kansas, 1987.

[4] Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation,* John Wiley & Sons, New York, 1992.

Example

See "Importing from USAF Digital DATCOM Files" (Aerospace Toolbox) for an example of how to create and format DATCOM data for this block.

See `asbSkyHogg` for an example of this block.

See Also

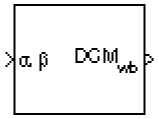
`datcomimport`

Aerodynamic Forces and Moments

Introduced in R2006b

Direction Cosine Matrix Body to Wind

Convert angle of attack and sideslip angle to direction cosine matrix



Library

Utilities/Axes Transformations

Description

The Direction Cosine Matrix Body to Wind block converts angle of attack and sideslip angle into a 3-by-3 direction cosine matrix (DCM). The DCM matrix performs the coordinate transformation of a vector in body axes (ox_0, oy_0, oz_0) into a vector in wind axes (ox_2, oy_2, oz_2). The order of the axis rotations required to bring this about is:

1. A rotation about oy_0 through the angle of attack (α) to axes (ox_1, oy_1, oz_1)
2. A rotation about oz_1 through the sideslip angle (β) to axes (ox_2, oy_2, oz_2)

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = DCM_{wb} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = \begin{bmatrix} \cos\beta & \sin\beta & 0 \\ -\sin\beta & \cos\beta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\alpha & 0 & \sin\alpha \\ 0 & 1 & 0 \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

Combining the two axis transformation matrices defines the following DCM.

$$DCM_{wb} = \begin{bmatrix} \cos\alpha\cos\beta & \sin\beta & \sin\alpha\cos\beta \\ -\cos\alpha\sin\beta & \cos\beta & -\sin\alpha\sin\beta \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix}$$

Inputs and Outputs

Input	Dimension Type	Description
First	2-by-1 vector	Contains the angle of attack and sideslip angle, in radians.

Output	Dimension Type	Description
First	3-by-3 direction cosine matrix	Transforms body-fixed vectors to wind-fixed vectors.

Reference

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

See Also

Direction Cosine Matrix Body to Wind to Alpha and Beta

Direction Cosine Matrix to Rotation Angles

Direction Cosine Matrix to Wind Angles

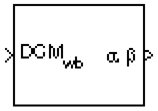
Rotation Angles to Direction Cosine Matrix

Wind Angles to Direction Cosine Matrix

Introduced before R2006a

Direction Cosine Matrix Body to Wind to Alpha and Beta

Convert direction cosine matrix to angle of attack and sideslip angle



Library

Utilities/Axes Transformations

Description

The Direction Cosine Matrix Body to Wind to Alpha and Beta block converts a 3-by-3 direction cosine matrix (DCM) into angle of attack and sideslip angle. The DCM matrix performs the coordinate transformation of a vector in body axes (ox_0, oy_0, oz_0) into a vector in wind axes (ox_2, oy_2, oz_2). The order of the axis rotations required to bring this about is:

1. A rotation about oy_0 through the angle of attack (α) to axes (ox_1, oy_1, oz_1)
2. A rotation about oz_1 through the sideslip angle (β) to axes (ox_2, oy_2, oz_2)

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = DCM_{wb} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = \begin{bmatrix} \cos\beta & \sin\beta & 0 \\ -\sin\beta & \cos\beta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\alpha & 0 & \sin\alpha \\ 0 & 1 & 0 \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

Combining the two axis transformation matrices defines the following DCM.

$$DCM_{wb} = \begin{bmatrix} \cos\alpha\cos\beta & \sin\beta & \sin\alpha\cos\beta \\ -\cos\alpha\sin\beta & \cos\beta & -\sin\alpha\sin\beta \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix}$$

To determine angles from the DCM, the following equations are used:

$$\alpha = \operatorname{asin}(-DCM(3,1))$$

$$\beta = \operatorname{asin}(DCM(1,2))$$

Parameters

Action for invalid DCM

Block behavior when direction cosine matrix is invalid (not orthogonal).

- Warning — Displays warning and indicates that the direction cosine matrix is invalid.
- Error — Displays error and indicates that the direction cosine matrix is invalid.
- None — Does not display warning or error (default).

Tolerance for DCM validation

Tolerance of direction cosine matrix validity, specified as a scalar. Default is `eps(2)`. The block considers the direction cosine matrix valid if these conditions are true:

- The transpose of the direction cosine matrix times itself equals `1` within the specified tolerance (`transpose(n)*n == 1±tolerance`)
- The determinant of the direction cosine matrix equals `1` within the specified tolerance (`det(n) == 1±tolerance`).

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-3 direction cosine matrix	Transforms body-fixed vectors to wind-fixed vectors.

Output	Dimension Type	Description
First	2-by-1 vector	Contains angle of attack and sideslip angle, in radians.

Assumptions and Limitations

This implementation generates angles that lie between ±90 degrees.

Reference

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

See Also

Direction Cosine Matrix Body to Wind

Direction Cosine Matrix to Rotation Angles

Direction Cosine Matrix to Wind Angles

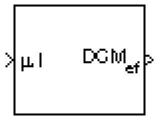
Rotation Angles to Direction Cosine Matrix

Wind Angles to Direction Cosine Matrix

Introduced before R2006a

Direction Cosine Matrix ECEF to NED

Convert geodetic latitude and longitude to direction cosine matrix



Library

Utilities/Axes Transformations

Description

The Direction Cosine Matrix ECEF to NED block converts geodetic latitude and longitude into a 3-by-3 direction cosine matrix (DCM). The DCM matrix performs the coordinate transformation of a vector in Earth-centered Earth-fixed (ECEF) axes (ox_0, oy_0, oz_0) into a vector in north-east-down (NED) axes (ox_2, oy_2, oz_2). The order of the axis rotations required to bring this about is:

1. A rotation about oz_0 through the longitude (ι) to axes (ox_1, oy_1, oz_1)
2. A rotation about oy_1 through the geodetic latitude (μ) to axes (ox_2, oy_2, oz_2)

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = DCM_{ef} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = \begin{bmatrix} -\sin\mu & 0 & \cos\mu \\ 0 & 1 & 0 \\ -\cos\mu & 0 & -\sin\mu \end{bmatrix} \begin{bmatrix} \cos\iota & \sin\iota & 0 \\ -\sin\iota & \cos\iota & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

Combining the two axis transformation matrices defines the following DCM.

$$DCM_{ef} = \begin{bmatrix} -\sin\mu\cos\iota & -\sin\mu\sin\iota & \cos\mu \\ -\sin\iota & \cos\iota & 0 \\ -\cos\mu\cos\iota & -\cos\mu\sin\iota & -\sin\mu \end{bmatrix}$$

Inputs and Outputs

Input	Dimension Type	Description
First	2-by-1 vector	Contains the geodetic latitude and longitude, in degrees. Latitude and longitude values can be any value. However, latitude values of +90 and -90 may return unexpected values because of singularity at the poles.

Output	Dimension Type	Description
First	3-by-3 direction cosine matrix	Transforms ECEF vectors to NED vectors.

Assumptions

The implementation of the ECEF coordinate system assumes that the origin is at the center of the planet, the *x*-axis intersects the Greenwich meridian and the equator, the *z*-axis is the mean spin axis of the planet, positive to the north, and the *y*-axis completes the right-hand system.

References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

Zipfel, P. H., *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA Education Series, Reston, Virginia, 2000.

“Atmospheric and Space Flight Vehicle Coordinate Systems,” ANSI/AIAA R-004-1992.

See Also

Direction Cosine Matrix ECEF to NED to Latitude and Longitude

Direction Cosine Matrix to Rotation Angles

Direction Cosine Matrix to Wind Angles

ECEF Position to LLA

Rotation Angles to Direction Cosine Matrix

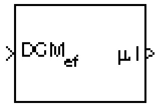
LLA to ECEF Position

Wind Angles to Direction Cosine Matrix

Introduced before R2006a

Direction Cosine Matrix ECEF to NED to Latitude and Longitude

Convert direction cosine matrix to geodetic latitude and longitude



Library

Utilities/Axes Transformations

Description

The Direction Cosine Matrix ECEF to NED to Latitude and Longitude block converts a 3-by-3 direction cosine matrix (DCM) into geodetic latitude and longitude. The DCM matrix performs the coordinate transformation of a vector in Earth-centered Earth-fixed (ECEF) axes (ox_0, oy_0, oz_0) into a vector in north-east-down (NED) axes (ox_2, oy_2, oz_2). The order of the axis rotations required to bring this about is:

1. A rotation about oz_0 through the longitude (ι) to axes (ox_1, oy_1, oz_1)
2. A rotation about oy_1 through the geodetic latitude (μ) to axes (ox_2, oy_2, oz_2)

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = DCM_{ef} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = \begin{bmatrix} -\sin\mu & 0 & \cos\mu \\ 0 & 1 & 0 \\ -\cos\mu & 0 & -\sin\mu \end{bmatrix} \begin{bmatrix} \cos\iota & \sin\iota & 0 \\ -\sin\iota & \cos\iota & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

Combining the two axis transformation matrices defines the following DCM.

$$DCM_{ef} = \begin{bmatrix} -\sin\mu\cos\iota & -\sin\mu\sin\iota & \cos\mu \\ -\sin\iota & \cos\iota & 0 \\ -\cos\mu\cos\iota & -\cos\mu\sin\iota & -\sin\mu \end{bmatrix}$$

To determine geodetic latitude and longitude from the DCM, the following equations are used:

$$\mu = \operatorname{asin}(-DCM(3,3))$$

$$\iota = \operatorname{atan}\left(\frac{-DCM(2,1)}{DCM(2,2)}\right)$$

Parameters

Action for invalid DCM

Block behavior when direction cosine matrix is invalid (not orthogonal).

- Warning — Displays warning and indicates that the direction cosine matrix is invalid.
- Error — Displays error and indicates that the direction cosine matrix is invalid.
- None — Does not display warning or error (default).

Tolerance for DCM validation

Tolerance of direction cosine matrix validity, specified as a scalar. Default is `eps(2)`. The block considers the direction cosine matrix valid if these conditions are true:

- The transpose of the direction cosine matrix times itself equals `1` within the specified tolerance (`transpose(n)*n == 1±tolerance`)
- The determinant of the direction cosine matrix equals `1` within the specified tolerance (`det(n) == 1±tolerance`).

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-3 direction cosine matrix	Transforms ECEF vectors to NED vectors.

Output	Dimension Type	Description
First	2-by-1 vector	Contains the geodetic latitude and longitude, in degrees.

Assumptions and Limitations

This implementation generates a geodetic latitude that lies between ±90 degrees, and longitude that lies between ±180 degrees.

The implementation of the ECEF coordinate system assumes that the origin is at the center of the planet, the *x*-axis intersects the Greenwich meridian and the equator, the *z*-axis is the mean spin axis of the planet, positive to the north, and the *y*-axis completes the right-hand system.

References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

Zipfel, P. H., *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA Education Series, Reston, Virginia, 2000.

“Atmospheric and Space Flight Vehicle Coordinate Systems,” ANSI/AIAA R-004-1992.

See Also

Direction Cosine Matrix ECEF to NED

Direction Cosine Matrix to Rotation Angles

Direction Cosine Matrix to Wind Angles

ECEF Position to LLA

Rotation Angles to Direction Cosine Matrix

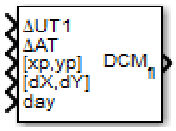
LLA to ECEF Position

Wind Angles to Direction Cosine Matrix

Introduced before R2006a

Direction Cosine Matrix ECI to ECEF

Convert Earth-centered inertial (ECI) to Earth-centered Earth-fixed (ECEF) coordinates



Library

Utilities/Axes Transformations

Description

The Direction Cosine Matrix ECI to ECEF block calculates the position direction cosine matrix (ECI to ECEF), based on the specified reduction method and Universal Coordinated Time (UTC), for the specified time and geophysical data.

Parameters

Reduction

Reduction method to calculate the direction cosine matrix. Method can be one of the following:

- `IAU-76/FK5`

  Reduce the calculation using the International Astronomical Union (IAU)-76/Fifth Fundamental Catalogue (FK5) (IAU-76/FK5) reference system. Choose this reduction method if the reference coordinate system for the conversion is FK5.

  Note This method uses the IAU 1976 precession model and the IAU 1980 theory of nutation to reduce the calculation. This model and theory are no longer current, but the software provides this reduction method for existing implementations.

Because of the polar motion approximation that this reduction method uses, the block calculates the transformation matrix rather than the direction cosine matrix.

- `IAU-2000/2006`

  Reduce the calculation using the International Astronomical Union (IAU)-2000/2006 reference system. Choose this reduction method if the reference coordinate system for the conversion is IAU-2000. This reduction method uses the P03 precession model to reduce the calculation.

Year

Specify the year used to calculate the Universal Coordinated Time (UTC) date. Enter a double value that is a whole number greater than 1, such as `2013`.

Month

Specify the month used to calculate the UTC date. From the list, select the month from `January` to `December`.

Day

Specify the day used to calculate the UTC date. From the list, select the day from `1` to `31`.

Hour

Specify the hour used to calculate the UTC date. Enter a double value that is a whole number, from `0` to `24`.

Minutes

Specify the minutes used to calculate the UTC date. Enter a double value that is a whole number, from `0` to `60`.

Seconds

Specify the seconds used to calculate the UTC date. Enter a double value that is a whole number, from `0` to `60`.

Time Increment

Specify the time increment between the specified date and the desired model simulation time. The block adjusts the calculated direction cosine matrix to take into account the time increment from model simulation. For example, selecting `Day` and connecting a simulation timer to the port means that each time increment unit is one day and the block adjusts its calculation based on that simulation time.

This parameter corresponds to the fifth block input, the clock source.

Possible values are `Day`, `Hour`, `Min`, `Sec`, and `None`. If you select `None`, the calculated Julian date does not take into account the model simulation time. Selecting this option removes the fifth block input.

Action for out-of-range input

Specify the block behavior when the block inputs are out of range.

Action	**Description**
`None`	No action.
`Warning`	Warning in the MATLAB Command Window, model simulation continues.
`Error` (default)	MATLAB returns an exception, model simulation stops.

Higher accuracy parameters

Select this check box to enable the following inputs. These inputs let you better control the conversion result. See “Inputs and Outputs” on page 4-271 for a description.

$\Delta UT1$
ΔAT
$[xp, yp]$
$[\Delta\delta\psi, \Delta\delta\varepsilon]$ or $[dX, dY]$

Inputs and Outputs

Input	**Dimension Type**	**Description**
First (Optional)	Scalar	$\Delta UT1$, difference between UTC and Universal Time (UT1) in seconds, for which the function calculates the direction cosine or transformation matrix, for example, `0.234`.
Second (Optional)	Scalar	ΔAT, difference between International Atomic Time (IAT) and UTC in seconds, for which the function calculates the direction cosine or transformation matrix, for example, `32`.

Input	Dimension Type	Description
Third (Optional)	1-by-2 array	[*xp*,*yp*], polar displacement of the Earth, in radians, from the motion of the Earth crust, along the *x*- and *y*-axes, for example, `[-0.0682e-5 0.1616e-5]`
Fourth (Optional)	1-by-2 array	• If reduction method is `IAU-2000/2006`, this input is the adjustment to the location of the Celestial Intermediate Pole (CIP), specified in radians. This location ([d*X*,d*Y*]) is along the *x*- and *y*-axis, for example, `[-0.2530e-6 -0.0188e-6]`. • If reduction method is `IAU-76/FK5`, this input is the adjustment to the longitude ([Δδψ, Δδε]), specified in radians, for example, `[-0.2530e-6 -0.0188e-6]`. For historical values, see the International Earth Rotation and Reference Systems Service Web site (`https://www.iers.org`) and navigate to the Earth Orientation Data Data/Products page.
Fifth (Optional)	Scalar	Time increment, for example the Clock block. If the **Higher accuracy parameters** check box is cleared and the **Time Increment** parameter is a value other than `None`, the block has no input.

Output	Dimension Type	Description
First	3-by-3 array	Direction cosine or transformation matrix.

See Also

Delta UT1 | ECEF Position to LLA | Earth Orientation Parameters | Geocentric to Geodetic Latitude | Geodetic to Geocentric Latitude | LLA to ECEF Position

Topics

https://www.iers.org

Introduced in R2013b

Direction Cosine Matrix to Rodrigues

Convert direction cosine matrix to Euler-Rodrigues vector
Library: Aerospace Blockset / Utilities / Axes Transformations

Description

The Direction Cosine Matrix to Rodrigues block determines the 3-by-3 direction cosine matrix from a 3-element Euler-Rodrigues vector.

Ports

Input

`DCM` — Direction cosine matrix
3-by-3 matrix

Direction cosine matrix from which to determine the Euler-Rodrigues vector.

Data Types: `double`

Output

`rod` — Euler-Rodrigues vector
3-element vector

Euler-Rodrigues vector determined from the direction cosine matrix.

Data Types: `double`

Parameters

`Action for invalid DCM` — Block behavior
None (default) | scalar

Block behavior when direction cosine matrix is invalid (not orthogonal).

- Warning — Displays warning and indicates that the direction cosine matrix is invalid.
- Error — Displays error and indicates that the direction cosine matrix is invalid.
- None — Does not display warning or error (default).

Data Types: `char` | `string`

`Tolerance for DCM validation` — Tolerance
`eps(2)` (default) | scalar

Tolerance of direction cosine matrix validity, specified as a scalar. The block considers the direction cosine matrix valid if these conditions are true:

- The transpose of the direction cosine matrix times itself equals `1` within the specified tolerance (`transpose(n)*n == 1±tolerance`)
- The determinant of the direction cosine matrix equals `1` within the specified tolerance (`det(n) == 1±tolerance`).

Data Types: `double`

Algorithms

An Euler-Rodrigues vector $\overrightarrow{b}$ represents a rotation by integrating a direction cosine of a rotation axis with the tangent of half the rotation angle as follows:

$$\overrightarrow{b} = [b_x\ b_y\ b_z]$$

where:

$$b_x = \tan\left(\frac{1}{2}\theta\right)s_x,$$

$$b_y = \tan\left(\frac{1}{2}\theta\right)s_y,$$

$$b_z = \tan\left(\frac{1}{2}\theta\right)s_z$$

are the Rodrigues parameters. Vector $\vec{s}$ represents a unit vector around which the rotation is performed. Due to the tangent, the rotation vector is indeterminate when the rotation angle equals ±pi radians or ±180 deg. Values can be negative or positive.

References

[1] Dai, J.S. "Euler-Rodrigues formula variations, quaternion conjugation and intrinsic connections." *Mechanism and Machine Theory*, 92, 144-152. Elsevier, 2015.

Extended Capabilities

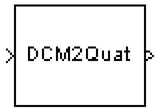
C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also
Quaternions to Rodrigues | Rodrigues to Direction Cosine Matrix | Rodrigues to Quaternions | Rodrigues to Rotation Angles | Rotation Angles to Rodrigues

Introduced in R2017a

Direction Cosine Matrix to Quaternions

Convert direction cosine matrix to quaternion vector



Library

Utilities/Axes Transformations

Description

The Direction Cosine Matrix to Quaternions block transforms a 3-by-3 direction cosine matrix (DCM) into a four-element unit quaternion vector (q_0, q_1, q_2, q_3). The DCM performs the coordinate transformation of a vector in inertial axes to a vector in body axes.

The DCM is defined as a function of a unit quaternion vector by the following:

$$DCM = \begin{bmatrix} (q_0^2 + q_1^2 - q_2^2 - q_3^2) & 2(q_1 q_2 + q_0 q_3) & 2(q_1 q_3 - q_0 q_2) \\ 2(q_1 q_2 - q_0 q_3) & (q_0^2 - q_1^2 + q_2^2 - q_3^2) & 2(q_2 q_3 + q_0 q_1) \\ 2(q_1 q_3 + q_0 q_2) & 2(q_2 q_3 - q_0 q_1) & (q_0^2 - q_1^2 - q_2^2 + q_3^2) \end{bmatrix}$$

Using this representation of the DCM, there are a number of calculations to arrive at the correct quaternion. The first of these is to calculate the trace of the DCM to determine which algorithms are used. If the trace is greater that zero, the quaternion can be automatically calculated. When the trace is less than or equal to zero, the major diagonal element of the DCM with the greatest value must be identified to determine the final algorithm used to calculate the quaternion. Once the major diagonal element is identified, the quaternion is calculated. For a detailed view of these algorithms, look under the mask of this block.

Parameters

Action for invalid DCM

Block behavior when direction cosine matrix is invalid (not orthogonal).

- Warning — Displays warning and indicates that the direction cosine matrix is invalid.
- Error — Displays error and indicates that the direction cosine matrix is invalid.
- None — Does not display warning or error (default).

Tolerance for DCM validation

Tolerance of direction cosine matrix validity, specified as a scalar. Default is `eps(2)`. The block considers the direction cosine matrix valid if these conditions are true:

- The transpose of the direction cosine matrix times itself equals `1` within the specified tolerance (`transpose(n)*n == 1±tolerance`)
- The determinant of the direction cosine matrix equals `1` within the specified tolerance (`det(n) == 1±tolerance`).

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-3 direction cosine matrix	

Output	Dimension Type	Description
First	4-by-1 quaternion vector	

See Also

Direction Cosine Matrix to Rotation Angles

Rotation Angles to Direction Cosine Matrix

Rotation Angles to Quaternions

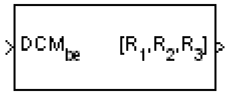
Quaternions to Direction Cosine Matrix

Quaternions to Rotation Angles

Introduced before R2006a

Direction Cosine Matrix to Rotation Angles

Convert direction cosine matrix to rotation angles



Library

Utilities/Axes Transformations

Description

The Direction Cosine Matrix to Rotation Angles block converts a 3-by-3 direction cosine matrix (DCM) into three rotation angles R1, R2, and R3, respectively the first, second, and third rotation angles. The DCM matrix performs the coordinate transformation of a vector in inertial axes into a vector in body axes. The block **Rotation Order** parameter specifies the order of the block output rotations. For example, if **Rotation Order** has a value of ZYX, the block outputs are in the rotation order *z-y-x* (psi theta phi).

Parameters

Rotation Order

Specifies the output rotation order for three rotation angles. From the list, select ZYX, ZYZ, ZXY, ZXZ, YXZ, YXY, YZX, YZY, XYZ, XYX, XZY, or XZX. The default is ZYX.

Rotation order for three wind rotation angles.

For the 'ZYX', 'ZXY', 'YXZ', 'YZX', 'XYZ', and 'XZY' rotations, the block generates an R2 angle that lies between ±pi/2 radians, and R1 and R3 angles that lie between ±pi radians.

For the 'ZYZ', 'ZXZ', 'YXY', 'YZY', 'XYX', and 'XZX' rotations, the block generates an R2 angle that lies between 0 and pi radians, and R1 and R3 angles that lie between ±pi radians. However, in the latter case, when R2 is 0 ±pi radians, R3 is set to 0 radians.

Action for invalid DCM

Block behavior when direction cosine matrix is invalid (not orthogonal).

- Warning — Displays warning and indicates that the direction cosine matrix is invalid.
- Error — Displays error and indicates that the direction cosine matrix is invalid.
- None — Does not display warning or error (default).

Tolerance for DCM validation

Tolerance of direction cosine matrix validity, specified as a scalar. Default is `eps(2)`. The block considers the direction cosine matrix valid if these conditions are true:

- The transpose of the direction cosine matrix times itself equals `1` within the specified tolerance (`transpose(n)*n == 1±tolerance`)
- The determinant of the direction cosine matrix equals `1` within the specified tolerance (`det(n) == 1±tolerance`).

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-3 matrix	Contains the direction cosine matrix.

Output	Dimension Type	Description
First	3-by-1 vector	Contains the rotation angles, in radians.

See Also

Direction Cosine Matrix to Quaternions

Quaternions to Direction Cosine Matrix

Rotation Angles to Direction Cosine Matrix

Introduced in R2007b

Direction Cosine Matrix to Wind Angles

Convert direction cosine matrix to wind angles

Library

Utilities/Axes Transformations

Description

The Direction Cosine Matrix to Wind Angles block converts a 3-by-3 direction cosine matrix (DCM) into three wind rotation angles. The DCM matrix performs the coordinate transformation of a vector in earth axes (ox_0, oy_0, oz_0) into a vector in wind axes (ox_3, oy_3, oz_3). The order of the axis rotations required to bring this about is:

1. A rotation about oz_0 through the heading angle (χ) to axes (ox_1, oy_1, oz_1)
2. A rotation about oy_1 through the flight path angle (γ) to axes (ox_2, oy_2, oz_2)
3. A rotation about ox_2 through the bank angle (μ) to axes (ox_3, oy_3, oz_3)

$$\begin{bmatrix} ox_3 \\ oy_3 \\ oz_3 \end{bmatrix} = DCM_{we} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

$$\begin{bmatrix} ox_3 \\ oy_3 \\ oz_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\mu & \sin\mu \\ 0 & -\sin\mu & \cos\mu \end{bmatrix} \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix} \begin{bmatrix} \cos\chi & \sin\chi & 0 \\ -\sin\chi & \cos\chi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

Combining the three axis transformation matrices defines the following DCM.

$$DCM_{we} = \begin{bmatrix} \cos\gamma\cos\chi & \cos\gamma\sin\chi & -\sin\gamma \\ (\sin\mu\sin\gamma\cos\chi - \cos\mu\sin\chi) & (\sin\mu\sin\gamma\sin\chi + \cos\mu\cos\chi) & \sin\mu\cos\gamma \\ (\cos\mu\sin\gamma\cos\chi + \sin\mu\sin\chi) & (\cos\mu\sin\gamma\sin\chi - \sin\mu\cos\chi) & \cos\mu\cos\gamma \end{bmatrix}$$

To determine wind angles from the DCM, the following equations are used:

$$\mu = \operatorname{atan}\left(\frac{DCM(2,3)}{DCM(3,3)}\right)$$

$$\gamma = \operatorname{asin}(-DCM(1,3))$$

$$\chi = \operatorname{atan}\left(\frac{DCM(1,2)}{DCM(1,1)}\right)$$

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-3 direction cosine matrix	Transforms earth vectors to wind vectors.

Output	Dimension Type	Description
First	3-by-1 vector	Contains the wind angles, in radians.

Assumptions and Limitations

This implementation generates a flight path angle that lies between ±90 degrees, and bank and heading angles that lie between ±180 degrees.

See Also

Direction Cosine Matrix Body to Wind

Direction Cosine Matrix Body to Wind to Alpha and Beta

Direction Cosine Matrix to Rotation Angles

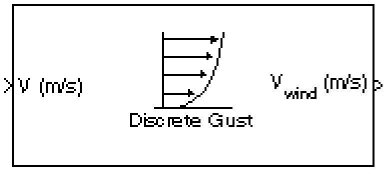
Rotation Angles to Direction Cosine Matrix

Wind Angles to Direction Cosine Matrix

Introduced before R2006a

Discrete Wind Gust Model

Generate discrete wind gust



Library

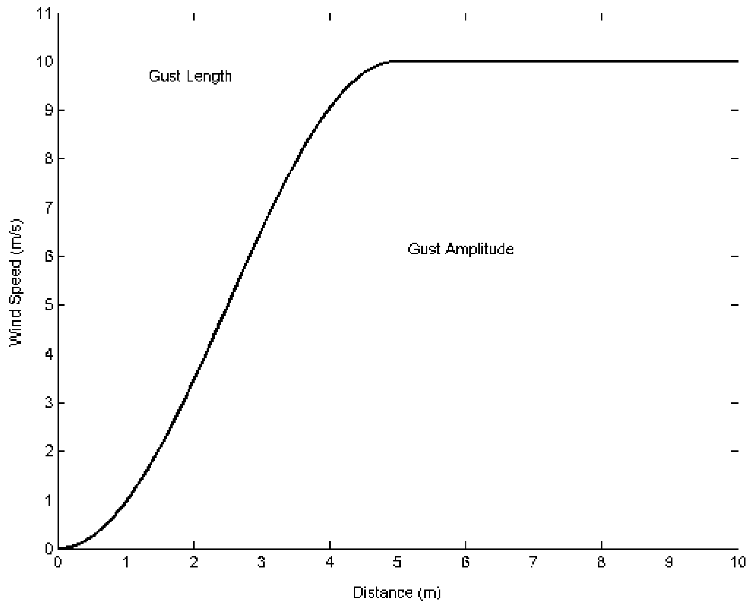
Environment/Wind

Description

The Discrete Wind Gust Model block implements a wind gust of the standard “1-cosine” shape. This block implements the mathematical representation in the Military Specification MIL-F-8785C [1]. The gust is applied to each axis individually, or to all three axes at once. You specify the gust amplitude (the increase in wind speed generated by the gust), the gust length (length, in meters, over which the gust builds up) and the gust start time.

The Discrete Wind Gust Model block can represent the wind speed in units of feet per second, meters per second, or knots.

The following figure shows the shape of the gust with a start time of zero. The parameters that govern the gust shape are indicated on the diagram.



The discrete gust can be used singly or in multiples to assess airplane response to large wind disturbances.

The mathematical representation of the discrete gust is

$$V_{wind} = \begin{cases} 0 & x < 0 \\ \frac{V_m}{2}\left(1 - \cos\left(\frac{\pi x}{d_m}\right)\right) & 0 \le x \le d_m \\ V_m & x > d_m \end{cases}$$

where V_{m} is the gust amplitude, d_{m} is the gust length, x is the distance traveled, and V_{wind} is the resultant wind velocity in the body axis frame.

Parameters

Units

Define the units of wind gust.

Units	Wind	Altitude
`Metric (MKS)`	Meters/second	Meters
`English (Velocity in ft/s)`	Feet/second	Feet
`English (Velocity in kts)`	Knots	Feet

Gust in u-axis

Select to apply the wind gust to the *u*-axis in the body frame.

Gust in v-axis

Select to apply the wind gust to the *v*-axis in the body frame.

Gust in w-axis

Select to apply the wind gust to the *w*-axis in the body frame.

Gust start time (sec)

The model time, in seconds, at which the gust begins.

Gust length [dx dy dz] (m or f)

The length, in meters or feet (depending on the choice of units), over which the gust builds up in each axis. These values must be positive.

Gust amplitude [ug vg wg] (m/s, f/s, or knots)

The magnitude of the increase in wind speed caused by the gust in each axis. These values may be positive or negative.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the airspeed in units selected.

Output	Dimension Type	Description
First		Contains the wind speed in units selected.

Examples

See `Discrete Wind Gust Model` in `aeroblk_HL20` for an example of this block.

Reference

U.S. Military Specification MIL-F-8785C, 5 November 1980.

See Also

Dryden Wind Turbulence Model (Continuous)

Dryden Wind Turbulence Model (Discrete)

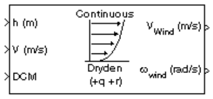
Von Karman Wind Turbulence Model (Continuous)

Wind Shear Model

Introduced before R2006a

Dryden Wind Turbulence Model (Continuous)

Generate continuous wind turbulence with Dryden velocity spectra



Library

Environment/Wind

Description

The Dryden Wind Turbulence Model (Continuous) block uses the Dryden spectral representation to add turbulence to the aerospace model by passing band-limited white noise through appropriate forming filters. This block implements the mathematical representation in the Military Specification MIL-F-8785C, Military Handbook MIL-HDBK-1797, Military Handbook MIL-HDBK-1797B.

Turbulence is a stochastic process defined by velocity spectra. For an aircraft flying at a speed V through a frozen turbulence field with a spatial frequency of Ω radians per meter, the circular frequency ω is calculated by multiplying V by Ω. MIL-F-8785C and MIL-HDBK-1797/1797B provide these definitions of longitudinal, lateral, and vertical component spectra functions:

	MIL-F-8785C	MIL-HDBK-1797 and MIL-HDBK-1797B
Longitudinal		
$\Phi_u(\omega)$	$\frac{2\sigma_u^2 L_u}{\pi V} \cdot \frac{1}{1+\left(L_u \frac{\omega}{V}\right)^2}$	$\frac{2\sigma_u^2 L_u}{\pi V} \cdot \frac{1}{1+\left(L_u \frac{\omega}{V}\right)^2}$

	MIL-F-8785C	MIL-HDBK-1797 and MIL-HDBK-1797B
$\Phi_{p_g}(\omega)$	$\frac{\sigma_w^2}{VL_w} \cdot \frac{0.8\left(\frac{\pi L_w}{4b}\right)^{1/3}}{1+\left(\frac{4b\omega}{\pi V}\right)^2}$	$\frac{\sigma_w^2}{2VL_w} \cdot \frac{0.8\left(\frac{2\pi L_w}{4b}\right)^{1/3}}{1+\left(\frac{4b\omega}{\pi V}\right)^2}$
Lateral		
$\Phi_v(\omega)$	$\frac{\sigma_v^2 L_v}{\pi V} \cdot \frac{1+3\left(L_v\frac{\omega}{V}\right)^2}{\left[1+\left(L_v\frac{\omega}{V}\right)^2\right]^2}$	$\frac{2\sigma_v^2 L_v}{\pi V} \cdot \frac{1+12\left(L_v\frac{\omega}{V}\right)^2}{\left[1+4\left(L_v\frac{\omega}{V}\right)^2\right]^2}$
$\Phi_r(\omega)$	$\frac{\mp\left(\frac{\omega}{V}\right)^2}{1+\left(\frac{3b\omega}{\pi V}\right)^2} \cdot \Phi_v(\omega)$	$\frac{\mp\left(\frac{\omega}{V}\right)^2}{1+\left(\frac{3b\omega}{\pi V}\right)^2} \cdot \Phi_v(\omega)$
Vertical		
$\Phi_w(\omega)$	$\frac{\sigma_w^2 L_w}{\pi V} \cdot \frac{1+3\left(L_w\frac{\omega}{V}\right)^2}{\left[1+\left(L_w\frac{\omega}{V}\right)^2\right]^2}$	$\frac{2\sigma_w^2 L_w}{\pi V} \cdot \frac{1+12\left(L_w\frac{\omega}{V}\right)^2}{\left[1+4\left(L_w\frac{\omega}{V}\right)^2\right]^2}$
$\Phi_q(\omega)$	$\frac{\pm\left(\frac{\omega}{V}\right)^2}{1+\left(\frac{4b\omega}{\pi V}\right)^2} \cdot \Phi_w(\omega)$	$\frac{\pm\left(\frac{\omega}{V}\right)^2}{1+\left(\frac{4b\omega}{\pi V}\right)^2} \cdot \Phi_w(\omega)$

where:

- b represents the aircraft wingspan.
- L_u, L_v, L_w represent the turbulence scale lengths.
- σ_u, σ_v, σ_w represent the turbulence intensities.

The spectral density definitions of turbulence angular rates are defined in the specifications as three variations:

$$p_g = \frac{\partial w_g}{\partial y} \qquad q_g = \frac{\partial w_g}{\partial x} \qquad r_g = -\frac{\partial v_g}{\partial x}$$

$$p_g = \frac{\partial w_g}{\partial y} \qquad q_g = \frac{\partial w_g}{\partial x} \qquad r_g = \frac{\partial v_g}{\partial x}$$

$$p_g = -\frac{\partial w_g}{\partial y} \qquad q_g = -\frac{\partial w_g}{\partial x} \qquad r_g = \frac{\partial v_g}{\partial x}$$

The variations affect only the vertical (q_g) and lateral (r_g) turbulence angular rates.

The longitudinal turbulence angular rate spectrum,

$$\Phi_{p_g}(\omega)$$

is a rational function. The rational function is derived from curve-fitting a complex algebraic function, not the vertical turbulence velocity spectrum, $\Phi_w(\omega)$, multiplied by a scale factor. The variations exist because the turbulence angular rate spectra contribute less to the aircraft gust response than the turbulence velocity.

The variations result in these combinations of vertical and lateral turbulence angular rate spectra.

Vertical	Lateral
$\Phi_q(\omega)$	$-\Phi_r(\omega)$
$\Phi_q(\omega)$	$\Phi_r(\omega)$
$-\Phi_q(\omega)$	$\Phi_r(\omega)$

To generate a signal with correct characteristics, a band-limited white noise signal is passed through forming filters. The forming filters are derived from the spectral square roots of the spectrum equations.

MIL-F-8785C and MIL-HDBK-1797/1797B provide these transfer functions:

	MIL-F-8785C	MIL-HDBK-1797 and MIL-HDBK-1797B
Longitudinal		

	MIL-F-8785C	MIL-HDBK-1797 and MIL-HDBK-1797B
$H_u(s)$	$\sigma_u\sqrt{\frac{2L_u}{\pi V}}\cdot\frac{1}{1+\frac{L_u}{V}s}$	$\sigma_u\sqrt{\frac{2L_u}{\pi V}}\cdot\frac{1}{1+\frac{L_u}{V}s}$
$H_p(s)$	$\sigma_w\sqrt{\frac{0.8}{V}}\cdot\frac{\left(\frac{\pi}{4b}\right)^{1/6}}{L_w{}^{1/3}\left(1+\left(\frac{4b}{\pi V}\right)s\right)}$	$\sigma_w\sqrt{\frac{0.8}{V}}\cdot\frac{\left(\frac{\pi}{4b}\right)^{1/6}}{(2L_w)^{1/3}\left(1+\left(\frac{4b}{\pi V}\right)s\right)}$
Lateral		
$H_v(s)$	$\sigma_v\sqrt{\frac{L_v}{\pi V}}\cdot\frac{1+\frac{\sqrt{3}L_v}{V}s}{\left(1+\frac{L_v}{V}s\right)^2}$	$\sigma_v\sqrt{\frac{2L_v}{\pi V}}\cdot\frac{1+\frac{2\sqrt{3}L_v}{V}s}{\left(1+\frac{2L_v}{V}s\right)^2}$
$H_r(s)$	$\frac{\mp\frac{s}{V}}{\left(1+\left(\frac{3b}{\pi V}\right)s\right)}\cdot H_v(s)$	$\frac{\mp\frac{s}{V}}{\left(1+\left(\frac{3b}{\pi V}\right)s\right)}\cdot H_v(s)$
Vertical		
$H_w(s)$	$\sigma_w\sqrt{\frac{L_w}{\pi V}}\cdot\frac{1+\frac{\sqrt{3}L_w}{V}s}{\left(1+\frac{L_w}{V}s\right)^2}$	$\sigma_w\sqrt{\frac{2L_w}{\pi V}}\cdot\frac{1+\frac{2\sqrt{3}L_w}{V}s}{\left(1+\frac{2L_w}{V}s\right)^2}$
$H_q(s)$	$\frac{\pm\frac{s}{V}}{\left(1+\left(\frac{4b}{\pi V}\right)s\right)}\cdot H_w(s)$	$\frac{\pm\frac{s}{V}}{\left(1+\left(\frac{4b}{\pi V}\right)s\right)}\cdot H_w(s)$

Divided into two distinct regions, the turbulence scale lengths and intensities are functions of altitude.

Note The military specifications result in the same transfer function after evaluating the turbulence scale lengths. The differences in turbulence scale lengths and turbulence transfer functions balance offset.

Low-Altitude Model (Altitude Under 1000 Feet)

According to the military references, the turbulence scale lengths at low altitudes, where h is the altitude in feet, are represented in the following table:

MIL-F-8785C	MIL-HDBK-1797 and MIL-HDBK-1797B
$L_w = h$ $L_u = L_v = \frac{h}{(0.177 + 0.000823h)^{1.2}}$	$2L_w = h$ $L_u = 2L_v = \frac{h}{(0.177 + 0.000823h)^{1.2}}$

Typically, at 20 feet (6 meters) the wind speed is 15 knots in light turbulence, 30 knots in moderate turbulence, and 45 knots for severe turbulence. See these turbulence intensities, where W_{20} is the wind speed at 20 feet (6 meters).

$$\sigma_w = 0.1W_{20}$$

$$\frac{\sigma_u}{\sigma_w} = \frac{\sigma_v}{\sigma_w} = \frac{1}{(0.177 + 0.000823h)^{0.4}}$$

The turbulence axes orientation in this region is defined:

- Longitudinal turbulence velocity, u_g, aligned along the horizontal relative mean wind vector
- Vertical turbulence velocity, w_g, aligned with vertical

At this altitude range, the output of the block is transformed into body coordinates.

Medium/High Altitudes (Altitude Above 2000 Feet)

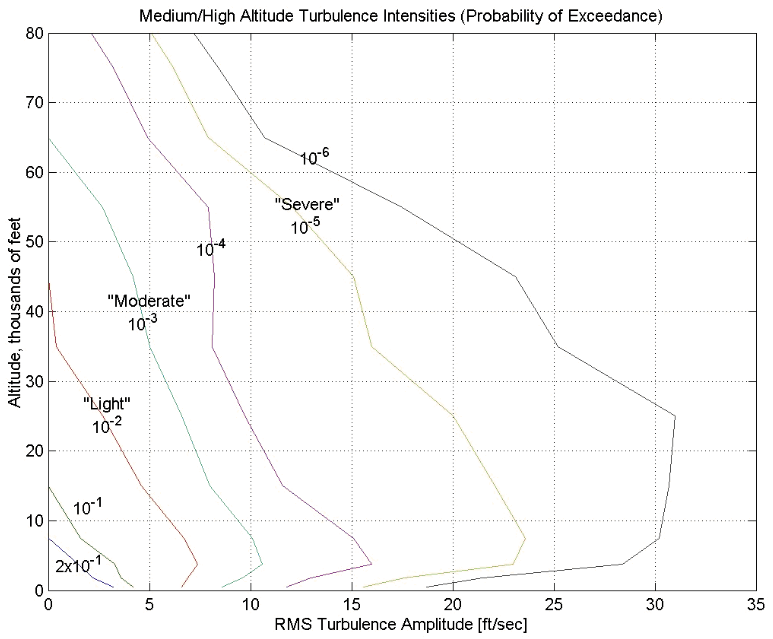
Turbulence scale lengths and intensities for medium-to-high altitudes the are based on the assumption that the turbulence is isotropic. MIL-F-8785C and MIL-HDBK-1797/1797B provide these representations of scale lengths:

MIL-F-8785C	MIL-HDBK-1797 and MIL-HDBK-1797B
$L_u = L_v = L_w = 1750$ ft	$L_u = 2L_v = 2L_w = 1750$ ft

The turbulence intensities are determined from a lookup table that provides the turbulence intensity as a function of altitude and the probability of the turbulence intensity being exceeded. The relationship of the turbulence intensities is represented in the following equation:

$\sigma_u = \sigma_v = \sigma_w$.

The turbulence axes orientation in this region is defined as being aligned with the body coordinates.



Between Low and Medium/High Altitudes (Between 1000 and 2000 Feet)

At altitudes between 1000 and 2000, the turbulence velocities and turbulence angular rates are determined by linearly interpolating between the value from the low-altitude model at 1000 feet transformed from mean horizontal wind coordinates to body coordinates and the value from the high-altitude model at 2000 feet in body coordinates.

Parameters

Units

Define the units of wind speed due to the turbulence.

Units	Wind Velocity	Altitude	Airspeed
`Metric (MKS)`	Meters/second	Meters	Meters/second
`English (Velocity in ft/s)`	Feet/second	Feet	Feet/second
`English (Velocity in kts)`	Knots	Feet	Knots

Specification

Define which military reference to use. This affects the application of turbulence scale lengths in the lateral and vertical directions.

Model type

Select the wind turbulence model to use.

`Continuous Von Karman (+q -r)`	Use continuous representation of Von Kármán velocity spectra with positive vertical and negative lateral angular rates spectra.
`Continuous Von Karman (+q +r)`	Use continuous representation of Von Kármán velocity spectra with positive vertical and lateral angular rates spectra.
`Continuous Von Karman (-q +r)`	Use continuous representation of Von Kármán velocity spectra with negative vertical and positive lateral angular rates spectra.
`Continuous Dryden (+q -r)`	Use continuous representation of Dryden velocity spectra with positive vertical and negative lateral angular rates spectra.

`Continuous Dryden (+q +r)`	Use continuous representation of Dryden velocity spectra with positive vertical and lateral angular rates spectra.
`Continuous Dryden (-q +r)`	Use continuous representation of Dryden velocity spectra with negative vertical and positive lateral angular rates spectra.
`Discrete Dryden (+q -r)`	Use discrete representation of Dryden velocity spectra with positive vertical and negative lateral angular rates spectra.
`Discrete Dryden (+q +r)`	Use discrete representation of Dryden velocity spectra with positive vertical and lateral angular rates spectra.
`Discrete Dryden (-q +r)`	Use discrete representation of Dryden velocity spectra with negative vertical and positive lateral angular rates spectra.

The Continuous Dryden selections conform to the transfer function descriptions.

Wind speed at 6 m defines the low altitude intensity

Measured wind speed at a height of 6 meters (20 feet) provides the intensity for the low-altitude turbulence model.

Wind direction at 6 m (degrees clockwise from north)

Measured wind direction at a height of 6 meters (20 feet) is an angle to aid in transforming the low-altitude turbulence model into a body coordinates.

Probability of exceedance of high-altitude intensity

Above 2000 feet, the turbulence intensity is determined from a lookup table that gives the turbulence intensity as a function of altitude and the probability of exceeding the turbulence intensity.

Scale length at medium/high altitudes (m)

Turbulence scale length above 2000 feet, assumed constant. MIL-F-8785C and MIL-HDBK-1797/1797B recommend 1750 feet for the longitudinal turbulence scale length of the Dryden spectra.

Note An alternative scale length value changes the power spectral density asymptote and gust load.

Wingspan

Wingspan required in the calculation of the turbulence on the angular rates.

Band-limited noise sample time (sec)

The sample time at which the unit variance white noise signal is generated.

Noise seeds

Four random numbers required to generate the turbulence signals, one for each of the three velocity components and one for the roll rate. The turbulences on the pitch and yaw angular rates are based on further shaping of the outputs from the shaping filters for the vertical and lateral velocities.

Turbulence on

Selecting this parameter generates the turbulence signals.

Ports

Input	Dimension Type	Description
First	scalar	Contains the altitude, in units selected.
Second	scalar	Contains the aircraft speed, in units selected.
Third	3-by-3 matrix	Contains the direction cosine matrix.

Output	Dimension Type	Description
First	Three-element signal	Contains the turbulence velocities, in the selected units.
Second	Three-element signal	Contains the turbulence angular rates, in radians per second.

Limitations

The frozen turbulence field assumption is valid for the cases of mean-wind velocity and the root-mean-square turbulence velocity, or intensity, is small relative to the aircraft ground speed.

The turbulence model describes an average of all conditions for clear air turbulence. These factors are not incorporated into the model:

- Terrain roughness
- Lapse rate
- Wind shears
- Mean wind magnitude
- Other meteorological factors

Examples

See Airframe/Environment Models/Wind Models in `aeroblk_HL20` for an example of this block.

References

Chalk, Charles, T.P. Neal, T.M. Harris, Francis E. Pritchard, and Robert J. Woodcock. *Background Information and User Guide for MIL-F-8785B(ASG), "Military Specification-Flying Qualities of Piloted Airplanes."* AD869856. Buffalo, NY: Cornell Aeronautical Laboratory, 1969.

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Yeager, Jessie, *Implementation and Testing of Turbulence Models for the F18-HARV Simulation* NASA CR-1998-206937. Hampton, VA: Lockheed Martin Engineering & Sciences, 1998.

See Also

Dryden Wind Turbulence Model (Discrete)

Discrete Wind Gust Model

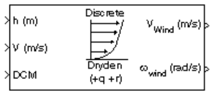
Wind Shear Model

Von Karman Wind Turbulence Model (Continuous)

Introduced before R2006a

Dryden Wind Turbulence Model (Discrete)

Generate discrete wind turbulence with Dryden velocity spectra



Library

Environment/Wind

Description

The Dryden Wind Turbulence Model (Discrete) block uses the Dryden spectral representation to add turbulence to the aerospace model by using band-limited white noise with appropriate digital filter finite difference equations. This block implements the mathematical representation in the Military Specification MIL-F-8785C, Military Handbook MIL-HDBK-1797, and Military Handbook MIL-HDBK-1797B.

According to the military references, turbulence is a stochastic process defined by velocity spectra. For an aircraft flying at a speed *V* through a frozen turbulence field with a spatial frequency of Ω radians per meter, the circular frequency ω is calculated by multiplying *V* by Ω. The following table displays the component spectra functions:

	MIL-F-8785C	**MIL-HDBK-1797 and MIL-HDBK-1797B**
Longitudinal		
$\Phi_u(\omega)$	$\frac{2\sigma_u^2 L_u}{\pi V} \cdot \frac{1}{1 + \left(L_u \frac{\omega}{V}\right)^2}$	$\frac{2\sigma_u^2 L_u}{\pi V} \cdot \frac{1}{1 + \left(L_u \frac{\omega}{V}\right)^2}$

	MIL-F-8785C	**MIL-HDBK-1797 and MIL-HDBK-1797B**
$\Phi_p(\omega)$	$\frac{\sigma_w^2}{VL_w} \cdot \frac{0.8\left(\frac{\pi L_w}{4b}\right)^{1/3}}{1 + \left(\frac{4b\omega}{\pi V}\right)^2}$	$\frac{\sigma_w^2}{2VL_w} \cdot \frac{0.8\left(\frac{2\pi L_w}{4b}\right)^{1/3}}{1 + \left(\frac{4b\omega}{\pi V}\right)^2}$
Lateral		
$\Phi_v(\omega)$	$\frac{\sigma_v^2 L_v}{\pi V} \cdot \frac{1 + 3\left(L_v\frac{\omega}{V}\right)^2}{\left[1 + \left(L_v\frac{\omega}{V}\right)^2\right]^2}$	$\frac{2\sigma_v^2 L_v}{\pi V} \cdot \frac{1 + 12\left(L_v\frac{\omega}{V}\right)^2}{\left[1 + 4\left(L_v\frac{\omega}{V}\right)^2\right]^2}$
$\Phi_r(\omega)$	$\frac{\mp\left(\frac{\omega}{V}\right)^2}{1 + \left(\frac{3b\omega}{\pi V}\right)^2} \cdot \Phi_v(\omega)$	$\frac{\mp\left(\frac{\omega}{V}\right)^2}{1 + \left(\frac{3b\omega}{\pi V}\right)^2} \cdot \Phi_v(\omega)$
Vertical		
$\Phi_w(\omega)$	$\frac{\sigma_w^2 L_w}{\pi V} \cdot \frac{1 + 3\left(L_w\frac{\omega}{V}\right)^2}{\left[1 + \left(L_w\frac{\omega}{V}\right)^2\right]^2}$	$\frac{2\sigma_w^2 L_w}{\pi V} \cdot \frac{1 + 12\left(L_w\frac{\omega}{V}\right)^2}{\left[1 + 4\left(L_w\frac{\omega}{V}\right)^2\right]^2}$
$\Phi_q(\omega)$	$\frac{\pm\left(\frac{\omega}{V}\right)^2}{1 + \left(\frac{4b\omega}{\pi V}\right)^2} \cdot \Phi_w(\omega)$	$\frac{\pm\left(\frac{\omega}{V}\right)^2}{1 + \left(\frac{4b\omega}{\pi V}\right)^2} \cdot \Phi_w(\omega)$

The variable b represents the aircraft wingspan. The variables L_u, L_v, L_w represent the turbulence scale lengths. The variables σ_u, σ_v, σ_w represent the turbulence intensities.

The spectral density definitions of turbulence angular rates are defined in the references as three variations, which are displayed in the following table:

$$p_g = \frac{\partial w_g}{\partial y} \qquad q_g = \frac{\partial w_g}{\partial x} \qquad r_g = -\frac{\partial v_g}{\partial x}$$

$$p_g = \frac{\partial w_g}{\partial y} \qquad q_g = \frac{\partial w_g}{\partial x} \qquad r_g = \frac{\partial v_g}{\partial x}$$

$$p_g = -\frac{\partial w_g}{\partial y} \qquad q_g = -\frac{\partial w_g}{\partial x} \qquad r_g = \frac{\partial v_g}{\partial x}$$

The variations affect only the vertical (q_g) and lateral (r_g) turbulence angular rates.

Keep in mind that the longitudinal turbulence angular rate spectrum, $\Phi_p(\omega)$, is a rational function. The rational function is derived from curve-fitting a complex algebraic function, not the vertical turbulence velocity spectrum, $\Phi_w(\omega)$, multiplied by a scale factor. Because the turbulence angular rate spectra contribute less to the aircraft gust response than the turbulence velocity spectra, it may explain the variations in their definitions.

The variations lead to the following combinations of vertical and lateral turbulence angular rate spectra:

Vertical	Lateral
$\Phi_q(\omega)$	$-\Phi_r(\omega)$
$\Phi_q(\omega)$	$\Phi_r(\omega)$
$-\Phi_q(\omega)$	$\Phi_r(\omega)$

To generate a signal with the correct characteristics, a unit variance, band-limited white noise signal is used in the digital filter finite difference equations.

The following table displays the digital filter finite difference equations:

	MIL-F-8785C	MIL-HDBK-1797 and MIL-HDBK-1797B
Longitudinal		
u_g	$\left(1 - \frac{V}{L_u}T\right)u_g + \sqrt{2\frac{V}{L_u}T}\frac{\sigma_u}{\sigma_\eta}\eta_1$	$\left(1 - \frac{V}{L_u}T\right)u_g + \sqrt{2\frac{V}{L_u}T}\frac{\sigma_u}{\sigma_\eta}\eta_1$

	MIL-F-8785C	**MIL-HDBK-1797 and MIL-HDBK-1797B**
p_g	$\left(1-\frac{2.6}{\sqrt{L_w b}}T\right)p_g +$ $\left(\sqrt{2\frac{2.6}{\sqrt{L_w b}}T}\right)\left(\frac{0.95}{\frac{\sqrt[3]{2L_w b^2}}{\sigma_\eta}\eta_4}\right)\sigma_w$	MIL-HDBK-1797 $\left(1-\frac{2.6}{\sqrt{2L_w b}}T\right)p_g +$ $\left(\sqrt{2\frac{2.6}{\sqrt{2L_w b}}T}\right)\left(\frac{1.9}{\frac{\sqrt{2L_w b}}{\sigma_\eta}\eta_4}\right)\sigma_w$
		MIL-HDBK-1797B $\left(1-\frac{2.6V}{\sqrt{2L_w b}}T\right)p_g +$ $\left(\sqrt{2\frac{2.6V}{\sqrt{2L_w b}}T}\right)\left(\frac{1.9}{\frac{\sqrt{2L_w b}}{\sigma_\eta}\eta_4}\right)\sigma_w$
Lateral		
v_g	$\left(1-\frac{V}{L_u}T\right)v_g+\sqrt{2\frac{V}{L_u}T}\frac{\sigma_v}{\sigma_\eta}\eta_2$	$\left(1-\frac{V}{L_u}T\right)v_g+\sqrt{2\frac{V}{L_u}T}\frac{\sigma_v}{\sigma_\eta}\eta_2$
r_g	$\left(1-\frac{\pi V}{3b}T\right)r_g \mp \frac{\pi}{3b}\left(v_g - v_{g_{past}}\right)$	$\left(1-\frac{\pi V}{3b}T\right)r_g \mp \frac{\pi}{3b}\left(v_g - v_{g_{past}}\right)$
Vertical		
w_g	$\left(1-\frac{V}{L_u}T\right)w_g+\sqrt{2\frac{V}{L_u}T}\frac{\sigma_w}{\sigma_\eta}\eta_3$	$\left(1-\frac{V}{L_u}T\right)w_g+\sqrt{2\frac{V}{L_u}T}\frac{\sigma_w}{\sigma_\eta}\eta_3$
q_g	$\left(1-\frac{\pi V}{4b}T\right)q_g \pm \frac{\pi}{4b}\left(w_g - w_{g_{past}}\right)$	$\left(1-\frac{\pi V}{4b}T\right)q_g \pm \frac{\pi}{4b}\left(w_g - w_{g_{past}}\right)$

Divided into two distinct regions, the turbulence scale lengths and intensities are functions of altitude.

Low-Altitude Model (Altitude < 1000 feet)

According to the military references, the turbulence scale lengths at low altitudes, where *h* is the altitude in feet, are represented in the following table:

MIL-F-8785C	MIL-HDBK-1797 and MIL-HDBK-1797B
$L_w = h$ $L_u = L_v = \dfrac{h}{(0.177 + 0.000823h)^{1.2}}$	$2L_w = h$ $L_u = 2L_v = \dfrac{h}{(0.177 + 0.000823h)^{1.2}}$

The turbulence intensities are given below, where W_{20} is the wind speed at 20 feet (6 m). Typically for light turbulence, the wind speed at 20 feet is 15 knots; for moderate turbulence, the wind speed is 30 knots, and for severe turbulence, the wind speed is 45 knots.

$$\sigma_w = 0.1W_{20}$$

$$\frac{\sigma_u}{\sigma_w} = \frac{\sigma_v}{\sigma_w} = \frac{1}{(0.177 + 0.000823h)^{0.4}}$$

The turbulence axes orientation in this region is defined as follows:

- Longitudinal turbulence velocity, u_g, aligned along the horizontal relative mean wind vector
- Vertical turbulence velocity, w_g, aligned with vertical.

At this altitude range, the output of the block is transformed into body coordinates.

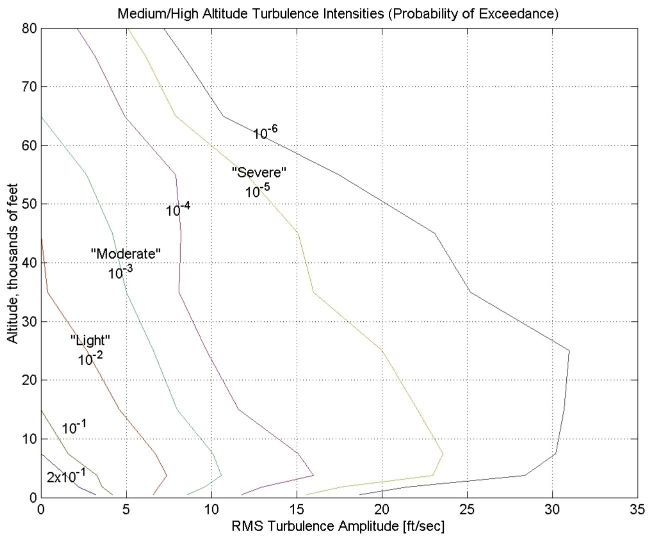
Medium/High Altitudes (Altitude > 2000 feet)

For medium to high altitudes the turbulence scale lengths and intensities are based on the assumption that the turbulence is isotropic. In the military references, the scale lengths are represented by the following equations:

MIL-F-8785C	MIL-HDBK-1797 and MIL-HDBK-1797B
$L_u = L_v = L_w = 1750$ ft	$L_u = 2L_v = 2L_w = 1750$ ft

The turbulence intensities are determined from a lookup table that provides the turbulence intensity as a function of altitude and the probability of the turbulence intensity being exceeded. The relationship of the turbulence intensities is represented in the following equation: $\sigma_u = \sigma_v = \sigma_w$.

The turbulence axes orientation in this region is defined as being aligned with the body coordinates.



Between Low and Medium/High Altitudes (1000 feet < Altitude < 2000 feet)

At altitudes between 1000 feet and 2000 feet, the turbulence velocities and turbulence angular rates are determined by linearly interpolating between the value from the low altitude model at 1000 feet transformed from mean horizontal wind coordinates to body coordinates and the value from the high altitude model at 2000 feet in body coordinates.

Parameters

Units

Define the units of wind speed due to the turbulence.

Units	Wind Velocity	Altitude	Airspeed
`Metric (MKS)`	Meters/second	Meters	Meters/ second
`English (Velocity in ft/s)`	Feet/second	Feet	Feet/second
`English (Velocity in kts)`	Knots	Feet	Knots

Specification

Define which military reference to use. This affects the application of turbulence scale lengths in the lateral and vertical directions

Model type

Select the wind turbulence model to use:

`Continuous Von Karman (+q -r)`	Use continuous representation of Von Kármán velocity spectra with positive vertical and negative lateral angular rates spectra.
`Continuous Von Karman (+q +r)`	Use continuous representation of Von Kármán velocity spectra with positive vertical and lateral angular rates spectra.
`Continuous Von Karman (-q +r)`	Use continuous representation of Von Kármán velocity spectra with negative vertical and positive lateral angular rates spectra.
`Continuous Dryden (+q -r)`	Use continuous representation of Dryden velocity spectra with positive vertical and negative lateral angular rates spectra.
`Continuous Dryden (+q +r)`	Use continuous representation of Dryden velocity spectra with positive vertical and lateral angular rates spectra.
`Continuous Dryden (-q +r)`	Use continuous representation of Dryden velocity spectra with negative vertical and positive lateral angular rates spectra.

`Discrete Dryden (+q -r)`	Use discrete representation of Dryden velocity spectra with positive vertical and negative lateral angular rates spectra.
`Discrete Dryden (+q +r)`	Use discrete representation of Dryden velocity spectra with positive vertical and lateral angular rates spectra.
`Discrete Dryden (-q +r)`	Use discrete representation of Dryden velocity spectra with negative vertical and positive lateral angular rates spectra.

The Discrete Dryden selections conform to the transfer function descriptions.

Wind speed at 6 m defines the low altitude intensity

The measured wind speed at a height of 6 meters (20 feet) provides the intensity for the low-altitude turbulence model.

Wind direction at 6 m (degrees clockwise from north)

The measured wind direction at a height of 6 meters (20 feet) is an angle to aid in transforming the low-altitude turbulence model into a body coordinates.

Probability of exceedance of high-altitude intensity

Above 2000 feet, the turbulence intensity is determined from a lookup table that gives the turbulence intensity as a function of altitude and the probability of the turbulence intensity's being exceeded.

Scale length at medium/high altitudes

The turbulence scale length above 2000 feet is assumed constant, and from the military references, a figure of 1750 feet is recommended for the longitudinal turbulence scale length of the Dryden spectra.

Note An alternate scale length value changes the power spectral density asymptote and gust load.

Wingspan

The wingspan is required in the calculation of the turbulence on the angular rates.

Band-limited noise and discrete filter sample time (sec)

The sample time at which the unit variance white noise signal is generated and at which the discrete filters are updated.

Noise seeds

There are four random numbers required to generate the turbulence signals, one for each of the three velocity components and one for the roll rate. The turbulences on the pitch and yaw angular rates are based on further shaping of the outputs from the shaping filters for the vertical and lateral velocities.

Turbulence on

Selecting the check box generates the turbulence signals.

Inputs and Outputs

Input	Dimension Type	Description
First	scalar	Contains the altitude, in units selected.
Second	scalar	Contains the aircraft speed, in units selected.
Third	3-by-3 matrix	Contains the NED direction cosine matrix.

Output	Dimension Type	Description
First	Three-element signal	Contains the turbulence velocities, in the selected units.
Second	Three-element signal	Contains the turbulence angular rates, in radians per second.

Assumptions and Limitations

The “frozen turbulence field” assumption is valid for the cases of mean-wind velocity and the root-mean-square turbulence velocity, or intensity, is small relative to the aircraft's ground speed.

The turbulence model describes an average of all conditions for clear air turbulence because the following factors are not incorporated into the model:

- Terrain roughness
- Lapse rate
- Wind shears
- Mean wind magnitude

- Other meteorological factions (except altitude)

References

U.S. Military Handbook MIL-HDBK-1797B, 9 April 2012.

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See Also

Dryden Wind Turbulence Model (Continuous)

Von Karman Wind Turbulence Model (Continuous)

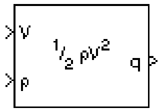
Discrete Wind Gust Model

Wind Shear Model

Introduced before R2006a

Dynamic Pressure

Compute dynamic pressure using velocity and air density



Library

Flight Parameters

Description

The Dynamic Pressure block computes dynamic pressure.

Dynamic pressure is defined as

$$\bar{q} = \frac{1}{2}\rho V^2$$

where ρ is air density and V is velocity.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the velocity.
Second		Contains the air density.

Output	Dimension Type	Description
First		Contains the dynamic pressure.

Examples

See the Airframe subsystem in `aeroblk_HL20` for an example of this block.

See Also

Aerodynamic Forces and Moments

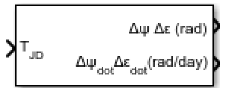
Mach Number

Introduced before R2006a

Earth Nutation

Implement Earth nutation

Library: Aerospace Blockset / Environment / Celestial Phenomena



Description

The Earth Nutation block implements the International Astronomical Union (IAU) 1980 nutation series for a given Julian date The block uses the Chebyshev coefficients that the NASA Jet Propulsion Laboratory provides.

The **Epoch** parameter controls the number of block inputs. If you select `Julian date`, the block has one input port, if you select `T0 and elapsed Julian time`, the block has two input ports.

Tip For T_{JD}, Julian date input for the block:

- Calculate the date using the Julian Date Conversion block or the Aerospace Toolbox `juliandate` function.
- Calculate the Julian date using some other means and input it using the Constant block.

Ports

Input

T_{JD} — Julian date

scalar | positive | between minimum and maximum Julian dates

Julian date, specified as a positive scalar between minimum and maximum Julian dates.

See the **Ephemeris model** parameter for the minimum and maximum Julian dates.

Dependencies

This port displays if the **Epoch** parameter is set to `Julian date`.

Data Types: `double`

$T0_{JD}$ — Fixed Julian date

scalar | positive

Fixed Julian date for a specific epoch that is the most recent midnight at or before the interpolation epoch, specified as a positive scalar. The sum of $T0_{JD}$ and ΔT_{JD} must fall between the minimum and maximum Julian dates.

See the **Ephemeris model** parameter for the minimum and maximum Julian dates.

Dependencies

This port displays if the **Epoch** parameter is set to `T0 and elapsed Julian time`.

Data Types: `double`

ΔT_{JD} — Elapsed Julian time

scalar | positive

Elapsed Julian time between the fixed Julian date and the ephemeris time, specified as a positive scalar. The sum of $T0_{JD}$ and ΔT_{JD} must fall between the minimum and maximum Julian date.

See the **Ephemeris model** parameter for the minimum and maximum Julian dates.

Dependencies

This port displays if the **Epoch** parameter is set to `T0 and elapsed Julian time`.

Data Types: `double`

Output

`Δψ Δε (rad)` — Earth nutation

vector

Earth nutation, output as a vector of longitude ($\Delta\psi$) and obliquity ($\Delta\varepsilon$), in rad.

Data Types: `double`

$\Delta\psi_{dot}$ $\Delta\varepsilon_{dot}$ (rad/day) — Earth nutation angular rate

scalar

Earth nutation angular rate for the longitude ($\Delta\psi_{dot}$) and obliquity ($\Delta\varepsilon_{dot}$), specified as a scalar in rad/day.

Dependencies

This port displays if the **Calculation rates** parameter is selected.

Data Types: `double`

Parameters

Epoch — Epoch

`Julian date` (default) | `T0 and elapsed Julian time`

Epoch, specified as:

- `Julian date`

  Julian date to calculate the Earth nutation. When this option is selected, the block has one input port, T_{JD}.
- `T0 and elapsed Julian time`

  Julian date, specified by two block inputs:

  - Fixed Julian date representing a starting epoch. The sum of fixed Julian date ($T0_{JD}$) and ΔT_{JD} must fall between the minimum and maximum Julian dates.
  - Elapsed Julian time between the $T0_{JD}$ and the desired model simulation time. The sum of $T0_{JD}$ and ΔT_{JD} must fall between the minimum and maximum Julian dates.

  T0 plus the variable elapsed time cannot exceed the maximum Julian date for the specified **Ephemeris model**.

Programmatic Use
Block Parameter: `epochflag`
Type: character vector
Values: `Julian date` | `T0 and elapsed Julian time`
Default: `'Julian date'`

Ephemeris model — Ephemeris model
DE405 (default) | DE421 | DE423 | DE430

Select an Ephemeris model from the list defined by the Jet Propulsion Laboratory:

Ephemeris Model	Description
DE405	Released in 1998. This ephemeris takes into account the Julian date range 2305424.50 (December 9, 1599) to 2525008.50 (February 20, 2201). This block implements these ephemerides with respect to the International Celestial Reference Frame version 1.0, adopted in 1998.
DE421	Released in 2008. This ephemeris takes into account the Julian date range 2414992.5 (December 4, 1899) to 2469808.5 (January 2, 2050). This block implements these ephemerides with respect to the International Celestial Reference Frame version 1.0, adopted in 1998.
DE423	Released in 2010. This ephemeris takes into account the Julian date range 2378480.5 (December 16, 1799) to 2524624.5 (February 1, 2200). This block implements these ephemerides with respect to the International Celestial Reference Frame version 2.0, adopted in 2010.
DE430	Released in 2013. This ephemeris takes into account the Julian date range 2287184.5 (December 21, 1549) to 2688976.5 (January 25, 2650). This block implements these ephemerides with respect to the International Celestial Reference Frame version 2.0, adopted in 2010.

Note This block requires that you download ephemeris data using the Add-On Explorer. To start the Add-On Explorer, in the MATLAB Command Window, type `aeroDataPackage`. on the MATLAB desktop toolstrip, click the **Add-Ons** button.

Programmatic Use
Block Parameter: `de`
Type: character vector
Values: `DE405` | `DE421` | `DE423` | `DE430`
Default: `'DE405'`

`Action for out-of-range input` — Out-of-range block behavior

`None` (default) | `Warning` | `Error`

Out-of-range block behavior, specified as follows.

Action	Description
`None`	No action.
`Warning`	Warning in the MATLAB Command Window, model simulation continues.
`Error` (default)	MATLAB returns an exception, model simulation stops.

Programmatic Use
Block Parameter: `errorflag`
Type: character vector
Values: `'None'` | `'Warning'` | `'Error'`
Default: `'Error'`

`Calculate rates` — Calculate rate of Earth nutation

`on` (default) | `off`

Calculate the rate of the Earth nutation by selecting this check box.

Dependencies

Select this check box to display the $\Delta\psi_{dot}\,\Delta\varepsilon_{dot}$ port.

Programmatic Use
Block Parameter: `velflag`
Type: character vector
Values: `'off'` | `'on'` |
Default: `'on'`

References

[1] Folkner, W. M., J. G. Williams, D. H. Boggs. "The Planetary and Lunar Ephemeris DE 421." *IPN Progress Report* 42-178, 2009.

[2] Vallado, D. A., *Fundamentals of Astrodynamics and Applications*, McGraw-Hill, New York, 1997.

See Also

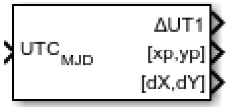
Moon Libration | Planetary Ephemeris | `aeroDataPackage`

Introduced in R2013a

Earth Orientation Parameters

Calculate Earth orientation parameters (EOP)

Library: Aerospace Blockset / Environment / Celestial Phenomena



Description

The Earth Orientation Parameters block calculates these parameters:

- Difference between the UTC and Universal Time (UT1)
- Movement of the rotation axis with respect to the crust of the Earth
- Adjustment to the location of the Celestial Intermediate Pole (CIP)

By default, this block uses a prepopulated list of International Earth Rotation and Reference Systems Service (IERS) data. This list contains measured and calculated (predicted) data supplied by the IERS. The IERS measures and calculates this data for a set of predetermined dates. For dates after those listed in the prepopulated list, Earth Orientation Parameters calculates the ΔUT1 using this equation, limiting the values to +/- 0.9 s:

```
UT1-UTC=0.5309-0.00123(MJD-57808)-(UT2-UT1)
```

Use this block when your application uses Earth Centered Inertial to Earth Centered Earth Fixed transformations, such as for high altitude applications.

Ports

Input

UTC$_{MJD}$ — UT1 for UTC
scalar

UT1 for UTC, specified as a scalar modified Julian date. Use the Julian Date Conversion block to convert the UTC date to a modified Julian date.

Data Types: `double`

Output

`ΔUT1` — Difference between UT1 and UTC
scalar

Difference between UT1 and UTC, specified as a scalar, in seconds.

Data Types: `double`

`[xp,yp]` — Polar displacement of Earth
vector

Polar displacement of the Earth, [*xp*,*yp*], specified as a vector, in radians, from the motion of the Earth crust, along the *x*- and *y*-axes.

Data Types: `double`

`[dX,dY]` — Adjustment to location of Celestial Intermediate Pole (CIP)
vector

Adjustment to the location of the Celestial Intermediate Pole (CIP), specified as a vector, in radians. This location ([d*X*,d*Y*]) is along the *x*- and *y*-axes.

Data Types: `double`

$\Delta UT1_{err}$ — Return errors for the measured and predicted values in the IERS data
vector

Return errors for the measured and predicted values in the IERS data for the difference between UT1 and UTC, specified as a vector, in seconds.

Dependencies

This port is enabled when the **Output parameter error** is selected.

$[xp,yp]_{err}$ — Return errors for the measured and predicted values in the IERS data
vector

Return errors for the measured and predicted values in the IERS data for the polar displacement of Earth, specified as a vector, in radians.

Dependencies

This port is enabled when the **Output parameter error** is selected.

`[dX,dY]`$_{err}$ — Return errors for the measured and predicted values in the IERS data
vector

Return errors for the measured and predicted values in the IERS data for the adjustment to location of Celestial Intermediate Pole (CIP), specified as a vector, in radians.

Dependencies

This port is enabled when the **Output parameter error** is selected.

Parameters

`IERS data file` — Earth orientation data
`aeroiersdata.mat` (default) | MAT-file

Custom list of Earth orientation data, specified in a MAT-file.

Programmatic Use
Block Parameter: `FileName`
Type: character vector
Values: scalar
Default: `'aeroiersdata.mat'`

`Output parameter error` — Enable output ports to return errors
`off` (default) | `on`

Select this parameter to enable output ports to return errors for the measured and predicted values in the IERS data file:

- Difference between UT1 and UTC
- Polar displacement of Earth
- Adjustment to location of Celestial Intermediate Pole (CIP)

Dependencies

Selecting this check box enables these ports:

- $\Delta UT1_{err}$
- $[xp,yp]_{err}$
- $[dX,dY]_{err}$

Programmatic Use
Block Parameter: `OutputError`
Type: character vector
Values: scalar
Default: `'off'`

`Action for out-of-range input` — Out-of-range action
Warning (default) | Error | None

Out-of-range action, specified as a string.

Action to take in case of out-of-range or predicted value dates, specified as a string:

- Warning — Displays warning and indicates that the dates were out-of-range or predicted values.
- Error — Displays error and indicates that the dates were out-of-range or predicted values.
- None — Does not display warning or error.

Programmatic Use
Block Parameter: `FileName`
Type: character vector
Values: `'Warning'` | `'Error'` | `'None'`
Default: `'Warning'`

`IERS data URL` — Website or Earth orientation data file
`http://maia.usno.navy.mil/ser7/finals2000A.data` (default) | website address | file name

Website or Earth orientation data file containing the Earth orientation data according to the IAU 2000A, specified as a website address or file name.

Programmatic Use
Block Parameter: `FileName`
Type: character vector
Values: scalar
Default: `'aeroiersdata.mat'`

`Destination folder` — Folder for IERS data file
current Folder (default)

Folder for IERS data file, specified as a character array or string. Before running this function, create *foldername* with write permission.

To create the IERS data file in the destination folder, click the **Create** button.

Programmatic Use
Block Parameter: `FileName`
Type: character vector
Values: scalar
Default: `'aeroiersdata.mat'`

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

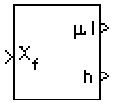
See Also

Delta UT1 | Direction Cosine Matrix ECI to ECEF | `aeroReadIERSData`

Introduced in R2018b

ECEF Position to LLA

Calculate geodetic latitude, longitude, and altitude above planetary ellipsoid from Earth-centered Earth-fixed (ECEF) position



Library

Utilities/Axes Transformations

Description

The ECEF Position to LLA block converts a 3-by-1 vector of ECEF position ($\bar{p}$) into geodetic latitude ($\bar{\mu}$), longitude ($\bar{\iota}$), and altitude $\left(\bar{h}\right)$ above the planetary ellipsoid.

The ECEF position is defined as

$$\bar{p} = \begin{bmatrix} \bar{p}_x \\ \bar{p}_y \\ \bar{p}_z \end{bmatrix}$$

Longitude is calculated from the ECEF position by

$$\iota = \operatorname{atan}\left(\frac{p_y}{p_x}\right)$$

Geodetic latitude ($\bar{\mu}$) is calculated from the ECEF position using Bowring's method, which typically converges after two or three iterations. The method begins with an initial guess for geodetic latitude ($\bar{\mu}$) and reduced latitude $\left(\bar{\beta}\right)$. An initial guess takes the form:

$$\bar{\beta} = \operatorname{atan}\left(\frac{p_z}{(1-f)s}\right)$$

$$\bar{\mu} = \operatorname{atan}\left(\frac{p_z + \frac{e^2(1-f)}{(1-e^2)}R(\sin\beta)^3}{s - e^2R(\cos\beta)^3}\right)$$

where R is the equatorial radius, f the flattening of the planet, $e^2 = 1-(1-f)^2$, the square of first eccentricity, and

$$s = \sqrt{p_x^2 + p_y^2}$$

After the initial guesses are calculated, the reduced latitude $(\bar{\beta})$ is recalculated using

$$\beta = \operatorname{atan}\left(\frac{(1-f)\sin\mu}{\cos\mu}\right)$$

and geodetic latitude $(\bar{\mu})$ is reevaluated. This last step is repeated until $\bar{\mu}$ converges.

The altitude $(\bar{h})$ above the planetary ellipsoid is calculated with

$$h = s\cos\mu + \left(p_z + e^2N\sin\mu\right)\sin\mu - N$$

where the radius of curvature in the vertical prime $(\bar{N})$ is given by

$$N = \frac{R}{\sqrt{1 - e^2(\sin\mu)^2}}$$

Parameters

Units

Specifies the parameter and output units:

Units	Position	Equatorial Radius	Altitude
`Metric (MKS)`	Meters	Meters	Meters
`English`	Feet	Feet	Feet

This option is only available when **Planet model** is set to `Earth (WGS84)`.

Planet model

Specifies the planet model to use, `Custom` or `Earth (WGS84)`.

Flattening

Specifies the flattening of the planet.

This option is available only with **Planet model** set to `Custom`.

Equatorial radius of planet

Specifies the radius of the planet at its equator. The equatorial radius units should be the same as the desired units for ECEF position.

This option is available only with **Planet model** set to `Custom`.

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-1 vector	Contains the position in ECEF frame.

Output	Dimension Type	Description
First	2-by-1 vector	Contains the geodetic latitude and longitude, in degrees.
Second	Scalar	Contains the altitude above the planetary ellipsoid, in the same units as the ECEF position.

Assumptions and Limitations

This implementation generates a geodetic latitude that lies between ±90 degrees, and longitude that lies between ±180 degrees. The planet is assumed to be ellipsoidal. By setting the flattening to 0, you model a spherical planet.

The implementation of the ECEF coordinate system assumes that its origin lies at the center of the planet, the *x*-axis intersects the prime (Greenwich) meridian and the equator, the *z*-axis is the mean spin axis of the planet (positive to the north), and the *y*-axis completes the right-handed system.

References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

Zipfel, P. H., *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA Education Series, Reston, Virginia, 2000.

"Atmospheric and Space Flight Vehicle Coordinate Systems," ANSI/AIAA R-004-1992.

See Also

See "About Aerospace Coordinate Systems" on page 2-10.

Direction Cosine Matrix ECEF to NED

Direction Cosine Matrix ECEF to NED to Latitude and Longitude

Geocentric to Geodetic Latitude

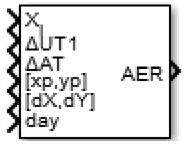
LLA to ECEF Position

Radius at Geocentric Latitude

Introduced before R2006a

ECI Position to AER

Convert Earth-centered inertial (ECI) coordinates to azimuth coordinates



Library

Utilities/Axes Transformations

Description

The ECI Position to AER block converts Earth-centered inertial (ECI) position coordinates to azimuth, elevation, and slant-range coordinates (AER), based on the geodetic position (latitude, longitude, and altitude).

- Azimuth (A) — Angle measured clockwise from true north. It ranges from 0 to 360 degrees.
- Elevation (E) — Angle between a plane perpendicular to the ellipsoid and the line that goes from the local reference to the object position. It ranges from –90 to 90 degrees.
- Slant range (R) — Straight line distance between the local reference and the object.

Parameters

Reduction

Reduction method to convert the coordinates. Select either:

- `IAU-76/FK5`

  Reduce the calculation using the International Astronomical Union 76/Fifth Fundamental Catalogue (IAU-76/FK5) reference system. Choose this reduction method if the reference coordinate system for the conversion is FK5.

Note This method uses the IAU 1976 precession model and the IAU 1980 theory of nutation to reduce the calculation. This model and theory are no longer current, but the software provides this reduction method for existing implementations. Because of the polar motion approximation that this reduction method uses, the block calculates the transformation matrix rather than the direction cosine matrix.

- `IAU-2000/2006`

  Reduce the calculation using the International Astronomical Union 2000/2006 reference system. Choose this reduction method if the reference coordinate system for the conversion is IAU-2000. This reduction method uses the P03 precession model to reduce the calculation.

Year

Specify the year used to calculate the Universal Coordinated Time (UTC) date. Enter a double value that is a whole number greater than 1, such as `2013`.

Month

Specify the month used to calculate the UTC date. From the list, select the month from `January` to `December`.

Day

Specify the day used to calculate the UTC date. From the list, select the day from `1` to `31`.

Hour

Specify the hour used to calculate the UTC date. Enter a double value that is a whole number from `0` to `24`.

Minutes

Specify the minutes used to calculate the UTC date. Enter a double value that is a whole number from `0` to `60`.

Seconds

Specify the seconds used to calculate the UTC date. Enter a double value that is a whole number from `0` to `60`.

Time Increment

Specify the time increment between the specified date and the desired model simulation time. The block adjusts the calculated direction cosine matrix to take into account the time increment from model simulation. For example, selecting `Day` and connecting a simulation timer to the port means that each time increment unit is one day. The block adjusts the calculation based on that simulation time.

This parameter corresponds to the fifth block input, the clock source.

Possible values are `Day`, `Hour`, `Min`, `Sec`, and `None`. If you select `None`, the calculated Julian date does not take into account the model simulation time. Selecting `None` removes the fifth block input.

Action for out-of-range input

Specify the block behavior when the block inputs are out of range.

Action	Description
`None`	No action.
`Warning`	Warning in the MATLAB Command Window, model simulation continues.
`Error` (default)	MATLAB returns an exception, model simulation stops.

Higher accuracy parameters

Select this check box to allow the following as block inputs. These inputs let you better control the conversion result. See “Inputs and Outputs” on page 4-336 for a description.

X_i
$\Delta UT1$
ΔAT
$[xp,yp]$
$[\Delta\delta\psi, \Delta\delta\varepsilon]$ or $[\mathrm{d}X,\mathrm{d}Y]$
day

Units

Specifies the parameter and output units.

Units	Position	Equatorial Radius	Altitude
`Metric (MKS)`	Meters	Meters	Meters
`English`	Feet	Feet	Feet

This option is available only when **Earth model** is set to `WGS84`.

Earth model

Specifies the planet model to use: `Custom` or `WGS84`.

Flattening

Specifies the flattening of the planet. This option is only available with **Earth model** set to `Custom`.

Equatorial radius

Specifies the radius of the planet at its equator. This option is only available with **Earth model** set to `Custom`.

Initial geodetic latitude and longitude [deg]

Specifies the reference location in latitude and longitude in degrees.

Angular direction of the local reference system (degrees clockwise from north)

Specifies angle for converting the flat Earth *x* and *y* coordinates to north and east coordinates, respectively. An example is the angle between the vessel and the true geodetic north.

Reference height

Specifies the reference height measured from the surface of the Earth to the flat Earth frame. It uses the same units as the ECI position. Estimate the reference height relative to the Earth frame.

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-1 element vector	*X*, position in ECI coordinates.
Second (Optional)	Scalar	Δ*UT1*, difference between UTC and Universal Time (UT1), in seconds, for which the function calculates the direction cosine or transformation matrix, for example, `0.234`.
Third (Optional)	Scalar	Δ*AT*, difference between International Atomic Time (IAT) and UTC, in seconds, for which the function calculates the direction cosine or transformation matrix, for example, `32`.
Fourth (Optional)	1-by-2 array	[*xp*,*yp*], polar displacement of the Earth, in radians, from the motion of the Earth crust, along the *x*- and *y*-axes, for example, `[-0.0682e-5 0.1616e-5]`.

Input	Dimension Type	Description
Fifth (Optional)	1-by-2 array	• If reduction method is `IAU-2000/2006`, this input is the adjustment to the location of the Celestial Intermediate Pole (CIP), specified in radians. This location ([d*X*,d*Y*]) is along the *x*- and *y*-axes, for example, `[-0.2530e-6 -0.0188e-6]`. • If reduction method is `IAU-76/FK5`, this input is the adjustment to the longitude ([Δδψ, Δδε]), specified in radians, for example, `[-0.2530e-6 -0.0188e-6]`. For historical values, see the International Earth Rotation and Reference Systems Service website (`https://www.iers.org`) and navigate to the Earth Orientation Data Data/ Products page.
Sixth	Scalar	Time increment, for example, the Clock block. If the **Higher accuracy parameters** check box is cleared and the **Time Increment** parameter is a value other than `None`, the block has no input.

Output	Dimension Type	Description
First	3-by-1 element vector	3-by-1 element vector with the local reference coordinates azimuth (degrees), elevation (degrees), and slant range (meters).

See Also

Direction Cosine Matrix ECI to ECEF | ECI Position to LLA | LLA to ECI Position

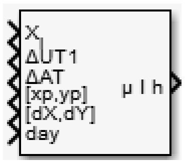
Topics

https://www.iers.org

Introduced in R2015a

ECI Position to LLA

Convert Earth-centered inertial (ECI) coordinates to geodetic latitude, longitude, altitude (LLA) coordinates



Library

Utilities/Axes Transformations

Description

The ECI Position to LLA block converts Earth-centered inertial (ECI) position coordinates to geodetic latitude, longitude, altitude (LLA) coordinates, based on the specified reduction method and Universal Coordinated Time (UTC), for the specified time and geophysical data.

Parameters

Reduction

Reduction method to convert the coordinates. Select one of the following:

- `IAU-76/FK5`

  Reduce the calculation using the International Astronomical Union (IAU)-76/Fifth Fundamental Catalogue (FK5) (IAU-76/FK5) reference system. Choose this reduction method if the reference coordinate system for the conversion is FK5.

  Note This method uses the IAU 1976 precession model and the IAU 1980 theory of nutation to reduce the calculation. This model and theory are no longer current, but the software provides this reduction method for existing implementations. Because of the polar motion approximation that this reduction method uses, the block calculates the transformation matrix rather than the direction cosine matrix.

- `IAU-2000/2006`

  Reduce the calculation using the International Astronomical Union (IAU)-2000/2006 reference system. Choose this reduction method if the reference coordinate system for the conversion is IAU-2000. This reduction method uses the P03 precession model to reduce the calculation.

Year

Specify the year used to calculate the Universal Coordinated Time (UTC) date. Enter a double value that is a whole number greater than 1, such as `2013`.

Month

Specify the month used to calculate the UTC date. From the list, select the month from `January` to `December`.

Day

Specify the day used to calculate the UTC date. From the list, select the day from `1` to `31`.

Hour

Specify the hour used to calculate the UTC date. Enter a double value that is a whole number from `0` to `24`.

Minutes

Specify the minutes used to calculate the UTC date. Enter a double value that is a whole number from `0` to `60`.

Seconds

Specify the seconds used to calculate the UTC date. Enter a double value that is a whole number from `0` to `60`.

Time Increment

Specify the time increment between the specified date and the desired model simulation time. The block adjusts the calculated direction cosine matrix to take into account the time increment from model simulation. For example, selecting `Day` and connecting a simulation timer to the port means that each time increment unit is one day. The block adjusts its calculation based on that simulation time.

This parameter corresponds to the fifth block input, the clock source.

Possible values are `Day`, `Hour`, `Min`, `Sec`, and `None`. If you select `None`, the calculated Julian date does not take into account the model simulation time. Selecting this option removes the fifth block input.

Action for out-of-range input

Specify the block behavior when the block inputs are out of range.

Action	Description
`None`	No action.
`Warning`	Warning in the MATLAB Command Window, model simulation continues.
`Error` (default)	MATLAB returns an exception, model simulation stops.

Higher accuracy parameters

Select this check box to enable the following inputs. These inputs let you better control the conversion result. See “Inputs and Outputs” on page 4-336 for a description.

X
$\Delta UT1$
ΔAT
$[xp,yp]$
$[\Delta\delta\psi, \Delta\delta\varepsilon]$ or $[\mathrm{d}X,\mathrm{d}Y]$
day

Units

Specifies the parameter and output units:

Units	Position	Equatorial Radius	Altitude
`Metric (MKS)`	Meters	Meters	Meters
`English`	Feet	Feet	Feet

This option is available only when **Planet model** is set to `Earth (WGS84)`.

Earth model

Specifies the planet model to use: `Custom` or `WGS84`.

Flattening

Specifies the flattening of the planet. This option is available only with **Earth model Custom**.

Equatorial radius

Specifies the radius of the planet at its equator. This option is available only with **Earth model Custom**.

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-1 element vector	*X*, position in ECI coordinates.
Second (Optional)	Scalar	Δ*UT1*, difference between UTC and Universal Time (UT1), in seconds, for which the function calculates the direction cosine or transformation matrix, for example, `0.234`.
Third (Optional)	Scalar	Δ*AT*, difference between International Atomic Time (IAT) and UTC, in seconds, for which the function calculates the direction cosine or transformation matrix, for example, `32`.
Fourth (Optional)	1-by-2 array	[*xp*,*yp*], polar displacement of the Earth, in radians, from the motion of the Earth crust, along the *x*- and *y*-axes, for example, `[-0.0682e-5 0.1616e-5]`.
Fifth (Optional)	1-by-2 array	• If reduction method is `IAU-2000/2006`, this input is the adjustment to the location of the Celestial Intermediate Pole (CIP), specified in radians. This location ([d*X*,d*Y*]) is along the *x*- and *y*-axes, for example, `[-0.2530e-6 -0.0188e-6]`. • If reduction method is `IAU-76/FK5`, this input is the adjustment to the longitude ([Δδψ, Δδε]), specified in radians, for example, `[-0.2530e-6 -0.0188e-6]`. For historical values, see the International Earth Rotation and Reference Systems Service website (`https://www.iers.org`) and navigate to the Earth Orientation Data Data/ Products page.

Input	Dimension Type	Description
Sixth	Scalar	Time increment, for example, the Clock block. If the **Higher accuracy parameters** check box is cleared and the **Time Increment** parameter is a value other than `None`, the block has no input.

Output	Dimension Type	Description
First	3-by-1 element vector	Original position vector in geodetic LLA coordinates, in degrees.

See Also

LLA to ECI Position

Topics

https://www.iers.org

Introduced in R2014a

EGM96 Geoid

Calculate geoid height as determined from EGM96 Geopotential Model

Library

Environment/Gravity

Description

The EGM96 Geoid block calculates the geoid height as determined from the EGM96 Geopotential Model. The block interpolates the geoid heights from a 15 minute grid of point values in the tide-free system. It uses the EGM96 Geopotential Model to degree and order 360. The geoid undulations are with respect to the WGS84 ellipsoid.

The interpolation scheme wraps over the poles to allow for geoid height calculations at and near these locations.

Parameters

Units

Specifies the parameter and output units:

Units	Height
`Metric (MKS)`	Meters
`English`	Feet

Data type

Specify the data type of the input and output signals. From the list, select `double` or `single`.

Inputs and Outputs

Input	Dimension Type	Description
First	Scalar	Contains geocentric latitude in degrees, where north latitude is positive, and south latitude is negative. Input latitude must be of type single or double. If latitude is not in the range from -90 to 90, the block wraps it to be within the range.
Second	Scalar	Contains geocentric longitude in degrees, where east longitude is positive in the range from 0 to 360. Input longitude must be of type single or double. If longitude is not in the range from 0 to 360, the block wraps it to be within the range.

Output	Dimension Type	Description
First	Scalar	Contains the geoid height, in meters.

Limitations

This block has the limitations of the 1996 Earth Geopotential Model. For more information, see `http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm96/egm96.html`.

The WGS84 EGM96 geoid undulations have an error range of +/-0.5 to +/-1.0 meters worldwide.

References

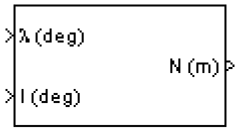
“Department of Defense World Geodetic System 1984, Its Definition and Relationship with Local Geodetic Systems”, NIMA TR8350.2.

“The Development of the Joint NASA GSFC and NIMA Geopotential Model EGM96”, NASA/TP-1998-206861.

National Geospatial-Intelligence Agency Web site: `http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm96/egm96.html`

See Also

WGS84 Gravity Model



Compatibility

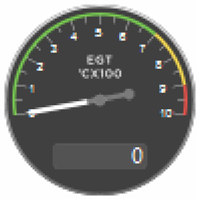
Note EGM96 Geoid will be removed in a future version. Use Geoid Height instead.

Introduced in R2007b

Exhaust Gas Temperature (EGT) Indicator

Display measurements for engine exhaust gas temperature (EGT)

Library: Aerospace Blockset / Flight Instruments



Description

The EGT Indicator block displays temperature measurements for engine exhaust gas temperature (EGT) in Celsius.

This block displays values using both:

- A needle on a gauge. A major tick is (**Maximum**-**Minimum**)/1,000 degrees, a minor tick is (**Maximum**-**Minimum**)/200 degrees Celsius.
- A numeric indicator. The operating range for the indicator goes from **Minimum** to **Maximum** degrees Celsius.

If the value of the signal is under **Minimum**, the needle displays 5 degrees under the **Minimum** value, the numeric display shows the **Minimum** value. If the value exceeds the **Maximum** value, the needle displays 5 degrees over the maximum tick, and the numeric displays the **Maximum** value.

Parameters

`Connection` — Connect to signal
signal name

Connect to signal for display, selected from list of signal names.

To view the data from a signal, select a signal in the model. The signal appears in the **Connection** table. Select the option button next to the signal you want to display. Click **Apply** to connect the signal.

The table has a row for the signal connected to the block. If there are no signals selected in the model, or the block is not connected to any signals, the table is empty.

`Minimum` — Minimum tick mark value

0 (default) | finite | real | double | scalar

Minimum tick mark value, specified as a finite, real, double, or scalar value, in ft/min.

Dependencies

The **Minimum** tick value must be less than the **Maximum** tick value.

Programmatic Use

Block Parameter: `Limits`
Type: double
Values: vector
Default: `[0 1000]`, where `0` is the minimum value

`Maximum` — Maximum tick mark value

1000 (default) | finite | real | double | scalar

Specify the maximum tick mark value, specified as a finite, real, double, or scalar value, in ft/min..

Dependencies

The **Maximum** tick value must be greater than the **Maximum** tick value.

Programmatic Use

Block Parameter: `Limits`
Type: double
Values: vector
Default: `[0 1000]`, where `1000` is the maximum value

`Scale Colors` — Ranges of color bands

0 (default) | real | double | scalar

Ranges of color bands on the outside of the scale, specified as a finite, real, double, or scalar value. Specify the minimum and maximum color range to display on the gauge.

To add a new color, click `+`. To remove a color, click `-`.

Programmatic Use
Block Parameter: `ScaleColors`
Type: *n*-by-1 struct array
Values: struct array with elements `Min`, `Max`, and `Color`

`Label` — Block label location
`Top` (default) | `Bottom` | `Hide`

Block label, displayed at the top or bottom of the block, or hidden.

- `Top`

  Show label at the top of the block.
- `Bottom`

  Show label at the bottom of the block.
- `Hide`

  Do not show the label or instructional text when the block is not connected.

Programmatic Use
Block Parameter: `LabelPosition`
Type: character vector
Values: `'Top'` | `'Bottom'` | `'Hide'`
Default: `'Top'`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

This block is ignored for code generation.

See Also

Indicator | Airspeed Indicator | Altimeter | Artificial Horizon | Climb Rate Indicator | Heading Indicator | Revolutions Per Minute (RPM) Indicator | Turn Coordinator

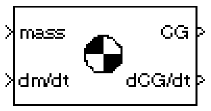
Topics

“Display Measurements with Cockpit Instruments” on page 2-49
“Programmatically Interact with Gauge Band Colors” on page 2-52
“Flight Instrument Gauges” on page 2-48

Introduced in R2016a

Estimate Center of Gravity

Calculate center of gravity location



Library

Mass Properties

Description

The Estimate Center of Gravity block calculates the center of gravity location and the rate of change of the center of gravity.

Linear interpolation is used to estimate the location of center of gravity as a function of mass. The rate of change of center of gravity is a linear function of rate of change of mass.

Parameters

Full mass

Specifies the gross mass of the craft.

Empty mass

Specifies the empty mass of the craft.

Full center of gravity

Specifies the center of gravity at gross mass of the craft.

Empty center of gravity

Specifies the center of gravity at empty mass of the craft.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the mass.
Second		Contains the rate of change of mass.

Output	Dimension Type	Description
First		Contains the center of gravity location.
Second		Contains the rate of change of center of gravity location.

See Also

Aerodynamic Forces and Moments

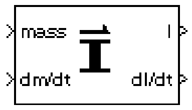
Estimate Inertia Tensor

Moments About CG Due to Forces

Introduced before R2006a

Estimate Inertia Tensor

Calculate inertia tensor



Library

Mass Properties

Description

The Estimate Inertia Tensor block calculates the inertia tensor and the rate of change of the inertia tensor.

Linear interpolation is used to estimate the inertia tensor as a function of mass. The rate of change of the inertia tensor is a linear function of rate of change of mass.

Parameters

Full mass

Specifies the gross mass of the craft.

Empty mass

Specifies the empty mass of the craft.

Full inertia matrix

Specifies the inertia tensor at gross mass of the craft.

Empty inertia matrix

Specifies the inertia tensor at empty mass of the craft.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the mass.
Second		Contains the rate of change of mass.

Output	Dimension Type	Description
First		Contains the inertia tensor.
Second		Contains the rate of change of inertia tensor.

See Also

Estimate Center of Gravity

Symmetric Inertia Tensor

Introduced before R2006a

Rodrigues to Direction Cosine Matrix

Convert Euler-Rodrigues vector to direction cosine matrix
Library: Aerospace Blockset / Utilities / Axes Transformations

Description

The Rodrigues to Direction Cosine Matrix block determines the 3-by-3 direction cosine matrix from a 3-element Euler-Rodrigues vector.

Ports

Input

`rod` — Euler-Rodrigues vector
3-element vector

Euler-Rodrigues vector from which to determine the direction cosine matrix.

Data Types: `double`

Output

`DCM` — Direction cosine matrix
3-by-3 matrix

Direction cosine matrix determined from the Euler-Rodrigues vector.

Data Types: `double`

Algorithms

An Euler-Rodrigues vector $\vec{b}$ represents a rotation by integrating a direction cosine of a rotation axis with the tangent of half the rotation angle as follows:

$$\vec{b} = [b_x \; b_y \; b_z]$$

where:

$$b_x = \tan\left(\frac{1}{2}\theta\right)s_x,$$

$$b_y = \tan\left(\frac{1}{2}\theta\right)s_y,$$

$$b_z = \tan\left(\frac{1}{2}\theta\right)s_z$$

are the Rodrigues parameters. Vector $\vec{s}$ represents a unit vector around which the rotation is performed. Due to the tangent, the rotation vector is indeterminate when the rotation angle equals ±pi radians or ±180 deg. Values can be negative or positive.

References

[1] Dai, J.S. "Euler-Rodrigues formula variations, quaternion conjugation and intrinsic connections." *Mechanism and Machine Theory*, 92, 144-152. Elsevier, 2015.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Direction Cosine Matrix to Rodrigues | Quaternions to Rodrigues | Rodrigues to Quaternions | Rodrigues to Rotation Angles | Rotation Angles to Rodrigues

Introduced in R2017a

Rodrigues to Quaternions

Convert Euler-Rodrigues vector to quaternion

Library: Aerospace Blockset / Utilities / Axes Transformations

Description

The Rodrigues to Quaternions block determines the 4-by-1 quaternion from a 3-element Euler-Rodrigues vector.

Ports

Input

`rod` — Euler-Rodrigues vector
3-element vector

Euler-Rodrigues vector from which to determine the quaternion.

Data Types: `double`

Output

`q` — Quaternion
4-by-1 matrix

Quaternion determined from the Euler-Rodrigues vector.

Data Types: `double`

Algorithms

An Euler-Rodrigues vector $\vec{b}$ represents a rotation by integrating a direction cosine of a rotation axis with the tangent of half the rotation angle as follows:

$$\vec{b} = [b_x \ b_y \ b_z]$$

where:

$$b_x = \tan\left(\frac{1}{2}\theta\right)s_x,$$

$$b_y = \tan\left(\frac{1}{2}\theta\right)s_y,$$

$$b_z = \tan\left(\frac{1}{2}\theta\right)s_z$$

are the Rodrigues parameters. Vector $\vec{s}$ represents a unit vector around which the rotation is performed. Due to the tangent, the rotation vector is indeterminate when the rotation angle equals ±pi radians or ±180 deg. Values can be negative or positive.

References

[1] Dai, J.S. "Euler-Rodrigues formula variations, quaternion conjugation and intrinsic connections." *Mechanism and Machine Theory*, 92, 144-152. Elsevier, 2015.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Direction Cosine Matrix to Rodrigues | Quaternions to Rodrigues | Rodrigues to Direction Cosine Matrix | Rodrigues to Rotation Angles | Rotation Angles to Rodrigues

Introduced in R2017a

Rodrigues to Rotation Angles

Convert Euler-Rodrigues vector to rotation angles

Library: Aerospace Blockset / Utilities / Axes Transformations

Description

The Rodrigues to Rotation Angles block converts the 3-element Euler-Rodrigues vector into rotation angles. For more information on Euler-Rodrigues vectors, see “Algorithms” on page 4-356.

Ports

Input

`rod` — Euler-Rodrigues vector
3-element vector

Euler-Rodrigues vector determined from rotation angles.

Data Types: `double`

Output

`R1,R2,R3` — Rotation angles
3-element vector

Rotation angles, in radians, from which to determine the Euler-Rodrigues vector. Quaternion scalar is the first element.

Data Types: `double`

Parameters

`Rotation order` — Rotation order
ZYX (default) | ZYZ | ZXY | ZXZ | YXZ | YXY | YZX | YZY | XYZ | XYX | XZY | XZX

Rotation order for three wind rotation angles.

For the 'ZYX', 'ZXY', 'YXZ', 'YZX', 'XYZ', and 'XZY' rotations, the block generates an R2 angle that lies between ±pi/2 radians (±90 degrees), and R1 and R3 angles that lie between ±pi radians (±180 degrees).

For the 'ZYZ', 'ZXZ', 'YXY', 'YZY', 'XYX', and 'XZX' rotations, the block generates an R2 angle that lies between 0 and pi radians (180 degrees), and R1 and R3 angles that lie between ±pi (±180 degrees). However, in the latter case, when R2 is 0, R3 is set to 0 radians.

Programmatic Use
Block Parameter: `rotationOrder`
Type: character vector
Values: `'ZYX'` | `'ZYZ'` |`'ZXY'` | `'ZXZ'` | `'YXZ'` | `'YXY'` | `'YZX'` | `'YZY'` | `'XYZ'` | `'XYX'` | `'XZY'` | `'XZX'`
Default: `'ZYX'`

Algorithms

An Euler-Rodrigues vector $\overrightarrow{b}$ represents a rotation by integrating a direction cosine of a rotation axis with the tangent of half the rotation angle as follows:

$$\overrightarrow{b} = [b_x \; b_y \; b_z]$$

where:

$$b_x = \tan\left(\frac{1}{2}\theta\right)s_x,$$

$$b_y = \tan\left(\frac{1}{2}\theta\right)s_y,$$

$$b_z = \tan\left(\frac{1}{2}\theta\right)s_z$$

are the Rodrigues parameters. Vector $\vec{s}$ represents a unit vector around which the rotation is performed. Due to the tangent, the rotation vector is indeterminate when the rotation angle equals ±pi radians or ±180 deg. Values can be negative or positive.

References

[1] Dai, J.S. "Euler-Rodrigues formula variations, quaternion conjugation and intrinsic connections." *Mechanism and Machine Theory*, 92, 144-152. Elsevier, 2015.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

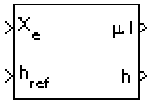
See Also

Direction Cosine Matrix to Rodrigues | Quaternions to Rodrigues | Rodrigues to Direction Cosine Matrix | Rodrigues to Quaternions | Rotation Angles to Rodrigues

Introduced in R2017a

Flat Earth to LLA

Estimate geodetic latitude, longitude, and altitude from flat Earth position



Library

Utilities/Axes Transformations

Description

The Flat Earth to LLA block converts a 3-by-1 vector of Flat Earth position($\bar{p}$) into geodetic latitude ($\bar{\mu}$), longitude ($\bar{\iota}$), and altitude (h). The flat Earth coordinate system assumes the z-axis is downward positive. The estimation begins by transforming the flat Earth x and y coordinates to North and East coordinates. The transformation has the form of

$$\begin{bmatrix} N \\ E \end{bmatrix} = \begin{bmatrix} \cos\psi & -\sin\psi \\ \sin\psi & \cos\psi \end{bmatrix} \begin{bmatrix} p_x \\ p_y \end{bmatrix}$$

where($\bar{\psi}$) is the angle in degrees clockwise between the x-axis and north.

To convert the North and East coordinates to geodetic latitude and longitude, the radius of curvature in the prime vertical (R_N) and the radius of curvature in the meridian (R_M) are used. (R_N) and (R_M) are defined by the following relationships:

$$R_N = \frac{R}{\sqrt{1-(2f-f^2)\sin^2\mu_0}}$$

$$R_M = R_N \frac{1-(2f-f^2)}{1-(2f-f^2)\sin^2\mu_0}$$

where (R) is the equatorial radius of the planet and$\left(\bar{f}\right)$ is the flattening of the planet.

Small changes in the in latitude and longitude are approximated from small changes in the North and East positions by

$$d\mu = \text{atan}\left(\frac{1}{R_M}\right)dN$$

$$d\iota = \text{atan}\left(\frac{1}{R_N\cos\mu}\right)dE$$

The output latitude and longitude are simply the initial latitude and longitude plus the small changes in latitude and longitude.

$$\mu = \mu_0 + d\mu$$

$$\iota = \iota_0 + d\iota$$

The altitude is the negative flat Earth z-axis value minus the reference height (h_{ref}).

$$h = -p_z - h_{ref}$$

Parameters

Units

Specifies the parameter and output units:

Units	Position	Equatorial Radius	Altitude
`Metric (MKS)`	Meters	Meters	Meters
`English`	Feet	Feet	Feet

This option is only available when **Planet model** is set to `Earth (WGS84)`.

Planet model

Specifies the planet model to use: `Custom` or `Earth (WGS84)`.

Flattening

Specifies the flattening of the planet. This option is only available with **Planet model** **Custom**.

Equatorial radius of planet

Specifies the radius of the planet at its equator. The units of the equatorial radius parameter should be the same as the units for flat Earth position. This option is only available with **Planet model Custom**.

Initial geodetic latitude and longitude

Specifies the reference location, in degrees of latitude and longitude, for the origin of the estimation and the origin of the flat Earth coordinate system.

Direction of flat Earth x-axis (degrees clockwise from north)

Specifies angle used for converting flat Earth x and y coordinates to North and East coordinates.

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-1 vector	Contains the position in flat Earth frame.
Second	Scalar	Contains the reference height from surface of Earth to flat Earth frame with regard to Earth frame, in same units as flat Earth position.

Output	Dimension Type	Description
First	2-by-1 vector	Contains the geodetic latitude and longitude, in degrees.
Second	Scalar	Contains the altitude above the input reference altitude, in same units as flat Earth position.

Assumptions and Limitations

This estimation method assumes the flight path and bank angle are zero.

This estimation method assumes the flat Earth *z*-axis is normal to the Earth at the initial geodetic latitude and longitude only. This method has higher accuracy over small distances from the initial geodetic latitude and longitude, and nearer to the equator. The longitude will have higher accuracy the smaller the variations in latitude. Additionally, longitude is singular at the poles.

References

Etkin, B., *Dynamics of Atmospheric Flight*, John Wiley & Sons, New York, 1972.

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, Second Edition, John Wiley & Sons, New York, 2003.

See Also

Direction Cosine Matrix ECEF to NED

Direction Cosine Matrix ECEF to NED to Latitude and Longitude

ECEF Position to LLA

Geocentric to Geodetic Latitude

LLA to ECEF Position

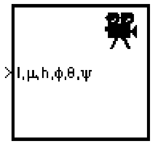
Radius at Geocentric Latitude

Introduced before R2006a

FlightGear Preconfigured 6DoF Animation

Connect model to FlightGear flight simulator

Library: Aerospace Blockset / Animation / Flight Simulator Interfaces



Description

The FlightGear Preconfigured 6DoF Animation block lets you drive position and attitude values to a FlightGear flight simulator vehicle given double-precision values for longitude (l), latitude (μ), altitude (h), roll (ϕ), pitch (θ), and yaw (ψ), respectively.

The block is configured as a sim viewing device. If you generate code for your model using Simulink Coder and connect to the running target code using external mode simulation, Simulink software can obtain the data from the target on the fly and transmit position and attitude data to FlightGear. For more information, see “Use C/C++ S-Functions as Sim Viewing Devices in External Mode” (Simulink).

This block does not produce deployable code. However, you can use it with Simulink Coder external mode as a sim viewing device.

Ports

Input

`l,μ,h,ϕ,θ,ψ` — Longitude, latitude, altitude, roll, pitch, and yaw
vector

Longitude, latitude, altitude, roll, pitch, and yaw, in double-precision, specified as a vector. Units are degrees west/north for longitude and latitude, meters above mean sea level for altitude, and radians for attitude values.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32` | `Boolean` | `fixed point` | `enumerated` | `bus`

Parameters

`FlightGear version` — FlightGear software version

`v2018.2` (default) | `v2018.1` | `v2017.3` | `v2017.1` | `v2016.3` | `v2016.1` | `v3.4` | `v3.2` | `v3.0` | `v2.12` | `v2.10` | `v2.8` | `v2.6` | `v2.4` | `v2.0`

Select your FlightGear software version from the list.

Note If you are using a FlightGear version older than 2.0, the model displays a notification from the Simulink Upgrade Advisor. Consider upgrading your FlightGear version using the Upgrade Advisor. For more information, see “Supported FlightGear Versions” on page 2-19.

Programmatic Use
Block Parameter: `xFlightGearVersion`
Type: character vector
Values: scalar
Default: `'v2018.2'`

`Destination IP address` — Destination IP address

`127.0.0.1` (default) | scalar

Destination IP address of the machine running FlightGear software, specified as a scalar.

Programmatic Use
Block Parameter: `DestinationIpAddress`
Type: character vector
Values: scalar
Default: `'127.0.0.1'`

`Destination port` — Destination port

scalar

Destination port of the machine running FlightGear software, specified as a scalar.

Programmatic Use
Block Parameter: `DestinationPort`
Type: character vector
Values: scalar
Default: `'5502'`

Sample time — Sample time
1/30 (default) | scalar

Sample time specified as a scalar (–1 for inherited).

Programmatic Use
Block Parameter: `SampleTime`
Type: character vector
Values: scalar
Default: `'1/30'`

Algorithms

The block is a masked subsystem containing principally a Pack net_fdm Packet for FlightGear block set for 6DoF inputs, a Send net_fdm Packet to FlightGear block, and a Simulation Pace block. To access the full capabilities of these blocks, use the individual corresponding blocks from the Aerospace Blockset library.

References

[1] Bowditch, N., *American Practical Navigator, An Epitome of Navigation*. US Navy Hydrographic Office, 1802.

See Also

Generate Run Script | Pack net_fdm Packet for FlightGear | Receive net_ctrl Packet from FlightGear | Send net_fdm Packet to FlightGear | Unpack net_ctrl Packet from FlightGear

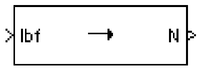
Topics

"Flight Simulator Interface" on page 2-19
"Work with the Flight Simulator Interface" on page 2-24

Introduced before R2006a

Force Conversion

Convert from force units to desired force units



Library

Utilities/Unit Conversions

Description

The Force Conversion block computes the conversion factor from specified input force units to specified output force units and applies the conversion factor to the input signal.

The Force Conversion block icon displays the input and output units selected from the **Initial unit** and the **Final unit** lists.

Parameters

Initial unit

Specifies the input units.

Final unit

Specifies the output units.

The following conversion units are available:

`lbf`	Pound force
`N`	Newtons

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the force in initial force units.

Output	Dimension Type	Description
First		Contains the force in final force units.

See Also

Acceleration Conversion

Angle Conversion

Angular Acceleration Conversion

Angular Velocity Conversion

Density Conversion

Length Conversion

Mass Conversion

Pressure Conversion

Temperature Conversion

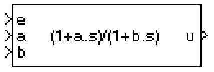
Velocity Conversion

Introduced before R2006a

Gain Scheduled Lead-Lag

Implement first-order lead-lag with gain-scheduled coefficients

Library: Aerospace Blockset / GNC / Control



Description

The Gain Scheduled Lead-Lag block implements a first-order lag of the form

$$u = \frac{1 + as}{1 + bs}e$$

where *e* is the filter input, and *u* is the filter output.

The coefficients *a* and *b* are inputs to the block. These values can depend on the flight condition or operating point. For example, you can produce them from the Lookup Table (n-D)Simulink block.

Ports

Input

e — Filter input
scalar

Filter input, specified as a scalar.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32` | `Boolean` | `fixed point` | `enumerated` | `bus`

a — Numerator coefficient
scalar

Numerator coefficient, specified as a scalar.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32` | `Boolean` | `fixed point` | `enumerated` | `bus`

b — Denominator coefficient
positive scalar

Denominator coefficient, specified as a positive scalar.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32` | `Boolean` | `fixed point` | `enumerated` | `bus`

Output

u — Filter output
scalar

Filter output, specified as a scalar.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32` | `Boolean` | `fixed point` | `enumerated` | `bus`

Parameters

`Initial state, x_initial` — Initial internal state
`0` (default) | vector

Initial internal state, specified as a vector, for the filter `x_initial`. Given this initial state, the initial output is given by

$$u|_{t\,=\,0} = \frac{x\_initial + ae}{b}$$

Programmatic Use
Block Parameter: `initial state, x_initial`
Type: character vector
Values: vector
Default: `'0'`

See Also

Lookup Table (n-D)

Introduced before R2006a

Generate Run Script

Generate FlightGear run script on current platform

Library: Aerospace Blockset / Animation / Flight Simulator Interfaces

GEN
FG
RUN

Description

The Generate Run Script block generates a customized FlightGear run script on the current platform.

To generate the run script, fill in the required information in the Parameters fields, then click **Generate Script**.

In the dialog box, fields marked with an asterisk (*) are evaluated as MATLAB expressions. The other fields are treated as literal text.

Parameters

`Select target architecture` — Target platform to run script

`Default` (default) | `Win64` | `Linux` | `Mac`

From the list, select the target platform on which you want to execute the run script. This platform can differ from the platform on which you create the run script. Select `Default` if you want to generate a run script to run on the platform from which you create the run script.

- `Win64`
- `Linux`
- `Mac`

Programmatic Use
Block Parameter: `Architecture`
Type: character vector

Values: `'Win64' | 'Linux' | 'Mac'`
Default: `'Default'`

`Select FlightGear data flow` — FlightGear data flow
`Send` (default) | `Receive` | `Send-Receive`

From the list, select the direction of the data flow:

- `Send`

  Creates the run script to set up the sending of the `net_fdm` control model from Simulink to FlightGear.
- `Receive`

  Creates the run script to set up the receiving of the `net_ctrl` control model from FlightGear to Simulink.
- `Send-Receive`

  Creates the run script to set up FlightGear to receive and broadcast data to and from Simulink.

Note Selecting the `Send-Receive` option does not mean that you receive the same data that you sent (for example, you might not see control surface position data). With this option, you see primarily user input (such as data input via joystick) and environmental data.

Programmatic Use
Block Parameter: `dataFlow`
Type: character vector
Values: `'Receive' | 'Send-Receive'`
Default: `'Send'`

`FlightGear geometry model name` — Folder containing FlightGear geometry
HL20 (default)

Specify the name of the folder containing the model geometry that you want in the *`FlightGear`*`\data\Aircraft` folder.

Programmatic Use
Block Parameter: `GeometryModelName`
Type: character vector

Values:'HL20'
Default: 'HL20'

Airport ID — ID of supported airport
KSFO (default)

ID of supported airport, selected from a list of supported airports available in the FlightGear interface, under **Location**.

Programmatic Use
Block Parameter: 'AirportId'
Type: character vector
Values:'KSFO'
Default: 'KSFO'

Runway ID — ID of supported runway
10L (default)

Specify the runway ID.

Programmatic Use
Block Parameter: RunwayId
Type: character vector
Values:'10L'
Default: '10L'

Initial altitude (ft)* — Initial aircraft altitude
7224 | MATLAB expression

Initial altitude of the aircraft, in feet. The block evaluates the value as a MATLAB expression.

Programmatic Use
Block Parameter: InitialAltitude
Type: character vector
Values:'7224'
Default: '7224'

Initial heading (deg)* — Initial aircraft heading
113 | MATLAB expression.

Initial heading of the aircraft, in degrees. The block evaluates the value as a MATLAB expression.

Programmatic Use
Block Parameter: `InitialHeading`
Type: character vector
Values:`'113'`
Default: `'113'`

`Offset distance (miles)*` — Offset distance
4.72 | MATLAB expression.

Offset distance of the aircraft from the airport, in miles. The block evaluates the value as a MATLAB expression.

Programmatic Use
Block Parameter: `OffsetDistance`
Type: character vector
Values:`'4.72'`
Default: `'4.72'`

`Offset azimuth (deg)*` — Aircraft offset azimuth
0 | MATLAB expression.

Offset azimuth of the aircraft, in degrees. The block evaluates the value as a MATLAB expression.

Programmatic Use
Block Parameter: `OffsetAzimuth`
Type: character vector
Values:`'0'`
Default: `'0'`

`Install FlightGear scenery during simulation (requires Internet connection)` — Install FlightGear scenery
`off` (default) | `on`

Select this check box to direct FlightGear to automatically install required scenery while the simulator is running. Selecting this check box requires a stable Internet connection.

Programmatic Use
Block Parameter: `InstallScenery`
Type: character vector
Values:`'off' | 'on'`
Default: `'off'`

`Disable FlightGear shader options` — Disable FlightGear shader
`off` (default) | `on`

Select this check box to disable FlightGear shader options. Your computer built-in video card, such as NVIDIA cards, can conflict with FlightGear shaders. Consider selecting this check box if you have this conflict.

Programmatic Use
Block Parameter: `DisableShaders`
Type: character vector
Values:`'off' | 'on'`
Default: `'off'`

`Destination/Origin IP address` — Network IP address of FlightGear machine
127.0.0.1

Network IP address of the machine on which the FlightGear software runs. This value is read-only.

Programmatic Use
Block Parameter: `OriginAddress`
Type: character vector
Values:`'127.0.0.1'`
Default: `'127.0.0.1'`

`Destination port` — Destination port of FlightGear machine
5502

Network flight dynamics model (fdm) port. For more information, see the Send net_fdm Packet to FlightGear block reference.

Programmatic Use
Block Parameter: `DestinationPort`
Type: character vector
Values:`'5502'`
Default: `'5502'`

`Origin port` — Origin port of FlightGear machine
5505

Network control (`ctrl`) port. For more information, see the Receive net_ctrl Packet from FlightGear block.

Programmatic Use
Block Parameter: `OriginPort`
Type: character vector
Values:`'5505'`
Default: `'5505'`

`Network IP address` — Network IP address of FlightGear machine

127.0.0.1

Network IP address of the machine on which the MATLAB software runs.

Programmatic Use
Block Parameter: `LocalAddress`
Type: character vector
Values:`'127.0.0.1'`
Default: `'127.0.0.1'`

`Output file name` — Output file

`runfg.bat`

Output file name. The file name is the name of the command that you use to start FlightGear with these initial parameters.

Note The run script file name must be composed of ASCII characters.

Use these file extensions:

Platform	Extension
Windows	`.bat`
Linux and macOS	`.sh`

Programmatic Use
Block Parameter: `OutputFileName`
Type: character vector
Values:`'runfg.bat'`
Default: `'runfg.bat'`

`FlightGear base directory` — FlightGear base directory

`C:\Program Files\FlightGear`

Specify the name of the FlightGear installation folder.

Note FlightGear must be installed in a folder path name composed of ASCII characters.

Programmatic Use
Block Parameter: `FlightGearBaseDirectory`
Type: character vector
Values:`'C:\Program Files\FlightGear'`
Default: `'C:\Program Files\FlightGear'`

`Generate Script` — Generate Script button
button

Click **Generate Script** to generate a run script for FlightGear. Do not click this button until you have entered the correct information in the dialog box parameters.

See Also

FlightGear Preconfigured 6DoF Animation | Pack net_fdm Packet for FlightGear | Receive net_ctrl Packet from FlightGear | Send net_fdm Packet to FlightGear | Unpack net_ctrl Packet from FlightGear

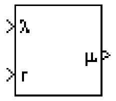
Topics

“Flight Simulator Interface” on page 2-19
“Work with the Flight Simulator Interface” on page 2-24

Introduced before R2006a

Geocentric to Geodetic Latitude

Convert geocentric latitude to geodetic latitude

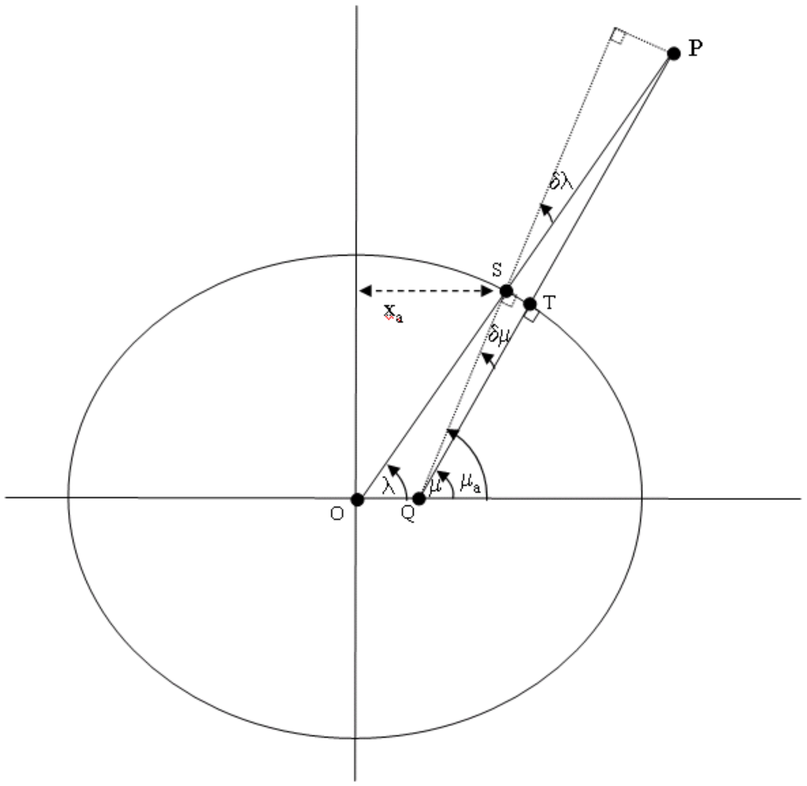


Library

Utilities/Axes Transformations

Description

The Geocentric to Geodetic Latitude block converts a geocentric latitude (λ) into geodetic latitude (μ). There are a number of geometric relationships that are used to calculate the geodetic latitude in this noniterative method. A number of angles and points are involved in the calculation, which are shown in following figure.



.

Given geocentric latitude (λ) and the radius (r) from the center of the planet (O) to the center of gravity (P), this noniterative method starts by computing values for the point of r that intercepts the surface of the planet (S). By rearranging the equation for an ellipse, the horizontal coordinate, (x_a) is determined. When equatorial radius (R), polar radius ($(1-f)R$) and $x_a\tan\lambda$, are substituted for semi-major axis, semi-minor axis and vertical coordinate (y_a), the resulting equation for x_a has the following form:

$$x_a = \frac{(1-f)R}{\sqrt{\tan^2\lambda + (1-f)^2}}$$

To determine the geodetic latitude at Sμ_a, the equation for an ellipse with equatorial radius (R), polar radius ($(1 - f)R$)is used again. This time it is used to define y_a in terms of x_a.

$$y_a = \sqrt{R^2 - x_a^2}(1 - f)$$

Additionally, the relationship between geocentric latitude at the planet's surface and geodetic latitude is used.

$$\mu_a = \operatorname{atan}\left(\frac{\tan\lambda}{(1 - f)^2}\right)$$

Using the relationship $\tan\lambda = y_a/x_a$ and the two equations above, the resulting equation for μ_a is obtained.

$$\mu_a = \operatorname{atan}\left(\frac{\sqrt{R^2 - x_a{}^2}}{(1 - f)x_a}\right)$$

The correct sign of μ_a is determined by testing λ and if λ is less than zero μ_a changes sign accordingly.

In order to calculate the geodetic latitude of P, a number of geometric relationships are required to be calculated. These calculations follow.

The radius (r_a) from the center of the planet (O) to the surface of the planet (S) is calculated by using trigonometric relationship.

$$r_a = \frac{x_a}{\cos\lambda}$$

The distance from S to P is defined by:

$$l = r - r_a$$

The angular difference between geocentric latitude and geodetic latitude at S($\delta\lambda$) is defined by:

$$\delta\lambda = \mu_a - \lambda$$

Using l and $\delta\lambda$, the segment TP or the mean sea-level altitude (h) is estimated.

$$h = l\cos\delta\lambda$$

The equation for the radius of curvature in the Meridian (ρ_a) at μ_a is

$$\rho_a = \frac{R(1-f)^2}{\left(1-(2f-f^2)\sin^2\mu_a\right)^{3/2}}$$

Using l, $\delta\lambda$, h, and ρ_a, the angular difference between geodetic latitude at S (μ)and geodetic latitude at P (μ_a)is defined as:

$$\delta\mu = \mathrm{atan}\left(\frac{l\sin\delta\lambda}{\rho_a + h}\right)$$

Subtracting $\delta\mu$ from μ_a then gives μ.

$$\mu = \mu_a - \delta\mu$$

Parameters

Units

Specifies the parameter and output units:

Units	Radius from CG to Center of Planet	Equatorial Radius
`Metric (MKS)`	Meters	Meters
`English`	Feet	Feet

This option is only available when **Planet model** is set to `Earth (WGS84)`.

Planet model

Specifies the planet model to use: `Custom` or `Earth (WGS84)`.

Flattening

Specifies the flattening of the planet. This option is only available with **Planet model** set to `Custom`.

Equatorial radius of planet

Specifies the radius of the planet at its equator. The units of the equatorial radius parameter should be the same as the units for radius. This option is only available with **Planet model** set to `Custom`.

Inputs and Outputs

Input	Dimension Type	Description
First	Scalar	Contains the geocentric latitude, in degrees. Latitude values can be any value. However, values of +90 and -90 may return unexpected values because of singularity at the poles.
Second	Scalar	Contains the radius from center of the planet to the center of gravity.

Output	Dimension Type	Description
First	Scalar	Contains the geodetic latitude, in degrees.

Assumptions and Limitations

This implementation generates a geodetic latitude that lies between ±90 degrees.

References

Jackson, E. B., *Manual for a Workstation-based Generic Flight Simulation Program (LaRCsim) Version 1.4*, NASA TM 110164, April, 1995.

Hedgley, D. R., Jr., “An Exact Transformation from Geocentric to Geodetic Coordinates for Nonzero Altitudes,” NASA TR R-458, March, 1976.

Clynch, J. R., “Radius of the Earth - Radii Used in Geodesy,” Naval Postgraduate School, 2002, http://www.oc.nps.edu/oc2902w/geodesy/radiigeo.pdf.

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

Edwards, C. H., and D. E. Penny, *Calculus and Analytical Geometry 2nd Edition*, Prentice-Hall, Englewood Cliffs, New Jersey, 1986.

See Also

ECEF Position to LLA

Flat Earth to LLA

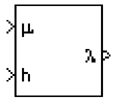
Geodetic to Geocentric Latitude

LLA to ECEF Position

Introduced before R2006a

Geodetic to Geocentric Latitude

Convert geodetic latitude to geocentric latitude



Library

Utilities/Axes Transformations

Description

The Geodetic to Geocentric Latitude block converts a geodetic latitude (μ) into geocentric latitude (λ). Geocentric latitude at the planet surface (λ_s) is defined by flattening (f), and geodetic latitude in the following relationship.

$$\lambda_s = \operatorname{atan}((1-f)^2 \tan\mu)$$

Geocentric latitude is defined by mean sea-level altitude (h), geodetic latitude, radius of the planet (r_s) and geocentric latitude at the planet surface in the following relationship.

$$\lambda = \operatorname{atan}\left(\frac{h\sin\mu + r_s\sin\lambda_s}{h\cos\mu + r_s\cos\lambda_s}\right)$$

Parameters

Units

Specifies the parameter and output units:

Units	Altitude	Equatorial Radius
`Metric (MKS)`	Meters	Meters

Units	Altitude	Equatorial Radius
`English`	Feet	Feet

This option is only available when **Planet model** is set to `Earth (WGS84)`.

Planet model

Specifies the planet model to use: `Custom` or `Earth (WGS84)`.

Flattening

Specifies the flattening of the planet. This option is only available with **Planet model** set to `Custom`.

Equatorial radius of planet

Specifies the radius of the planet at its equator. The units of the equatorial radius parameter should be the same as the units for altitude. This option is only available with **Planet model** set to `Custom`.

Inputs and Outputs

Input	Dimension Type	Description
First	Scalar	Contains the geodetic latitude, in degrees. Latitude values can be any value. However, values of +90 and -90 may return unexpected values because of singularity at the poles.
Second	Scalar	Contains the mean sea-level altitude (MSL).

Output	Dimension Type	Description
First	Scalar	Contains the geocentric latitude, in degrees.

Assumptions and Limitations

This implementation generates a geocentric latitude that lies between ±90 degrees.

Reference

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

See Also

ECEF Position to LLA

Flat Earth to LLA

Geocentric to Geodetic Latitude

LLA to ECEF Position

Radius at Geocentric Latitude

Introduced before R2006a

Heading Indicator

Display measurements for aircraft heading
Library: Aerospace Blockset / Flight Instruments

Description

The Heading Indicator block displays measurements for aircraft heading in degrees.

The block represents values between 0 and 360 degrees.

Parameters

`Connection` — Connect to signal

signal name

Connect to signal for display, selected from list of signal names.

To view the data from a signal, select a signal in the model. The signal appears in the **Connection** table. Select the option button next to the signal you want to display. Click **Apply** to connect the signal.

The table has a row for the signal connected to the block. If there are no signals selected in the model, or the block is not connected to any signals, the table is empty.

`Label` — Block label location

`Top` (default) | `Bottom` | `Hide`

Block label, displayed at the top or bottom of the block, or hidden.

- `Top`

Show label at the top of the block.

- `Bottom`

  Show label at the bottom of the block.
- `Hide`

  Do not show the label or instructional text when the block is not connected.

Programmatic Use
Block Parameter: `LabelPosition`
Type: character vector
Values: `'Top'` | `'Bottom'` | `'Hide'`
Default: `'Top'`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

This block is ignored for code generation.

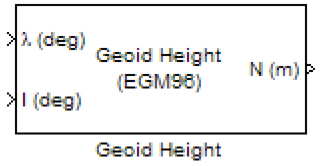
See Also
Airspeed Indicator | Altimeter | Artificial Horizon | Climb Rate Indicator | Exhaust Gas Temperature (EGT) Indicator | Revolutions Per Minute (RPM) Indicator | Turn Coordinator

Topics
“Display Measurements with Cockpit Instruments” on page 2-49
“Flight Instrument Gauges” on page 2-48

Introduced in R2016a

Geoid Height

Calculate undulations/height



Library

Environment/Gravity

Description

The Geoid Height block calculates the geoid height using the **Geopotential model** parameter. The block interpolates the geoid heights from a grid of point values in the tide-free system. It uses the specified geopotential model to degree and order 360. The geoid undulations are relative to the WGS84 ellipsoid.

The interpolation scheme wraps over the poles to allow for geoid height calculations at and near these locations.

Parameters

Units

Specifies the parameter and output units:

Units	Height
`Metric (MKS)`	Meters
`English`	Feet

Geopotential model

From the list, select the geopotential model.

Geopotential Model	Description
`EGM96 (Earth)`	Default. EGM96 Geopotential Model to degree and order 360. This model uses a 15-minute grid of point values in the tide-free system. This block calculates geoid heights to an accuracy of 0.01 m for this model.
`EGM2008 (Earth)`	EGM2008 Geopotential Model to degree and order 2159. This model uses a 2.5-minute grid of point values in the tide-free system. This block calculates geoid heights to an accuracy of 0.001 m for this model. **Note** This block requires that you download geoid data for the EGM2008 Geopotential Model with the Add-On Explorer. Click the **Get data** button to start the Add-On Explorer. For more information, see `aeroDataPackage`. If the data is installed, the **Get data** button does not appear.
`Custom`	Custom geopotential model that you define in **Geopotential mat-file**. This block calculates geoid heights to an accuracy of 0.01 m for custom models. Selecting `Custom` enables the **Geopotential mat-file** parameter.

Geopotential mat-file

Specifies the MAT-file the defines your custom geopotential model. Selecting **Geopotential model** > **Custom** enables this parameter.

Data type

Specifies the data type of the input and output signals. From the list, select `double` or `single`.

Action for out-of-range input

Defines action for out-of-range input. Specify one:

`'Error'`
`'Warning'` (default)
`'None'`

Inputs and Outputs

Input	Dimension Type	Description
First	Scalar	Contains geocentric latitude in degrees, where north latitude is positive, and south latitude is negative. Input latitude must be of type single or double. If latitude is not in the range from –90 to 90, the block wraps it to be within the range.
Second	Scalar	Contains geocentric longitude in degrees, where east longitude is positive in the range from 0 to 360. Input longitude must be of type single or double. If longitude is not in the range from 0 to 360, the block wraps it to be within the range.

Output	Dimension Type	Description
N	Scalar	Contains the geoid height in selected length units. The data type is the same as the latitude in the first input.

Limitations

This block has the limitations of the selected geopotential model.

References

Vallado, D. A. “Fundamentals of Astrodynamics and Applications.” McGraw-Hill, New York, 1997.

NIMA TR8350.2: "Department of Defense World Geodetic System 1984, Its Definition and Relationship with Local Geodetic Systems."

National Geospatial-Intelligence Agency Web site: `http://earth-info.nga.mil/GandG/publications/vertdatum.html`

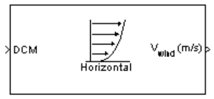
See Also

WGS84 Gravity Model, Spherical Harmonic Gravity Model

Introduced in R2010b

Horizontal Wind Model

Transform horizontal wind into body-axes coordinates



Library

Environment/Wind

Description

The Horizontal Wind Model block computes the wind velocity in body-axes coordinates.

The wind is specified by wind speed and wind direction in Earth axes. The speed and direction can be constant or variable over time. The direction of the wind is in degrees clockwise from the direction of the Earth *x*-axis (north). The wind direction is defined as the direction from which the wind is coming. Using the direction cosine matrix (DCM), the wind velocities are transformed into body-axes coordinates.

Parameters

Units

Specifies the input and output units:

Units	Wind Speed	Wind Velocity
`Metric (MKS)`	Meters per second	Meters per second
`English (Velocity in ft/s)`	Feet per second	Feet per second
`English (Velocity in kts)`	Knots	Knots

Wind speed source

Specify source of wind speed:

`External`	Variable wind speed input to block
`Internal`	Constant wind speed specified in mask

Wind speed at altitude (m/s)

Constant wind speed used if internal wind speed source is selected.

Wind direction source

Specify source of wind direction:

`External`	Variable wind direction input to block
`Internal`	Constant wind direction specified in mask

Wind direction at altitude (degrees clockwise from north)

Constant wind direction used if internal wind direction source is selected. The direction of the wind is in degrees clockwise from the direction of the Earth *x*-axis (north). The wind direction is defined as the direction from which the wind is coming.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the direction cosine matrix.
Second (Optional)		Contains the wind speed in selected units.
Third (Optional)		Contains the wind direction in degrees.

Output	Dimension Type	Description
First		Contains the wind velocity in body-axes, in selected units.

See Also

Dryden Wind Turbulence Model (Continuous)

Dryden Wind Turbulence Model (Discrete)

Discrete Wind Gust Model

Horizontal Wind Model 07

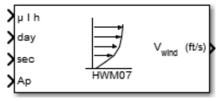
Von Karman Wind Turbulence Model (Continuous)

Wind Shear Model

Introduced before R2006a

Horizontal Wind Model 07

Implement Horizontal Wind Model 07



Library

Environment/Wind

Description

The Horizontal Wind Model 07 block implements the U.S. Naval Research Laboratory HWM™ routine to calculate the meridional and zonal components of the wind for a set of geophysical data: latitude, longitude, and altitude.

Parameters

Units

Specify the input and output units. The units you select determine the input and output wind speed and velocity, as shown in the table.

Units	Wind Speed	Wind Velocity
`Metric (MKS)`	Meters per second	Meters per second
`English (Velocity in ft/s)`	Feet per second	Feet per second
`English (Velocity in kts)`	Knots	Knots

Model

Select the horizontal wind model type for which to calculate the wind components.

- `Disturbance`

  Calculate the effect of only magnetic disturbances in the wind. For this model type, input Ap index values greater than or equal to 0.
- `Quiet`

  Calculate the horizontal wind model without the magnetic disturbances. For this model type, do not input an Ap index value.
- `Total`

  Calculate the combined effect of the quiet and magnetic disturbances. For this model type, input Ap index values greater than or equal to 0.

Action for out-of-range input

Specify the block behavior when the block inputs are out of range.

Value	Description
`None`	No action. The block imposes upper and lower limits on an input signal.
`Warning`	Warning in the Diagnostic Viewer, model simulation continues. For Accelerator and Rapid Accelerator modes, setting the action to Warning has no effect and the model behaves as though the action is set to `None`.
`Error` (default)	MATLAB returns an exception, model simulation stops. For Accelerator and Rapid Accelerator modes, setting the action to Error has no effect and the model behaves as though the action is set to `None`.

Inputs and Outputs

Input	Dimension Type	Description
First	Three-element vector of doubles	The input specifies the geodetic latitude (μ), longitude (l), and geopotential altitude (h) where the block implements the model. Latitude and longitude values are in degrees. The altitude value is in the units you selected in the **Units** parameter. Specify the altitude element as a value between 0 and 500 km.
Second	Scalar double	The input specifies the day of year in Universal Coordinated Time (UTC). The input specifies the day as a value between 1 and 366 (for a leap year).
Third	Scalar double	Contains elapsed seconds since midnight for the selected day, in UTC.
Fourth (Optional)	Scalar double	Contains the Ap index for the Universal Time (UT) when the block evaluates the model. Select the index from the NOAA National Geophysical Data Center, which contains 3 hour interval geomagnetic disturbance index values. If the Ap index value is greater than zero, the software takes into account magnetic effects during model evaluation. This input appears when you select the total or disturbance wind model type. Specify the Ap index as a value between 0 and 400. This input disappears when you select the quiet model type in the **Model** parameter.

Output	Dimension Type	Description
First	1-by-2 vector of doubles	The wind velocity vector contains the meridional and zonal wind components in that order.

Limitation

For code generation, use this block only for targets whose type is int 32 or higher.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Discrete Wind Gust Model | Dryden Wind Turbulence Model (Discrete) | Dryden Wind Turbulence Model (Continuous) | Horizontal Wind Model | Von Karman Wind Turbulence Model (Continuous) | Wind Shear Model

External Websites

NOAA National Geophysical Data Center

Introduced in R2014b

Horizontal Wind Model 14

Implement Horizontal Wind Model 14
Library: Aerospace Blockset / Environment / Wind

μ l h
day
sec
HWM14
V_wind(m/s)

Description

The Horizontal Wind Model 14 block implements the U.S. Naval Research Laboratory (HWM) routine to calculate the meridional and zonal components of the wind for a set of geophysical data: latitude, longitude, and altitude.

Limitation

For code generation, use this block only for targets whose type is int 32 or higher.

Ports

Input

`First` — geodetic latitude (μ), longitude (`l`), and geopotential altitude (`h`)
three-element vector of doubles

The input specifies the geodetic latitude (μ), longitude (`l`), and geopotential altitude (`h`) where the block implements the model.

Latitude and longitude values are in degrees.

The altitude value is in the units you selected in the **Units** parameter. Specify the altitude element as a value between 0 and 500 km.

Second — day of year
scalar double

The input specifies the day of year in Universal Coordinated Time (UTC). The input specifies the day as a value between 1 and 366 (for a leap year).

`Third` — elapsed seconds
scalar double

Contains elapsed seconds since midnight for the selected day, in UTC.

`Fourth (Optional)` — Ap index
scalar double

Contains the Ap index for the Universal Time (UT) when the block evaluates the model. Select the index from the NOAA National Geophysical Data Center, which contains 3 hour interval geomagnetic disturbance index values. If the Ap index value is greater than zero, the software takes into account magnetic effects during model evaluation.

Output

`First` — wind velocity vector
1-by-2 vector of doubles

The wind velocity vector contains the meridional and zonal wind components in that order.

Parameters

`Units` — input and output units
`Metric (MKS)` (default) | `English (Velocity in ft/s)` | `English (Velocity in kts)`

Specify the input and output units. The units you select determine the input and output wind speed and velocity, as shown in the table.

Units	Wind Speed	Wind Velocity
`Metric (MKS)`	Meters per second	Meters per second
`English (Velocity in ft/s)`	Feet per second	Feet per second
`English (Velocity in kts)`	Knots	Knots

Model — horizontal wind model

Quiet (default) | Total | Disturbance

Select the horizontal wind model type for which to calculate the wind components.

- Quiet

  Calculate the horizontal wind model without the magnetic disturbances. For this model type, do not input an Ap index value.
- Total

  Calculate the combined effect of the quiet and magnetic disturbances. For this model type, input Ap index values greater than or equal to zero.
- Disturbance

  Calculate the effect of magnetic disturbances in the wind. For this model type, input Ap index values greater than or equal to zero.

Action for out-of-range input — block behavior

Error (default) | Warning | None

Specify the block behavior when the block inputs are out of range.

Value	Description
Error (default)	MATLAB returns an exception, and model simulation stops. For Accelerator and Rapid Accelerator modes, setting the action to Error has no effect and the model behaves as though the action is set to None.
Warning	Warning in the Diagnostic Viewer, and model simulation continues. For Accelerator and Rapid Accelerator modes, setting the action to Warning has no effect and the model behaves as though the action is set to None.
None	No action. The block imposes upper and lower limits on an input signal.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

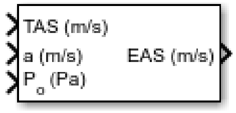
External Websites

NOAA National Geophysical Data Center

Introduced in R2016b

Ideal Airspeed Correction

Calculate equivalent airspeed (EAS), calibrated airspeed (CAS), or true airspeed (TAS) from each other



Library

Flight Parameters

Description

The Ideal Airspeed Correction block calculates one of these airspeeds from one of the other two airspeeds:

- Equivalent airspeed (EAS)
- Calibrated airspeed (CAS)
- True airspeed (TAS)

Parameters

Units

Specifies the input and output units:

Units	Airspeed Input	Speed of Sound	Air Pressure	Airspeed Output
`Metric (MKS)`	Meters per second	Meters per second	Pascal	Meters per second

Units	Airspeed Input	Speed of Sound	Air Pressure	Airspeed Output
`English (Velocity in ft/s)`	Feet per second	Feet per second	Pound force per square inch	Feet per second
`English (Velocity in kts)`	Knots	Knots	Pound force per square inch	Knots

Airspeed input

Specify the airspeed input type:

`TAS`	True airspeed
`EAS`	Equivalent airspeed
`CAS`	Calibrated airspeed

Airspeed output

Specify the airspeed output type:

Velocity Input	Velocity Output
`TAS`	EAS (equivalent airspeed)
	CAS (calibrated airspeed)
`EAS`	TAS (true airspeed)
	CAS (calibrated airspeed)
`CAS`	TAS (true airspeed)
	EAS (equivalent airspeed)

Method

Specify a method for computing the conversion factor. The block might generate associated lookup table data depending on the setting of the **Subsonic airspeeds only** check box.

`Table Lookup`	(Default) Generate output airspeed by looking up or estimating table values based on block inputs. If the **Subsonic airspeeds only** check box is selected, the Ideal Airspeed Correction block generates code that includes subsonic (Mach < 1) lookup table data. If the **Subsonic airspeeds only** check box is cleared, the Ideal Airspeed Correction block generates code that includes all (Mach < 5) lookup table data. Beyond Mach 5, use the `Equation` method. The `Table Lookup` method is not recommended for either of these instances: • Speed of sound less than 200 m/s or greater than 350 m/s. • Static pressure less than 1000 Pa or greater than 106,500 Pa. Using the `Table Lookup` method in these instances causes inaccuracies.
`Equation`	Compute output airspeed directly using block input values. Calculations involving supersonic airspeeds (greater than Mach 1) require an iterative computation. If the function does not find a solution within 30 iterations, it displays an error message. The block does not include lookup table data in generated code.

The Ideal Airspeed Correction block automatically uses the `Equation` method for any of these instances:

- Conversion with **Airspeed input** set to `TAS` and **Airspeed output** set to `EAS`.
- Conversion with **Airspeed input** set to `EAS` and **Airspeed output** set to `TAS`.
- Conversion with block input airspeed is greater than five times the speed of sound at sea level (approximately 1700 m/s).

Subsonic airspeeds only

Select this check box to use this block only with subsonic airspeed (airspeeds less than Mach 1) applications. Selecting this check box may improve performance.

The block generates code as follows:

- If this check box is selected, the Ideal Airspeed Correction block generates code that includes subsonic (Mach < 1) lookup table data if **Method** is set to `Table Lookup`.

  Selecting this check box displays the **Action for out-of-range input** parameter.
- If this check box is cleared, the Ideal Airspeed Correction block generates code that includes all (Mach < 5) lookup table data if **Method** is set to `Table Lookup`.

Action for out-of-range input

Specify action to take in case of out-of-range input, where airspeed is greater than Mach 1. This parameter displays if the **Subsonic airspeeds only** check box is selected.

Value	Description
`None` (default)	Does not display warning or error.
`Warning`	Displays warning and indicates that the airspeed is greater than Mach 1.
`Error`	Displays error and indicates that the airspeed is greater than Mach 1.

Inputs and Outputs

Input	Dimension Type	Description
TAS/EAS/CAS	double	Contains the selected airspeed in the selected units.
a	double	Contains the speed of sound in the selected units.
P_0	double	Contains the static pressure in the selected units.

Output	Dimension Type	Description
TAS/EAS/CAS	double	Contains the selected airspeed in the selected units.

Assumptions and Limitations

This block assumes that the air flow is compressible dry air with constant specific heat ratio, γ.

Examples

See the `aeroblk_indicated` model and the `aeroblk_calibrated` model for examples of this block.

References

Lowry, J. T., *Performance of Light Aircraft*, AIAA Education Series, Washington, DC, 1999.

Aeronautical Vestpocket Handbook, United Technologies Pratt & Whitney, August, 1986.

Gracey, William, *Measurement of Aircraft Speed and Altitude*, NASA Reference Publication 1046, 1980.

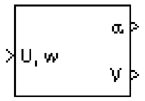
See Also

COESA Atmosphere Model, ISA Atmosphere Model, Lapse Rate Model, Non-Standard Day 210C, Non-Standard Day 310

Introduced before R2006a

Incidence & Airspeed

Calculate incidence and airspeed



Library

Flight Parameters

Description

The Incidence & Airspeed block supports the 3DoF equations of motion model by calculating the angle between the velocity vector and the body, and also the total airspeed from the velocity components in the body-fixed coordinate frame.

$$\alpha = \operatorname{atan}\left(\frac{w}{u}\right)$$

$$V = \sqrt{u^2 + w^2}$$

Inputs and Outputs

Input	Dimension Type	Description
First	Two-element vector	Contains the velocity of the body resolved into the body-fixed coordinate frame.

Output	Dimension Type	Description
First		Contains the incidence angle, in radians.
Second		Contains the airspeed of the body.

Examples

See the Aerodynamics & Equations of Motion subsystem of the `aeroblk_guidance_airframe` model for examples of this block.

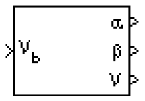
See Also

Incidence, Sideslip & Airspeed

Introduced before R2006a

Incidence, Sideslip & Airspeed

Calculate incidence, sideslip, and airspeed



Library

Flight Parameters

Description

The Incidence, Sideslip & Airspeed block supports the 6DoF (Euler Angles) and 6DoF (Quaternion) models by calculating the angles between the velocity vector and the body, and also the total airspeed from the velocity components in the body-fixed coordinate frame.

$$\alpha = a\tan\left(\frac{w}{u}\right)$$

$$\beta = a\sin\left(\frac{v}{V}\right)$$

$$V = \sqrt{u^2 + v^2 + w^2}$$

$$\alpha = \operatorname{atan}\left(\frac{w}{u}\right)$$

$$\beta = \operatorname{asin}\left(\frac{v}{V}\right)$$

$$V = \sqrt{u^2 + v^2 + w^2}$$

Inputs and Outputs

Input	Dimension Type	Description
First	Three-element vector	Contains the velocity of the body resolved into the body-fixed coordinate frame.

Output	Dimension Type	Description
First		Contains the incidence angle in radians.
Second		Contains the sideslip angle in radians.
Third		Contains the airspeed of the body.

Examples

See Airframe in the `aeroblk_HL20` model for an example of this block.

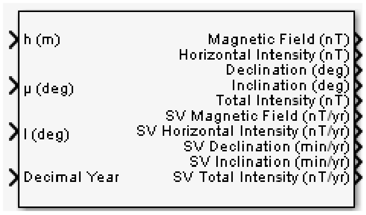
See Also

Incidence & Airspeed

Introduced before R2006a

International Geomagnetic Reference Field 12

Calculate Earth magnetic field and secular variation using 12th generation International Geomagnetic Reference Field



Library

Environment/Gravity

Description

The International Geomagnetic Reference Field 12 block calculates the Earth magnetic field and secular variation using the 12th generation International Geomagnetic Reference Field. It calculates these values at a location and time that you define.

Parameters

Units

Specifies the parameter and output units.

Units	Height
`Metric (MKS)`	Meters
`English`	Feet

Input decimal year

When you select this check box, the decimal year is an input for the International Geomagnetic Reference Field 12 block. Otherwise, specify a date using the **Month**, **Day**, and **Year** parameters.

Month

Specifies the month to calculate decimal year.

Day

Specifies the day to calculate decimal year.

Year

Specifies the year to calculate decimal year. From the list, select from `1900` to `2020`.

Action for out-of-range input

Specifies whether out-of-range input causes a warning, error, or no action.

Output secular variance

Select this check box to enable the output of secular variances (annual rate of change) with nonsecular variances.

Secular Variance	Description
Magnetic Field	Magnetic field vector, in nanotesla (nT). *Z* is the vertical component (+ve down)
Horizontal Intensity	Horizontal intensity, in nanotesla (nT)
Declination	Declination, in degrees (+ve east)
Inclination	Inclination, in degrees (+ve down)
Total Intensity	Total intensity, in nanotesla (nT)
SV Magnetic Field	Secular variation of magnetic field
SV Horizontal Intensity	Secular variation of horizontal intensity
SV Declination	Secular variation of declination, the angle between true north and the magnetic field vector (positive eastward)
SV Inclination	Secular variation of inclination, the angle between the horizontal plane and the magnetic field vector (positive downward)

Secular Variance	Description
SV Total Intensity	Secular variation of total intensity

Clear this check box to enable just the nonsecular variances:

- Magnetic Field
- Horizontal Intensity
- Declination
- Inclination
- Total Intensity

Inputs and Outputs

Input	Dimension Type	Description
First	Scalar	Contains the height, in selected units.
Second	Scalar	Contains the latitude, in degrees.
Third	Scalar	Contains the longitude, in degrees.
Fourth (Optional)	Scalar	Contains the desired year in a decimal format to include any fraction of the year that has already passed. The value is the current year plus the number of days that have passed in this year divided by 365. This code shows how to calculate the decimal year, `dyear`, for March 21, 2015: `dyear = decyear('21-March-2015','dd-mmm-yyyy')`

Output	Dimension Type	Description
First		Contains the magnetic field vector, in selected units.
Second		Contains the horizontal intensity, in selected units.
Third		Contains the declination, in degrees.
Fourth		Contains the inclination, in degrees.

Output	Dimension Type	Description
Fifth		Contains the total intensity, in selected units.
Sixth (Optional)		Contains the secular variation of magnetic field vector, in selected units per years.
Seventh (Optional)		Contains the secular variation of horizontal intensity, in selected units per year.
Eight (Optional)		Contains the secular variation of declination, in minutes per year.
Ninth (Optional)		Contains the secular variation of inclination, in minutes per year.
Tenth (Optional)		Contains the secular variation of total intensity, in selected units per year.

Limitations

This block is valid between the heights of –1000 m and 600,000 m.

This block is valid between the years 1900 and 2020.

This site shows additional limitations:

`https://www.ngdc.noaa.gov/IAGA/vmod/igrfhw.html`

References

International Association of Geomagnetism and Aeronomy. 12th Generation International Geomagnetic Reference Field: https://www.ngdc.noaa.gov/IAGA/vmod/igrf.html.

Blakely, R. J., *Potential Theory in Gravity & Magnetic Applications*. Cambridge, UK: Cambridge University Press, 1996.

Lowes, F. J. “The International Geomagnetic Reference Field: A 'Health' Warning.” January, 2010. https://www.ngdc.noaa.gov/IAGA/vmod/igrfhw.html.

Introduced in R2015b

Interpolate Matrix(x)

Return interpolated matrix for given input
Library: Aerospace Blockset / GNC / Control

x_k
x_f
Matrix(x)

Description

The Interpolate Matrix(x) block interpolates a one-dimensional array of matrices. The block assumes a one-dimensional array as defined in “Algorithms” on page 4-417.

The matrix to be interpolated must be three dimensional, the first two dimensions corresponding to the matrix at each value of *x*. For example, if you have three matrices *A*, *B*, and *C* defined at `x = 0`, `x = 0.5`, and `x = 1.0`, then the input matrix is given by

```
matrix(:,:,1) = A;

matrix(:,:,2) = B;

matrix(:,:,3) = C;
```

Limitations

This block must be driven from the Prelookup block.

Ports

Input

x_k — Interpolation index *i*
scalar

Interpolation index *i*, specified as a scalar.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32` | `Boolean` | `fixed point` | `enumerated` | `bus`

`x_f` — Interpolation fraction
scalar

Interpolation fraction *λ*, specified as a scalar.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32` | `Boolean` | `fixed point` | `enumerated` | `bus`

Output

`Matrix(x)` — Interpolated matrix
matrix

Interpolated matrix, specified as a matrix.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32` | `Boolean` | `fixed point` | `enumerated` | `bus`

Parameters

`Matrix to interpolate` — Matrix
`matrix` (default)

Matrix to be interpolated, with three indices and the third index labeling the interpolating values of *x*.

Programmatic Use
Block Parameter: `matrix`
Type: character vector
Values: matrix
Default: `'matrix'`

Algorithms

This one-dimensional case assumes a matrix *M* is defined at a discrete number of values of an independent variable

$x = [\ x_1 x_2 x_3 \ldots x_i x_{i+1} \ldots x_n\ ]$.

Then for $x_i < x < x_{i+1}$, the block output is given by

$$(1 - \lambda)M(x_i) + \lambda M(x_{i+1})$$

where the interpolation fraction is defined as

$$\lambda = (x - x_i)/(x_{i+1} - x_i)$$

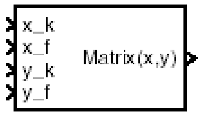
See Also

on page 4-2 | 1D Observer Form [A(v),B(v),C(v),F(v),H(v)] | 1D Self-Conditioned [A(v),B(v),C(v),D(v)] | Interpolate Matrix(x,y) | Interpolate Matrix(x,y,z)

Introduced before R2006a

Interpolate Matrix(x,y)

Return interpolated matrix for given inputs
Library: Aerospace Blockset / GNC / Control



Description

The Interpolate Matrix(x,y) block interpolates a two-dimensional array of matrices. In two-dimensional cases, the interpolation is carried out first on *x* and then *y*. For more information, see “Algorithms” on page 4-421.

The matrix to be interpolated must be four-dimensional, the first two dimensions corresponding to the matrix at each value of *x* and *y*. For example, if you have four matrices *A*, *B*, *C*, and *D* defined at `(x = 0.0,y = 1.0)`, `(x = 0.0,y = 3.0)`, `(x = 1.0,y = 1.0)` and `(x = 1.0,y = 3.0)`, then the input matrix is given by

```
matrix(:,:,1,1) = A;

matrix(:,:,1,2) = B;

matrix(:,:,2,1) = C;

matrix(:,:,2,2) = D;
```

Limitations

This block must be driven from the Prelookup block.

Ports

Input

x_k — First interpolation index
scalar

First interpolation index *i*, specified as a scalar and vector.

Data Types: `double`

x_f — First interpolation fraction
scalar

First interpolation fraction λ_x, specified as a scalar

Data Types: `double`

y_k — Second interpolation index
scalar

Second interpolation index *j*, specified as a scalar.

Data Types: `double`

y_f — Second interpolation fraction
scalar

Second interpolation fraction λ_y, specified as a scalar.

Data Types: `double`

Output

`Matrix(x,y)` — Interpolated matrix
matrix

Interpolated matrix, specified as a matrix.

Data Types: `double`

Parameters

`Matrix to interpolate` — Matrix
`matrix` (default)

Matrix to be interpolated, with four indices and the third and fourth indices labeling the interpolating values of *x* and *y*.

Programmatic Use
Block Parameter: `matrix`
Type: character vector
Values: matrix
Default: `'matrix'`

Algorithms

This two-dimensional case assumes the matrix is defined as a function of two independent variables, $\boldsymbol{x} = [\ x_1 x_2 x_3 \ldots\ x_i x_{i+1}\ \ldots\ x_n]$ and $\boldsymbol{y} = [\ y_1 y_2 y_3\ \ldots\ y_j y_{j+1}\ \ldots\ y_m]$. For given values of x and y, four matrices are interpolated. Then for $x_i < x < x_{i+1}$ and $y_j < y < y_{j+1}$, the output matrix is given by

$$(1 - \lambda_y)[(1 - \lambda_x)M(x_i, y_j) + \lambda_x M(x_{i+1}, y_j)] +$$
$$\lambda_y[(1 - \lambda_x)M(x_i, y_{j+1}) + \lambda_x M(x_{i+1}, y_{j+1})]$$

where the two interpolation fractions are denoted by

$$\lambda_x = (x - x_i)/(x_{i+1} - x_i)$$

and

$$\lambda_y = (y - y_j)/(y_{j+1} - y_j)$$

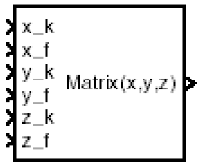
See Also

2D Controller [A(v),B(v),C(v),D(v)] | 2D Observer Form [A(v),B(v),C(v),F(v),H(v)] | 2D Self-Conditioned [A(v),B(v),C(v),D(v)] | Interpolate Matrix(x) | Interpolate Matrix(x,y,z) | Prelookup

Introduced before R2006a

Interpolate Matrix(x,y,z)

Return interpolated matrix for given inputs
Library: Aerospace Blockset / GNC / Control



Description

The Interpolate Matrix(x,y,z) block interpolates a three-dimensional array of matrices.

This three-dimensional case assumes the matrix is defined as a function of three independent variables:

$$x = [\; x_1 \; x_2 \; x_3 \; \ldots \; x_i \; x_{i+1} \; \ldots \; x_n \;]$$

$$y = [\; y_1 \; y_2 \; y_3 \; \ldots \; y_j \; y_{j+1} \; \ldots \; y_m \;]$$

$$z = [\; z_1 \; z_2 \; z_3 \; \ldots \; z_k \; z_{k+1} \; \ldots \; z_p \;]$$

For given values of *x*, *y*, and *z*, eight matrices are interpolated. Then for

$$x_i < x < x_{i+1}$$

$$y_j < y < y_{j+1}$$

$$z_k < z < z_{k+1}$$

the output matrix is given by

$$\begin{aligned}
&(1-\lambda_z)\Big\{(1-\lambda_y)\big[(1-\lambda_x)M(x_i, y_j, z_k) + \lambda_x M(x_{i+1}, y_j, z_k)\big] \\
&\qquad + \lambda_y\big[(1-\lambda_x)M(x_i, y_{j+1}, z_k) + \lambda_x M(x_{i+1}, y_{j+1}, z_k)\big]\Big\} \\
&+ \lambda_z\Big\{(1-\lambda_y)\big[(1-\lambda_x)M(x_i, y_j, z_{k+1}) + \lambda_x M(x_{i+1}, y_j, z_{k+1})\big] \\
&\qquad + \lambda_y\big[(1-\lambda_x)M(x_i, y_{j+1}, z_{k+1}) + \lambda_x M(x_{i+1}, y_{j+1}, z_{k+1})\big]\Big\}
\end{aligned}$$

where the three interpolation fractions are denoted by

$$\lambda_x = (x - x_i)/(x_{i+1} - x_i)$$

$$i_y = (y - y_j)/\left(y_{j+1} - y_j\right)$$

$$\lambda_z = (z - z_k)/(z_{k+1} - z_k)$$

In the three-dimensional case, the interpolation is carried out first on x, then y, and finally z.

The matrix to be interpolated should be five-dimensional, the first two dimensions corresponding to the matrix at each value of x, y, and z. For example, if you have eight matrices A, B, C, D, E, F, G, and H defined at the following values of x, y, and z, then the corresponding input matrix is given by

`(x = 0.0,y = 1.0,z = 0.1)`	`matrix(:,:,1,1,1) = A;`
`(x = 0.0,y = 1.0,z = 0.5)`	`matrix(:,:,1,1,2) = B;`
`(x = 0.0,y = 3.0,z = 0.1)`	`matrix(:,:,1,2,1) = C;`
`(x = 0.0,y = 3.0,z = 0.5)`	`matrix(:,:,1,2,2) = D;`
`(x = 1.0,y = 1.0,z = 0.1)`	`matrix(:,:,2,1,1) = E;`
`(x = 1.0,y = 1.0,z = 0.5)`	`matrix(:,:,2,1,2) = F;`
`(x = 1.0,y = 3.0,z = 0.1)`	`matrix(:,:,2,2,1) = G;`
`(x = 1.0,y = 3.0,z = 0.5)`	`matrix(:,:,2,2,2) = H;`

Limitations

This block must be driven from the Prelookup block.

Ports

Input

x_k — First interpolation index
scalar

First interpolation index *i*, specified as a scalar.

Data Types: `double`

`x_f` — First interpolation fraction
scalar

First interpolation fraction λ_x, specified as a scalar .

Data Types: `double`

`y_k` — Second interpolation index
scalar

Second interpolation index *j*, specified as a scalar.

Data Types: `double`

`y_f` — Second interpolation fraction
scalar

Second interpolation fraction λ_y, specified as a scalar.

Data Types: `double`

`z_k` — Third interpolation index
scalar

Third interpolation index *k*, specified as a scalar.

Data Types: `double`

`z_f` — Third interpolation fraction
scalar

Third interpolation fraction λ_z, specified as a scalar.

Data Types: `double`

Output

`Matrix(x,y,z)` — Interpolated matrix
matrix

Interpolated matrix, specified as a matrix.

Data Types: `double`

Parameters

`Matrix to interpolate` — Matrix to interpolate

`matrix` (default)

Matrix to be interpolated, with five indices and the third, fourth, and fifth indices labeling the interpolating values of *x*, *y*, and *z*.

Programmatic Use
Block Parameter: `matrix`
Type: character vector
Values: matrix
Default: `'matrix'`

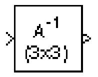
See Also

3D Controller [A(v),B(v),C(v),D(v)] | 3D Observer Form [A(v),B(v),C(v),F(v),H(v)] | 3D Self-Conditioned [A(v),B(v),C(v),D(v)] | Interpolate Matrix(x) | Interpolate Matrix(x,y) | Prelookup

Introduced before R2006a

Invert 3x3 Matrix

Compute inverse of 3-by-3 matrix



Library

Utilities/Math Operations

Description

The Invert 3x3 Matrix block computes the inverse of 3-by-3 matrix.

If $det(A) = 0$, an error occurs and the simulation stops.

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-3 matrix	

Output	Dimension Type	Description
First	3-by-3 matrix	Contains the matrix inverse of input matrix.

See Also

Adjoint of 3x3 Matrix

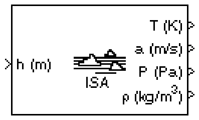
Create 3x3 Matrix

Determinant of 3x3 Matrix

Introduced before R2006a

ISA Atmosphere Model

Implement International Standard Atmosphere (ISA)



Library

Environment/Atmosphere

Description

The ISA Atmosphere Model block implements the mathematical representation of the international standard atmosphere values for ambient temperature, pressure, density, and speed of sound for the input geopotential altitude.

The ISA Atmosphere Model block icon displays the input and output metric units.

Parameters

Change atmospheric parameters

Select to customize various atmospheric parameters to be different from the ISA values.

Selecting this check box enables the parameters .

Acceleration due to gravity (m/s^2)

Enter acceleration from gravity in m/s^2.

Ratio of specific heats

Enter a ratio of specific hits.

Characteristic gas constant (J/Kg/K)

Enter the characteristic gas constant in J/Kg/K.

Lapse rate (K/m)

Enter the lapse rate in K/m.

Height of troposphere (m)

Enter the height of the troposphere in m.

Height of tropopause (m)

Enter the height of the tropopause in m.

Air density at mean sea level (Kg/m^3)

Enter the air density at mean sea level in Kg/m^3.

Ambient pressure at mean sea level (N/m^2)

Enter the ambient pressure at mean sea level in N/m^2.

Ambient temperature at mean sea level (K)

Enter the ambient temperature at mean sea level in K.

Lowest altitude (m)

Enter the lowest altitude in m.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the geopotential height.

Output	Dimension Type	Description
First		Contains the temperature.
Second		Contains the speed of sound.
Third		Contains the air pressure.
Fourth		Contains the air density.

Assumptions and Limitations

Below the geopotential altitude of 0 km and above the geopotential altitude of 20 km, temperature and pressure values are held. Density and speed of sound are calculated using a perfect gas relationship.

Reference

[1] U.S. Standard Atmosphere, 1976, U.S. Government Printing Office, Washington, D.C.

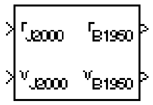
See Also

COESA Atmosphere Model, CIRA-86 Atmosphere Model, Lapse Rate Model

Introduced before R2006a

Julian Epoch to Besselian Epoch

Transform position and velocity components from Standard Julian Epoch (J2000) to discontinued Standard Besselian Epoch (B1950)



Library

Utilities/Axes Transformations

Description

The Julian Epoch to Besselian Epoch block transforms two 3-by-1 vectors of Julian Epoch position $\left(\bar{r}_{J2000}\right)$, and Julian Epoch velocity $\left(\bar{v}_{J2000}\right)$ into Besselian Epoch position $(\bar{r}_{B1950})$, and Besselian Epoch velocity $(\bar{v}_{B1950})$. The transformation is calculated using:

$$\begin{bmatrix} \bar{r}_{B1950} \\ \bar{v}_{B1950} \end{bmatrix} = \begin{bmatrix} \bar{M}_{rr} & \bar{M}_{vr} \\ \bar{M}_{rv} & \bar{M}_{vv} \end{bmatrix}^T \begin{bmatrix} \bar{r}_{J2000} \\ \bar{v}_{J2000} \end{bmatrix}$$

where

$$\left(\bar{M}_{rr}, \bar{M}_{vr}, \bar{M}_{rv}, \bar{M}_{vv}\right)$$

are defined as:

$$\bar{M}_{rr} = \begin{bmatrix} 0.9999256782 & -0.0111820611 & -0.0048579477 \\ 0.0111820610 & 0.9999374784 & -0.0000271765 \\ 0.0048579479 & -0.0000271474 & 0.9999881997 \end{bmatrix}$$

$$\bar{M}_{vr} = \begin{bmatrix} 0.00000242395018 & -0.00000002710663 & -0.00000001177656 \\ 0.00000002710663 & 0.00000242397878 & -0.00000000006587 \\ 0.00000001177656 & -0.00000000006582 & 0.00000242410173 \end{bmatrix}$$

$$\overline{M}_{rv} = \begin{bmatrix} -0.000551 & -0.238565 & 0.435739 \\ 0.238514 & -0.002667 & -0.008541 \\ -0.435623 & 0.012254 & 0.002117 \end{bmatrix}$$

$$\overline{M}_{vv} = \begin{bmatrix} 0.99994704 & -0.01118251 & -0.00485767 \\ 0.01118251 & 0.99995883 & -0.00002718 \\ 0.00485767 & -0.00002714 & 1.00000956 \end{bmatrix}$$

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-1 vector	Contains the position in Standard Julian Epoch (J2000).
Second	3-by-1 vector	Contains the velocity in Standard Julian Epoch (J2000).

Output	Dimension Type	Description
First	3-by-1 vector	Contains the position in Standard Besselian Epoch (B1950).
Second	3-by-1 vector	Contains the velocity in Standard Besselian Epoch (B1950).

Reference

“Supplement to Department of Defense World Geodetic System 1984 Technical Report: Part I - Methods, Techniques and Data Used in WGS84 Development,” DMA TR8350.2-A.

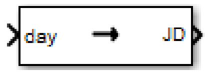
See Also

Besselian Epoch to Julian Epoch

Introduced before R2006a

Julian Date Conversion

Calculate Julian date or modified Julian date



Library

Utilities/Unit Conversions

Description

This block converts the specified date to the Julian date or modified Julian date.

Parameters

Year

Specify the year used to calculate the Julian date. Enter a double value that is a whole number greater than 1, such as `2013`.

Month

Specify the month used to calculate the Julian date. From the list, select the month from `January` to `December`.

Day

Specify the day used to calculate the Julian date. From the list, select the day from `1` to `31`.

Hour

Specify the hour used to calculate the Julian date. Enter a double value that is a whole number, from `0` to `24`.

Minutes

Specify the minutes used to calculate the Julian date. Enter a double value that is a whole number, from `0` to `60`.

Seconds

Specify the seconds used to calculate the Julian date. Enter a double value that is a whole number, from `0` to `60`.

Calculate modified Julian date

Select this check box to calculate the modified Julian date (MJD) for corresponding elements of the year, month, day, hour, minute, and second.

Time Increment

Specify the time increment between the specified date and the desired model simulation time. The block adjusts the calculated Julian date to take into account the time increment from model simulation. For example, selecting `Day` and connecting a simulation timer to the port means that each time increment unit is one day and the block adjusts its calculation based on that simulation time.

This parameter corresponds to the first block input, the clock source.

Possible values are `Day`, `Hour`, `Min`, `Sec`, and `None`. If you select `None`, the calculated Julian date does not take into account the model simulation time. Selecting this option removes the first block input.

Action for out-of-range input

Specify the block behavior when the block inputs are out of range.

Action	Description
`None`	No action.
`Warning`	Warning in the MATLAB Command Window, model simulation continues.
`Error` (default)	MATLAB returns an exception, model simulation stops.

Inputs and Outputs

Input	Dimension Type	Description
First (Optional)	Scalar	Clock source for model simulation.

Output	Dimension Type	Description
First	Scalar	Julian date.

Assumptions and Limitations

This block is valid for all common era (CE) dates in the Gregorian calendar.

The calculation of Julian date does not take into account leap seconds.

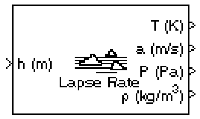
See Also

`juliandate`

Introduced in R2013b

Lapse Rate Model

Implement lapse rate model for atmosphere



Library

Environment/Atmosphere

Description

The Lapse Rate Model block implements the mathematical representation of the lapse rate atmospheric equations for ambient temperature, pressure, density, and speed of sound for the input geopotential altitude. You can customize this atmospheric model, described below, by specifying atmospheric properties in the block dialog.

The following equations define the troposphere

$$T = T_0 - Lh$$

$$P = P_0\left(\frac{T}{T_0}\right)^{\frac{g}{LR}}$$

$$\rho = \rho_0\left(\frac{T}{T_0}\right)^{\frac{g}{LR} - 1}$$

$$a = \sqrt{\gamma RT}$$

The following equations define the tropopause (lower stratosphere)

$$T = T_0 - Lhts$$

$$P = P_0\left(\frac{T}{T_0}\right)^{\frac{g}{LR}} e^{\frac{g}{RT}(hts - h)}$$

$$\rho = \rho_0\left(\frac{T}{T_0}\right)^{\frac{g}{LR} - 1} e^{\frac{g}{RT}(hts - h)}$$

$$a = \sqrt{\gamma RT}$$

where:

T_0	Absolute temperature at mean sea level in kelvin (K)
ρ_0	Air density at mean sea level in kg/m^3
P_0	Static pressure at mean sea level in N/m^2
h	Altitude in m
hts	Height of the troposphere in m
T	Absolute temperature at altitude h in kelvin (K)
ρ	Air density at altitude h in kg/m^3
P	Static pressure at altitude h in N/m^2
a	Speed of sound at altitude h in m/s^2
L	Lapse rate in K/m
R	Characteristic gas constant J/kg-K
γ	Specific heat ratio
g	Acceleration due to gravity in m/s^2

The Lapse Rate Model block icon displays the input and output metric units.

Parameters

Change atmospheric parameters

When selected, the following atmospheric parameters can be customized to be different from the ISA values.

Acceleration due to gravity

Specify the acceleration due to gravity (g).

Ratio of specific heats

Specify the ratio of specific heats γ.

Characteristic gas constant

Specify the characteristic gas constant (R).

Lapse rate

Specify the lapse rate of the troposphere (L).

Height of troposphere

Specify the upper altitude of the troposphere, a range of decreasing temperature.

Height of tropopause

Specify the upper altitude of the tropopause, a range of constant temperature.

Air density at mean sea level

Specify the air density at sea level (ρ_0).

Ambient pressure at mean sea level

Specify the ambient pressure at sea level (P_0).

Ambient temperature at mean sea level

Specify the ambient temperature at sea level (T_0).

Lowest altitude (m)

Specify the lowest altitude above which temperature and pressure lapse. **Lowest altitude (m)** must be below **Height of tropopause**. Default value is 0 m.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the geopotential height.

Output	Dimension Type	Description
First		Contains the temperature.
Second		Contains the speed of sound.
Third		Contains the air pressure.
Fourth		Contains the air density.

Assumptions and Limitations

Below the geopotential altitude of 0 km and above the geopotential altitude of the tropopause, temperature and pressure values are held. Density and speed of sound are calculated using a perfect gas relationship.

Reference

[1] U.S. Standard Atmosphere, 1976, U.S. Government Printing Office, Washington, D.C.

See Also

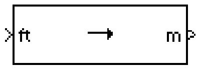
COESA Atmosphere Model

ISA Atmosphere Model

Introduced before R2006a

Length Conversion

Convert from length units to desired length units



Library

Utilities/Unit Conversions

Description

The Length Conversion block computes the conversion factor from specified input length units to specified output length units and applies the conversion factor to the input signal.

The Length Conversion block icon displays the input and output units selected from the **Initial unit** and the **Final unit** lists.

Parameters

Initial unit

Specifies the input units.

Final unit

Specifies the output units.

The following conversion units are available:

`m`	Meters
`ft`	Feet
`km`	Kilometers
`in`	Inches

`mi`	Miles
`naut mi`	Nautical miles

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the length in initial length units.

Output	Dimension Type	Description
First		Contains the length in final length units.

See Also

Acceleration Conversion

Angle Conversion

Angular Acceleration Conversion

Angular Velocity Conversion

Density Conversion

Force Conversion

Mass Conversion

Pressure Conversion

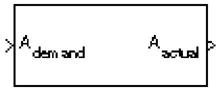
Temperature Conversion

Velocity Conversion

Introduced before R2006a

Linear Second-Order Actuator

Implement second-order linear actuator



Library

Actuators

Description

The Second Order Linear Actuator block outputs the actual actuator position using the input demanded actuator position and other dialog box parameters that define the system.

Parameters

Natural frequency

The natural frequency of the actuator. The units of natural frequency are radians per second.

Damping ratio

The damping ratio of the actuator. A dimensionless parameter.

Initial position

The initial position of the actuator. The units of initial position must be the same as the units of demanded actuator position.

Initial velocity

The initial velocity of the actuator. The units of initial velocity must be the same as the units of demanded actuator velocity per second.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the demanded actuator position.

Output	Dimension Type	Description
First		Contains the actual actuator position.

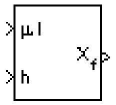
See Also

Nonlinear Second-Order Actuator

Introduced in R2012a

LLA to ECEF Position

Calculate Earth-centered Earth-fixed (ECEF) position from geodetic latitude, longitude, and altitude above planetary ellipsoid



Library

Utilities/Axes Transformations

Description

The LLA to ECEF Position block converts geodetic latitude ($\bar{\mu}$), longitude ($\bar{\iota}$), and altitude $\left(\bar{h}\right)$ above the planetary ellipsoid into a 3-by-1 vector of ECEF position ($\bar{p}$). Latitude and longitude values can be any value. However, latitude values of +90 and -90 may return unexpected values because of singularity at the poles. The ECEF position is calculated from geocentric latitude at mean sea-level (λ_s) and longitude using:

$$\bar{p} = \begin{bmatrix} \bar{p}_x \\ \bar{p}_y \\ \bar{p}_z \end{bmatrix} = \begin{bmatrix} r_s \cos\lambda_s \cos\iota + h\cos\mu\cos\iota \\ r_s \cos\lambda_s \sin\iota + h\cos\mu\sin\iota \\ r_s \sin\lambda_s + h\sin\mu \end{bmatrix}$$

where geocentric latitude at mean sea-level and the radius at a surface point (r_s) are defined by flattening $\left(\bar{f}\right)$, and equatorial radius $\left(\bar{R}\right)$ in the following relationships.

$$\lambda_s = \mathrm{atan}((^1\tan\mu)$$

$$r_s = \sqrt{\frac{R^2}{1 + \left(1/(1-f)^2 - 1\right)\sin^2\lambda_s}}$$

Parameters

Units

Specifies the parameter and output units:

Units	Altitude	Equatorial Radius	Position
`Metric (MKS)`	Meters	Meters	Meters
`English`	Feet	Feet	Feet

This option is only available when **Planet model** is set to `Earth (WGS84)`.

Planet model

Specifies the planet model to use: `Custom` or `Earth (WGS84)`.

Flattening

Specifies the flattening of the planet. This option is only available with **Planet model** set to `Custom`.

Equatorial radius of planet

Specifies the radius of the planet at its equator. The units of the equatorial radius parameter should be the same as the units for altitude. This option is only available with **Planet model** set to `Custom`.

Inputs and Outputs

Input	Dimension Type	Description
First	2-by-1 vector	Contains the geodetic latitude and longitude, in degrees.
Second	Scalar	Contains the altitude above the planetary ellipsoid.

Output	Dimension Type	Description
First	3-by-1 vector	Contains the position in ECEF frame, in same units as altitude.

Assumptions and Limitations

The planet is assumed to be ellipsoidal. To use a spherical planet, set the **Flattening** parameter to zero.

The implementation of the ECEF coordinate system assumes that the origin is at the center of the planet, the *x*-axis intersects the Greenwich meridian and the equator, the *z*-axis being the mean spin axis of the planet, positive to the north, and the *y*-axis completes the right-handed system.

References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

Zipfel, P. H., *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA Education Series, Reston, Virginia, 2000.

“Atmospheric and Space Flight Vehicle Coordinate Systems,” ANSI/AIAA R-004-1992.

See Also

See “About Aerospace Coordinate Systems” on page 2-10.

Direction Cosine Matrix ECEF to NED

Direction Cosine Matrix ECEF to NED to Latitude and Longitude

ECEF Position to LLA

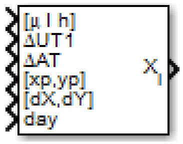
Flat Earth to LLA

Radius at Geocentric Latitude

Introduced before R2006a

LLA to ECI Position

Convert latitude, longitude, altitude (LLA) coordinates to Earth-centered inertial (ECI) coordinates



Library

Utilities/Axes Transformations

Description

LLA to ECI Position block converts latitude, longitude, altitude (LLA) coordinates to Earth-centered inertial (ECI) position coordinates, based on the specified reduction method and Universal Coordinated Time (UTC), for the specified time and geophysical data. Latitude and longitude values can be any value. However, latitude values of +90 and -90 may return unexpected values because of singularity at the poles.

Parameters

Reduction

Reduction method to convert the coordinates. Select one of the following:

- `IAU-76/FK5`

  Reduce the calculation using the International Astronomical Union (IAU)-76/Fifth Fundamental Catalogue (FK5) (IAU-76/FK5) reference system. Choose this reduction method if the reference coordinate system for the conversion is FK5.

  Note This method uses the IAU 1976 precession model and the IAU 1980 theory of nutation to reduce the calculation. This model and theory are no longer current, but the software provides this reduction method for existing implementations. Because of the polar motion approximation that this reduction method uses, the block calculates the transformation matrix rather than the direction cosine matrix.

- `IAU-2000/2006`

  Reduce the calculation using the International Astronomical Union (IAU)-2000/2006 reference system. Choose this reduction method if the reference coordinate system for the conversion is IAU-2000. This reduction method uses the P03 precession model to reduce the calculation.

Year

Specify the year used to calculate the Universal Coordinated Time (UTC) date. Enter a double value that is a whole number greater than 1, such as `2013`.

Month

Specify the month used to calculate the UTC date. From the list, select the month from `January` to `December`.

Day

Specify the day used to calculate the UTC date. From the list, select the day from `1` to `31`.

Hour

Specify the hour used to calculate the UTC date. Enter a double value that is a whole number from `0` to `24`.

Minutes

Specify the minutes used to calculate the UTC date. Enter a double value that is a whole number from `0` to `60`.

Seconds

Specify the seconds used to calculate the UTC date. Enter a double value that is a whole number from `0` to `60`.

Time Increment

Specify the time increment between the specified date and the desired model simulation time. The block adjusts the calculated direction cosine matrix to take into account the time increment from model simulation. For example, selecting `Day` and connecting a simulation timer to the port means that each time increment unit is one day. The block adjusts its calculation based on that simulation time.

This parameter corresponds to the sixth block input, the clock source.

Possible values are `Day`, `Hour`, `Min`, `Sec`, and `None`. If you select `None`, the calculated Julian date does not take into account the model simulation time. Selecting this option removes the fifth block input.

Action for out-of-range input

Specify the block behavior when the block inputs are out of range.

Action	Description
`None`	No action.
`Warning`	Warning in the MATLAB Command Window, model simulation continues.
`Error` (default)	MATLAB returns an exception, model simulation stops.

Higher accuracy parameters

Select this check box to enable the following inputs. These inputs let you better control the conversion result. See “Inputs and Outputs” on page 4-451 for a description.

[μ l h]
$\Delta UT1$
ΔAT
[xp,yp]
[$\Delta\delta\psi$, $\Delta\delta\varepsilon$] or [dX,dY]
day

Units

Specifies the parameter and output units:

Units	Position	Equatorial Radius	Altitude
`Metric (MKS)`	Meters	Meters	Meters
`English`	Feet	Feet	Feet

This option is available only when **Planet model** is set to `Earth (WGS84)`.

Earth model

Specifies the planet model to use: `Custom` or `WGS84`.

Flattening

Specifies the flattening of the planet. This option is available only with **Earth model Custom**.

Equatorial radius

Specifies the radius of the planet at its equator. This option is available only with **Earth model Custom**.

Inputs and Outputs

Input	Dimension Type	Description
First	Three-element vector	[*μ l h*], latitude, longitude, and altitude values of coordinates to convert, in degrees.
Second (Optional)	Scalar	Δ*UT1*, difference between UTC and Universal Time (UT1), in seconds, for which the function calculates the direction cosine or transformation matrix, for example, `0.234`.
Third (Optional)	Scalar	Δ*AT*, difference between International Atomic Time (IAT) and UTC, in seconds, for which the function calculates the direction cosine or transformation matrix, for example, `32`.
Fourth (Optional)	1-by-2 array	[*xp*,*yp*], polar displacement of the Earth, in radians, from the motion of the Earth crust, along the *x*- and *y*-axes, for example, `[-0.0682e-5 0.1616e-5]`.

Input	Dimension Type	Description
Fifth (Optional)	1-by-2 array	• If reduction method is `IAU-2000/2006`, this input is the adjustment to the location of the Celestial Intermediate Pole (CIP), specified in radians. This location ([d*X*,d*Y*]) is along the *x*- and *y*-axes, for example, `[-0.2530e-6 -0.0188e-6]`. • If reduction method is `IAU-76/FK5`, this input is the adjustment to the longitude ([Δδψ, Δδε]), specified in radians, for example, `[-0.2530e-6 -0.0188e-6]`. For historical values, see the International Earth Rotation and Reference Systems Service website (`https://www.iers.org`) and navigate to the Earth Orientation Data Data/ Products page.
Sixth	Scalar	Time increment, for example, the Clock block. If the **Higher accuracy parameters** check box is cleared and the **Time Increment** parameter is a value other than `None`, the block has no input.

Output	Dimension Type	Description
First	3-by-1 element vector	Original position vector with respect to the ECI reference system.

See Also

ECI Position to LLA

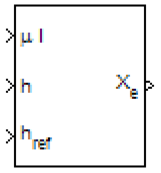
Topics

https://www.iers.org

Introduced in R2014a

LLA to Flat Earth

Estimate flat Earth position from geodetic latitude, longitude, and altitude



LLA to Flat Earth

Library

Utilities/Axes Transformations

Description

The LLA to Flat Earth block converts a geodetic latitude ($\bar{\mu}$), longitude ($\bar{\iota}$), and altitude (h) into a 3-by-1 vector of Flat Earth position($\bar{p}$). Latitude and longitude values can be any value. However, latitude values of +90 and -90 may return unexpected values because of singularity at the poles. The flat Earth coordinate system assumes the *z*-axis is downward positive. The estimation begins by finding the small changes in latitude and longitude from the output latitude and longitude minus the initial latitude and longitude.

$$d\mu = \mu - \mu_0$$
$$d\iota = \iota - \iota_0$$

To convert geodetic latitude and longitude to the North and East coordinates, the estimation uses the radius of curvature in the prime vertical (R_N) and the radius of curvature in the meridian (R_M). R_N and R_M are defined by the following relationships:

$$R_N = \frac{R}{\sqrt{1 - (2f - f^2)\sin^2\mu_0}}$$
$$R_M = R_N \frac{1 - (2f - f^2)}{1 - (2f - f^2)\sin^2\mu_0}$$

where (R) is the equatorial radius of the planet and f is the flattening of the planet.

Small changes in the North (dN) and East (dE) positions are approximated from small changes in the North and East positions by

$$dN = \frac{d\mu}{\operatorname{atan}\left(\frac{1}{R_M}\right)}$$

$$dE = \frac{d\iota}{\operatorname{atan}\left(\frac{1}{R_N \cos\mu_0}\right)}$$

With the conversion of the North and East coordinates to the flat Earth x and y coordinates, the transformation has the form of

$$\begin{bmatrix} p_x \\ p_y \end{bmatrix} = \begin{bmatrix} \cos\psi & \sin\psi \\ -\sin\psi & \cos\psi \end{bmatrix} \begin{bmatrix} N \\ E \end{bmatrix}$$

where

$$(\psi)$$

is the angle in degrees clockwise between the x-axis and north.

The flat Earth z-axis value is the negative altitude minus the reference height (h_{ref}).

$$p_z = -h - h_{ref}$$

Parameters

Units

Specifies the parameter and output units:

Units	Position	Equatorial Radius	Altitude
`Metric (MKS)`	Meters	Meters	Meters
`English`	Feet	Feet	Feet

This option is available only when **Planet model** is set to `Earth (WGS84)`.

Planet model

Specifies the planet model to use: `Custom` or `Earth (WGS84)`.

Flattening

Specifies the flattening of the planet. This option is available only with **Planet model Custom**.

Equatorial radius of planet

Specifies the radius of the planet at its equator. The units of the equatorial radius parameter should be the same as the units for flat Earth position. This option is available only with **Planet model Custom**.

Initial geodetic latitude and longitude

Specifies the reference location, in degrees of latitude and longitude, for the origin of the estimation and the origin of the flat Earth coordinate system.

Direction of flat Earth x-axis

Specifies angle for converting flat Earth *x* and *y* coordinates to North and East coordinates.

Inputs and Outputs

Input	Dimension Type	Description
First	2-by-1 vector	Contains the geodetic latitude and longitude, in degrees.
Second	Scalar	Contains the altitude above the input reference altitude, in same units as flat Earth position.
Third	Scalar	Contains the reference height from the surface of the Earth to the flat Earth frame, in same units as flat Earth position. The reference height is estimated with regard to Earth frame.

Output	Dimension Type	Description
First	3-by-1 vector	Contains the position in flat Earth frame.

Assumptions and Limitations

This estimation method assumes the flight path and bank angle are zero.

This estimation method assumes the flat Earth *z*-axis is normal to the Earth at the initial geodetic latitude and longitude only. This method has higher accuracy over small distances from the initial geodetic latitude and longitude, and nearer to the equator. The longitude has higher accuracy with smaller variations in latitude. Additionally, longitude is singular at the poles.

References

Etkin, B. *Dynamics of Atmospheric Flight* New York: John Wiley & Sons, 1972.

Stevens, B. L., and F. L. Lewis. *Aircraft Control and Simulation*, 2nd ed. New York: John Wiley & Sons, 2003.

See Also

Direction Cosine Matrix ECEF to NED

Direction Cosine Matrix ECEF to NED to Latitude and Longitude

ECEF Position to LLA

Flat Earth to LLA

Geocentric to Geodetic Latitude

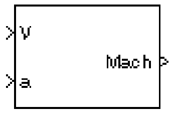
LLA to ECEF Position

Radius at Geocentric Latitude

Introduced in R2011a

Mach Number

Compute Mach number using velocity and speed of sound



Library

Flight Parameters

Description

The Mach Number block computes Mach number.

Mach number is defined as

$$Mach = \frac{\sqrt{V \cdot V}}{a}$$

where α is speed of sound and V is velocity vector.

Inputs and Outputs

Input	Dimension Type	Description
First	*m*-by-3	Contains the velocity vector.
Second	1-by-1	Contains the speed of sound.

Output	Dimension Type	Description
First	*m*-by-1	Contains the Mach number.

Examples

See Airframe in the `aeroblk_HL20` model for an example of this block.

See Also

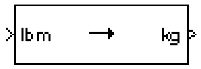
Aerodynamic Forces and Moments

Dynamic Pressure

Introduced before R2006a

Mass Conversion

Convert from mass units to desired mass units



Library

Utilities/Unit Conversions

Description

The Mass Conversion block computes the conversion factor from specified input mass units to specified output mass units and applies the conversion factor to the input signal.

The Mass Conversion block icon displays the input and output units selected from the **Initial unit** and the **Final unit** lists.

Parameters

Initial unit

Specifies the input units.

Final unit

Specifies the output units.

The following conversion units are available:

`lbm`	Pound mass
`kg`	Kilograms
`slug`	Slugs

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the mass in initial mass units.

Output	Dimension Type	Description
First	3-by-1 vector	Contains the mass in final mass units.

See Also

Acceleration Conversion

Angle Conversion

Angular Acceleration Conversion

Angular Velocity Conversion

Density Conversion

Force Conversion

Length Conversion

Pressure Conversion

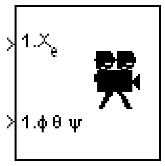
Temperature Conversion

Velocity Conversion

Introduced before R2006a

MATLAB Animation

Create six-degrees-of-freedom multibody custom geometry block



Library

Animation/MATLAB-Based Animation

Description

The MATLAB Animation block creates a six-degrees-of-freedom multibody custom geometry block based on the `Aero.Animation` object. This block animates one or more vehicle geometries with *x*-*y*-*z* position and Euler angles through the specified bounding box, camera offset, and field of view. This block expects the rotation order *z*-*y*-*x* (psi, theta, phi).

To update the camera parameters in the animation, first set the parameters then close and double-click the block to reopen the MATLAB Animation window.

To access the Parameters for this block, right-click the block, then select **Mask Parameters**. Alternatively, double-click the block to display the MATLAB Animation window, then click the **Block Parameters** icon.

Note The underlying graphics system stores values in single precision. As a result, you might notice that motion at coordinate positions greater than approximately 1e6 appear unstable. This is because a single-precision number has approximately six digits of precision. The instability is due to quantization at the local value of the `eps` MATLAB function. To visualize more stable motion for coordinates beyond 1e6, either offset the input data to a local zero, or scale down the coordinate values feeding the visualization.

Parameters

Vehicles

Specifies the vehicle to animate. From the list, select from `1` to `10`. The block mask inputs change to reflect the number of vehicles you select. Each vehicle has its own set of inputs, denoted by the number at the beginning of the input label.

Geometries

Specifies the vehicle geometries. You can specify these geometries using one of the following:

- Variable name, for example `geomVar`
- Cell array of variable names, for example `{geomVar, AltGeomVar}`
- Character vector with single quotes, for example, `'astredwedge.mat'`
- Mixed cell array of variable names and character vectors, for example `{'file1.mat', 'file2.mat', 'file3.ac', geomVar}`

Note All specified geometries specified must exist in the MATLAB workspace and file names must exist in the current folder or be on the MATLAB path.

Bounding box coordinates

Specifies the boundary coordinates for the vehicle.

This parameter is not tunable during simulation. A change to this parameter takes effect after simulation stops.

Camera offset

Specifies the distance from the camera aim point to the camera itself.

This parameter is not tunable during simulation. A change to this parameter takes effect after simulation stops.

Camera view angle

Specifies the camera view angle. By default, the camera aim point is the position of the first body lagged dynamically to indicate motion.

This parameter is not tunable during simulation. A change to this parameter takes effect after simulation stops.

Sample time

Specify the sample time (-1 for inherited).

Inputs and Outputs

This block has the following inputs:

Input	Dimension Type	Description
First	Vector	Contains the downrange position, the crossrange position, and the altitude of the vehicle in Earth coordinates. The number indicates the vehicle number.
Second	Vector	Contains the Euler angles (roll, pitch, and yaw) of the vehicle. The number indicates the vehicle number.

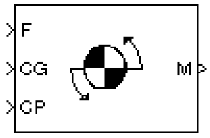
See Also

`Aero.Animation` in the Aerospace Toolbox documentation

Introduced in R2007a

Moments About CG Due to Forces

Compute moments about center of gravity due to forces applied at a point, not center of gravity



Library

Mass Properties

Description

The Moments about CG Due to Forces block computes moments about center of gravity due to forces that are applied at point CP, not at the center of gravity.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the forces applied at point CP.
Second		Contains the center of gravity.
Third		Contains the application point of forces.

Output	Dimension Type	Description
First		Contains the moments at the center of gravity in *x*-axes, *y*-axes and *z*-axes.

See Also

Aerodynamic Forces and Moments

Estimate Center of Gravity

Introduced before R2006a

Moon Libration

Implement Moon librations

Library: Aerospace Blockset / Environment / Celestial Phenomena

φ θ ψ (rad)
T_JD
ω (rad/day)

Description

The Moon Libration block implements the Moon librations using Chebyshev coefficients or a given Julian date. The block uses the Chebyshev coefficients that the NASA Jet Propulsion Laboratory provides.

Tip For T_{JD}, Julian date input for the block:

- Calculate the date using the Julian Date Conversion block or the Aerospace Toolbox `juliandate` function.
- Calculate the Julian date using some other means and input it using the Constant block.

Ports

Input

T_{JD} — Julian date

scalar | positive | between minimum and maximum Julian dates

Julian date, specified as a positive scalar between minimum and maximum Julian dates.

See the **Ephemeris model** parameter for the minimum and maximum Julian dates.

Dependencies

This port displays if the **Epoch** parameter is set to `Julian date`.

Data Types: `double`

`T0`$_{JD}$ — Fixed Julian date

scalar | positive

Fixed Julian date for a specific epoch that is the most recent midnight at or before the interpolation epoch, specified as a positive scalar. The sum of $T0_{JD}$ and ΔT_{JD} must fall between the minimum and maximum Julian dates.

See the **Ephemeris model** parameter for the minimum and maximum Julian dates.

Dependencies

This port displays if the **Epoch** parameter is set to `T0 and elapsed Julian time`.

Data Types: `double`

ΔT$_{JD}$ — Elapsed Julian time

scalar | positive

Elapsed Julian time between the fixed Julian date and the ephemeris time, specified as a positive scalar. The sum of $T0_{JD}$ and ΔT_{JD} must fall between the minimum and maximum Julian date.

See the **Ephemeris model** parameter for the minimum and maximum Julian dates.

Dependencies

This port displays if the **Epoch** parameter is set to `T0 and elapsed Julian time`.

Data Types: `double`

Output

`φ θ ψ (rad)` — Euler angles

vector

Euler angles (φ θ ψ) for Moon attitude, in rad.

Data Types: `double`

`ω (rad/day)` — Moon libration Euler angular rate

vector

Moon libration Euler angular rates (ω), in rad/day.

Data Types: `double`

Parameters

Epoch — Epoch
`Julian date` (default) | `T0 and elapsed Julian time`

Epoch, specified as:

- `Julian date`

  Julian date to calculate the Moon libration. When this option is selected, the block has one input port, T_{JD}.
- `T0 and elapsed Julian time`

  Julian date, specified by two block inputs:

  - Fixed Julian date representing a starting epoch. The sum of $T0_{JD}$ and ΔT_{JD} must fall between the minimum and maximum Julian dates.
  - Elapsed Julian time between the fixed Julian date ($T0_{JD}$) and the desired model simulation time. The sum of $T0_{JD}$ and ΔT_{JD} must fall between the minimum and maximum Julian dates.

  T0 plus the variable elapsed time cannot exceed the maximum Julian date for the specified **Ephemeris model**.

Programmatic Use
Block Parameter: `epochflag`
Type: character vector
Values: `Julian date` | `T0 and elapsed Julian time`
Default: `'Julian date'`

`Ephemeris model` — Ephemeris model
`DE405` (default) | `DE421` | `DE423` | `DE430` | `DE432t`

Select one of the following ephemeris models defined by the Jet Propulsion Laboratory.

Ephemeris Model	Description
DE405	Released in 1998. This ephemeris takes into account the Julian date range 2305424.50 (December 9, 1599) to 2525008.50 (February 20, 2201). This block implements these ephemerides with respect to the International Celestial Reference Frame version 1.0, adopted in 1998.
DE421	Released in 2008. This ephemeris takes into account the Julian date range 2414992.5 (December 4, 1899) to 2469808.5 (January 2, 2050). This block implements these ephemerides with respect to the International Celestial Reference Frame version 1.0, adopted in 1998.
DE423	Released in 2010. This ephemeris takes into account the Julian date range 2378480.5 (December 16, 1799) to 2524624.5 (February 1, 2200). This block implements these ephemerides with respect to the International Celestial Reference Frame version 2.0, adopted in 2010.
DE430	Released in 2013. This ephemeris takes into account the Julian date range 2287184.5 (December 21, 1549) to 2688976.5 (January 25, 2650). This block implements these ephemerides with respect to the International Celestial Reference Frame version 2.0, adopted in 2010.
DE432t	Released in April 2014. This ephemeris takes into account the Julian date range 2287184.5, (December 21, 1549) to 2688976.5, (January 25, 2650). This block implements these ephemerides with respect to the International Celestial Reference Frame version 2.0, adopted in 2010.

Note This block requires that you download ephemeris data using the Add-On Explorer. To start the Add-On Explorer, in the MATLAB Command Window, type `aeroDataPackage`. on the MATLAB desktop toolstrip, click the **Add-Ons** button.

Programmatic Use
Block Parameter: `de`
Type: character vector
Values: `DE405` | `DE421` | `DE423` | `DE430`
Default: `'DE405'`

`Action for out-of-range input` — Out-of-range block behavior

`None` (default) | `Warning` | `Error`

Out-of-range block behavior, specified as follows.

Action	Description
`None`	No action.
`Warning`	Warning in the MATLAB Command Window, model simulation continues.
`Error` (default)	MATLAB returns an exception, model simulation stops.

Programmatic Use
Block Parameter: `errorflag`
Type: character vector
Values: `'None'` | `'Warning'` | `'Error'`
Default: `'Error'`

`Calculate rates` — Calculate rate of Moon libration

`on` (default) | `off`

Select to calculate the rate of the Moon libration.

Dependencies

Select this check box to display the ω port.

Programmatic Use
Block Parameter: `velflag`
Type: character vector
Values: `'off'` | `'on'` |

Default: `'on'`

References

[1] Folkner, W. M., J. G. Williams, D. H. Boggs. "The Planetary and Lunar Ephemeris DE 421." *IPN Progress Report* 42-178, 2009.

[2] Vallado, D. A. *Fundamentals of Astrodynamics and Applications*. New York: McGraw-Hill, 1997.

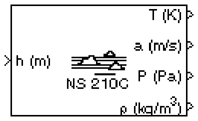
See Also

Earth Nutation | Planetary Ephemeris | `aeroDataPackage`

Introduced in R2013a

Non-Standard Day 210C

Implement MIL-STD-210C climatic data



Library

Environment/Atmosphere

Description

The Non-Standard Day 210C block implements a portion of the climatic data of the MIL-STD-210C worldwide air environment to 80 km (geometric or approximately 262,000 feet geometric) for absolute temperature, pressure, density, and speed of sound for the input geopotential altitude.

The Non-Standard Day 210C block icon displays the input and output units selected from the **Units** list.

Parameters

Units

Specifies the input and output units:

Units	Height	Temperature	Speed of Sound	Air Pressure	Air Density
`Metric (MKS)`	Meters	Kelvin	Meters per second	Pascal	Kilograms per cubic meter
`English (Velocity in ft/s)`	Feet	Degrees Rankine	Feet per second	Pound force per square inch	Slug per cubic foot

Units	Height	Temperature	Speed of Sound	Air Pressure	Air Density
English (Velocity in kts)	Feet	Degrees Rankine	Knots	Pound force per square inch	Slug per cubic foot

Specification

Specify the atmosphere model type from one of the following atmosphere models. The default is `MIL-STD-210C`.

`1976 COESA-extended U.S. Standard Atmosphere` This selection is linked to the COESA Atmosphere Model block. See the block reference for more information.
`MIL-HDBK-310` This selection is linked to the Non-Standard Day 310 block. See the block reference for more information.
`MIL-STD-210C` This selection is linked to the Non-Standard Day 210C block. See the block reference for more information.

Atmospheric model type

Select the representation of the atmospheric data.

`Profile`	Realistic atmospheric profiles associated with extremes at specified altitudes. Recommended for simulation of vehicles vertically traversing the atmosphere or when the total influence of the atmosphere is needed.
`Envelope`	Uses extreme atmospheric values at each altitude. Recommended for vehicles only horizontally traversing the atmosphere without much change in altitude.

Extreme parameter

Select the atmospheric parameter that is the extreme value.

`High temperature`	Option always available

`Low temperature`	Option always available
`High density`	Option always available
`Low density`	Option always available
`High pressure`	This option is available only when `Envelope` is selected for **Atmospheric model type**
`Low pressure`	This option is available only when `Envelope` is selected for **Atmospheric model type**

Frequency of occurrence

Select percent of time the values would occur.

`Extreme values`	This option is available only when `Envelope` is selected for **Atmospheric model type**.
`1%`	Option always available
`5%`	This option is available only when `Envelope` is selected for **Atmospheric model type**.
`10%`	Option always available
`20%`	This option is available only when `Envelope` is selected for **Atmospheric model type**.

Altitude of extreme value

Select geometric altitude at which the extreme values occur. Applies to the profile atmospheric model only.

`5 km (16404 ft)`
`10 km (32808 ft)`
`20 km (65617 ft)`
`30 km (98425 ft)`
`40 km (131234 ft)`

Action for out of range input

Specify if out-of-range input invokes a warning, error, or no action.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the geopotential height.

Output	Dimension Type	Description
First		Contains the temperature.
Second		Contains the speed of sound.
Third		Contains the air pressure.
Fourth		Contains the air density.

Assumptions and Limitations

All values are held below the geometric altitude of 0 m (0 feet) and above the geometric altitude of 80,000 meters (approximately 262,000 feet). The envelope atmospheric model has a few exceptions where values are held below the geometric altitude of 1 kilometer (approximately 3,281 feet) and above the geometric altitude of 30,000 meters (approximately 98,425 feet). These exceptions arise from lack of data in MIL-STD-210C for these conditions.

In general, temperature values are interpolated linearly, and density values are interpolated logarithmically. Pressure and speed of sound are calculated using a perfect gas law. The envelope atmospheric model has a few exceptions where the extreme value is the only value provided as an output. Pressure in these cases is interpolated logarithmically. These envelope atmospheric model exceptions apply to all cases of high and low pressure, high and low temperature, and high and low density, excluding the extreme values and 1% frequency of occurrence. These exceptions arise from lack of data in MIL-STD-210C for these conditions.

Another limitation is that climatic data for the region south of 60°S latitude is excluded from consideration in MIL-STD-210C.

This block uses the metric version of data from the MIL-STD-210C specifications. Certain data within the envelope are inconsistent between metric and English versions for low density, low temperature, high temperature, low pressure, and high pressure. The most significant differences occur in the following values:

- For low density envelope data with 5% frequency, the density values in metric units are inconsistent at 4 km and 18 km and the density values in English units are inconsistent at 14 km.
- For low density envelope data with 10% frequency,
  - The density values in metric units are inconsistent at 18 km.
  - The density values in English units are inconsistent at 14 km.
- For low density envelope data with 20% frequency, the density values in English units are inconsistent at 14 km.
- For low temperature envelope data with 20% frequency, the temperature values at 20 km are inconsistent.
- For high pressure envelope data with 10% frequency, the pressure values in metric units at 8 km are inconsistent.

Reference

Global Climatic Data for Developing Military Products (MIL-STD-210C), 9 January 1987, Department of Defense, Washington, D.C.

See Also

COESA Atmosphere Model

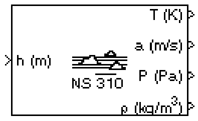
ISA Atmosphere Model

Non-Standard Day 310

Introduced before R2006a

Non-Standard Day 310

Implement MIL-HDBK-310 climatic data



Library

Environment/Atmosphere

Description

The Non-Standard Day 310 block implements a portion of the climatic data of the MIL-HDBK-310 worldwide air environment to 80 km (geometric or approximately 262,000 feet geometric) for absolute temperature, pressure, density, and speed of sound for the input geopotential altitude.

The Non-Standard Day 310 block icon displays the input and output units selected from the **Units** list.

Parameters

Units

Specifies the input and output units:

Units	Height	Temperature	Speed of Sound	Air Pressure	Air Density
`Metric (MKS)`	Meters	Kelvin	Meters per second	Pascal	Kilograms per cubic meter

Units	Height	Temperature	Speed of Sound	Air Pressure	Air Density
`English (Velocity in ft/s)`	Feet	Degrees Rankine	Feet per second	Pound force per square inch	Slug per cubic foot
`English (Velocity in kts)`	Feet	Degrees Rankine	Knots	Pound force per square inch	Slug per cubic foot

Specification

Specify the atmosphere model type from one of the following atmosphere models. The default is `MIL-HDBK-310`.

`1976 COESA-extended U.S. Standard Atmosphere` This selection is linked to the COESA Atmosphere Model block. See the block reference for more information.
`MIL-HDBK-310` This selection is linked to the Non-Standard Day 310 block. See the block reference for more information.
`MIL-STD-210C` This selection is linked to the Non-Standard Day 210C block. See the block reference for more information.

Atmospheric model type

Select the representation of the atmospheric data.

`Profile`	Realistic atmospheric profiles associated with extremes at specified altitudes. Recommended for simulation of vehicles vertically traversing the atmosphere or when the total influence of the atmosphere is needed.
`Envelope`	Uses extreme atmospheric values at each altitude. Recommended for vehicles only horizontally traversing the atmosphere without much change in altitude.

Extreme parameter

Select the atmospheric parameter which is the extreme value.

`High temperature`	Option always available
`Low temperature`	Option always available
`High density`	Option always available
`Low density`	Option always available
`High pressure`	This option is available only when `Envelope` is selected for **Atmospheric model type**.
`Low pressure`	This option is available only when `Envelope` is selected for **Atmospheric model type**.

Frequency of occurrence

Select percent of time the values would occur.

`Extreme values`	This option is available only when `Envelope` is selected for **Atmospheric model type**.
`1%`	Option always available
`5%`	This option is available only when `Envelope` is selected for **Atmospheric model type**.
`10%`	Option always available
`20%`	This option is available only when `Envelope` is selected for **Atmospheric model type**.

Altitude of extreme value

Select geometric altitude at which the extreme values occur. Applies to the profile atmospheric model only.

`5 km (16404 ft)`
`10 km (32808 ft)`
`20 km (65617 ft)`
`30 km (98425 ft)`
`40 km (131234 ft)`

Action for out of range input

Specify if out-of-range input invokes a warning, error, or no action.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the geopotential height.

Output	Dimension Type	Description
First		Contains the temperature.
Second		Contains the speed of sound.
Third		Contains the air pressure.
Fourth		Contains the air density.

Assumptions and Limitations

All values are held below the geometric altitude of 0 m (0 feet) and above the geometric altitude of 80,000 meters (approximately 262,000 feet). The envelope atmospheric model has a few exceptions where values are held below the geometric altitude of 1 kilometer (approximately 3,281 feet) and above the geometric altitude of 30,000 meters (approximately 98,425 feet). These exceptions arise from lack of data in MIL-HDBK-310 for these conditions.

In general, temperature values are interpolated linearly, and density values are interpolated logarithmically. Pressure and speed of sound are calculated using a perfect gas law. The envelope atmospheric model has a few exceptions where the extreme value is the only value provided as an output. Pressure in these cases is interpolated logarithmically. These envelope atmospheric model exceptions apply to all cases of high and low pressure, high and low temperature, and high and low density, excluding the extreme values and 1% frequency of occurrence. These exceptions arise from lack of data in MIL-HDBK-310 for these conditions.

Another limitation is that climatic data for the region south of 60°S latitude is excluded from consideration in MIL-HDBK-310.

This block uses the metric version of data from the MIL-STD-310 specifications. Certain data within the envelope are inconsistent between metric and English versions for low density, low temperature, high temperature, low pressure, and high pressure. The most significant differences occur in the following values:

- For low density envelope data with 5% frequency, the density values in metric units are inconsistent at 4 km and 18 km and the density values in English units are inconsistent at 14 km.
- For low density envelope data with 10% frequency,
  - The density values in metric units are inconsistent at 18 km.
  - The density values in English units are inconsistent at 14 km.
- For low density envelope data with 20% frequency, the density values in English units are inconsistent at 14 km.
- For low temperature envelope data with 20% frequency, the temperature values at 20 km are inconsistent.
- For high pressure envelope data with 10% frequency, the pressure values in metric units at 8 km are inconsistent.

Reference

Global Climatic Data for Developing Military Products (MIL-HDBK-310), 23 June 1997, Department of Defense, Washington, D.C.

See Also

COESA Atmosphere Model

ISA Atmosphere Model

Non-Standard Day 210C

Introduced before R2006a

Nonlinear Second-Order Actuator

Implement second-order actuator with rate and deflection limits

A_{demand}
A_{actual}

Library

Actuators

Description

The Second Order Nonlinear Actuator block outputs the actual actuator position using the input demanded actuator position and other dialog box parameters that define the system.

Parameters

Natural frequency

The natural frequency of the actuator. The units of natural frequency are radians per second.

Damping ratio

The damping ratio of the actuator. A dimensionless parameter.

Maximum deflection

The largest actuator position allowable. The units of maximum deflection must be the same as the units of demanded actuator position.

Minimum deflection

The smallest actuator position allowable. The units of minimum deflection must be the same as the units of demanded actuator position.

Rate limit

The fastest speed allowable for actuator motion. The units of maximum rate must be the units of demanded actuator position per second.

Initial position

The initial position of the actuator. The units of initial position must be the same as the units of demanded actuator position.

If the specified value is less than the value of **Minimum deflection**, the block sets the value of **Minimum deflection** as the initial position value. If the specified value is greater than the value of **Maximum deflection**, the block sets the value of **Maximum deflection** as the initial position value.

Initial velocity

The initial velocity of the actuator. The units of initial velocity must be the same as the units of demanded actuator position per second.

If the absolute value of the specified value is greater than the absolute value of **Rate Limit**, this block sets the value of **Rate Limit** as the initial velocity value.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the demanded actuator position.

Output	Dimension Type	Description
First		Contains the actual actuator position.

Examples

See the Airframe & Autopilot subsystem in the `aero_guidance` model and the Actuators subsystem in the `aeroblk_HL20` model.

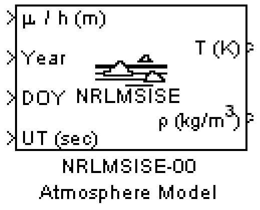
See Also

Linear Second-Order Actuator

Introduced in R2012a

NRLMSISE-00 Atmosphere Model

Implement mathematical representation of 2001 United States Naval Research Laboratory Mass Spectrometer and Incoherent Scatter Radar Exosphere



Library

Environment/Atmosphere

Description

The NRLMSISE-00 Atmosphere Model block implements the mathematical representation of the 2001 United States Naval Research Laboratory Mass Spectrometer and Incoherent Scatter Radar Exosphere (NRLMSISE-00) of the MSIS® class model. This block calculates the neutral atmosphere empirical model from the surface to lower exosphere (0 to 1,000,000 meters). When configuring the block for this calculation, you can also take into account the anomalous oxygen, which can affect the satellite drag above 500,000 meters.

This block has the limitations of the NRLMSISE-00 model. For more information, see the NRLMSISE-00 model documentation.

Note This block is valid only for altitudes between 0 and 1,000,000 meters (1,000 kilometers).

Parameters

Units

Specifies the input and output units:

Units	Temperature	Height	Density
`Metric (MKS)`	Kelvin	Meters	kg/m^3, some density outputs 1/m^3
`English`	Rankine	Feet	lbm/ft^3, some density outputs 1/ft^3

Input local apparent solar time

Select this check box to input the local apparent solar time, in hours. Otherwise, the block inputs the default value.

Input flux and magnetic index information

Select this check box to input the 81-day average of F10.7, the daily F10.7 flux for the previous day, and the array of 7 magnetic index information (see the `aph` argument in the Aerospace Toolbox `atmosnrlmsise00` function). Otherwise, the block inputs the default value.

Source for flags

Specify the variation flag source. If you specify `External`, you must enter the variation flag as an array of 23. If you specify `Internal`, the flag source is internal to the block.

Flags

Specify the variation flag as an array of 23. This parameter applies only when **Source for flags** has a value of `Internal`. You can specify one of the following values for a field. The default value for each field is `1`.

- 0.0

  Removes that value's effect on the output.
- 1.0

  Applies the main and the cross-term effects of that value on the output.

- 2.0

  Applies only the cross-term effect of that value on the output.

The array has the following fields.

Field	Description
`Flags(1)`	F10.7 effect on mean
`Flags(2)`	Independent of time
`Flags(3)`	Symmetrical annual
`Flags(4)`	Symmetrical semiannual
`Flags(5)`	Asymmetrical annual
`Flags(6)`	Asymmetrical semiannual
`Flags(7)`	Diurnal
`Flags(8)`	Semidiurnal
`Flags(9)`	Daily AP. If you set this field to -1, the block uses the entire matrix of magnetic index information (APH) instead of `APH(:,1)`
`Flags(10)`	All UT, longitudinal effects
`Flags(11)`	Longitudinal
`Flags(12)`	UT and mixed UT, longitudinal
`Flags(13)`	Mixed AP, UT, longitudinal
`Flags(14)`	Terdiurnal
`Flags(15)`	Departures from diffusive equilibrium
`Flags(16)`	All exospheric temperature variations
`Flags(17)`	All variations from 120,000 meter temperature (TLB)
`Flags(18)`	All lower thermosphere (TN1) temperature variations
`Flags(19)`	All 120,000 meter gradient (S) variations
`Flags(20)`	All upper stratosphere (TN2) temperature variations
`Flags(21)`	All variations from 120,000 meter values (ZLB)
`Flags(22)`	All lower mesosphere temperature (TN3) variations

Field	Description
`Flags(23)`	Turbopause scale height variations

Include anomalous oxygen number density in total mass density

Select this check box to take into account the anomalous oxygen when calculating the neutral atmosphere empirical model from the surface to lower exosphere (0 to 1,000,000 meters). Taking into account this number can affect the satellite drag above 500,000 meters.

Action for out-of-range input

Specify if out-of-range input invokes a warning, error, or no action.

Inputs and Outputs

Input	Dimension Type	Description
First	Three-element matrix	Contains geodetic latitudes, in degrees, longitude, in degrees, and altitude, in selected length units.
Second	Array	Contains *N* years.
Third	Array	Contains *N* days of a year (1 to 365 (or 366)).
Fourth	Array	Contains *N* seconds in a day, in universal time (UT).
Fifth (Optional)	Array	Contains *N* local apparent solar time, in hours.
Sixth (Optional)	Array	Contains *N* 81-day average of F10.7 flux, centered on day of year (doy).
Seventh (Optional)	Array	Contains *N* daily F10.7 flux for previous day.

Input	Dimension Type	Description
Eight (Optional)	*N*-by-7 array	Contains an array of *N*-by-7 of magnetic index information. If you specify *`magneticIndex`*, you must also specify *`f107Average`* and *`f107Daily`*. This information consists of: Daily magnetic index (AP) 3 hour AP for current time 3 hour AP for 3 hours before current time 3 hour AP for 6 hours before current time 3 hour AP for 9 hours before current time Average of eight 3 hour AP indices from 12 to 33 hours before current time Average of eight 3 hour AP indices from 36 to 57 hours before current time The effects of daily magnetic index are not large or established below 80,000 m. As a result, the function sets the default value to 4. See the limitations in Description on page 4-485 for more information.
Ninth (Optional)	Array of 23	Contains flags to enable or disable particular variations for the outputs. See following table.

These flags, associated with the ninth input, enable or disable particular variations for the outputs.

Field	Description
`Flags(1)`	F10.7 effect on mean
`Flags(2)`	Independent of time
`Flags(3)`	Symmetrical annual
`Flags(4)`	Symmetrical semiannual
`Flags(5)`	Asymmetrical annual
`Flags(6)`	Asymmetrical semiannual
`Flags(7)`	Diurnal
`Flags(8)`	Semidiurnal
`Flags(9)`	Daily AP. If you set this field to -1, the block uses the entire matrix of magnetic index information (APH) instead of `APH(:,1)`

Field	Description
`Flags(10)`	All UT, longitudinal effects
`Flags(11)`	Longitudinal
`Flags(12)`	UT and mixed UT, longitudinal
`Flags(13)`	Mixed AP, UT, longitudinal
`Flags(14)`	Terdiurnal
`Flags(15)`	Departures from diffusive equilibrium
`Flags(16)`	All exospheric temperature variations
`Flags(17)`	All variations from 120,000 meter temperature (TLB)
`Flags(18)`	All lower thermosphere (TN1) temperature variations
`Flags(19)`	All 120,000 meter gradient (S) variations
`Flags(20)`	All upper stratosphere (TN2) temperature variations
`Flags(21)`	All variations from 120,000 meter values (ZLB)
`Flags(22)`	All lower mesosphere temperature (TN3) variations
`Flags(23)`	Turbopause scale height variations

The outputs are:

Output	Dimension Type	Description
First	Array	Contains *N*-by-2 values of temperature, in selected temperature units. The first column is exospheric temperature, the second column is temperature at altitude.
Second	Array	Contains *N*-by-9 values of densities in selected density units. See the following table:

These densities are associated with the second output.

Density	Description
`Density(1)`	Density of He
`Density(2)`	Density of O
`Density(3)`	Density of N2

Density	Description
`Density(4)`	Density of O2
`Density(5)`	Density of Ar
`Density(6)`	Total mass density `Density(6)`, total mass density, is defined as the sum of the mass densities of He, O, N2, O2, Ar, H, and N. Optionally, `Density(6)` can include the mass density of anomalous oxygen making `Density(6)`, the effective total mass density for drag.
`Density(7)`	Density of H
`Density(8)`	Density of N
`Density(9)`	Anomalous oxygen number density

Assumptions and Limitations

The F107 and F107A values that are used to generate the model correspond to the 10.7 cm radio flux at the actual distance of the Earth from the Sun rather than the radio flux at 1 AU. The following site provides both classes of values:

- `ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES/KP_AP/`
- `ftp://ftp.ngdc.noaa.gov/STP/space-weather/solar-data/solar-features/solar-radio/noontime-flux/penticton/`

The format for the data indices for these values are located here:

`ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES/KP_AP/kp_ap.fmt`

References

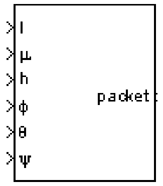
`https://ccmc.gsfc.nasa.gov/modelweb/atmos/nrlmsise00.html`

Introduced in R2007b

Pack net_fdm Packet for FlightGear

Generate `net_fdm` packet for FlightGear

Library: Aerospace Blockset / Animation / Flight Simulator Interfaces



Description

The Pack net_fdm Packet for FlightGear block creates, from separate inputs, a FlightGear `net_fdm` data packet compatible with a particular version of FlightGear flight simulator. This block accepts all signals supported by the FlightGear `net_fdm` data packet. These signals are arranged into six groups:

- Position/attitude inputs
- Velocity/acceleration inputs
- Control surface position inputs
- Engine/fuel inputs
- Landing gear inputs
- Environment inputs

To enable or disable the inputs for these groups, select the associated block parameter. The block input ports change depending on the requested signal groups. The block inserts zeros for packet values that are part of inactive signal groups.

Ports

Input

Position/Attitude Inputs

l — Longitude
scalar

Longitude, specified as a scalar, in rad.

Dependencies

To enable this port, select the **Show position/attitude inputs** check box.

Data Types: `double`

μ — Latitude
scalar

Latitude, specified as a scalar, in rad.

Dependencies

To enable this port, select the **Show position/attitude inputs** check box.

Data Types: `double`

h — Altitude
scalar

Altitude, specified as a scalar, in m.

Dependencies

To enable this port, select the **Show position/attitude inputs** check box.

Data Types: `double`

ϕ — Roll
scalar

Roll, specified as a scalar, in rad.

Dependencies

To enable this port, select the **Show position/attitude inputs** check box.

Data Types: `single`

θ — Pitch
scalar

Roll, specified as a scalar, in rad.

Dependencies

To enable this port, select the **Show position/attitude inputs** check box.

Data Types: `single`

ψ — Yaw
scalar

Roll, specified as a scalar, in rad.

Dependencies

To enable this port, select the **Show position/attitude inputs** check box.

Data Types: `single`

Velocity/Acceleration Inputs

α — Angle of attack
scalar

Angle of attack, specified as a scalar, in rad.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

β — Sideslip angle
scalar

Sideslip angle, specified as a scalar, in rad.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `double`

`dφ/dt` — Roll rate
scalar

Roll rate, specified as a scalar, in rad/sec.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `double`

`dθ/dt` — Pitch rate
scalar

Pitch rate, specified as a scalar, in rad/sec.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

`dψ/dt` — Yaw rate
scalar

Yaw rate, specified as a scalar, in rad/sec.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

V_{cas} — Calibrated airspeed
scalar

Calibrated airspeed, specified as a scalar, in knots.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

`climb_rate` — Rate of climb
scalar

Rate of climb, specified as a scalar, in feet/sec.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

v_{north} — North velocity in body frame
scalar

North velocity in body frame, specified as a scalar, in ft/sec.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

v_{east} — East velocity in body frame
scalar

East velocity in body frame, specified as a scalar, in feet/sec.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

v_{down} — Down velocity
scalar

Down velocity, specified as a scalar, in feet/sec.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

$\mathrm{V}_{\texttt{wind body north}}$ — North velocity in body frame relative to local airmass
scalar

North velocity in body frame relative to local airmass, specified as a scalar, in feet/sec.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

$\mathrm{V}_{\texttt{wind body east}}$ — East velocity in body frame relative to local airmass
scalar

East velocity in body frame relative to local airmass, specified as a scalar, in feet/sec.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

$\mathrm{V}_{\texttt{wind body down}}$ — Down velocity in body frame relative to airmass
scalar

Down velocity in body frame relative to airmass, specified as a scalar, in feet/sec.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

$\mathrm{A}_{\mathrm{X}\ \texttt{pilot}}$ — *X* acceleration in body frame
scalar

X acceleration in body frame, specified as a scalar, in feet/sec^2.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

$\mathrm{A}_{\mathrm{Y}\ \texttt{pilot}}$ — *Y* acceleration in body frame
scalar

Y acceleration in body frame, specified as a scalar, in feet/sec^2.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

$A_{Z\ pilot}$ — *Z* acceleration in body frame
scalar

Z acceleration in body frame, specified as a scalar, in feet/sec^2.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

`stall_warning` — Amount of stall
scalar

Amount of stall [0-1], specified as a scalar, in feet/sec^2.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

`slip_degree` — Slip ball deflection
scalar

Slip ball deflection. specified as a scalar, in deb.

Dependencies

To enable this port, select the **Show velocity/acceleration inputs** check box.

Data Types: `single`

Control Surface Position Inputs

`elevator` — Normalized elevator position
scalar

Normalized elevator position, specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position inputs** check box.

Data Types: `double`

`elevator_trim_tab` — Normalized elevator trim tab position
scalar

Normalized elevator trim tab position, specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position inputs** check box.

Data Types: `double`

`left_flap` — Normalized left flap position
scalar

Normalized left flap position, specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position inputs** check box.

Data Types: `double`

`right_flap` — Normalized right flap position
scalar

Normalized right flap position, specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position inputs** check box.

Data Types: `single`

`left_aileron` — Normalized left aileron position
scalar

Normalized left aileron position. specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position inputs** check box.

Data Types: `single`

`right_aileron` — Normalized right aileron position
scalar

Normalized right aileron position, specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position inputs** check box.

Data Types: `single`

`rudder` — Normalized rudder position
scalar

Normalized rudder position, specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position inputs** check box.

Data Types: `single`

`nose_wheel` — Normalized nose wheel position
scalar

Normalized nose wheel position, specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position inputs** check box.

Data Types: `single`

`speedbrake` — Normalized speedbrake position
scalar

Normalized speedbrake position, specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position inputs** check box.

Data Types: `single`

`spoilers` — Normalized spoilers position
scalar

Normalized spoilers position, specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position inputs** check box.

Data Types: `single`

Engine/Fuel Inputs

`num_engines` — Number of engines
scalar

Number of engines, specified as a scalar.

Dependencies

To enable this port, select the **Show engine/fuel inputs** check box.

Data Types: `uint32`

`eng_state` — Engine state
vector

Engine state (off, cranking, running), specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel inputs** check box.

Data Types: `uint32`

`rpm` — Engine RPM
vector

Engine RPM, specified as a vector, in rev/min.

Dependencies

To enable this port, select the **Show engine/fuel inputs** check box.

Data Types: `double`

`fuel_flow` — Fuel flow
vector

Fuel flow, specified as a vector, in gal/hr.

Dependencies

To enable this port, select the **Show engine/fuel inputs** check box.

Data Types: `single`

`fuel_px` — Fuel pressure
vector

Fuel pressure, specified as a vector, in gal/hour.

Dependencies

To enable this port, select the **Show engine/fuel inputs** check box.

Data Types: `single`

`egt` — Exhaust gas temperature
vector

Exhaust gas temperature, specified as a vector, in deg F.

Dependencies

To enable this port, select the **Show engine/fuel inputs** check box.

Data Types: `single`

`cht` — Cylinder head temperature
scalar

Cylinder head temperature, specified as a vector, in deg F.

Dependencies

To enable this port, select the **Show engine/fuel inputs** check box.

Data Types: `single`

`mp_osi` — Manifold pressure
vector

Manifold pressure, specified as a vector, in psi.

Dependencies

To enable this port, select the **Show engine/fuel inputs** check box.

Data Types: `single`

`tit` — Turbine inlet temperature
vector

Turbine inlet temperature, specified as a vector, in deg F.

Dependencies

To enable this port, select the **Show engine/fuel inputs** check box.

Data Types: `single`

`oil_temp` — Oil temperature
vector

Oil temperature, specified as a vector, in deg F.

Dependencies

To enable this port, select the **Show engine/fuel inputs** check box.

Data Types: `single`

`oil_px` — Oil pressure
vector

Oil pressure, specified as a vector, in psi.

Dependencies

To enable this port, select the **Show engine/fuel inputs** check box.

Data Types: `single`

`num_tanks` — Number of fuel tanks
scalar

Number of fuel tanks, specified as a scalar.

Dependencies

To enable this port, select the **Show engine/fuel inputs** check box.

Data Types: `uin32`

`fuel_quantity` — Fuel quantity per tank
vector

Fuel quantity per tank, specified as a vector, in gal.

Dependencies

To enable this port, select the **Show engine/fuel inputs** check box.

Data Types: `single`

Landing Gear Inputs

`num_wheels` — Number of wheels
uint32

Number of wheels, specified as a scalar.

Dependencies

To enable this port, select the **Show landing gear inputs** check box.

Data Types: `uit32`

`wow` — Weight on wheels switch
vector

Weight on wheels switch, specified as a vector.

Dependencies

To enable this port, select the **Show landing gear inputs** check box.

Data Types: `uint32`

`gear_pos` — Landing gear normalized position
vector

Landing gear normalized position, specified as a vector.

Dependencies

To enable this port, select the **Show landing gear inputs** check box.

Data Types: `single`

`gear_steer` — Landing gear normalized steering
vector

Landing gear normalized steering, specified as a vector.

Dependencies

To enable this port, select the **Show landing gear inputs** check box.

Data Types: `single`

`gear_compression` — Landing gear normalized compression
vector

Landing gear normalized compression, specified as a vector.

Dependencies

To enable this port, select the **Show landing gear inputs** check box.

Data Types: `single`

Environment Inputs

`agl` — Above ground level
scalar

Above ground level, specified as a scalar, in m.

Dependencies

To enable this port, select the **Show environment inputs** check box.

Data Types: `single`

`cur_time` — Current UNIX® time
scalar

Current UNIX time, specified as a scalar, in sec.

Dependencies

To enable this port, select the **Show environment inputs** check box.

Data Types: `uint32`

`warp` — Offset in seconds to UNIX time
scalar

Offset in seconds to UNIX time, specified as a scalar, in sec.

Dependencies

To enable this port, select the **Show environment inputs** check box.

Data Types: `double`

`visibility` — Visibility
scalar

Visibility (for visual effects), specified as a scalar, in m.

Dependencies

To enable this port, select the **Show environment inputs** check box.

Data Types: `single`

Output

`Output 1` — Packet generated for FlightGear
array

Packet generated for FlightGear, specified as an array.

Data Types: `single` | `double` | `uint32`

Parameters

`FlightGear version` — FlightGear version
`v2018.2` (default) | `v2018.1` | `v2017.3` | `v2017.1` | `v2016.3` | `v2016.1` | `v3.4` | `v3.2` | `v3.0` | `v2.12` | `v2.10` | `v2.8` | `v2.6` | `v2.4` | `v2.0`

FlightGear software version, selected from the list.

Note If you are using a FlightGear version older than 2.0, the model displays a notification from the Simulink Upgrade Advisor. Consider using the Upgrade Advisor to upgrade your FlightGear version. For more information, see “Supported FlightGear Versions” on page 2-19.

Programmatic Use
Block Parameter: `FlightGearVersion`
Type: character vector
Values: scalar
Default: `'v2018.2'`

`Show position/altitude inputs` — Position and altitude inputs
`on` (default) | `off`

Select this check box to include the position and altitude inputs in the FlightGear `net_fdm` data packet.

Dependencies

Select this check box to enable these input ports.

Signal Group 1: Position/Altitude Inputs

Name	Units	Type	Width	Description
longitude	rad	double	1	Geodetic longitude
latitude	rad	double	1	Geodetic latitude
altitude	m	double	1	Altitude above sea level
theta	rad	single	1	Pitch
phi	rad	single	1	Roll
psi	rad	single	1	Yaw

Programmatic Use
Block Parameter: `ShowPositionAttitudeInputs`
Type: character vector
Values: `'off' | 'on'`
Default: `'on'`

`Show velocity/acceleration inputs` — Velocity and acceleration inputs
`off` (default) | `on`

Select this check box to include the velocity and acceleration inputs in the FlightGear `net_fdm` data packet.

Dependencies

Select this check box to enable these input ports.

Signal Group 2: Velocity/Acceleration Inputs

Name	Units	Type	Width	Description
alpha	rad	single	1	Angle of attack
beta	rad	single	1	Sideslip angle
dphi/dt	rad/sec	single	1	Roll rate
dtheta/dt	rad/sec	single	1	Pitch rate
dpsi/dt	rad/sec	single	1	Yaw rate
Vcas	knot	single	1	Calibrated airspeed
climb_rate	feet/sec	single	1	Rate of climb
v_north	feet/sec	single	1	North velocity in body frame
v_east	feet/sec	single	1	East velocity in body frame
v_down	feet/sec	single	1	Down velocity
v_wind_body_north	feet/sec	single	1	North velocity in body frame relative to local airmass
v_wind_body_east	feet/sec	single	1	East velocity in body frame relative to local airmass
v_wind_body_down	feet/sec	single	1	Down velocity in body frame relative to airmass
Axpilot	feet/sec^2	single	1	*X* acceleration in body frame
Aypilot	feet/sec^2	single	1	*Y* acceleration in body frame
Azpilot	feet/sec^2	single	1	*Z* acceleration in body frame
stall_warning	—	single	1	Amount of stall [0-1]
slip_deg	deb	single	1	Slip ball deflection

Programmatic Use
Block Parameter: `ShowVelocityAccelerationInputs`
Type: character vector
Values: `'off' | 'on'`
Default: `'off'`

`Show control surface position inputs` — Control surface position inputs

`off` (default) | `on`

Select this check box to include the control surface position inputs in the FlightGear `net_fdm` data packet.

Dependencies

Select this check box to enable these input ports.

Signal Group 3: Control Surface Position Inputs

Name	Units	Type	Width	Description
elevator	1 (dimensionless)	single	1	Normalized elevator position
elevator_trim_tab	1 (dimensionless)	single	1	Normalized elevator trim tab position
left_flap	1 (dimensionless)	single	1	Normalized left flap position
right_flap	1 (dimensionless)	single	1	Normalized right flap position
left_aileron	1 (dimensionless)	single	1	Normalized left aileron position
right_aileron	1 (dimensionless)	single	1	Normalized right aileron position
rudder	1 (dimensionless)	single	1	Normalized rudder position
nose_wheel	1 (dimensionless)	single	1	Normalized nose wheel position
speedbrake	1 (dimensionless)	single	1	Normalized speedbrake position
spoilers	1 (dimensionless)	single	1	Normalized spoilers position

Programmatic Use
Block Parameter: `ShowControlSurfacePositionInputs`
Type: character vector
Values: `'off' | 'on'`
Default: `'off'`

`Show engine/fuel inputs` — Engine and fuel inputs
`off` (default) | `on`

Select this check box to include the engine and fuel inputs in the FlightGear `net_fdm` data packet.

Dependencies

Select this check box to enable these input ports.

Signal Group 4: Engine/Fuel Inputs

Name	Units	Type	Width	Description
num_engines	—	uint32	1	Number of engines
eng_state	—	uint32	4	Engine state (off, cranking, running)
rpm	rev/min	single	4	Engine RPM
fuel_flow	gal/hour	single	4	Fuel flow
fuel_px	psi	single	4	Fuel pressure
egt	deg F	single	4	Exhaust gas temperature
cht	deg F	single	4	Cylinder head temperature
mp_osi	psi	single	4	Manifold pressure
tit	deg F	single	4	Turbine inlet temperature
oil_temp	deg F	single	4	Oil temperature
oil_px	psi	single	4	Oil pressure
num_tanks	—	uint32	1	Number of fuel tanks
fuel_quantity	gal	single	4	Fuel quantity per tank

Programmatic Use
Block Parameter: `ShowEngineFuelInputs`
Type: character vector
Values: `'off' | 'on'`
Default: `'off'`

`Show landing gear inputs` — Landing gear inputs
`off` (default) | `on`

Select this check box to include the landing gear inputs in the FlightGear `net_fdm` data packet.

Dependencies

Select this check box to enable these input ports.

Signal Group 5: Landing Gear Inputs

Name	Units	Type	Width	Description
num_wheels	—	uint32	1	Number of wheels
wow	—	uint32	3	Weight on wheels switch
gear_pos	—	single	3	Landing gear normalized position
gear_steer	—	single	3	Landing gear normalized steering
gear_compression	—	single	3	Landing gear normalized compression

Programmatic Use
Block Parameter: `ShowLandingGearInputs`
Type: character vector
Values: `'off' | 'on'`
Default: `'off'`

`Show environment inputs` — Environment inputs
`off` (default) | `on`

Select this check box to include the environment inputs in the FlightGear `net_fdm` data packet.

Dependencies

Select this check box to enable these input ports.

Signal Group 6: Environment Inputs

Name	Units	Type	Width	Description
agl	m	single	1	Above ground level
cur_time	sec	uint32	1	Current UNIX time
warp	sec	uint32	1	Offset in seconds to UNIX time
visibility	m	single	1	Visibility in meters (for visual effects)

Programmatic Use
Block Parameter: `ShowEnvironmentInputs`
Type: character vector
Values: `'off' | 'on'`
Default: `'off'`

`Sample time` — Sample time

`1/30` (default) | scalar

Specify the sample time (-1 for inherited).

Programmatic Use
Block Parameter: `SampleTime`
Type: character vector
Values: scalar
Default: `'1/30'`

See Also

FlightGear Preconfigured 6DoF Animation | Generate Run Script | Receive net_ctrl Packet from FlightGear | Send net_fdm Packet to FlightGear | Unpack net_ctrl Packet from FlightGear

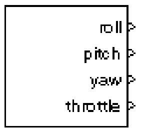
Topics

“Flight Simulator Interface” on page 2-19
“Work with the Flight Simulator Interface” on page 2-24

Introduced before R2006a

Pilot Joystick

Provide joystick interface on Windows platform



Library

Animation/Animation Support Utilities

Description

The Pilot Joystick block provides a pilot joystick interface for a Windows platform. Roll, pitch, yaw, and throttle are mapped to the joystick *X*, *Y*, *R*, and *Z* channels respectively.

You can also configure the block to output all channels by setting the **Output configuration** parameter to `AllOutputs`.

This block does not produce deployable code.

Parameters

Joystick ID

Specify the joystick ID: `Joystick 1`, `Joystick 2`, or `None`.

Output configuration

Specify the output configuration: `FourAxis` or `AllOutputs` (see Pilot Joystick All). `FourAxis` is the default.

Sample time

Specify the sample time (-1 for inherited).

Inputs and Outputs

The block has the following outputs.

Four Axis Mode (All Double Precision Values)

Port Number	Output Range	Joystick	Description
1	[-1, 1]	[left, right]	Roll command
2	[-1, 1]	[forward/down, back/up]	Pitch command
3	[-1, 1]	[left, right]	Yaw command
4	[0, 1]	[min, max]	Throttle command

All Outputs Mode (All Values Double Precision, Except for Buttons)

Port Number	Array Number	Channel	Output Range	Joystick	Description
1	1	X	[-1, 1]	[left, right]	Roll command
1	2	Y	[-1, 1]	[forward/down, back/up]	Pitch command
1	3	Z	[0, 1]	[min, max]	Throttle command
1	4	R	[-1, 1]	[left, right]	Yaw command
1	5	U	[0, 1]	[min, max]	U channel value
1	6	V	[0, 1]	[min, max]	V channel value
2		buttons			uint32 flagword containing up to 32 button states. Bit 0 is button 1, etc.
3		POV			Point-of-view hat value in degrees as a double. Zero degrees is straight ahead, 90 is to the left, etc.

Output values are [-1,1] for centered values, [0,1] for noncentered values, and uint32 for the buttons in All Outputs mode. Output sense is positive for right-hand rule rotations on centered values (roll, pitch, and yaw).

Assumptions and Limitations

If the joystick does not support an *R* (rudder or “twist”) channel, yaw output is set to zero. Outputs are of type double except for the buttons output in `AllOutputs` mode, which is a uint32 flagword of bits. On non-Windows platforms, this block currently outputs zeros.

Note Pitch value has the opposite sense as that delivered by FlightGear's joystick interface.

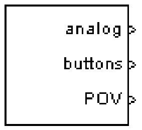
See Also

Pilot Joystick All, Simulation Pace

Introduced before R2006a

Pilot Joystick All

Provide joystick interface in All Outputs configuration on Windows platform



Library

Animation/Animation Support Utilities

Description

The Pilot Joystick All block provides a pilot joystick interface for a Windows platform. Analog is mapped to the joystick X, Y, Z, R, U, and V channels. Buttons and POV are mapped to up to 32 joystick button states and the joystick point-of-view hat.

You can also configure the block to output four axes by setting the **Output configuration** parameter to `FourAxis`.

This block does not produce deployable code.

Parameters

Joystick ID

Specify the joystick ID: `Joystick 1`, `Joystick 2`, or `None`.

Output configuration

Specify the output configuration: `FourAxis` (see Pilot Joystick) or `AllOutputs`. `AllOutputs` is the default.

Sample time

Specify the sample time (-1 for inherited).

Inputs and Outputs

The block has the following outputs.

Four Axis Mode (All Double Precision Values)

Port Number	Output Range	Joystick	Description
1	[-1, 1]	[left, right]	Roll command
2	[-1, 1]	[forward/down, back/up]	Pitch command
3	[-1, 1]	[left, right]	Yaw command
4	[0, 1]	[min, max]	Throttle command

All Outputs Mode (All Values Double Precision, Except for Buttons)

Port Number	Array Number	Channel	Output Range	Joystick	Description
1	1	X	[-1, 1]	[left, right]	Roll command
1	2	Y	[-1, 1]	[forward/down, back/up]	Pitch command
1	3	Z	[0, 1]	[min, max]	Throttle command
1	4	R	[-1, 1]	[left, right]	Yaw command
1	5	U	[0, 1]	[min, max]	U channel value
1	6	V	[0, 1]	[min, max]	V channel value
2		buttons			uint32 flagword containing up to 32 button states. Bit 0 is button 1, etc.
3		POV			Point-of-view hat value in degrees as a double. Zero degrees is straight ahead, 90 is to the left, etc.

Output values are [-1,1] for centered values, [0,1] for noncentered values, and uint32 for the buttons in All Outputs mode. Output sense is positive for right-hand rule rotations on centered values (roll, pitch, and yaw).

Assumptions and Limitations

If the joystick does not support an R (rudder or “twist”) channel, yaw output is set to zero. Outputs are of type double except for the buttons output in `AllOutputs` mode, which is a uint32 flagword of bits. On non-Windows platforms, this block currently outputs zeros.

Note Pitch value has the opposite sense as that delivered by FlightGear's joystick interface.

See Also

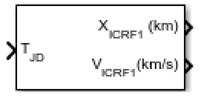
Pilot Joystick, Simulation Pace

Introduced in R2007a

Planetary Ephemeris

Implement position and velocity of astronomical objects

Library: Aerospace Blockset / Environment / Celestial Phenomena



Description

The Planetary Ephemeris block uses Chebyshev coefficients to implement the position and velocity of the target object relative to the specified center object for a given Julian date. The **Target** parameter specifies an astronomical object. The block implements the ephemerides using the **Center** parameter for an astronomical object as the reference.

The block uses the Chebyshev coefficients that the NASA Jet Propulsion Laboratory provides.

Tip For T_{JD}, Julian date input for the block:

- Calculate the date using the Julian Date Conversion block or the Aerospace Toolbox `juliandate` function.
- Calculate the Julian date using some other means and input it using the Constant block.

This block implements the position and velocity using the International Celestial Reference Frame. If you require the planetary ephemeris position value relative to Earth in Earth-fixed (ECEF) coordinates, use the Direction Cosine Matrix ECI to ECEF block.

Ports

Input

T_{JD} — Julian date

scalar | positive | between minimum and maximum Julian dates

Julian date, specified as a positive scalar between minimum and maximum Julian datas.

See the **Ephemeris model** parameter for the minimum and maximum Julian dates.

Dependencies

This port displays if the **Epoch** parameter is set to `Julian date`.

Data Types: `double`

$T0_{JD}$ — Fixed Julian date

scalar | positive

Fixed Julian date for a specific epoch that is the most recent midnight at or before the interpolation epoch, specified as a positive scalar. The sum of $T0_{JD}$ and ΔT_{JD} must fall between the minimum and maximum Julian date.

See the **Ephemeris model** parameter for the minimum and maximum Julian dates.

Dependencies

This port displays if the **Epoch** parameter is set to `T0 and elapsed Julian time`.

Data Types: `double`

ΔT_{JD} — Elapsed Julian time

scalar | positive

Elapsed Julian time between the fixed Julian date and the ephemeris time, specified as a positive scalar. The sum of $T0_{JD}$ and ΔT_{JD} must fall between the minimum and maximum Julian date.

See the **Ephemeris model** parameter for the minimum and maximum Julian dates.

Dependencies

This port displays if the **Epoch** parameter is set to `T0 and elapsed Julian time`.

Data Types: `double`

Output

X_{ICRF1} — Barycenter position

vector

Barycenter position (X_{ICRF1}) of the **Target** object relative to the barycenter of the **Center** object, output as a vector, in km or astronomical units (AU).

Tip This block outputs the barycenter position in Earth-centered inertial (ECI) coordinates. To convert these coordinates to Earth-centered Earth-fixed (ECEF), use the Direction Cosine Matrix ECI to ECEF block.

Data Types: `double`

V_{ICRF} — Velocity
vector

Velocity (V_{ICRF}) of the barycenter of the **Target** object relative to the barycenter of the **Center** object, specified as a vector, in km/s or astronomical units (AU)/day.

Data Types: `double`

Parameters

`Units` — Output units

`km,km/s` (default) | `AU,AU/day`

Output units, specified as `km,km/s` or `AU,AU/day`.

Units	Position	Velocity
`km,km/s`	km	km/s
`Au,AU/day`	astronomical units (AU)	AU/day

Programmatic Use
Block Parameter: `kmflag`
Type: character vector
Values: `km,km/s` | `AU,AU/day`
Default: `'km,km/s'`

`Epoch` — Epoch

`Julian date` (default) | `T0 and elapsed Julian time`

Epoch, specified as:

- `Julian date`

  Julian date to implement the position and velocity of the **Target** object.. When this option is selected, the block has one input port, T_{JD}.
- `T0 and elapsed Julian time`

  Julian date, specified by two block inputs:

  - Fixed Julian date representing a starting epoch. The sum of $T0_{JD}$ and ΔT_{JD} must fall between the minimum and maximum Julian date.
  - Elapsed Julian time between the fixed Julian date ($T0_{JD}$) and the desired model simulation time. The sum of $T0_{JD}$ and ΔT_{JD} must fall between the minimum and maximum Julian date.

  T0 plus the variable elapsed time cannot exceed the maximum Julian date for the specified **Ephemeris model**.

Programmatic Use
Block Parameter: `epochflag`
Type: character vector
Values: `Julian date` | `T0 and elapsed Julian time`
Default: `'Julian date'`

`Ephemeris model` — Ephemeris model

`DE405` (default) | `DE421` | `DE423` | `DE430` | `DE432t`

Select one of the following ephemerides models defined by the Jet Propulsion Laboratory.

Ephemeris Model	Description
`DE405`	Released in 1998. This ephemeris takes into account the Julian date range 2305424.50 (December 9, 1599) to 2525008.50 (February 20, 2201). This block implements these ephemerides with respect to the International Celestial Reference Frame version 1.0, adopted in 1998.

Ephemeris Model	Description
`DE421`	Released in 2008. This ephemeris takes into account the Julian date range 2414992.5 (December 4, 1899) to 2469808.5 (January 2, 2050). This block implements these ephemerides with respect to the International Celestial Reference Frame version 1.0, adopted in 1998.
`DE423`	Released in 2010. This ephemeris takes into account the Julian date range 2378480.5 (December 16, 1799) to 2524624.5 (February 1, 2200). This block implements these ephemerides with respect to the International Celestial Reference Frame version 2.0, adopted in 2010.
`DE430`	Released in 2013. This ephemeris takes into account the Julian date range 2287184.5 (December 21, 1549) to 2688976.5 (January 25, 2650). This block implements these ephemerides with respect to the International Celestial Reference Frame version 2.0, adopted in 2010.
`DE432t`	Released in April 2014. This ephemeris takes into account the Julian date range 2287184.5, (December 21, 1549) to 2688976.5, (January 25, 2650). This block implements these ephemerides with respect to the International Celestial Reference Frame version 2.0, adopted in 2010.

Note This block requires that you download ephemeris data using the Add-On Explorer. To start the Add-On Explorer, in the MATLAB Command Window, type `aeroDataPackage`. on the MATLAB desktop toolstrip, click the **Add-Ons** button.

Center — Center body

`Sun` (default) | `Mercury` | `Venus` | `Earth` | `Moon` | `Mars` | `Jupiter` | `Saturn` | `Uranus` | `Neptune` | `Pluto` | `Solar system barycenter` | `Earth-Moon barycenter`

Center body (astronomical object) or reference body, specified as a point of reference for the **Target** barycenter position and velocity measurement.

Programmatic Use
Block Parameter: `nCenter`
Type: character vector
Values: `Sun` | `Mercury` | `Venus` | `Earth` | `Moon` | `Mars` | `Jupiter` | `Saturn` | `Uranus` | `Neptune` | `Pluto` | `Solar system barycenter` | `Earth-Moon barycenter`
Default: `'Sun'`

`Target` — Target body

`Sun` (default) | `Mercury` | `Venus` | `Earth` | `Moon` | `Mars` | `Jupiter` | `Saturn` | `Uranus` | `Neptune` | `Pluto` | `Solar system barycenter` | `Earth-Moon barycenter`

Target body (astronomical object) or reference body, specified as a point of reference for the barycenter position and velocity measurement.

`Action for out-of-range input` — Out-of-range block behavior

`None` (default) | `Warning` | `Error`

Out-of-range block behavior, specified as follows.

Action	Description
`None`	No action.
`Warning`	Warning in the MATLAB Command Window, model simulation continues.
`Error` (default)	MATLAB returns an exception, model simulation stops.

Programmatic Use
Block Parameter: `errorflag`
Type: character vector
Values: `'None'` | `'Warning'` | `'Error'`
Default: `'Error'`

`Calculate velocity` — Calculate rate of target barycenter

`on` (default) | `off`

Select this check box to calculate the velocity of the **Target** barycenter relative to the **Center** barycenter.

Programmatic Use
Block Parameter: `velflag`
Type: character vector
Values: `'off'` | `'on'` |
Default: `'on'`

References

[1] Folkner, W. M., J. G. Williams, D. H. Boggs. "The Planetary and Lunar Ephemeris DE 421." *IPN Progress Report* 42-178, 2009.

[2] Ma, C. et al. "The International Celestial Reference Frame as Realized by Very Long Baseline Interferometry." *Astronomical Journal*, Vol. 116, 516–546, 1998.

[3] Vallado, D. A. *Fundamentals of Astrodynamics and Applications*, New York: McGraw-Hill, 1997.

See Also

Constant | Direction Cosine Matrix ECI to ECEF | Earth Nutation | Julian Date Conversion | Moon Libration | `aeroDataPackage` | `juliandate`

Introduced in R2013a

Precision Pilot Model

Represent precision pilot model

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Precision Pilot Model

Library

Pilot Models

Description

The Precision Pilot Model block represents the pilot model described in *Mathematical Models of Human Pilot Behavior*. (For more information, see [1] on page 4-531). This pilot model is a single input, single output (SISO) model that represents some aspects of human behavior when controlling aircraft. When modeling human pilot models, use this block for the most accuracy, compared to that provided by the Tustin Pilot Model and Crossover Pilot Model blocks.

This block is an extension of the Crossover Pilot Model block. When calculating the model, this block also takes into account the neuromuscular dynamics of the pilot. This block implements the following equation:

$$Y_p = K_p e^{-\tau s}\left(\frac{T_L s + 1}{T_I s + 1}\right)\left[\frac{1}{(T_{N1}s + 1)\left(\frac{s^2}{\omega_N{}^2} + \frac{2\zeta_N}{\omega_N}s + 1\right)}\right].$$

In this equation:

Variable	Description
K_p	Pilot gain.
τ	Pilot delay time.

Variable	Description
T_L	Time lead constant for the equalizer term.
T_I	Time lag constant.
T_{N1}	Time constant for the neuromuscular system.
ω_N	Undamped frequency for the neuromuscular system.
ζ_N	Damping ratio for the neuromuscular system.

A sample value for the natural frequency and the damping ratio of a human is 20 rad/s and 0.7, respectively. The term containing the lead-lag term is the equalizer form. This form changes depending on the characteristics of the controlled system. A consistent behavior of the model can occur at different frequency ranges other than the crossover frequency.

This block has non-linear behavior. If you want to linearize the block (for example, with one of the Simulink `linmod` functions), you might need to change the Pade approximation order. The Precision Pilot Model block implementation incorporates the Simulink Transport Delay block with the **Pade order (for linearization)** parameter set to `2` by default. To change this value, use the `set_param` function, for example:

```
set_param(gcb,'pade','3')
```

Parameters

Type of control

From the list, select one of the following options to specify the type of aircraft dynamics that you want to control. The equalizer form changes according to these values. For more information, see [2].

Option (Controlled Element Transfer Function)	Transfer Function of Controlled Element (Y_c)	Transfer Function of Pilot (Y_p)
Proportional	K_c	Lag-lead, $T_I >> T_L$
Rate or velocity	$\frac{K_c}{s}$	1

Option (Controlled Element Transfer Function)	Transfer Function of Controlled Element (Y_c)	Transfer Function of Pilot (Y_p)
Acceleration	$\frac{K_c}{s^2}$	Lead-lag, $T_L >> T_I$
Second order	$\frac{K_c \omega_n{}^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$	Lead-lag if $\omega_m << 2/\tau$. Lag-lead if $\omega_m >> 2/\tau$.

Pilot gain

Specifies the pilot gain.

Pilot time delay (s)

Specifies the total pilot time delay, in seconds. This value typically ranges from 0.1 s to 0.2 s.

Equalizer lead constant

Specifies the equalizer lead constant.

Equalizer lag constant

Specifies the equalizer lag constant.

Lag constant for neuromuscular system

Specifies the neuromuscular system lag constant.

Undamped natural frequency neuromuscular system (rad/s)

Specifies the undamped natural frequency neuromuscular system in rad/s.

Damping neuromuscular system

Specifies the damping neuromuscular system.

Controlled element undamped natural frequency (rad/s)

Specifies the controlled element undamped natural frequency in rad/s.

Inputs and Outputs

Input	Dimension Type	Description
First	1-by-1	Contains the command for the signal that the pilot model controls.

Input	Dimension Type	Description
Second	1-by-1	Contains the signal that the pilot model controls.

Output	Dimension Type	Description
First	1-by-1	Contains the command for the aircraft.

References

[1] McRuer, D. T., Krendel, E., *Mathematical Models of Human Pilot Behavior*. Advisory Group on Aerospace Research and Development AGARDograph 188, Jan. 1974.

[2] McRuer, D. T., Graham, D., Krendel, E., and Reisener, W., *Human Pilot Dynamics in Compensatory Systems*. Air Force Flight Dynamics Lab. AFFDL-65-15. 1965.

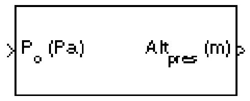
See Also

Crossover Pilot Model | Tustin Pilot Model

Introduced in R2012b

Pressure Altitude

Calculate pressure altitude based on ambient pressure



Library

Environment/Atmosphere

Description

The Pressure Altitude block computes the pressure altitude based on ambient pressure. Pressure altitude is the altitude in the 1976 Committee on the Extension of the Standard Atmosphere (COESA) United States with specified ambient pressure.

Pressure altitude is also known as the mean sea level (MSL) altitude.

The Pressure Altitude block icon displays the input and output units selected from the **Units** list.

Parameters

Units

Specifies the input units:

Units	Pstatic	Alt_p
`Metric (MKS)`	Pascal	Meters
`English`	Pound force per square inch	Feet

Action for out-of-range input

Specify if out-of-range input invokes a warning, error, or no action.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the static pressure.

Output	Dimension Type	Description
First		Contains the pressure altitude.

Assumptions and Limitations

Below the pressure of 0.3961 Pa (approximately 0.00006 psi) and above the pressure of 101325 Pa (approximately 14.7 psi), altitude values are extrapolated logarithmically.

Air is assumed to be dry and an ideal gas.

Reference

U.S. Standard Atmosphere, 1976, U.S. Government Printing Office, Washington, D.C.

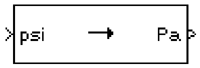
See Also

COESA Atmosphere Model

Introduced before R2006a

Pressure Conversion

Convert from pressure units to desired pressure units



Library

Utilities/Unit Conversions

Description

The Pressure Conversion block computes the conversion factor from specified input pressure units to specified output pressure units and applies the conversion factor to the input signal.

The Pressure Conversion block icon displays the input and output units selected from the **Initial unit** and the **Final unit** lists.

Parameters

Initial unit

Specifies the input units.

Final unit

Specifies the output units.

The following conversion units are available:

`psi`	Pound mass per square inch
`Pa`	Pascals
`psf`	Pound mass per square foot
`atm`	Atmospheres

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the pressure in initial pressure units.

Output	Dimension Type	Description
First		Contains the pressure in final pressure units.

See Also

Acceleration Conversion

Angle Conversion

Angular Acceleration Conversion

Angular Velocity Conversion

Density Conversion

Force Conversion

Length Conversion

Mass Conversion

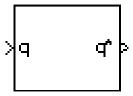
Temperature Conversion

Velocity Conversion

Introduced before R2006a

Quaternion Conjugate

Calculate conjugate of quaternion



Library

Utilities/Math Operations

Description

The Quaternion Conjugate block calculates the conjugate for a given quaternion.

The quaternion has the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3\,.$$

The quaternion conjugate has the form of

$$q' = q_0 - \mathbf{i}q_1 - \mathbf{j}q_2 - \mathbf{k}q_3\,.$$

Inputs and Outputs

Input	Dimension Type	Description
First	Quaternion or vector	Contains quaternions in the form of $[q_0, r_0, \ldots, q_1, r_1, \ldots, q_2, r_2, \ldots, q_3, r_3, \ldots]$.

Output	Dimension Type	Description
First	Quaternion conjugate or vector	Contains quaternion conjugates in the form of $[q_0', r_0', \ldots, q_1', r_1', \ldots, q_2', r_2', \ldots, q_3', r_3', \ldots]$.

References

Stevens, Brian L., Frank L. Lewis, *Aircraft Control and Simulation*, Wiley–Interscience, 2nd Edition.

See Also

Quaternion Division

Quaternion Inverse

Quaternion Modulus

Quaternion Multiplication

Quaternion Norm

Quaternion Normalize

Quaternion Rotation

Introduced before R2006a

Quaternion Division

Divide quaternion by another quaternion

Library

Utilities/Math Operations

Description

The Quaternion Division block divides a given quaternion by another.

The quaternions have the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3$$

and

$$r = r_0 + \mathbf{i}r_1 + \mathbf{j}r_2 + \mathbf{k}r_3\,.$$

The resulting quaternion from the division has the form of

$$t = \frac{q}{r} = t_0 + \mathbf{i}t_1 + \mathbf{j}t_2 + \mathbf{k}t_3,$$

where

$$t_0 = \frac{(r_0q_0 + r_1q_1 + r_2q_2 + r_3q_3)}{r_0^2 + r_1^2 + r_2^2 + r_3^2}$$

$$t_1 = \frac{(r_0q_1 - r_1q_0 - r_2q_3 + r_3q_2)}{r_0^2 + r_1^2 + r_2^2 + r_3^2}$$

$$t_2 = \frac{(r_0q_2 + r_1q_3 - r_2q_0 - r_3q_1)}{r_0^2 + r_1^2 + r_2^2 + r_3^2}$$

$$t_3 = \frac{(r_0q_3 - r_1q_2 + r_2q_1 - r_3q_0)}{r_0^2 + r_1^2 + r_2^2 + r_3^2}$$

Inputs and Outputs

Input	Dimension Type	Description
First	Quaternion or vector	Contains quaternions in the form of [q_0, p_0, ..., q_1, p_1, ... , q_2, p_2, ... , q_3, p_3, ...].
Second	Quaternion or vector	Contains quaternions in the form of [s_0, r_0, ..., s_1, r_1, ... , s_2, r_2, ... , s_3, r_3, ...].

Output	Dimension Type	Description
First	Quaternion or vector	Contains resulting quaternion or vector of resulting quaternions from division.

The output is the resulting quaternion from the division or vector of resulting quaternions from division.

References

Stevens, Brian L., Frank L. Lewis, *Aircraft Control and Simulation*, Wiley–Interscience, 2nd Edition.

See Also

Quaternion Conjugate

Quaternion Inverse

Quaternion Modulus

Quaternion Multiplication

Quaternion Norm

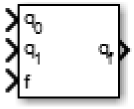
Quaternion Normalize

Quaternion Rotation

Introduced before R2006a

Quaternion Interpolation

Quaternion interpolation between two quaternions



Library

Utilities/Math Operations

Description

The Quaternion Interpolation block calculates the quaternion interpolation between two normalized quaternions by an interval fraction.

The two normalized quaternions are the two extremes between which the block calculates the quaternion.

Parameters

Methods

Specify the quaternion interpolation method to calculate the quaternion interpolation. These methods have different rotational velocities, depending on the interval fraction. For more information on interval fractions, see `http://web.mit.edu/2.998/www/QuaternionReport1.pdf`.

- `SLERP`

  Quaternion slerp. Spherical linear quaternion interpolation method.

  $Slerp(p, q, h) = p(p^*q)^h$ with $h \in [0, 1]$.
- `LERP`

Quaternion lerp. Linear quaternion interpolation method.

$LERP(p,q,h) = p(1-h) + qh$ with $h \in [0,1]$.

- `NLERP`

  Normalized quaternion linear interpolation method.

  With $r = LERP(p,q,h)$, $NLERP(p,q,h) = \frac{r}{|r|}$.

Action for out-of-range input

Specifies whether out-of-range input causes a warning, error, or no action.

Inputs and Outputs

Input	Dimension Type	Description
First	4-by-1 or 1-by-4 vector	First normalized quaternion for which to calculate the interpolation. This quaternion must be a normalized quaternion
Second	4-by-1 or 1-by-4 vector	Second normalized quaternion for which to calculate the interpolation. This quaternion must be a normalized quaternion.
Third	Scalar	Interval fraction by which to calculate the quaternion interpolation . This value varies between 0 and 1. It represents the intermediate rotation of the quaternion to be calculated. This fraction affects the interpolation method rotational velocities.

Output	Dimension Type	Description
First	double	Natural logarithm of quaternion.

References

`http://web.mit.edu/2.998/www/QuaternionReport1.pdf`

Extended Capabilities

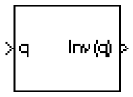
C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Introduced in R2016a

Quaternion Inverse

Calculate inverse of quaternion



Library

Utilities/Math Operations

Description

The Quaternion Inverse block calculates the inverse for a given quaternion.

The quaternion has the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3 .$$

The quaternion inverse has the form of

$$q^{-1} = \frac{q_0 - \mathbf{i}q_1 - \mathbf{j}q_2 - \mathbf{k}q_3}{q_0^2 + q_1^2 + q_2^2 + q_3^2} .$$

Inputs and Outputs

Input	Dimension Type	Description
First	Quaternion or vector	Contains quaternions in the form of [q_0, r_0, …, q_1, r_1, … , q_2, r_2, … , q_3, r_3, …].

Output	Dimension Type	Description
First	Quaternion inverse or vector	Contains quaternion inverse or vector of quaternion inverses.

References

Stevens, Brian L., Frank L. Lewis, *Aircraft Control and Simulation*, Wiley–Interscience, 2nd Edition.

See Also

Quaternion Conjugate

Quaternion Division

Quaternion Modulus

Quaternion Multiplication

Quaternion Norm

Quaternion Normalize

Quaternion Rotation

Introduced before R2006a

Quaternion Modulus

Calculate modulus of quaternion

Library

Utilities/Math Operations

Description

The Quaternion Modulus block calculates the magnitude for a given quaternion.

The quaternion has the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3 .$$

The quaternion modulus has the form of

$$|q| = \sqrt{q_0^2 + q_1^2 + q_2^2 + q_3^2}$$

Inputs and Outputs

Input	Dimension Type	Description
First	Quaternion or vector	Contains quaternions in the form of [q_0, r_0, ..., q_1, r_1, ... , q_2, r_2, ... , q_3, r_3, ...].

Output	Dimension Type	Description
First	Quaternion modulus or vector	Contains quaternion modulus or vector of quaternion modulus in the form of [$|q|$, $|r|$, ...].

References

Stevens, Brian L., Frank L. Lewis, *Aircraft Control and Simulation*, Wiley–Interscience, 2nd Edition.

See Also

Quaternion Conjugate

Quaternion Division

Quaternion Inverse

Quaternion Multiplication

Quaternion Norm

Quaternion Normalize

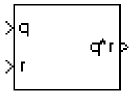
Quaternion Rotation

Introduced before R2006a

Quaternion Multiplication

Calculate product of two quaternions

Library: Aerospace Blockset / Utilities / Math Operations



Description

The Quaternion Multiplication block calculates the product for two given quaternions. For more information on the quaternion forms, see "Algorithms" on page 4-549.

Ports

Input

q — First quaternion

vector | vector of quaternions

First quaternion, specified as a vector or vector of quaternions. A vector of quaternions has this form, where *q* and *p* are quaternions:

$[q_0, p_0, ..., q_1, p_1, ..., q_2, p_2, ..., q_3, p_3, ...]$

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `Boolean` | `fixed point`

r — Second quaternion

vector | vector of quaternions

Second quaternion, specified as a vector or vector of quaternions. A vector of quaternions has this form, where *s* and *r* are quaternions:

$[s_0, r_0, ..., s_1, r_1, ..., s_2, r_2, ..., s_3, r_3, ...]$

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `Boolean` | `fixed point` | `enumerated` | `bus`

Output

q*r — Product
vector | vector of quaternion products

Product of two quaternions, output as a vector or vector of quaternion products.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | Boolean | fixed point | enumerated | bus

Algorithms

This block uses quaternions of the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3$$

and

$$r = r_0 + \mathbf{i}r_1 + \mathbf{j}r_2 + \mathbf{k}r_3\,.$$

The quaternion product has the form of

$$t = q \times r = t_0 + \mathbf{i}t_1 + \mathbf{j}t_2 + \mathbf{k}t_3,$$

where

$$\begin{aligned}
t_0 &= (r_0q_0 - r_1q_1 - r_2q_2 - r_3q_3)\\
t_1 &= (r_0q_1 + r_1q_0 - r_2q_3 + r_3q_2)\\
t_2 &= (r_0q_2 + r_1q_3 + r_2q_0 - r_3q_1)\\
t_3 &= (r_0q_3 - r_1q_2 + r_2q_1 + r_3q_0)
\end{aligned}$$

References

[1] Stevens, Brian L., Frank L. Lewis, *Aircraft Control and Simulation*, 2nd edition Hoboken, NJ: John Wiley & Sons, 2003.

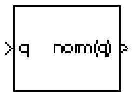
See Also

Quaternion Conjugate | Quaternion Division | Quaternion Inverse | Quaternion Modulus | Quaternion Norm | Quaternion Normalize | Quaternion Rotation

Introduced before R2006a

Quaternion Norm

Calculate norm of quaternion



Library

Utilities/Math Operations

Description

The Quaternion Norm block calculates the norm for a given quaternion.

The quaternion has the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3 .$$

The quaternion norm has the form of

$$norm(q) = q_0^2 + q_1^2 + q_2^2 + q_3^2$$

Inputs and Outputs

Input	Dimension Type	Description
First	Quaternion or vector	Contains quaternions in the form of [q_0, r_0, ..., q_1, r_1, ... , q_2, r_2, ... , q_3, r_3, ...].

Output	Dimension Type	Description
First	Quaternion norm or vector	Contains quaternion norm or vector of quaternion norms in the form of [*norm*(q), *norm*(r), ...].

References

Stevens, Brian L., Frank L. Lewis, *Aircraft Control and Simulation*, Wiley–Interscience, 2nd Edition.

See Also

Quaternion Conjugate

Quaternion Division

Quaternion Inverse

Quaternion Modulus

Quaternion Multiplication

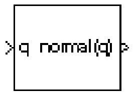
Quaternion Normalize

Quaternion Rotation

Introduced before R2006a

Quaternion Normalize

Normalize quaternion



Library

Utilities/Math Operations

Description

The Quaternion Normalize block calculates a normalized quaternion for a given quaternion.

The quaternion has the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3 .$$

The normalized quaternion has the form of

$$normal(q) = \frac{q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3}{\sqrt{q_0^2 + q_1^2 + q_2^2 + q_3^2}} .$$

Inputs and Outputs

Input	Dimension Type	Description
First	Quaternion or vector	Contains quaternions in the form of [q_0, r_0, ..., q_1, r_1, ... , q_2, r_2, ... , q_3, r_3, ...].

Output	Dimension Type	Description
First	Normalized quaternion or vector	Contains normalized quaternion or vector of normalized quaternions.

References

Stevens, Brian L., Frank L. Lewis, *Aircraft Control and Simulation*, Wiley–Interscience, 2nd Edition.

See Also

Quaternion Conjugate

Quaternion Division

Quaternion Inverse

Quaternion Modulus

Quaternion Multiplication

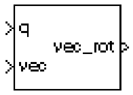
Quaternion Norm

Quaternion Rotation

Introduced before R2006a

Quaternion Rotation

Rotate vector by quaternion



Library

Utilities/Math Operations

Description

The Quaternion Rotation block rotates a vector by a quaternion.

The quaternion has the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3\,.$$

The vector has the form of

$$v = \mathbf{i}v_1 + \mathbf{j}v_2 + \mathbf{k}v_3\,.$$

The rotated vector has the form of

$$v' = \begin{bmatrix} v_1' \\ v_2' \\ v_3' \end{bmatrix} = \begin{bmatrix} (1 - 2q_2^2 - 2q_3^2) & 2(q_1q_2 + q_0q_3) & 2(q_1q_3 - q_0q_2) \\ 2(q_1q_2 - q_0q_3) & (1 - 2q_1^2 - 2q_3^2) & 2(q_2q_3 + q_0q_1) \\ 2(q_1q_3 + q_0q_2) & 2(q_2q_3 - q_0q_1) & (1 - 2q_1^2 - 2q_2^2) \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix}$$

For more information, see Representing Attitude: Euler Angles, Unit Quaternions, and Rotation Vectors.

Inputs and Outputs

Input	Dimension Type	Description
First	Quaternion or vector	Contains quaternions in the form of [q_0, r_0, ..., q_1, r_1, ... , q_2, r_2, ... , q_3, r_3, ...].
Second	Vector	Contains vector or vector of vectors in the form of [v_1, u_1, ... , v_2, u_2, ... , v_3, u_3, ...].

Output	Dimension Type	Description
First	Rotated quaternion or vector	Contains rotated vector or vector of rotated vectors.

References

Stevens, Brian L., Frank L. Lewis, *Aircraft Control and Simulation*, Wiley–Interscience, 2nd Edition.

Representing Attitude: Euler Angles, Unit Quaternions, and Rotation Vectors

See Also

Quaternion Conjugate

Quaternion Division

Quaternion Inverse

Quaternion Modulus

Quaternion Multiplication

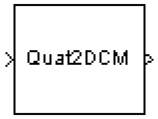
Quaternion Norm

Quaternion Normalize

Introduced before R2006a

Quaternions to Direction Cosine Matrix

Convert quaternion vector to direction cosine matrix



Library

Utilities/Axes Transformations

Description

The Quaternions to Direction Cosine Matrix block transforms the four-element unit quaternion vector (q_0, q_1, q_2, q_3) into a 3-by-3 direction cosine matrix (DCM). The outputted DCM performs the coordinate transformation of a vector in inertial axes to a vector in body axes.

Using quaternion algebra, if a point P is subject to the rotation described by a quaternion q, it changes to P' given by the following relationship:

$$P' = qPq^c$$

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3$$

$$q^c = q_0 - \mathbf{i}q_1 - \mathbf{j}q_2 - \mathbf{k}q_3$$

$$P = 0 + \mathbf{i}x + \mathbf{j}y + \mathbf{k}z$$

Expanding P' and collecting terms in x, y, and z gives the following for P' in terms of P in the vector quaternion format:

$$P' = \begin{bmatrix} 0 \\ x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} 0 \\ (q_0^2 + q_1^2 - q_2^2 - q_3^2)x + 2(q_1q_2 - q_0q_3)y + 2(q_1q_3 + q_0q_2)z \\ 2(q_0q_3 + q_1q_2)x + (q_0^2 - q_1^2 + q_2^2 - q_3^2)y + 2(q_2q_3 - q_0q_1)z \\ 2(q_1q_3 - q_0q_2)x + 2(q_0q_1 + q_2q_3)y + (q_0^2 - q_1^2 - q_2^2 + q_3^2)z \end{bmatrix}$$

Since individual terms in P' are linear combinations of terms in x, y, and z, a matrix relationship to rotate the vector (x, y, z) to (x', y', z') can be extracted from the preceding. This matrix rotates a vector in inertial axes, and hence is transposed to generate the DCM that performs the coordinate transformation of a vector in inertial axes into body axes.

$$DCM = \begin{bmatrix} (q_0^2 + q_1^2 - q_2^2 - q_3^2) & 2(q_1 q_2 + q_0 q_3) & 2(q_1 q_3 - q_0 q_2) \\ 2(q_1 q_2 - q_0 q_3) & (q_0^2 - q_1^2 + q_2^2 - q_3^2) & 2(q_2 q_3 + q_0 q_1) \\ 2(q_1 q_3 + q_0 q_2) & 2(q_2 q_3 - q_0 q_1) & (q_0^2 - q_1^2 - q_2^2 + q_3^2) \end{bmatrix}$$

Inputs and Outputs

Input	Dimension Type	Description
First	4-by-1 quaternion vector	Contains the quaternion vector.

Output	Dimension Type	Description
First	3-by-3 direction cosine matrix.	Contains the direction cosine matrix.

See Also

Direction Cosine Matrix to Rotation Angles

Direction Cosine Matrix to Quaternions

Rotation Angles to Direction Cosine Matrix

Rotation Angles to Quaternions

Introduced before R2006a

Quaternions to Rodrigues

Convert quaternion to Euler-Rodrigues vector

Library: Aerospace Blockset / Utilities / Axes Transformations

Description

The Quaternions to Rodrigues block converts the 4-by-1 quaternion to the 3-element Euler-Rodrigues vector.

Ports

Input

`Quaternion` — Quaternion
4-by-1 matrix

Quaternion from which to determine Euler-Rodrigues vector. Quaternion scalar is the first element.

Data Types: `double`

Output

`rod` — Euler-Rodrigues vector
3-element vector

Euler-Rodrigues vector determined from the quaternion.

Data Types: `double`

Algorithms

- An Euler-Rodrigues vector $\vec{b}$ represents a rotation by integrating a direction cosine of a rotation axis with the tangent of half the rotation angle as follows:

  $$\vec{b} = [b_x\ b_y\ b_z]$$

  where:

  $$b_x = \tan\left(\frac{1}{2}\theta\right)s_x,$$

  $$b_y = \tan\left(\frac{1}{2}\theta\right)s_y,$$

  $$b_z = \tan\left(\frac{1}{2}\theta\right)s_z$$

  are the Rodrigues parameters. Vector $\vec{s}$ represents a unit vector around which the rotation is performed. Due to the tangent, the rotation vector is indeterminate when the rotation angle equals ±pi radians or ±180 deg. Values can be negative or positive.

References

[1] Dai, J.S. "Euler-Rodrigues formula variations, quaternion conjugation and intrinsic connections." *Mechanism and Machine Theory*, 92, 144-152. Elsevier, 2015.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

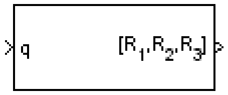
See Also

Direction Cosine Matrix to Rodrigues | Rodrigues to Direction Cosine Matrix | Rodrigues to Quaternions | Rodrigues to Rotation Angles | Rotation Angles to Rodrigues

Introduced in R2017a

Quaternions to Rotation Angles

Determine rotation vector from quaternion



Library

Utilities/Axes Transformations

Description

The Quaternions to Rotation Angles block converts the four-element quaternion vector (q_0, q_1, q_2, q_3) into the rotation described by the three rotation angles (R1, R2, R3). The block generates the conversion by comparing elements in the direction cosine matrix (DCM) as a function of the rotation angles. The elements in the DCM are functions of a unit quaternion vector. For example, for the rotation order *z*-*y*-*x*, the DCM is defined as:

$$DCM = \begin{bmatrix} \cos\theta\cos\psi & \cos\theta\sin\psi & -\sin\theta \\ (\sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi) & (\sin\phi\sin\theta\sin\psi + \cos\phi\cos\psi) & \sin\phi\cos\theta \\ (\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi) & (\cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi) & \cos\phi\cos\theta \end{bmatrix}$$

The DCM defined by a unit quaternion vector is:

$$DCM = \begin{bmatrix} (q_0^2 + q_1^2 - q_2^2 - q_3^2) & 2(q_1q_2 + q_0q_3) & 2(q_1q_3 - q_0q_2) \\ 2(q_1q_2 - q_0q_3) & (q_0^2 - q_1^2 + q_2^2 - q_3^2) & 2(q_2q_3 + q_0q_1) \\ 2(q_1q_3 + q_0q_2) & 2(q_2q_3 - q_0q_1) & (q_0^2 - q_1^2 - q_2^2 + q_3^2) \end{bmatrix}$$

From the preceding equation, you can derive the following relationships between DCM elements and individual rotation angles for a ZYX rotation order:

$$\begin{aligned}\phi &= \operatorname{atan}(DCM(2,3), DCM(3,3)) \\ &= \operatorname{atan}(2(q_2q_3 + q_0q_1), (q_0^2 - q_1^2 - q_2^2 + q_3^2)) \\ \theta &= \operatorname{asin}(-DCM(1,3)) \\ &= \operatorname{asin}(-2(q_1q_3 - q_0q_2)) \\ \psi &= \operatorname{atan}(DCM(1,2), DCM(1,1)) \\ &= \operatorname{atan}(2(q_1q_2 + q_0q_3), (q_0^2 + q_1^2 - q_2^2 - q_3^2))\end{aligned}$$

where Ψ is R1, Θ is R2, and Φ is R3.

Parameters

Rotation Order

Specifies the output rotation order for three rotation angles. From the list, select ZYX, ZYZ, ZXY, ZXZ, YXZ, YXY, YZX, YZY, XYZ, XYX, XZY, or XZX. The default is ZYX.

Inputs and Outputs

Input	Dimension Type	Description
First	4-by-1 quaternion vector	Contains the quaternion vector.

Output	Dimension Type	Description
First	3-by-1 vector	Contains the rotation angles, in radians.

Assumptions and Limitations

For the 'ZYX', 'ZXY', 'YXZ', 'YZX', 'XYZ', and 'XZY' rotations, the block generates an R2 angle that lies between ±pi/2 radians, and R1 and R3 angles that lie between ±pi radians.

For the 'ZYZ', 'ZXZ', 'YXY', 'YZY', 'XYX', and 'XZX' rotations, the block generates an R2 angle that lies between 0 and pi radians, and R1 and R3 angles that lie between ±pi radians. However, in the latter case, when R2 is 0, R3 is set to 0 radians.

See Also

Direction Cosine Matrix to Rotation Angles

Direction Cosine Matrix to Quaternions

Quaternions to Direction Cosine Matrix

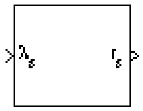
Rotation Angles to Direction Cosine Matrix

Rotation Angles to Quaternions

Introduced in R2007b

Radius at Geocentric Latitude

Estimate radius of ellipsoid planet at geocentric latitude

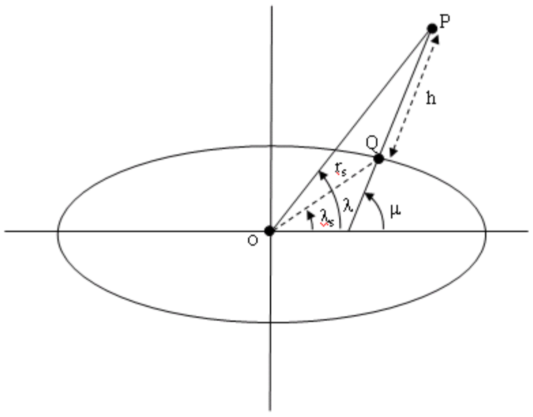


Library

Flight Parameters

Description

The Radius at Geocentric Latitude block estimates the radius (r_s) of an ellipsoid planet at a particular geocentric latitude (λ_s).



The following equation estimates the ellipsoid radius (r_s) using flattening ($\bar{f}$), geocentric latitude ($\bar{\lambda}_s$), and equatorial radius ($\bar{R}$).

$$r_s = \sqrt{\frac{R^2}{1 + \left[1/(1-f)^2 - 1\right]\sin^2\lambda_s}}$$

Parameters

Units

Specifies the parameter and output units:

Units	Equatorial Radius	Radius at Geocentric Latitude
`Metric (MKS)`	Meters	Meters
`English`	Feet	Feet

This option is only available when **Planet model** is set to `Earth (WGS84)`.

Planet model

Specifies the planet model to use:

`Custom`

`Earth (WGS84)`

Flattening

Specifies the flattening of the planet. This option is only available with **Planet model** set to `Custom`.

Equatorial radius of planet

Specifies the radius of the planet at its equator. This option is only available with **Planet model** set to `Custom`.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the geocentric latitude, in degrees.

Output	Dimension Type	Description
First		Contains the radius of planet at geocentric latitude, in the same as the units as flattening.

References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

Zipfel, P. H., *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA Education Series, Reston, Virginia, 2000.

See Also

ECEF Position to LLA

Direction Cosine Matrix ECEF to NED

Direction Cosine Matrix ECEF to NED to Latitude and Longitude

Geocentric to Geodetic Latitude

Geodetic to Geocentric Latitude

LLA to ECEF Position

Introduced before R2006a

Receive net_ctrl Packet from FlightGear

Receive `net_ctrl` packet from FlightGear

Library: Aerospace Blockset / Animation / Flight Simulator Interfaces

Description

The Receive net_ctrl Packet from FlightGear block receives a network control and environment data packet, `net_ctrl`, from the simulation of a Simulink model in the FlightGear simulator, or from a FlightGear session. This data packet is compatible with a particular version of FlightGear flight simulator. This block supports all signals supported by the FlightGear `net_ctrl` data packet. The block arranges the signals into multiple groups. To enable or disable the signal groups, select the FlightGear version. The block inserts zeros for packet values that are part of inactive signal groups.

If you run a model that contains this block in Rapid Accelerator mode, the block produces zeros (`0`s) and it does not produce deployable code. In Accelerator mode, the block works as expected.

For details on signals and signal groups, see “Output” on page 4-568.

Ports

Output

`Output 1` — Controls information from FlightGear
744-by-1 vector | 732-by-1 vector

Controls information from FlightGear, specified as a vector. The block returns packets according to platform and FlightGear version.

Platform	FlightGear Version	Dimension Type
Windows and Linux	v2018.2, v2018.1, v2017.3, v2017.1, v2016.3, v2016.1, v3.4, v3.2, v3.0, v2.12, v2.10, v2.8, v2.6, v2.4, v2.0	744-by-1 vector
macOS	v2.6*, v2.8*, v2.10*, v2.12*, v3.0*, v3.2*, v3.4*, v2016.1*, v2016.3*, v2017.1*, v2017.3*, v2018.1*, v2018.2*	744-by-1 vector
	v2.0, v2.4	732-by-1 vector

* On a Mac OS system with FlightGear 2.6, 2.8, 2.10, 2.12, 3.0, 3.2, 3.4, 2016.1, 2016.3, v2017.1, v2017.3, v2018.1, v2018.2 you might see unexpected results (for example, very large or very small data values). For more information, see “Macintosh Platform and FlightGear Version 2.6 or Later” on page 2-42.

Data Types: `uint8`

`Output 2` — Received FlightGear packet size
`0` | `744` | `732`

Received FlightGear packet size, specified as a scalar.

- 0, if no data is received
- Size of the packet in bytes (depending on the FlightGear version and architecture)

Platform	FlightGear Version	Dimension Type
Windows and Linux	—	0
	v2018.2, v2018.1, v2017.3, v2017.1, v2016.3, v2016.1, v3.4, v3.2, v3.0, v2.12, v2.10, v2.8, v2.6, v2.4, v2.0	744
macOS	—	0

Platform	FlightGear Version	Dimension Type
	v2.6*, v2.8*, v2.10*, v2.12*, v3.0*, v3.2*, v3.4*, v2016.1*, v2016.3*, v2017.1*, v2017.3*, v2018.1*, v2018.2*	744
	v2.0, v2.4	732

* On a macOS system with FlightGear 2.6, 2.8, 2.10, 2.12, 3.0, 3.2, 3.4, 2016.1, 2016.3, v2017.1, v2017.3, v2018.1, v2018.2 you might see unexpected results (for example, very large or very small data values). For more information, see "Macintosh Platform and FlightGear Version 2.6 or Later" on page 2-42.

Data Types: `double`

Parameters

`FlightGear version` — FlightGear software version
`v2018.2` (default) | `v2018.1` | `v2017.3` | `v2017.1` | `v2016.3` | `v2016.1` | `v3.4` | `v3.2` | `v3.0` | `v2.12` | `v2.10` | `v2.8` | `v2.6` | `v2.4` | `v2.0`

Select your FlightGear software version.

Note If you are using a FlightGear version older than 2.0, the model displays a notification from the Simulink Upgrade Advisor. Consider upgrading your FlightGear version using the Upgrade Advisor. For more information, see "Supported FlightGear Versions" on page 2-19.

Programmatic Use
Block Parameter: `FlightGearVersion`
Type: character vector
Values: scalar
Default: `'v2018.2'`

`Origin IP address` — Origin IP address
`127.0.0.1` (default) | scalar

Enter a valid IP address as a dot-decimal string. This IP address must be the address of the computer from which FlightGear is run, for example, `10.10.10.3`.

You can also use a MATLAB expression that returns a valid IP address as a character vector. If FlightGear is run on the local computer, leave the default value of `127.0.0.1` (localhost).

To determine the source IP address, you can use one of several techniques, such as:

- Use 127.0.0.1 for the local computer (localhost).
- Ping another computer from a Windows`cmd.exe` (or Linux shell) prompt:

```
C:\> ping andyspc

Pinging andyspc [144.213.175.92] with 32 bytes of data:

Reply from 144.213.175.92: bytes=32 time=30ms TTL=253
Reply from 144.213.175.92: bytes=32 time=20ms TTL=253
Reply from 144.213.175.92: bytes=32 time=20ms TTL=253
Reply from 144.213.175.92: bytes=32 time=20ms TTL=253

Ping statistics for 144.213.175.92:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 20ms, Maximum =  30ms, Average =  22ms
```

- On a Windows machine, type `ipconfig` and use the returned IP address:

```
H:\>ipconfig

Windows IP Configuration

Ethernet adapter Local Area Connection:

        Connection-specific DNS Suffix  . :
        IP Address. . . . . . . . . . . . : 192.168.42.178
        Subnet Mask . . . . . . . . . . . : 255.255.255.0
        Default Gateway . . . . . . . . . : 192.168.42.254
```

Programmatic Use
Block Parameter: `ReceiveAddress`
Type: character vector
Values: scalar
Default: `'127.0.0.1'`

`Origin port` — Origin port

5505 (default)

UDP port that the block accepts data from. The sender sends data to the port specified in this parameter. This value must match the **Origin port** parameter of the Generate Run Script block. It must be a unique port number that no other application on the computer uses. The site, `https://en.wikipedia.org/wiki/List_of_TCP_and_UDP_port_numbers`, lists commonly known UDP port numbers. To identify UDP port numbers already in use on your computer, type:

```
netstat -a -p UDP
```

Programmatic Use
Block Parameter: `ReceivePort`
Type: character vector
Values: scalar
Default: `'5505'`

`Sample time` — Sample time

1/30 (default) | scalar

Specify the sample time (-1 for inherited).

Programmatic Use
Block Parameter: `SampleTime`
Type: character vector
Values: scalar
Default: `'1/30'`

`Enable received flag port` — Enable received flag output port

`off` (default) | `on`

Enable a received flag output port. Use this check box to determine if a FlightGear network packet has been received.

Programmatic Use
Block Parameter: `packetFlag`
Type: character vector
Values:`'off' | 'on'`
Default: `'off'`

See Also

FlightGear Preconfigured 6DoF Animation | Generate Run Script | Pack net_fdm Packet for FlightGear | Send net_fdm Packet to FlightGear | Unpack net_ctrl Packet from FlightGear

Topics

"Flight Simulator Interface" on page 2-19
"Work with the Flight Simulator Interface" on page 2-24

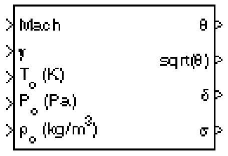
External Websites

https://en.wikipedia.org/wiki/List_of_TCP_and_UDP_port_numbers

Introduced in R2012a

Relative Ratio

Calculate relative atmospheric ratios



Library

Flight Parameters

Description

The Relative Ratio block computes the relative atmospheric ratios, including relative temperature ratio (θ), $\sqrt{\theta}$, relative pressure ratio (δ), and relative density ratio (σ).

θ represents the ratio of the air stream temperature at a chosen reference station relative to sea level standard atmospheric conditions.

$$\theta = \frac{T}{T_0}$$

δ represents the ratio of the air stream pressure at a chosen reference station relative to sea level standard atmospheric conditions.

$$\delta = \frac{P}{P_0}$$

σ represents the ratio of the air stream density at a chosen reference station relative to sea level standard atmospheric conditions.

$$\sigma = \frac{\rho}{\rho_0}$$

The Relative Ratio block icon displays the input units selected from the **Units** list.

Parameters

Units

Specifies the input units:

Units	Tstatic	Pstatic	rho_static
`Metric (MKS)`	Kelvin	Pascal	Kilograms per cubic meter
`English`	Degrees Rankine	Pound force per square inch	Slug per cubic foot

Theta

When selected, the θ is calculated and static temperature is a required input.

Square root of theta

When selected, the $\sqrt{\theta}$ is calculated and static temperature is a required input.

Delta

When selected, the δ is calculated and static pressure is a required input.

Sigma

When selected, the σ is calculated and static density is a required input.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the Mach number.
Second		Contains the ratio between the specific heat at constant pressure (C_p) and the specific heat at constant volume (C_v). For example, ($\gamma = C_p/C_v$).
Third		Contains the static temperature.
Fourth		Contains the static pressure.
Fifth		Contains the static density.

Output	Dimension Type	Description
First		Contains the θ.
Second		Contains the $\sqrt{\theta}$.
Third		Contains the δ.
Fourth		Contains the σ.

Assumptions

For cases in which total temperature, total pressure, or total density ratio is desired (Mach number is nonzero), the total temperature, total pressure, and total densities are calculated assuming perfect gas (with constant molecular weight, constant pressure specific heat, and constant specific heat ratio) and dry air.

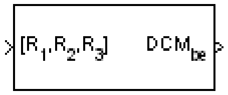
Reference

Aeronautical Vestpocket Handbook, United Technologies Pratt & Whitney, August, 1986.

Introduced before R2006a

Rotation Angles to Direction Cosine Matrix

Convert rotation angles to direction cosine matrix



Library

Utilities/Axes Transformations

Description

The Rotation Angles to Direction Cosine Matrix block determines the direction cosine matrix (DCM) from a given set of rotation angles, R1, R2, and R3, respectively the first, second, and third rotation angles. For example, the default rotation angle order ZYX represents a sequence where R1 is *z*-axis rotation (yaw), R2 is *y*-axis rotation (pitch), and R3 is *x*-axis rotation (roll). Use the **Rotation Order** parameter to change the sequence.

The output is a 3-by-3 DCM that performs coordinate transformations based on rotation angles.

Parameters

Rotation Order

Specifies the input rotation order for three rotation angles. From the list, select ZYX, ZYZ, ZXY, ZXZ, YXZ, YXY, YZX, YZY, XYZ, XYX, XZY, or XZX. The default is ZYX.

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-1 vector	Contains the rotation angles, in radians.

Output	Dimension Type	Description
First	3-by-3 matrix	Contains the direction cosine matrix.

See Also

Direction Cosine Matrix to Quaternions

Direction Cosine Matrix to Rotation Angles

Quaternions to Direction Cosine Matrix

Introduced in R2007b

Rotation Angles to Rodrigues

Convert rotation angles to Euler-Rodrigues vector

Library: Aerospace Blockset / Utilities / Axes Transformations

Description

The Rotation Angles to Rodrigues block converts the rotation described by the three rotation angles `R1,R2,R3` into the 3-element Euler-Rodrigues vector.

Ports

Input

`R1,R2,R3` — Rotation angles
3-element vector

Rotation angles, in radians, from which to determine the Euler-Rodrigues vector. Values must be real.

Data Types: `double`

Output

`rod` — Euler-Rodrigues vector
3-element vector

Euler-Rodrigues vector determined from rotation angles.

Data Types: `double`

Parameters

`Rotation order` — Rotation order

ZYX (default) | ZYX | ZYZ | ZXY | ZXZ | YXZ | YXY | YZX | YZY | XYZ | XYX | XZY | XZX

Rotation order for three wind rotation angles.

The default limitations for the `'ZYX'`, `'ZXY'`, `'YXZ'`, `'YZX'`, `'XYZ'`, and `'XZY'` sequences generate an R2 angle that lies between ±pi/2 radians (± 90 degrees), and R1 and R3 angles that lie between ±pi radians (±180 degrees).

The default limitations for the `'ZYZ'`, `'ZXZ'`, `'YXY'`, `'YZY'`, `'XYX'`, and `'XZX'` sequences generate an R2 angle that lies between 0 and pi radians (180 degrees), and R1 and R3 angles that lie between ±pi (±180 degrees).

Rodrigues transformation is not defined for rotation angles equal to ±pi radians (±180 deg).

Algorithms

An Euler-Rodrigues vector $\vec{b}$ represents a rotation by integrating a direction cosine of a rotation axis with the tangent of half the rotation angle as follows:

$$\vec{b} = [b_x \ b_y \ b_z]$$

where:

$$b_x = \tan\left(\frac{1}{2}\theta\right)s_x,$$

$$b_y = \tan\left(\frac{1}{2}\theta\right)s_y,$$

$$b_z = \tan\left(\frac{1}{2}\theta\right)s_z$$

are the Rodrigues parameters. Vector $\vec{s}$ represents a unit vector around which the rotation is performed. Due to the tangent, the rotation vector is indeterminate when the rotation angle equals ±pi radians or ±180 deg. Values can be negative or positive.

References

[1] Dai, J.S. "Euler-Rodrigues formula variations, quaternion conjugation and intrinsic connections." *Mechanism and Machine Theory*, 92, 144-152. Elsevier, 2015.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

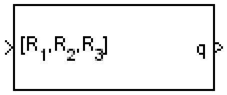
See Also

Direction Cosine Matrix to Rodrigues | Quaternions to Rodrigues | Rodrigues to Direction Cosine Matrix | Rodrigues to Quaternions | Rodrigues to Rotation Angles

Introduced in R2017a

Rotation Angles to Quaternions

Calculate quaternion from rotation angles



Library

Utilities/Axes Transformations

Description

The Rotation Angles to Quaternions block converts the rotation described by the three rotation angles (R1, R2, R3) into the four-element quaternion vector (q_0, q_1, q_2, q_3). A quaternion vector represents a rotation about a unit vector $\left(\mu_x, \mu_y, \mu_z\right)$ through an angle θ. A unit quaternion itself has unit magnitude, and can be written in the following vector format.

$$q = \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix} = \begin{bmatrix} \cos(\theta/2) \\ \sin(\theta/2)\mu_x \\ \sin(\theta/2)\mu_y \\ \sin(\theta/2)\mu_z \end{bmatrix}$$

An alternative representation of a quaternion is as a complex number,

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3$$

where, for the purposes of multiplication,

$$\begin{aligned} i^2 &= j^2 = k^2 = -1 \\ ij &= -ji = k \\ jk &= -kj = i \\ ki &= -ik = j \end{aligned}$$

The benefit of representing the quaternion in this way is the ease with which the quaternion product can represent the resulting transformation after two or more rotations.

Parameters

Rotation Order

Specifies the output rotation order for three wind rotation angles. From the list, select ZYX, ZYZ, ZXY, ZXZ, YXZ, YXY, YZX, YZY, XYZ, XYX, XZY, or XZX. The default is ZYX.

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-1 vector	Contains the rotation angles, in radians.

Output	Dimension Type	Description
First	4-by-1 quaternion vector	Contains the quaternion vector.

Assumptions and Limitations

The limitations for the `'ZYX'`, `'ZXY'`, `'YXZ'`, `'YZX'`, `'XYZ'`, and `'XZY'` implementations generate an R2 angle that is between ±90 degrees, and R1 and R3 angles that are between ±180 degrees.

The limitations for the `'ZYZ'`, `'ZXZ'`, `'YXY'`, `'YZY'`, `'XYX'`, and `'XZX'` implementations generate an R2 angle that is between 0 and 180 degrees, and R1 and R3 angles that are between ±180 degrees.

See Also

Direction Cosine Matrix to Quaternions

Quaternions to Direction Cosine Matrix

Quaternions to Rotation Angles

Rotation Angles to Direction Cosine Matrix

Introduced in R2007b

Revolutions Per Minute (RPM) Indicator

Display measurements for engine revolutions per minute (RPM) in percentage of RPM
Library: Aerospace Blockset / Flight Instruments

110
10
100
20
90
30
80
40
70
50
60
PERCENT
RPM

Description

The RPM Indicator block displays measurements for engine revolutions per minute in percentage of RPM.

The range of values for RPM goes from 0 to 110 %. Minor ticks represent increments of 5 % RPM and major ticks represent increments of 10 % RPM.

Parameters

`Connection` — Connect to signal

signal name

Connect to signal for display, selected from list of signal names.

To view the data from a signal, select a signal in the model. The signal appears in the **Connection** table. Select the option button next to the signal you want to display. Click **Apply** to connect the signal.

The table has a row for the signal connected to the block. If there are no signals selected in the model, or the block is not connected to any signals, the table is empty.

`Scale Colors` — Ranges of color bands

0 (default) | real | double | scalar

Ranges of color bands on the outside of the scale, specified as a finite, real, double, or scalar value. Specify the minimum and maximum color range to display on the gauge.

To add a new color, click `+`. To remove a color, click `-`.

Programmatic Use
Block Parameter: `ScaleColors`
Type: *n*-by-1 struct array
Values: struct array with elements `Min`, `Max`, and `Color`

`Label` — Block label location
`Top` (default) | `Bottom` | `Hide`

Block label, displayed at the top or bottom of the block, or hidden.

- `Top`

  Show label at the top of the block.
- `Bottom`

  Show label at the bottom of the block.
- `Hide`

  Do not show the label or instructional text when the block is not connected.

Programmatic Use
Block Parameter: `LabelPosition`
Type: character vector
Values: `'Top'` | `'Bottom'` | `'Hide'`
Default: `'Top'`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

This block is ignored for code generation.

See Also

Indicator | Airspeed Indicator | Altimeter | Artificial Horizon | Climb Rate Indicator | Exhaust Gas Temperature (EGT) Indicator | Heading Indicator | Turn Coordinator

Topics

“Display Measurements with Cockpit Instruments” on page 2-49
“Programmatically Interact with Gauge Band Colors” on page 2-52
“Flight Instrument Gauges” on page 2-48

Introduced in R2016a

Self-Conditioned [A,B,C,D]

Implement state-space controller in self-conditioned form
Library: Aerospace Blockset / GNC / Control

e
u_meas
u_dem

Description

The Self-Conditioned [A,B,C,D] block can be used to implement the state-space controller defined by

$$\begin{bmatrix} \dot{x} = Ax + Be \\ u = Cx + De \end{bmatrix}$$

in the self-conditioned form

$$\dot{z} = (A - HC)z + (B - HD)e + Hu_{meas}$$
$$u_{dem} = Cz + De$$

The input u_{meas} is a vector of the achieved actuator positions, and the output u_{dem} is the vector of controller actuator demands. In the case that the actuators are not limited, then $u_{meas} = u_{dem}$ and substituting the output equation into the state equation returns the nominal controller. In the case that they are not equal, the dynamics of the controller are set by the poles of A-HC.

Hence H must be chosen to make the poles sufficiently fast to track u_{meas} but at the same time not so fast that noise on e is propagated to u_{dem}. The matrix H is designed by a callback to the Control System Toolbox command `place` to place the poles at defined locations.

Limitations

This block requires the Control System Toolbox license.

Ports

Input

`e` — Control error
vector

Control error, specified as a vector.

Data Types: `double`

`u_meas` — Achieved actuator positions
vector

Achieved actuator positions, specified as a vector.

Data Types: `double`

Output

`u_dem` — Actuator demands
vector

Actuator demands, specified as a vector.

Data Types: `double`

Parameters

`A-matrix` — *A*-matrix of the state-space implementation
`[-1 -0.2;0 -3]` (default) | array

A-matrix of the state-space implementation. The *A*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *A*-matrix corresponding to the first entry of *v* is the identity matrix, then `A(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `Ak`
Type: character vector

Values: vector
Default: `'[-1 -0.2;0 -3]'`

`B-matrix` — *B*-matrix of the state-space implementation

`[1;1]` (default) | array

B-matrix of the state-space implementation, specified as a array. The *B*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *B*-matrix corresponding to the first entry of *v* is the identity matrix, then `B(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `Bk`
Type: character vector
Values: vector
Default: `'[1;1]'`

`C-matrix` — *C*-matrix of the state-space implementation

`[1 0]` (default) | array

C-matrix of the state-space implementation, specified as a array. The *C*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *C*-matrix corresponding to the first entry of *v* is the identity matrix, then `C(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `Ck`
Type: character vector
Values: vector
Default: `'[1 0]'`

`D-matrix` — *D*-matrix of the state-space implementation

`0.02` (default) | array | scalar

D-matrix of the state-space implementation. The *D*-matrix should have three dimensions, the last one corresponding to the scheduling variable *v*. For example, if the *D*-matrix corresponding to the first entry of *v* is the identity matrix, then `D(:,:,1) = [1 0;0 1];`.

Programmatic Use
Block Parameter: `Dk`
Type: character vector

Values: vector
Default: `'0.02'`

`Initial state, x_initial` — Initial states

0 (default) | vector

Initial states for the controller, that is, initial values for the state vector, z. It should have length equal to the size of the first dimension of A.

Programmatic Use
Block Parameter: `x_initial`
Type: character vector
Values: vector
Default: `'0'`

`Poles of A-H*C` — Desired poles

`[-5 -2]` (default) | vector

Desired poles of A-H*C, specified as a vector. Hence the number of pole locations defined should be equal to the dimension of the A-matrix.

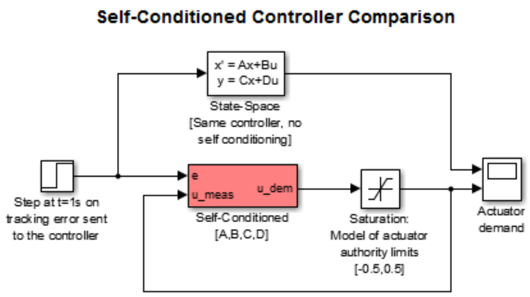
Programmatic Use
Block Parameter: `vec_w`
Type: character vector
Values: vector
Default: `'[-5 -2]'`

Definitions

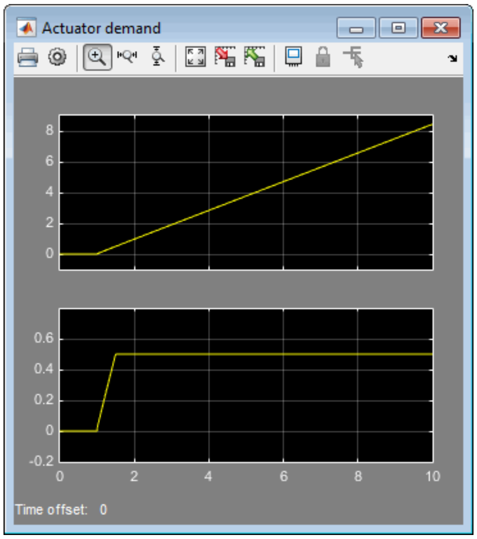
State-Space Controller

State-space controller implemented in both self-conditioned and standard state-space forms.

This Simulink model shows a state-space controller implemented in both self-conditioned and standard state-space forms. The actuator authority limits of ±0.5 units are modeled by the Saturation block.


Self-Conditioned Controller Comparison
x' = Ax+Bu
y = Cx+Du
State-Space
[Same controller, no self conditioning]
Step at t=1s on tracking error sent to the controller
e
u_meas
u_dem
Self-Conditioned
[A,B,C,D]
Saturation: Model of actuator authority limits
[-0.5,0.5]
Actuator demand

Notice that the *A*-matrix has a zero in the 1,1 element, indicating integral action.



The top trace shows the conventional state-space implementation. The output of the controller winds up well past the actuator upper authority limit of +0.5. The lower trace shows that the self-conditioned form results in an actuator demand that tracks the upper authority limit, which means that when the sign of the control error, e, is reversed, the actuator demand responds immediately.

References

[1] Kautsky, Nichols, and Van Dooren, "Robust Pole Assignment in Linear State Feedback," *International Journal of Control*, Vol. 41, Number 5, 1985, pp. 1129-1155.

See Also

1D Self-Conditioned [A(v),B(v),C(v),D(v)] | 2D Self-Conditioned [A(v),B(v),C(v),D(v)] | 3D Self-Conditioned [A(v),B(v),C(v),D(v)] | Linear Second-Order Actuator | Nonlinear Second-Order Actuator | Saturation

Introduced before R2006a

Send net_fdm Packet to FlightGear

Transmit `net_fdm` packet to destination IP address and port for FlightGear session

Library: Aerospace Blockset / Animation / Flight Simulator Interfaces

Description

The Send net_fdm Packet to FlightGear block transmits the `net_fdm` packet to FlightGear on the current computer, or a remote computer on the network. The packet is constructed using the Pack net_fdm Packet for FlightGear block. The destination port should be an unused port that you can use when you launch FlightGear with the FlightGear command line flag:

```
--fdm=network,localhost,5501,5502,5503
```

This block does not produce deployable code.

Ports

Input

`Input 1` — FlightGear `net_fdm` data packet
scalar

FlightGear `net_fdm` data packet, specified as a scalar.

Data Types: `uint8`

Parameters

`Destination IP address` — Destination IP address for remote computer
`127.0.0.1` (default) | scalar

Destination IP address, specified as a scalar.

You can use one of several techniques to determine the destination IP address, such as:

- Use 127.0.0.1 for the local computer
- Ping another computer from a Windows `cmd.exe` (or UNIX shell) prompt:

```
C:\> ping andyspc

Pinging andyspc [144.213.175.92] with 32 bytes of data:

Reply from 144.213.175.92: bytes=32 time=30ms TTL=253
Reply from 144.213.175.92: bytes=32 time=20ms TTL=253
Reply from 144.213.175.92: bytes=32 time=20ms TTL=253
Reply from 144.213.175.92: bytes=32 time=20ms TTL=253

Ping statistics for 144.213.175.92:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 20ms, Maximum =  30ms, Average =  22ms
```

- On a Windows machine, type `ipconfig` and use the returned *`IP Address`*:

```
H:\>ipconfig

Windows IP Configuration

Ethernet adapter Local Area Connection:

        Connection-specific DNS Suffix  . :
        IP Address. . . . . . . . . . . . : 192.168.42.178
        Subnet Mask . . . . . . . . . . . : 255.255.255.0
        Default Gateway . . . . . . . . . : 192.168.42.254
```

Programmatic Use
Block Parameter: `DestinationIpAddress`
Type: character vector
Values: scalar
Default: `127.0.0.1`

`Destination port` — Destination port for remote computer
5502 (default) | scalar

Destination port, specified as a scalar

Programmatic Use
Block Parameter: `DestinationPort`
Type: character vector
Values: scalar
Default: `5502`

`Sample time` — Sample time

`1/30` (default) | scalar

Sample time (-1 for inherited), specified as a scalar.

Programmatic Use
Block Parameter: `SampleTime`
Type: character vector
Values: scalar
Default: `1/30`

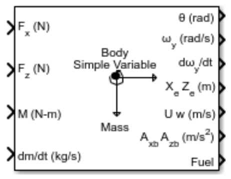
See Also

FlightGear Preconfigured 6DoF Animation | Generate Run Script | Pack net_fdm Packet for FlightGear | Receive net_ctrl Packet from FlightGear | Unpack net_ctrl Packet from FlightGear

Introduced before R2006a

Simple Variable Mass 3DOF (Body Axes)

Implement three-degrees-of-freedom equations of motion of simple variable mass with respect to body axes

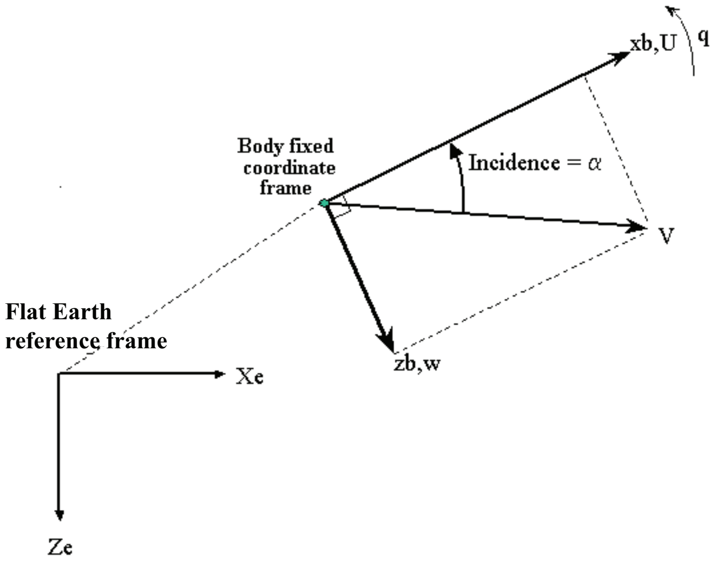


Library

Equations of Motion/3DOF

Description

The Simple Variable Mass 3DOF (Body Axes) block considers the rotation in the vertical plane of a body-fixed coordinate frame about a flat Earth reference frame.



The equations of motion are

$$A_{xb} = \dot{u} = \frac{F_x}{m} - \frac{\dot{m}Ure_b}{m} - qw - g\sin\theta$$

$$A_{be} = \begin{bmatrix} A_{xe} \\ A_{ze} \end{bmatrix} = \frac{F_b - \dot{m}V_{re}}{m} - \bar{g}$$

$$Vre_b = [Ure \;\; Wre]_b$$

$$A_{zb} = \dot{w} = \frac{F_z}{m} - \frac{\dot{m}Wre_b}{m} + qu + g\cos\theta$$

$$\dot{q} = \frac{M - \dot{I}_{yy}q}{I_{yy}}$$

$$\dot{\theta} = q$$

$$\dot{I}_{yy} = \frac{I_{yyfull} - I_{yyempty}}{m_{full} - m_{empty}}\dot{m}$$

where the applied forces are assumed to act at the center of gravity of the body. *Ure*$_b$ and *Wre*$_b$ are the relative velocities of the mass flow ($\dot{m}$) being added to or ejected from the body in body-fixed axes.

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Simple Variable` selection conforms to the previously described equations of motion.

Initial velocity

A scalar value for the initial velocity of the body, (V_0).

Initial body attitude

A scalar value for the initial pitch attitude of the body, (θ_0).

Initial incidence

A scalar value for the initial angle between the velocity vector and the body, (α_0).

Initial body rotation rate

A scalar value for the initial body rotation rate, (q_0).

Initial position (x,z)

A two-element vector containing the initial location of the body in the flat Earth reference frame.

Initial mass

A scalar value for the initial mass of the body.

Inertia

A scalar value for the inertia of the body.

Empty mass

A scalar value for the empty mass of the body.

Full mass

A scalar value for the full mass of the body.

Empty inertia

A scalar value for the empty inertia of the body.

Full inertia

A scalar value for the full inertia of the body.

Gravity source

Specify source of gravity:

`External`	Variable gravity input to block
`Internal`	Constant gravity specified in **Acceleration due to gravity**

Acceleration due to gravity

A scalar value for the acceleration due to gravity used if internal gravity source is selected. If gravity is to be neglected in the simulation, this value can be set to 0. This parameter appears if you set **Gravity source** to `Internal`.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Velocity: e.g., {'u', 'w'}

Specify velocity state names.

Default value is `''`.

Pitch attitude: e.g., 'theta'

Specify pitch attitude state name.

Default value is `''`.

Position: e.g., {'Xe', 'Ze'}

Specify position state names.

Default value is `''`.

Pitch angular rate: e.g., 'q'

Specify pitch angular rate state name.

Default value is `''`.

Mass: e.g., 'mass'

Specify mass state name.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the force acting along the body *x*-axis, (F_x).
Second		Contains the force acting along the body *z*-axis, (F_z).
Third		Contains the applied pitch moment, (M).
Fourth		Contains one or more rates of change of mass, ($\dot{m}$) (positive if accreted, negative if ablated).
Fifth (Optional)		Contains the gravity in the selected units.
Sixth (Optional)	Two-element vector	Contains one or more relative velocities at which the mass is accreted to or ablated from the body in body-fixed axes.

Output	Dimension Type	Description
First		Contains the pitch attitude, within ±pi, in radians (θ).
Second		Contains the pitch angular rate, in radians per second (q).
Third		Contains the pitch angular acceleration, in radians per second squared ($\dot{q}$).
Fourth	Two-element vector	Contains the location of the body, in the flat Earth reference frame, (Xe, Ze).

Output	Dimension Type	Description
Fifth	Two-element vector	Contains the velocity of the body resolved into the body-fixed coordinate frame, (*u*, *w*).
Sixth	Two-element vector	Contains the acceleration of the body resolved into the body-fixed coordinate frame, (*Ax*,*Az*).
Seventh	Scalar element	Contains a flag for fuel tank status, (*Fuel*): • 1 indicates that the tank is full. • 0 indicates that the integral is neither full nor empty. • -1 indicates that the tank is empty.
Eighth (Optional)	Two-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

See Also

3DOF (Body Axes)

3DOF (Wind Axes)

Custom Variable Mass 3DOF (Body Axes)

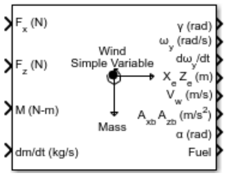
Custom Variable Mass 3DOF (Wind Axes)

Simple Variable Mass 3DOF (Wind Axes)

Introduced in R2006a

Simple Variable Mass 3DOF (Wind Axes)

Implement three-degrees-of-freedom equations of motion of simple variable mass with respect to wind axes

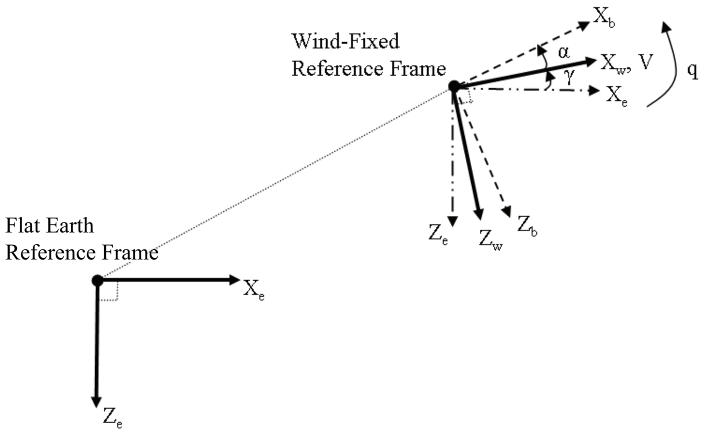


Library

Equations of Motion/3DOF

Description

The Simple Variable Mass 3DOF (Wind Axes) block considers the rotation in the vertical plane of a wind-fixed coordinate frame about a flat Earth reference frame.



The equations of motion are

$$\dot{V} = \frac{F_{x_{wind}}}{m} - \frac{\dot{m}Vre_{x_{wind}}}{m} - g\sin\gamma$$

$$A_{be} = \begin{bmatrix} A_{xe} \\ A_{ze} \end{bmatrix} = DCM_{wb}\left[\frac{F_w - \dot{m}V_{re}}{m} - g\right]$$

$$A_{bb} = \begin{bmatrix} A_{xb} \\ A_{zb} \end{bmatrix} = DCM_{wb}\left[\frac{F_w - \dot{m}V_{re}}{m} - g - \omega_w \times \bar{V}_w\right]$$

$$\dot{\alpha} = \frac{F_{z_{wind}}}{mV} + q + \frac{g}{V}\cos\gamma - \frac{\dot{m}Vre_{z_{wind}}}{mV}$$

$$\dot{q} = \dot{\theta} = \frac{M_{y_{body}} - \dot{I}_{yy}q}{I_{yy}}$$

$$\dot{\gamma} = q - \dot{\alpha}$$

$$\dot{I}_{yy} = \frac{I_{yyfull} - I_{yyempty}}{m_{full} - m_{empty}}\dot{m}$$

where the applied forces are assumed to act at the center of gravity of the body. Vre_w is the relative velocity in the wind axes at which the mass flow ($\dot{m}$) is ejected or added to the wind axes.

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Simple Variable` selection conforms to the previously described equations of motion.

Initial airspeed

A scalar value for the initial velocity of the body, (V_0).

Initial flight path angle

A scalar value for the initial flight path angle of the body, (γ_0).

Initial incidence

A scalar value for the initial angle between the velocity vector and the body, (α_0) .

Initial body rotation rate

A scalar value for the initial body rotation rate, (q_0).

Initial position (x,z)

A two-element vector containing the initial location of the body in the flat Earth reference frame.

Initial mass

A scalar value for the initial mass of the body.

Inertia body axes

A scalar value for the inertia of the body.

Empty mass

A scalar value for the empty mass of the body.

Full mass

A scalar value for the full mass of the body.

Empty inertia

A scalar value for the empty inertia of the body.

Full inertia

A scalar value for the full inertia of the body.

Gravity source

Specify source of gravity:

`External`	Variable gravity input to block
`Internal`	Constant gravity specified in **Acceleration due to gravity**

Acceleration due to gravity

A scalar value for the acceleration due to gravity used if internal gravity source is selected. If gravity is to be neglected in the simulation, this value can be set to 0. This parameter appears if you set **Gravity source** to `Internal`.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.

- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Velocity: e.g., 'V'

Specify velocity state name.

Default value is `''`.

Incidence angle: e.g., 'alpha'

Specify incidence angle state name.

Default value is `''`.

Flight path angle: e.g., 'gamma'

Specify flight path angle state name.

Default value is `''`.

Body rotation rate: e.g., 'q'

Specify body rotation rates state name.

Default value is `''`.

Position: e.g., {'Xe', 'Ze'}

Specify position state names.

Default value is `''`.

Mass: e.g., 'mass'

Specify mass state name.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the force acting along the wind *x*-axis, (F_x).
Second		Contains the force acting along the wind *z*-axis, (F_z).
Third		Contains the applied pitch moment in body axes, (M).
Fourth		Contains one or more rates of change of mass, ($\dot{m}$) (positive if accreted, negative if ablated).
Fifth (Optional)		Contains the gravity in the selected units.
Sixth (Optional)	Two-element vector	Contains one or more relative velocities at which the mass is accreted to or ablated from the body in wind axes.

Output	Dimension Type	Description
First		Contains the flight path angle, within ±pi, in radians (γ).
Second		Contains the pitch angular rate, in radians per second (ω_y).
Third		Contains the pitch angular acceleration, in radians per second squared ($d\omega_y/dt$).
Fourth	Two-element vector	Contains the location of the body, in the flat Earth reference frame, (Xe, Ze).
Fifth	Two-element vector	Contains the velocity of the body resolved into the wind-fixed coordinate frame, ($V, 0$).
Sixth	Two-element vector	Contains the acceleration of the body resolved into the body-fixed coordinate frame, (Ax, Az).
Seventh	Scalar	Contain the angle of attack, (α_0) .
Eight	Scalar element	Contains a flag for fuel tank status, (*Fuel*): • 1 indicates that the tank is full. • 0 indicates that the integral is neither full nor empty. • -1 indicates that the tank is empty.

Output	Dimension Type	Description
Ninth (Optional)	Two-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Reference

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, 1992.

See Also

3DOF (Body Axes)

3DOF (Wind Axes)

Custom Variable Mass 3DOF (Body Axes)

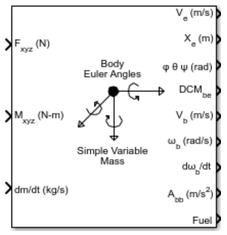
Custom Variable Mass 3DOF (Wind Axes)

Simple Variable Mass 3DOF (Body Axes)

Introduced in R2006a

Simple Variable Mass 6DOF (Euler Angles)

Implement Euler angle representation of six-degrees-of-freedom equations of motion of simple variable mass

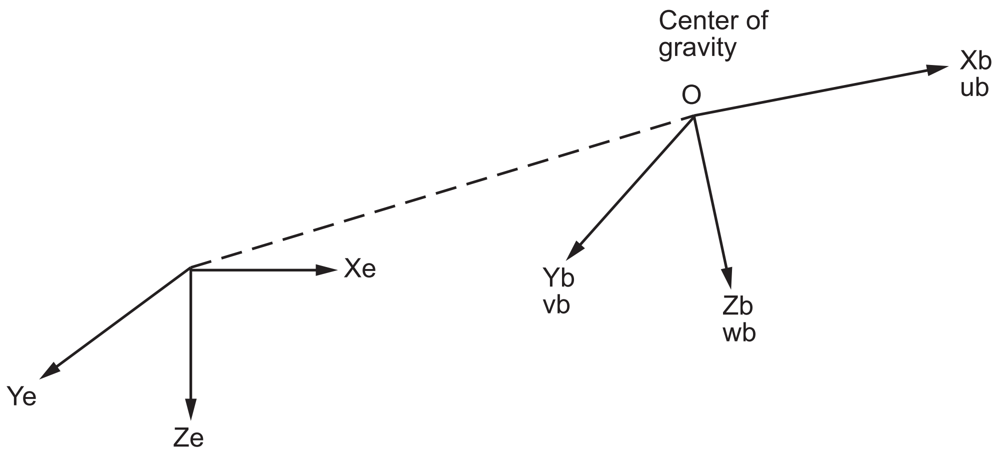


Library

Equations of Motion/6DOF

Description

The Simple Variable Mass 6DOF (Euler Angles) block considers the rotation of a body-fixed coordinate frame (X_b, Y_b, Z_b) about a flat Earth reference frame (X_e, Y_e, Z_e). The origin of the body-fixed coordinate frame is the center of gravity of the body, and the body is assumed to be rigid, an assumption that eliminates the need to consider the forces acting between individual elements of mass. The flat Earth reference frame is considered inertial, an excellent approximation that allows the forces due to the Earth's motion relative to the “fixed stars” to be neglected.



Flat Earth reference frame

The translational motion of the body-fixed coordinate frame is given below, where the applied forces $[F_x\ F_y\ F_z]^T$ are in the body-fixed frame. *Vre*$_b$ is the relative velocity in the body axes at which the mass flow ($\dot{m}$) is ejected or added to the body in body axes.

$$\bar{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\bar{V}}_b + \bar{\omega} \times \bar{V}_b) + \dot{m}\bar{V}re_b$$

$$A_{be} = \frac{\bar{F}_b - \dot{m}\bar{V}_{re}}{m}$$

$$A_{bb} = \begin{bmatrix} \dot{u}_b \\ \dot{v}_b \\ \dot{\omega}_b \end{bmatrix} = \frac{\bar{F}_b - \dot{m}\bar{V}_{re}}{m} - \bar{\omega} \times \bar{V}_b$$

$$\bar{V}_b = \begin{bmatrix} u_b \\ v_b \\ w_b \end{bmatrix}, \bar{\omega} = \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

The rotational dynamics of the body-fixed frame are given below, where the applied moments are $[L\ M\ N]^T$, and the inertia tensor *I* is with respect to the origin O.

$$\overline{M}_B = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I\dot{\overline{\omega}} + \overline{\omega} \times (I\overline{\omega}) + \dot{I}\,\overline{\omega}$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

The inertia tensor is determined using a table lookup which linearly interpolates between I_{full} and I_{empty} based on mass (m). While the rate of change of the inertia tensor is estimated by the following equation.

$$\dot{I} = \frac{I_{full} - I_{empty}}{m_{full} - m_{empty}}\dot{m}$$

The relationship between the body-fixed angular velocity vector, $[p\ q\ r]^T$, and the rate of change of the Euler angles, $[\dot{\phi}\dot{\theta}\,\dot{\psi}]^T$, can be determined by resolving the Euler rates into the body-fixed coordinate frame.

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} \dot{\phi} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix}\begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix}\begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix} \equiv J^{-1}\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

Inverting J then gives the required relationship to determine the Euler rate vector.

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = J\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & (\sin\phi\tan\theta) & (\cos\phi\tan\theta) \\ 0 & \cos\phi & -\sin\phi \\ 0 & \dfrac{\sin\phi}{\cos\theta} & \dfrac{\cos\phi}{\cos\theta} \end{bmatrix}\begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Simple Variable` selection conforms to the previously described equations of motion.

Representation

Select the representation to use:

`Euler Angles`	Use Euler angles within equations of motion.
`Quaternion`	Use quaternions within equations of motion.

The `Euler Angles` selection conforms to the previously described equations of motion.

Initial position in inertial axes

The three-element vector for the initial location of the body in the flat Earth reference frame.

Initial velocity in body axes

The three-element vector for the initial velocity in the body-fixed coordinate frame.

Initial Euler rotation

The three-element vector for the initial Euler rotation angles [roll, pitch, yaw], in radians.

Initial body rotation rates

The three-element vector for the initial body-fixed angular rates, in radians per second.

Initial mass

The initial mass of the rigid body.

Empty mass

A scalar value for the empty mass of the body.

Full mass

A scalar value for the full mass of the body.

Empty inertia matrix

A 3-by-3 inertia tensor matrix for the empty inertia of the body.

Full inertia matrix

A 3-by-3 inertia tensor matrix for the full inertia of the body.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Position: e.g., {'Xe', 'Ye', 'Ze'}

Specify position state names.

Default value is `''`.

Velocity: e.g., {'U', 'v', 'w'}

Specify velocity state names.

Default value is `''`.

Euler rotation angles: e.g., {'phi', 'theta', 'psi'}

Specify Euler rotation angle state names. This parameter appears if the **Representation** parameter is set to `Euler Angles`.

Default value is `''`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rate state names.

Default value is `''`.

Mass: e.g., 'mass'

Specify mass state name.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces.
Second	Vector	Contains the three applied moments.
Third	Scalar	Contains one or more rates of change of mass.
Fourth (Optional)	Three-element vector	Contains one or more relative velocities at which the mass is accreted to or ablated from the body in body-fixed axes.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity in the flat Earth reference frame.
Second	Three-element vector	Contains the position in the flat Earth reference frame.
Third	Three-element vector	Contains the Euler rotation angles [roll, pitch, yaw], within ±pi, in radians.
Fourth	3-by-3 matrix	Applies to the coordinate transformation from flat Earth axes to body-fixed axes.
Fifth	Three-element vector	Contains the velocity in the body-fixed frame.
Sixth	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Seventh	Three-element vector	Contains the angular accelerations in body-fixed axes, in radians per second squared.
Eight	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Ninth	Scalar element	Contains a flag for fuel tank status: • 1 indicates that the tank is full. • 0 indicates that the integral is neither full nor empty. • -1 indicates that the tank is empty.

Output	Dimension Type	Description
Tenth (Optional)	Three-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

Reference

Stevens, Brian, and Frank Lewis, *Aircraft Control and Simulation*, Second Edition, John Wiley & Sons, 2003.

Zipfel, Peter H., *Modeling and Simulation of Aerospace Vehicle Dynamics*. Second Edition, AIAA Education Series, 2007.

See Also

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

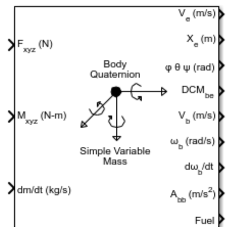
Simple Variable Mass 6DOF Wind (Wind Angles)

“About Aerospace Coordinate Systems” on page 2-10

Introduced in R2006a

Simple Variable Mass 6DOF (Quaternion)

Implement quaternion representation of six-degrees-of-freedom equations of motion of simple variable mass with respect to body axes



Library

Equations of Motion/6DOF

Description

For a description of the coordinate system and the translational dynamics, see the block description for the Simple Variable Mass 6DOF (Euler Angles) block.

The integration of the rate of change of the quaternion vector is given below. The gain *K* drives the norm of the quaternion state vector to 1.0 should ε become nonzero. You must choose the value of this gain with care, because a large value improves the decay rate of the error in the norm, but also slows the simulation because fast dynamics are introduced. An error in the magnitude in one element of the quaternion vector is spread equally among all the elements, potentially increasing the error in the state vector.

$$\begin{bmatrix}\dot{q}_0\\ \dot{q}_1\\ \dot{q}_2\\ \dot{q}_3\end{bmatrix} = {}^1\!/_2\begin{bmatrix}0 & -p & -q & -r\\ p & 0 & r & -q\\ q & -r & 0 & p\\ r & q & -p & 0\end{bmatrix}\begin{bmatrix}q_0\\ q_1\\ q_2\\ q_3\end{bmatrix} + K\varepsilon\begin{bmatrix}q_0\\ q_1\\ q_2\\ q_3\end{bmatrix}$$

$$\varepsilon = 1 - (q_0{}^2 + q_1{}^2 + q_3{}^2 + q_4{}^2)$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Simple Variable` selection conforms to the previously described equations of motion.

Representation

Select the representation to use:

`Euler Angles`	Use Euler angles within equations of motion.
`Quaternion`	Use quaternions within equations of motion.

The `Quaternion` selection conforms to the previously described equations of motion.

Initial position in inertial axes

The three-element vector for the initial location of the body in the flat Earth reference frame.

Initial velocity in body axes

The three-element vector for the initial velocity in the body-fixed coordinate frame.

Initial Euler rotation

The three-element vector for the initial Euler rotation angles [roll, pitch, yaw], in radians.

Initial body rotation rates

The three-element vector for the initial body-fixed angular rates, in radians per second.

Initial mass

The initial mass of the rigid body.

Inertia

A scalar value for the inertia of the body.

Empty mass

A scalar value for the empty mass of the body.

Full mass

A scalar value for the full mass of the body.

Empty inertia matrix

A 3-by-3 inertia tensor matrix for the empty inertia of the body.

Full inertia matrix

A 3-by-3 inertia tensor matrix for the full inertia of the body.

Gain for quaternion normalization

The gain to maintain the norm of the quaternion vector equal to 1.0.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Position: e.g., {'Xe', 'Ye', 'Ze'}

Specify position state names.

Default value is `''`.

Velocity: e.g., {'U', 'v', 'w'}

Specify velocity state names.

Default value is `''`.

Quaternion vector: e.g., {'qr', 'qi', 'qj', 'qk'}

Specify quaternion vector state names. This parameter appears if the **Representation** parameter is set to `Quaternion`.

Default value is `''`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rate state names.

Default value is `''`.

Euler rotation angles: e.g., {'phi', 'theta', 'psi'}

Specify Euler rotation angle state names.

Default value is `''`.

Mass: e.g., 'mass'

Specify mass state name.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces.
Second	Vector	Contains the three applied moments.
Third	Scalar	Contains one or more rates of change of mass (positive if accreted, negative if ablated).
Fourth (Optional)	Three-element vector	Contains one or more relative velocities at which the mass is accreted to or ablated from the body in body-fixed axes.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity in the flat Earth reference frame.
Second	Three-element vector	Contains the position in the flat Earth reference frame.
Third	Three-element vector	Contains the Euler rotation angles [roll, pitch, yaw], in radians.
Fourth	3-by-3 matrix	Applies to the coordinate transformation from flat Earth axes to body-fixed axes.

Output	Dimension Type	Description
Fifth	Three-element vector	Contains the velocity in the body-fixed frame.
Sixth	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Seventh	Three-element vector	Contains the angular accelerations in body-fixed axes, in radians per second squared.
Eight	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Ninth	Scalar element	Contains a flag for fuel tank status: • 1 indicates that the tank is full. • 0 indicates that the integral is neither full nor empty. • -1 indicates that the tank is empty.
Tenth (Optional)	Three-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

Reference

Stevens, Brian, and Frank Lewis, *Aircraft Control and Simulation*, Second Edition, John Wiley & Sons, 2003.

Zipfel, Peter H., *Modeling and Simulation of Aerospace Vehicle Dynamics*. Second Edition, AIAA Education Series, 2007.

See Also

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF ECEF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

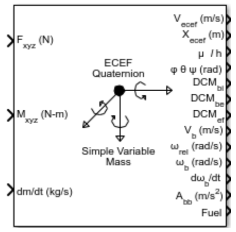
Simple Variable Mass 6DOF Wind (Wind Angles)

“About Aerospace Coordinate Systems” on page 2-10

Introduced in R2006a

Simple Variable Mass 6DOF ECEF (Quaternion)

Implement quaternion representation of six-degrees-of-freedom equations of motion of simple variable mass in Earth-centered Earth-fixed (ECEF) coordinates

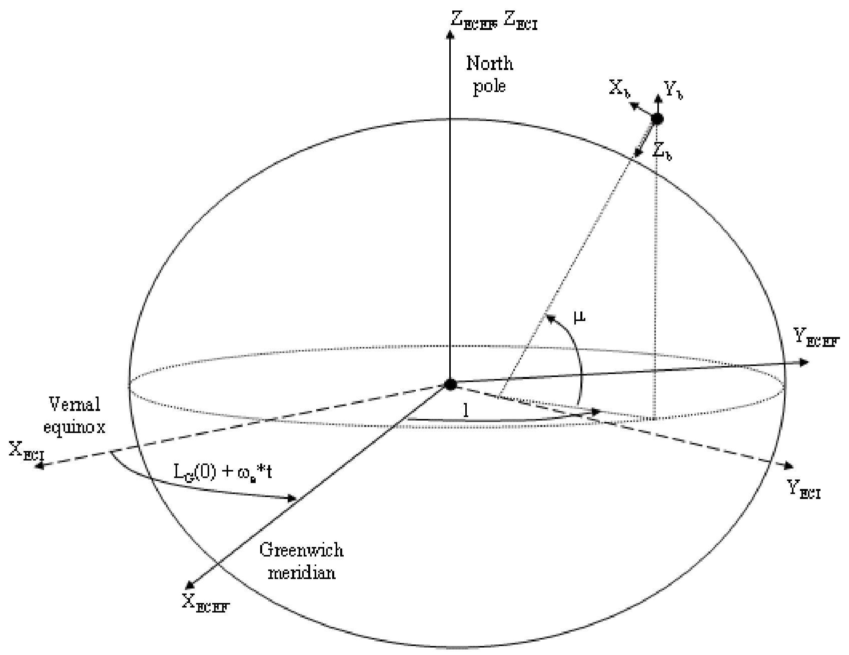


Library

Equations of Motion/6DOF

Description

The Simple Variable Mass 6DOF ECEF (Quaternion) block considers the rotation of a Earth-centered Earth-fixed (ECEF) coordinate frame (X_{ECEF}, Y_{ECEF}, Z_{ECEF}) about an Earth-centered inertial (ECI) reference frame (X_{ECI}, Y_{ECI}, Z_{ECI}). The origin of the ECEF coordinate frame is the center of the Earth, additionally the body of interest is assumed to be rigid, an assumption that eliminates the need to consider the forces acting between individual elements of mass. The representation of the rotation of ECEF frame from ECI frame is simplified to consider only the constant rotation of the ellipsoid Earth (ω_e) including an initial celestial longitude ($L_G(0)$). This excellent approximation allows the forces due to the Earth's complex motion relative to the “fixed stars” to be neglected.



The translational motion of the ECEF coordinate frame is given below, where the applied forces $[F_x\ F_y\ F_z]^T$ are in the body frame. Vre_b is the relative velocity in the wind axes at which the mass flow ($\dot{m}$) is ejected or added to the body axes.

$$\bar{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m\left(\dot{\bar{V}}_b + \bar{\omega}_b \times \bar{V}_b + DCM_{bf}\bar{\omega}_e \times \bar{V}_b + DCM_{bf}\left(\bar{\omega}_e \times \left(\bar{\omega}_e \times \bar{X}_f\right)\right)\right)$$

$$+\dot{m}\left(\bar{V}re_b + DCM_{bf}\left(\bar{\omega}_e \times \bar{X}_f\right)\right)$$

$$A_{bb} = \begin{bmatrix} \dot{u}_b \\ \dot{v}_b \\ \dot{w}_b \end{bmatrix} = \frac{\bar{F}_b - \dot{m}\left(\bar{V}_{re_b} + DCM_{bf}\left(w_e \times X_f\right)\right)}{m}$$

$$-\left[\bar{\omega}_b \times \bar{V}_b + DCM\bar{\omega}_e \times \bar{V}_b + DCM_{bf}\left(\bar{\omega}_e\left(\bar{\omega}_e \times X_f\right)\right)\right]$$

$$A_{becef} = \frac{\bar{F}_b - \dot{m}\left(\bar{V}_{re_b} + DCM_{bf}\left(\omega_e \times X_f\right)\right)}{m}$$

where the change of position in ECEF $\dot{\bar{x}}_f(\dot{\bar{x}}_i)$ is calculated by

$$\dot{\bar{x}}_f = DCM_{fb}\bar{V}_b$$

and the velocity of the body with respect to ECEF frame, expressed in body frame ($\bar{V}_b$), angular rates of the body with respect to ECI frame, expressed in body frame ($\bar{\omega}_b$). Earth rotation rate ($\bar{\omega}_e$), and relative angular rates of the body with respect to north-east-down (NED) frame, expressed in body frame ($\bar{\omega}_{rel}$) are defined as

$$\bar{V}_b = \begin{bmatrix} u \\ v \\ w \end{bmatrix} \bar{\omega}_{rel} = \begin{bmatrix} p \\ q \\ r \end{bmatrix} \bar{\omega}_e = \begin{bmatrix} 0 \\ 0 \\ \omega_e \end{bmatrix}$$

$$\bar{\omega}_b = \bar{\omega}_{rel} + DCM_{bf}\bar{\omega}_e + DCM_{be}\bar{\omega}_{ned}$$

$$\bar{\omega}_{ned} = \begin{bmatrix} \dot{l}\cos\mu \\ -\dot{\mu} \\ -\dot{l}\sin\mu \end{bmatrix} = \begin{bmatrix} V_E/(N+h) \\ -V_N/(M+h) \\ V_E\tan\mu/(N+h) \end{bmatrix}$$

The rotational dynamics of the body defined in body-fixed frame are given below, where the applied moments are $[L\ M\ N]^{\mathrm{T}}$, and the inertia tensor I is with respect to the origin O.

$$\bar{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = \bar{I}\dot{\bar{\omega}}_b + \bar{\omega}_b \times (\bar{I}\bar{\omega}_b) + \dot{I}\,\bar{\omega}_b$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

The inertia tensor is determined using a table lookup which linearly interpolates between I_{full} and I_{empty} based on mass (m). The rate of change of the inertia tensor is estimated by the following equation.

$$\dot{I} = \frac{I_{full} - I_{empty}}{m_{full} - m_{empty}}\dot{m}$$

The integration of the rate of change of the quaternion vector is given below.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = -\,{}^1\!/_2 \begin{bmatrix} 0 & \omega_b(1) & \omega_b(2) & \omega_b(3) \\ -\omega_b(1) & 0 & -\omega_b(3) & \omega_b(2) \\ -\omega_b(2) & \omega_b(3) & 0 & -\omega_b(1) \\ -\omega_b(3) & -\omega_b(2) & \omega_b(1) & 0 \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation (see 6DOF ECEF (Quaternion)).
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable (see Custom Variable Mass 6DOF ECEF (Quaternion)).

The `Simple Variable` selection conforms to the previously described equations of motion.

Initial position in geodetic latitude, longitude and altitude

The three-element vector for the initial location of the body in the geodetic reference frame. Latitude and longitude values can be any value. However, latitude values of +90 and -90 may return unexpected values because of singularity at the poles.

Initial velocity in body axes

The three-element vector containing the initial velocity of the body with respect to the ECEF frame, expressed in the body frame.

Initial Euler orientation

The three-element vector containing the initial Euler rotation angles [roll, pitch, yaw], in radians. Euler rotation angles are those between the body and NED coordinate systems.

Initial body rotation rates

The three-element vector for the initial angular rates of the body with respect to the NED frame, expressed the body frame, in radians per second.

Initial mass

The mass of the rigid body.

Inertia

A scalar value for the inertia of the body.

Empty mass

A scalar value for the empty mass of the body.

Full mass

A scalar value for the full mass of the body.

Empty inertia matrix

A 3-by-3 inertia tensor matrix for the empty inertia of the body.

Full inertia matrix

A 3-by-3 inertia tensor matrix for the full inertia of the body.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

Planet model

Specifies the planet model to use: `Custom` or `Earth (WGS84)`.

Equatorial radius of planet

Specifies the radius of the planet at its equator. The units of the equatorial radius parameter should be the same as the units for ECEF position. This option is only available when **Planet model** is set to `Custom`.

Flattening

Specifies the flattening of the planet. This option is only available when **Planet model** is set to `Custom`.

Rotational rate

Specifies the scalar rotational rate of the planet in rad/s. This option is only available when **Planet model** is set to `Custom`.

Celestial longitude of Greenwich source

Specifies the source of Greenwich meridian's initial celestial longitude:

`Internal`	Use celestial longitude value from **Celestial longitude of Greenwich**.
`External`	Use external input for celestial longitude value.

Celestial longitude of Greenwich

The initial angle between Greenwich meridian and the *x*-axis of the ECI frame. This parameter appears if you set **Celestial longitude of Greenwich source** to `Internal`.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.

- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Quaternion vector: e.g., {'qr', 'qi', 'qj', 'qk'}

Specify quaternion vector state names.

Default value is `' '`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rate state names.

Default value is `' '`.

Velocity: e.g., {'U', 'v', 'w'}

Specify velocity state names.

Default value is `' '`.

ECEF position: e.g., {'Xecef', 'Yecef', 'Zecef'}

Specify the ECEF position state names.

Default value is `' '`.

Inertial position: e.g., {'Xeci', 'Yeci', 'Zeci'}

Specify the inertial position state names.

Default value is `' '`.

Celestial longitude of Greenwich: e.g., 'LG'

Specify the Celestial longitude of Greenwich state name.

Default value is `' '`.

Mass: e.g., 'mass'

Specify mass state name.

Default value is `' '`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces in body-fixed axes.
Second	Vector	Contains the three applied moments in body-fixed axes.
Third	Scalar	Contains one or more rates of change of mass (positive if accreted, negative if ablated).
Fourth (Optional)	Three-element vector	Contains one or more relative velocities at which the mass is accreted to or ablated from the body-fixed axes.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity of body respect to ECEF frame, expressed in ECEF frame.
Second	Three-element vector	Contains the position in the ECEF reference frame.
Third	Three-element vector	Contains the position in geodetic latitude, longitude and altitude, in degrees, degrees and selected units of length respectively.
Fourth	Three-element vector	Contains the body rotation angles [roll, pitch, yaw], in radians. Euler rotation angles are those between body and NED coordinate systems.
Fifth	3-by-3 matrix	Applies to the coordinate transformation from ECI axes to body-fixed axes.
Sixth	3-by-3 matrix	Applies to the coordinate transformation from NED axes to body-fixed axes.
Seventh	3-by-3 matrix	Applies to the coordinate transformation from ECEF axes to NED axes.
Eighth	Three-element vector	Contains the velocity of body with respect to ECEF frame, expressed in body frame.

Output	Dimension Type	Description
Ninth	Three-element vector	Contains the relative angular rates of body with respect to NED frame, expressed in body frame, in radians per second.
Tenth	Three-element vector	Contains the angular rates of the body with respect to ECI frame, expressed in body frame, in radians per second.
Eleventh	Three-element vector	Contains the angular accelerations of the body with respect to ECI frame, expressed in body frame, in radians per second squared.
Twelfth	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Thirteenth	Scalar	Is an element containing a flag for fuel tank status: • 1 indicates that the tank is full. • 0 indicates that the integral is neither full nor empty. • -1 indicates that the tank is empty.
Fourteenth (Optional)	Three-element vector	Contains the accelerations in body-fixed axes with respect to ECEF frame.

Assumptions and Limitations

This implementation assumes that the applied forces are acting at the center of gravity of the body.

This implementation generates a geodetic latitude that lies between ±90 degrees, and longitude that lies between ±180 degrees. Additionally, the MSL altitude is approximate.

The Earth is assumed to be ellipsoidal. By setting flattening to 0.0, a spherical planet can be achieved. The Earth's precession, nutation, and polar motion are neglected. The celestial longitude of Greenwich is Greenwich Mean Sidereal Time (GMST) and provides a rough approximation to the sidereal time.

The implementation of the ECEF coordinate system assumes that the origin is at the center of the planet, the *x*-axis intersects the Greenwich meridian and the equator, the *z*-

axis is the mean spin axis of the planet, positive to the north, and the *y*-axis completes the right-hand system.

The implementation of the ECI coordinate system assumes that the origin is at the center of the planet, the *x*-axis is the continuation of the line from the center of the Earth toward the vernal equinox, the *z*-axis points in the direction of the mean equatorial plane's north pole, positive to the north, and the *y*-axis completes the right-hand system.

References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation, Second Edition*, John Wiley & Sons, New York, 2003.

McFarland, Richard E., *A Standard Kinematic Model for Flight simulation at NASA-Ames*, NASA CR-2497.

“Supplement to Department of Defense World Geodetic System 1984 Technical Report: Part I - Methods, Techniques and Data Used in WGS84 Development,” DMA TR8350.2-A.

See Also

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

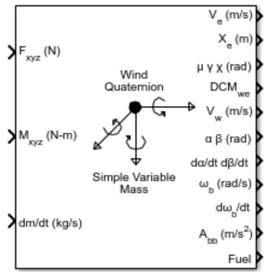
Simple Variable Mass 6DOF Wind (Wind Angles)

“About Aerospace Coordinate Systems” on page 2-10

Introduced in R2006a

Simple Variable Mass 6DOF Wind (Quaternion)

Implement quaternion representation of six-degrees-of-freedom equations of motion of simple variable mass with respect to wind axes

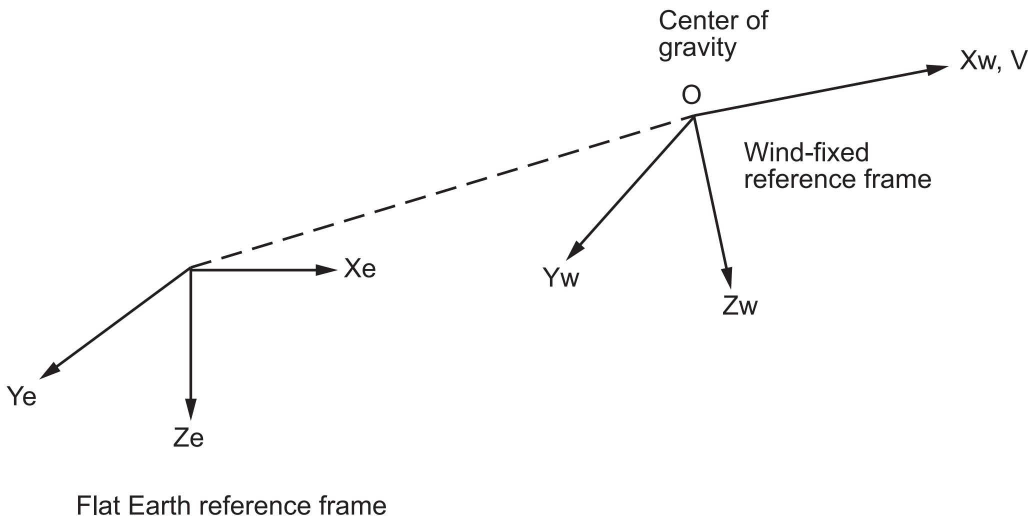


Library

Equations of Motion/6DOF

Description

The Simple Variable Mass 6DOF Wind (Quaternion) block considers the rotation of a wind-fixed coordinate frame (X_w, Y_w, Z_w) about an flat Earth reference frame (X_e, Y_e, Z_e). The origin of the wind-fixed coordinate frame is the center of gravity of the body, and the body is assumed to be rigid, an assumption that eliminates the need to consider the forces acting between individual elements of mass. The flat Earth reference frame is considered inertial, an excellent approximation that allows the forces due to the Earth's motion relative to the “fixed stars” to be neglected.



The translational motion of the wind-fixed coordinate frame is given below, where the applied forces $[F_x\ F_y\ F_z]^T$ are in the wind-fixed frame. Vre_w is the relative velocity in the wind axes at which the mass flow ($\dot{m}$) is ejected or added to the body.

$$\bar{F}_w = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\bar{V}}_w + \bar{\omega}_w \times \bar{V}_w) + \dot{m}\bar{V}re_w$$

$$\bar{V}_w = \begin{bmatrix} V \\ 0 \\ 0 \end{bmatrix}, \bar{\omega}_w = \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = DMC_{wb}\begin{bmatrix} p_b - \dot{\beta}\sin\alpha \\ q_b - \dot{\alpha} \\ r_b + \dot{\beta}\cos\alpha \end{bmatrix}, \bar{w}_b \begin{bmatrix} p_b \\ q_b \\ r_b \end{bmatrix}$$

The rotational dynamics of the body-fixed frame are given below, where the applied moments are $[L\ M\ N]^T$, and the inertia tensor *I* is with respect to the origin O. Inertia tensor *I* is much easier to define in body-fixed frame.

$$\bar{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I\dot{\bar{\omega}}_b + \bar{\omega}_b \times (I\bar{\omega}_b) + \dot{I}\,\bar{\omega}_b$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

The inertia tensor is determined using a table lookup which linearly interpolates between I_{full} and I_{empty} based on mass (m). While the rate of change of the inertia tensor is estimated by the following equation.

$$\dot{I} = \frac{I_{full} - I_{empty}}{m_{full} - m_{empty}}\dot{m}$$

The integration of the rate of change of the quaternion vector is given below.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = -1/2\begin{bmatrix} 0 & p & q & r \\ -p & 0 & -r & q \\ -q & r & 0 & -p \\ -r & -q & p & 0 \end{bmatrix}\begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Simple Variable` selection conforms to the previously described equations of motion.

Representation

Select the representation to use:

`Wind Angles`	Use wind angles within equations of motion.
`Quaternion`	Use quaternions within equations of motion.

The `Quaternion` selection conforms to the previously described equations of motion.

Initial position in inertial axes

The three-element vector for the initial location of the body in the flat Earth reference frame.

Initial airspeed, sideslip angle, and angle of attack

The three-element vector containing the initial airspeed, initial sideslip angle and initial angle of attack.

Initial wind orientation

The three-element vector containing the initial wind angles [bank, flight path, and heading], in radians.

Initial body rotation rates

The three-element vector for the initial body-fixed angular rates, in radians per second.

Initial mass

The initial mass of the rigid body.

Inertia in body axis

A scalar value for the inertia of the body.

Empty mass

A scalar value for the empty mass of the body.

Full mass

A scalar value for the full mass of the body.

Empty inertia matrix

A 3-by-3 inertia tensor matrix for the empty inertia of the body, in body-fixed axes.

Full inertia matrix

A 3-by-3 inertia tensor matrix for the full inertia of the body, in body-fixed axes.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.
- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Position: e.g., {'Xe', 'Ye', 'Ze'}

Specify position state names.

Default value is `''`.

Velocity: e.g., 'V'

Specify velocity state name.

Default value is `''`.

Incidence angle: e.g., 'alpha'

Specify incidence angle state name.

Default value is `''`.

Sideslip angle: e.g., 'beta'

Specify sideslip angle state name.

Default value is `''`.

Wind orientation: e.g., {'mu', 'gamma', 'chi'}

Specify wind orientation state names. This parameter appears if the **Representation** parameter is set to `Wind Angles`.

Default value is `''`.

Quaternion vector: e.g., {'qr', 'qi', 'qj', 'qk'}

Specify quaternion vector state names. This parameter appears if the **Representation** parameter is set to `Quaternion`.

Default value is `''`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rate state names.

Default value is `''`.

Mass: e.g., 'mass'

Specify mass state name.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces in wind-fixed axes.
Second	Vector	Contains the three applied moments in body-fixed axes.
Third	Scalar or vector	Contains one or more rates of change of mass.
Fourth (Optional)	Vector	Contains one or more relative velocities at which the mass is accreted to or ablated from the body in wind axes.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity in the flat Earth reference frame.
Second	Three-element vector	Contains the position in the flat Earth reference frame.
Third	Three-element vector	Contains the wind rotation angles [bank, flight path, heading], in radians.
Fourth	3-by-3 matrix	Applies to the coordinate transformation from flat Earth axes to wind-fixed axes.

Output	Dimension Type	Description
Fifth	Three-element vector	Contains the velocity in the wind-fixed frame.
Sixth	Two-element vector	Contains the angle of attack and sideslip angle, in radians.
Seventh	Two-element vector	Contains the rate of change of angle of attack and rate of change of sideslip angle, in radians per second.
Eighth	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Ninth	Three-element vector	Contains the angular accelerations in body-fixed axes, in radians per second squared.
Tenth	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Eleventh	Scalar element	Contains a flag for fuel tank status: • 1 indicates that the tank is full. • 0 indicates that the integral is neither full nor empty. • -1 indicates that the tank is empty.
Twelfth	Three-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

References

Stevens, Brian, and Frank Lewis, *Aircraft Control and Simulation*, Second Edition, John Wiley & Sons, 2003.

Zipfel, Peter H., *Modeling and Simulation of Aerospace Vehicle Dynamics*. Second Edition, AIAA Education Series, 2007.

See Also

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

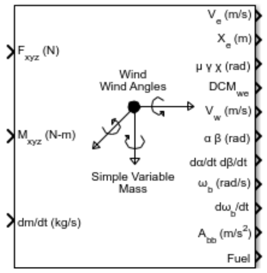
Simple Variable Mass 6DOF Wind (Wind Angles)

“About Aerospace Coordinate Systems” on page 2-10

Introduced in R2006a

Simple Variable Mass 6DOF Wind (Wind Angles)

Implement wind angle representation of six-degrees-of-freedom equations of motion of simple variable mass



Library

Equations of Motion/6DOF

Description

For a description of the coordinate system employed and the translational dynamics, see the block description for the Simple Variable Mass 6DOF (Quaternion) block.

The relationship between the wind angles, $[\mu\gamma\chi]^T$, can be determined by resolving the wind rates into the wind-fixed coordinate frame.

$$\begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} \dot{\mu} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\mu & \sin\mu \\ 0 & -\sin\mu & \cos\mu \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\gamma} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\mu & \sin\mu \\ 0 & -\sin\mu & \cos\mu \end{bmatrix} \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\chi} \end{bmatrix} \equiv J^{-1} \begin{bmatrix} \dot{\mu} \\ \dot{\gamma} \\ \dot{\chi} \end{bmatrix}$$

Inverting J then gives the required relationship to determine the wind rate vector.

$$\begin{bmatrix}\dot{\mu}\\ \dot{\gamma}\\ \dot{\chi}\end{bmatrix} = J\begin{bmatrix}p_w\\ q_w\\ r_w\end{bmatrix} = \begin{bmatrix}1 & (\sin\mu\tan\gamma) & (\cos\mu\tan\gamma)\\ 0 & \cos\mu & -\sin\mu\\ 0 & \dfrac{\sin\mu}{\cos\gamma} & \dfrac{\cos\mu}{\cos\gamma}\end{bmatrix}\begin{bmatrix}p_w\\ q_w\\ r_w\end{bmatrix}$$

The body-fixed angular rates are related to the wind-fixed angular rate by the following equation.

$$\begin{bmatrix}p_w\\ q_w\\ r_w\end{bmatrix} = DMC_{wb}\begin{bmatrix}p_b - \dot{\beta}\sin\alpha\\ q_b - \dot{\alpha}\\ r_b + \dot{\beta}\cos\alpha\end{bmatrix}$$

Using this relationship in the wind rate vector equations, gives the relationship between the wind rate vector and the body-fixed angular rates.

$$\begin{bmatrix}\dot{\mu}\\ \dot{\gamma}\\ \dot{\chi}\end{bmatrix} = J\begin{bmatrix}p_w\\ q_w\\ r_w\end{bmatrix} = \begin{bmatrix}1 & (\sin\mu\tan\gamma) & (\cos\mu\tan\gamma)\\ 0 & \cos\mu & -\sin\mu\\ 0 & \dfrac{\sin\mu}{\cos\gamma} & \dfrac{\cos\mu}{\cos\gamma}\end{bmatrix} DMC_{wb}\begin{bmatrix}p_b - \dot{\beta}\sin\alpha\\ q_b - \dot{\alpha}\\ r_b + \dot{\beta}\cos\alpha\end{bmatrix}$$

Parameters

Main

Units

Specifies the input and output units:

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`Metric (MKS)`	Newton	Newton meter	Meters per second squared	Meters per second	Meters	Kilogram	Kilogram meter squared
`English (Velocity in ft/s)`	Pound	Foot pound	Feet per second squared	Feet per second	Feet	Slug	Slug foot squared

Units	Forces	Moment	Acceleration	Velocity	Position	Mass	Inertia
`English (Velocity in kts)`	Pound	Foot pound	Feet per second squared	Knots	Feet	Slug	Slug foot squared

Mass Type

Select the type of mass to use:

`Fixed`	Mass is constant throughout the simulation.
`Simple Variable`	Mass and inertia vary linearly as a function of mass rate.
`Custom Variable`	Mass and inertia variations are customizable.

The `Simple Variable` selection conforms to the previously described equations of motion.

Representation

Select the representation to use:

`Wind Angles`	Use wind angles within equations of motion.
`Quaternion`	Use quaternions within equations of motion.

The `Wind Angles` selection conforms to the previously described equations of motion.

Initial position in inertial axes

The three-element vector for the initial location of the body in the flat Earth reference frame.

Initial airspeed, sideslip angle, and angle of attack

The three-element vector containing the initial airspeed, initial sideslip angle and initial angle of attack.

Initial wind orientation

The three-element vector containing the initial wind angles [bank, flight path, and heading], in radians.

Initial body rotation rates

The three-element vector for the initial body-fixed angular rates, in radians per second.

Initial mass

The initial mass of the rigid body.

Empty mass

A scalar value for the empty mass of the body.

Full mass

A scalar value for the full mass of the body.

Empty inertia matrix

A 3-by-3 inertia tensor matrix for the empty inertia of the body, in body-fixed axes.

Full inertia matrix

A 3-by-3 inertia tensor matrix for the full inertia of the body, in body-fixed axes.

Include mass flow relative velocity

Select this check box to add a mass flow relative velocity port. This is the relative velocity at which the mass is accreted or ablated.

Include inertial acceleration

Select this check box to enable an additional output port for the accelerations in body-fixed axes with respect to the inertial frame. You typically connect this signal to the accelerometer.

State Attributes

Assign unique name to each state. You can use state names instead of block paths during linearization.

- To assign a name to a single state, enter a unique name between quotes, for example, `'velocity'`.
- To assign names to multiple states, enter a comma-delimited list surrounded by braces, for example, `{'a', 'b', 'c'}`. Each name must be unique.

- If a parameter is empty (`' '`), no name assignment occurs.
- The state names apply only to the selected block with the name parameter.
- The number of states must divide evenly among the number of state names.
- You can specify fewer names than states, but you cannot specify more names than states.

  For example, you can specify two names in a system with four states. The first name applies to the first two states and the second name to the last two states.
- To assign state names with a variable in the MATLAB workspace, enter the variable without quotes. A variable can be a character vector, cell array, or structure.

Position: e.g., {'Xe', 'Ye', 'Ze'}

Specify position state names.

Default value is `''`.

Velocity: e.g., 'V'

Specify velocity state name.

Default value is `''`.

Incidence angle: e.g., 'alpha'

Specify incidence angle state name.

Default value is `''`.

Sideslip angle: e.g., 'beta'

Specify sideslip angle state name.

Default value is `''`.

Wind orientation: e.g., {'mu', 'gamma', 'chi'}

Specify wind orientation state names. This parameter appears if the **Representation** parameter is set to `Wind Angles`.

Default value is `''`.

Body rotation rates: e.g., {'p', 'q', 'r'}

Specify body rotation rates state names.

Default value is `''`.

Mass: e.g., 'mass'

Specify mass state name.

Default value is `''`.

Inputs and Outputs

Input	Dimension Type	Description
First	Vector	Contains the three applied forces in wind-fixed axes.
Second	Vector	Contains the three applied moments in body-fixed axes.
Third	Scalar or vector	Contains one or more rates of change of mass. This value is positive if the mass is added (accreted) to the body in wind axes. It is negative if the mass is ejected (ablated) from the body in wind axes.
Fourth (Optional)	Three-element vector	Contains one or more relative velocities at which the mass is accreted to or ablated from the body in wind axes.

Output	Dimension Type	Description
First	Three-element vector	Contains the velocity in the fixed Earth reference frame.
Second	Three-element vector	Contains the position in the flat Earth reference frame.
Third	Three-element vector	Contains the wind rotation angles [bank, flight path, heading], within ±pi, in radians.
Fourth	3-by-3 matrix	Applies to the coordinate transformation from flat Earth axes to wind-fixed axes.
Fifth	Three-element vector	Contains the velocity in the wind-fixed frame.
Sixth	Two-element vector	Contains the angle of attack and sideslip angle, in radians.
Seventh	Two-element vector	Contains the rate of change of angle of attack and rate of change of sideslip angle, in radians per second.

Output	Dimension Type	Description
Eighth	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Ninth	Three-element vector	Contain the angular accelerations in body-fixed axes, in radians per second squared.
Tenth	Three-element vector	Contains the accelerations in body-fixed axes with respect to body frame.
Eleventh	Scalar element	Contains a flag for fuel tank status: • 1 indicates that the tank is full. • 0 indicates that the integral is neither full nor empty. • -1 indicates that the tank is empty.
Twelfth (Output)	Three-element vector	Contains the accelerations in body-fixed axes with respect to inertial frame (flat Earth). You typically connect this signal to the accelerometer.

Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

References

Stevens, Brian, and Frank Lewis, *Aircraft Control and Simulation*, Second Edition, John Wiley & Sons, 2003.

Zipfel, Peter H., *Modeling and Simulation of Aerospace Vehicle Dynamics*. Second Edition, AIAA Education Series, 2007.

See Also

6DOF (Euler Angles)

6DOF (Quaternion)

6DOF ECEF (Quaternion)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)

Custom Variable Mass 6DOF (Euler Angles)

Custom Variable Mass 6DOF (Quaternion)

Custom Variable Mass 6DOF ECEF (Quaternion)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 6DOF (Euler Angles)

Simple Variable Mass 6DOF (Quaternion)

Simple Variable Mass 6DOF ECEF (Quaternion)

Simple Variable Mass 6DOF Wind (Quaternion)

"About Aerospace Coordinate Systems" on page 2-10

Introduced in R2006a

Simulation Pace

Set simulation rate for animation viewing

Library: Aerospace Blockset / Animation / Animation Support Utilities

Description

The Simulation Pace block lets you run model simulation at a slower pace so that you can comfortably view connected animations and understand and observe the system behavior. Visualizing simulations at a slower rate makes it easier to understand underlying system design, identify design issues and demonstrate near real-time behavior. You can view the results and inspect your system while the simulation is in progress.

Use this block in scenarios where one simulation-second is completed in a few wall clock time milliseconds.

When configuring this block, also consider the block sample time, which affects the simulation pace. The default is 1/30th of a second, which corresponds to a 30 frames-per-second visualization rate (typical for desktop computers). For more information, see “Sample time” on page 4-0 .

To use this block:

- Set the model solver to `Fixed-step`.
- Use a discrete sample time.

This block does not produce deployable code.

Ports

Output

`Port_1` — Pace error
scalar

Pace error, specified as a scalar.

The block optionally outputs the pace error value (*simulationTime* minus *ClockTime*), in seconds. The pace error is positive if the simulation is running faster than the specified pace and negative if slower than the specified pace.

Outputting the pace error from the block lets you record the overall pace achieved during the simulation or routing the signal to other blocks to determine if the simulation is too slow to keep up with the specified pace.

Dependencies

To enable this port, select the **Output pace error (sec)** check box.

Data Types: `double`

Parameters

`Simulation pace` — Ratio of simulation time to clock time

`1` (default) | scalar

Ratio of simulation time to clock time, specified as a scalar, in seconds of simulation time per second of clock time.

Programmatic Use
Block Parameter: `OutputPaceError`
Type: character vector
Values:`'1'` | scalar
Default: `'1'`

`Sleep mode` — Control simulation pace

`Auto` (default) | `MATLAB Thread` | `Off` | `Busy-Wait`

Control simulation pace of model using one of these methods. `MATLAB Thread`, `Busy-Wait`, and `Auto` slow down the simulation pace at simulation-second 0.1 to wait for the wall clock to get to time 1. Use this parameter when one simulation-second is completed in a few wall clock time milliseconds.

- `Auto` — Use the model configuration parameter setting **Enable pacing to slow down simulation** to control the simulation pace. If the model configuration parameter setting **Enable pacing to slow down simulation** is not selected, the block behaves as though the `MATLAB Thread` option is selected.

- `MATLAB Thread` — Use the operating system `sleep` function during simulation to wait for the wall clock to get to time 1.
- `Off` — Disable the pace functionality and let the simulation run as fast as possible.
- `Busy-Wait` — Use a while loop in conjunction with the Simstruct to wait for the simulation to wait for the wall clock to get to time 1.

Programmatic Use
Block Parameter: `SleepMode`
Type: character vector
Values:`'MATLAB Thread'` | `'Off'` | `'Busy-Wait'` | `'Auto'`
Default: `'Auto'`

`Output pace error` — Display pace error

`off` (default) | `on`

Select this check box to output the pace error value (*simulationTime* minus *ClockTime*), in seconds. The pace error is positive if the simulation is running faster than the specified pace and negative if slower than the specified pace. To disable the display, clear this check box .

Programmatic Use
Block Parameter: `OutputPaceError`
Type: character vector
Values:`'off' | 'on'`
Default: `'off'`

`Sample time` — Sample time

1/30 (default) | `-1` | scalar | vector

Specify the sample time as a scalar. The default 1/30th of a second corresponds to a 30 frames-per-second visualization rate (typical for desktop computers). To set how often the Simulink interface synchronizes with the wall clock, use this parameter.

The block sample time must be:

- Discrete
- Greater than 0.0 or an inherited sample time (-1)

The block sample time and its optional offset time ([T_s, T_o]) must be finite and discrete.

Caution Choose as slow a sample time as needed for smooth animation, since oversampling has little benefit and undersampling can cause animation jumpiness. Undersampling can also potentially block the MATLAB main thread on your computer.

Programmatic Use
Block Parameter: `SampleTime`
Type: character vector
Values: scalar | vector
Default: `'1/30'`

Algorithms

The simulation pace is implemented by putting the entire MATLAB thread to sleep until it must run again to keep up the pace. The Simulink software is single threaded and runs on the one MATLAB thread, so only one Simulation Pace block can be active at a time.

See Also

Pilot Joystick

Topics

"Specify Sample Time" (Simulink)
"Simulation Pacing" (Simulink)

Introduced before R2006a

SinCos

Compute sine and cosine of angle

Library

Utilities/Math Operations

Description

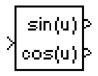
The SinCos block computes the sine and cosine of the input angle, theta.

Inputs and Outputs

The first input is an angle, in radians.

The first output is the sine of the input angle.

The second output is the cosine of the input angle.



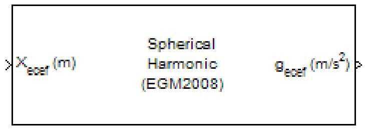
Compatibility

Note SinCos will be removed in a future release. Use the Simulink Trigonometric Function block instead.

Introduced before R2006a

Spherical Harmonic Gravity Model

Implement spherical harmonic representation of planetary gravity



Spherical Harmonic Gravity Model

Library

Environment/Gravity

Description

The Spherical Harmonic Gravity Model block implements the mathematical representation of spherical harmonic planetary gravity based on planetary gravitational potential. It provides a convenient way to describe a planet gravitational field outside of its surface in spherical harmonic expansion.

You can use spherical harmonics to modify the magnitude and direction of spherical gravity (-GM/r^2). The most significant or largest spherical harmonic term is the second degree zonal harmonic, J2, which accounts for oblateness of a planet.

Use this block if you want more accurate gravity values than spherical gravity models. For example, nonatmospheric flight applications might require higher accuracy.

Parameters

Units

Specifies the parameter and output units:

Units	Height
`Metric (MKS)`	Meters

Units	Height
English	Feet

Degree

Specify the degree of harmonic model. Recommended degrees are:

Planet Model	Degree
EGM2008	120
EGM96	70
LP100K	60
LP165P	60
GMM2B	60
EIGENGL04C	70

Action for out-of-range input

Specify if out-of-range input invokes a warning, error, or no action.

Planet model

Specify the planetary model. From the list, select:

Planet Model	Notes
EGM2008	Earth — Is the latest Earth spherical harmonic gravitational model from National Geospatial-Intelligence Agency (NGA). This block provides the WGS-84 version of this gravitational model. You can use the EGM96 planetary model if you need to use the older standard for Earth.
EGM96	Earth
LP100K	Moon — Is best for lunar orbit determination based upon computational time required to compute orbits. This planet model was created in approximately the same year as LP165P with similar data.

Planet Model	Notes
`LP165P`	Moon — Is best for extended lunar mission orbit accuracy. This planet model was created in approximately the same year as LP165P with similar data.
`GMM2B`	Mars
`Custom`	Enables you to specify your own planetary model. This option enables the **Planet mat-file** parameter.
`EIGENGL04C`	Earth — Supports the gravity field model, EIGEN-GL04C (`http://icgem.gfz-potsdam.de/tom_longtime`). This model is an upgrade to EIGEN-CG03C.

When defining your own planetary model, the **Degree** parameter is limited to the maximum value for int16. When inputting a large degree, you might receive an out-of-memory error. For more information about avoiding out-of-memory errors in the MATLAB environment, see “Resolve “Out of Memory” Errors” (MATLAB).

Planet mat-file

Specify a MAT-file that contains definitions for a custom planetary model. The `aerogmm2b.mat` file in the Aerospace Toolbox is the default MAT-file for a custom planetary model.

This file must contain:

Variable	Description
Re	Scalar of planet equatorial radius in meters (m).
GM	Scalar of planetary gravitational parameter in meters cubed per second squared (m^3/s^2)
degree	Scalar of maximum degree.
C	(*degree*+1)-by-(*degree*+1) matrix containing normalized spherical harmonic coefficients matrix, *C*.
S	(*degree*+1)-by-(*degree*+1) matrix containing normalized spherical harmonic coefficients matrix, *S*.

When using a large value for **Degree**, you might receive an out-of-memory error. For more information about avoiding out-of-memory errors in the MATLAB environment, see “Resolve “Out of Memory” Errors” (MATLAB).

References

[1] Gottlieb, R. G., “Fast Gravity, Gravity Partials, Normalized Gravity, Gravity Gradient Torque and Magnetic Field: Derivation, Code and Data,” *Technical Report NASA Contractor Report 188243*, NASA Lyndon B. Johnson Space Center, Houston, Texas, February 1993.

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[3] “NIMA TR8350.2: Department of Defense World Geodetic System 1984, Its Definition and Relationship with Local Geodetic Systems”.

[4] Konopliv, A. S., S. W. Asmar, E. Carranza, W. L. Sjogen, D. N. Yuan., “Recent Gravity Models as a Result of the Lunar Prospector Mission, Icarus”, Vol. 150, no. 1, pp 1–18, 2001.

[5] Lemoine, F. G., D. E. Smith, D.D. Rowlands, M.T. Zuber, G. A. Neumann, and D. S. Chinn, “An improved solution of the gravity field of Mars (GMM-2B) from Mars Global Surveyor”, *Journal Of Geophysical Research*, Vol. 106, No. E10, pp 23359-23376, October 25, 2001.

[6] Kenyon S., J. Factor, N. Pavlis, and S. Holmes, “Towards the Next Earth Gravitational Model”, Society of Exploration Geophysicists 77th Annual Meeting, San Antonio, Texas, September 23–28, 2007.

[7] Pavlis, N.K., S.A. Holmes, S.C. Kenyon, and J.K. Factor, “An Earth Gravitational Model to Degree 2160: EGM2008”, presented at the 2008 General Assembly of the European Geosciences Union, Vienna, Austria, April 13–18, 2008.

[8] Grueber, T., and A. Köhl, “Validation of the EGM2008 Gravity Field with GPS-Leveling and Oceanographic Analyses”, presented at the IAG International Symposium on Gravity, Geoid & Earth Observation 2008, Chania, Greece, June 23–27, 2008.

[9] Förste, C., Flechtner, F., Schmidt, R., König, R., Meyer, U., Stubenvoll, R., Rothacher, M., Barthelmes, F., Neumayer, H., Biancale, R., Bruinsma, S., Lemoine, J.M., Loyer, S., “A Mean Global Gravity Field Model From the Combination of Satellite

Mission and Altimetry/Gravmetry Surface Data - EIGEN-GL04C”, *Geophysical Research Abstracts*, Vol. 8, 03462, 2006.

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[11] Colombo, Oscar L., “Numerical Methods for Harmonic Analysis on the Sphere”, Reports of the department of Geodetic Science, Report No. 310, The Ohio State University, Columbus, OH., March 1981.

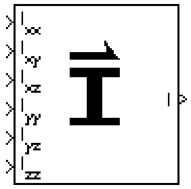
[12] Colombo, Oscar L., “The Global Mapping of Gravity with Two Satellites", Nederlands Geodetic Commission, vol. 7 No. 3, Delft, The Nederlands, 1984., Reports of the department of Geodetic Science, Report No. 310, The Ohio State University, Columbus, OH., March 1981.

[13] Jones, Brandon A. (2010). Efficient Models for the Evaluation and Estimation of the Gravity Field. Doctoral dissertation, University of Colorado, Boulder.

Introduced in R2010a

Symmetric Inertia Tensor

Create inertia tensor from moments and products of inertia



Library

Mass Properties

Description

The Symmetric Inertia Tensor block creates an inertia tensor from moments and products of inertia. Each input corresponds to an element of the tensor.

The inertia tensor has the form of

$$Inertia = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{xy} & I_{yy} & -I_{yz} \\ -I_{xz} & -I_{yz} & I_{zz} \end{bmatrix}$$

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the moment of inertia about the *x*-axis.
Second		Contains the product of inertia in the *xy* plane.
Third		Contains the product of inertia in the *xz* plane.
Fourth		Contains the moment of inertia about the *y*-axis.

Input	Dimension Type	Description
Fifth		Contains the product of inertia in the *yz* plane.
Sixth		Contains the moment of inertia about the *z*-axis.

Output	Dimension Type	Description
First		Contains a symmetric 3-by-3 inertia tensor.

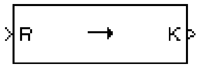
See Also

Create 3x3 Matrix

Introduced before R2006a

Temperature Conversion

Convert from temperature units to desired temperature units



Library

Utilities/Unit Conversions

Description

The Temperature Conversion block computes the conversion factor from specified input temperature units to specified output temperature units and applies the conversion factor to the input signal.

The Temperature Conversion block icon displays the input and output units selected from the **Initial unit** and the **Final unit** lists.

Parameters

Initial unit

Specifies the input units.

Final unit

Specifies the output units.

The following conversion units are available:

K	Kelvin
F	Degrees Fahrenheit
C	Degrees Celsius
R	Degrees Rankine

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the temperature in initial temperature units.

Output	Dimension Type	Description
First		Contains the temperature in final temperature units.

See Also

Acceleration Conversion

Angle Conversion

Angular Acceleration Conversion

Angular Velocity Conversion

Density Conversion

Force Conversion

Length Conversion

Mass Conversion

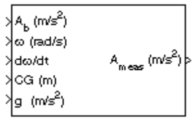
Pressure Conversion

Velocity Conversion

Introduced before R2006a

Three-Axis Accelerometer

Implement three-axis accelerometer



Library

GNC/Navigation

Description

The Three-Axis Accelerometer block implements an accelerometer on each of the three axes. The ideal measured accelerations ($\bar{A}_{imeas}$) include the acceleration in body axes at the center of gravity ($\bar{A}_b$), lever arm effects due to the accelerometer not being at the center of gravity, and, optionally, gravity in body axes can be removed.

$$\bar{A}_{imeas} = \bar{A}_b + \bar{\omega}_b \times (\bar{\omega}_b \times \bar{d}) + \dot{\bar{\omega}}_b \times \bar{d} - \bar{g}$$

where $\bar{\omega}_b$ are body-fixed angular rates, $\dot{\bar{\omega}}_b$ are body-fixed angular accelerations and $\bar{d}$ is the lever arm. The lever arm ($\bar{d}$) is defined as the distances that the accelerometer group is forward, right and below the center of gravity.

$$\bar{d} = \begin{bmatrix} d_x \\ d_y \\ d_z \end{bmatrix} = \begin{bmatrix} -(x_{acc} - x_{CG}) \\ y_{acc} - y_{CG} \\ -(z_{acc} - z_{CG}) \end{bmatrix}$$

The orientation of the axes used to determine the location of the accelerometer group (x_{acc}, y_{acc}, z_{acc}) and center of gravity (x_{CG}, y_{CG}, z_{CG}) is from the zero datum (typically the nose) to aft, to the right of the vertical centerline and above the horizontal centerline. The *x*-axis and *z*-axis of this measurement axes are opposite the body-fixed axes producing the negative signs in the lever arms for *x*-axis and *z*-axis.

Measured accelerations ($\bar{A}_{meas}$) output by this block contain error sources and are defined as

$$\bar{A}_{meas} = \bar{A}_{imeas} \times \bar{A}_{SFCC} + \bar{A}_{bias} + noise$$

where $\bar{A}_{SFCC}$ is a 3-by-3 matrix of scaling factors on the diagonal and misalignment terms in the nondiagonal, and $\bar{A}_{bias}$are the biases.

Optionally discretizations can be applied to the block inputs and dynamics along with nonlinearizations of the measured accelerations via a Saturation block.

Parameters

Units

Specifies the input and output units:

Units	Acceleration	Length
`Metric (MKS)`	Meters per second squared	Meters
`English`	Feet per second squared	Feet

Accelerometer location

The location of the accelerometer group is measured from the zero datum (typically the nose) to aft, to the right of the vertical centerline and above the horizontal centerline. This measurement reference is the same for the center of gravity input. The units are in selected length units.

Subtract gravity

Select to subtract gravity from acceleration readings.

Second order dynamics

Select to apply second-order dynamics to acceleration readings.

Natural frequency (rad/sec)

The natural frequency of the accelerometer. The units of natural frequency are radians per second.

Damping ratio

The damping ratio of the accelerometer. A dimensionless parameter.

Scale factors and cross-coupling

The 3-by-3 matrix used to skew the accelerometer from body axes and to scale accelerations along body axes.

Measurement bias

The three-element vector containing long-term biases along the accelerometer axes. The units are in selected acceleration units.

Update rate (sec)

Specify the update rate of the accelerometer. An update rate of 0 will create a continuous accelerometer. If noise is selected and the update rate is 0, then the noise will be updated at the rate of 0.1. The units of update rate are seconds.

If you:

- Update this parameter value to 0 (continuous)
- Configure a fixed-step solver for the model

you must also select the **Automatically handle rate transition for data transfer** check box in the **Solver** pane. This check box enables the software to handle rate transitions correctly.

Noise on

Select to apply white noise to acceleration readings.

Noise seeds

The scalar seeds for the Gaussian noise generator for each axis of the accelerometer.

Noise power

The height of the PSD of the white noise for each axis of the accelerometer. The units are:

- $(m/s^2)/Hz$ for `Metric (MKS)`
- $(ft/s^2)/Hz$ for `English`

Lower and upper output limits

The six-element vector containing three minimum values and three maximum values of acceleration in each of the accelerometer axes. The units are in selected acceleration units.

Inputs and Outputs

Input	Dimension Type	Description
First	Three-element vector	Contains the actual accelerations in body-fixed axes, in selected units.
Second	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Third	Three-element vector	Contains the angular accelerations in body-fixed axes, in radians per second squared.
Fourth	Three-element vector	Contains the location of the center of gravity, in selected units.
Fifth (Optional)	Three-element vector	Contains the gravity in body axis, in selected units.

Output	Dimension Type	Description
First	Three-element vector	Contains the measured accelerations from the accelerometer, in selected units.

Assumptions and Limitations

Vibropendulous error and hysteresis effects are not accounted for in this block. Additionally, this block is not intended to model the internal dynamics of different forms of the instrument.

Reference

Rogers, R. M., *Applied Mathematics in Integrated Navigation Systems*, AIAA Education Series, 2000.

See Also

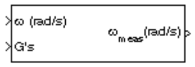
Three-Axis Gyroscope

Three-Axis Inertial Measurement Unit

Introduced before R2006a

Three-Axis Gyroscope

Implement three-axis gyroscope



Library

GNC/Navigation

Description

The Three-Axis Gyroscope block implements a gyroscope on each of the three axes. The measured body angular rates ($\bar{\omega}_{meas}$) include the body angular rates ($\bar{\omega}_b$), errors, and optionally discretizations and nonlinearizations of the signals.

$$\bar{\omega}_{meas} = \bar{\omega}_b \times \bar{\omega}_{SFCC} + \bar{\omega}_{bias} + Gs \times \bar{\omega}_{gsens} + noise$$

where $\bar{\omega}_{SFCC}$ is a 3-by-3 matrix of scaling factors on the diagonal and misalignment terms in the nondiagonal, $\bar{\omega}_{bias}$ are the biases, (Gs) are the Gs on the gyroscope, and $\bar{\omega}_{gsens}$ are the g-sensitive biases.

Optionally, discretizations can be applied to the block inputs and dynamics along with nonlinearizations of the measured body angular rates via a Saturation block.

Parameters

Second order dynamics

Select to apply second-order dynamics to gyroscope readings.

Natural frequency (rad/sec)

The natural frequency of the gyroscope. The units of natural frequency are radians per second.

Damping ratio

The damping ratio of the gyroscope. A dimensionless parameter.

Scale factors and cross-coupling

The 3-by-3 matrix used to skew the gyroscope from body axes and to scale angular rates along body axes.

Measurement bias

The three-element vector containing long-term biases along the gyroscope axes. The units are in radians per second.

G-sensitive bias

The three-element vector contains the maximum change in rates due to linear acceleration. The units are in radians per second per g-unit.

Update rate (sec)

Specify the update rate of the gyroscope. An update rate of 0 will create a continuous gyroscope. If noise is selected and the update rate is 0, then the noise will be updated at the rate of 0.1. The units of update rate are seconds.

If you:

- Update this parameter value to 0 (continuous)
- Configure a fixed-step solver for the model

you must also select the **Automatically handle rate transition for data transfer** check box in the **Solver** pane. This check box enables the software to handle rate transitions correctly.

Noise on

Select to apply white noise to gyroscope readings.

Noise seeds

The scalar seeds for the Gaussian noise generator for each axis of the gyroscope.

Noise power

The height of the PSD of the white noise for each axis of the gyroscope. The units are $(rad/s)^2/Hz$.

Lower and upper output limits

The six-element vector containing three minimum values and three maximum values of angular rates in each of the gyroscope axes. The units are in radians per second.

Inputs and Outputs

Input	Dimension Type	Description
First	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Second	Three-element vector	Contains the accelerations in body-fixed axes, in Gs.

Output	Dimension Type	Description
First	Three-element vector	Contains the measured angular rates from the gyroscope, in radians per second.

Assumptions and Limitations

Anisoelastic bias and anisoinertial bias effects are not accounted for in this block. Additionally, this block is not intended to model the internal dynamics of different forms of the instrument.

Reference

Rogers, R. M., *Applied Mathematics in Integrated Navigation Systems*, AIAA Education Series, 2000.

See Also

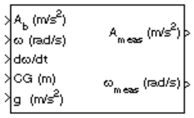
Three-Axis Accelerometer

Three-Axis Inertial Measurement Unit

Introduced before R2006a

Three-Axis Inertial Measurement Unit

Implement three-axis inertial measurement unit (IMU)



Library

GNC/Navigation

Description

The Three-Axis Inertial Measurement Unit block implements an inertial measurement unit (IMU) containing a three-axis accelerometer and a three-axis gyroscope.

For a description of the equations and application of errors, see the Three-Axis Accelerometer block and the Three-Axis Gyroscope block reference pages.

Parameters

Units

Specifies the input and output units:

Units	Acceleration	Length
`Metric (MKS)`	Meters per second squared	Meters
`English`	Feet per second squared	Feet

IMU location

The location of the IMU, which is also the accelerometer group location, is measured from the zero datum (typically the nose) to aft, to the right of the vertical centerline and above the horizontal centerline. This measurement reference is the same for the center of gravity input. The units are in selected length units.

Update rate (sec)

Specify the update rate of the accelerometer and gyroscope. An update rate of 0 will create a continuous accelerometer and continuous gyroscope. If noise is selected and the update rate is 0, then the noise will be updated at the rate of 0.1. The units of update rate are seconds.

If you:

- Update this parameter value to 0 (continuous)
- Configure a fixed-step solver for the model

you must also select the **Automatically handle rate transition for data transfer** check box in the **Solver** pane. This check box enables the software to handle rate transitions correctly.

Second order dynamics for accelerometer

Select to apply second-order dynamics to acceleration readings.

Accelerometer natural frequency (rad/sec)

The natural frequency of the accelerometer. The units of natural frequency are radians per second.

Accelerometer damping ratio

The damping ratio of the accelerometer. A dimensionless parameter.

Accelerometer scale factors and cross-coupling

The 3-by-3 matrix used to skew the accelerometer from body-axis and to scale accelerations along body-axis.

Accelerometer measurement bias

The three-element vector containing long-term biases along the accelerometer axes. The units are in selected acceleration units.

Accelerometer lower and upper output limits

The six-element vector containing three minimum values and three maximum values of acceleration in each of the accelerometer axes. The units are in selected acceleration units.

Gyro second order dynamics

Select to apply second-order dynamics to gyroscope readings.

Gyro natural frequency (rad/sec)

The natural frequency of the gyroscope. The units of natural frequency are radians per second.

Gyro damping ratio

The damping ratio of the gyroscope. A dimensionless parameter.

Gyro scale factors and cross-coupling

The 3-by-3 matrix used to skew the gyroscope from body axes and to scale angular rates along body axes.

Gyro measurement bias

The three-element vector containing long-term biases along the gyroscope axes. The units are in radians per second.

G-sensitive bias

The three-element vector contains the maximum change in rates due to linear acceleration. The units are in radians per second per g-unit.

Gyro lower and upper output limits

The six-element vector containing three minimum values and three maximum values of angular rates in each of the gyroscope axes. The units are in radians per second.

Noise on

Select to apply white noise to acceleration and gyroscope readings.

Noise seeds

The scalar seeds for the Gaussian noise generator for each axis of the accelerometer and gyroscope.

Noise power

The height of the PSD of the white noise for each axis of the accelerometer and gyroscope.

Inputs and Outputs

Input	Dimension Type	Description
First	Three-element vector	Contains the actual accelerations in body-fixed axes, in selected units.

Input	Dimension Type	Description
Second	Three-element vector	Contains the angular rates in body-fixed axes, in radians per second.
Third	Three-element vector	Contains the angular accelerations in body-fixed axes, in radians per second squared.
Fourth	Three-element vector	Contains the location of the center of gravity, in selected units.
Fifth	Three-element vector	Contains the gravity in body axis, in selected units.

Output	Dimension Type	Description
First	Three-element vector	Contains the measured accelerations from the accelerometer, in selected units.
Second	Three-element vector	Contains the measured angular rates from the gyroscope, in radians per second.

Assumptions and Limitations

Vibropendulous error, hysteresis affects, anisoelastic bias and anisoinertial bias are not accounted for in this block. Additionally, this block is not intended to model the internal dynamics of different forms of the instrument.

Examples

See `asbhl20` for an example of this block.

Reference

Rogers, R. M., *Applied Mathematics in Integrated Navigation Systems*, AIAA Education Series, 2000.

See Also

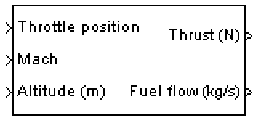
Three-Axis Accelerometer

Three-Axis Gyroscope

Introduced before R2006a

Turbofan Engine System

Implement first-order representation of turbofan engine with controller



Library

Propulsion

Description

The Turbofan Engine System block computes the thrust and the weight of fuel flow of a turbofan engine and controller at a specific throttle position, Mach number, and altitude.

This system is represented by a first-order system with unitless heuristic lookup tables for thrust, thrust specific fuel consumption (TSFC), and engine time constant. For the lookup table data, thrust is a function of throttle position and Mach number, TSFC is a function of thrust and Mach number, and engine time constant is a function of thrust. The unitless lookup table outputs are corrected for altitude using the relative pressure ratio δ and relative temperature ratio θ, and scaled by maximum sea level static thrust, fastest engine time constant at sea level static, sea level static thrust specific fuel consumption, and ratio of installed thrust to uninstalled thrust.

The Turbofan Engine System block icon displays the input and output units selected from the **Units** list.

Parameters

Units

Specifies the input and output units:

Units	Altitude	Thrust	Fuel Flow
`Metric (MKS)`	Meters	Newtons	Kilograms per second
`English`	Feet	Pound force	Pound mass per second

Initial thrust source

Specifies the source of initial thrust:

`Internal`	Use initial thrust value from mask dialog.
`External`	Use external input for initial thrust value.

Initial thrust

Initial value for thrust.

Maximum sea-level static thrust

Maximum thrust at sea-level and at Mach = 0.

Fastest engine time constant at sea-level static

Fastest engine time at sea level.

Sea-level static thrust specific fuel consumption

Thrust specific fuel consumption at sea level, at Mach = 0, and at maximum thrust, in specified mass units per hour per specified thrust units.

Ratio of installed thrust to uninstalled thrust

Coefficient representing the loss in thrust due to engine installation.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the throttle position, which can vary from zero to one, corresponding to no and full throttle.
Second		Contains the Mach number.
Third		Contains the altitude in specified length units.

Output	Dimension Type	Description
First		Contains the thrust in specified force units.
Second		Contains the fuel flow in specified mass units per second.

Assumptions and Limitations

The atmosphere is at standard day conditions and an ideal gas.

The Mach number is limited to less than 1.0.

This engine system is for indication purposes only. It is not meant to be used as a reference model.

This engine system is assumed to have a high bypass ratio.

References

Aeronautical Vestpocket Handbook, United Technologies Pratt & Whitney, August, 1986.

Raymer, D. P., *Aircraft Design: A Conceptual Approach*, AIAA Education Series, Washington, DC, 1989.

Hill, P. G., and C. R. Peterson, *Mechanics and Thermodynamics of Propulsion,* Addison-Wesley Publishing Company, Reading, Massachusetts, 1970.

Introduced before R2006a

Turn Coordinator

Display measurements on turn coordinator and inclinometer
Library: Aerospace Blockset / Flight Instruments

Description

The Turn Coordinator block displays measurements on a turn coordinator and inclinometer. These measurements help determine if the turn is coordinated, slipped, or skidded. The turn is a coordinated turn that combines the rolling and yawing of a turn. The turn indicator signal turns the airplane in the gauge, in degrees. The inclinometer turns the ball in the gauge, in degrees. Together, these signals show the slip and skid of an airplane as it turns. Both values cannot exceed +/–15 degrees. If values exceed 15 degrees, the gauge stays fixed at the minimum or maximum value.

Combine the turn indicator and inclinometer signals in a Mux block in order:

1. Turn indicator
2. Inclinometer

Parameters

`Connection` — Connect to signal

signal name | 2-element signal

Connect to 2-element signal for display, selected from a list of signal names. The 2-element signal consists of turn indicator and inclinometer signals combined in a Mux block, in degrees. You connect and display this combined signal. This input cannot be a bus signal.

To view the data from a signal, select a signal in the model. The signal appears in the **Connection** table. Select the option button next to the signal you want to display. Click **Apply** to connect the signal.

The table has a row for the signal connected to the block. If there are no signals selected in the model, or the block is not connected to any signals, the table is empty.

Label — Block label location

`Top` (default) | `Bottom` | `Hide`

Block label, displayed at the top or bottom of the block, or hidden.

- `Top`

  Show label at the top of the block.
- `Bottom`

  Show label at the bottom of the block.
- `Hide`

  Do not show the label or instructional text when the block is not connected.

Programmatic Use
Block Parameter: `LabelPosition`
Type: character vector
Values: `'Top'` | `'Bottom'` | `'Hide'`
Default: `'Top'`

See Also

Airspeed Indicator | Altimeter | Artificial Horizon | Climb Rate Indicator | Exhaust Gas Temperature (EGT) Indicator | Heading Indicator | Revolutions Per Minute (RPM) Indicator

Topics

"Display Measurements with Cockpit Instruments" on page 2-49
"Flight Instrument Gauges" on page 2-48

Introduced in R2016a

Tustin Pilot Model

Represent Tustin pilot model

x com
Tustin
u
x
Tustin Pilot Model

Library

Pilot Models

Description

The Tustin Pilot Model block represents the pilot model that A. Tustin describes in *The Nature of the Operator's Response in Manual Control, and its Implications for Controller Design*. (For more information, see [1].) When modeling human pilot models, use this block for the least accuracy, compared to that provided by the Crossover Pilot Model and Precision Pilot Model blocks. This block requires less input than those blocks, and provides better performance. However, the results might be less accurate.

This pilot model is a single input, single output (SISO) model that represents human behavior, based on the transfer function:

$$\frac{u(s)}{e(s)} = \frac{K_p(1 + Ts)}{s} e^{-\tau s}.$$

In this equation:

Variable	Description
K_p	Pilot gain.
T	Lead constant.
τ	Transport delay time caused by the pilot neuromuscular system.

Variable	Description
u(s)	Input to the aircraft model and output to the pilot model.
e(s)	Error between the desired pilot value and the actual value.

This block has non-linear behavior. If you want to linearize the block (for example, with one of the Simulink `linmod` functions), you might need to change the Pade approximation order. The Tustin Pilot Model block implementation incorporates the Simulink Transport Delay block with the **Pade order (for linearization)** parameter set to `2` by default. To change this value, use the `set_param` function, for example:

```
set_param(gcb,'pade','3')
```

Parameters

Pilot gain

Specifies the pilot gain.

Pilot time delay (s)

Specifies the total pilot time delay, in seconds. This value typically ranges from 0.1 s to 0.2 s.

Pilot lead constant

Specifies the pilot lead constant.

Inputs and Outputs

Input	Dimension Type	Description
First	1-by-1	Contains the command for the signal that the pilot model controls.
Second	1-by-1	Contains the signal that the pilot model controls.

Output	Dimension Type	Description
First	1-by-1	Contains the command for the aircraft.

References

[1] Tustin, A., *The Nature of the Operator's Response in Manual Control, and its Implications for Controller Design*. Convention on Automatic Regulators and Servo Mechanisms. May, 1947.

See Also

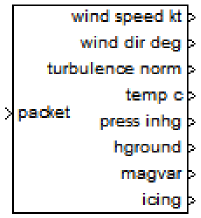
Crossover Pilot Model | Precision Pilot Model

Introduced in R2012b

Unpack net_ctrl Packet from FlightGear

Unpack `net_ctrl` variable packet received from FlightGear

Library: Aerospace Blockset / Animation / Flight Simulator Interfaces



Description

The Unpack net_ctrl Packet from FlightGear block unpacks `net_ctrl` variable packets received from FlightGear via the Receive net_ctrl Packet from FlightGear block, and makes them available for the Simulink environment.

Ports

Input

`packet` — FlightGear packet to be unpacked
array

FlightGear packet to be unpacked, specified as an array.

Data Types: `uint8`

Output

Environment Outputs

`wind_speed_kt` — Wind speed
scalar

Wind speed, specified as a scalar, in knots.

Dependencies

To enable this port, select the **Show environment outputs** check box.

Data Types: `double`

`wind_dir_deg` — Wind direction
scalar

Wind direction, specified as a scalar, in deg.

Dependencies

To enable this port, select the **Show environment outputs** check box.

Data Types: `double`

`turbulence_norm` — Turbulence norm
scalar

Turbulence norm, specified as a scalar.

Dependencies

To enable this port, select the **Show environment outputs** check box.

Data Types: `double`

`temp_c` — Ambient temperature
scalar

Ambient temperature, specified as a scalar, in deg C.

Dependencies

To enable this port, select the **Show environment outputs** check box.

Data Types: `double`

`press_inhg` — Ambient pressure
scalar

Ambient pressure, specified as a scalar, in inHg.

Dependencies

To enable this port, select the **Show environment outputs** check box.

Data Types: `double`

`hground` — Ground elevation
scalar

Ground elevation, specified as a scalar, in m.

Dependencies

To enable this port, select the **Show environment outputs** check box.

Data Types: `double`

`magvar` — Local magnetic variation
scalar

Local magnetic variation, specified as a scalar.

Dependencies

To enable this port, select the **Show environment outputs** check box.

Data Types: `double`

`icing` — Icing status
scalar

Icing status, specified as a scalar, in deg.

Dependencies

To enable this port, select the **Show environment outputs** check box.

Data Types: `uint32`

Control Surface Position Inputs

`aileron` — Normalized aileron position
`1` | scalar

Normalized aileron position [-1,1], specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position outputs** check box.

Data Types: `double`

`elevator` — Normalized elevator position
1 | scalar

Normalized elevator position [-1,1], specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position outputs** check box.

Data Types: `double`

`rudder` — Normalized rudder position
1 | scalar

Normalized rudder position [-1,1], specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position outputs** check box.

Data Types: `double`

`aileron_trim` — Normalized aileron trim position
scalar

Normalized aileron trim position [-1,1], specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position outputs** check box.

Data Types: `double`

`elevator_trim` — Normalized elevator trim position
1 | scalar

Normalized elevator trim position [-1,1], specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position outputs** check box.

Data Types: `double`

`rudder_trim` — Normalized rudder trim position
1 | scalar

Normalized rudder trim position [-1,1], specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position outputs** check box.

Data Types: `double`

`flaps` — Normalized flaps position
`1` | scalar

Normalized flaps position [-0,1], specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position outputs** check box.

Data Types: `double`

`spoilers` — Normalized spoilers position
`1` | scalar

Normalized spoilers position [0,1], specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position outputs** check box.

Data Types: `single`

`speedbrake` — Normalized speedbrake position
`1` | scalar

Normalized speedbrake position [0,1], specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position outputs** check box.

Data Types: `single`

`flaps_power` — Power for flaps
`1` | scalar

Power for flaps, specified as a scalar. A value of `1` indicates that power is available.

Dependencies

To enable this port, select the **Show control surface position outputs** check box.

Data Types: `uint32`

`flap_motor_ok` — Flap motor powered
scalar

Flap motor powered, specified as a scalar.

Dependencies

To enable this port, select the **Show control surface position outputs** check box.

Data Types: `uint32`

Engine/Fuel Outputs

`num_engines` — Number of valid engines
scalar

Number of valid engines, specified as a scalar.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`master_bat` — Master battery switch
vector

Master battery switch, specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`master_alt` — Master alternator switch
vector

Master alternator switch, specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`magnetos` — Magnetos switch
scalar

Magnetos switch, specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`starter_power` — Power to start motor
`1` | vector

Power to starter motor, specified as a vector. A value of `1` indicates that power is available.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`throttle` — Normalized throttle position
`1` | vector

Normalized throttle position [0,1], specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `double`

`mixture` — Normalized mixture lever position
`1` | vector

Normalized mixture lever position [0,1], specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `double`

`condition` — Normalized condition
1 | vector

Normalized condition [0,1], specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`fuel_pump_power` — Normalized speedbrake position
1 | scalar

Power to fuel pump, specified as a vector. A value of `1` indicates that pump is on.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`prop_advance` — Propeller advance
1 | vector

Propeller advance [0,1], specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `double`

`feed_tank_to` — Feed tank to switch
vector

Feed tank to switch, specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`reverse` — Reverse switch
vector

Reverse switch, specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`engine_ok` — Engine status indicator
vector

Engine status indicator, specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`mag_left_ok` — Left magneto status indicator
vector

Left magneto status indicator, specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`mag_right_ok` — Right magneto status indicator
vector

Right magneto status indicator, specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`spark_plugs_ok` — Normalized speedbrake position
vector

Spark plugs status indicator, specified as a vector. A value of `0` indicates that the plugs have failed.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`oil_press_status` — Oil pressure status indicator
`0` | `1` | `2` | scalar

Oil pressure status indicator, specified as a vector.

- `0` — Normal oil pressure
- `1` — Low oil pressure
- `2` — Failed oil pressure

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`fuel_pump_ok` — Fuel management status indicator
vector

Fuel management status indicator, specified as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`num_tanks` — Number of valid tanks
scalar

Number of valid tanks, specified as a scalar.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`fuel_selector` — Fuel selector
scalar

Fuel selector, specified as a vector.

- `0` — Off
- `1` — On

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `single`

`xfer_pump` — Specify transfer
vector

Specifies transfer from array value to tank, specified by value as a vector.

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `uint32`

`cross_feed` — Cross feed valve
scalar

Cross feed valve, specified as a scalar.

- `0` — False
- `1` — On

Dependencies

To enable this port, select the **Show engine/fuel outputs** check box.

Data Types: `single`

Landing Gear Outputs

`brake_left` — Left brake pedal position pilot
scalar

Left brake pedal position pilot, specified as a scalar.

Dependencies

To enable this port, select the **Show landing gear outputs** check box.

Data Types: `double`

`brake_right` — Right brake pedal position pilot
scalar

Right brake pedal position pilot, specified as a scalar.

Dependencies

To enable this port, select the **Show landing gear outputs** check box.

Data Types: `double`

`copilot_brake_left` — Left brake pedal position pilot
scalar

Left brake pedal position pilot, specified as a scalar.

Dependencies

To enable this port, select the **Show landing gear outputs** check box.

Data Types: `double`

`copilot_brake_right` — Right brake pedal position pilot
scalar

Right brake pedal position pilot, specified as a scalar.

Dependencies

To enable this port, select the **Show landing gear outputs** check box.

Data Types: `double`

`brake_parking` — Brake parking position
scalar

Brake parking position, specified as a scalar.

Dependencies

To enable this port, select the **Show landing gear outputs** check box.

Data Types: `double`

`gear_handle` — Gear handle position
scalar

Gear handle position, specified as a scalar.

- `0` — Gear handle up
- `1` — Gear handle down

Dependencies

To enable this port, select the **Show landing gear outputs** check box.

Data Types: `uint32`

Avionic Outputs

`master_avionics` — Master avionics switch
scalar

Master avionics switch, specified as a scalar.

Dependencies

To enable this port, select the **Show avionic outputs** check box.

Data Types: `uint32`

`comm_1` — Comm 1 frequency
scalar

Comm 1 frequency, specified as a scalar, in Hz.

Dependencies

To enable this port, select the **Show avionic outputs** check box.

Data Types: `double`

`comm_2` — Comm 2 frequency
scalar

Comm 2 frequency, specified as a scalar, in Hz.

Dependencies

To enable this port, select the **Show avionic outputs** check box.

Data Types: `double`

`nav_1` — Nav 1 frequency
scalar

Nav 1 frequency, specified as a scalar, in Hz.

Dependencies

To enable this port, select the **Show avionic outputs** check box.

Data Types: `double`

`nav_2` — Nav 2 frequency
scalar

Nav 2 frequency, specified as a scalar, in Hz.

Dependencies

To enable this port, select the **Show avionic outputs** check box.

Data Types: `double`

Parameters

`FlightGear version` — FlightGear version
`v2018.2` (default) | `v2018.1` | `v2017.3` | `v2017.1` | `v2016.3` | `v2016.1` | `v3.4` | `v3.2` | `v3.0` | `v2.12` | `v2.10` | `v2.8` | `v2.6` | `v2.4` | `v2.0`

FlightGear software version, selected from the list.

Note If you are using a FlightGear version older than 2.0, the model displays a notification from the Simulink Upgrade Advisor. Consider upgrading your FlightGear version using the Upgrade Advisor. For more information, see "Supported FlightGear Versions" on page 2-19.

Programmatic Use
Block Parameter: `FlightGearVersion`
Type: character vector
Values: scalar
Default: `'v2018.2'`

`Show control surface position outputs` — Control surface position outputs
`off` (default) | `on`

Select this check box to include the control surface position outputs from the FlightGear `net_ctrl` data packet.

Dependencies

Select this check box to enable these input ports.

Signal Group 1: Control surface position outputs

Name	Units	Type	Width	Description
aileron	1 (dimensionless)	double	1	Normalized aileron position [-1,1]
elevator	1 (dimensionless)	double	1	Normalized elevator position [-1,1]
rudder	1 (dimensionless)	double	1	Normalized rudder position [-1,1]
aileron_trim	1 (dimensionless)	double	1	Normalized aileron trim position [-1,1]
elevator_trim	1 (dimensionless)	double	1	Normalized elevator trim position [-1,1]
rudder_trim	1 (dimensionless)	double	1	Normalized rudder trim position [-1,1]
flaps	1 (dimensionless)	double	1	Normalized flaps position [-0,1]
spoilers	1 (dimensionless)	double	1	Normalized spoilers position [0,1]
speedbrake	1 (dimensionless)	double	1	Normalized speedbrake position [0,1]
flaps_power	1 (dimensionless)	uint32	1	Power for flaps (`1` = power available)
flap_motor_ok	—	uint32	1	Flap motor powered

Programmatic Use
Block Parameter: `ShowControlSurfacePositionOutputs`
Type: character vector
Values: `'off' | 'on'`
Default: `'off'`

`Show engine/fuel outputs` — Engine/fuel outputs
`off` (default) | `on`

Select this check box to include the engine and fuel outputs from the FlightGear `net_ctrl` data packet.

Dependencies

Select this check box to enable these input ports.

Signal Group 2: Engine/fuel outputs

Name	Units	Type	Width	Description
num_engines	—	uint32	1	Number of valid engines
master_bat	—	uint32	4	Master battery switch
master_alt	—	uint32	4	Master alternator switch
magnetos	—	uint32	4	Magnetos switch
starter_power	—	uint32	4	Power to starter motor (1 = starter power available)
throttle	1 (dimensionless)	double	4	Normalized throttle position [0,1]
mixture	1 (dimensionless)	double	4	Normalized mixture lever position [0,1]
condition	1 (dimensionless)	double	4	Normalized condition [0,1]
fuel_pump_power	—	uint32	4	Power to fuel pump 1 = on)
prop_advance	1 (dimensionless)	double	4	Propeller advance [0,1]
feed_tank_to	—	uint32	4	Feed tank to switch
reverse	—	uint32	4	Reverse switch
engine_ok	—	uint32	4	Engine status indicator
mag_left_ok	—	uint32	4	Left magneto status indicator
mag_right_ok	—	uint32	4	Right magneto status indicator
spark_plugs_ok	—	uint32	4	Spark plugs status indicator (0 = failed plugs)

Name	Units	Type	Width	Description
oil_press_status	—	uint32	4	Oil pressure status indicator (0 = normal, 1 = low, 2 = full failure)
fuel_pump_ok	—	uint32	4	Fuel management status indicator
num_tanks	—	uint32	1	Number of valid tanks
fuel_selector	—	uint32	8	Fuel selector. (`0` = off, `1` = on)
xfer_pump	—	uint32	5	Specifies transfer from array value to tank specified by value
cross_feed	—	uint32	1	Cross feed valve (`0` = false, `1` = on)

Programmatic Use
Block Parameter: `ShowEngineFuelOutputs`
Type: character vector
Values: `'off' | 'on'`
Default: `'off'`

`Show landing gear outputs` — Landing gear outputs

`off` (default) | `on`

Select this check box to include the landing gear outputs from the FlightGear `net_ctrl` data packet.

Dependencies

Select this check box to enable these input ports.

Signal Group 3: Landing gear outputs

Name	Units	Type	Width	Description
brake_left	—	double	1	Left brake pedal position pilot
brake_right	—	double	1	Right brake pedal position pilot
copilot_brake_left	—	double	1	Left brake pedal position copilot
copilot_brake_right	—	double	1	Right brake pedal position copilot
brake_parking	—	double	1	Brake parking position
gear_handle	—	uint32	1	Gear handle position (`1` = gear handle down, `0` = gear handle up)

Programmatic Use
Block Parameter: `ShowLandingGearOutputs`
Type: character vector
Values: `'off' | 'on'`
Default: `'off'`

`Show avionic outputs` — Avionic outputs

`off` (default) | `on`

Select this check box to include the avionic outputs from the FlightGear `net_ctrl` data packet.

Dependencies

Select this check box to enable these input ports.

Signal Group 4: Avionics outputs

Name	Units	Type	Width	Description
master_avionics	—	uint32	1	Master avionics switch
comm_1	Hz	double	1	Comm 1 frequency
comm_2	Hz	double	1	Comm 2 frequency
nav_1	Hz	double	1	Nav 1 frequency
nav_2	Hz	double	1	Nav 2 frequency

Programmatic Use
Block Parameter: `ShowAvionicOutputs`
Type: character vector
Values: `'off' | 'on'`
Default: `'off'`

`Show environment outputs` — Environment outputs
`on` (default) | `off`

Select this check box to include the environment outputs from the FlightGear `net_ctrl` data packet.

Dependencies

Select this check box to enable these input ports.

Signal Group 5: Environment outputs

Name	Units	Type	Width	Description
wind_speed_kt	knot	double	1	Wind speed
wind_dir_deg	deg	double	1	Wind direction
turbulence_norm	—	double	1	Turbulence norm
temp_c	deg C	double	1	Ambient temperature
press_inhg	inHg	double	1	Ambient pressure
hground	m	double	1	Ground elevation
magvar	deg	double	1	Local magnetic variation
icing	-	uint32	1	Icing status

Programmatic Use
Block Parameter: `ShowEnvironmentOutputs`
Type: character vector
Values: `'off' | 'on'`
Default: `'on'`

`Sample time` — Sample time
1/30 (default) | scalar

Specify the sample time (-1 for inherited), as a scalar.

Programmatic Use
Block Parameter: `SampleTime`
Type: character vector
Values: scalar
Default: `'1/30'`

See Also

FlightGear Preconfigured 6DoF Animation | Generate Run Script | Pack net_fdm Packet for FlightGear | Receive net_ctrl Packet from FlightGear | Send net_fdm Packet to FlightGear

Topics

"Flight Simulator Interface" on page 2-19
"Work with the Flight Simulator Interface" on page 2-24

Introduced in R2012a

Velocity Conversion

Convert from velocity units to desired velocity units

Library

Utilities/Unit Conversions

Description

The Velocity Conversion block computes the conversion factor from specified input velocity units to specified output velocity units and applies the conversion factor to the input signal.

The Velocity Conversion block icon displays the input and output units selected from the **Initial unit** and the **Final unit** lists.

Parameters

Initial unit

Specifies the input units.

Final unit

Specifies the output units.

The following conversion units are available:

`m/s`	Meters per second
`ft/s`	Feet per second
`km/s`	Kilometers per second
`in/s`	Inches per second

`km/h`	Kilometers per hour
`mph`	Miles per hour
`kts`	Nautical miles per hour
`ft/min`	Feet per minute

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the velocity in initial velocity units.

Output	Dimension Type	Description
First		Contains the velocity in final velocity units.

See Also

Acceleration Conversion

Angle Conversion

Angular Acceleration Conversion

Angular Velocity Conversion

Density Conversion

Force Conversion

Length Conversion

Mass Conversion

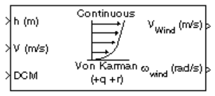
Pressure Conversion

Temperature Conversion

Introduced before R2006a

Von Karman Wind Turbulence Model (Continuous)

Generate continuous wind turbulence with Von Kármán velocity spectra



Library

Environment/Wind

Description

The Von Kármán Wind Turbulence Model (Continuous) block uses the Von Kármán spectral representation to add turbulence to the aerospace model by passing band-limited white noise through appropriate forming filters. This block implements the mathematical representation in the Military Specification MIL-F-8785C and Military Handbook MIL-HDBK-1797.

According to the military references, turbulence is a stochastic process defined by velocity spectra. For an aircraft flying at a speed V through a frozen turbulence field with a spatial frequency of Ω radians per meter, the circular frequency ω is calculated by multiplying V by Ω. The following table displays the component spectra functions:

	MIL-F-8785C	MIL-HDBK-1797
Longitudinal		
$\Phi_u(\omega)$	$\frac{2\sigma_u^2 L_u}{\pi V} \cdot \frac{1}{\left[1+\left(1.339 L_u \frac{\omega}{V}\right)^2\right]^{5/6}}$	$\frac{2\sigma_u^2 L_u}{\pi V} \cdot \frac{1}{\left[1+\left(1.339 L_u \frac{\omega}{V}\right)^2\right]^{5/6}}$

	MIL-F-8785C	**MIL-HDBK-1797**
$\Phi_p(\omega)$	$\frac{\sigma_w^2}{VL_w} \cdot \frac{0.8\left(\frac{\pi L_w}{4b}\right)^{1/3}}{1+\left(\frac{4b\omega}{\pi V}\right)^2}$	$\frac{\sigma_w^2}{2VL_w} \cdot \frac{0.8\left(\frac{2\pi L_w}{4b}\right)^{1/3}}{1+\left(\frac{4b\omega}{\pi V}\right)^2}$
Lateral		
$\Phi_v(\omega)$	$\frac{\sigma_v^2 L_v}{\pi V} \cdot \frac{1+\frac{8}{3}\left(1.339L_v\frac{\omega}{V}\right)^2}{\left[1+\left(1.339L_v\frac{\omega}{V}\right)^2\right]^{11/6}}$	$\frac{2\sigma_v^2 L_v}{\pi V} \cdot \frac{1+\frac{8}{3}\left(2.678L_v\frac{\omega}{V}\right)^2}{\left[1+\left(2.678L_v\frac{\omega}{V}\right)^2\right]^{11/6}}$
$\Phi_r(\omega)$	$\frac{\mp\left(\frac{\omega}{V}\right)^2}{1+\left(\frac{3b\omega}{\pi V}\right)^2} \cdot \Phi_v(\omega)$	$\frac{\mp\left(\frac{\omega}{V}\right)^2}{1+\left(\frac{3b\omega}{\pi V}\right)^2} \cdot \Phi_v(\omega)$
Vertical		
$\Phi_w(\omega)$	$\frac{\sigma_w^2 L_w}{\pi V} \cdot \frac{1+\frac{8}{3}\left(1.339L_w\frac{\omega}{V}\right)^2}{\left[1+\left(1.339L_w\frac{\omega}{V}\right)^2\right]^{11/6}}$	$\frac{2\sigma_w^2 L_w}{\pi V} \cdot \frac{1+\frac{8}{3}\left(2.678L_w\frac{\omega}{V}\right)^2}{\left[1+\left(2.678L_w\frac{\omega}{V}\right)^2\right]^{11/6}}$
$\Phi_q(\omega)$	$\frac{\pm\left(\frac{\omega}{V}\right)^2}{1+\left(\frac{4b\omega}{\pi V}\right)^2} \cdot \Phi_w(\omega)$	$\frac{\pm\left(\frac{\omega}{V}\right)^2}{1+\left(\frac{4b\omega}{\pi V}\right)^2} \cdot \Phi_w(\omega)$

The variable b represents the aircraft wingspan. The variables L_u, L_v, L_w represent the turbulence scale lengths. The variables σ_u, σ_v, σ_w represent the turbulence intensities:

The spectral density definitions of turbulence angular rates are defined in the references as three variations, which are displayed in the following table:

$p_g = \frac{\partial w_g}{\partial y}$	$q_g = \frac{\partial w_g}{\partial x}$	$r_g = -\frac{\partial v_g}{\partial x}$
$p_g = \frac{\partial w_g}{\partial y}$	$q_g = \frac{\partial w_g}{\partial x}$	$r_g = \frac{\partial v_g}{\partial x}$
$p_g = -\frac{\partial w_g}{\partial y}$	$q_g = -\frac{\partial w_g}{\partial x}$	$r_g = \frac{\partial v_g}{\partial x}$

The variations affect only the vertical (q_g) and lateral (r_g) turbulence angular rates.

Keep in mind that the longitudinal turbulence angular rate spectrum, $\Phi_p(\omega)$, is a rational function. The rational function is derived from curve-fitting a complex algebraic function, not the vertical turbulence velocity spectrum, $\Phi_w(\omega)$, multiplied by a scale factor. Because the turbulence angular rate spectra contribute less to the aircraft gust response than the turbulence velocity spectra, it may explain the variations in their definitions.

The variations lead to the following combinations of vertical and lateral turbulence angular rate spectra.

Vertical	**Lateral**
$\Phi_q(\omega)$	$-\Phi_r(\omega)$
$\Phi_q(\omega)$	$\Phi_r(\omega)$
$-\Phi_q(\omega)$	$\Phi_r(\omega)$

To generate a signal with the correct characteristics, a unit variance, band-limited white noise signal is passed through forming filters. The forming filters are approximations of the Von Kármán velocity spectra which are valid in a range of normalized frequencies of less than 50 radians. These filters can be found in both the Military Handbook MIL-HDBK-1797 and the reference by Ly and Chan.

The following two tables display the transfer functions.

	MIL-F-8785C
Longitudinal	
$H_u(s)$	$\dfrac{\sigma_u\sqrt{\frac{2}{\pi}\cdot\frac{L_u}{V}}\left(1+0.25\frac{L_u}{V}s\right)}{1+1.357\frac{L_u}{V}s+0.1987\left(\frac{L_u}{V}\right)^2s^2}$
$H_p(s)$	$\sigma_w\sqrt{\dfrac{0.8}{V}}\cdot\dfrac{\left(\frac{\pi}{4b}\right)^{1/6}}{L_w{}^{1/3}\left(1+\left(\frac{4b}{\pi V}\right)s\right)}$
Lateral	

	MIL-F-8785C
$H_v(s)$	$\dfrac{\sigma_v\sqrt{\frac{1}{\pi}\cdot\frac{L_v}{V}}\left(1+2.7478\frac{L_v}{V}s+0.3398\left(\frac{L_v}{V}\right)^2 s^2\right)}{1+2.9958\frac{L_v}{V}s+1.9754\left(\frac{L_v}{V}\right)^2 s^2+0.1539\left(\frac{L_v}{V}\right)^3 s^3}$
$H_r(s)$	$\dfrac{\mp\frac{s}{V}}{\left(1+\left(\frac{3b}{\pi V}\right)s\right)}\cdot H_v(s)$
Vertical	
$H_w(s)$	$\dfrac{\sigma_w\sqrt{\frac{1}{\pi}\cdot\frac{L_w}{V}}\left(1+2.7478\frac{L_w}{V}s+0.3398\left(\frac{L_w}{V}\right)^2 s^2\right)}{1+2.9958\frac{L_w}{V}s+1.9754\left(\frac{L_w}{V}\right)^2 s^2+0.1539\left(\frac{L_w}{V}\right)^3 s^3}$
$H_q(s)$	$\dfrac{\pm\frac{s}{V}}{\left(1+\left(\frac{4b}{\pi V}\right)s\right)}\cdot H_w(s)$

	MIL-HDBK-1797
Longitudinal	
$H_u(s)$	$\dfrac{\sigma_u\sqrt{\frac{2}{\pi}\cdot\frac{L_u}{V}}\left(1+0.25\frac{L_u}{V}s\right)}{1+1.357\frac{L_u}{V}s+0.1987\left(\frac{L_u}{V}\right)^2 s^2}$
$H_p(s)$	$\sigma_w\sqrt{\dfrac{0.8}{V}}\cdot\dfrac{\left(\frac{\pi}{4b}\right)^{1/6}}{(2L_w)^{1/3}\left(1+\left(\frac{4b}{\pi V}\right)s\right)}$
Lateral	
$H_v(s)$	$\dfrac{\sigma_v\sqrt{\frac{1}{\pi}\cdot\frac{2L_v}{V}}\left(1+2.7478\frac{2L_v}{V}s+0.3398\left(\frac{2L_v}{V}\right)^2 s^2\right)}{1+2.9958\frac{2L_v}{V}s+1.9754\left(\frac{2L_v}{V}\right)^2 s^2+0.1539\left(\frac{2L_v}{V}\right)^3 s^3}$

	MIL-HDBK-1797
$H_r(s)$	$\dfrac{\mp\frac{s}{V}}{\left(1+\left(\frac{3b}{\pi V}\right)s\right)}\cdot H_v(s)$
Vertical	
$H_w(s)$	$\dfrac{\sigma_w\sqrt{\frac{1}{\pi}\cdot\frac{2L_w}{V}}\left(1+2.7478\frac{2L_w}{V}s+0.3398\left(\frac{2L_w}{V}\right)^2 s^2\right)}{1+2.9958\frac{2L_w}{V}s+1.9754\left(\frac{2L_w}{V}\right)^2 s^2+0.1539\left(\frac{2L_w}{V}\right)^3 s^3}$
$H_q(s)$	$\dfrac{\pm\frac{s}{V}}{\left(1+\left(\frac{4b}{\pi V}\right)s\right)}\cdot H_w(s)$

Divided into two distinct regions, the turbulence scale lengths and intensities are functions of altitude.

Note The same transfer functions result after evaluating the turbulence scale lengths. The differences in turbulence scale lengths and turbulence transfer functions balance offset.

Low-Altitude Model (Altitude < 1000 feet)

According to the military references, the turbulence scale lengths at low altitudes, where *h* is the altitude in feet, are represented in the following table:

MIL-F-8785C	**MIL-HDBK-1797**
$L_w = h$ $L_u = L_v = \dfrac{h}{(0.177+0.000823h)^{1.2}}$	$2L_w = h$ $L_u = 2L_v = \dfrac{h}{(0.177+0.000823h)^{1.2}}$

The turbulence intensities are given below, where W_{20} is the wind speed at 20 feet (6 m). Typically for light turbulence, the wind speed at 20 feet is 15 knots; for moderate turbulence, the wind speed is 30 knots; and for severe turbulence, the wind speed is 45 knots.

$$\sigma_w = 0.1W_{20}$$

$$\frac{\sigma_u}{\sigma_w} = \frac{\sigma_v}{\sigma_w} = \frac{1}{(0.177 + 0.000823h)^{0.4}}$$

The turbulence axes orientation in this region is defined as follows:

- Longitudinal turbulence velocity, u_g, aligned along the horizontal relative mean wind vector
- Vertical turbulence velocity, w_g, aligned with vertical.

At this altitude range, the output of the block is transformed into body coordinates.

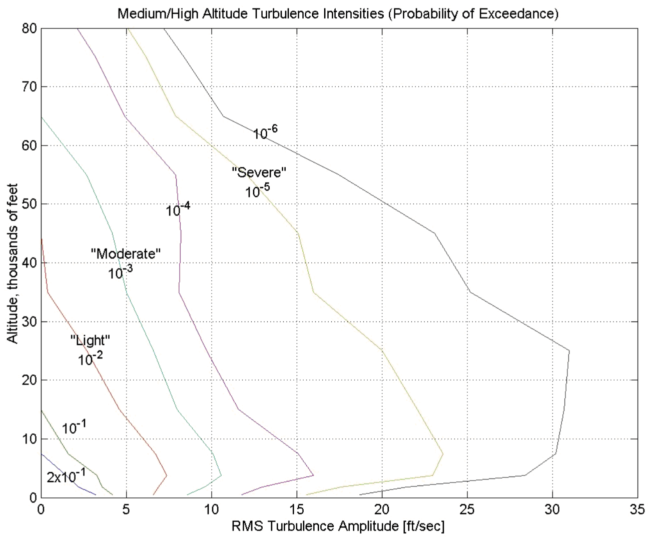
Medium/High Altitudes (Altitude > 2000 feet)

For medium to high altitudes the turbulence scale lengths and intensities are based on the assumption that the turbulence is isotropic. In the military references, the scale lengths are represented by the following equations:

MIL-F-8785C	MIL-HDBK-1797
$L_u = L_v = L_w = 2500$ ft	$L_u = 2L_v = 2L_w = 2500$ ft

The turbulence intensities are determined from a lookup table that provides the turbulence intensity as a function of altitude and the probability of the turbulence intensity being exceeded. The relationship of the turbulence intensities is represented in the following equation: $\sigma_u=\sigma_v=\sigma_w$.

The turbulence axes orientation in this region is defined as being aligned with the body coordinates:



Between Low and Medium/High Altitudes (1000 feet < Altitude < 2000 feet)

At altitudes between 1000 feet and 2000 feet, the turbulence velocities and turbulence angular rates are determined by linearly interpolating between the value from the low altitude model at 1000 feet transformed from mean horizontal wind coordinates to body coordinates and the value from the high altitude model at 2000 feet in body coordinates.

Parameters

Units

Define the units of wind speed due to the turbulence.

Units	Wind Velocity	Altitude	Air Speed
`Metric (MKS)`	Meters/second	Meters	Meters/second

Units	Wind Velocity	Altitude	Air Speed
`English (Velocity in ft/s)`	Feet/second	Feet	Feet/second
`English (Velocity in kts)`	Knots	Feet	Knots

Specification

Define which military reference to use. This affects the application of turbulence scale lengths in the lateral and vertical directions

Model type

Select the wind turbulence model to use:

`Continuous Von Karman (+q -r)`	Use continuous representation of Von Kármán velocity spectra with positive vertical and negative lateral angular rates spectra.
`Continuous Von Karman (+q +r)`	Use continuous representation of Von Kármán velocity spectra with positive vertical and lateral angular rates spectra.
`Continuous Von Karman (-q +r)`	Use continuous representation of Von Kármán velocity spectra with negative vertical and positive lateral angular rates spectra.
`Continuous Dryden (+q -r)`	Use continuous representation of Dryden velocity spectra with positive vertical and negative lateral angular rates spectra.
`Continuous Dryden (+q +r)`	Use continuous representation of Dryden velocity spectra with positive vertical and lateral angular rates spectra.

`Continuous Dryden (-q +r)`	Use continuous representation of Dryden velocity spectra with negative vertical and positive lateral angular rates spectra.
`Discrete Dryden (+q -r)`	Use discrete representation of Dryden velocity spectra with positive vertical and negative lateral angular rates spectra.
`Discrete Dryden (+q +r)`	Use discrete representation of Dryden velocity spectra with positive vertical and lateral angular rates spectra.
`Discrete Dryden (-q +r)`	Use discrete representation of Dryden velocity spectra with negative vertical and positive lateral angular rates spectra.

The Continuous Von Kármán selections conform to the transfer function descriptions.

Wind speed at 6 m defines the low altitude intensity

The measured wind speed at a height of 20 feet (6 meters) provides the intensity for the low-altitude turbulence model.

Wind direction at 6 m (degrees clockwise from north)

The measured wind direction at a height of 20 feet (6 meters) is an angle to aid in transforming the low-altitude turbulence model into a body coordinates.

Probability of exceedance of high-altitude intensity

Above 2000 feet, the turbulence intensity is determined from a lookup table that gives the turbulence intensity as a function of altitude and the probability of the turbulence intensity's being exceeded.

Scale length at medium/high altitudes

The turbulence scale length above 2000 feet is assumed constant, and from the military references, a figure of 1750 feet is recommended for the longitudinal turbulence scale length of the Dryden spectra.

Note An alternate scale length value changes the power spectral density asymptote and gust load.

Wingspan

The wingspan is required in the calculation of the turbulence on the angular rates.

Band-limited noise sample time (seconds)

The sample time at which the unit variance white noise signal is generated.

Noise seeds

There are four random numbers required to generate the turbulence signals, one for each of the three velocity components and one for the roll rate. The turbulences on the pitch and yaw angular rates are based on further shaping of the outputs from the shaping filters for the vertical and lateral velocities.

Turbulence on

Selecting the check box generates the turbulence signals.

Inputs and Outputs

Input	Dimension Type	Description
First	scalar	Contains the altitude in units selected.
Second	scalar	Contains the aircraft speed in units selected.
Third	3-by-3 matrix	Contains a direction cosine matrix.

Output	Dimension Type	Description
First	Three-element signal	Contains the turbulence velocities, in the selected units.
Second	Three-element signal	Contains the turbulence angular rates, in radians per second.

Assumptions and Limitations

The frozen turbulence field assumption is valid for the cases of mean-wind velocity and the root-mean-square turbulence velocity, or intensity, are small relative to the aircraft's ground speed.

The turbulence model describes an average of all conditions for clear air turbulence because the following factors are not incorporated into the model:

- Terrain roughness
- Lapse rate
- Wind shears
- Mean wind magnitude
- Other meteorological factions (except altitude)

References

U.S. Military Handbook MIL-HDBK-1797, 19 December 1997.

U.S. Military Specification MIL-F-8785C, 5 November 1980.

Chalk, C., Neal, P., Harris, T., Pritchard, F., Woodcock, R., “Background Information and User Guide for MIL-F-8785B(ASG), `Military Specification-Flying Qualities of Piloted Airplanes',” AD869856, Cornell Aeronautical Laboratory, August 1969.

Hoblit, F., *Gust Loads on Aircraft: Concepts and Applications*, AIAA Education Series, 1988.

Ly, U., Chan, Y., “Time-Domain Computation of Aircraft Gust Covariance Matrices,” AIAA Paper 80-1615, Atmospheric Flight Mechanics Conference, Danvers, MA., August 11-13, 1980.

McRuer, D., Ashkenas, I., Graham, D., *Aircraft Dynamics and Automatic Control*, Princeton University Press, July 1990.

Moorhouse, D., Woodcock, R., “Background Information and User Guide for MIL-F-8785C, `Military Specification-Flying Qualities of Piloted Airplanes',” ADA119421, Flight Dynamic Laboratory, July 1982.

McFarland, R., “A Standard Kinematic Model for Flight Simulation at NASA-Ames,” NASA CR-2497, Computer Sciences Corporation, January 1975.

Tatom, F., Smith, R., Fichtl, G., “Simulation of Atmospheric Turbulent Gusts and Gust Gradients,” AIAA Paper 81-0300, Aerospace Sciences Meeting, St. Louis, MO., January 12-15, 1981.

Yeager, J., “Implementation and Testing of Turbulence Models for the F18-HARV Simulation,” NASA CR-1998-206937, Lockheed Martin Engineering & Sciences, March 1998.

See Also

Dryden Wind Turbulence Model (Continuous)

Dryden Wind Turbulence Model (Discrete)

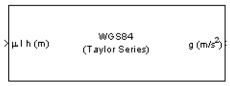
Discrete Wind Gust Model

Wind Shear Model

Introduced in R2006b

WGS84 Gravity Model

Implement 1984 World Geodetic System (WGS84) representation of Earth's gravity



Library

Environment/Gravity

Description

The WGS84 Gravity Model block implements the mathematical representation of the geocentric equipotential ellipsoid of the World Geodetic System (WGS84). The block output is the Earth's gravity at a specific location. Gravity precision is controlled via the **Type of gravity model** parameter.

The WGS84 Gravity Model block icon displays the input and output units selected from the **Units** list.

Parameters

Type of gravity model

Specifies the method to calculate gravity:

- `WGS84 Taylor Series`
- `WGS84 Close Approximation`
- `WGS84 Exact`

Units

Specifies the input and output units:

Units	Height	Gravity
`Metric (MKS)`	Meters	Meters per second squared
`English`	Feet	Feet per second squared

Exclude Earth's atmosphere

Select for the value for the Earth's gravitational field to exclude the mass of the atmosphere.

Clear for the value for the Earth's gravitational field to include the mass of the atmosphere.

This option is available only with **Type of gravity model WGS84 Close Approximation** or **WGS84 Exact**.

Precessing reference frame

When selected, the angular velocity of the Earth is calculated using the International Astronomical Union (IAU) value of the Earth's angular velocity and the precession rate in right ascension. To obtain the precession rate in right ascension, Julian centuries from Epoch J2000.0 is calculated using the dialog parameters of **Month**, **Day**, and **Year**.

If cleared, the angular velocity of the Earth used is the value of the standard Earth rotating at a constant angular velocity.

This option is available only with **Type of gravity model WGS84 Close Approximation** or **WGS84 Exact**.

Input Julian date

When selected, another input port, JD, appears on the block mask. Select this check box if you want to manually specify the Julian date for the block. Otherwise, the block calculates the Julian date given the values of **Month**, **Day**, and **Year**. The year must be after January 1, 2000 (2451545). Selecting this block disables the **Month**, **Day**, and **Year** parameters.

Month

Specifies the month used to calculate Julian centuries from Epoch J2000.0.

This option is available only with **Type of gravity model WGS84 Close Approximation** or **WGS84 Exact** and only when **Precessing reference frame** is selected. It is disabled if you select **Input Julian Date**.

Day

Specifies the day used to calculate Julian centuries from Epoch J2000.0.

This option is available only with **Type of gravity model WGS84 Close Approximation** or **WGS84 Exact** and only when **Precessing reference frame** is selected. It is disabled if you select **Input Julian Date**.

Year

Specifies the year used to calculate Julian centuries from Epoch J2000.0. The year must be 2000 or greater.

This option is available only with **Type of gravity model WGS84 Close Approximation** or **WGS84 Exact** and only when **Precessing reference frame** is selected. It is disabled if you select **Input Julian Date**.

No centrifugal effects

When selected, calculated gravity is based on pure attraction resulting from the normal gravitational potential.

If cleared, calculated gravity includes the centrifugal force resulting from the Earth's angular velocity.

This option is available only with **Type of gravity model WGS84 Close Approximation** or **WGS84 Exact**.

Action for out-of-range input

Specify if out-of-range input invokes a warning, error, or no action.

Inputs and Outputs

Input	Dimension Type	Description
First	Three-element vector or *M*-by-3 array	Contains the position in geodetic latitude, longitude and altitude, with units in degrees, degrees, and selected units of length respectively. Altitude must be less than 20,000.0 m (approximately 65,620.0 feet).
Second (Optional)	Scalar	Contains the Julian centuries that you specified.

Output	Dimension Type	Description
Output	Three-element vector or *M*-by-3 array	Gravity in the north-east-down (NED) coordinate system. The Taylor Series and Close Approximation methods output only normal gravity (down in the NED Coordinate system). The Exact method outputs both normal and tangent gravity (down and north in the NED coordinate system).

Assumptions and Limitations

The WGS84 gravity calculations are based on the assumption of a geocentric equipotential ellipsoid of revolution. Since the gravity potential is assumed to be the same everywhere on the ellipsoid, there must be a specific theoretical gravity potential that can be uniquely determined from the four independent constants defining the ellipsoid.

Use of the WGS84 Taylor Series model should be limited to low geodetic heights. It is sufficient near the surface when submicrogal precision is not necessary. At medium and high geodetic heights, it is less accurate.

The WGS84 Close Approximation model gives results with submicrogal precision.

To predict and determine a satellite orbit with high accuracy, use the EGM96 through degree and order 70.

Examples

See the Environment Models subsystem in the Airframe subsystem of the `aeroblk_HL20` model for an example of this block.

Reference

[1] NIMA TR8350.2: “Department of Defense World Geodetic System 1984, Its Definition and Relationship with Local Geodetic Systems.”

Extended Capabilities

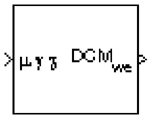
C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Introduced before R2006a

Wind Angles to Direction Cosine Matrix

Convert wind angles to direction cosine matrix



Library

Utilities/Axes Transformations

Description

The Wind Angles to Direction Cosine Matrix block converts three wind rotation angles into a 3-by-3 direction cosine matrix (DCM). The DCM matrix performs the coordinate transformation of a vector in earth axes (ox_0, oy_0, oz_0) into a vector in wind axes (ox_3, oy_3, oz_3). The order of the axis rotations required to bring this about is:

1. A rotation about oz_0 through the heading angle (χ) to axes (ox_1, oy_1, oz_1)
2. A rotation about oy_1 through the flight path angle (γ) to axes (ox_2, oy_2, oz_2)
3. A rotation about ox_2 through the bank angle (μ) to axes (ox_3, oy_3, oz_3)

$$\begin{bmatrix} ox_3 \\ oy_3 \\ oz_3 \end{bmatrix} = DCM_{we} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

$$\begin{bmatrix} ox_3 \\ oy_3 \\ oz_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\mu & \sin\mu \\ 0 & -\sin\mu & \cos\mu \end{bmatrix} \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix} \begin{bmatrix} \cos\chi & \sin\chi & 0 \\ -\sin\chi & \cos\chi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

Combining the three axis transformation matrices defines the following DCM.

$$DCM_{we} = \begin{bmatrix} \cos\gamma\cos\chi & \cos\gamma\sin\chi & -\sin\gamma \\ (\sin\mu\sin\gamma\cos\chi - \cos\mu\sin\chi) & (\sin\mu\sin\gamma\sin\chi + \cos\mu\cos\chi) & \sin\mu\cos\gamma \\ (\cos\mu\sin\gamma\cos\chi + \sin\mu\sin\chi) & (\cos\mu\sin\gamma\sin\chi - \sin\mu\cos\chi & \cos\mu\cos\gamma \end{bmatrix}$$

Inputs and Outputs

Input	Dimension Type	Description
First	3-by-1 vector	Contains wind angles, in radians.

Output	Dimension Type	Description
First	3-by-3 direction cosine matrix	Transforms earth vectors to wind vectors.

Assumptions and Limitations

This implementation generates a flight path angle that lies between ±90 degrees, and bank and heading angles that lie between ±180 degrees.

See Also

Direction Cosine Matrix Body to Wind

Direction Cosine Matrix to Rotation Angles

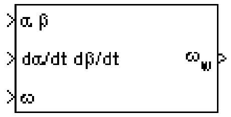
Direction Cosine Matrix to Wind Angles

Rotation Angles to Direction Cosine Matrix

Introduced before R2006a

Wind Angular Rates

Calculate wind angular rates from body angular rates, angle of attack, sideslip angle, rate of change of angle of attack, and rate of change of sideslip



Library

Flight Parameters

Description

The Wind Angular Rates block supports the equations of motion in wind-fixed frame models by calculating the wind-fixed angular rates (p_w, q_w, r_w). The body-fixed angular rates (p_b, q_b, r_b), angle of attack (α), sideslip angle (β), rate of change of angle of attack ($\dot{\alpha}$), and rate of change of sideslip ($\dot{\beta}$)are related to the wind-fixed angular rate by the following equation.

$$\begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} \cos\alpha\cos\beta & \sin\beta & \sin\alpha\cos\beta \\ -\cos\alpha\sin\beta & \cos\beta & -\sin\alpha\sin\beta \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix} \begin{bmatrix} p_b - \dot{\beta}\sin\alpha \\ q_b - \dot{\alpha} \\ r_b + \dot{\beta}\cos\alpha \end{bmatrix}$$

Inputs and Outputs

Input	Dimension Type	Description
First	2-by-1 vector	Contains angle of attack and sideslip, in radians.
	2-by-1 vector	Contains rate of change of angle of attack and rate of change of sideslip, in radians per second.

Input	Dimension Type	Description
		Contains the body angular rates, in radians per second.

Output	Dimension Type	Description
First		Contains the wind angular rates, in radians per second.

See Also

3DOF (Body Axes)

6DOF Wind (Quaternion)

6DOF Wind (Wind Angles)

Custom Variable Mass 3DOF (Body Axes)

Custom Variable Mass 6DOF Wind (Quaternion)

Custom Variable Mass 6DOF Wind (Wind Angles)

Simple Variable Mass 3DOF (Body Axes)

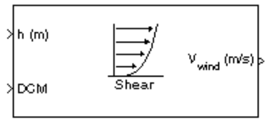
Simple Variable Mass 6DOF Wind (Quaternion)

Simple Variable Mass 6DOF Wind (Wind Angles)

Introduced before R2006a

Wind Shear Model

Calculate wind shear conditions



Library

Environment/Wind

Description

The Wind Shear Model block adds wind shear to the aerospace model. This implementation is based on the mathematical representation in the Military Specification MIL-F-8785C [1]. The magnitude of the wind shear is given by the following equation for the mean wind profile as a function of altitude and the measured wind speed at 20 feet (6 m) above the ground.

$$u_w = W_{20}\frac{\ln\left(\frac{h}{z_0}\right)}{\ln\left(\frac{20}{z_0}\right)},\ 3ft < h < 1000ft$$

where u_w is the mean wind speed, W_{20} is the measured wind speed at an altitude of 20 feet, h is the altitude, and z_0 is a constant equal to 0.15 feet for Category C flight phases and 2.0 feet for all other flight phases. Category C flight phases are defined in reference [1] to be terminal flight phases, which include takeoff, approach, and landing.

The resultant mean wind speed in the flat Earth axis frame is changed to body-fixed axis coordinates by multiplying by the direction cosine matrix (DCM) input to the block. The block output is the mean wind speed in the body-fixed axis.

Parameters

Units

Define the units of wind shear.

Units	Wind	Altitude
`Metric (MKS)`	Meters/second	Meters
`English (Velocity in ft/s)`	Feet/second	Feet
`English (Velocity in kts)`	Knots	Feet

Flight phase

Select flight phase:

- `Category C — Terminal Flight Phases`
- `Other`

Wind speed at 6 m (20 feet) altitude (m/s, f/s, or knots)

The measured wind speed at an altitude of 20 feet (6 m) above the ground.

Wind direction at 6 m (20 feet) altitude (degrees clockwise from north)

The direction of the wind at an altitude of 20 feet (6 m), measured in degrees clockwise from the direction of the Earth *x*-axis (north). The wind direction is defined as the direction from which the wind is coming.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the altitude in units selected.
Second	3-by-3 direction cosine matrix	

Output	Dimension Type	Description
First	3-by-1 vector	Contains the mean wind speed in the body axes frame, in the selected units.

Examples

See `Wind Shear Model` in `aeroblk_HL20` for an example of this block.

Reference

U.S. Military Specification MIL-F-8785C, 5 November 1980.

See Also

Discrete Wind Gust Model

Dryden Wind Turbulence Model (Continuous)

Dryden Wind Turbulence Model (Discrete)

Von Karman Wind Turbulence Model (Continuous)

Introduced before R2006a

World Magnetic Model 2000

Calculate Earth's magnetic field at specific location and time using World Magnetic Model 2000 (WMM2000)

Library

Environment/Gravity

Description

The WMM2000 block implements the mathematical representation of the National Geospatial Intelligence Agency (NGA) World Magnetic Model 2000. The WMM2000 block calculates the Earth's magnetic field vector, horizontal intensity, declination, inclination, and total intensity at a specified location and time. The reference frame is north-east-down (NED).

Parameters

Units

Specifies the input and output units:

Units	Height	Magnetic Field	Horizontal Intensity	Total Intensity
`Metric (MKS)`	Meters	Nanotesla	Nanotesla	Nanotesla
`English`	Feet	Nanogauss	Nanogauss	Nanogauss

Input decimal year

When selected, the decimal year is an input for the World Magnetic Model 2000 block. Otherwise, a date must be specified using the dialog parameters of **Month**, **Day**, and **Year**.

Month

Specifies the month used to calculate decimal year.

Day

Specifies the day used to calculate decimal year.

Year

Specifies the year used to calculate decimal year.

Action for out of range input

Specify if out-of-range input invokes a warning, error or no action.

Output horizontal intensity

When selected, the horizontal intensity is output.

Output declination

When selected, the declination, the angle between true north and the magnetic field vector (positive eastwards), is output.

Output inclination

When selected, the inclination, the angle between the horizontal plane and the magnetic field vector (positive downwards), is output.

Output total intensity

When selected, the total intensity is output.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the height, in selected units.
Second		Contains the latitude in degrees.
Third		Contains the longitude in degrees.

Input	Dimension Type	Description

Fourth (Optional)		Contains the desired year in a decimal format to include any fraction of the year that has already passed. The value is the current year plus the number of days that have passed in this year divided by 365.
		
		The following code illustrates how to calculate the decimal year, `dyear`, for March 21, 2005:
		
		`%%%BEGIN CODE%%%`
		`dyear=decyear('21-March-2005','dd-mmm-yyyy')`
		`%%%END CODE%%%`

Output	Dimension Type	Description
First		Contains the magnetic field vector in selected units.
Second (Optional)		Contains the horizontal intensity in selected units.
Third (Optional)		Contains the declination in degrees.
Fourth (Optional)		Contains the inclination in degrees.
Fifth (Optional)		Contains the total intensity in selected units.

Limitations

The WMM2000 specification produces data that is reliable five years after the epoch of the model, which is January 1, 2000.

The internal calculation of decimal year does not take into account local time or leap seconds.

The WMM2000 specification describes only the long-wavelength spatial magnetic fluctuations due to the Earth's core. Intermediate and short-wavelength fluctuations, contributed from the crustal field (the mantle and crust), are not included. Also, the substantial fluctuations of the geomagnetic field, which occur constantly during magnetic storms and almost constantly in the disturbance field (auroral zones), are not included.

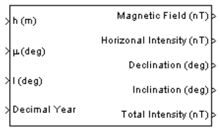
Reference

Macmillian, S. and J. M. Quinn, 2000. “The Derivation of the World Magnetic Model 2000,” *British Geological Survey Technical Report* WM/00/17R.

`https://www.ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml`

See Also

International Geomagnetic Reference Field 12, World Magnetic Model 2010



Compatibility

Note World Magnetic Model 2000 will be removed in a future version. For model years between 2000 and the start of 2015, use International Geomagnetic Reference Field 12. For model years between 2015 and the start of 2020, use World Magnetic Model 2015.

Introduced before R2006a

World Magnetic Model 2005

Calculate Earth's magnetic field at specific location and time using World Magnetic Model 2005 (WMM2005)

Library

Environment/Gravity

Description

The WMM2005 block implements the mathematical representation of the National Geospatial Intelligence Agency (NGA) World Magnetic Model 2005. The WMM2005 block calculates the Earth's magnetic field vector, horizontal intensity, declination, inclination, and total intensity at a specified location and time. The reference frame is north-east-down (NED).

Note You cannot use this block to model the Earth magnetic field above an altitude of 1,000,000 meters.

Parameters

Units

Specifies the input and output units:

Units	Height	Magnetic Field	Horizontal Intensity	Total Intensity
`Metric (MKS)`	Meters	Nanotesla	Nanotesla	Nanotesla
`English`	Feet	Nanogauss	Nanogauss	Nanogauss

Input decimal year

When selected, the decimal year is an input for the World Magnetic Model 2005 block. Otherwise, a date must be specified using the dialog parameters of **Month**, **Day**, and **Year**.

Month

Specifies the month used to calculate decimal year.

Day

Specifies the day used to calculate decimal year.

Year

Specifies the year used to calculate decimal year.

Action for out of range input

Specify if out-of-range input invokes a warning, error or no action.

Output horizontal intensity

When selected, the horizontal intensity is output.

Output declination

When selected, the declination, the angle between true north and the magnetic field vector (positive eastwards), is output.

Output inclination

When selected, the inclination, the angle between the horizontal plane and the magnetic field vector (positive downwards), is output.

Output total intensity

When selected, the total intensity is output.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the height, in selected units.
Second		Contains the latitude in degrees.
Third		Contains the longitude in degrees.

Input	Dimension Type	Description

Fourth (Optional)		Contains the desired year in a decimal format to include any fraction of the year that has already passed. The value is the current year plus the number of days that have passed in this year divided by 365.
		
		The following code illustrates how to calculate the decimal year, `dyear`, for March 21, 2005:
		
		`%%%BEGIN CODE%%%`
		`dyear=decyear('21-March-2005','dd-mmm-yyyy')`
		`%%%END CODE%%%`

Output	Dimension Type	Description
First	Vector	Contains the magnetic field in selected units. The reference frame is north-east-down (NED).
Second (Optional)		Contains the horizontal intensity in selected units.
Third (Optional)		Contains the declination in degrees.
Fourth (Optional)		Contains the inclination in degrees.
Fifth (Optional)		Contains the total intensity in selected units.

Limitations

The WMM2005 specification produces data that is reliable five years after the epoch of the model, which is January 1, 2005.

The internal calculation of decimal year does not take into account local time or leap seconds.

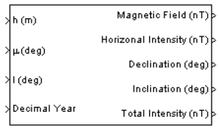
The WMM2005 specification describes only the long-wavelength spatial magnetic fluctuations due to the Earth's core. Intermediate and short-wavelength fluctuations, contributed from the crustal field (the mantle and crust), are not included. Also, the substantial fluctuations of the geomagnetic field, which occur constantly during magnetic storms and almost constantly in the disturbance field (auroral zones), are not included.

Reference

`https://www.ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml`

See Also

International Geomagnetic Reference Field 12, World Magnetic Model 2010



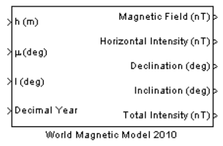
Compatibility

Note World Magnetic Model 2005 will be removed in a future version. For model years between 2000 and the start of 2015, use International Geomagnetic Reference Field 12. For model years between 2015 and the start of 2020, use World Magnetic Model 2015.

Introduced before R2006a

World Magnetic Model 2010

Calculate Earth's magnetic field at specific location and time using World Magnetic Model 2010 (WMM2010)



Library

Environment/Gravity

Description

The WMM2010 block implements the mathematical representation of the National Geospatial Intelligence Agency (NGA) World Magnetic Model 2010. The WMM2010 block calculates the Earth's magnetic field vector, horizontal intensity, declination, inclination, and total intensity at a specified location and time. The reference frame is north-east-down (NED).

Note You cannot use this block to model the Earth magnetic field above an altitude of 1,000,000 meters.

Parameters

Units

Specifies the input and output units:

Units	Height	Magnetic Field	Horizontal Intensity	Total Intensity
`Metric (MKS)`	Meters	Nanotesla	Nanotesla	Nanotesla

Units	Height	Magnetic Field	Horizontal Intensity	Total Intensity
`English`	Feet	Nanogauss	Nanogauss	Nanogauss

Input decimal year

When selected, the decimal year is an input for the World Magnetic Model 2010 block. Otherwise, a date must be specified using the dialog parameters of **Month**, **Day**, and **Year**.

Month

Specifies the month used to calculate decimal year.

Day

Specifies the day used to calculate decimal year.

Year

Specifies the year used to calculate decimal year.

Action for out-of-range input

Specify if out-of-range input invokes a warning, error or no action.

Output horizontal intensity

When selected, the horizontal intensity is output.

Output declination

When selected, the declination, the angle between true north and the magnetic field vector (positive eastwards), is output.

Output inclination

When selected, the inclination, the angle between the horizontal plane and the magnetic field vector (positive downwards), is output.

Output total intensity

When selected, the total intensity is output.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the height, in selected units.

Input	Dimension Type	Description
Second		Contains the latitude in degrees.
Third		Contains the longitude in degrees.

Fourth (Optional)		Contains the desired year in a decimal format to include any fraction of the year that has already passed. The value is the current year plus the number of days that have passed in this year divided by 365.
		
		The following code illustrates how to calculate the decimal year, `dyear`, for March 21, 2010:
		
		`%%%BEGIN CODE%%%`
		`dyear=decyear('21-March-2010','dd-mmm-yyyy')`
		`%%%END CODE%%%`

Output	Dimension Type	Description
First	Vector	Contains the magnetic field in selected units.
Second (Optional)		Contains the horizontal intensity in selected units.
Third (Optional)		Contains the declination in degrees.
Fourth (Optional)		Contains the inclination in degrees.
Fifth (Optional)		Contains the total intensity in selected units.

Limitations

The WMM2010 specification produces data that is reliable five years after the epoch of the model, which is January 1, 2015.

The internal calculation of decimal year does not take into account local time or leap seconds.

The WMM2010 specification describes only the long-wavelength spatial magnetic fluctuations due to the Earth's core. Intermediate and short-wavelength fluctuations, contributed from the crustal field (the mantle and crust), are not included. Also, the substantial fluctuations of the geomagnetic field, which occur constantly during magnetic storms and almost constantly in the disturbance field (auroral zones), are not included.

Reference

`https://www.ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml`

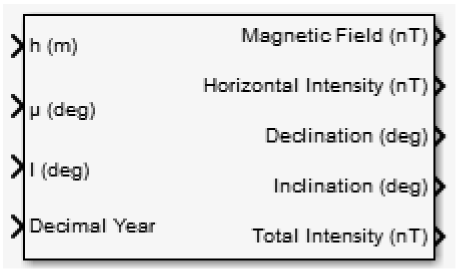
See Also

World Magnetic Model 2000, World Magnetic Model 2005

Introduced in R2010a

World Magnetic Model 2015

Calculate Earth's magnetic field at specific location and time using World Magnetic Model 2015 (WMM2015)



Library

Environment/Gravity

Description

The WMM2015 block implements the mathematical representation of the National Geospatial Intelligence Agency (NGA) World Magnetic Model 2015. The WMM2015 block calculates the Earth's magnetic field vector, horizontal intensity, declination, inclination, and total intensity at a specified location and time. The reference frame is north-east-down (NED).

Note You cannot use this block to model the Earth magnetic field above an altitude of 1,000,000 meters.

Parameters

Units

Specifies the input and output units:

Units	Height	Magnetic Field	Horizontal Intensity	Total Intensity
`Metric (MKS)`	Meters	Nanotesla	Nanotesla	Nanotesla
`English`	Feet	Nanogauss	Nanogauss	Nanogauss

Input decimal year

When selected, the decimal year is an input for the World Magnetic Model 2015 block. Otherwise, a date must be specified using the dialog parameters of **Month**, **Day**, and **Year**.

Month

Specifies the month used to calculate decimal year.

Day

Specifies the day used to calculate decimal year.

Year

Specifies the year used to calculate decimal year.

Action for out-of-range input

Specify if out-of-range input invokes a warning, error or no action.

Output horizontal intensity

When selected, the horizontal intensity is output.

Output declination

When selected, the declination, the angle between true north and the magnetic field vector (positive eastwards), is output.

Output inclination

When selected, the inclination, the angle between the horizontal plane and the magnetic field vector (positive downwards), is output.

Output total intensity

When selected, the total intensity is output.

Inputs and Outputs

Input	Dimension Type	Description
First		Contains the height, in selected units.
Second		Contains the latitude in degrees.
Third		Contains the longitude in degrees.

Fourth (Optional)		Contains the desired year in a decimal format to include any fraction of the year that has already passed. The value is the current year plus the number of days that have passed in this year divided by 365.
		
		The following code illustrates how to calculate the decimal year, `dyear`, for March 21, 2015:
		
		`%%%BEGIN CODE%%%`
		`dyear=decyear('21-March-2015','dd-mmm-yyyy')`
		`%%%END CODE%%%`

Output	Dimension Type	Description
First	Vector	Contains the magnetic field in selected units.
Second (Optional)		Contains the horizontal intensity in selected units.
Third (Optional)		Contains the declination in degrees.
Fourth (Optional)		Contains the inclination in degrees.
Fifth (Optional)		Contains the total intensity in selected units.

Limitations

The WMM2015 specification produces data that is reliable five years after the epoch of the model, which is January 1, 2015.

The internal calculation of decimal year does not take into account local time or leap seconds.

The WMM2015 specification describes only the long-wavelength spatial magnetic fluctuations due to the Earth's core. Intermediate and short-wavelength fluctuations, contributed from the crustal field (the mantle and crust), are not included. Also, the substantial fluctuations of the geomagnetic field, which occur constantly during magnetic storms and almost constantly in the disturbance field (auroral zones), are not included.

Reference

`https://www.ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml`

See Also

World Magnetic Model 2000, World Magnetic Model 2005

Introduced in R2015a

Zonal Harmonic Gravity Model

Calculate zonal harmonic representation of planetary gravity

X_{ecef} (m)
g_{ecef} (m/s^2)

Library

Environment/Gravity

Description

The Zonal Harmonic Gravity Model block calculates the zonal harmonic representation of planetary gravity at a specific location based on planetary gravitational potential. This block provides a convenient way to describe the gravitational field of a planet outside its surface.

By default, the block uses the fourth order zonal coefficient for Earth to calculate the zonal harmonic gravity. It also allows you to specify the second or third zonal coefficient.

`gravityzonal` is implemented using the following planetary parameter values for each planet:

Planet	Equatorial Radius (Re) in Meters	Gravitational Parameter (GM) in m^3/s^2	Zonal Harmonic Coefficients (J Values)
Earth	6378.1363e3	3.986004415e14	[0.0010826269 -0.0000025323 -0.0000016204]
Jupiter	71492.e3	1.268e17	[0.01475 0 -0.00058]
Mars	3397.2e3	4.305e13	[0.001964 0.000036]
Mercury	2439.0e3	2.2032e13	0.00006

Planet	Equatorial Radius (Re) in Meters	Gravitational Parameter (GM) in m^3/s^2	Zonal Harmonic Coefficients (J Values)
Moon	1738.0e3	4902.799e9	0.0002027
Neptune	24764e3	6.809e15	0.004
Saturn	60268.e3	3.794e16	[0.01645 0 -0.001]
Uranus	25559.e3	5.794e15	0.012
Venus	6052.0e3	3.257e14	0.000027

Parameters

Units

Specify the input units:

Units	Position	Equatorial Radius	Gravitational Parameter
`Metric (MKS)`	Meters	Meters	Meters cubed per second squared
`English`	Feet	Feet	Feet cubed per second squared

Degree

Specify the degree of harmonic model.

- 2 — Second degree, J2. Most significant or largest spherical harmonic term, which accounts for the oblateness of a planet.
- 3 — Third degree, J3.
- 4 — Fourth degree, J4 (default).

Action for out-of-range input

Specify if out-of-range input invokes a warning, error, or no action.

Planet model

Specify the planetary model. From the list, select `Mercury`, `Venus`, `Earth`, `Moon`, `Mars`, `Jupiter`, `Saturn`, `Uranus`, `Neptune`, or `Custom`.

Selecting `Custom` enables you to specify your own planetary model. This option enables the **Equatorial radius**, **Gravitational parameter**, and **J values** parameters.

Selecting `Mercury`, `Venus`, `Moon`, `Uranus`, or `Neptune` limits the degree to `2`.

Selecting `Mars` limits the degree to `3`.

Equatorial radius

Specify the planetary equatorial radius in the length units that the **Units** parameter defines.

Gravitational parameter

Specify the planetary gravitational parameter in the length units cubed per second squared that the **Units** parameter defines.

J values

Specify a 3-element array that defines the zonal harmonic coefficients.

Inputs and Outputs

This block accepts only scalar inputs (m=1).

Input	Dimension Type	Description
First	m-by-3 matrix	Contains planet-centered planet-fixed coordinates from the center of the planet in the selected length units. If **Planet model** has a value of `Earth`, this matrix contains Earth-centered Earth-fixed (ECEF) coordinates.

Output	Dimension Type	Description
First	m-by-3 array	Contains gravity values in the *x*-axis, *y*-axis and *z*-axis of the planet-centered planet-fixed coordinates in the selected length units per second squared.

References

Vallado, D. A., *Fundamentals of Astrodynamics and Applications*, McGraw-Hill, New York, 1997.

Fortescue, P., J. Stark, G. Swinerd, (Eds.). *Spacecraft Systems Engineering*, Third Edition, Wiley & Sons, West Sussex, 2003.

Tewari, A., *Atmospheric and Space Flight Dynamics Modeling and Simulation with MATLAB and Simulink*, Birkhäuser, Boston, 2007.

Introduced in R2009b

Functions — Alphabetical List

asbFlightControlAnalysis

Start flight control analysis template

Syntax

```
asbFlightControlAnalysis()
asbFlightControlAnalysis(configuration)
asbFlightControlAnalysis(configuration,modelToAnalyze)
asbFlightControlAnalysis(configuration,modelToAnalyze,airframe)
```

Description

`asbFlightControlAnalysis()` creates a flight control analysis template for a 3DOF configuration.

`asbFlightControlAnalysis(configuration)` creates a flight control analysis template for a specified configuration.

`asbFlightControlAnalysis(configuration,modelToAnalyze)` creates a flight control analysis model with the specified model name.

`asbFlightControlAnalysis(configuration,modelToAnalyze,airframe)` creates a flight control analysis template for a specified airframe model.

Examples

Start Flight Control Analysis Template for 3DOF Configuration

Start default flight control analysis template for 3DOF configuration.

```
asbFlightControlAnalysis
```

Start Flight Control Analysis Template for 6DOF Configuration

Start default flight control analysis template for 6DOF configuration.

```
asbFlightControlAnalysis('6DOF')
```

Start Flight Control Analysis Template Using a Different Airframe Model

Start the 3DOF flight control analysis template `SkyHoggAnalysisModel` and trim the model around the `opSpecDefault` operating point specification object. The example then linearizes the airframe model around the `opTrim` operating point and calculates the short- and long-period (phugoid) mode characteristics of `linSys`.

```
asbFlightControlAnalysis('3DOF', 'SkyHoggAnalysisModel');
opSpecDefault = SkyHogg3DOFOpSpec('SkyHoggAnalysisModel');
opTrim = trimAirframe('SkyHoggAnalysisModel', opSpecDefault);
linSys = linearizeAirframe('SkyHoggAnalysisModel', opTrim)
flyingQual = computeLongitudinalFlyingQualities('SkyHoggAnalysisModel', linSys)
```

Input Arguments

`configuration` — Configuration for flight control analysis
`'3DOF'` (default) | `'6DOF'`

Configuration for flight control analysis

Data Types: `char` | `string`

`modelToAnalyze` — Name for flight control analysis model being created
model name

Name for flight control analysis model being created.

Data Types: `char` | `string`

`airframe` — Airframe to analyze
airframe subsystem specified as a block path (default) | airframe model specified as a model name

Airframe to analyze, specified as an airframe model name (inserted as a referenced model). Otherwise, the subsystem must be loaded.

Data Types: `char` | `string`

See Also

`computeLateralDirectionalFlyingQualities` | `computeLongitudinalFlyingQualities` | `linearizeAirframe` | `trimAirframe`

Topics

"Analyze Dynamic Response and Flying Qualities of Aerospace Vehicles" on page 2-58

Introduced in R2018b

computeLateralDirectionalFlyingQualities

Calculate dutch roll mode, roll mode, and spiral mode characteristics of state-space model

Syntax

```
computeLateralDirectionalFlyingQualities(modelToAnalyze)
computeLateralDirectionalFlyingQualities(modelToAnalyze,linSys)
computeLateralDirectionalFlyingQualities(modelToAnalyze,linSys,
generatePlots)
```

Description

`computeLateralDirectionalFlyingQualities(modelToAnalyze)` calculates the lateral-directional flying qualities (dutch roll mode, roll mode, and spiral mode) characteristics using the linear system state-space model selected in the input dialog window and compares the results against MIL-F-8785C requirements.

`computeLateralDirectionalFlyingQualities(modelToAnalyze,linSys)` calculates lateral-directional flying qualities using the linear system state-space model selected in the input dialog window. The state-space model must have at least these four states:

- `v`
- `p`
- `r`
- `phi`

or all eight of these states:

- `v`
- `p`
- `r`
- `phi`

- `U`
- `w`
- `q`
- `theta`

To create a compatible state-space model, use the `linearizeAirframe` function.

`computeLateralDirectionalFlyingQualities(modelToAnalyze,linSys, generatePlots)` calculates lateral-directional flying qualities using linear system state-space model `linSys`.

Examples

Calculate Lateral-Directional Flying Qualities While Specifying a State-Space Model

Calculate lateral-directional flying qualities of `linSys`, a state space model of airframe `DehavillandBeaverAnalysisModel`. This example starts the flight control analysis template using `asbFlightControlAnalysis` and trims the model around the `opSpecDefault` operating point specification object. It then linearizes the airframe model around the `opTrim` operating point and calculates the dutch roll mode, roll mode, and spiral mode characteristics of `linSys`. The example also optionally calculates the longitudinal characteristics for the model.

```
asbFlightControlAnalysis('6DOF', 'DehavillandBeaverAnalysisModel');
opSpecDefault = DehavillandBeaver6DOFOpSpec('DehavillandBeaverAnalysisModel');
opTrim = trimAirframe('DehavillandBeaverAnalysisModel', opSpecDefault);
linSys = linearizeAirframe('DehavillandBeaverAnalysisModel', opTrim);
lonFlyingQual = computeLongitudinalFlyingQualities('DehavillandBeaverAnalysisModel', linSys)
latFlyingQual = computeLateralDirectionalFlyingQualities('DehavillandBeaverAnalysisModel', linSys)
```

Compare Lateral-Directional Flying Qualities Results to MIL-F-8785C Requirements

Compare against MIL-F_8785C requirements.

Calculate lateral-directional flying qualities for the model `DehavillandBeaverAnalysisModel` and specify a state-space, `linSys`.

```
asbFlightControlAnalysis('6DOF', 'DehavillandBeaverAnalysisModel');
opSpecDefault = DehavillandBeaver6DOFOpSpec('DehavillandBeaverAnalysisModel');
opTrim = trimAirframe('DehavillandBeaverAnalysisModel', opSpecDefault);
linSys = linearizeAirframe('DehavillandBeaverAnalysisModel', opTrim);
lonFlyingQual = computeLongitudinalFlyingQualities('DehavillandBeaverAnalysisModel', linSys);
latFlyingQual = computeLateralDirectionalFlyingQualities('DehavillandBeaverAnalysisModel', linSys);
```

Get the list of lateral-directional flying qualities for the model.

```
latFlyingQual
```

```
latFlyingQual = 

  struct with fields:

    DutchRollMode: [1×1 struct]
         RollMode: [1×1 struct]
       SpiralMode: [1×1 struct]
```

Get the dutch roll flying quality.

```
latFlyingQual.DutchRollMode
```

```
ans = 

  struct with fields:

                   root: [2×1 double]
         oscillatoryMode: 'Dutch Roll Mode'
    MILF8785CRequirement: 'Satisfies MIL-F-8785C Level 1 Criteria (zeta_d >= 0.08, omeg
            DampingRatio: 0.4337
             NaturalFreq: 1.4872
         TimeToDoubleAmp: -1.0747
            TimeConstant: []
                response: 'converging oscillatory motion'
             description: 'complex conjugate pair with negative real components'
```

Get the results of the comparison with the MIL-F-8785C requirements.

```
latFlyingQual.DutchRollMode.MILF8785CRequirement
```

```
ans =

    'Satisfies MIL-F-8785C Level 1 Criteria (zeta_d >= 0.08, omega_n >= 0.4, zeta_d*omega_n_d >= 0.15)'
```

Input Arguments

`modelToAnalyze` — Model on which to perform flight control analysis
model name

Model on which to perform flight control analysis using the linear state-space model `linSys`.

Data Types: `char` | `string`

`linSys` — Linear state-space model object
linear state-space model object name

Linear state-space model object used to perform flight control analysis on `modelToAnalyze`.

Data Types: `char` | `string`

`generatePlots` — Display pole-zero map
model name

Display pole-zero map for the linear system state-space model.

Data Types: `char` | `string`

Limitations

This function requires the Simulink Control Design license

See Also

`asbFlightControlAnalysis` | `computeLongitudinalFlyingQualities` | `linearizeAirframe` | `trimAirframe`

Topics

"Analyze Dynamic Response and Flying Qualities of Aerospace Vehicles" on page 2-58

Introduced in R2019a

computeLongitudinalFlyingQualities

Calculate short-period and long-period (phugoid) mode characteristics of specified state-space model

Syntax

```
computeLongitudinalFlyingQualities(modelToAnalyze)
computeLongitudinalFlyingQualities(modelToAnalyze,linSys)
computeLongitudinalFlyingQualities(modelToAnalyze,linSys,
generatePlots)
```

Description

`computeLongitudinalFlyingQualities(modelToAnalyze)` calculates longitudinal flying qualities (short-period and phugoid mode) using the linear system state-space model selected in the input dialog window and compares the results against MIL-F-8785C requirements.

`computeLongitudinalFlyingQualities(modelToAnalyze,linSys)` calculates longitudinal flying qualities (short-period and phugoid mode) using the linear system state-space model selected in the input dialog window. The state-space model must have at least these four states:

- `U`
- `w`
- `q`
- `theta`

or all eight of these states:

- `U`
- `w`
- `q`

- `theta`
- `v`
- `p`
- `r`
- `phi`

To create a usable state-space model, use the `linearizeAirframe` function.

`computeLongitudinalFlyingQualities(modelToAnalyze,linSys, generatePlots)` calculates longitudinal flying qualities (short-period and phugoid mode) using linear system state-space model `linSys`.

Examples

Calculate Longitudinal Flying Qualities While Specifying a State-Space Model

Calculate longitudinal flying qualities of `linSys`, a state space model `DehavillandBeaverAnalysisModel` This example starts the flight control analysis template using `asbFlightControlAnalysis` and trims the model around the `opSpecDefault` operating point specification object. It then linearizes the airframe model around the `opTrim` operating point and calculates the short- and long-period (phugoid) mode characteristics of `linSys`.

```
asbFlightControlAnalysis('3DOF', 'SkyHoggAnalysisModel');
opSpecDefault = SkyHogg3DOFOpSpec('SkyHoggAnalysisModel');
opTrim = trimAirframe('SkyHoggAnalysisModel', opSpecDefault);
linSys = linearizeAirframe('SkyHoggAnalysisModel', opTrim)
flyingQual = computeLongitudinalFlyingQualities('SkyHoggAnalysisModel', linSys)
```

Compare Longitudinal Flying Qualities Results to MIL-F-8785C Requirements

Compare against MIL-F_8785C requirements.

Calculate longitudinal flying qualities for the model `DehavillandBeaverAnalysisModel` and specify a state-space, `linSys`.

```
asbFlightControlAnalysis('6DOF', 'DehavillandBeaverAnalysisModel');
opSpecDefault = DehavillandBeaver6DOFOpSpec('DehavillandBeaverAnalysisModel');
opTrim = trimAirframe('DehavillandBeaverAnalysisModel', opSpecDefault);
```

```
linSys = linearizeAirframe('DehavillandBeaverAnalysisModel', opTrim);
lonFlyingQual = computeLongitudinalFlyingQualities('DehavillandBeaverAnalysisModel', linSys);
latFlyingQual = computeLateralDirectionalFlyingQualities('DehavillandBeaverAnalysisModel', linSys);
```

Get the list of longitudinal flying qualities for the model.

```
lonFlyingQual
```

```
lonFlyingQual = 

  struct with fields:

        PhugoidMode: [1×1 struct]
    ShortPeriodMode: [1×1 struct]
```

Get the phugoid flying quality.

```
lonFlyingQual.PhugoidMode
```

```
ans = 

  struct with fields:

                   root: [2×1 double]
         oscillatoryMode: 'Phugoid (Long-Period Mode)'
    MILF8785CRequirement: 'Satisfies MIL-F-8785C Level 1 Criteria (zeta_ph >= 0.04)'
            DampingRatio: 0.0926
             NaturalFreq: 0.1540
         TimeToDoubleAmp: -48.5747
            TimeConstant: []
                response: 'converging oscillatory motion'
             description: 'complex conjugate pair with negative real components'
```

Get the results of the comparison with the MIL-F-8785C requirements.

```
lonFlyingQual.PhugoidMode.MILF8785CRequirement
```

```
ans = 

    'Satisfies MIL-F-8785C Level 1 Criteria (zeta_ph >= 0.04)'
```

Input Arguments

`modelToAnalyze` — Model on which to perform flight control analysis
model name

Model on which to perform flight control analysis using the linear state-space model `linSys`.

Data Types: `char` | `string`

`linSys` — Linear state-space model object
linear state-space model object name

Linear state-space model object used to perform flight control analysis on `modelToAnalyze`.

Data Types: `char` | `string`

`generatePlots` — Display pole-zero map
model name

Display pole-zero map for the linear system state-space model.

Data Types: `char` | `string`

See Also

`asbFlightControlAnalysis` | `computeLateralDirectionalFlyingQualities` | `linearizeAirframe` | `trimAirframe`

Topics

"Analyze Dynamic Response and Flying Qualities of Aerospace Vehicles" on page 2-58

Introduced in R2018b

linearizeAirframe

Linearize airframe model around operating points

Syntax

```
linSys = linearizeAirframe(modelToAnalyze)
linSys = linearizeAirframe(modelToAnalyze)
linSys = linearizeAirframe(modelToAnalyze,opPoint)
linSys = linearizeAirframe(modelToAnalyze,opPoint,generatePlots)
```

Description

`linSys = linearizeAirframe(modelToAnalyze)` linearizes an airframe model around a specified operating point or operating point specification object and generates an output state-space model that contains only longitudinal states. A **Linearize Airframe** dialog window prompts you to select an operating point or operating point specification object from the base workspace. If an operating point or operating point specification object does not exist in the base workspace, click the **Launch Trim Tool** button in the **Linearize Airframe** dialog window. This button starts the Simulink Control Design Linear Analysis Tool in which you can create the operating point specification object. The `linearizeAirframe` function uses this object as the operating condition around which to linearize the airframe model.

`linSys = linearizeAirframe(modelToAnalyze)` linearizes an airframe model around the specified operating point object or operating point specification object.

`linSys = linearizeAirframe(modelToAnalyze,opPoint)` linearizes an airframe model around the specified operating point object or operating point specification object.

`linSys = linearizeAirframe(modelToAnalyze,opPoint,generatePlots)` displays bode and step plot results of longitudinal linearization.

Examples

Linearize Model Around a Provided Operating Point Specification Object

Linearize the model `SkyHoggAnalysisModel` around the operating point, `opTrim`. This example starts the flight control analysis template using `asbFlightControlAnalysis` and trims the model around the `opSpecDefault` operating point specification object. It then linearizes the airframe model around the `opTrim` operating point and calculates the short- and long-period (phugoid) mode characteristics of `linSys`.

```
asbFlightControlAnalysis('3DOF', 'SkyHoggAnalysisModel');
opSpecDefault = SkyHogg3DOFOpSpec('SkyHoggAnalysisModel');
opTrim = trimAirframe('SkyHoggAnalysisModel', opSpecDefault);
linSys = linearizeAirframe('SkyHoggAnalysisModel', opTrim)
flyingQual = computeLongitudinalFlyingQualities('SkyHoggAnalysisModel', linSys)
```

Input Arguments

`modelToAnalyze` — Model on which to perform flight control analysis
model name

Model on which to perform flight control analysis. This model must be previously created with the `asbFlightControlAnalysis` function.

Data Types: `char` | `string`

`opPoint` — Operating point object
operating point object

Operating point object used to linearize the model `modelToAnalyze`.

Data Types: `char` | `string`

`generatePlots` — Display pole-zero map
model name

Display pole-zero map for the linear system state-space model.

Data Types: `char` | `string`

Output Arguments

`linSys` — State-space model object
linear state-space model object name

State space model object representing the linearized airframe model at a specified operating point.

Data Types: `char` | `string`

Limitations

This function requires the Simulink Control Design license.

See Also

Linear Analysis Tool | `asbFlightControlAnalysis` | `computeLateralDirectionalFlyingQualities` | `computeLongitudinalFlyingQualities` | `trimAirframe`

Topics

"Analyze Dynamic Response and Flying Qualities of Aerospace Vehicles" on page 2-58

Introduced in R2018b

linearizeLongitudinalAirframe (Obsolete)

Linearize airframe model around operating points

Syntax

```
linearizeLongitudinalAirframe(modelToAnalyze)
linearizeLongitudinalAirframe(modelToAnalyze,opPoint)
linearizeLongitudinalAirframe(modelToAnalyze,opPoint,generatePlots)
```

Description

Note This function is obsolete. Use `linearizeAirframe` instead.

`linearizeLongitudinalAirframe(modelToAnalyze)` linearizes an airframe model around a specified operating point or operating point specification object and generates an output state-space model that contains only longitudinal states. A **Linearize Airframe** dialog window prompts you to select an operating point or operating point specification object from the base workspace. If an operating point or operating point specification object does not exist in the base workspace, click the **Launch Trim Tool** button in the **Trim Airframe** dialog window. This button starts the Simulink Control Design Linear Analysis Tool in which you can create the operating point specification object. From this object, the `linearizeLongitudinalAirframe` function creates the operating point.

`linearizeLongitudinalAirframe(modelToAnalyze,opPoint)` linearizes an airframe model around the specified operating point object or operating point specification object.

`linearizeLongitudinalAirframe(modelToAnalyze,opPoint,generatePlots)` displays bode and step plot results of longitudinal linearization.

Examples

Linearize Model While Specifying an Operating Point Specification Object

Linearize the model `SkyHoggAnalysisModel` and specify an operating point, `opTrim`. This example starts the flight control analysis template using `asbFlightControlAnalysis` and trims the model around the `opSpecDefault` operating point specification object. It then linearizes the airframe model around the `opTrim` operating point and calculates the short- and long-period (phugoid) mode characteristics of `linSys`.

```
asbFlightControlAnalysis('3DOF', 'SkyHoggAnalysisModel');
opSpecDefault = SkyHogg3DOFOpSpec('SkyHoggAnalysisModel');
opTrim = trimAirframe('SkyHoggAnalysisModel', opSpecDefault);
linSys = linearizeLongitudinalAirframe('SkyHoggAnalysisModel', opTrim)
flyingQual = computeLongitudinalFlyingQualities('SkyHoggAnalysisModel', linSys)
```

Input Arguments

`modelToAnalyze` — Model on which to perform flight control analysis
model name

Model on which to perform flight control analysis using the linear state-space model `linSys`. This model must be previously created with the `asbFlightControlAnalysis` function.

Data Types: `char` | `string`

`opPoint` — Linear state-space model
linear state-space model name

Linear state-space model used to perform flight control analysis on `modelToAnalyze`.

Data Types: `char` | `string`

`generatePlots` — Display pole-zero map
model name

Display pole-zero map for the linear system state-space model.

Data Types: `char` | `string`

Limitations

This function requires the Simulink Control Design license.

See Also

Linear Analysis Tool | `asbFlightControlAnalysis` | `computeLongitudinalFlyingQualities` | `linearizeAirframe` | `trimAirframe`

Topics

"Analyze Dynamic Response and Flying Qualities of Aerospace Vehicles" on page 2-58

Introduced in R2018b

trimAirframe

Trim airframe around operating point specification object

Syntax

```
trimAirframe(modelToAnalyze)
trimAirframe(modelToAnalyze,opSpec)
```

Description

`trimAirframe(modelToAnalyze)` trims the airframe around an operating point specification object. A **Trim Airframe** dialog window prompts you to select an operating point specification object from the base workspace. If an operating point specification object does not exist in the base workspace, click the **Launch Trim Tool** button in the **Trim Airframe** dialog window. This button starts the Simulink Control Design Linear Analysis Tool in which you can create the operating point specification object. From this object, the `trimAirframe` function trims the airframe.

`trimAirframe(modelToAnalyze,opSpec)` trims the airframe model around the specified operating point specification object.

Examples

Trim Model While Specifying an Operating Point Specification Object

Trim the model `SkyHoggAnalysisModel` around an operating point specification object, `opSpecDefault`. This example starts the flight control analysis template using `asbFlightControlAnalysis` and trims the model around the `opSpecDefault` operating point. It then linearizes the airframe model around the `opTrim` operating point specification object and calculates the short- and long-period (phugoid) mode characteristics of `linSys`.

```
asbFlightControlAnalysis('3DOF', 'SkyHoggAnalysisModel');
opSpecDefault = SkyHogg3DOFOpSpec('SkyHoggAnalysisModel');
```

```
opTrim = trimAirframe('SkyHoggAnalysisModel', opSpecDefault);
linSys = linearizeAirframe('SkyHoggAnalysisModel', opTrim)
flyingQual = computeLongitudinalFlyingQualities('SkyHoggAnalysisModel', linSys)
```

Input Arguments

`modelToAnalyze` — Model on which to perform flight control analysis
model name

Model on which to perform flight control analysis using the linear state-space model `linSys`. This model must be previously created with the `asbFlightControlAnalysis` function.

Data Types: `char` | `string`

opSpec — Linear state-space model
linear state-space model name

Linear state-space model used to perform flight control analysis on `modelToAnalyze`.

Data Types: `char` | `string`

Limitations

This function requires the Simulink Control Design license.

See Also

Linear Analysis Tool | `asbFlightControlAnalysis` | `computeLateralDirectionalFlyingQualities` | `computeLongitudinalFlyingQualities` | `linearizeAirframe`

Topics

“Analyze Dynamic Response and Flying Qualities of Aerospace Vehicles” on page 2-58

Introduced in R2018b

Aerospace Blockset Examples

1903 Wright Flyer and Pilot with Scopes for Data Visualization

This model shows how to model the Wright Brother's 1903 Flyer modeled in Simulink®, and Aerospace Blockset™ software. This model simulates the longitudinal motion of the Flyer in response to the pitch commands of a simulated pilot.

December 17, 2003 marked the centennial of the first powered, heavier-than-air controlled flight. This first flight happened at Kitty Hawk, North Carolina, on December 17, 1903 at 10:30 am. With a flight lasting only 12 seconds and traveling a distance of 120 feet, Orville Wright piloted his way into flight history. Three other flights occurred that day with Wilbur and Orville taking turns at the controls. Each of the flights was of increasing distance. The fourth and final flight of the day completed by Wilbur was an impressive 59 seconds traveling 852 feet. The 1903 Flyer would not take to the skies again. After the last flight of the day, the Flyer was damaged beyond repair when it was caught by a gust of wind and rolled over.

Additional information about the 1903 Flyer can be found at NASA Web Site: Re-Living The Wright Way https://wright.nasa.gov and on MathWorks® web site: The Wright Stuff Celebrating The 1903 Flyer https://www.mathworks.com/company/newsletters/articles/the-wright-stuff-celebrating-the-1903-flyer.html

A technical reference is Hooven, Frederick J., "Longitudinal Dynamics of the Wright Brothers' Early Flyers 'A Study in Computer Simulation of Flight', from The Wright Flyer An Engineering Perspective edited by Howard S. Wolko, 1987.

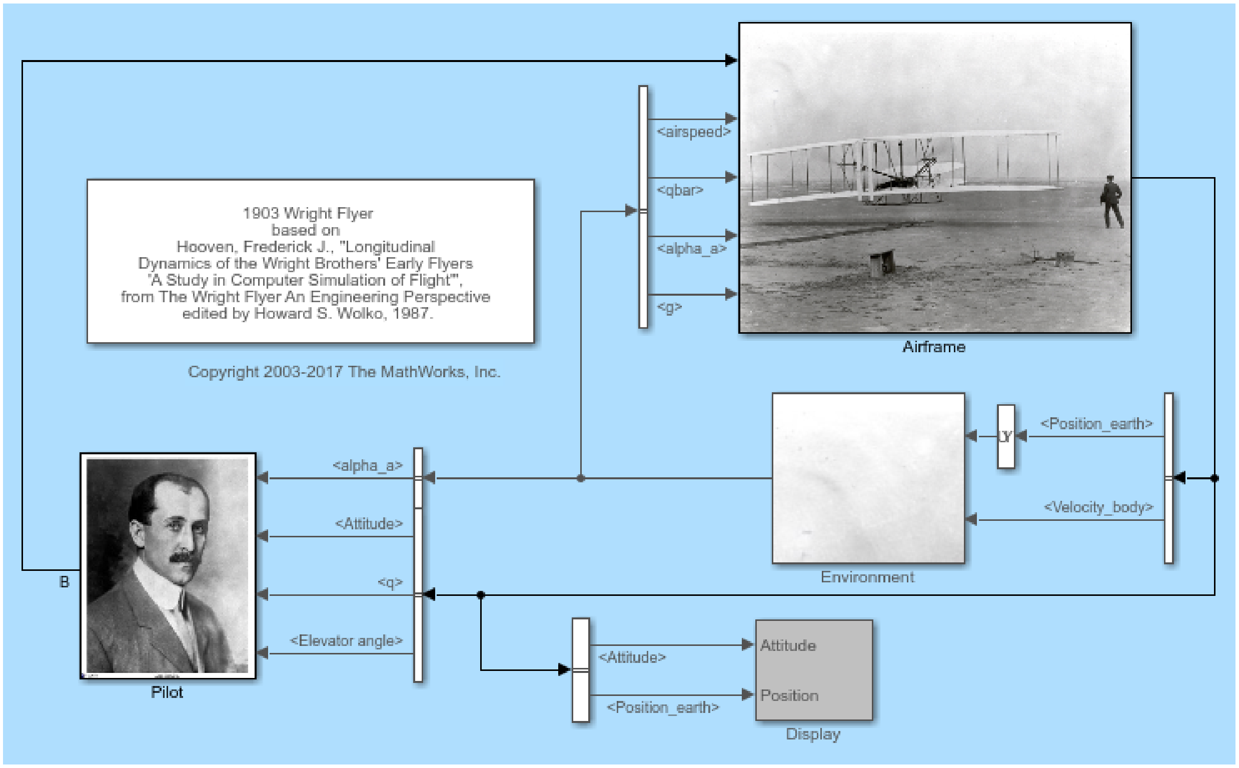
Note that the following warning messages are from a Simulink assertion block, used to determine if the Flyer has landed or stalled. Information messages display in the MATLAB® Command Window and warning messages display in the Simulink Diagnostic Viewer.

Landing

Warning: Assertion detected in 'aeroblk_wf_3dof_noVR/Airframe/Touch Down?/Check Touch Down/Land?' at time 2.529176.

Hitting Ground

Warning: Assertion detected in 'aeroblk_wf_3dof_noVR/Airframe/Touch Down?/Altitude?' at time 2.529176.


1903 Wright Flyer
based on
Hooven, Frederick J., "Longitudinal
Dynamics of the Wright Brothers' Early Flyers
'A Study in Computer Simulation of Flight'",
from The Wright Flyer An Engineering Perspective
edited by Howard S. Wolko, 1987.
Copyright 2003-2017 The MathWorks, Inc.
<airspeed>
<qbar>
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<g>
Airframe
<Position_earth>
<Velocity_body>
Environment
<alpha_a>
<Attitude>
<q>
<Elevator angle>
B
Pilot
<Attitude>
<Position_earth>
Attitude
Position
Display

1903 Wright Flyer and Pilot with Simulink® 3D Animation™

This model shows how to model the Wright Brother's 1903 Flyer modeled in Simulink®, Aerospace Blockset™ and Simulink® 3D Animation™ software. This model simulates the longitudinal motion of the Flyer in response to the pitch commands of a simulated pilot.

December 17, 2003 marked the centennial of the first powered, heavier-than-air controlled flight. This first flight happened at Kitty Hawk, North Carolina, on December 17, 1903 at 10:30 am. With a flight lasting only 12 seconds and traveling a distance of 120 feet, Orville Wright piloted his way into flight history. Three other flights occurred that day with Wilbur and Orville taking turns at the controls. Each of the flights was of increasing distance. The fourth and final flight of the day completed by Wilbur was an impressive 59 seconds traveling 852 feet. The 1903 Flyer would not take to the skies again. After the last flight of the day, the Flyer was damaged beyond repair when it was caught by a gust of wind and rolled over.

Additional information about the 1903 Flyer can be found at NASA Web Site: Re-Living The Wright Way https://wright.nasa.gov and on MathWorks® web site: The Wright Stuff Celebrating The 1903 Flyer https://www.mathworks.com/company/newsletters/articles/the-wright-stuff-celebrating-the-1903-flyer.html

A technical reference is Hooven, Frederick J., "Longitudinal Dynamics of the Wright Brothers' Early Flyers 'A Study in Computer Simulation of Flight', from The Wright Flyer An Engineering Perspective edited by Howard S. Wolko, 1987.

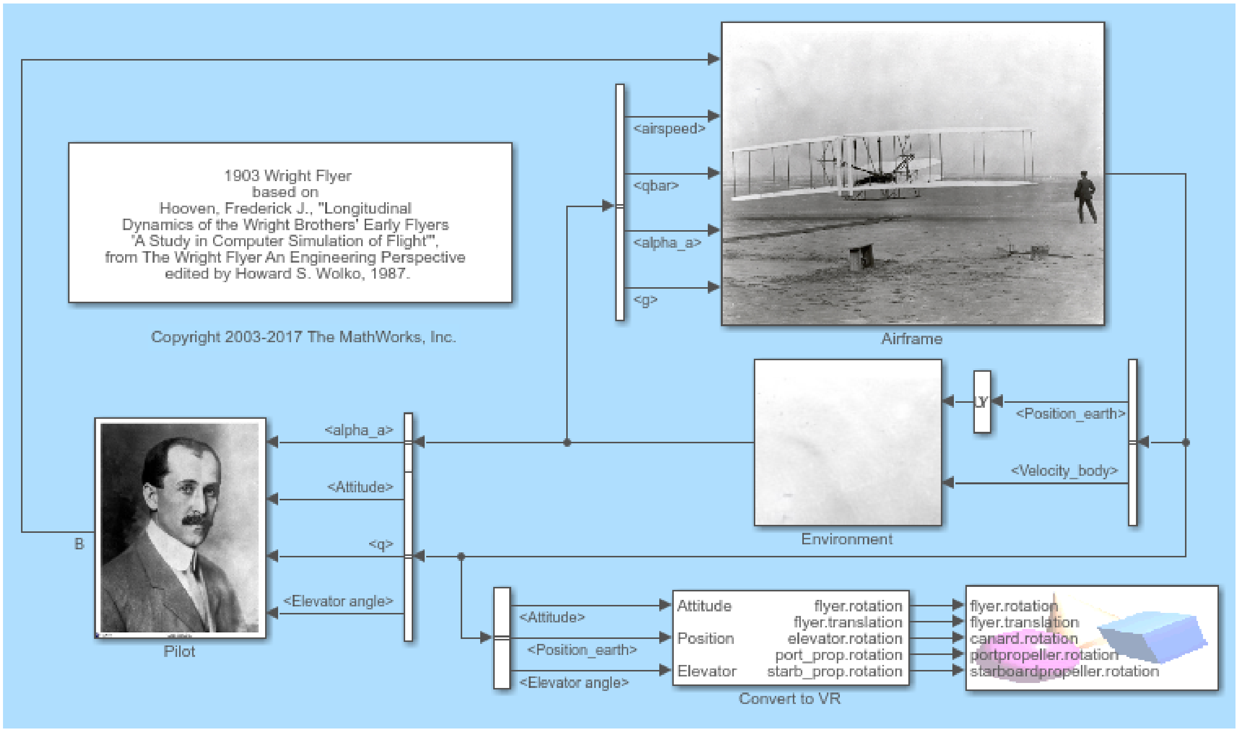
Note that the following warning messages are from a Simulink assertion block, used to determine if the Flyer has landed or stalled. Information messages display in the MATLAB® Command Window and warning messages display in the Simulink Diagnostic Viewer.

Landing

Warning: Assertion detected in 'aeroblk_wf_3dof/Airframe/Touch Down?/Check Touch Down/Land?' at time 2.529176.

Hitting Ground

Warning: Assertion detected in 'aeroblk_wf_3dof/Airframe/Touch Down?/Altitude?' at time 2.529176.


1903 Wright Flyer
based on
Hooven, Frederick J., "Longitudinal
Dynamics of the Wright Brothers' Early Flyers
'A Study in Computer Simulation of Flight'",
from The Wright Flyer An Engineering Perspective
edited by Howard S. Wolko, 1987.

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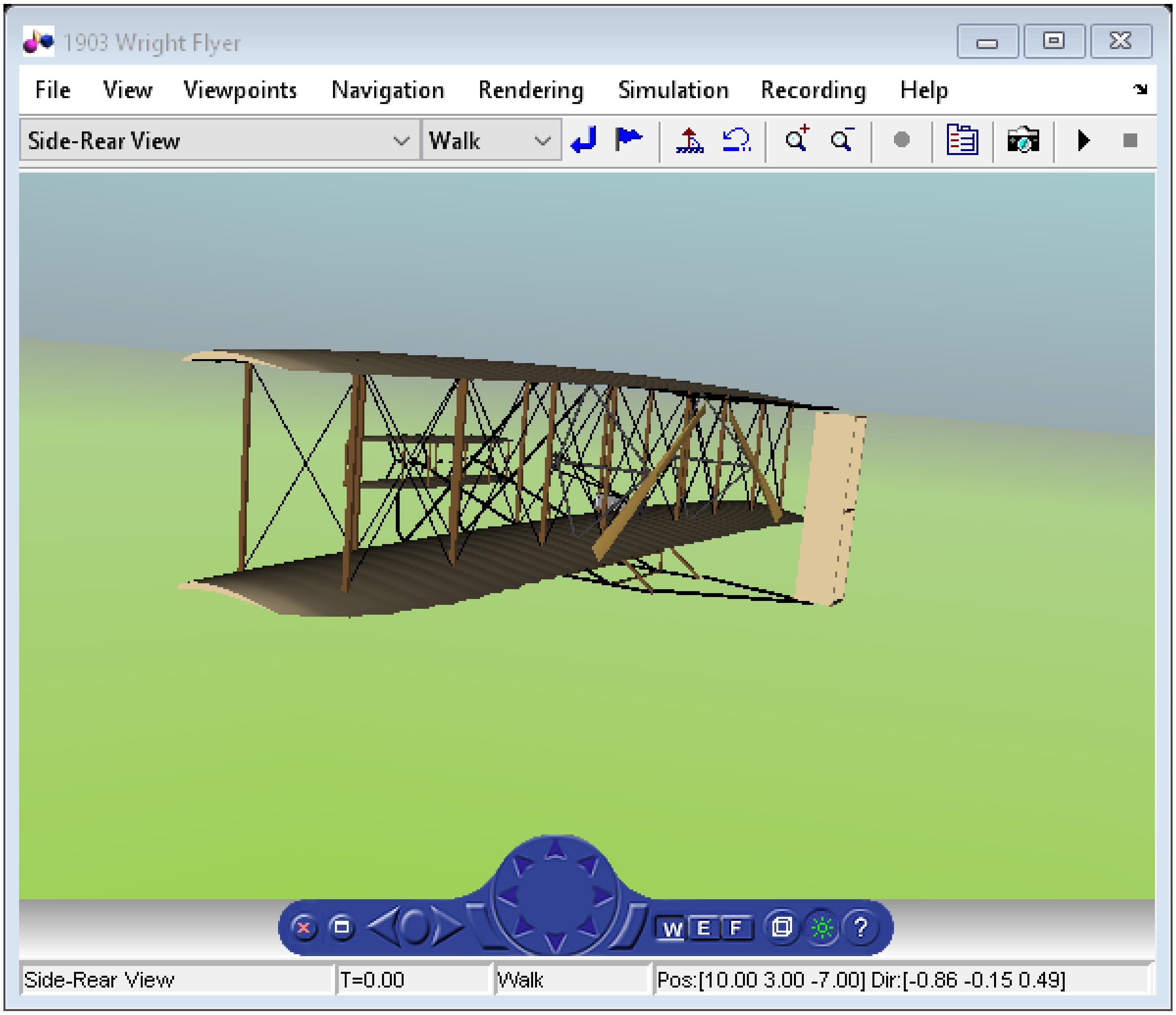


Side-Rear View T=0.00 Walk Pos:[10.00 3.00 -7.00] Dir:[-0.86 -0.15 0.49]

Fly the DeHavilland Beaver

This model shows how to model the DeHavilland Beaver using Simulink® and Aerospace Blockset™ software. It also shows how to use a pilot's joystick to fly the DeHavilland Beaver This model has been color-coded to aid in locating Aerospace Blockset blocks. The red blocks are Aerospace Blockset blocks, the orange blocks are subsystems containing additional Aerospace Blockset blocks, and the white blocks are Simulink blocks.

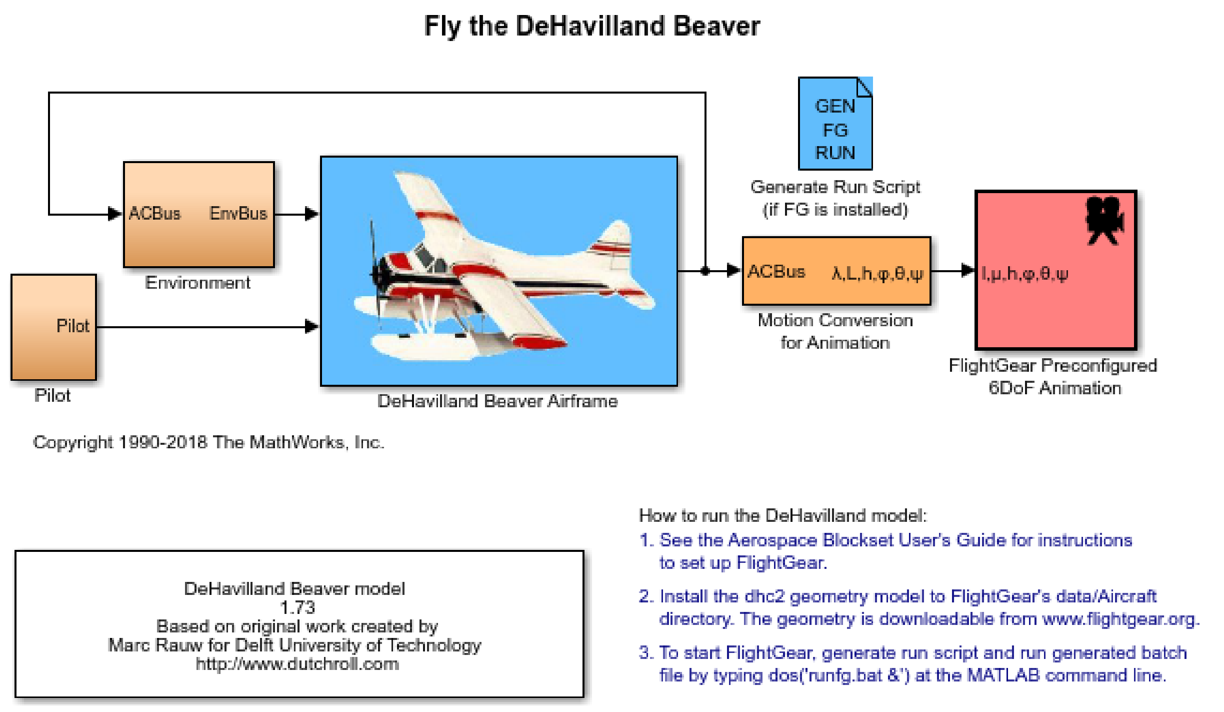
The DeHavilland Beaver model includes the airframe dynamics and aerodynamics. Effects of the environment are also modeled, such as wind profiles for the landing phase. Visualization for this model is done via an interface to FlightGear, a open source flight simulator package.

For more information on the FlightGear interface, read these documentation topics:

Installing the Flight Simulator

Working with the Flight Simulator Interface

Modeling the HL20 with the Flight Simulator


Fly the DeHavilland Beaver
GEN FG RUN
Generate Run Script (if FG is installed)
ACBus
EnvBus
Environment
Pilot
Pilot
DeHavilland Beaver Airframe
ACBus
λ,L,h,φ,θ,ψ
Motion Conversion for Animation
l,μ,h,φ,θ,ψ
FlightGear Preconfigured 6DoF Animation
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DeHavilland Beaver model
1.73
Based on original work created by
Marc Rauw for Delft University of Technology
http://www.dutchroll.com

How to run the DeHavilland model:

1. See the Aerospace Blockset User's Guide for instructions to set up FlightGear.
2. Install the dhc2 geometry model to FlightGear's data/Aircraft directory. The geometry is downloadable from www.flightgear.org.
3. To start FlightGear, generate run script and run generated batch file by typing dos('runfg.bat &') at the MATLAB command line.

The DeHavilland Beaver was first flown in 1947. Today it is still prized by pilots for its reliability and versatility. The DeHavilland Beaver can be operated on wheels, skis or float landing gear.

Speed maximum: 110 kts, Altitude maximum: 10,000 ft, Range maximum: 400 nm, Load: 6 passengers, Crew: 1 member.

Lightweight Airplane Design

This model shows how to use MathWorks® products to address the technical and process challenges of aircraft design using the design of a lightweight aircraft.

To run this example model, you need Aerospace Blockset™ software and its required products. Additional products you will need to explore this model further are:

- Control System Toolbox™
- Simulink® Control Design™
- Simulink® Design Optimization™

The design process is iterative; you will try many vehicle configurations before selecting the final one. Ideally, you perform iterations before building any hardware. The challenge is to perform the iterations quickly. Typically, different groups work on different steps of the process. Effective collaboration among these groups and the right set of tools are essential to addressing this challenge.

Defining Vehicle Geometry

The geometry of this lightweight aircraft is from reference 1. The original design objective for this geometry was a four-seat general aviation aircraft that was safe, simple to fly, and easily maintainable with specific mission and performance constraints. For more details on these constraints, see reference 1.

Potential performance requirements for this aircraft include:

- Level cruise speed
- Acceptable rate of climb
- Acceptable stall speed.

For the aircraft flight control, rate of climb is the design requirement and assumed to be greater than 2 meters per second (m/s) at 2,000 meters.

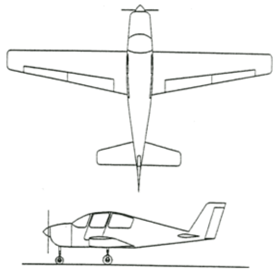

Figure 1: Lightweight four-seater monoplane [1].

Determining Vehicle Aerodynamic Characteristics

The aircraft's geometrical configuration determines its aerodynamic characteristics, and therefore its performance and handling qualities. Once you choose the geometric configuration, you can obtain the aerodynamic characteristics by means of:

- Analytical prediction
- Wind tunnel testing of the scaled model or a full-sized prototype
- Flight tests.

While wind tunnel tests and flight tests provide high-fidelity results, they are expensive and time- consuming, because they must be performed on the actual hardware. It is best to use these methods when the aircraft's geometry is finalized. **Note**: Analytical prediction is a quicker and less expensive way to estimate aerodynamic characteristics in the early stages of design.

In this example, we will use Digital Datcom, a popular software program, for analytical prediction. The U.S. Air Force developed it as a digital version of its Data Compendium (DATCOM). This software is publicly available.

To start, create a Digital Datcom input file that defines the geometric configuration of our aircraft and the flight conditions that we will need to obtain the aerodynamic coefficients.

```
$FLTCON NMACH=4.0,MACH(1)=0.1,0.2,0.3,0.35$
$FLTCON NALT=8.0,ALT(1)=1000.0,3000.0,5000.0,7000.0,9000.0,
  11000.0,13000.0,15000.0$
$FLTCON NALPHA=10.,ALSCHD(1)=-16.0,-12.0,-8.0,-4.0,-2.0,0.0,2.0,
  ALSCHD(8)=4.0,8.0,12.0,LOOP=2.0$
```

```
 $OPTINS SREF=225.8,CBARR=5.75,BLREF=41.15$
 $SYNTHS XCG=7.9,ZCG=-1.4,XW=6.1,ZW=0.0,ALIW=1.1,XH=20.2,
    ZH=0.4,ALIH=0.0,XV=21.3,ZV=0.0,VERTUP=.TRUE.$
 $BODY NX=10.0,
    X(1)=-4.9,0.0,3.0,6.1,9.1,13.3,20.2,23.5,25.9,
    R(1)=0.0,1.0,1.75,2.6,2.6,2.6,2.0,1.0,0.0$
 $WGPLNF CHRDTP=4.0,SSPNE=18.7,SSPN=20.6,CHRDR=7.2,SAVSI=0.0,CHSTAT=0.25,
    TWISTA=-1.1,SSPNDD=0.0,DHDADI=3.0,DHDADO=3.0,TYPE=1.0$
 $HTPLNF CHRDTP=2.3,SSPNE=5.7,SSPN=6.625,CHRDR=0.25,SAVSI=11.0,
    CHSTAT=1.0,TWISTA=0.0,TYPE=1.0$
 $VTPLNF CHRDTP=2.7,SSPNE=5.0,SSPN=5.2,CHRDR=5.3,SAVSI=31.3,
    CHSTAT=0.25,TWISTA=0.0,TYPE=1.0$
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    CHRDFO=1.3,SPANFI=.1,SPANFO=6.0,FTYPE=1.0,CB=1.3,TC=.0225,
    PHETEP=.0391,NTYPE=1.$
NACA-W-4-0012
NACA-H-4-0012
NACA-V-4-0012
CASEID SKYHOGG BODY-WING-HORIZONTAL TAIL-VERTICAL TAIL CONFIG
DAMP
NEXT CASE
```

Digital Datcom provides the vehicle's aerodynamic stability and control derivatives and coefficients at specified flight conditions. Flight control engineers can gain insight into the vehicle's performance and handling characteristics by examining stability and control derivatives. We must import this data into the MATLAB® technical computing environment for analysis. Normally, this is a manual process.

With the Aerospace Toolbox software, we can bring multiple Digital Datcom output files into the MATLAB technical computing environment with just one command. There is no need for manual input. Each Digital Datcom output is imported into the MATLAB technical computing environment as a cell array of structures, with each structure corresponding to a different Digital Datcom output file. After importing the Digital Datcom output, we can run multiple configurations through Digital Datcom and compare the results in the MATLAB technical computing environment.

In our model, we need to check whether the vehicle is inherently stable. To do this, we can use Figure 2 to check whether the pitching moment described by the corresponding coefficient, Cm, provides a restoring moment for the aircraft. A restoring moment returns the aircraft angle of attack to zero.

In configuration 1 (Figure 2), Cm is negative for some angles of attack less than zero. This means that this configuration will not provide a restoring moment for those negative angles of attack and will not provide the flight characteristics that are desirable. Configuration 2 fixes this problem by moving the center of gravity rearward. Shifting the center of gravity produces a Cm that provides a restoring moment for all negative angles of attack.

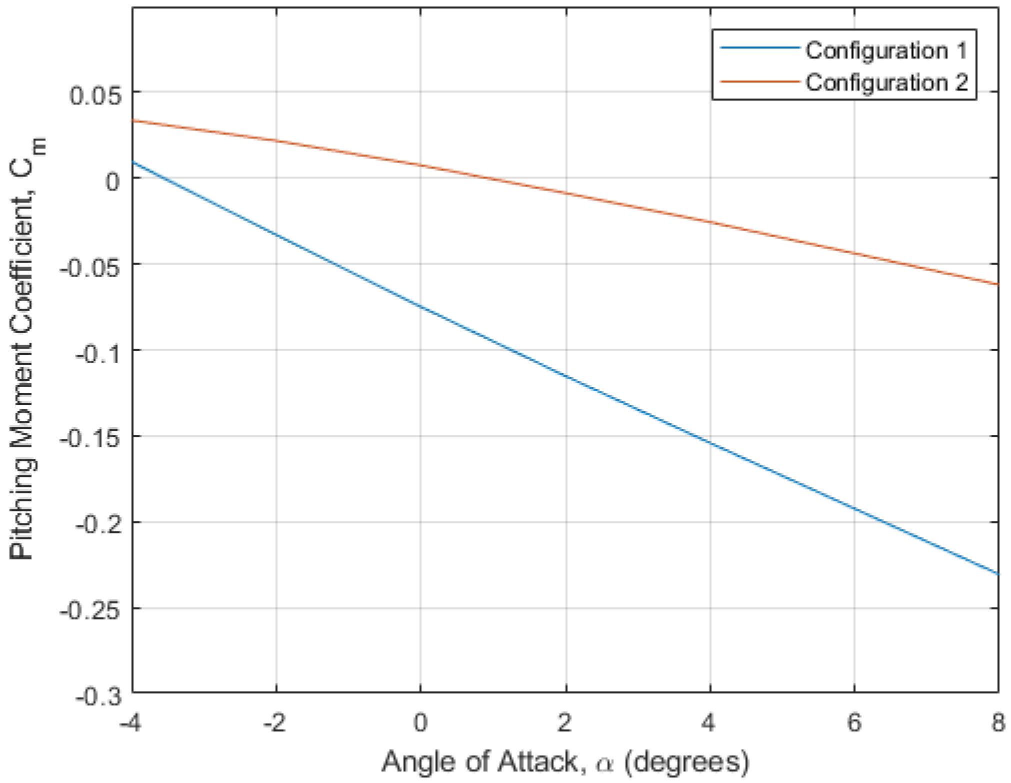

Figure 2: Visual analysis of Digital Datcom pitching moment coefficients.

Creating Flight Vehicle Simulation

Once we determine aerodynamic stability and control derivatives, we can build an open-loop plant model to evaluate the aircraft longitudinal dynamics. Once the model is complete, we can show it to colleagues, including those who do not have Simulink® software, by using Simulink® Report Generator™ software to export the model to a Web view. A Web view is an interactive HTML replica of the model that lets you navigate model hierarchy and check the properties of subsystems, blocks, and signals.

A typical plant model includes the following components:

- **Equations of motion**: calculate vehicle position and attitude from forces and moments
- **Forces and moments**: calculate aerodynamic, gravity, and thrust forces and moments
- **Actuator positions**: calculate displacements based on actuator commands
- **Environment**: include environmental effects of wind disturbances, gravity, and atmosphere
- **Sensors**: model the behavior of the measurement devices

We can implement most of this functionality using Aerospace Blockset™ blocks. This model highlights subsystems containing Aerospace Blockset blocks in orange. It highlights Aerospace Blockset blocks in red.

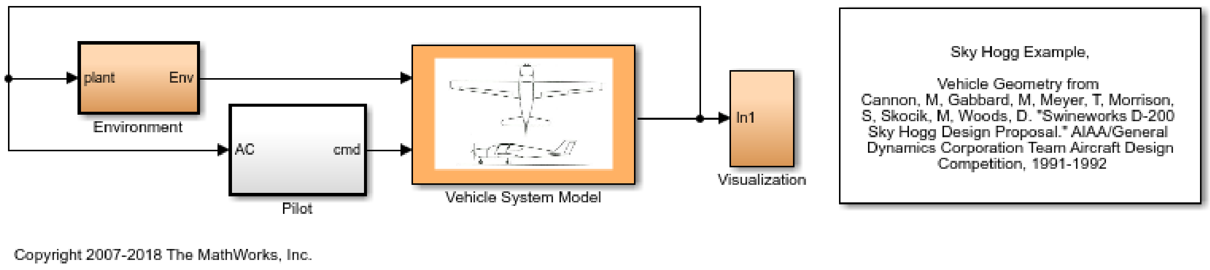
plant
Env
Environment
AC
cmd
Pilot
Vehicle System Model
In1
Visualization
Sky Hogg Example,
Vehicle Geometry from Cannon, M, Gabbard, M, Meyer, T, Morrison, S, Skocik, M, Woods, D. "Swineworks D-200 Sky Hogg Design Proposal." AIAA/General Dynamics Corporation Team Aircraft Design Competition, 1991-1992
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Figure 3: Top Level of Lightweight Aircraft Model

We begin by building a plant model using a 3DOF block from the Equations of Motion library in the Aerospace Blockset library (Figure 4). This model will help us determine whether the flight vehicle is longitudinally stable and controllable. We design our subsystem to have the same interface as a six degrees-of-freedom (DOF) version. When we are satisfied with three DOF performance, stability, and controllability, we can implement the six DOF version, iterating on the other control surface geometries until we achieve the desired behavior from the aircraft.

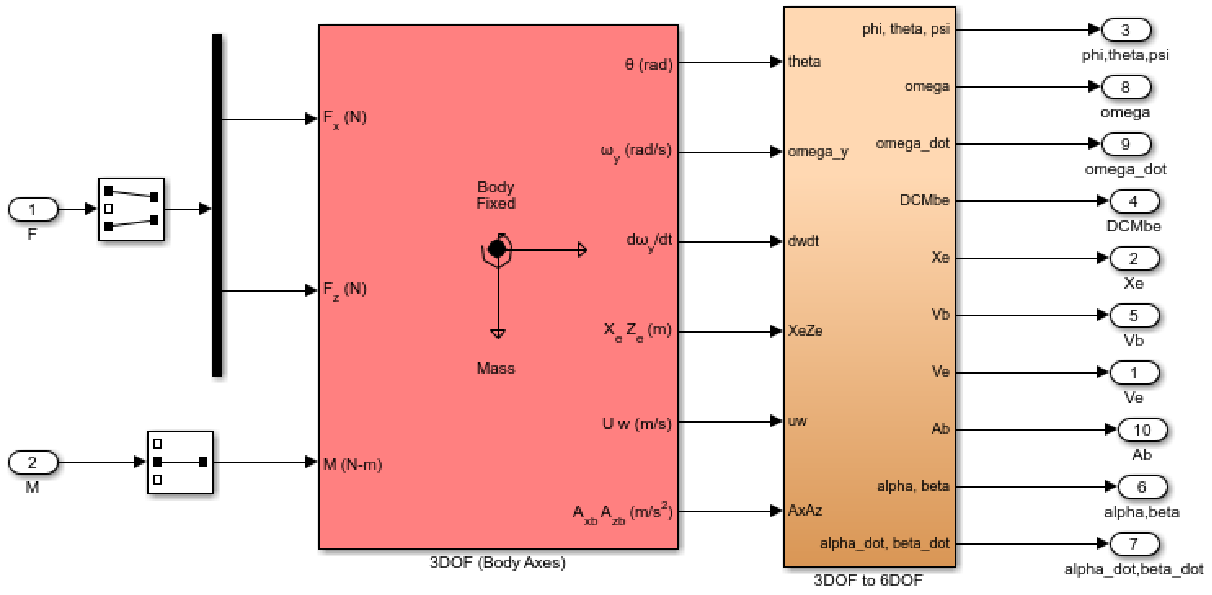
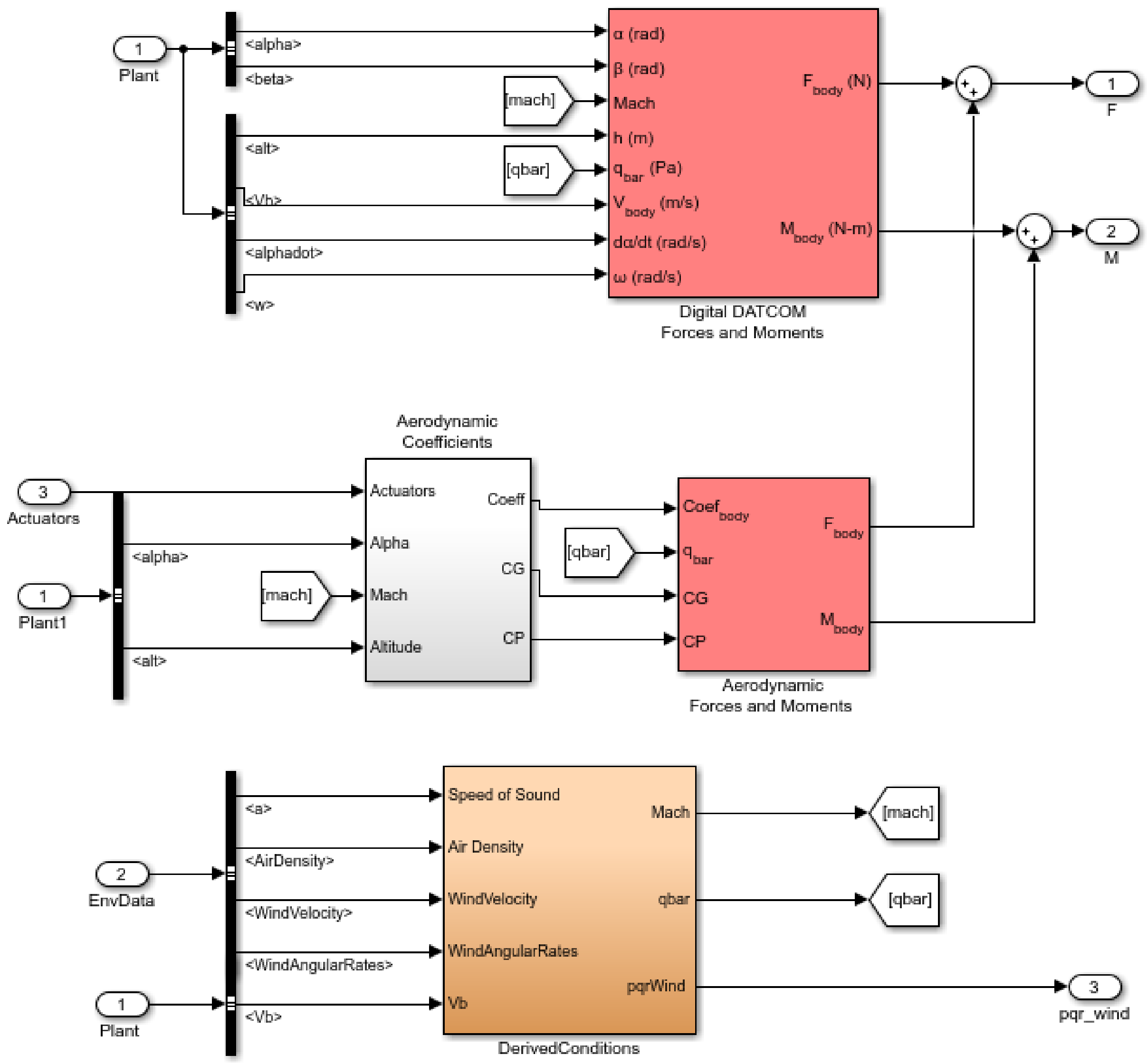


Figure 4: Equations of Motion implemented using 3DoF Euler block from the Aerospace Blockset library.

To calculate the aerodynamic forces and moments acting on our vehicle, we use a Digital Datcom Forces and Moments block from the Aerospace Blockset library (Figure 5). This block uses a structure that Aerospace Toolbox creates when it imports aerodynamic coefficients from Digital Datcom.

For some Digital Datcom cases, dynamic derivative have values for only the first angle of attack. The missing data points can be filled with the values for the first angle of attack, since these derivatives are independent of angle of attack. To see example code of how to fill in missing data in Digital Datcom data points, you can examine the asbPrepDatcom function.



Aerodynamics model may add landing gear and ground effects at a later time.

Figure 5: Aerodynamic Forces and Moments implemented in part with the Aerospace Blockset Digital Datcom Forces and Moment block.

We also use Aerospace Blockset blocks to create actuator, sensor, and environment models (Figures 6, 7, and 8, respectively). **Note**: In addition to creating the following parts of the model, we use standard Aerospace Blockset blocks to ensure that we convert from body axes to wind axes and back correctly.

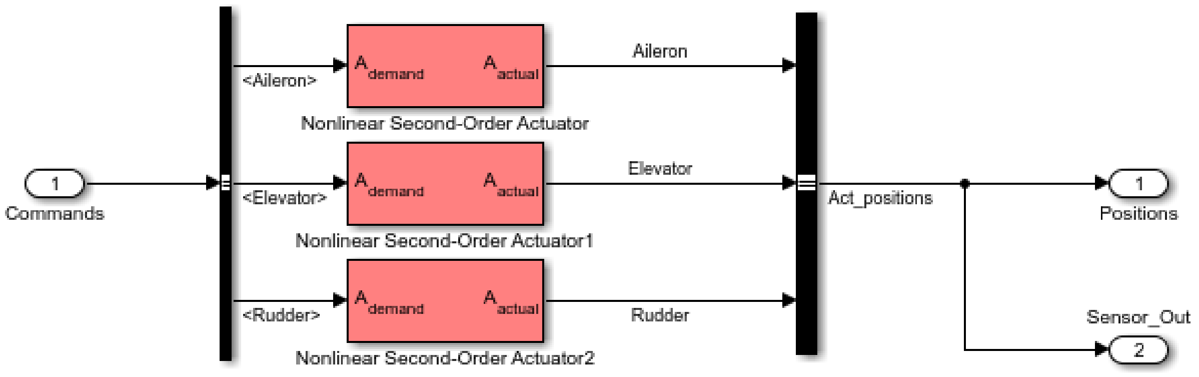


Figure 6: Implementation of actuator models using Aerospace Blockset blocks.

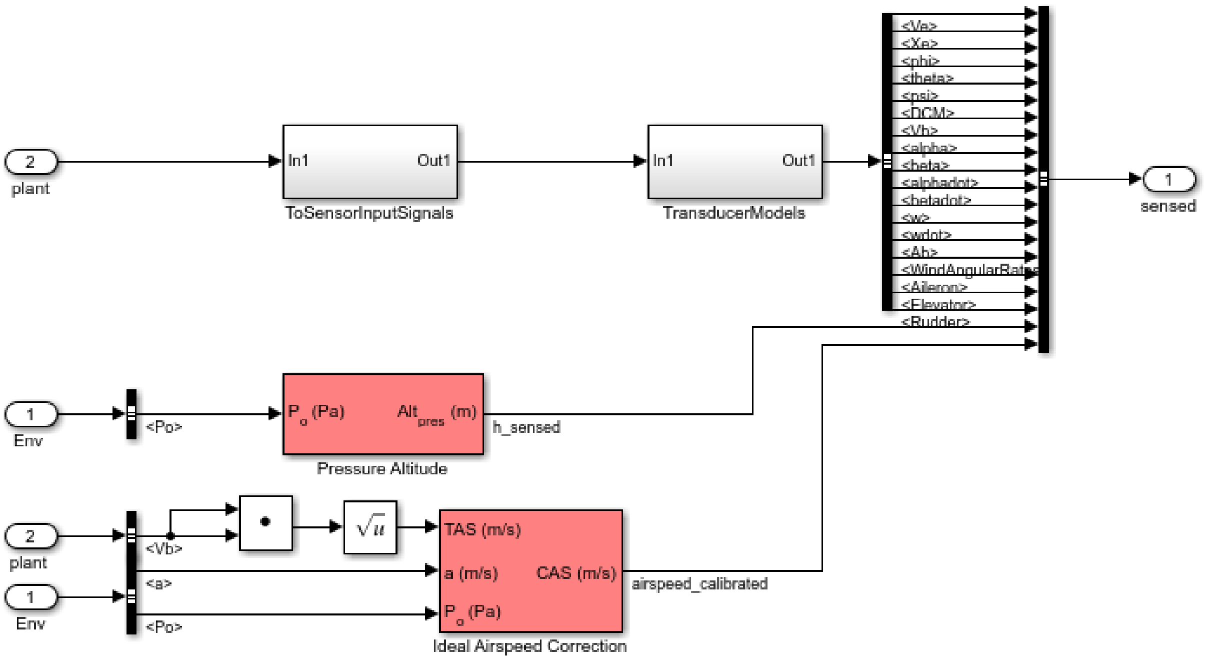


Figure 7: Implementation of flight sensor model using Aerospace Blockset blocks.

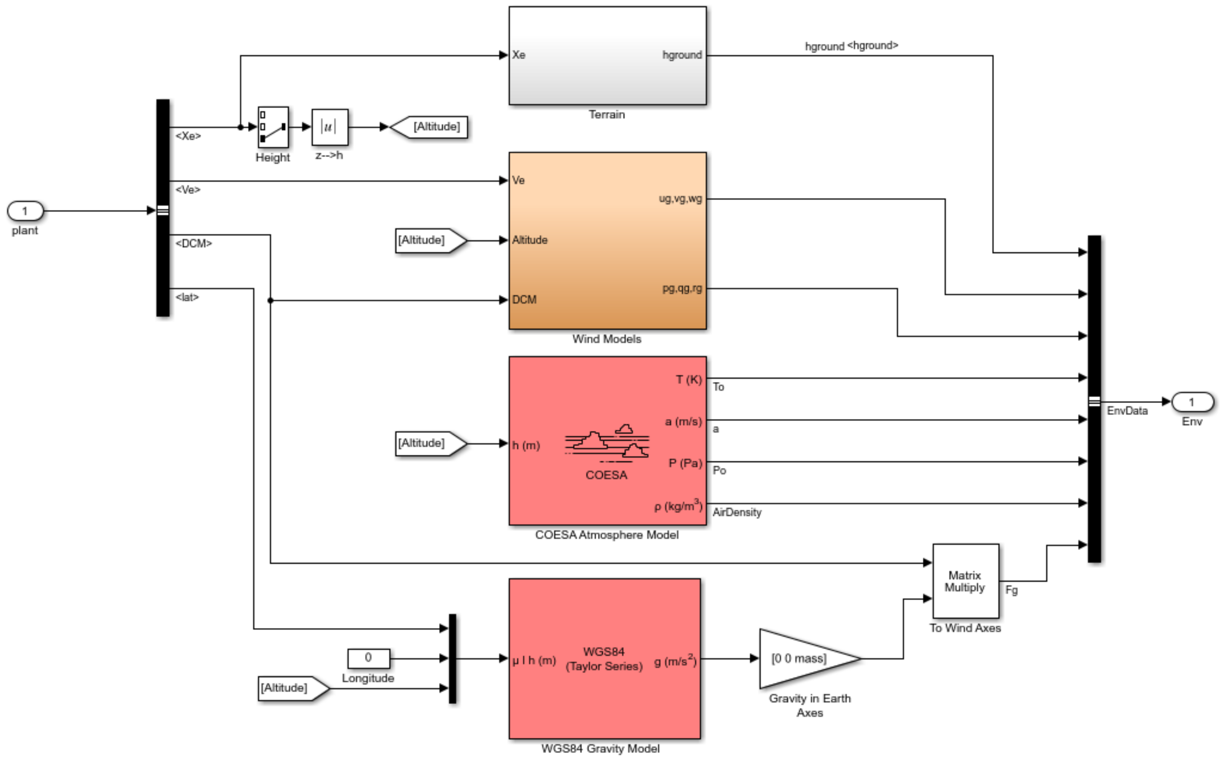


Figure 8: Environmental effect of wind, atmosphere, and gravity using Aerospace Blockset blocks.

Designing Flight Control Laws

Once we have created the Simulink plant model, we design a longitudinal controller that commands elevator position to control altitude. The traditional two-loop feedback control structure chosen for this design (Figure 9) has an outer loop for controlling altitude (compensator C1 in yellow) and an inner loop for controlling pitch angle (compensator C2 in blue). Figure 10 shows the corresponding controller configuration in our Simulink model.

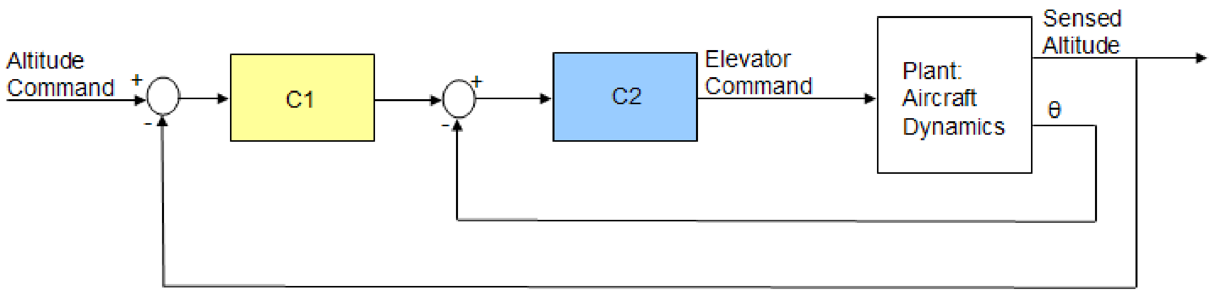


Figure 9: Structure of the longitudinal controller.

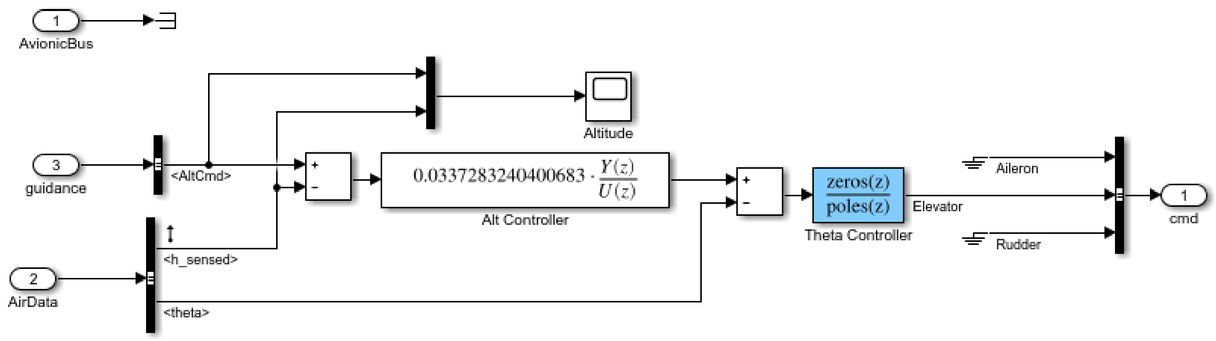


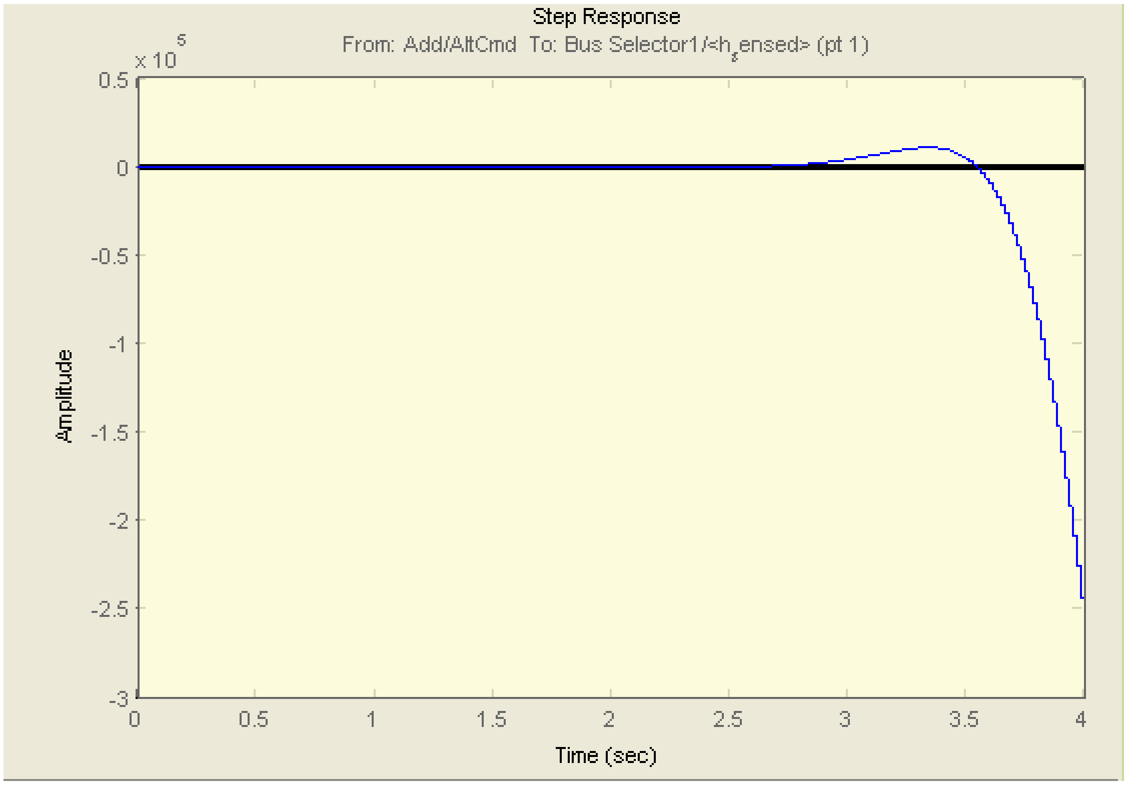
Figure 10: Longitudinal controller in Simulink model.

With Simulink® Control Design™ software, we can tune the controllers directly in Simulink using a range of tools and techniques.

Using the Simulink Control Design interface, we set up the control problem by specifying:

- Two controller blocks
- Closed-loop input or altitude command
- Closed-loop output signals or sensed altitude
- Steady-state or trim condition.

Using this information, Simulink Control Design software automatically computes linear approximations of the model and identifies feedback loops to be used in the design. To design the controllers for the inner and outer loops, we use root locus and bode plots for the open loops and a step response plot for the closed-loop response (Figure 11).



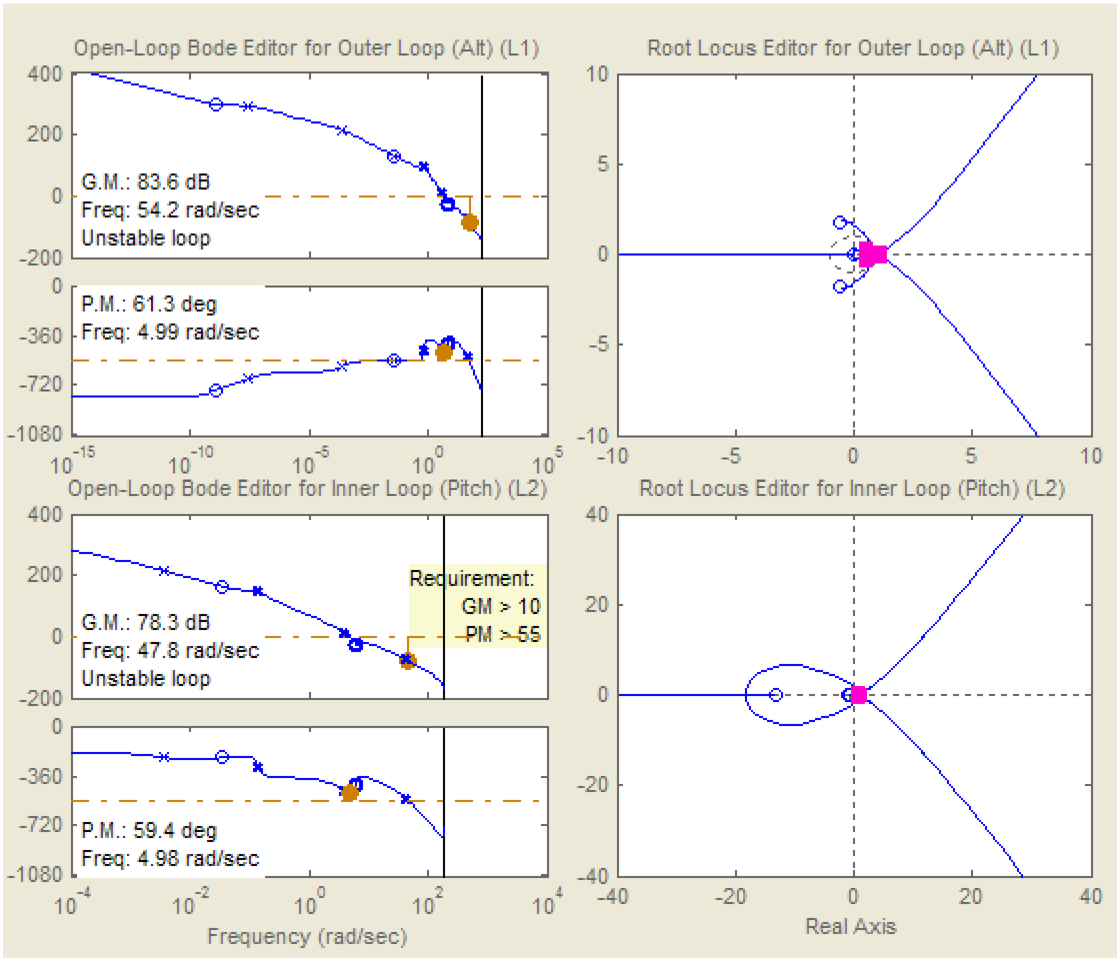


Figure 11: Design plots before controller tuning.

We then interactively tune the compensators for the inner and outer loops using these plots. Because the plots update in real time as we tune the compensators, we can see the coupling effects that these changes have on other loops and on the closed-loop response.

To make the multi-loop design more systematic, we use a sequential loop closure technique. This technique lets us incrementally take into account the dynamics of the other loops during the design process. With Simulink Control Design, we configure the inner loop to have an additional loop opening at the output of the outer loop controller

(C1 in Figure 12). This approach decouples the inner loop from the outer loop and simplifies the inner-loop controller design. After designing the inner loop, we design the outer loop controller. Figure 13 shows the resulting tuned compensator design at the final trimmed operating point.

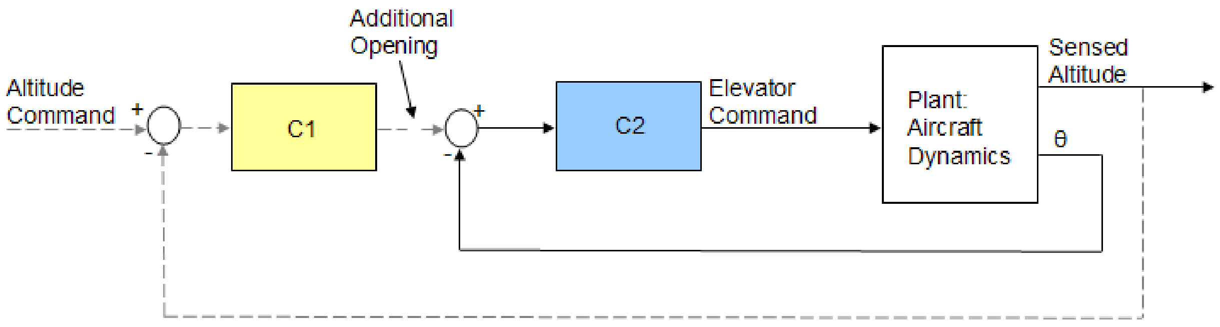
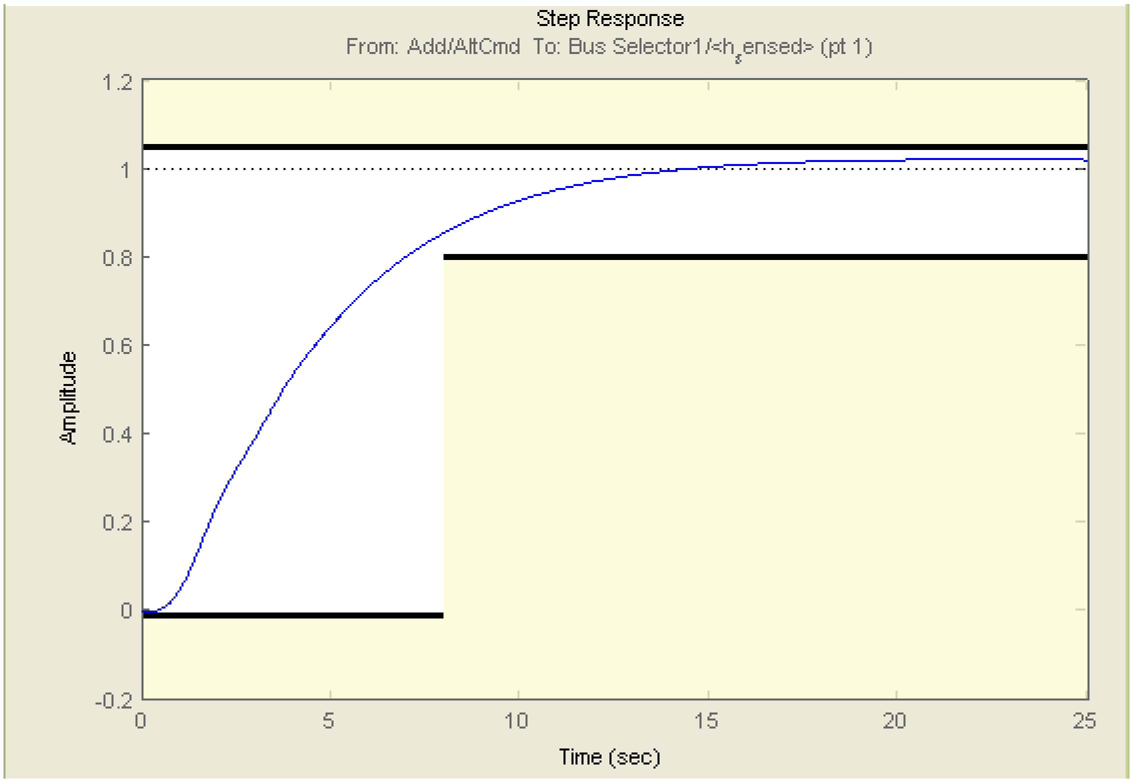


Figure 12: Block diagram of inner loop, isolated by configuring an additional loop opening.


Step Response
From: Add/AltCmd To: Bus Selector1/<h_sensed> (pt 1)
Amplitude
Time (sec)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
5
10
15
20
25

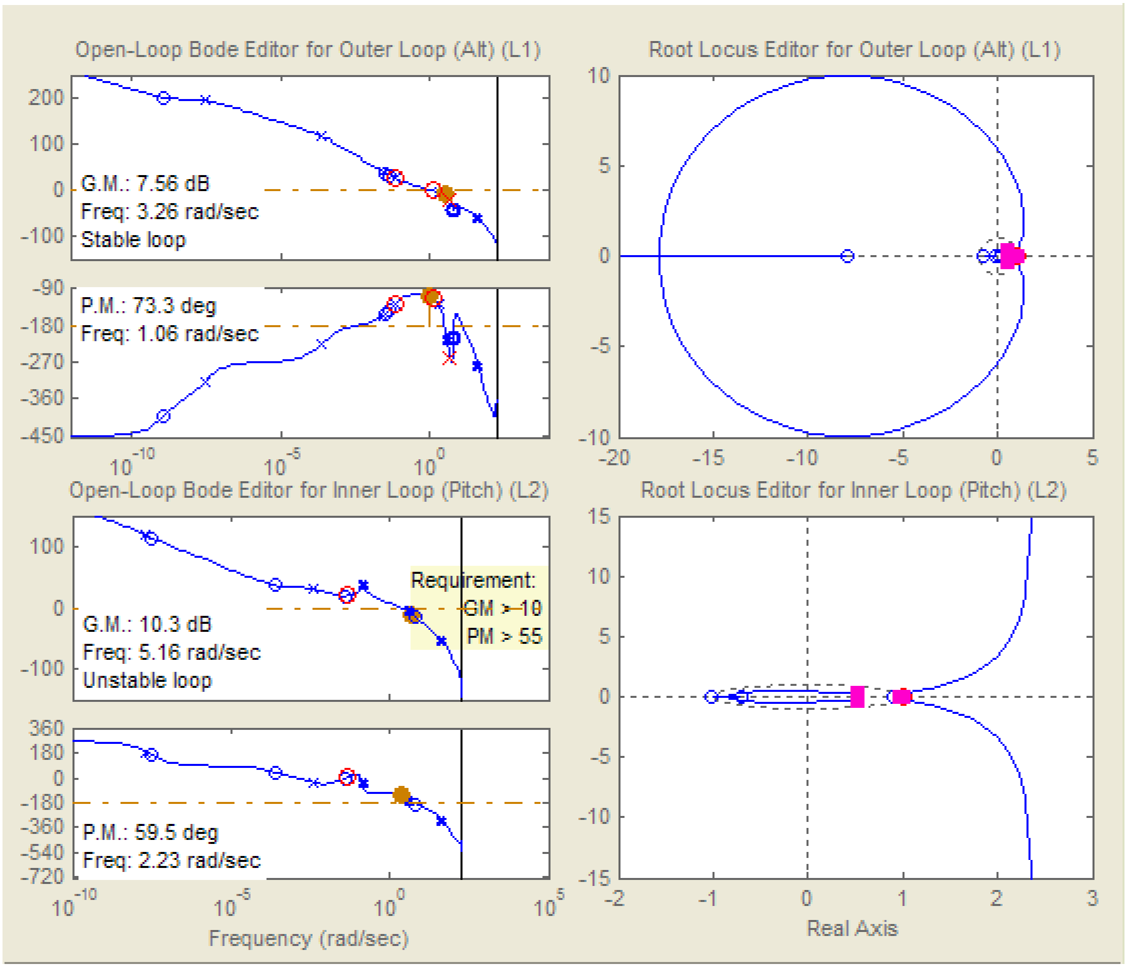


Figure 13: Design plots at trim condition after controller tuning.

You can tune the controller in Simulink Control Design software in several ways. For example:

- You can use a graphical approach, and interactively move controller gain, poles, and zeros until you get a satisfactory response (Figure 13).
- You can use Simulink® Design Optimization™ software within Simulink Control Design software to tune the controller automatically.

After you specify frequency domain requirements, such as gain margin and phase margin and time domain requirements, Simulink Design Optimization software automatically tunes controller parameters to satisfy those requirements. Once we have developed an acceptable controller design, the control blocks in the Simulink model are automatically updated. See the examples Getting Started With The Control System Designer in Control Systems Toolbox examples and Tune Simulink Blocks Using Compensator Editor in Simulink Control Design examples for more information on tuning controllers.

We can now run our nonlinear simulation with flight control logic and check that the controller performance is acceptable. Figure 15 shows the results from a closed-loop simulation of our nonlinear Simulink model for a requested altitude increase from 2,000 meters to 2,050 meters starting from a trimmed operating point. Although a pilot requests a step change in altitude, the actual controller altitude request rate is limited to provide a comfortable and safe ride for the passengers.

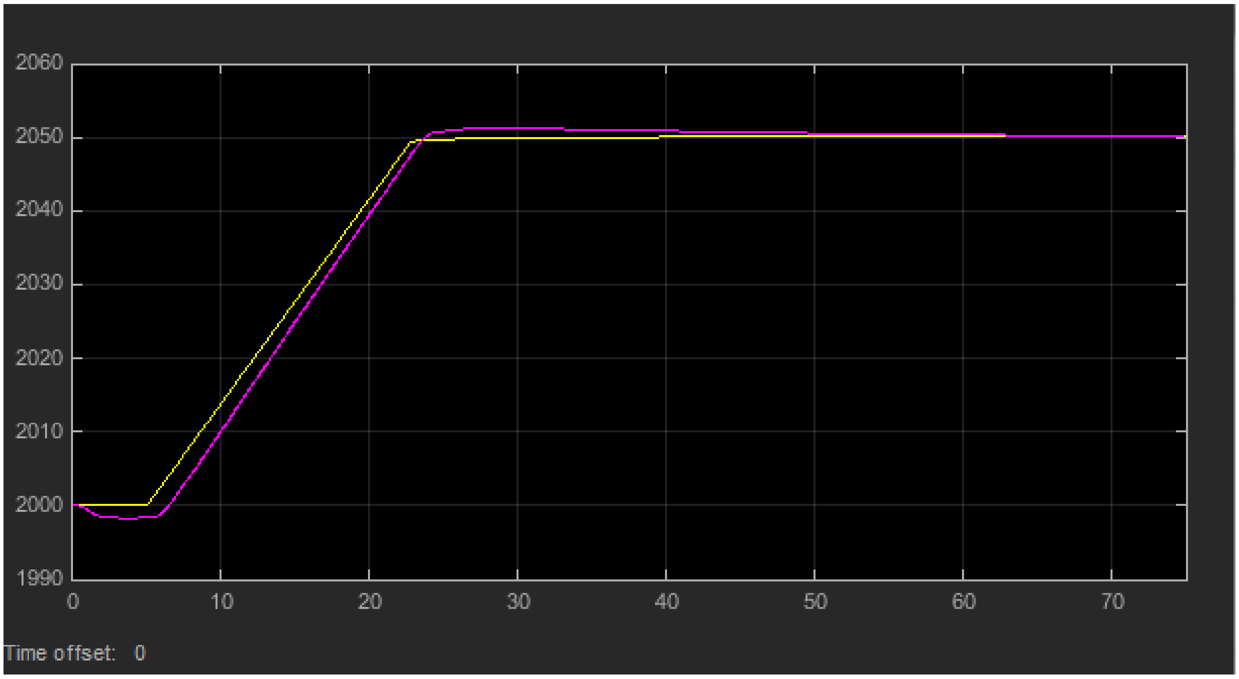


Figure 14: The final check is to run nonlinear simulation with our controller design and check that altitude (purple) tracks altitude request (yellow) in the stable and acceptable fashion.

We can now use these simulation results to determine whether our aircraft design meets its performance requirements. The requirement called for the climb rate to be above 2 m/s. As we can see, the aircraft climbed from 2,000 to 2,050 meters in less than 20 seconds, providing a climb rate higher than 2.5 m/s. Therefore, this particular geometric configuration and controller design meets our performance requirements.

In addition to traditional time plots, we can visualize simulation results using the Aerospace Blockset interface to FlightGear (Figure 15).

Figure 15: Visualizing simulation results using the Aerospace Blockset interface to FlightGear.

We can also use the Aerospace Toolbox interface to FlightGear to play back MATLAB data using either simulation results or actual flight test data.

Completing the Design Process

The next steps involve

- Building a hardware-in-the-loop system to test real-time performance

- Building the actual vehicle hardware and software
- Conducting the flight test
- Analyzing and visualizing the flight test data.

Because these steps are not the focus of this example, we will not describe them here. Instead, we will simply mention that they can all be streamlined and simplified using the appropriate tools, such as Embedded Coder®, Simulink® Real-Time™, and Aerospace Toolbox software.

Summary

In this example we showed how to:

- Use Digital Datcom and Aerospace Toolbox software to rapidly develop the initial design of your flight vehicle and evaluate different geometric configurations.
- Use Simulink and Aerospace Blockset software to rapidly create a flight simulation of your vehicle.
- Use Simulink Control Design software to design flight control laws.

This approach enables you to determine the optimal geometrical configuration of your vehicle and estimate its performance and handling qualities well before any hardware is built, reducing design costs and eliminating errors. In addition, using a single tool chain helps facilitate communication among different groups and accelerates design time.

References

[1] Cannon, M, Gabbard, M, Meyer, T, Morrison, S, Skocik, M, Woods, D. "Swineworks D-200 Sky Hogg Design Proposal." AIAA®/General Dynamics Corporation Team Aircraft Design Competition, 1991-1992.

[2] Turvesky, A., Gage, S., and Buhr, C., "Accelerating Flight Vehicle Design", MATLAB® Digest, January 2007.

[3] Turvesky, A., Gage, S., and Buhr, C., "Model-based Design of a New Lightweight Aircraft", AIAA paper 2007-6371, AIAA Modeling and Simulation Technologies Conference and Exhibit, Hilton Head, South Carolina, Aug. 20-23, 2007.

Multiple Aircraft with Collaborative Control

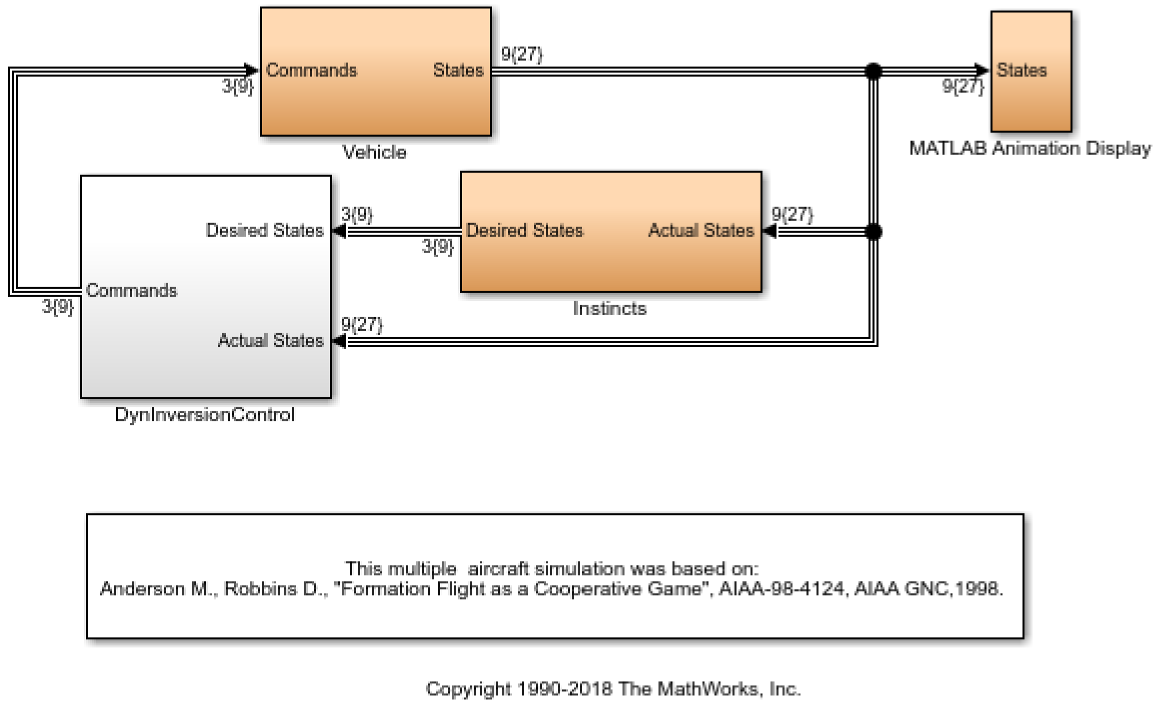
This model shows the simulation of multiple aircraft in formation flight, with emphasis on the necessary requirements and the realized benefits in making the simulation vectorized so that it can easily be updated for an arbitrary number of vehicles. To perform their avoidance task, this set of aircraft uses cooperative control.

This model uses color coding to aid in locating Aerospace Blockset™ blocks. The red blocks are Aerospace Blockset blocks, the orange blocks are subsystems that contain additional Aerospace Blockset blocks, and the white blocks are Simulink® blocks.

The simulation uses Simulink and Aerospace Blockset software, which allow for a hierarchal block diagram representation to include the control laws, vehicle models and visualization.

The MATLAB® Animation Display subsystem contains the MATLAB® Animation block from Aerospace Blockset to visualize the simulation. There are three types of bodies. The blue body is the first body in the formation. It is the target of the camera. The second and third bodies in the formation are red. The two black bodies represent the obstacles.

The basis of this simulation comes from previous research performed in the study of aircraft formation flight in the context of cooperative game theory and the natural aggregate motion of flocking birds, schooling fish, and the herding of land animals.



This multiple aircraft simulation was based on:
Anderson M., Robbins D., "Formation Flight as a Cooperative Game", AIAA-98-4124, AIAA GNC,1998.

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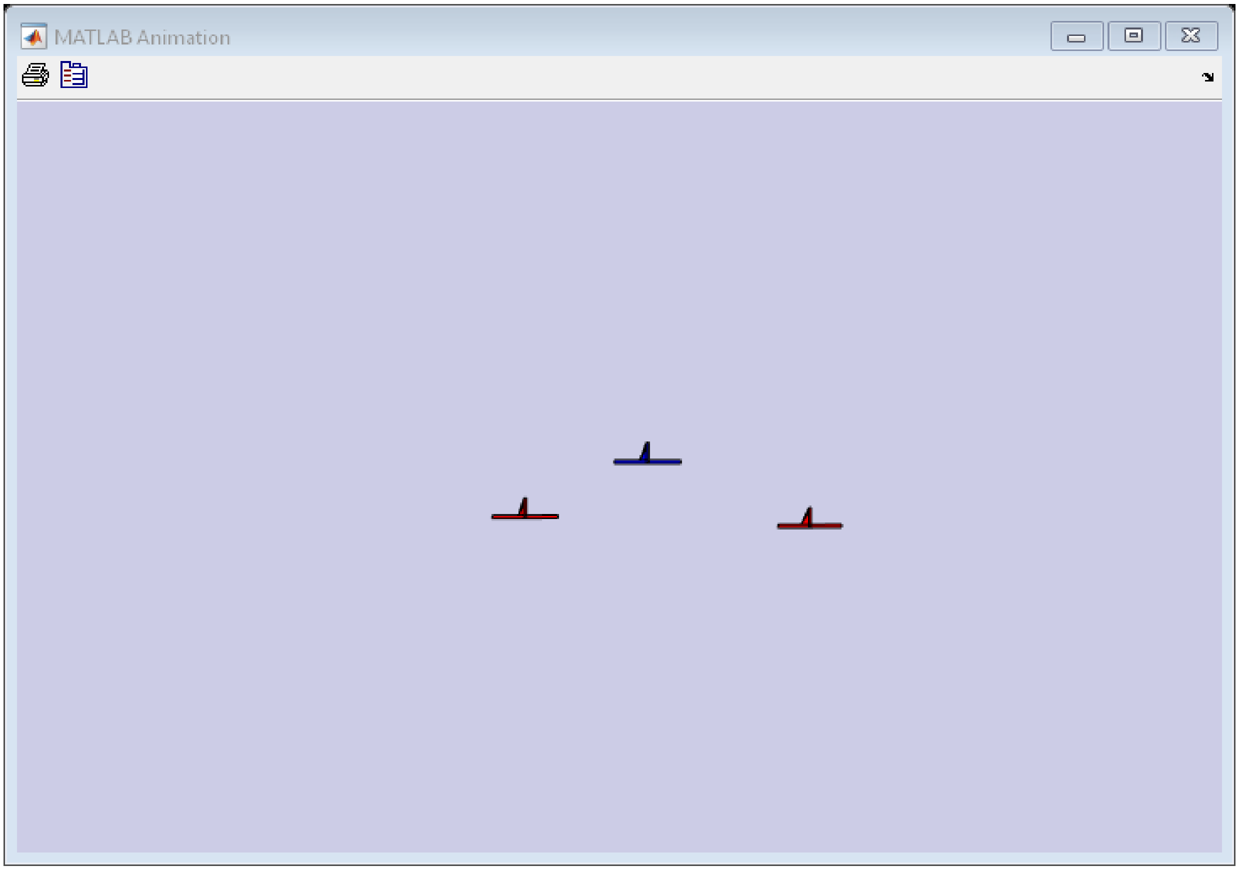

MATLAB Animation

HL-20 with Flight Instrumentation Blocks

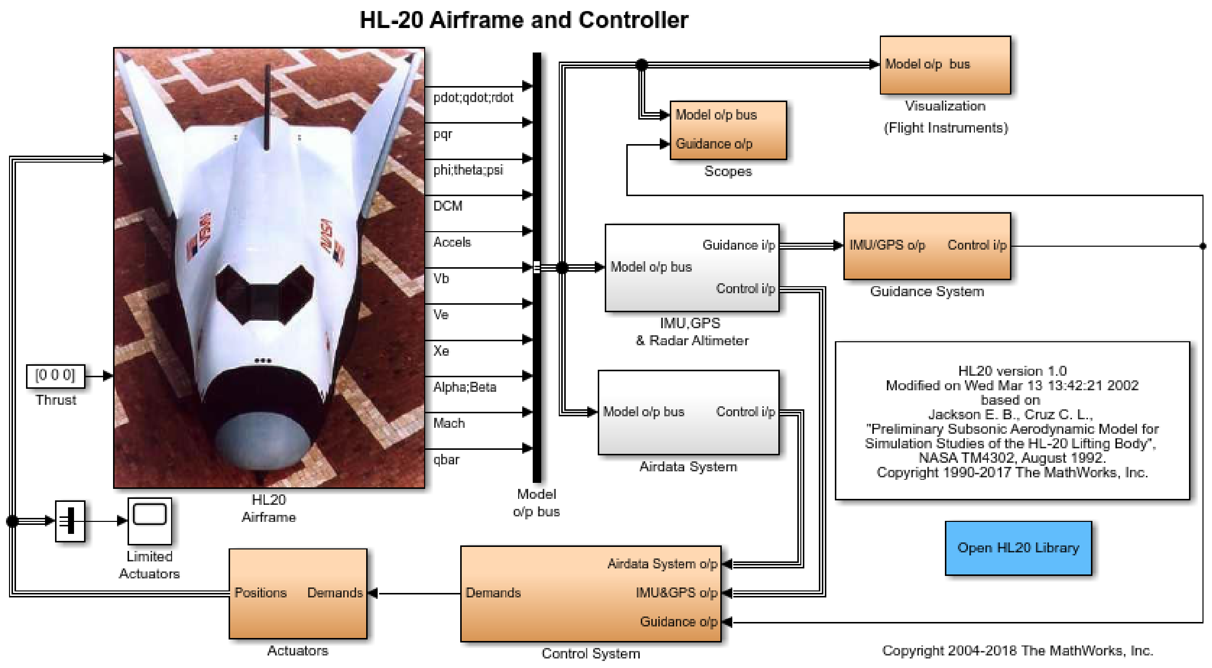
This model shows NASA's HL-20 lifting body and controller modeled in Simulink® and Aerospace Blockset™ software. This model simulates approach and landing flight phases using an auto-landing controller. The Visualization subsystem uses aircraft-specific gauges from the Aerospace Blockset™ Flight Instrumentation library.

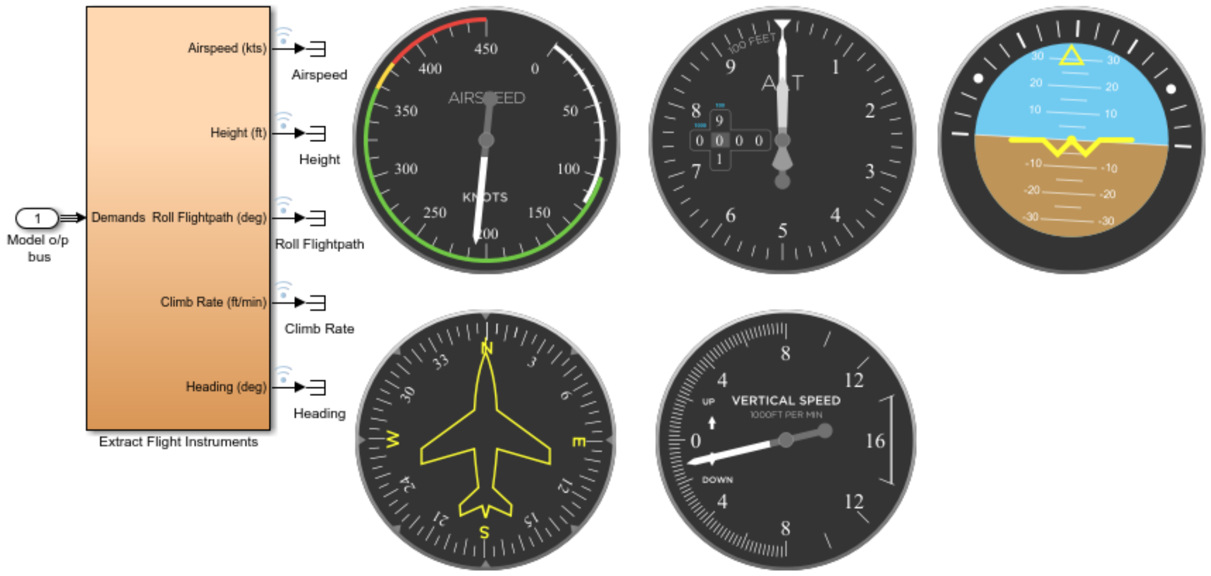
The HL-20 also known as personnel launch system (PLS) is a lifting body re-entry vehicle that was designed to complement the Space Shuttle orbiter. Designed to carry up to ten people and very little cargo[1], the HL-20 lifting body was to be placed in orbit either launched vertically via booster rockets or transported in the payload bay of the Space Shuttle orbiter. HL-20 lifting body was designed to have a powered deorbiting accomplished with an onboard propulsion system while its reentry was to be nose-first, horizontal and unpowered.

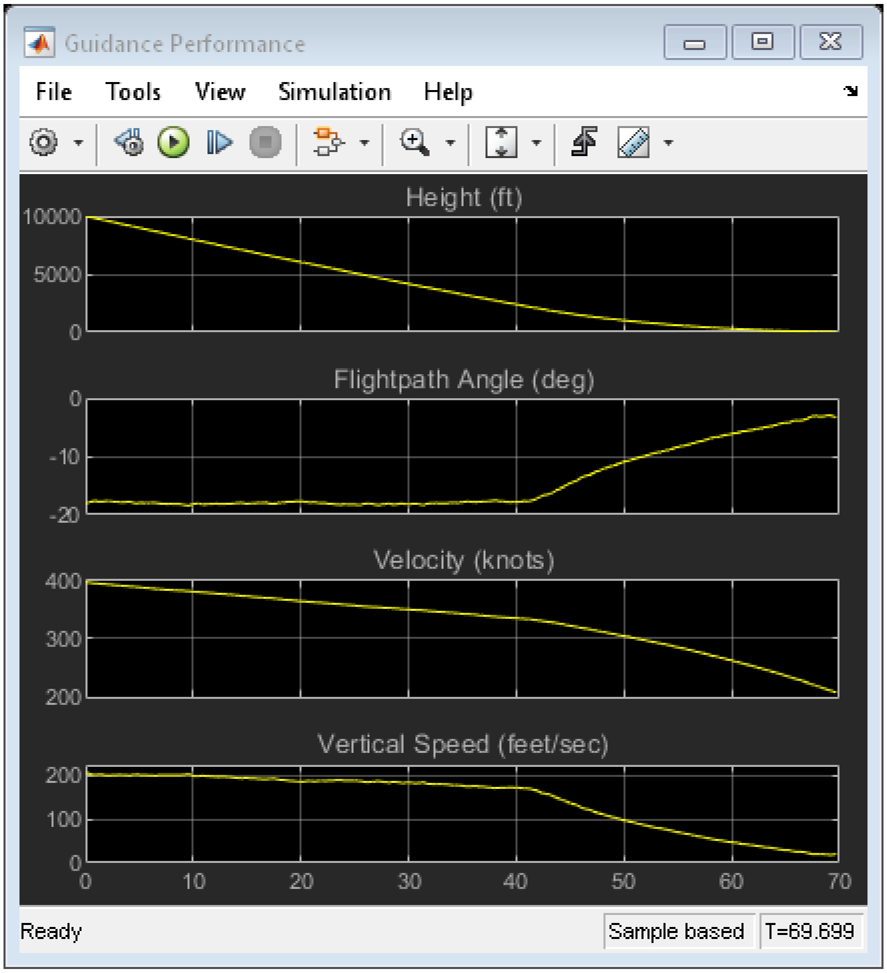
The HL-20 lifting body was developed as a low cost solution for getting to and from low Earth orbit. The proposed benefits of the HL-20 were reduced operating costs due to rapid turnaround between landing and launch, improved flight safety, and ability to land conventionally on runways. Potential scenarios for the HL-20 were orbital rescue of stranded astronauts, International Space Station crew exchange if the Space Shuttle orbiter was not available, observation missions, and satellite servicing missions.

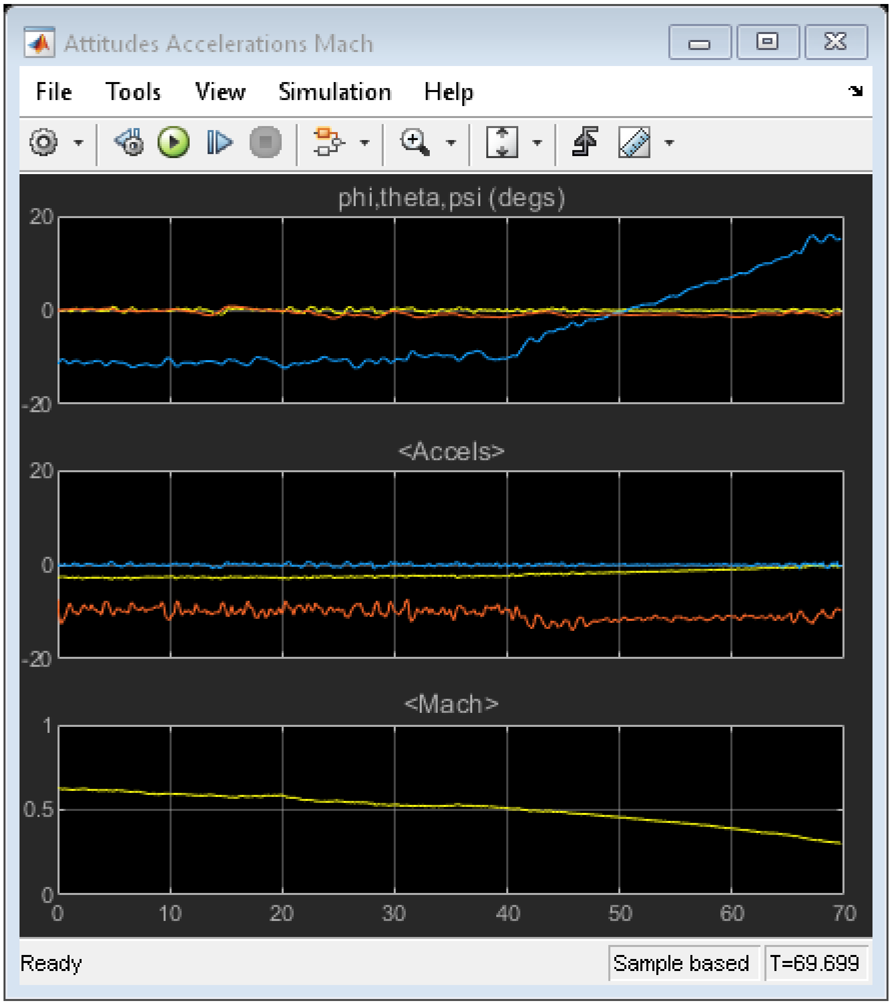
Additional information about HL-20

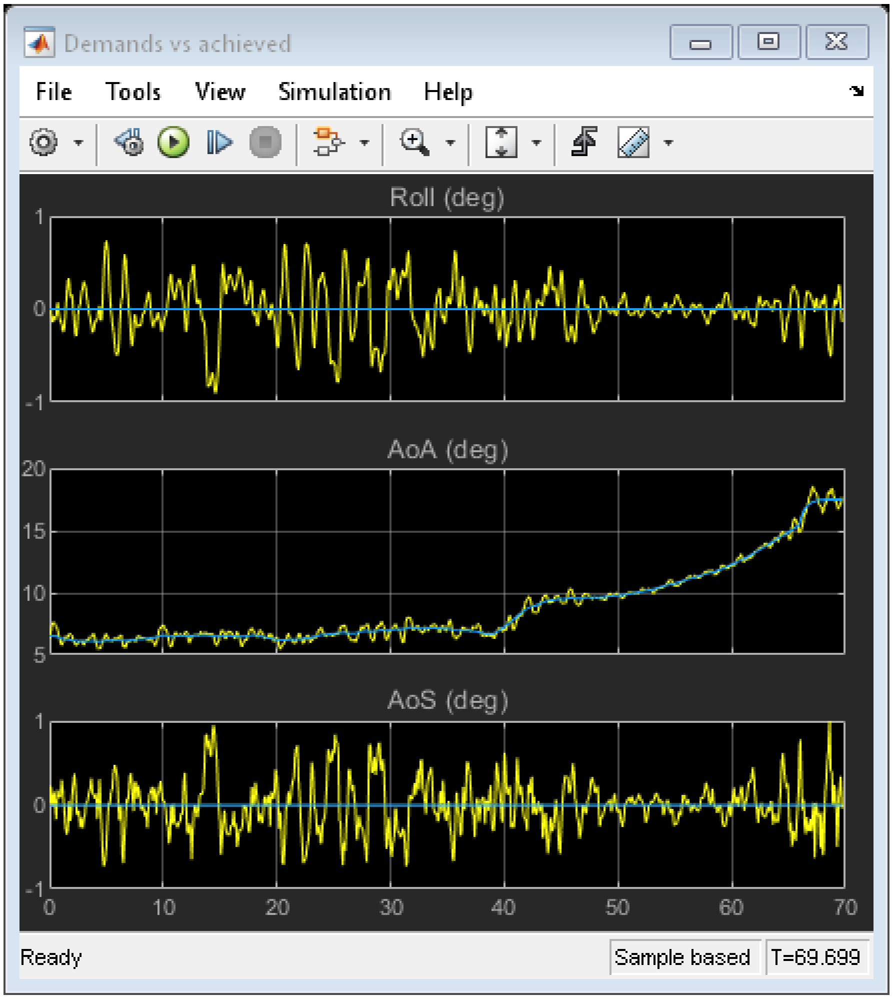
[1] Jackson E. B., Cruz C. L., "Preliminary Subsonic Aerodynamic Model for Simulation Studies of the HL-20 Lifting Body," NASA TM4302 (August 1992)

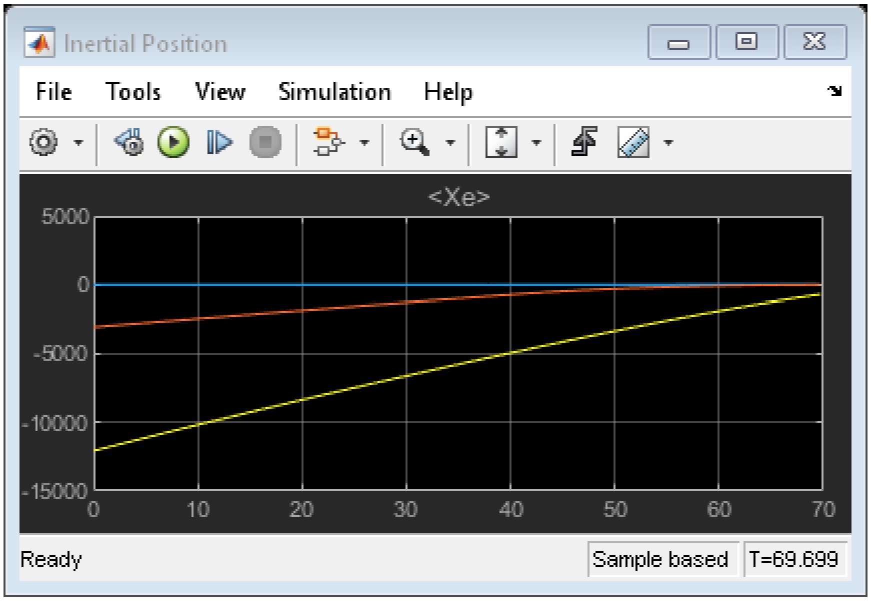

HL-20 Airframe and Controller
pdot;qdot;rdot
pqr
phi;theta;psi
DCM
Accels
Vb
Ve
Xe
Alpha;Beta
Mach
qbar
HL20
Airframe
[0 0 0]
Thrust
Limited
Actuators
Model
o/p bus
Model o/p bus
Visualization
(Flight Instruments)
Model o/p bus
Guidance o/p
Scopes
Guidance i/p
Model o/p bus
Control i/p
IMU,GPS
& Radar Altimeter
IMU/GPS o/p
Control i/p
Guidance System
Model o/p bus
Control i/p
Airdata System
HL20 version 1.0
Modified on Wed Mar 13 13:42:21 2002
based on
Jackson E. B., Cruz C. L.,
"Preliminary Subsonic Aerodynamic Model for
Simulation Studies of the HL-20 Lifting Body",
NASA TM4302, August 1992.
Copyright 1990-2017 The MathWorks, Inc.
Open HL20 Library
Positions
Demands
Actuators
Demands
Airdata System o/p
IMU&GPS o/p
Guidance o/p
Control System
Copyright 2004-2018 The MathWorks, Inc.


1
Model o/p bus
Demands
Airspeed (kts)
Height (ft)
Roll Flightpath (deg)
Climb Rate (ft/min)
Heading (deg)
Extract Flight Instruments
Airspeed
Height
Roll Flightpath
Climb Rate
Heading
AIRSPEED
KNOTS
ALT
100 FEET
VERTICAL SPEED
1000FT PER MIN
UP
DOWN


Guidance Performance
File
Tools
View
Simulation
Help
Height (ft)
10000
5000
0
Flightpath Angle (deg)
0
-10
-20
Velocity (knots)
400
300
200
Vertical Speed (feet/sec)
200
100
0
0
10
20
30
40
50
60
70
Ready
Sample based
T=69.699


Attitudes Accelerations Mach
File
Tools
View
Simulation
Help
phi,theta,psi (degs)
20
0
-20
<Accels>
20
0
-20
<Mach>
1
0.5
0
0
10
20
30
40
50
60
70
Ready
Sample based
T=69.699


Demands vs achieved
File Tools View Simulation Help
Roll (deg)
1
0
-1
AoA (deg)
20
15
10
5
AoS (deg)
1
0
-1
0 10 20 30 40 50 60 70
Ready
Sample based
T=69.699


Inertial Position
File
Tools
View
Simulation
Help
<Xe>
5000
0
-5000
-10000
-15000
0
10
20
30
40
50
60
70
Ready
Sample based
T=69.699

HL-20 with Simulink® 3D Animation™ and Flight Instrumentation Blocks

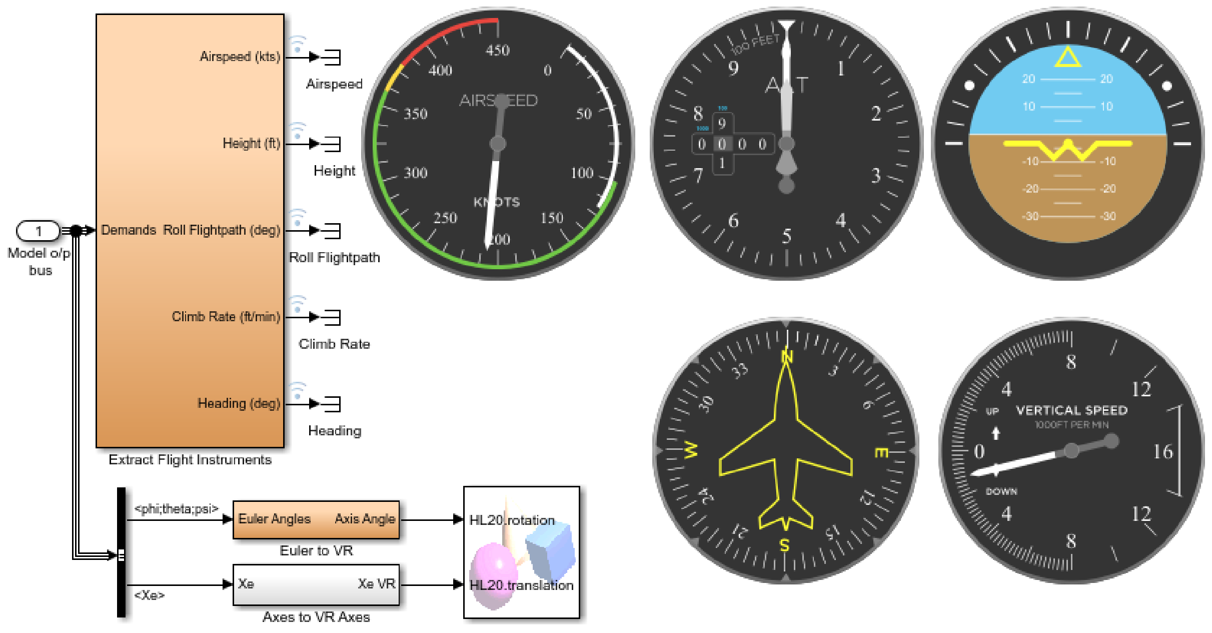
This model shows NASA's HL-20 lifting body and controller modeled in Simulink®, Aerospace Blockset™, and Simulink® 3D Animation™ software. This model simulates approach and landing flight phases using an auto-landing controller. The Visualization subsystem uses aircraft-specific gauges from the Aerospace Blockset™ Flight Instrumentation library.

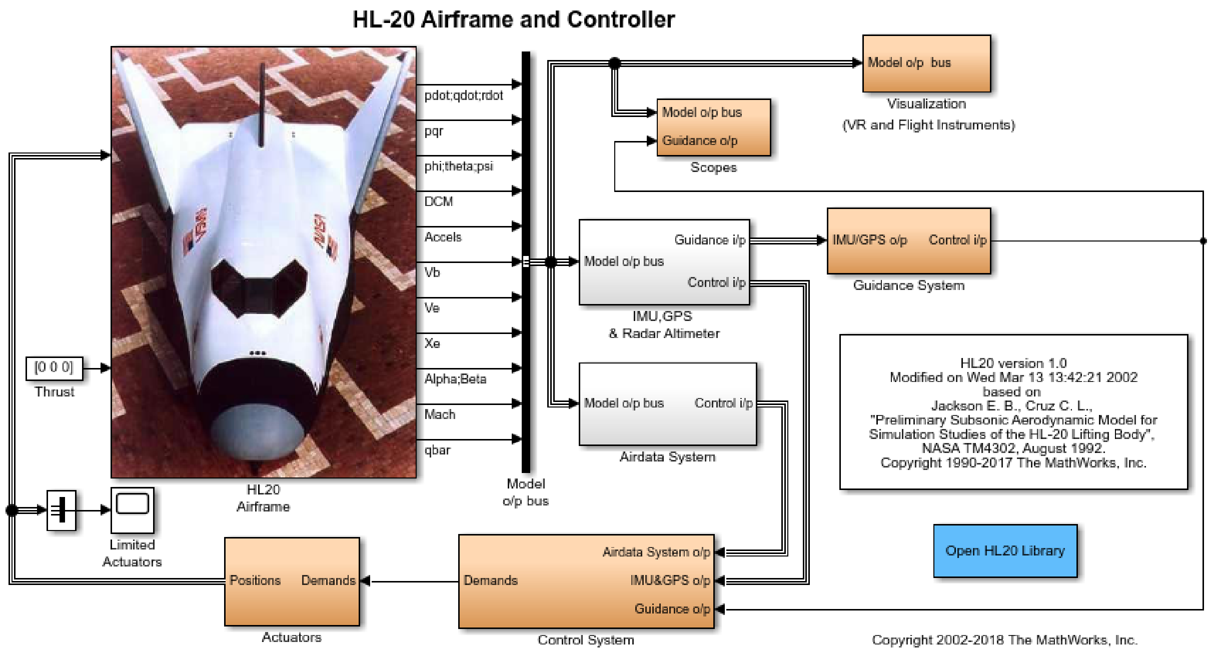
The HL-20 also known as personnel launch system (PLS) is a lifting body re-entry vehicle that was designed to complement the Space Shuttle orbiter. Designed to carry up to ten people and very little cargo[1], the HL-20 lifting body was to be placed in orbit either launched vertically via booster rockets or transported in the payload bay of the Space Shuttle orbiter. HL-20 lifting body was designed to have a powered deorbiting accomplished with an onboard propulsion system while its reentry was to be nose-first, horizontal and unpowered.

The HL-20 lifting body was developed as a low cost solution for getting to and from low Earth orbit. The proposed benefits of the HL-20 were reduced operating costs due to rapid turnaround between landing and launch, improved flight safety, and ability to land conventionally on runways. Potential scenarios for the HL-20 were orbital rescue of stranded astronauts, International Space Station crew exchange if the Space Shuttle orbiter was not available, observation missions, and satellite servicing missions.

Additional information about HL-20

[1] Jackson E. B., Cruz C. L., "Preliminary Subsonic Aerodynamic Model for Simulation Studies of the HL-20 Lifting Body," NASA TM4302 (August 1992)


Airspeed (kts)
Height (ft)
Demands Roll Flightpath (deg)
Climb Rate (ft/min)
Heading (deg)
Extract Flight Instruments
1
Model o/p bus
Airspeed
Height
Roll Flightpath
Climb Rate
Heading
<phi;theta;psi>
Euler Angles Axis Angle
Euler to VR
<Xe>
Xe Xe VR
Axes to VR Axes
HL20.rotation
HL20.translation
AIRSPEED
KNOTS
ALT
100 FEET
VERTICAL SPEED
1000FT PER MIN
UP
DOWN



HL20 version 1.0
Modified on Wed Mar 13 13:42:21 2002
based on
Jackson E. B., Cruz C. L.,
"Preliminary Subsonic Aerodynamic Model for
Simulation Studies of the HL-20 Lifting Body",
NASA TM4302, August 1992.
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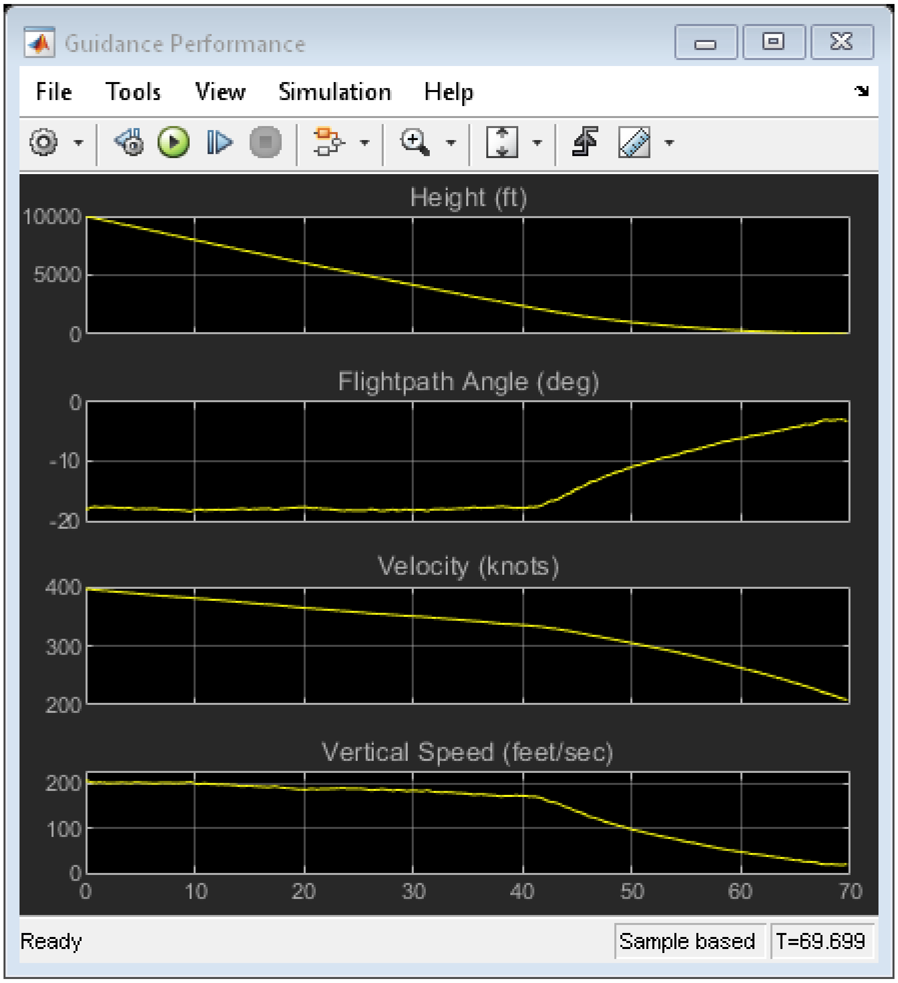
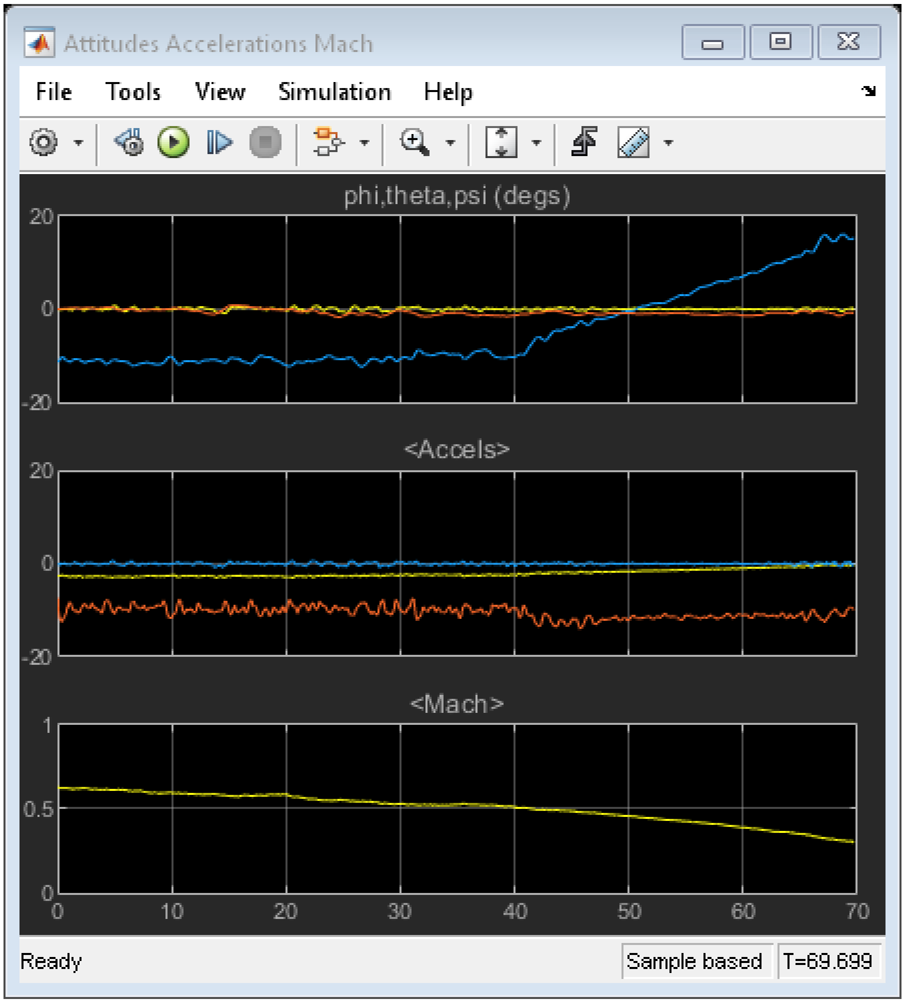
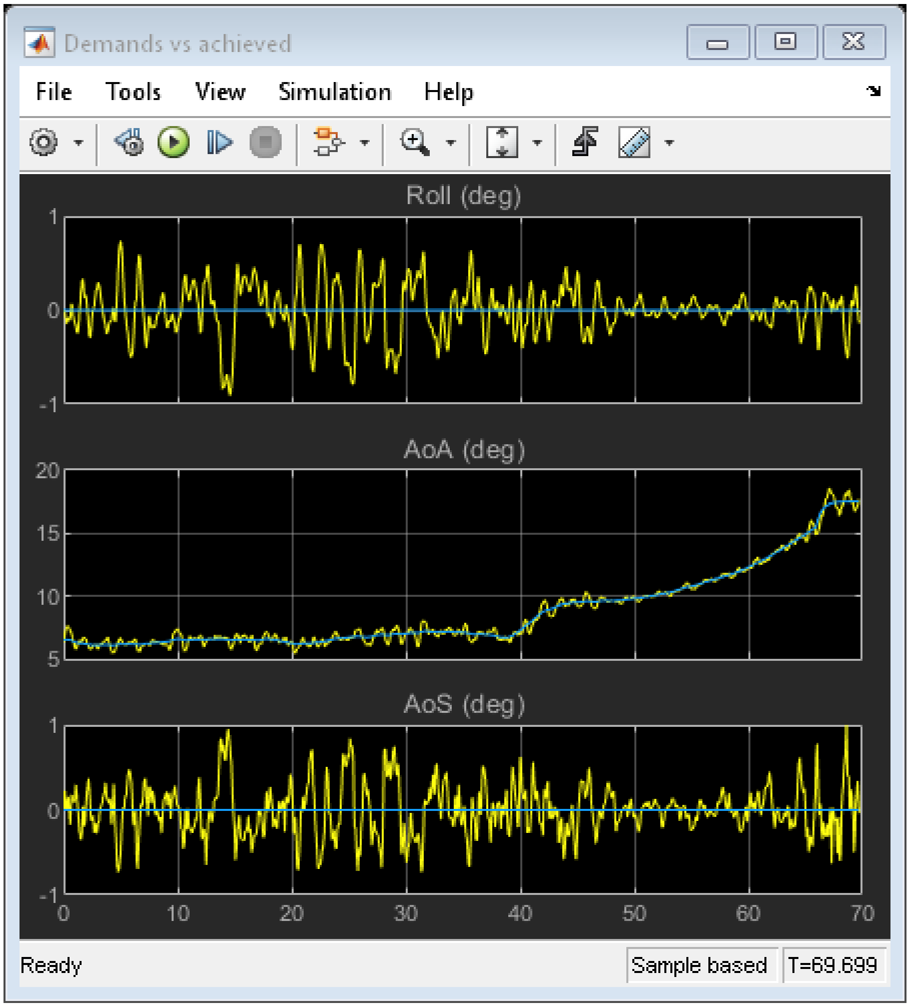
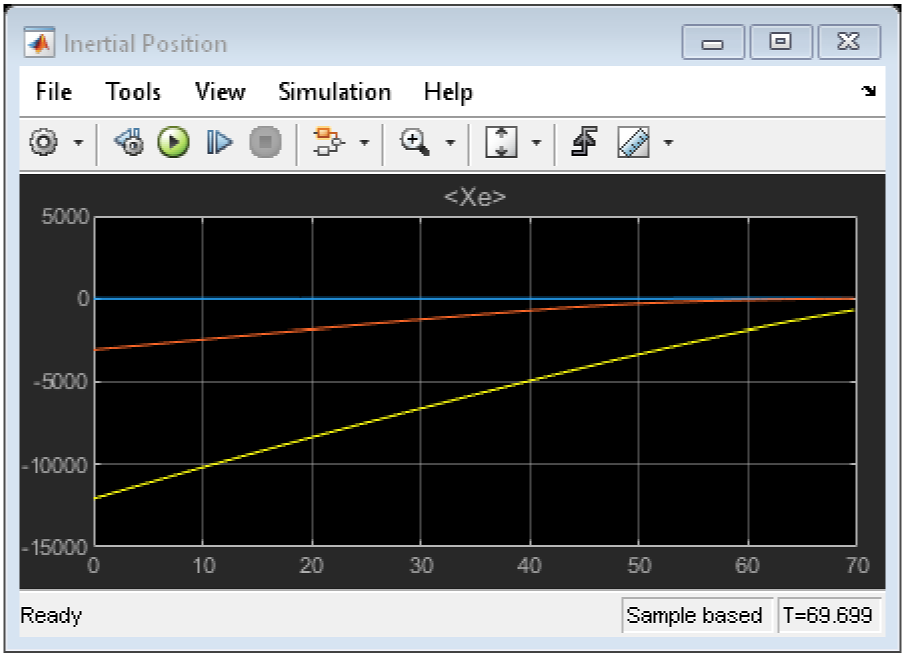
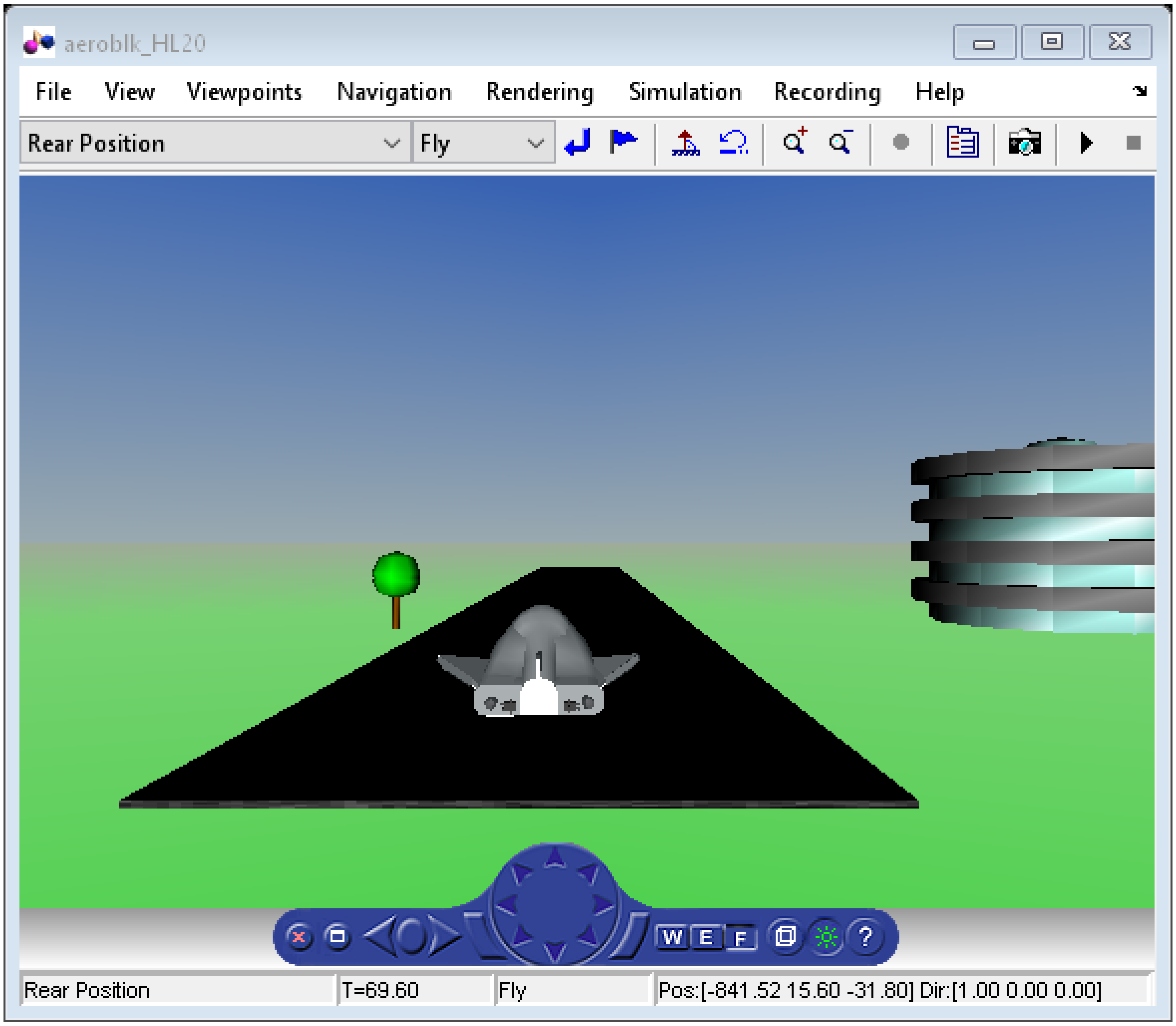

Guidance Performance
File
Tools
View
Simulation
Help
Height (ft)
10000
5000
0
Flightpath Angle (deg)
0
-10
-20
Velocity (knots)
400
300
200
Vertical Speed (feet/sec)
200
100
0
0
10
20
30
40
50
60
70
Ready
Sample based
T=69.699


Attitudes Accelerations Mach
File
Tools
View
Simulation
Help
phi,theta,psi (degs)
20
0
-20
<Accels>
20
0
-20
<Mach>
1
0.5
0
0
10
20
30
40
50
60
70
Ready
Sample based
T=69.699


Demands vs achieved
File
Tools
View
Simulation
Help
Roll (deg)
1
0
-1
AoA (deg)
20
15
10
5
AoS (deg)
1
0
-1
0
10
20
30
40
50
60
70
Ready
Sample based
T=69.699


Inertial Position
File Tools View Simulation Help
<Xe>
5000
0
-5000
-10000
-15000
0
10
20
30
40
50
60
70
Ready
Sample based
T=69.699



Rear Position | T=69.60 | Fly | Pos:[-841.52 15.60 -31.80] Dir:[1.00 0.00 0.00]

HL-20 Project with Optional FlightGear Interface

This project shows how to model NASA's HL-20 lifting body with Simulink®, Stateflow® and Aerospace Blockset™ software. The vehicle model includes the aerodynamics, control logic, fault management systems (FDIR), and engine controls (FADEC). It also includes effects of the environment, such as wind profiles for the landing phase. The entire model simulates approach and landing flight phases using an auto-landing controller. To analyze the effects of actuator failures and wind gust variation on the stability of the vehicle, use the "Run Failure Analysis in Parallel" project shortcut. If Parallel Computing Toolbox™ is installed, the analysis is run in parallel. If Parallel Computing Toolbox™ is not installed, the analysis is run in serial. Visualization for this model is done via an interface to FlightGear, an open source flight simulator package. If the FlightGear interface is unavailable, you can simulate the model by closing the loop using the alternative data sources provided in the Variant block. In this block, you can choose a previously saved data file, a Signal Editor block, or a set of constant values. This example requires Control System Toolbox™.

FlightGear Interface

For more information on the FlightGear interface, read these documentation topics:

- Installing the Flight Simulator
- Working with the Flight Simulator Interface
- Modeling the HL20 with the Flight Simulator

For a more detailed description of this model components, view a recorded navigation through the model using this link:

- NASA HL-20 WebEx Recording

NASA HL-20 Background

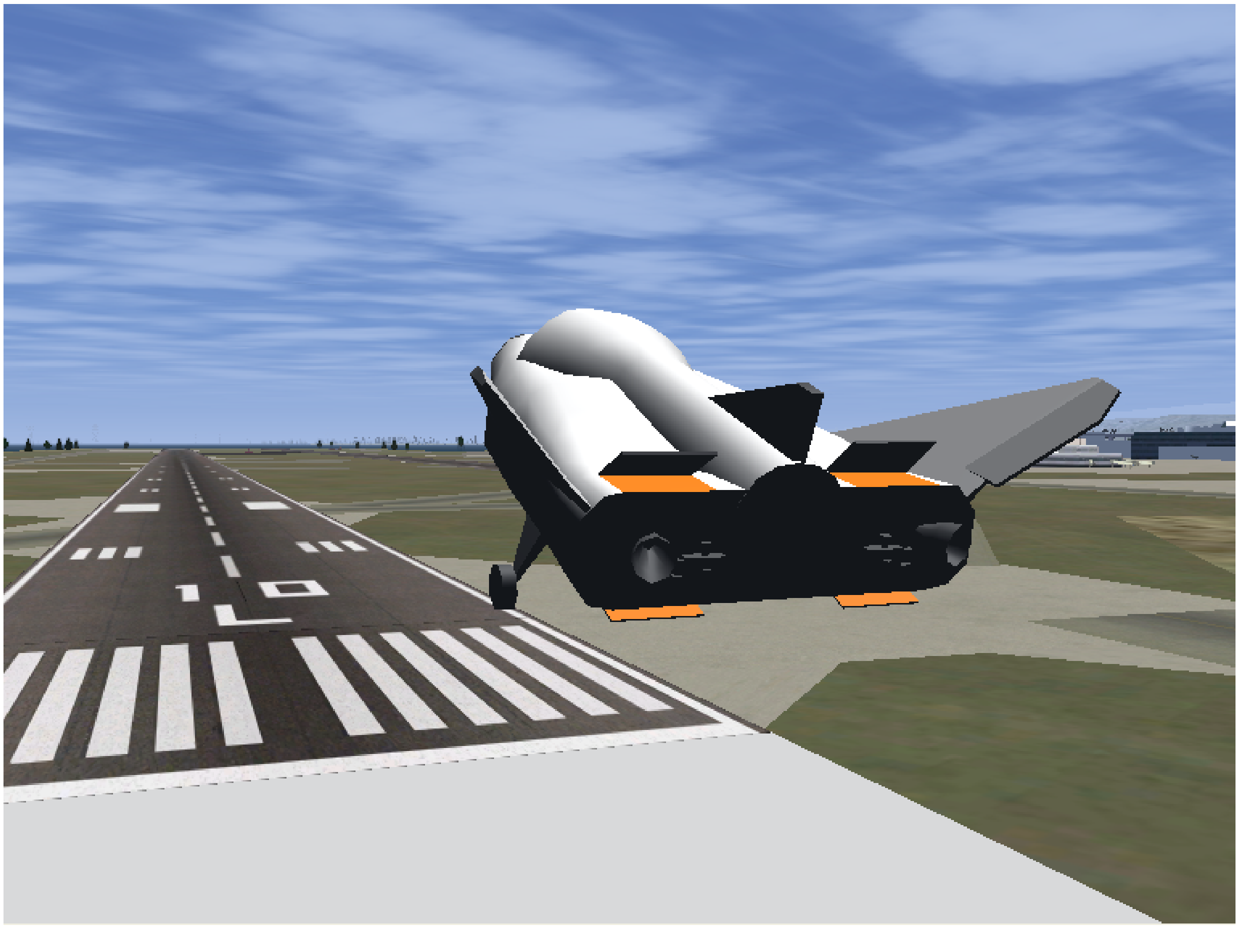
The HL-20, also known as personnel launch system (PLS), is a lifting body re-entry vehicle that was designed to complement the Space Shuttle orbiter. Designed to carry up to ten people and very little cargo[1], the HL-20 lifting body was to be placed in orbit either launched vertically via booster rockets or transported in the payload bay of the Space Shuttle orbiter. HL-20 lifting body was designed to have a powered deorbiting accomplished with an onboard propulsion system while its reentry was to be nose-first, horizontal and unpowered.

The HL-20 lifting body was developed as a low cost solution for getting to and from low Earth orbit. The proposed benefits of the HL-20 were reduced operating costs due to rapid turnaround between landing and launch, improved flight safety, and ability to land conventionally on runways. Potential scenarios for the HL-20 were orbital rescue of stranded astronauts, International Space Station crew exchange if the Space Shuttle orbiter was not available, observation missions, and satellite servicing missions.

Opening HL-20 Project

Run the following command to create and open a working copy of the project files for this example.

```
asbhl20
```



For more information on using Simulink Projects and HL-20, see:

- Tamayo S., Gage S., Walker G., "Integrated Project Management Tool for Modeling Simulation of Complex Systems" AIAA Modeling and Simulation Technologies Conference (August 2012)

Additional Information About NASA HL-20

[1] Jackson E. B., Cruz C. L., "Preliminary Subsonic Aerodynamic Model for Simulation Studies of the HL-20 Lifting Body," NASA TM4302 (August 1992)

Quaternion Estimate from Measured Rates

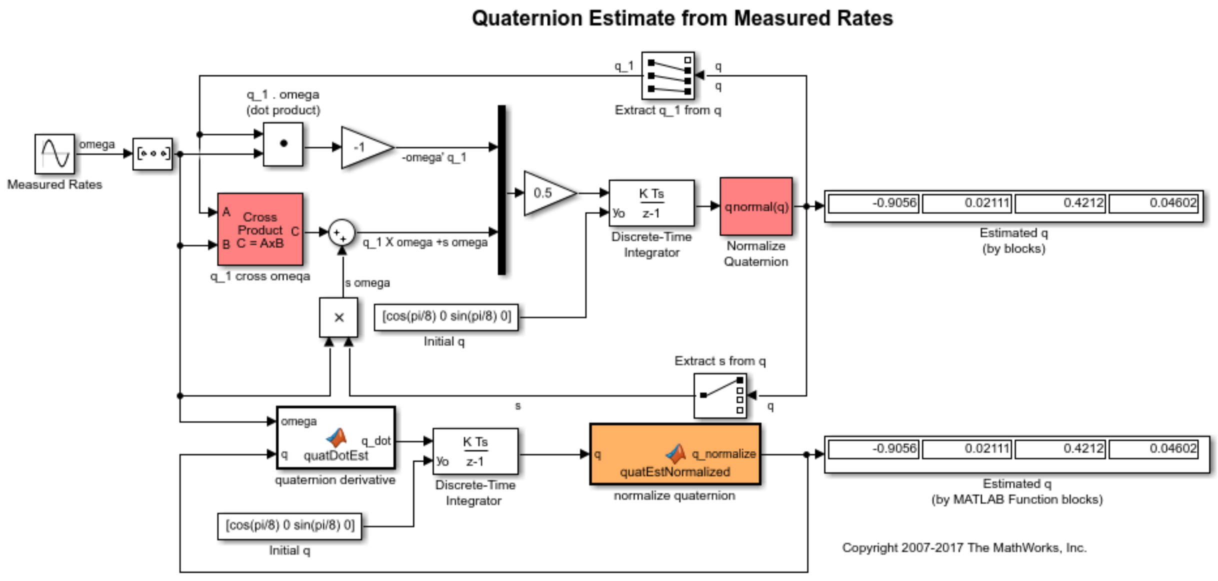
This model shows how to estimate a quaternion and model the equations in the following ways:

*Using Simulink® and Aerospace Blockset™ software to implement the equations.

*Using MATLAB® Function block to incorporate an Aerospace Toolbox quaternion function.

This model has been color coded to aid in locating Aerospace Blockset blocks.

The red blocks are Aerospace Blockset blocks, the orange block is a MATLAB Function block containing a function with MATLAB function block support provided by Aerospace Blockset and the white blocks are Simulink blocks.



Indicated Airspeed from True Airspeed Calculation

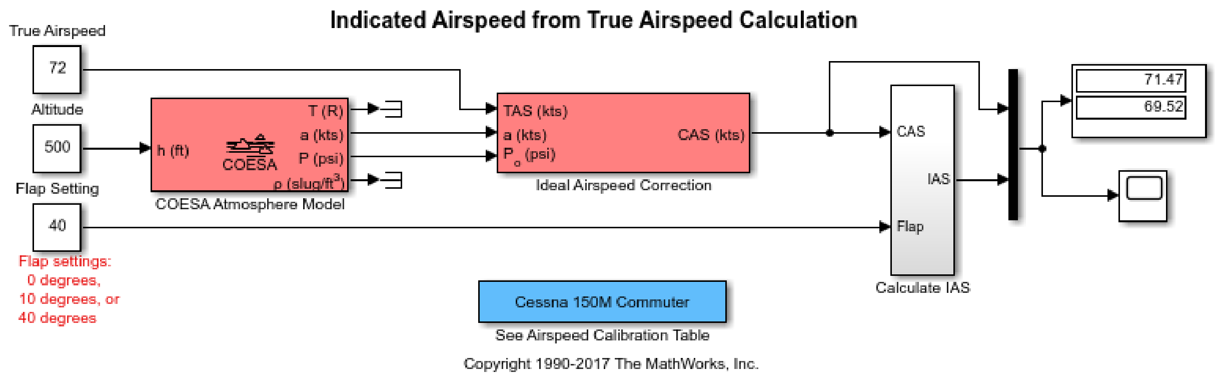
This model shows how to compute the indicated airspeed from true airspeed using the Ideal Airspeed Correction block. The Aerospace Blockset™ blocks are indicated in red.

True airspeed is the airspeed that we would read ideally (and the airspeed value easily calculated within a simulation). However there are errors introduced through the pitot-static airspeed indicators used to determine airspeed. These measurement errors are density error, compressibility error and calibration error. Applying these errors to true airspeed will result in indicated airspeed. (the ideal airspeed correction block can handle the density error and compressibility error)

Density Error -- It is a fact that an airspeed indicator reads lower than true airspeed at higher altitudes. This is due to lower air density at altitude. When the difference or error in air density at altitude from air density on a standard day at sea level is applied to true airspeed, it results in equivalent airspeed (EAS). Equivalent airspeed is true airspeed modified with the changes in atmospheric density which affect the airspeed indicator.

Compressibility Error -- Air has a limited ability to resist compression. This ability is reduced by an increase in altitude, an increase in speed, or a restricted volume. Within the airspeed indicator, there is a certain amount of trapped air. When flying at high altitudes and higher airspeeds, calibrated airspeed (CAS) is always higher than equivalent airspeed. Calibrated airspeed is equivalent airspeed modified with compressibility effects of air which affect the airspeed indicator.

Calibration Error -- The airspeed indicator has static vent(s) to maintain a pressure equal to atmospheric pressure inside the instrument. Position and placement of the static vent along with angle of attack and velocity of the aircraft will determine the pressure inside the airspeed indicator and thus the amount of calibration error of the airspeed indicator. Needless to say, calibration error is specific to a given aircraft design. A calibration table is usually given in the pilot operating handbook (POH) or in other aircraft specifications. Using this calibration table, the indicated airspeed (IAS) is determined from calibrated airspeed by modifying it with calibration error of the airspeed indicator. Indicated airspeed is displayed in the cockpit instrumentation.


Indicated Airspeed from True Airspeed Calculation
True Airspeed
72
Altitude
500
Flap Setting
40
Flap settings:
0 degrees,
10 degrees, or
40 degrees
h (ft)
T (R)
a (kts)
P (psi)
ρ (slug/ft³)
COESA
COESA Atmosphere Model
TAS (kts)
a (kts)
Po (psi)
CAS (kts)
Ideal Airspeed Correction
CAS
IAS
Flap
Calculate IAS
71.47
69.52
Cessna 150M Commuter
See Airspeed Calibration Table
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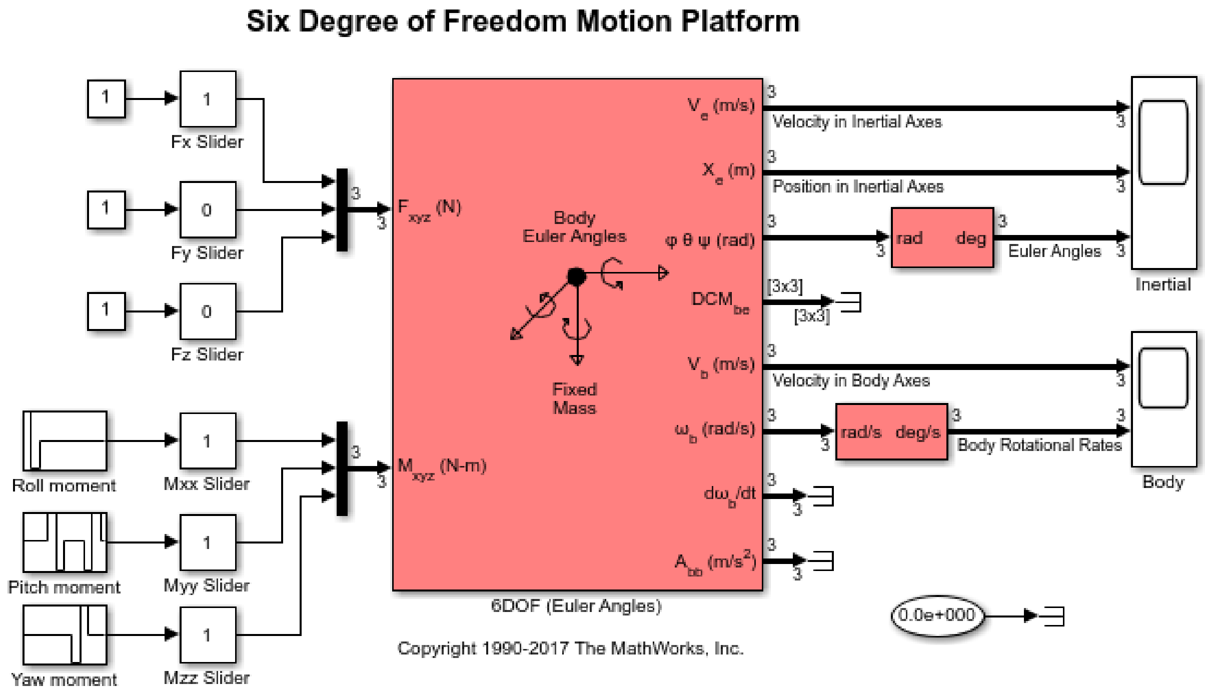
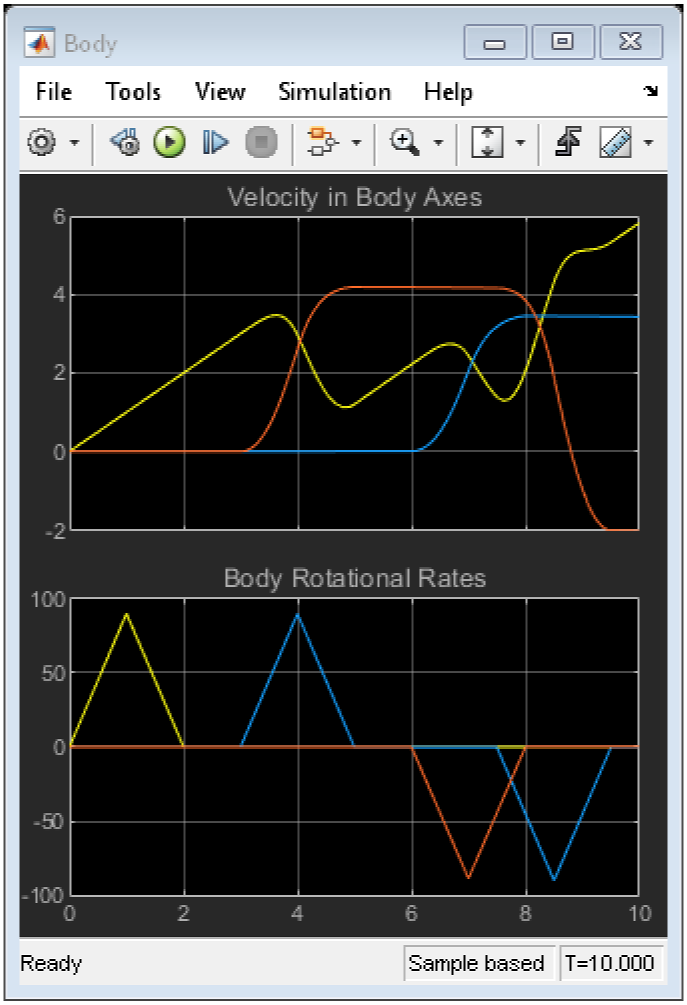
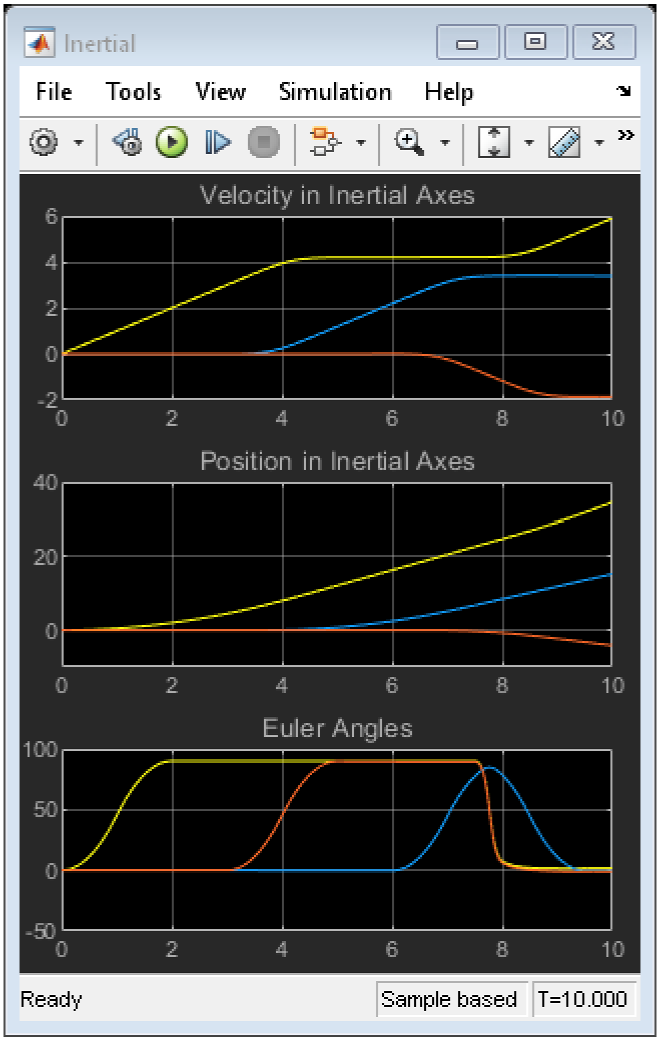
Six Degree of Freedom Motion Platform

This model shows how to connect an Aerospace Blockset™ six degree of freedom equation of motion block.

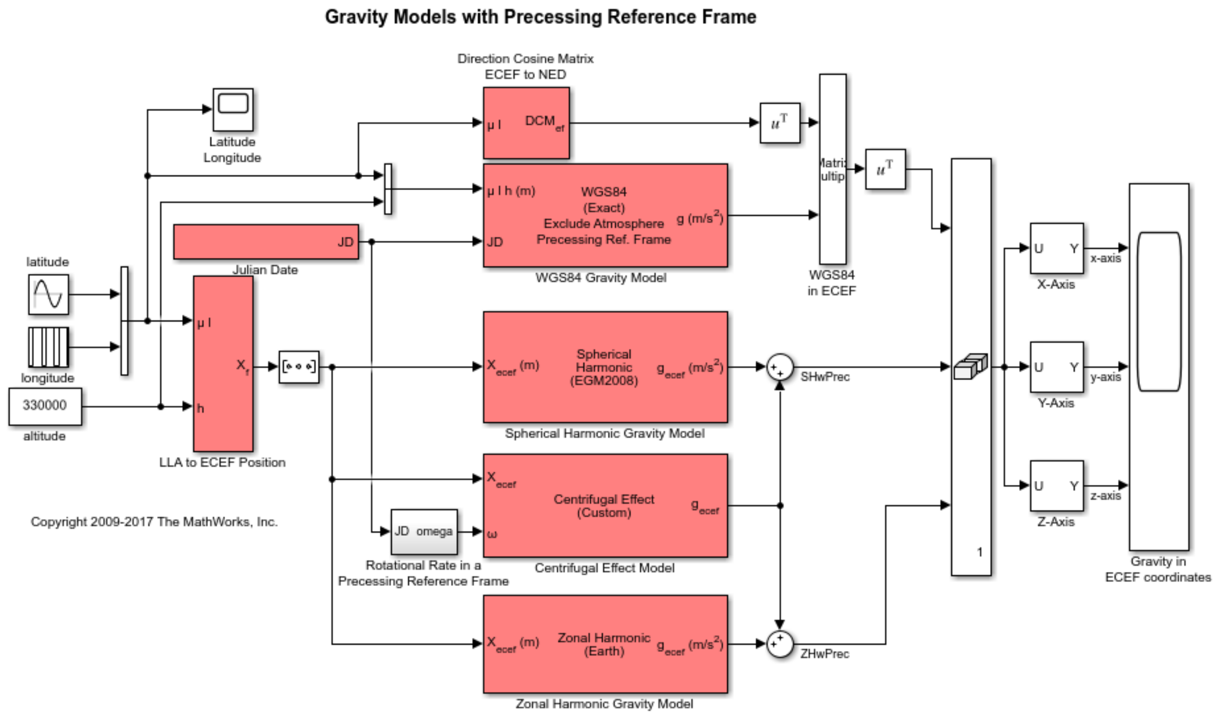


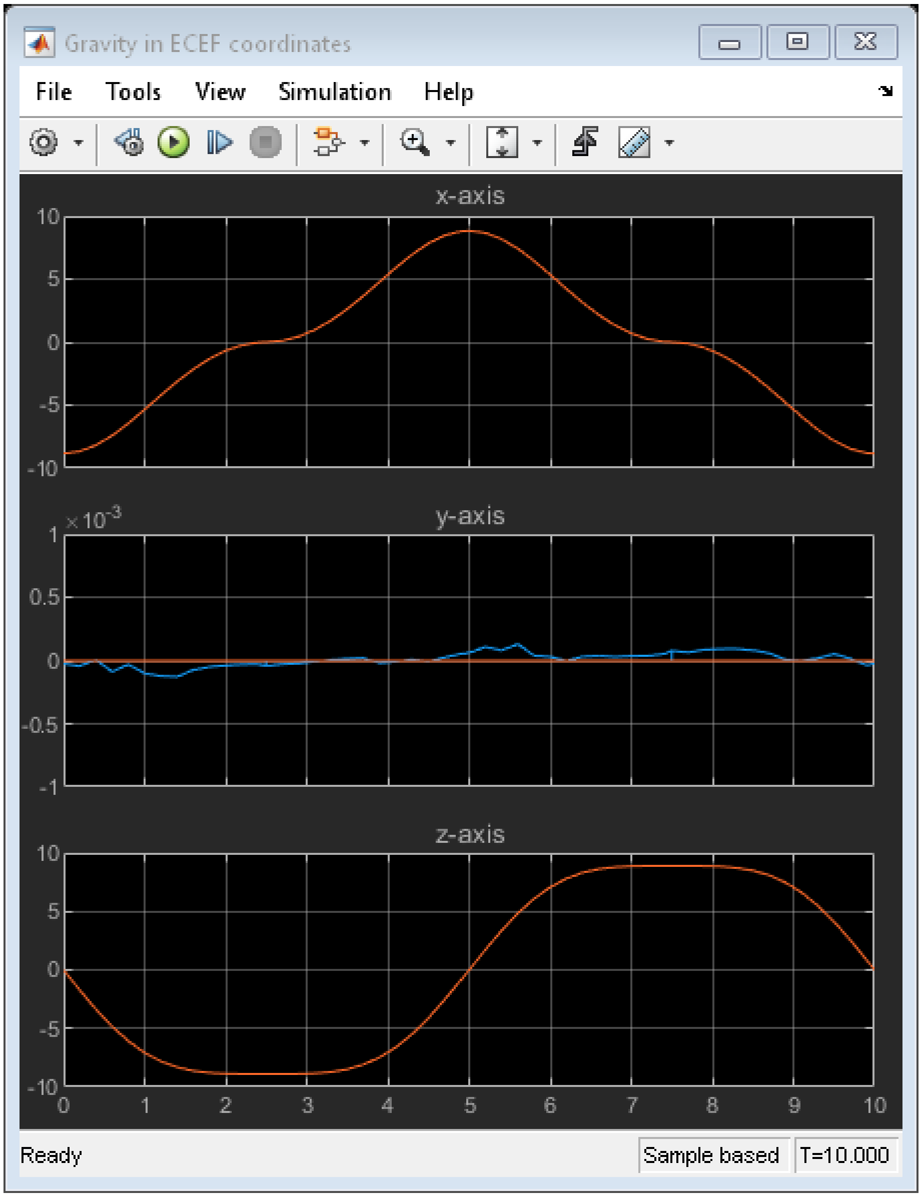

Body
File
Tools
View
Simulation
Help
Velocity in Body Axes
6
4
2
0
-2
Body Rotational Rates
100
50
0
-50
-100
0
2
4
6
8
10
Ready
Sample based
T=10.000

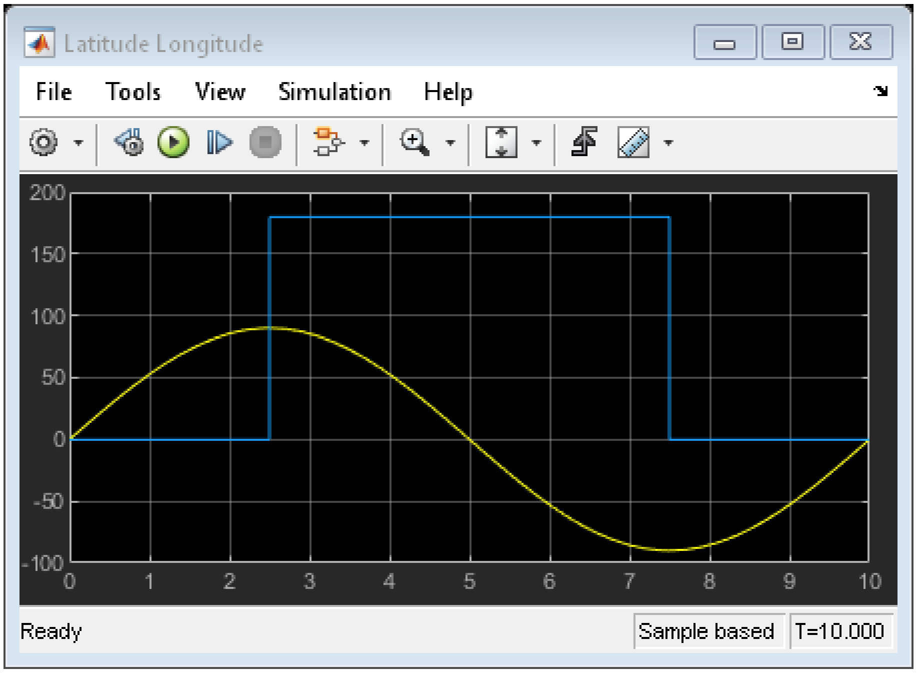

Inertial
File Tools View Simulation Help
Velocity in Inertial Axes
Position in Inertial Axes
Euler Angles
Ready
Sample based
T=10.000

Gravity Models with Precessing Reference Frame

This model shows how to implement various gravity models with precessing reference frames using Aerospace Blockset™ blocks. The Aerospace Blockset blocks are shown in red.


Gravity Models with Precessing Reference Frame
Direction Cosine Matrix ECEF to NED
DCM
Latitude Longitude
WGS84 (Exact) Exclude Atmosphere Precessing Ref. Frame
JD
Julian Date
WGS84 Gravity Model
WGS84 in ECEF
latitude
longitude
330000
altitude
LLA to ECEF Position
Spherical Harmonic (EGM2008)
Spherical Harmonic Gravity Model
SHwPrec
X-Axis
Y-Axis
Z-Axis
x-axis
y-axis
z-axis
Centrifugal Effect (Custom)
Centrifugal Effect Model
JD omega
Rotational Rate in a Precessing Reference Frame
Copyright 2009-2017 The MathWorks, Inc.
Zonal Harmonic (Earth)
Zonal Harmonic Gravity Model
ZHwPrec
Gravity in ECEF coordinates


Gravity in ECEF coordinates
File
Tools
View
Simulation
Help
x-axis
y-axis
z-axis
×10^-3
Ready
Sample based
T=10.000


Latitude Longitude
File
Tools
View
Simulation
Help
200
150
100
50
0
-50
-100
0
1
2
3
4
5
6
7
8
9
10
Ready
Sample based
T=10.000

True Airspeed from Indicated Airspeed Calculation

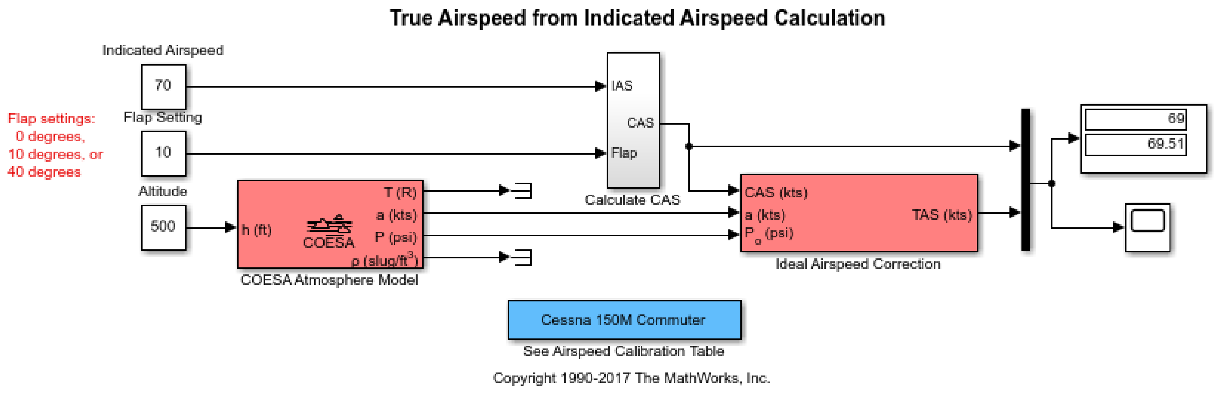
This model shows how to compute true airspeed from indicated airspeed using the Ideal Airspeed Correction block. The Aerospace Blockset™ blocks are indicated in red.

True airspeed is the airspeed that we would read ideally (and the airspeed value easily calculated within a simulation). However there are errors introduced through the pitot-static airspeed indicators used to determine airspeed. These measurement errors are density error, compressibility error and calibration error. Applying these errors to true airspeed will result in indicated airspeed. (the ideal airspeed correction block can handle the density error and compressibility error)

Density Error -- It is a fact that an airspeed indicator reads lower than true airspeed at higher altitudes. This is due to lower air density at altitude. When the difference or error in air density at altitude from air density on a standard day at sea level is applied to true airspeed, it results in equivalent airspeed (EAS). Equivalent airspeed is true airspeed modified with the changes in atmospheric density which affect the airspeed indicator.

Compressibility Error -- Air has a limited ability to resist compression. This ability is reduced by an increase in altitude, an increase in speed, or a restricted volume. Within the airspeed indicator, there is a certain amount of trapped air. When flying at high altitudes and higher airspeeds, calibrated airspeed (CAS) is always higher than equivalent airspeed. Calibrated airspeed is equivalent airspeed modified with compressibility effects of air which affect the airspeed indicator.

Calibration Error -- The airspeed indicator has static vent(s) to maintain a pressure equal to atmospheric pressure inside the instrument. Position and placement of the static vent along with angle of attack and velocity of the aircraft will determine the pressure inside the airspeed indicator and thus the amount of calibration error of the airspeed indicator. Needless to say, calibration error is specific to a given aircraft design. A calibration table is usually given in the pilot operating handbook (POH) or in other aircraft specifications. Using this calibration table, the indicated airspeed (IAS) is determined from calibrated airspeed by modifying it with calibration error of the airspeed indicator. Indicated airspeed is displayed in the cockpit instrumentation.


True Airspeed from Indicated Airspeed Calculation
Indicated Airspeed
70
Flap settings:
0 degrees,
10 degrees, or
40 degrees
Flap Setting
10
Altitude
500
h (ft)
COESA
T (R)
a (kts)
P (psi)
ρ (slug/ft^3)
COESA Atmosphere Model
IAS
CAS
Flap
Calculate CAS
CAS (kts)
a (kts)
P_o (psi)
TAS (kts)
Ideal Airspeed Correction
69
69.51
Cessna 150M Commuter
See Airspeed Calibration Table
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Airframe Trim and Linearize with Simulink® Control Design™

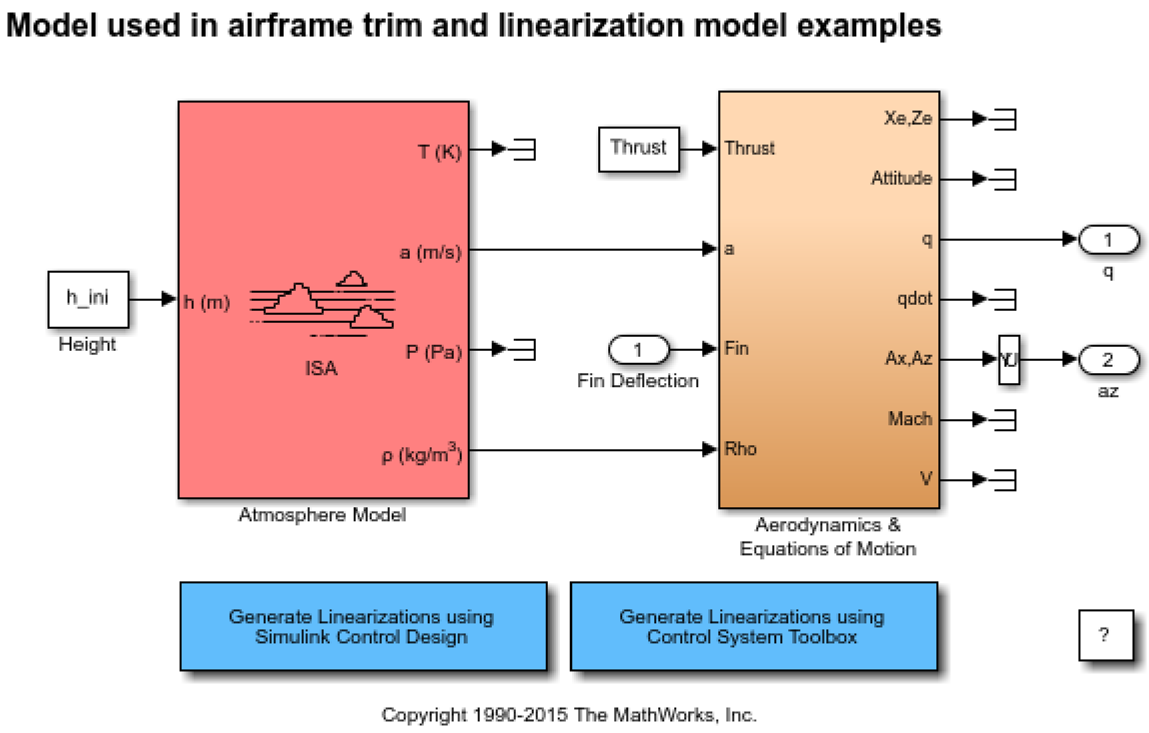
This example shows how to trim and linearize an airframe using Simulink® Control Design™ software

Designing an autopilot with classical design techniques requires linear models of the airframe pitch dynamics for several trimmed flight conditions. The MATLAB® technical computing environment can determine the trim conditions and derive linear state-space models directly from the nonlinear Simulink® and Aerospace Blockset™ model. This step saves time and helps to validate the model. The Simulink Control Design functions allow you to visualize the motion of the airframe in terms of open-loop frequency or time responses.

Initialize Guidance Model

The first problem is to find the elevator deflection, and the resulting trimmed body rate (q), which will generate a given incidence value when the missile is traveling at a set speed. Once the trim condition is found, a linear model can be derived for the dynamics of the perturbations in the states around the trim condition.

```
open_system('aeroblk_guidance_airframe');
```


Model used in airframe trim and linearization model examples
h_ini
Height
h (m)
ISA
T (K)
a (m/s)
P (Pa)
ρ (kg/m3)
Atmosphere Model
Thrust
Thrust
a
1
Fin Deflection
Fin
Rho
Xe,Ze
Attitude
q
qdot
Ax,Az
Mach
V
Aerodynamics & Equations of Motion
1
q
2
az
Generate Linearizations using Simulink Control Design
Generate Linearizations using Control System Toolbox
?
Copyright 1990-2015 The MathWorks, Inc.

Define State Values

```
h_ini     = 10000/m2ft;      % Trim Height [m]
M_ini     = 3;               % Trim Mach Number
alpha_ini = -10*d2r;         % Trim Incidence [rad]
theta_ini = 0*d2r;           % Trim Flightpath Angle [rad]
v_ini = M_ini*(340+(295-340)*h_ini/11000);     % Total Velocity [m/s]

q_ini = 0;                 % Initial pitch Body Rate [rad/sec]
```

Set Operating Point and State Specifications

The first state specifications are Position states. The second state specification is Theta. Both are known, but not at steady state. The third state specifications are body axis angular rates, of which the variable w is at steady state.

```
opspec = operspec('aeroblk_guidance_airframe');
opspec.State(1).Known = [1;1];
opspec.State(1).SteadyState = [0;0];
opspec.State(2).Known = 1;
opspec.State(2).SteadyState = 0;
opspec.State(3).Known = [1 1];
opspec.State(3).SteadyState = [0 1];
```

Search for Operating Point, Set I/O, Then Linearize

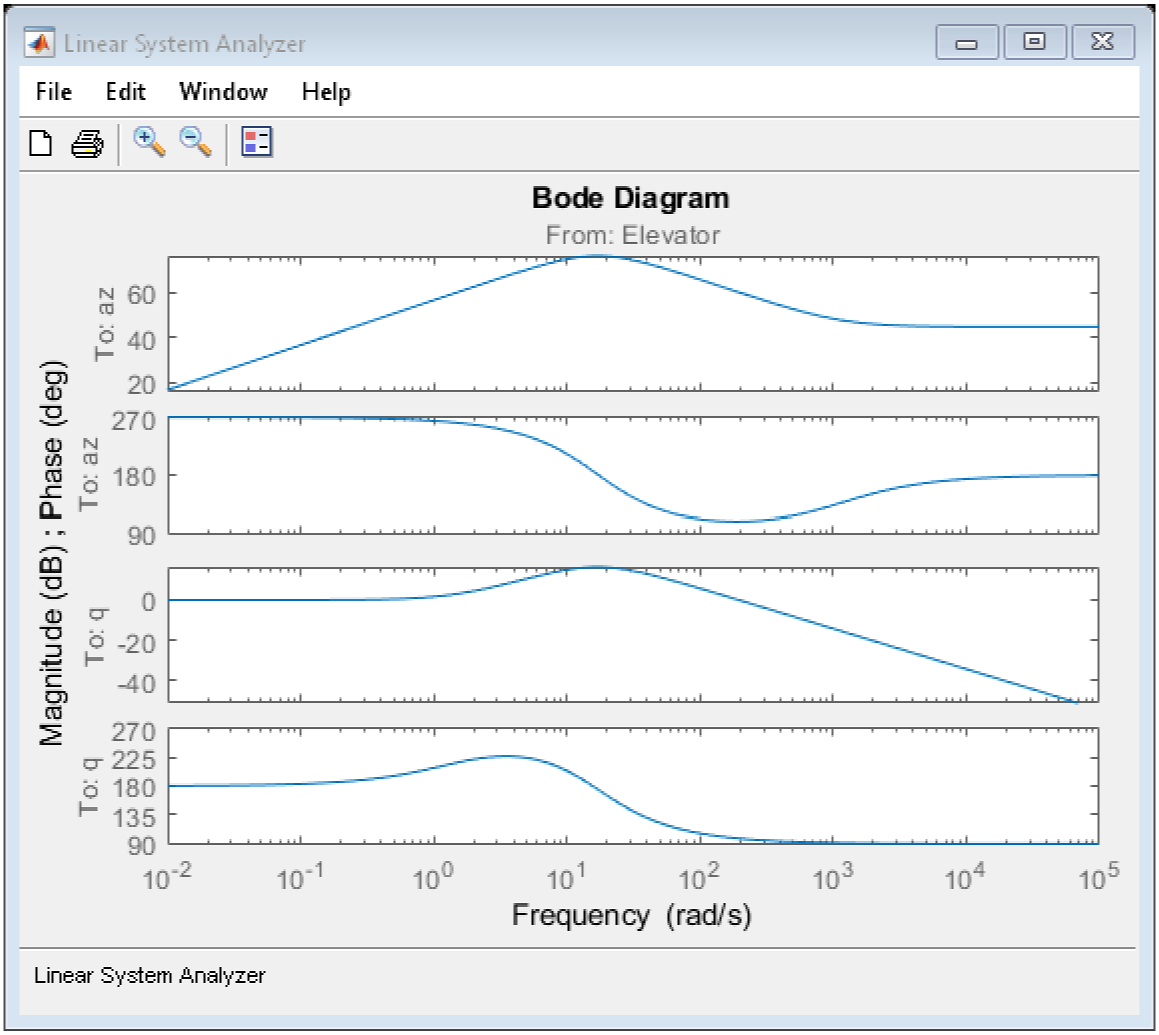
```
op = findop('aeroblk_guidance_airframe',opspec);

io(1) = linio('aeroblk_guidance_airframe/Fin Deflection',1,'input');
io(2) = linio('aeroblk_guidance_airframe/Selector',1,'output');
io(3) = linio(sprintf(['aeroblk_guidance_airframe/Aerodynamics &\n', ...
                    'Equations of Motion']),3,'output');

sys = linearize('aeroblk_guidance_airframe',op,io);
```

```
 Operating point search report:
---------------------------------

 Operating point search report for the Model aeroblk_guidance_airframe.
 (Time-Varying Components Evaluated at time t=0)

Operating point specifications were successfully met.
States:
----------
(1.) aeroblk_guidance_airframe/Aerodynamics & Equations of Motion/3DOF (Body Axes)/Posi
      x:              0      dx:           968
      x:      -3.05e+03      dx:          -171
(2.) aeroblk_guidance_airframe/Aerodynamics & Equations of Motion/3DOF (Body Axes)/Thet
      x:              0      dx:        -0.216
(3.) aeroblk_guidance_airframe/Aerodynamics & Equations of Motion/3DOF (Body Axes)/U,w
      x:            968      dx:         -14.1
      x:           -171      dx:     -7.44e-08 (0)
(4.) aeroblk_guidance_airframe/Aerodynamics & Equations of Motion/3DOF (Body Axes)/q
      x:         -0.216      dx:      3.36e-08 (0)

Inputs:
----------
(1.) aeroblk_guidance_airframe/Fin Deflection
      u:          0.136    [-Inf Inf]
```

```
Outputs:
----------
(1.) aeroblk_guidance_airframe/q
      y:        -0.216    [-Inf Inf]
(2.) aeroblk_guidance_airframe/az
      y:     -7.44e-08    [-Inf Inf]
```

Select Trimmed States, Create LTI Object, and Plot Bode Response

```
% find index of desired states in the state vector
names = sys.StateName;
q_idx = find(strcmp('q',names));
az_idx = find(strcmp('U,w(2)',names));

airframe = ss(sys.A([az_idx q_idx],[az_idx q_idx]),sys.B([az_idx q_idx],:),sys.C(:,[az_

set(airframe,'inputname',{'Elevator'}, ...
             'outputname',[{'az'} {'q'}]);

ltiview('bode',airframe);
```


Linear System Analyzer
File
Edit
Window
Help
Bode Diagram
From: Elevator
Magnitude (dB) ; Phase (deg)
To: az
60
40
20
To: az
270
180
90
To: q
0
-20
-40
To: q
270
225
180
135
90
10^-2
10^-1
10^0
10^1
10^2
10^3
10^4
10^5
Frequency (rad/s)
Linear System Analyzer

Airframe Trim and Linearize with Control System Toolbox™

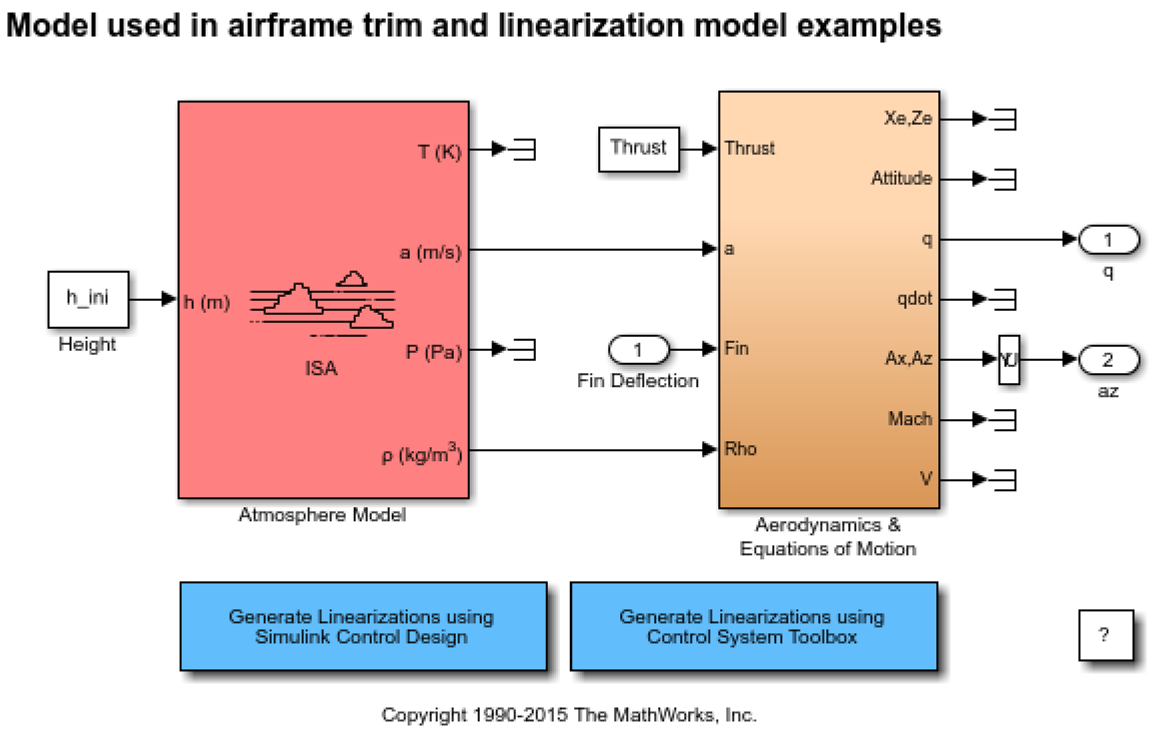
This example shows how to trim and linearize an airframe in the Simulink® environment using the Control System Toolbox™ software

Designing an autopilot with classical design techniques requires linear models of the airframe pitch dynamics for several trimmed flight conditions. The MATLAB® technical computing environment can determine the trim conditions and derive linear state-space models directly from the nonlinear Simulink and Aerospace Blockset™ model. This step saves time and helps to validate the model. The Control System Toolbox functions allow you to visualize the motion of the airframe in terms of open-loop frequency or time responses.

Initialize Guidance Model

The first problem is to find the elevator deflection, and the resulting trimmed body rate (q), which will generate a given incidence value when the missile is traveling at a set speed. Once the trim condition is found, a linear model can be derived for the dynamics of the perturbations in the states around the trim condition.

```
open_system('aeroblk_guidance_airframe');
```


Model used in airframe trim and linearization model examples
h_ini
Height
h (m)
ISA
T (K)
a (m/s)
P (Pa)
ρ (kg/m^3)
Atmosphere Model
Thrust
Fin Deflection
1
Thrust
a
Fin
Rho
Xe,Ze
Attitude
q
qdot
Ax,Az
Mach
V
Aerodynamics & Equations of Motion
1
q
2
az
Generate Linearizations using Simulink Control Design
Generate Linearizations using Control System Toolbox
?
Copyright 1990-2015 The MathWorks, Inc.

Define State Values

```
h_ini     = 10000/m2ft;      % Trim Height [m]
M_ini     = 3;               % Trim Mach Number
alpha_ini = -10*d2r;         % Trim Incidence [rad]
theta_ini = 0*d2r;           % Trim Flightpath Angle [rad]
v_ini = M_ini*(340+(295-340)*h_ini/11000);     % Total Velocity [m/s]

q_ini = 0;              % Initial pitch Body Rate [rad/sec]
```

Find Names and Ordering of States from Simulink® Model

```
[sizes,x0,names]=aeroblk_guidance_airframe([],[],[],'sizes');

state_names = cell(1,numel(names));
for i = 1:numel(names)
  n = max(strfind(names{i},'/'));
  state_names{i}=names{i}(n+1:end);
end
```

Specify Which States to Trim and Which States Remain Fixed

```
fixed_states            = [{'U,w'} {'Theta'} {'Position'}];
fixed_derivatives       = [{'U,w'} {'q'}];        % w and q
fixed_outputs           = [];                     % Velocity
fixed_inputs            = [];

n_states=[];n_deriv=[];
for i = 1:length(fixed_states)
  n_states=[n_states find(strcmp(fixed_states{i},state_names))]; %#ok<AGROW>
end
for i = 1:length(fixed_derivatives)
  n_deriv=[n_deriv find(strcmp(fixed_derivatives{i},state_names))]; %#ok<AGROW>
end
n_deriv=n_deriv(2:end);                          % Ignore U
```

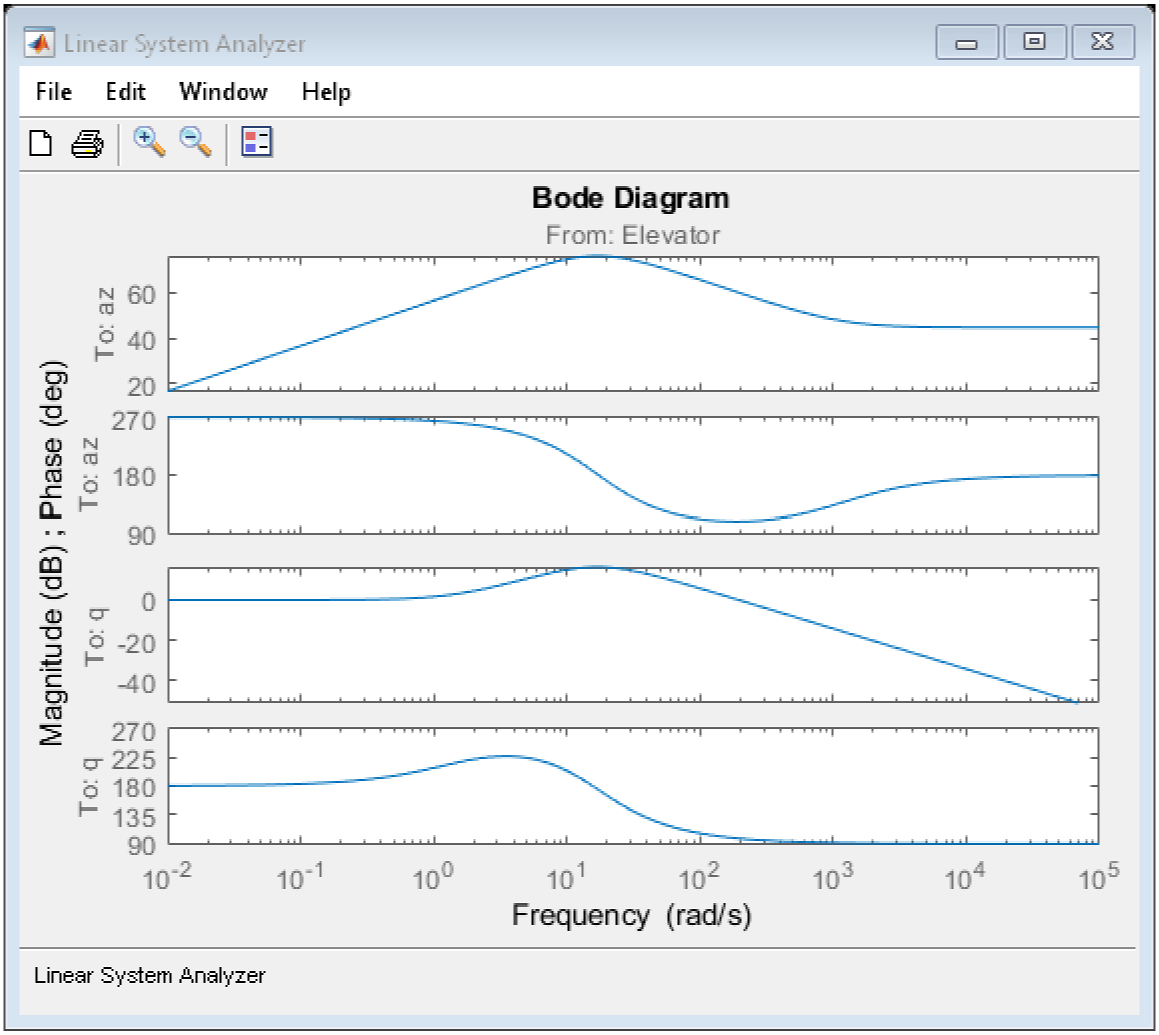
Trim Model

```
[X_trim,U_trim,Y_trim,DX]=trim('aeroblk_guidance_airframe',x0,0,[0 0 v_ini]', ...
                               n_states,fixed_inputs,fixed_outputs, ...
                               [],n_deriv)  %#ok<NOPTS>


X_trim =

   1.0e+03 *

   -0.0002
         0
    0.9677
   -0.1706
         0
   -3.0480


U_trim =

    0.1362


Y_trim =
   -0.2160
         0


DX =

         0
   -0.2160
  -14.0977
         0
  967.6649
 -170.6254
```

Derive Linear Model and View Frequency Response

```
[A,B,C,D]=linmod('aeroblk_guidance_airframe',X_trim,U_trim);
if exist('control','dir')
  airframe = ss(A(n_deriv,n_deriv),B(n_deriv,:),C([2 1],n_deriv),D([2 1],:));
  set(airframe,'StateName',state_names(n_deriv), ...
               'InputName',{'Elevator'}, ...
               'OutputName',[{'az'} {'q'}]);

  zpk(airframe)
  ltiview('bode',airframe)
end
```

```
ans =

  From input "Elevator" to output...
          -170.45 s (s+1133)
   az:  ----------------------
        (s^2 + 30.04s + 288.9)

         -194.66 (s+1.475)
   q:  ----------------------
       (s^2 + 30.04s + 288.9)

Continuous-time zero/pole/gain model.
```

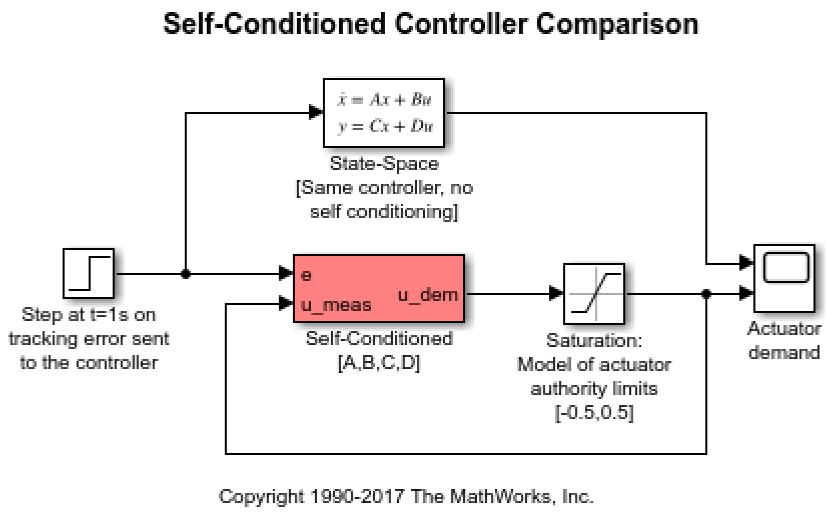

Linear System Analyzer
File Edit Window Help
Bode Diagram
From: Elevator
To: az
To: az
To: q
To: q
Magnitude (dB) ; Phase (deg)
60
40
20
270
180
90
0
-20
-40
270
225
180
135
90
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
Frequency (rad/s)
Linear System Analyzer

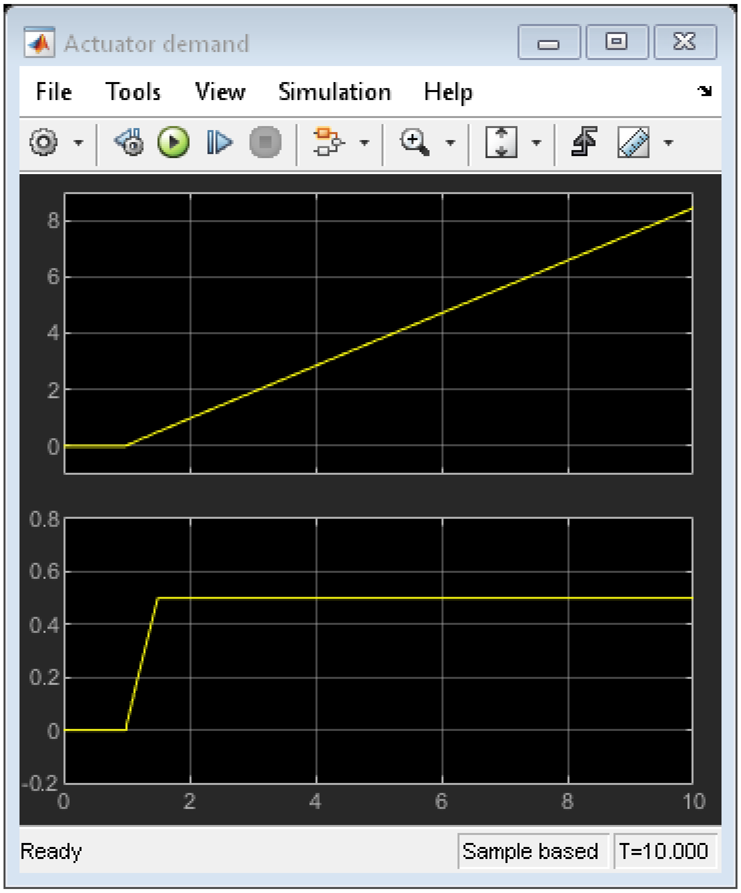
Self-conditioned Controller Comparison

This model shows how to compare the implementation of a state-space controller [A,B,C,D] in a self-conditioned form versus a typical state-space controller [A,B,C,D]. This model requires Control System Toolbox™ software.

For the self-conditioned state-space controller, if measured control value is equal to the demanded control value (u_meas = u_dem), then the controller implementation is the typical state-space controller [A,B,C,D]. However if measured control value (u_meas) is limited, e.g., rate limiting, then the poles of the controller become those defined in the mask dialog box.

The results of a typical state-space controller [A,B,C,D] and a self-conditioned state-space controller with a limited measured control value are shown below.


Self-Conditioned Controller Comparison
$\dot{x} = Ax + Bu$
$y = Cx + Du$
State-Space [Same controller, no self conditioning]
Step at t=1s on tracking error sent to the controller
e
u_meas
u_dem
Self-Conditioned [A,B,C,D]
Saturation: Model of actuator authority limits [-0.5,0.5]
Actuator demand
Copyright 1990-2017 The MathWorks, Inc.


Actuator demand
File
Tools
View
Simulation
Help
8
6
4
2
0
0.8
0.6
0.4
0.2
0
-0.2
0
2
4
6
8
10
Ready
Sample based
T=10.000

Quadcopter Project

This example shows how to use Simulink® to model a quadcopter, based on the PARROT® series of mini-drones.

- To manage the model and source files, it uses Simulink® Projects.
- To show the quadcopter in a three-dimensional environment, it uses Simulink® 3D Animation.
- For the collaborative development of a flight simulation application, it provides an implementation of the Flight Simulation application template.

This example works with the Simulink Support Package for PARROT Minidrones.

Note: To successfully run this example you must have a C/C++ compiler installed.

Open the Quadcopter Project

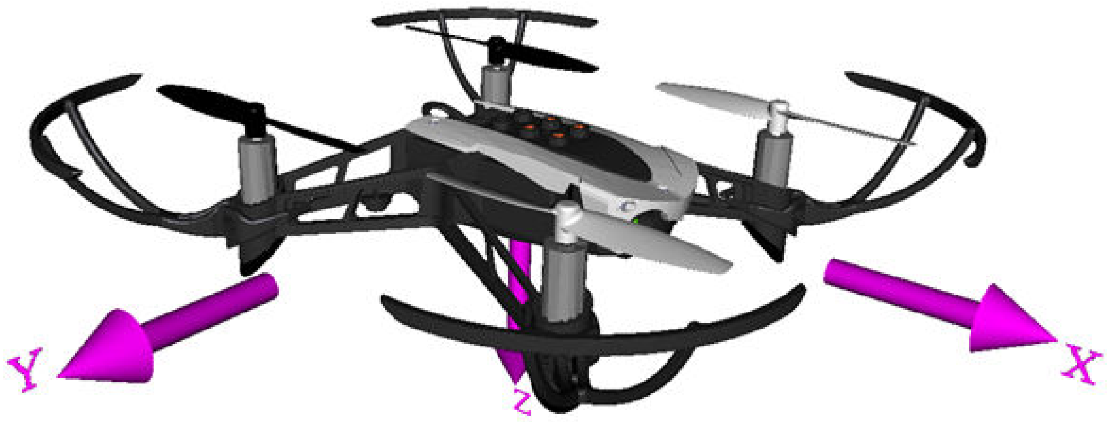
Run the following command to create and open a working copy of the project files for this example:

```
asbQuadcopterStart
```

Quadcopter Physical Characteristics

The following schematic shows the quadcopter physical characteristics:

- Axis
- Mass and Inertia
- Rotors



Axis

The quadcopter body axis is centered in the center of gravity.

- The *x*-axis starts at the center of gravity and points in the direction along the nose of the quadcopter.
- The *y*-axis starts at the center of gravity and points to the right of the quadcopter.
- The *z*-axis starts at the center of gravity and points downward from the quadcopter, following the right-hand rule.

Mass and Inertia

We assume that the whole body works as a particle. The file `vehicleVars` contains the values for the inertia and mass.

Rotors

- Rotor #1 rotates positively with respect to the *z*-axis. It is located parallel to the *xy*-plane, -45 degrees from the *x*-axis.
- Rotor #2 rotates negatively with respect to the body's *z*-axis. It is located parallel to the *xy*-plane, -135 degrees from the *x*-axis.
- Rotor #3 has the same rotation direction as rotor #1. It is located parallel to the *xy*-plane, 135 degrees from the *x*-axis.

- Rotor #4 has the same rotation direction as rotor #2. It is located parallel to the *xy*-plane, 45 degrees from the *x*-axis.

This example uses the approach defined by Prouty[1] and adapted to a heavy-lift quadcopter by Ponds et al[2].

Control

For control, the quadcopter uses a complementary filter to estimate attitude, and Kalman filters to estimate position and velocity. The example implements:

- A PID controller for pitch/roll control
- A PD controller for yaw
- A PD controller for position control in North-East-Down coordinates

The `controllerVars` file contains variables pertinent to the controller. The `estimatorVars` file contains variables pertinent to the estimator.

The example implements the controller and estimators as model subsystems, enabling several combinations of estimators and controllers to be evaluated for design.

To provide inputs to the quadcopter (in pitch, roll, yaw, North (X), East (Y), Down (Z) coordinates), use one of the following and change the `VSS_COMMAND` variable in the workspace:

- A Signal Editor block
- A joystick
- Previously saved data
- Spreadsheet data

Sensors

The example uses a set of sensors to determine its states:

- An Inertial Measurement Unit (IMU) to measure the angular rates and translational accelerations.
- A camera for optical flow estimation.
- A sonar for altitude measurement.

The example stores the characteristics for the sensors in the file `sensorVars`. To include sensor dynamics with these measurements, you can change the `VSS_SENSORS` variable in the workspace.

Environment

The models implement several Aerospace Blockset™ environment blocks, including those for atmosphere and gravity models. To include these models, you can change the `VSS_ENVIRONMENT` variable in the workspace to toggle between variable and fixed environment models.

Linearization

The model uses the `trimLinearizeOpPoint` to linearize the nonlinear model of the quadcopter using Simulink Control Design (R).

Testing

To make sure that the trajectory generation tool works properly, the example implements a test in the `trajectoryTest` file. For more information on how to do this, see the Simulink Control Design documentation).

Visualization

You can visualize the variables for the quadcopter in one of the following ways:

- Using Simulation Data Inspector.
- Using the flight instrument blocks.
- Toggling between the different visualization variant subsystems. You can toggle between the different variant subsystems by changing the `VSS_VISUALIZATION` variable. Note that one of these variants is a FlightGear animation. To use this animation, you must add a FlightGear compatible model of the quadcopter to the project. The software does not include this model.

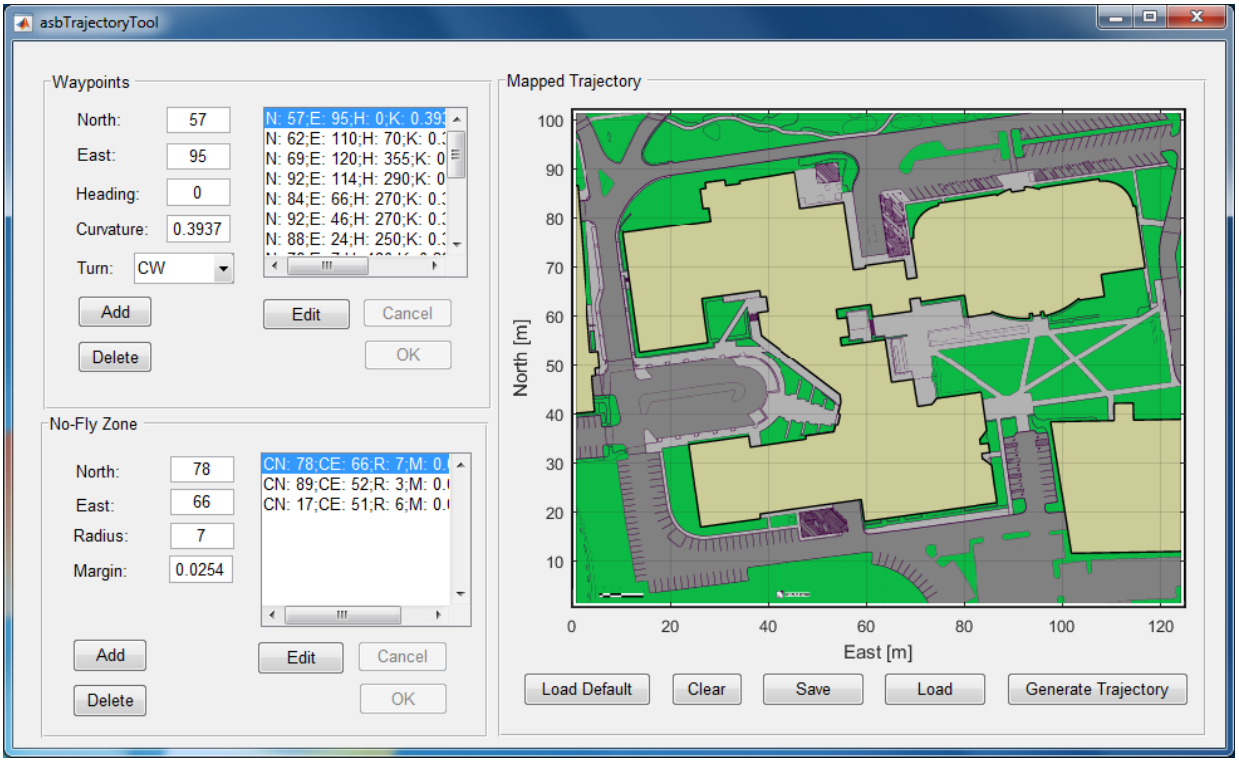
Trajectory Generation

A trajectory generation tool, using the Dubin method, creates a set of navigational waypoints. To create a trajectory with a set of waypoints this method uses a set of poses defined by position, heading, turn curvature, and turn direction.

To start the tool, open the project and run:

```
asbTrajectoryTool
```

The following interface displays:



Waypoints

North: 57
East: 95
Heading: 0
Curvature: 0.3937
Turn: CW

```
N: 57;E: 95;H: 0;K: 0.39
N: 62;E: 110;H: 70;K: 0.3
N: 69;E: 120;H: 355;K: 0
N: 92;E: 114;H: 290;K: 0
N: 84;E: 66;H: 270;K: 0.3
N: 92;E: 46;H: 270;K: 0.3
N: 88;E: 24;H: 250;K: 0.3
```

No-Fly Zone

North: 78
East: 66
Radius: 7
Margin: 0.0254

```
CN: 78;CE: 66;R: 7;M: 0.
CN: 89;CE: 52;R: 3;M: 0.
CN: 17;CE: 51;R: 6;M: 0.
```

The interface has several panels:

Waypoints

This panel describes the poses the trajectory tool requires. To define these poses, the panel uses text boxes:

- **North** and **East** (position in meters)
- **Heading** (degrees from North)
- **Curvature** (turning curvature in meters^-1)
- **Turn** (direction clockwise or counter-clockwise)

A list of poses appears in the waypoint list to the right of the text boxes.

To add a waypoint, enter pose values in the edit boxes and click **Add**. The new waypoint appears in the waypoint list in the same panel.

To edit the characteristics of a waypoint, select the waypoint in the list and click **Edit**. The characteristics of the waypoints display in the edit boxes. Edit the characteristics as desired, then click **OK**. To cancel the changes click **Cancel**.

To delete a waypoint, in the waypoint list, select the waypoint and click **Delete**.

No-Fly Zone

The panel defines the location and characteristics of the no-fly zones. To define the no-fly zone, the panel uses text boxes:

- **North** and **East** (position in meters)
- **Radius** (distance in meters)
- **Margin** (safety margin in meters)

Use the **Add**, **Delete**, **Edit**, **OK**, and **Cancel** buttons in the same way as for the Waypoints panel.

Mapped Trajectory

This panel plots the trajectory over the Apple Hill campus aerial schematic based on the waypoints and no-fly zone characteristics.

To generate the trajectory, add the waypoint and no-fly zone characteristics to the respective panels, then click **Generate Trajectory**.

To save the trajectory that is currently in your panel, click the **Save** button. This button only saves your last trajectory.

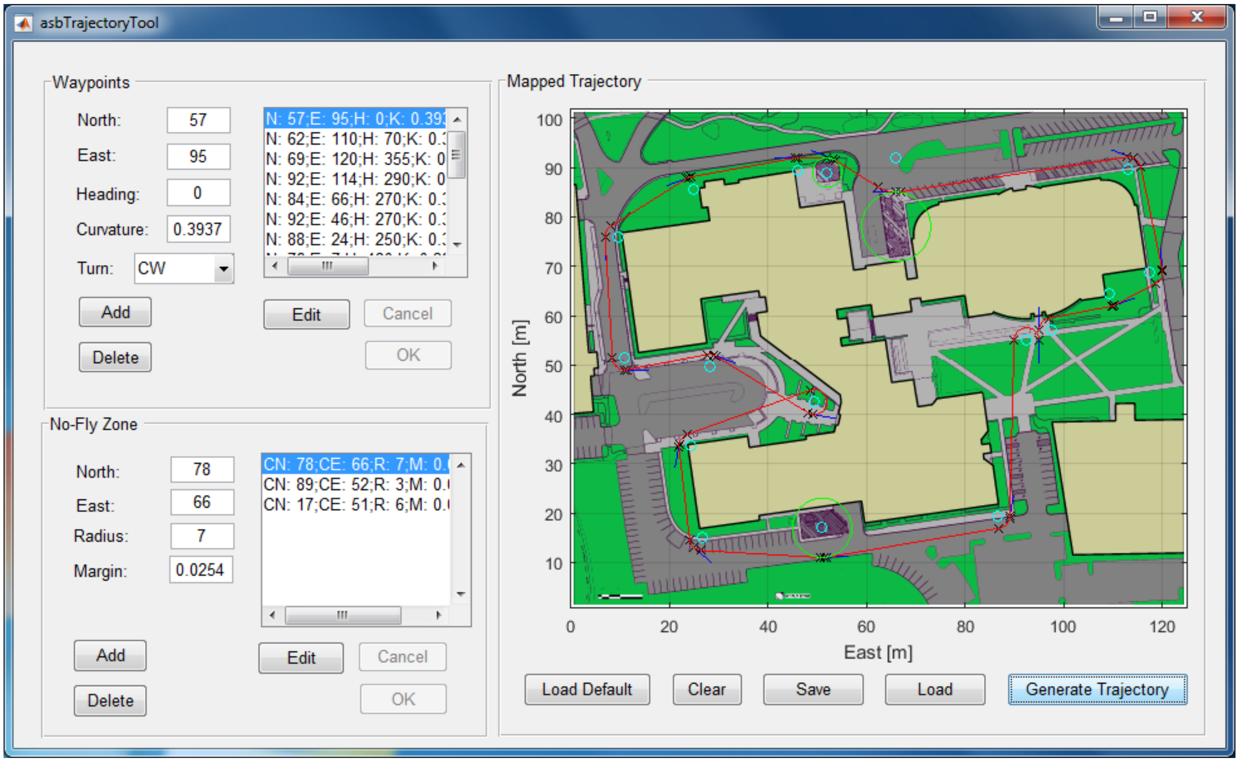
To load the last saved trajectory, click **Load**.

To load the default trajectory, press the **Load Default** button.

To clear the values in the waypoint and no-fly zone panel, click **Clear**.

The default data contains poses for specific locations at which the toy quadcopter uses its cameras so the pilot on the ground can estimate the height of the snow on the roof. Three no-fly zones were defined for each of the auxiliary power generators, so in case there is a failure in the quadcopter, it does not cause any damage to the campus infrastructure.

When the example generates the trajectory for the default data, the plot should appear as follows:



Waypoints

North: 57
East: 95
Heading: 0
Curvature: 0.3937
Turn: CW

N: 57;E: 95;H: 0;K: 0.39
N: 62;E: 110;H: 70;K: 0.
N: 69;E: 120;H: 355;K: 0
N: 92;E: 114;H: 290;K: 0
N: 84;E: 66;H: 270;K: 0.
N: 92;E: 46;H: 270;K: 0.
N: 88;E: 24;H: 250;K: 0.

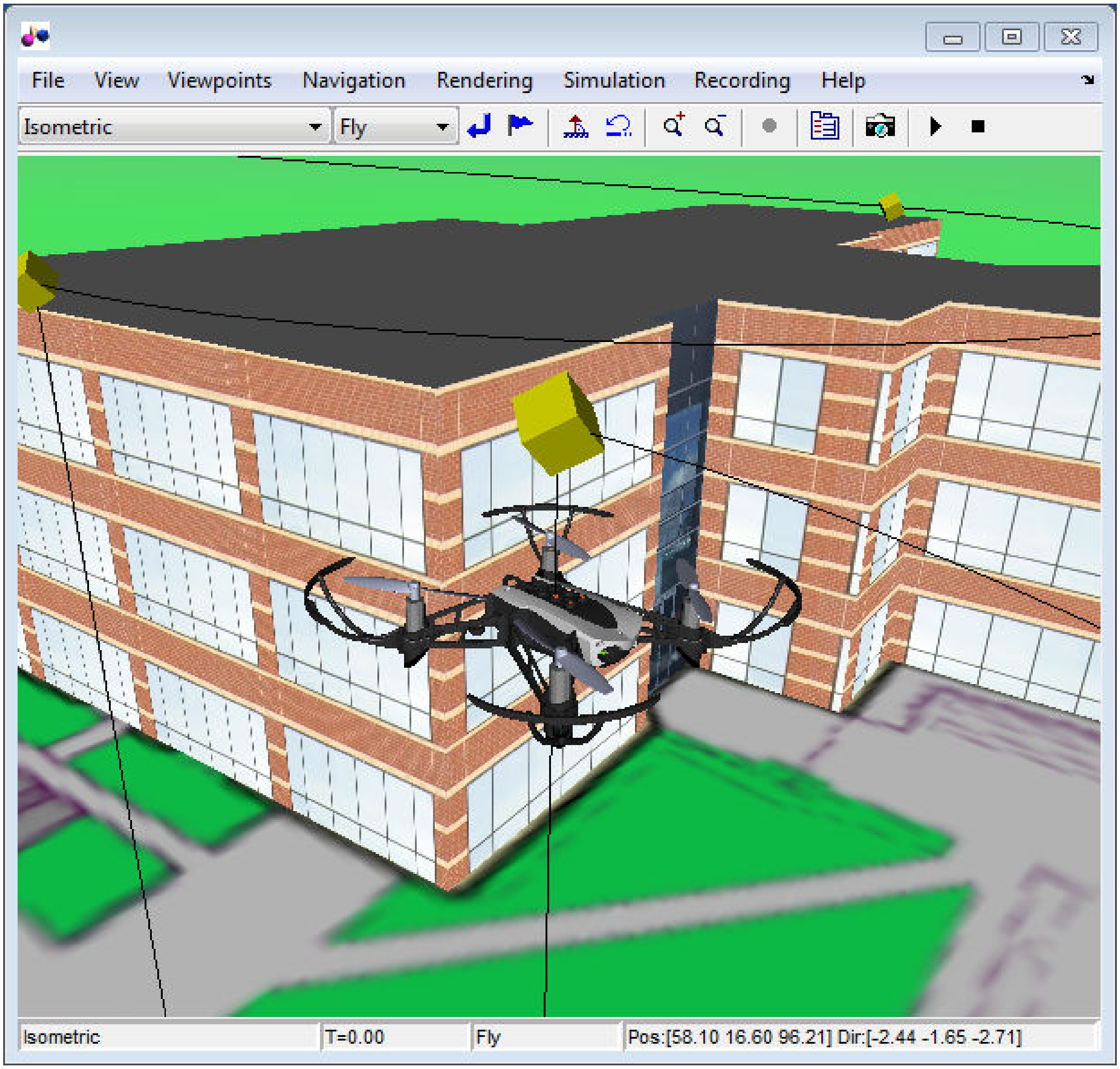
No-Fly Zone

North: 78
East: 66
Radius: 7
Margin: 0.0254

CN: 78;CE: 66;R: 7;M: 0.
CN: 89;CE: 52;R: 3;M: 0.
CN: 17;CE: 51;R: 6;M: 0.

The red line represents the trajectory, black **x** markers determine either a change in the trajectory or a specific pose. Blue lines that represent the heading for that specific waypoint accompany specific poses. No-fly zones are represented as green circles.

If you have a Simulink 3D Animation license, you can also view the trajectory in a 3-D representation of the Apple Hill campus:



Isometric T=0.00 Fly Pos:[58.10 16.60 96.21] Dir:[-2.44 -1.65 -2.71]

Note: For visualization reasons the 3D representation of the quadcopter is not at the same scale as the environment.

References

[1] Prouty, R. Helicopter Performance, Stability, and Control. PWS Publishers, 2005.

[2] Ponds, P., Mahony, R., Corke, P. Modelling and control of a large quadrotor robot. Control Engineering Practice. 2010.

A

Aerospace Units Appendix

Aerospace Units

The main blocks of the Aerospace Blockset library support standard measurement systems. The Unit Conversion blocks support all units listed in this table.

Quantity	Metric (MKS)	English
Acceleration	meters/second^2 (m/s^2), kilometers/second^2 (km/s^2), (kilometers/hour)/second (km/h-s), g-unit (*g*)	inches/second^2 (in/s^2), feet/second^2 (ft/s^2), (miles/hour)/second (mph/s), g-unit (*g*)
Angle	radian (rad), degree (deg), revolution	radian (rad), degree (deg), revolution
Angular acceleration	radians/second^2 (rad/s^2), degrees/second^2 (deg/s^2), revolutions/minute (rpm), revolutions/second (rps)	radians/second^2 (rad/s^2), degrees/second^2 (deg/s^2), revolutions/minute (rpm), revolutions/second (rps)
Angular velocity	radians/second (rad/s), degrees/second (deg/s), revolutions/minute (rpm)	radians/second (rad/s), degrees/second (deg/s), revolutions/minute (rpm)
Density	kilogram/meter^3 (kg/m^3)	pound mass/foot^3 (lbm/ft^3), slug/foot^3 (slug/ft^3), pound mass/inch^3 (lbm/in^3)
Force	newton (N)	pound (lb)
Inertia	kilogram-meter^2 (kg-m^2)	slug-foot^2 (slug-ft^2)
Length	meter (m)	inch (in), foot (ft), mile (mi), nautical mile (nm)
Mass	kilogram (kg)	slug (slug), pound mass (lbm)
Pressure	Pascal (Pa)	pound/inch^2 (psi), pound/foot^2 (psf), atmosphere (atm)
Temperature	kelvin (K), degrees Celsius (^{o}C)	degrees Fahrenheit (^{o}F), degrees Rankine (^{o}R)
Torque	newton-meter (N-m)	pound-feet (lb-ft)
Velocity	meters/second (m/s), kilometers/second (km/s), kilometers/hour (km/h)	inches/second (in/s), feet/second (ft/s), feet/minute (ft/min), miles/hour (mph), knots