

# Aerospace Blockset

For Use with Simulink®

- Modeling
- Simulation
- Implementation

User's Guide

*Version 1*



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### *Aerospace Blockset User's Guide*

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## Aerospace Units

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# Getting Started

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The Aerospace Blockset lets you model aerospace systems for use with Simulink® and MATLAB®.

What Is the Aerospace Blockset? (p. 1-2)

Introduction to the Aerospace Blockset and the Simulink environment

Required Products (p. 1-3)

Products you might want to use with the Aerospace Blockset and requirements for virtual reality visualization

Opening the Aerospace Blockset in Simulink (p. 1-4)

How to open the Aerospace Blockset in Simulink

Running a Demo Model (p. 1-8)

Learn how to execute an aerospace model in Simulink, examine the results, and modify the model settings and parameters

## **What Is the Aerospace Blockset?**

The Aerospace Blockset brings the full power of Simulink to aerospace system design, integration, and simulation by providing key aerospace subsystems and components in the adaptable Simulink block format. From environmental models to equations of motion, from gain scheduling to animation, the blockset gives you the core components to assemble a broad range of large aerospace system architectures rapidly and efficiently.

You can use the Aerospace Blockset and Simulink to develop your aerospace system concepts and to efficiently revise and test your models throughout the life cycle of your design. Use the Aerospace Blockset together with Real-Time Workshop<sup>®</sup> to automatically generate code for real-time execution in rapid prototyping and for hardware-in-the-loop systems.

### **What's in This Chapter**

This chapter introduces you to the capabilities of the Aerospace Blockset and its relationship to other MathWorks products:

- “Required Products” on page 1-3
- “Opening the Aerospace Blockset in Simulink” on page 1-4

## Required Products

The MathWorks provides several products that are especially relevant to the kinds of tasks you can perform with the Aerospace Blockset. In particular, the Aerospace Blockset requires these products:

- MATLAB 7
- Control System Toolbox 5.2
- Simulink 6

### Virtual Reality-Based Visualization

The optional virtual reality-based visualization blocks in the Aerospace Blockset require the Virtual Reality Toolbox Version 4.0. The Virtual Reality Toolbox includes a default viewer, which works on all platforms.

You can also install the blaxxun Contact plug-in viewer, Version 4.4, for Web browsers. This plug-in is included with the Virtual Reality Toolbox and works on Windows platforms only. It requires Java-enabled Microsoft Internet Explorer 4.0, Netscape Navigator 4.0, or a later version Web browser.

For more information about any of these products

- Consult the online documentation for that product
- Visit the MathWorks Web site, at [www.mathworks.com](http://www.mathworks.com); see the “Products” section

## Opening the Aerospace Blockset in Simulink

To get started with the Aerospace Blockset, you need to use Simulink. All the blocks in the Aerospace Blockset are designed for use together with the blocks in the Simulink libraries. This section describes how to open the Aerospace Blockset on Windows and on UNIX platforms:

“Opening the Aerospace Blockset on Windows Platforms” on page 1-4

“Opening the Aerospace Blockset on UNIX Platforms” on page 1-7

### Opening the Aerospace Blockset on Windows Platforms

You can open the Aerospace Blockset from the Simulink Library Browser.

#### Opening the Simulink Library Browser

To start Simulink, click the  icon in the MATLAB toolbar, or enter

```
simulink
```

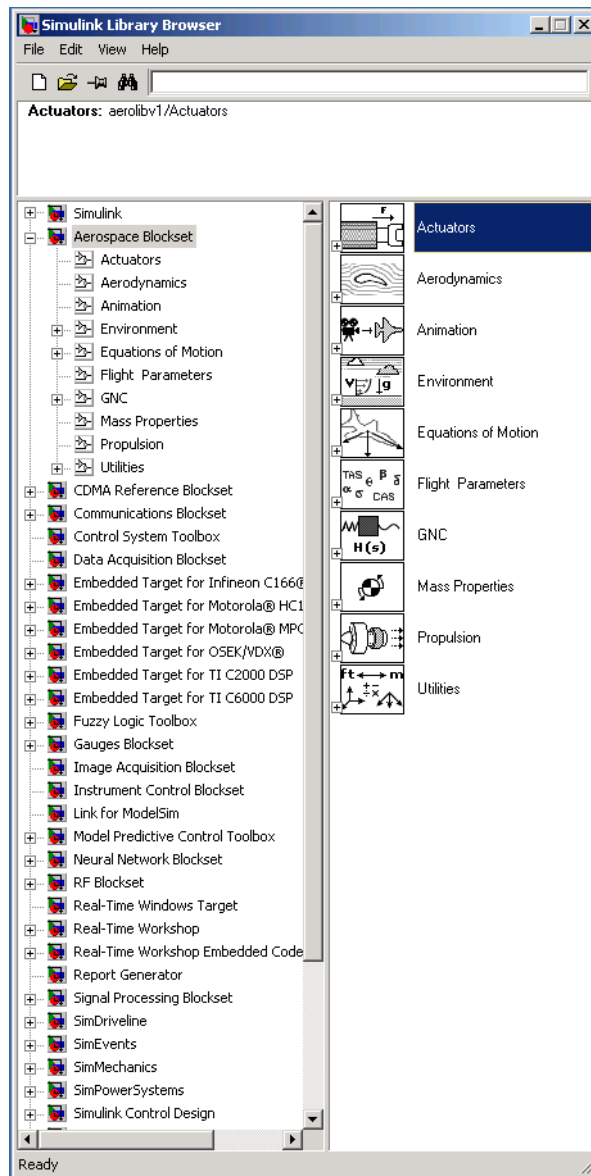
at the command line.

#### The Simulink Libraries

The libraries in the Simulink Library Browser contain all the basic elements you need to construct a model. Look here for basic math operations, switches, connectors, simulation control elements, and other items that do not have a specific aerospace orientation.

#### Opening the Aerospace Blockset

On Windows platforms, the **Simulink Library Browser** opens when you start Simulink. The left pane contains a list of all the blocksets that you currently have installed.

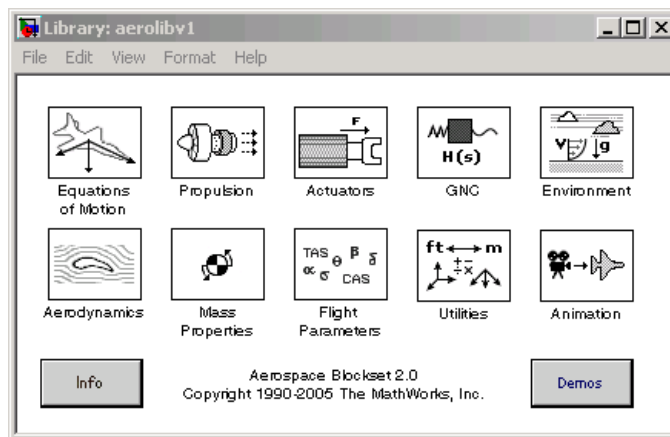


The first item in the list is the Simulink blockset itself, which is already expanded to show the available Simulink libraries. Click the  $\oplus$  symbol to the left of any blockset name to expand the hierarchical list and display that blockset's libraries within the browser.

To open the Aerospace Blockset window from the MATLAB command line, enter

```
aerolib
```

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



For a complete list of all the blocks in the Aerospace Blockset by library, see "Blocks — Categorical List" on page 4-2.

See the Simulink documentation for a complete description of the Simulink Library Browser.

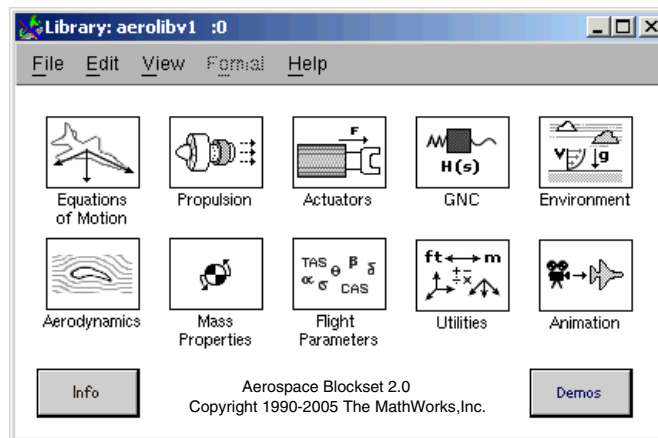
## Opening the Aerospace Blockset on UNIX Platforms

On UNIX platforms, the Simulink Library window opens when you start Simulink. To open the Aerospace Blockset, double-click the **Aerospace Blockset** icon to open the Aerospace Blockset.

To open the Aerospace Blockset window from the MATLAB command line, enter

```
aerolib
```

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



For a complete list of all the blocks in the Aerospace Blockset by library, see "Blocks — Categorical List" on page 4-2.

## Running a Demo Model

This demo model uses some of the blocks in the Aerospace Blockset to simulate a three-degrees-of-freedom missile guidance system. You will see how the demo implements the Aerospace Blockset in conjunction with other Simulink blocks.

The demo model simulates a missile guidance system with a target acquisition and interception subsystem. The model implements a nonlinear representation of the rigid body dynamics of the missile airframe, including aerodynamic forces and moments. In addition, the missile autopilot was developed using the trimmed and linearized missile airframe, and the missile homing guidance systems regulates missile acceleration and measures the distance between the missile and the target.

---

**Note** For more information on the missile guidance model, see Chapter 3, “Case Studies.”

---

### What This Demo Illustrates

The missile guidance demo illustrates the following features of the Aerospace Blockset:

- Representing bodies and degrees of freedom with the Equations of Motion library blocks
- Using the Aerospace Blockset with other Simulink blocks
- Using the Aerospace Blockset with other Mathworks products like Stateflow
- Feeding in and feeding out Simulink signals to and from Aerospace Blockset blocks with Actuator and Sensor blocks
- Encapsulating groups of blocks into subsystems
- Visualizing and animating an aircraft with the Animation library blocks

### Opening the Model

To open a Aerospace Blockset demo from the Help browser, open the Demos library in the Help browser by clicking the **Demos** tab in the **Help Navigator** pane on the left. Locate the demo in the list and open it. You can also open demos by entering the demo name at the command line.



Here is the general procedure for starting Aerospace Blockset demos from the **Start** button of the MATLAB desktop:

- 1 Click the **Start** button.
- 2 Select **Blocksets**, then **Aerospace**, and then **Demos**.

This opens the MATLAB Help browser with **Demos** selected in the left **Help Navigator** pane.

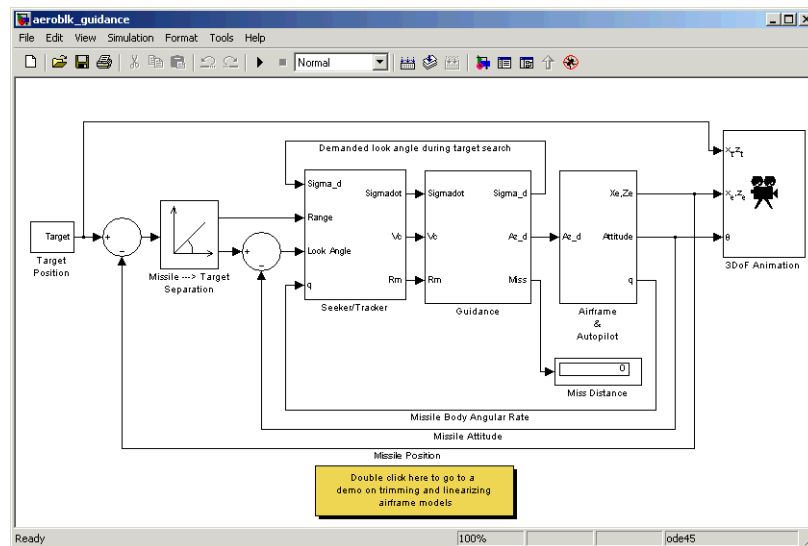
- 3 Double-click **Three Degrees of Freedom Guided Missile** from the list of models in the list.

Alternatively, you can open the same MATLAB **Demos** window by entering demos at the MATLAB command line.

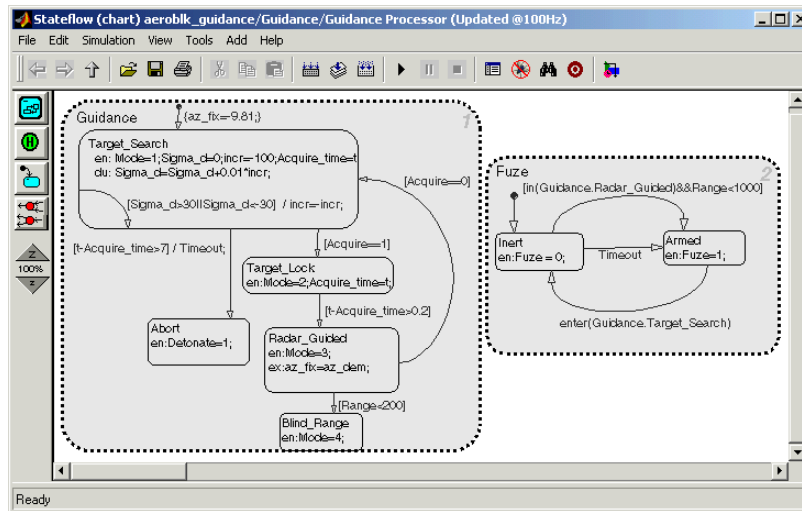
To get started quickly with this specific demo, you can enter `aeroblk_guidance` at the MATLAB command line.

## The Block Diagram Model

The block diagram model opens in a model window.



At the same time, a Stateflow® statechart appears that shows a chart for the guidance control processor.

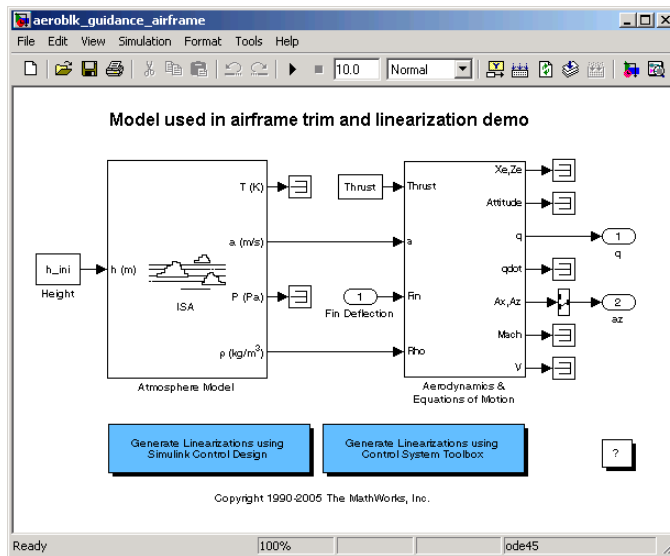


## What the Model Contains

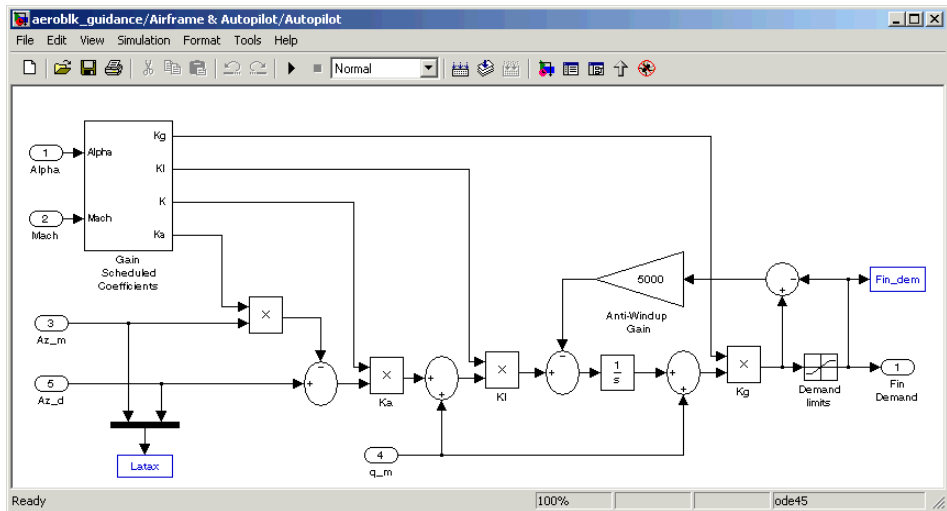
Note some features of the model:

- The Airframe & Autopilot subsystem implements the ISA Atmosphere Model block, the Incidence & Airspeed block, and the 3DoF (Body Axes) block, along with other Simulink blocks.

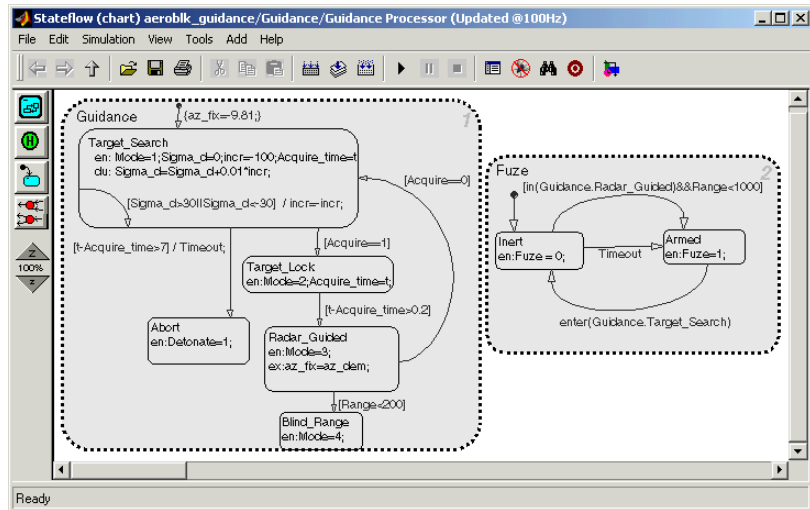
The airframe model is a nonlinear representation of rigid body dynamics. The aerodynamic forces and moments acting on the missile body are generated from coefficients that are nonlinear functions of both incidence and Mach number.



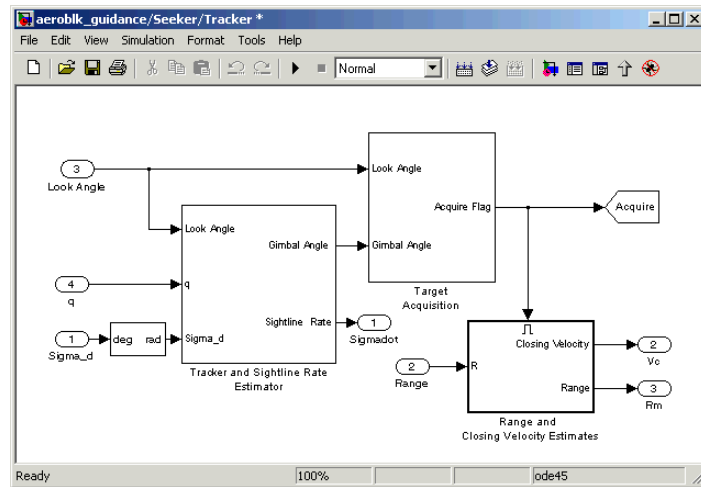
- The model implements the missile autopilot as a classical three-loop design using measurements from an accelerometer located ahead of the missile's center of gravity and from a rate gyro to provide additional damping.



- The model implements the homing guidance system as two subsystems: the Guidance subsystem and the Seeker/Tracker subsystem.
  - The Guidance subsystem uses a Stateflow statechart to control the tracker directly by sending demands to the seeker gimbals.



- The Seeker/Tracker subsystem consists of Simulink blocks that control the seeker gimbals to keep the seeker dish aligned with the target and provide the guidance law with an estimate of the sight line rate.



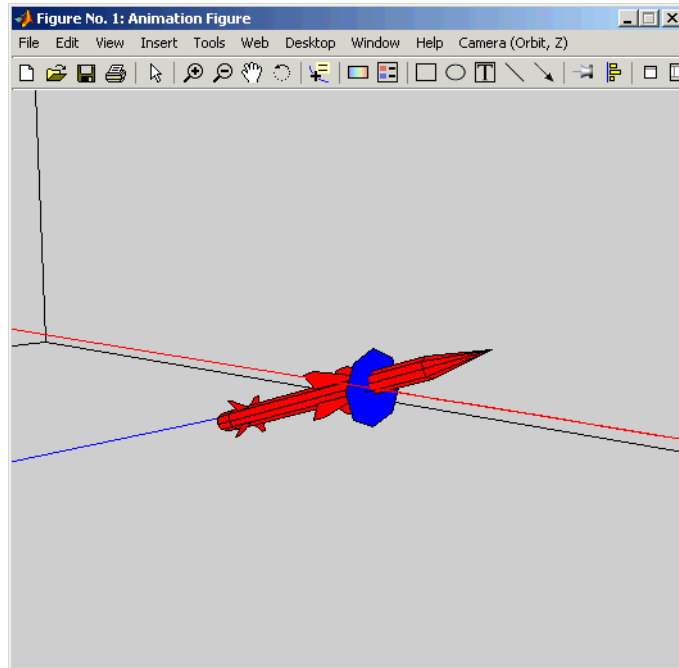
## Running the Demo

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

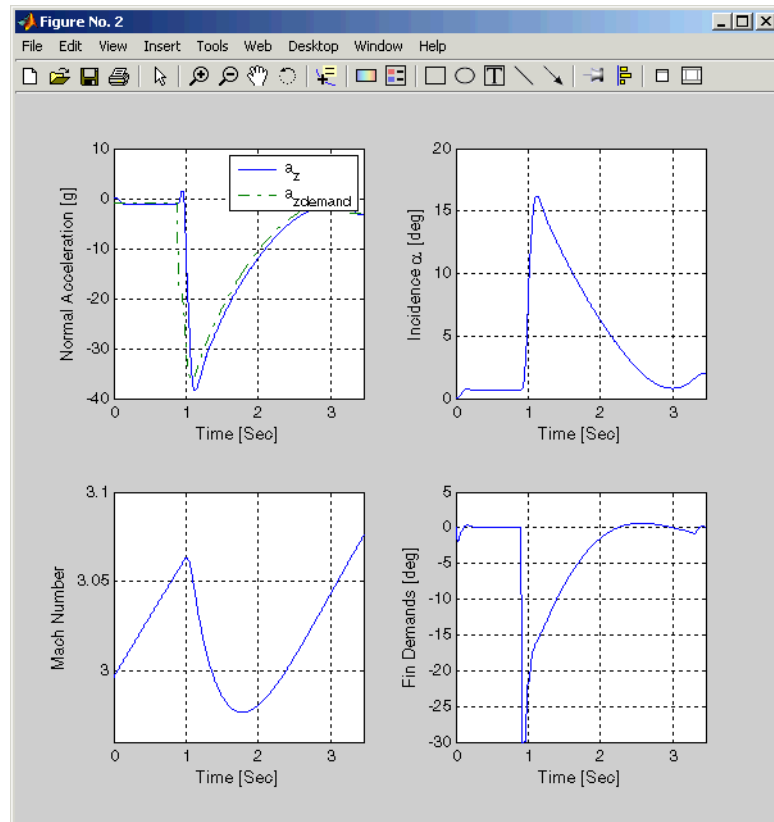
- 1 Open the aeroblk\_guidance demo.
- 2 From the **Simulation** menu, select **Start**. In Microsoft Windows, you can also click the **Start** button in the model window toolbar.

The simulation proceeds until the missile intercepts the target, which takes approximately 3 seconds. Once the interception has occurred, four scope figures open to display the following data:

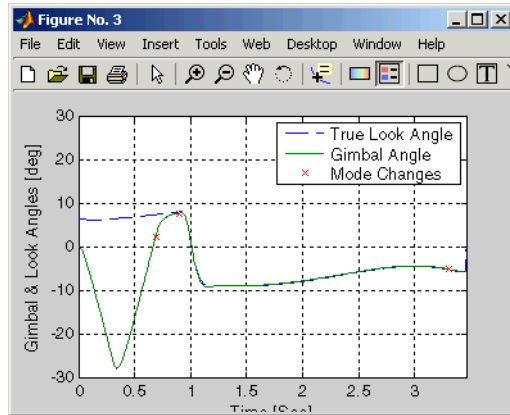
- A three-dimensional animation of the missile and target interception course



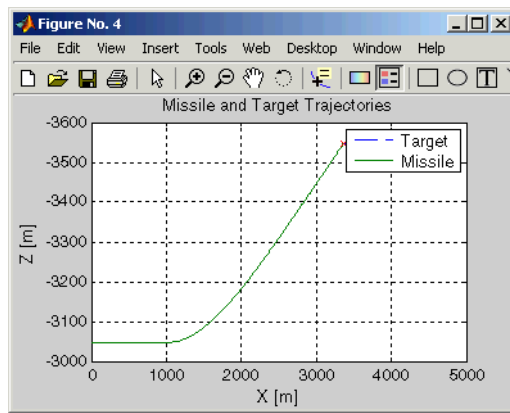
- b** Plots that measure flight parameters over time, including Mach number, fin demand, acceleration, and degree of incidence



- c A plot that measures gimbal versus true look angles



- d A plot that measures missile and target trajectories



## Modifying the Model

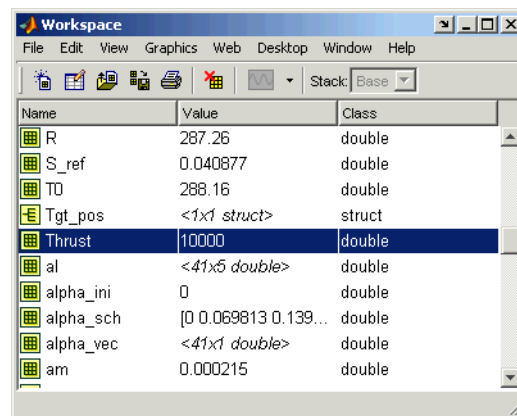
You can adjust model settings and examine the effects on simulation performance. Here are two modifications that you can try. The first modification adjusts the dynamic pressure for the simulation. The second modification changes the camera point of view for the interception animation.



## Adjusting the Thrust

Like any Simulink model, you can adjust aerospace model parameters from the MATLAB workspace. To demonstrate this functionality, you will change the Thrust variable in the model and evaluate the results in the simulation. Follow these steps:

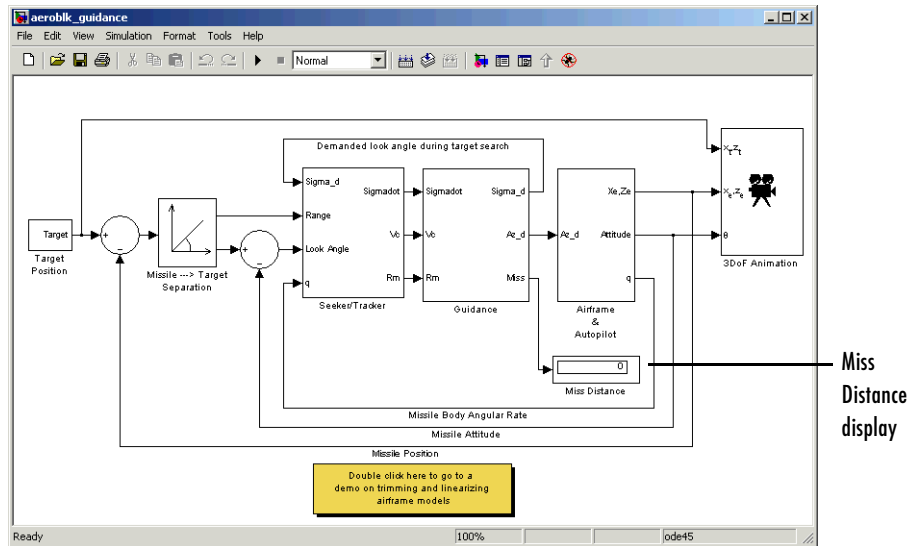
- 1 Open the `aeroblk_guidance` model in Simulink.
- 2 In the MATLAB desktop, find the Thrust variable in the **Workspace** panel.



The Thrust variable is defined in the `aeroblk_guid_dat.m` file, which the `aeroblk_guidance` model uses to populate parameter and variable values. By default, the Thrust variable should be set to 10000.

- 3 Single-click the Thrust variable to select it. To edit the value, right-click on the Thrust variable and select **Edit Value**. Change the value to 5000.

Before you run the demo again, note the **Miss Distance** display in the `aeroblk_guidance` window.

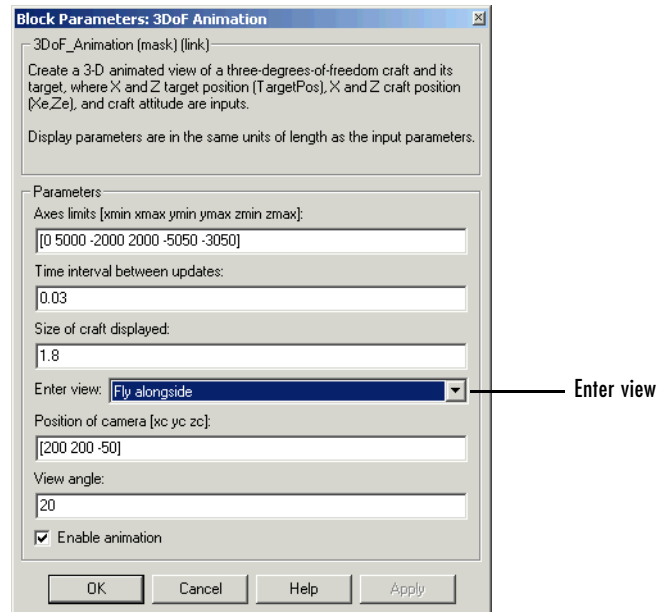


Start the demo, and after it finishes, note the miss distance display again. The miss distance should become greater than the original distance. You can experiment with different values in the Thrust variable and assess the effects on missile accuracy.

## Changing the Animation Point of View

By default, the `aeroblk_guidance` model animation view is Fly Alongside, which means the view tracks with the missile's flight path. You can easily change the animation point of view by adjusting a parameter of the 3DoF Animation block:

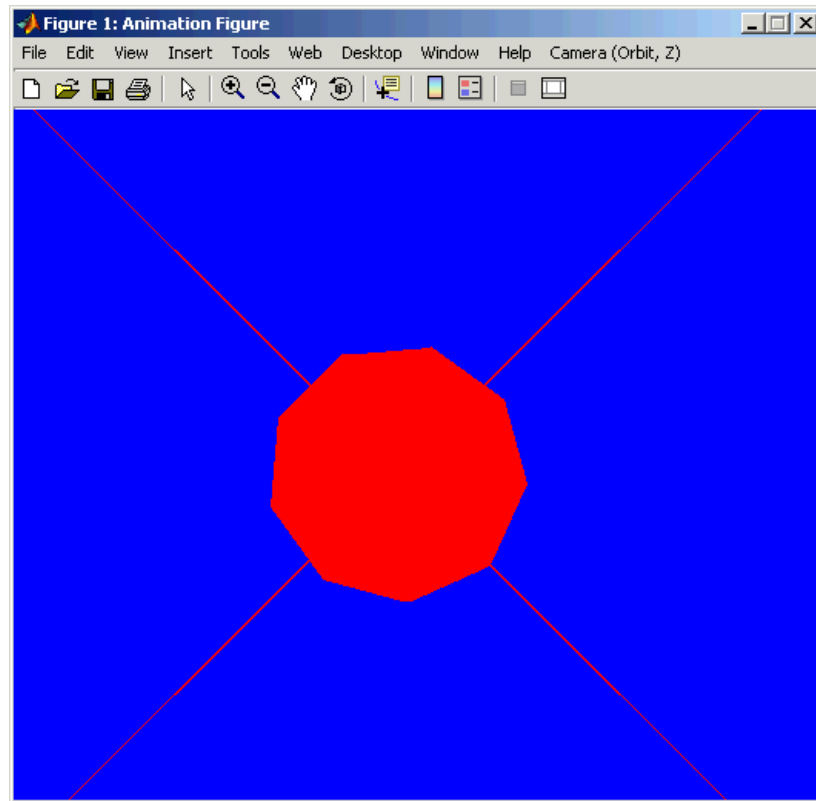
- 1 Open the `aeroblk_guidance` model, and double-click the 3DoF Animation block. The **Block Parameters** dialog box appears.



**2** Change the view to Cockpit.

**3** Click the **OK** button.

Run the demo again, and watch the animation. Instead of moving alongside the missile's flight path, the animation point of view lies in the cockpit. Upon target interception, the screen fills with blue, the target's color.



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

# Using the Aerospace Blockset

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Constructing a simple model with the Aerospace Blockset is easy to learn if you already know how to make Simulink models. If you are not already familiar with Simulink, please see the Simulink documentation.

Introducing the Aerospace Blockset Libraries (p. 2-2)	Overview of the Aerospace Blockset libraries
Creating Aerospace Models (p. 2-6)	Summary of the most important steps for building models with the Aerospace Blockset
Building a Simple Actuator System (p. 2-7)	A tutorial to model and simulate a simple actuator system
Working with the Flight Simulator Interface (p. 2-18)	A tutorial on setting up and using the interface, included with the Aerospace Blockset, to a third-party FlightGear Flight Simulator.

# Introducing the Aerospace Blockset Libraries

The Aerospace Blockset is organized into hierarchical libraries of closely related blocks. The following sections summarize the blocks in each library. You can view the general Aerospace Blockset reference in Chapter 4, “Block Reference.”

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**Note** For more information on viewing the Aerospace Blockset, see Chapter 1, “Getting Started.”

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## Actuators Library

The Actuators library provides blocks for representing linear and nonlinear actuators with saturation and rate limits.

## Aerodynamics Library

The Aerodynamics library provides the Aerodynamic Forces and Moments block using the aerodynamic coefficients, dynamic pressure, center of gravity and center of pressure.

## Animation Library

The Animation library provides the animation blocks for visualizing flight paths and trajectories and for working with a flight simulator interface. The Animation library contains the MATLAB-Based Animation, Flight Simulator Interfaces, and Animation Support Utilities sublibraries.

### MATLAB-Based Animation Sublibrary

The MATLAB-Based Animation sublibrary provides the 3DoF Animation block and the 6DoF Animation block. Using the animation blocks, you can visualize flight paths and trajectories.

### Flight Simulator Interfaces Sublibrary

The Flight Simulator Interfaces sublibrary provides the interface blocks to connect Aerospace Blockset to the third-party FlightGear Flight Simulator.

### **Animation Support Utilities Sublibrary**

The Animation Support Utilities sublibrary provides additional blocks for running the FlightGear Flight Simulator. It contains a joystick interface for Windows platform and a block that lets you set the simulation pace.

### **Environment Library**

The Environment library provides blocks that simulate various aspects of an aircraft environment, such as atmosphere conditions, gravity, magnetic fields, and wind. The Environment library contains the Atmosphere, Gravity, and Wind sublibraries.

### **Atmosphere Sublibrary**

The Atmosphere sublibrary provides general atmospheric models, such as ISA and COESA, and other blocks, including nonstandard day simulations, lapse rate atmosphere, and pressure altitude.

### **Gravity Sublibrary**

The Gravity sublibrary provides blocks that calculate the gravity and magnetic fields for any point on the Earth.

### **Wind Sublibrary**

The Wind sublibrary provides blocks for wind-related simulations, including turbulence, gust, shear, and horizontal wind.

### **Equations of Motion Library**

The Equations of Motion library provides blocks for implementing the equations of motion to determine body position, velocity, attitude, and related values. The Equations of Motion library contains the 3DoF, 6DoF, and Point Mass sublibraries.

### **3DoF Sublibrary**

The 3DoF sublibrary provides blocks for implementing three-degrees-of-freedom equations of motion in your simulations, including custom variable mass models.

### **6DoF Sublibrary**

The 6DoF sublibrary provides blocks for implementing six-degrees-of-freedom equations of motion in your simulations, using Euler angles and quaternion representations.

### **Point Mass Sublibrary**

The Point Mass sublibrary provides blocks for implementing point mass equations of motion in your simulations.

### **Flight Parameters Library**

The Flight Parameters library provides blocks for various parameters, including ideal airspeed correction, mach number, and dynamic pressure.

### **GNC Library**

The GNC library provides blocks for creating control and guidance systems, including various controller models. The GNC library contains the Control, Guidance, and Navigation sublibraries.

### **Control Sublibrary**

The Control sublibrary provides blocks for simulating various control types, such as one-dimensional, two-dimensional, and three-dimensional models.

### **Guidance Sublibrary**

The Guidance sublibrary provides the Calculate Range block, which computes the range between two vehicles.

### **Navigation Sublibrary**

The Navigation sublibrary provides blocks for three-axis measurement of accelerations, angular rates, and inertias.

### **Mass Properties Library**

The Mass Properties library provides blocks for simulating the center of gravity and inertia tensors.



## **Propulsion Library**

The Propulsion library provides the Turbofan Engine System block, which simulates an engine system and controller.

## **Utilities Library**

The Utilities library contains miscellaneous blocks useful in building models. The library contains the Axes Transformations, Math Operations, and Unit Conversions sublibraries.

### **Axes Transformations Sublibrary**

The Axes Transformations sublibrary provides blocks for transforming axes of coordinate systems to different types, such as Euler angles to quaternions and vice versa.

### **Math Operations Sublibrary**

The Math Operations sublibrary provides blocks for common mathematical and matrix operations, including sine and cosine generation and various 3-by-3 matrix operations.

### **Unit Conversions Sublibrary**

The Unit Conversions sublibrary provides blocks for converting common measurement units from one system to another, such as converting acceleration from feet per second to meter per second and vice versa.

# Creating Aerospace Models

Regardless of its complexity, you use the same procedure for creating an aerospace model as you would for creating any other Simulink model. Here are the basic steps:

- 1** *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 will select one block 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. Usually, a simulation block represents a part of the model and design functionality to be simulated, such as an actuator block, a mathematical operation, a block from the Aerospace Blockset, and so on.
  - c** Signal Routing blocks route signals from one point in a model to another. If you have two or more signals in your block, you will likely use a signal routing block in your models, including Mux blocks.
  - d** Sink blocks display or write model output. To see the results of the simulation, you must use a Sink block.
- 2** *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.
- 3** *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. For more information on connecting blocks, see the Simulink documentation.
- 4** *Encapsulate subsystems.* Systems made with the Aerospace Blockset can function as subsystems of larger, more complex models, like subsystems in normal Simulink models. For more information on subsystems, see the Simulink documentation.

## Building a Simple Actuator System

In this tutorial, you drag, drop, and configure a few basic blocks to drive, simulate, and measure an actuator. The tutorial guides you through these aspects of model building:

- “Building the Model” on page 2-7
- “Running the Simulation” on page 2-16

At the end of the tutorial, you will have constructed a simple actuator model that measures the actuator’s position in relation to a sine wave.

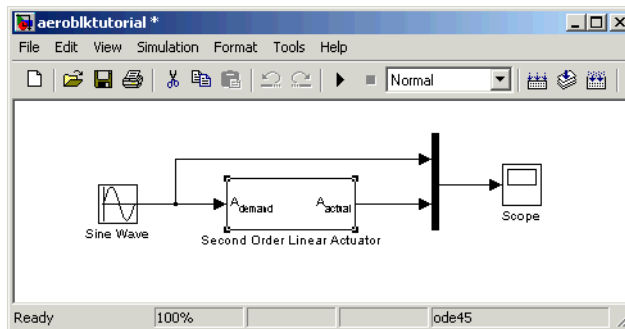
### Building the Model

Simulink 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.

---




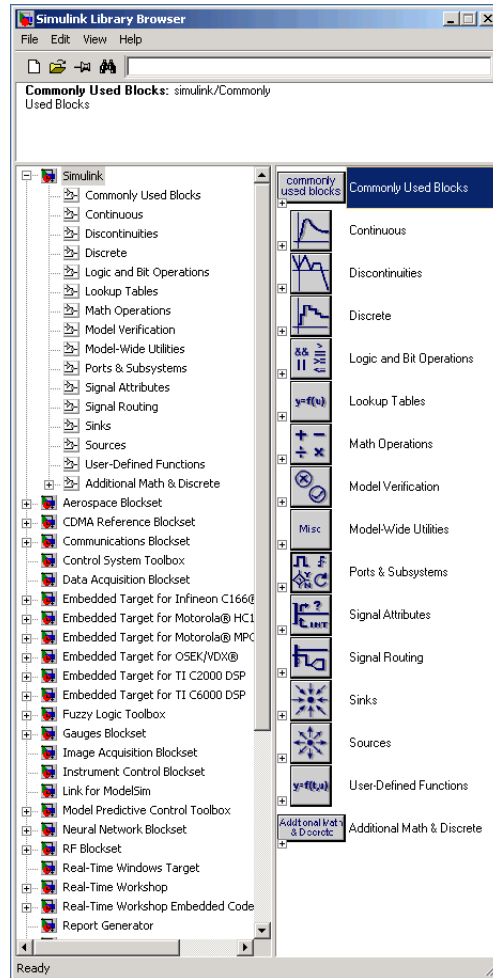
The following sections explain how to build a model on Windows and UNIX platforms:

- “Creating a Model on Windows Platforms” on page 2-8
- “Creating a Model on UNIX Platforms” on page 2-12

### Creating a Model on Windows Platforms

#### 1 Start Simulink.

Click the  button in the MATLAB toolbar or enter `simulink` at the MATLAB command line. The **Simulink Library Browser** appears.




**2** Open a new model.

Select **New -> Model** from the **File** menu in the Library Browser. A new model window appears on your screen.

**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 Second Order Linear 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 Second Order Linear 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.

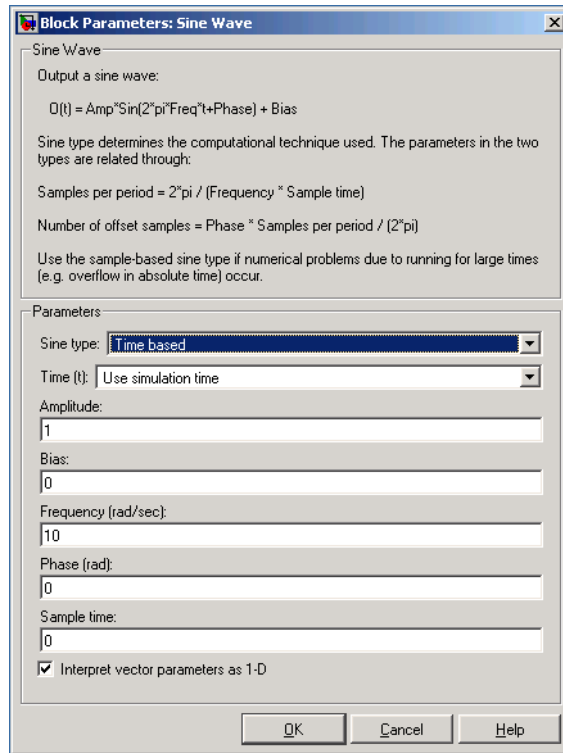
- a** Click **Sinks** in the Library Browser to view the blocks in the Simulink Sinks library.
- b** Drag the Scope block from the Sinks library into the model window.

**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 Second Order Linear Actuator block. Release the mouse button.
  - b Using the same technique, connect the output of the Second Order Linear 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.

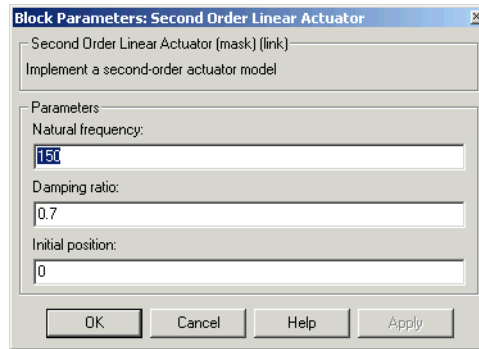
For this example, configure the block to generate a 10 rad/sec sine wave by entering 10 for the **Frequency** parameter. The sinusoid has the default amplitude of 1 and phase of 0 specified by the **Amplitude** and **Phase offset** parameters.
  - b Click **OK**.



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

In this example, the actuator has the default natural frequency of 150 rad/sec, 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**.

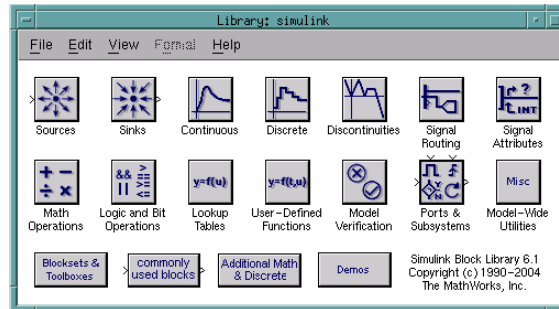


### Creating a Model on UNIX Platforms

For this section, the screenshots were taken from an X Windows client in Microsoft Windows:

#### 1 Start Simulink.

Enter `simulink` at the MATLAB command line. The Simulink Library window appears.



#### 2 Open a new model.

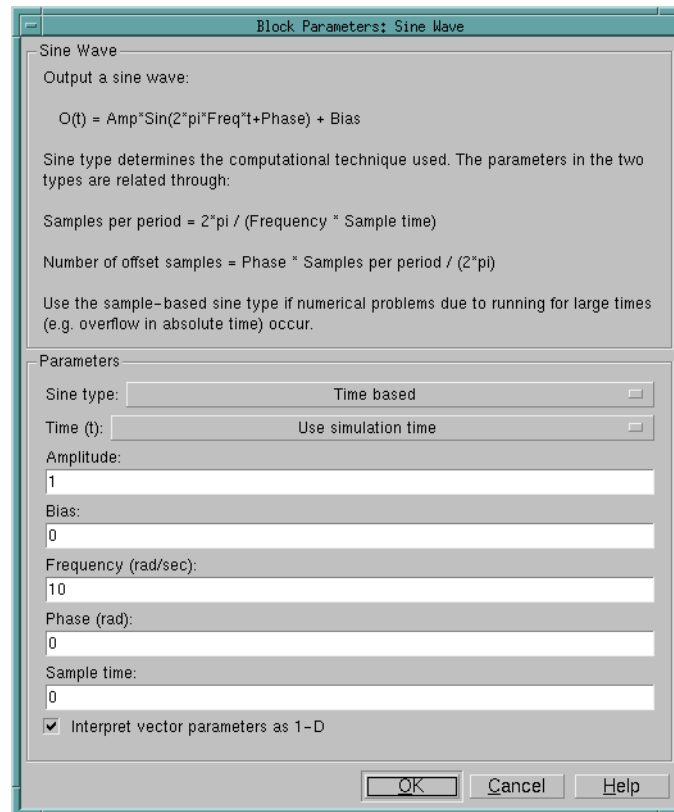
Select **New** -> **Model** from the **File** menu in the Simulink Library window. A new model window appears on your screen.

#### 3 Add a Sine Wave block to the model.





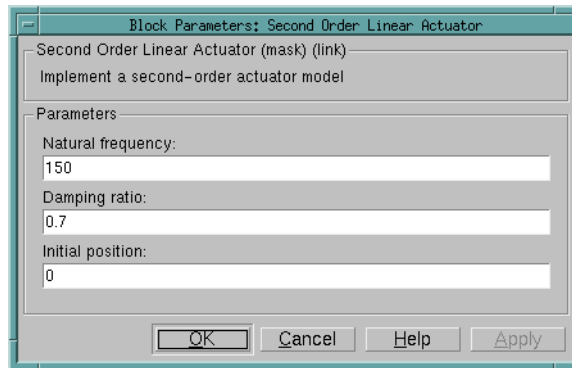




- c Double-click the Second Order Linear Actuator block.

For this example, the actuator has the default natural frequency of 150 rad/sec, 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**.



### Running the Simulation

You can now run the simulation block diagram 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 **Start** from the **Simulation** menu in the block diagram 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. This will cause the simulation to pause.
  - 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 and allow the simulation to continue. 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. There are some parameters, however, like the Sine Wave **Frequency** parameter, that you can *tune* without terminating the simulation.

---

**Note** Opening a dialog box for a source block causes the simulation to pause. While the simulation is paused, you can edit the parameter values. You must close the dialog box to have the changes take effect and allow the simulation to continue.

---

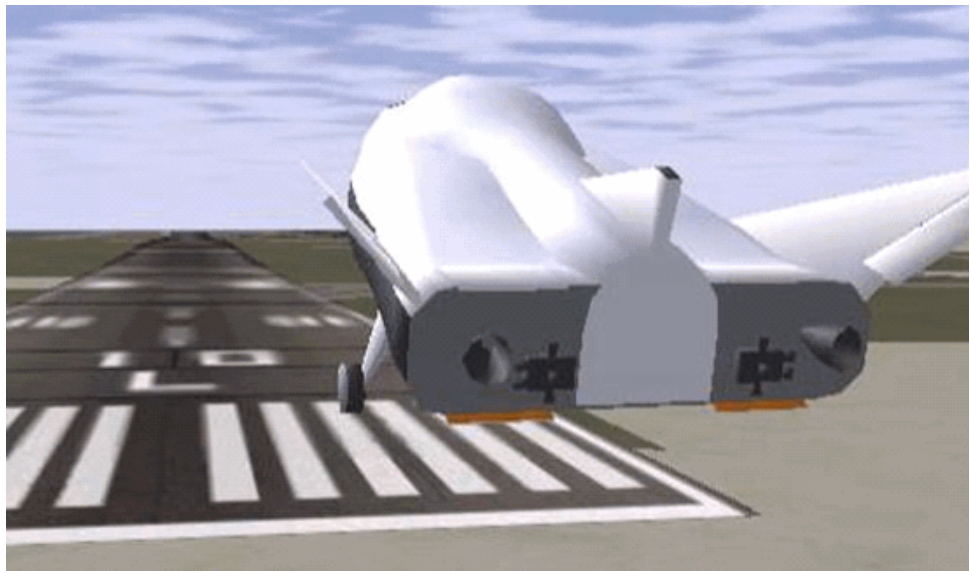
### **Running a Simulation from an M-File**

You can also modify and run a Simulink simulation from within a MATLAB M-file. 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 “Running a Simulation Programmatically” in the Simulink documentation.

### Working with the Flight Simulator Interface

The Aerospace Blockset supports an interface to the third-party FlightGear Flight Simulator, an open source flight simulator software package currently licensed through GPL. See the following topics to learn how to use the Flight Simulator and Aerospace Blockset to visualize your Simulink aircraft models:

- “About the FlightGear Interface” on page 2-19
- “Obtaining and Installing FlightGear” on page 2-19
- “Computer Setup for Using FlightGear” on page 2-19
- “Working with FlightGear Aircraft Geometry Models” on page 2-23
- “Running FlightGear With Simulink” on page 2-27
- “Running the NASA HL-20 Demo with FlightGear Interface” on page 2-36



**Simulink Driven HL-20 Model in a Landing Flare at KSFO**

## About the FlightGear Interface

The FlightGear Flight Simulator is an open source flight simulator software package, currently licensed through GPL. The simulator interface included with Aerospace Blockset is a unidirectional transmission from Simulink to FlightGear using FlightGear's published `net_fdm` binary data exchange specification transmitted via UDP network packets to a running instance of FlightGear.

FlightGear is a separate software entity; it is not created, owned, or maintained by The MathWorks. To report bugs or request enhancements to the Aerospace Blockset FlightGear Interface blocks, contact MathWorks Technical Support by sending e-mail to [support@mathworks.com](mailto:support@mathworks.com), or send e-mail to [suggest@mathworks.com](mailto:suggest@mathworks.com). To report bugs or request enhancements to FlightGear Flight Simulator itself, please visit [www.flightgear.org](http://www.flightgear.org) and use the contact page.

## Obtaining and Installing FlightGear

You can obtain FlightGear Flight Simulator from <http://www.flightgear.org> in the download area or by ordering CDs from FlightGear. The download area contains extensive documentation on installing and configuring FlightGear. Since it is an open source project, source downloads are also available for customization and porting to custom environments.

Aerospace Blockset currently supports the standard binary distributions of FlightGear versions 0.9.3 and 0.9.8a. If you have other stable releases that you would like Aerospace Blockset to interface with, please contact MathWorks Technical Support, or send e-mail to [suggest@mathworks.com](mailto:suggest@mathworks.com).

## Computer Setup for Using FlightGear

The MathWorks tests found FlightGear Flight Simulator's performance and stability to be sensitive to computer video cards, driver versions, and driver settings. The OpenGL settings are particularly important. You need to activate the OpenGL hardware acceleration on your video card. Without proper setup, performance can drop from approximately 30 frames-per-second (fps) update rates down to less than 1 fps.

Operational stability of FlightGear appears to be sensitive during its startup phase. Test results indicate that it is best to not move, resize, mouse over,

overlap, or cover up the FlightGear window until the initial simulation scene appears after the splash screen fades out.

You must have a high performance graphics card with stable drivers to use FlightGear. For more information, see the FlightGear CD distribution or the Hardware Requirements and Documentation areas of the FlightGear Web site.

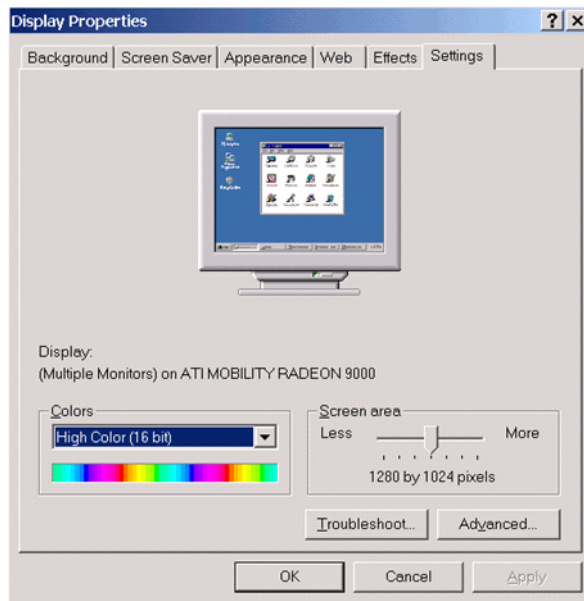
### **Setup on Windows 2000 and XP**

The MathWorks recommends the following Windows setup tips:

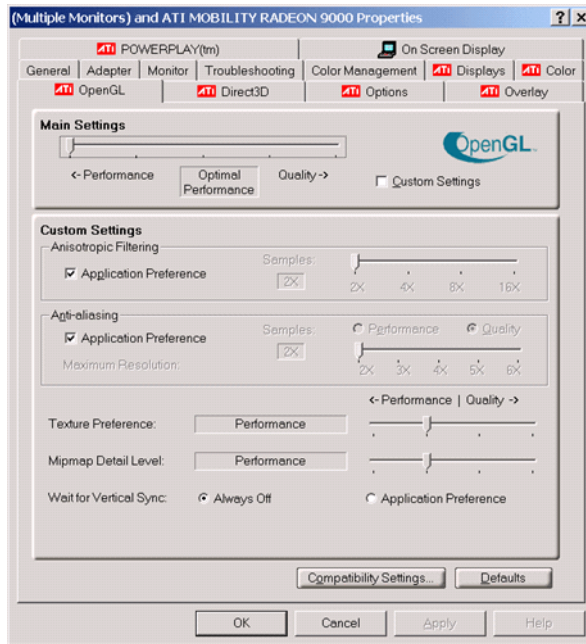
- Choose a graphics card with good OpenGL performance.
- Always use the latest tested, stable driver release for your video card. Test the driver thoroughly on one or two machines before deploying to other machines. For Microsoft Windows 2000 or XP systems running on x86 (32-bit) or AMD-64 / EM64T chip architectures, the graphics card operates in the unprotected kernel space known as Ring Zero. This means that glitches in the driver can cause the entire Windows OS to crash or lock up. Before buying a large number of computers for 3-D applications, it is best to do a pilot project with your vendor on one or two computers to find a combination of hardware, OS, drivers, and settings that are stable for the applications you use.



- Ensure that you have activated the OpenGL hardware acceleration on your video card. On Windows, this is accessed through **Start -> Settings -> Control Panel -> Display** menu item, which in turn opens the following dialog box:



Click the **Advanced** button in the lower right of the dialog box, which brings up the graphics card's custom configuration dialog box, and go to the **OpenGL** tab. For an ATI Radeon, the **OpenGL** pane looks like this:



The best performance is obtained by moving the **Main Settings** slider near the top of the dialog box to the **Performance** end of the slider. Your driver's panes may look completely different.

- Many cards perform much better at 16 bits-per-pixel color depth (also known as 65536 color mode, 16-bit color). For example, on an ATI Mobility Radeon 9000 running a given model, 30 fps are achieved in 16-bit color mode, while 2 fps are achieved in 32-bit color mode. If stability is an issue, try other screen resolutions, color depths in the Display dialog box, and other OpenGL acceleration modes.
- For additional information on OpenGL settings, go to the OpenGL Web site: <http://www.opengl.org/documentation/index.html>

## Setup on Linux, Macintosh, and Other Platforms

FlightGear binary distributions are currently available from the FlightGear Web site (<http://www.flightgear.org>) for linux, Macintosh, SGI, and other platforms. Like Windows, installation on unix and Macintosh platforms requires careful configuration of graphics cards and drivers. See the Hardware Requirements and documentation sections at the FlightGear Web site to access the official documentation.

## Working with FlightGear Aircraft Geometry Models

Attaching your Simulink model to FlightGear is a simple process. The essential step is to create or modify the top-level aircraft description file to indicate that the flight dynamics model (FDM) is external to FlightGear. Aircraft models are located in directories under the *<FlightGearRoot>/data/Aircraft* directory. A complete aircraft model consists of a directory linked through the required aircraft master file named *<model>-set.xml*. All other elements are optional. Default behaviors exist when these elements are not used (for example, default sound: no vehicle-related sounds are emitted, default instrument panel: no instruments are shown). The following is a partial list of the optional elements in an aircraft data directory:

- 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
- Sub-models (independently movable items) associated with the vehicle

Many 3-D aircraft geometry models are available for use with FlightGear. 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.

The only required element for an aircraft description is the flight dynamics model specification. To set Simulink as the source of the flight dynamics model data stream for a given geometry model, you put a line like this in `data/Aircraft/<model>/<model>-set.xml`:

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

You can build models from scratch without a lot of investment by referencing instruments, sounds, and other optional elements from existing FlightGear models. Be sure to comply with copyright rules when distributing these files.

A “mini-HOWTO” document for doing the optional tasks is included in the FlightGear documentation. You can access the mini-HOWTO at:

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

### Aircraft Geometry Models

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](http://www.ac3d.org). Another popular 3-D editor for aircraft models is Flight Sim Design Studio, authored by Louis Sinclair and distributed by Abacus Publications at [www.abacuspub.com](http://www.abacuspub.com).

---

**Note** This is not an endorsement of these products; the names are provided for your reference.

---

Over 12 geometry file formats are supported by FlightGear, so you have a choice of competitive 3-D geometry file formats. Visit the download area of [www.flightgear.org](http://www.flightgear.org) to see some of the aircraft models available. Additional models can be obtained via web search. Search words such as “flight gear aircraft model” are a good starting point.

When creating your own geometry files, an important item to note is the number of surfaces that can be quickly rendered on your graphics card. Some cards only do well with vehicles described using fewer than 1000 surfaces with bitmaps and specular reflections, while other cards can easily render 10,000 surfaces. If a performance issue occurs using a particular geometry, one thing to check is that the number of surfaces is not causing a performance problem. An easy way to check this is to replace the geometry file with a simple shape, such as a single triangle, and test FlightGear performance with this more

trivial geometry to gauge the effect of geometry complexity on graphics performance on your computer. If a geometry file is too complex for smooth display, you can often use 3-D geometry editor tools to simplify a model by reducing the number of surfaces in the geometry.

### Installing New Aircraft into FlightGear

Use the following procedure to install a compatible model into FlightGear:

- 1 Go to the FlightGear installation directory.
- 2 Open the data directory, then the Aircraft directory.
- 3 Make a directory for your aircraft data.
- 4 Put the `<model>-set.xml` file in that directory, plus any other files needed.

It is common practice to make subdirectories for the vehicle geometry files (Model), instruments (Instruments), and sounds (Sounds).

To work with Simulink, the model must indicate that its flight dynamics model is network and that any pre-existing FDM data is removed from the file. It is essential to put a line like this in `<model>-set.xml`:

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

Look at other aircraft data files for examples in geometry models, instruments (geometries and dynamics), views, and sounds. It is fairly simple to copy an aircraft directory 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`.

### Extended Notes for Animating Vehicle Geometries

This additional information may prove helpful in the course of preparing hinge line definitions for animated elements such as vehicle control surfaces and landing gear, each of which must be a named entity in a geometry file to be able to be animated:

- 1 The standard body coordinate system used in FlightGear geometry models is a right-hand-rule system, rotated from the standard body coordinate system in Y by -180 degrees:

X = positive towards the back of the vehicle

Y = positive towards the right of the vehicle

Z = positive is up, e.g., wheels typically have the lowest Z values

- 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 Here is how the hinge point goes 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 differential motion vector in the animation axis:

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

The following is an example of a complete hinge line animation from the HL20 demo 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>
```

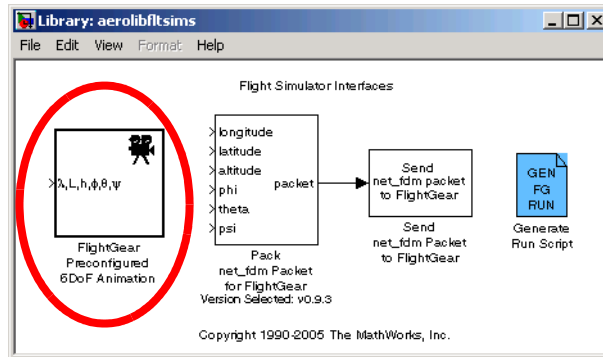
## Running FlightGear With Simulink

There are three main steps to connecting Simulink to FlightGear for visualization:

- “Adding and Connecting Interface Blocks” on page 2-28 – Add and connect interface and pace blocks to your Simulink model
- “Creating a FlightGear Run Script” on page 2-31 – Create a FlightGear run script compatible with your Simulink model
- “Starting FlightGear” on page 2-34 – Start FlightGear first, then run the Simulink model

### Adding and Connecting Interface Blocks

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

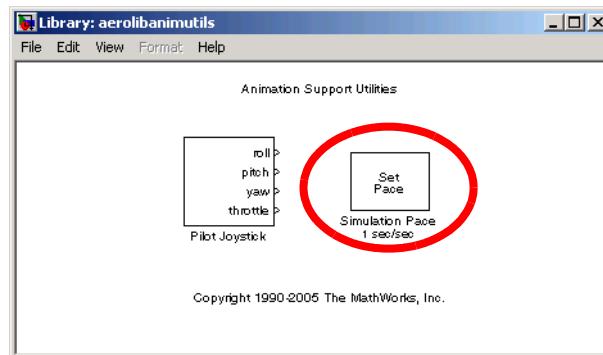
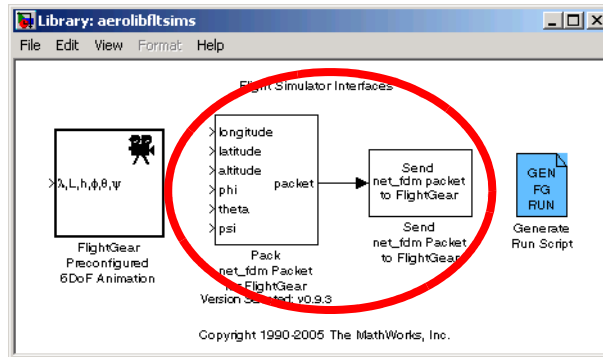


### FlightGear Preconfigured 6DoF Animation Block

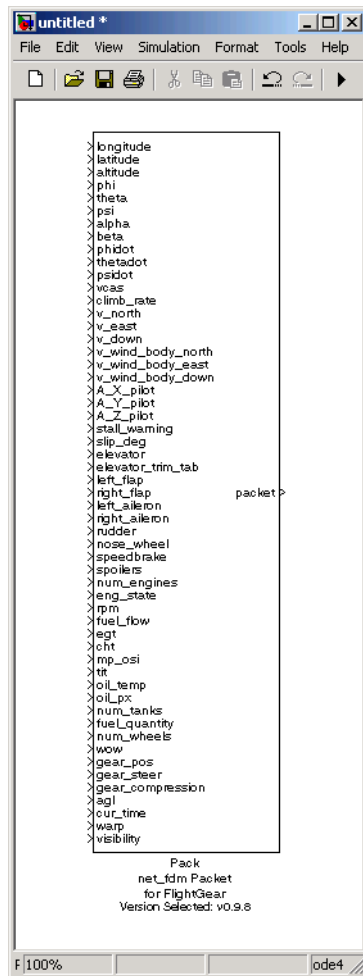
The FlightGear Preconfigured 6DoF Animation block is actually just a subsystem containing the Pack net\_fdm Packet for FlightGear and Send



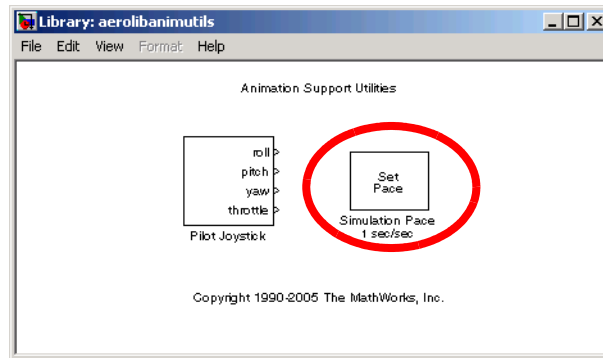
net\_fdm Packet to FlightGear blocks as well as the Simulation Pace block, which is available in the Animation Support Utilities sublibrary:



In general, these three blocks are needed to run a simulation that transmits data to a FlightGear session. The Pack net\_fdm Packet for FlightGear block formats a binary structure compatible with FlightGear from model inputs. In its default configuration, only the 6DoF ports are shown, 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 there is a waiting FlightGear session. The Simulation Pace block slows down 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.



The blocks are provided separately for maximum flexibility and compatibility with future capabilities.

If your Simulink model is complex and cannot run at the aggregate rate needed for the visualization, you may need to use the Simulink Accelerator to speed up the execution of your model. Another way to get more CPU available is to run the Simulink model on one computer and FlightGear on another computer. Use the **Destination IP Address** parameter of the Send block to specify the network address of the computer where FlightGear is running.

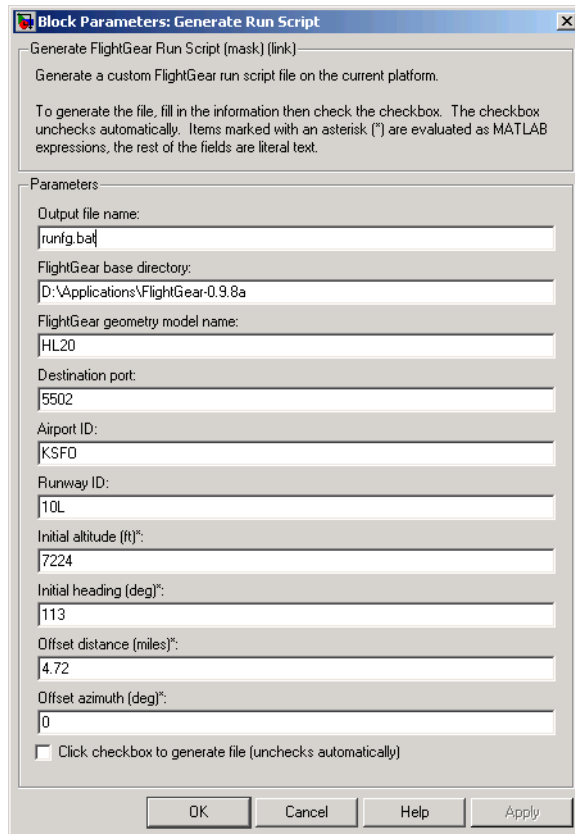
### Creating a FlightGear Run Script

In order to start FlightGear with the desired initial conditions (location, date, time, weather, operating modes), it is best to create a run script. You can do this by using the Generate Run Script block or by using the GUI provided with FlightGear.

If you make separate run scripts for each model you intend to interface to FlightGear and they are in separate directories, run the appropriate script from MATLAB just before simulating your Simulink model.

**Using 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 of the Animation library of the Aerospace Blockset.
- 2 Create a new Simulink model or open an existing model.
- 3 Drag the Generate Run Script block onto an empty space in the Simulink diagram.
- 4 Double-click the Generate Run Script block. The dialog box opens, as shown below.



- 5 In the **Output file name** field, type the name of the output file. This should be the name of the command you want to use to start FlightGear with these initial parameters, with the .bat extension. For example, if your file name is runfg.bat, you will use the runfg command to execute the run script and start FlightGear.
- 6 In the **FlightGear base directory** field, specify the name of your FlightGear installation directory.
- 7 In the **FlightGear geometry model name** field, specify the name of the folder containing the desired model geometry in the *FlightGear\data\Aircraft* directory.
- 8 Specify the initial conditions, as needed.
- 9 Select the checkbox at the bottom of the dialog box.

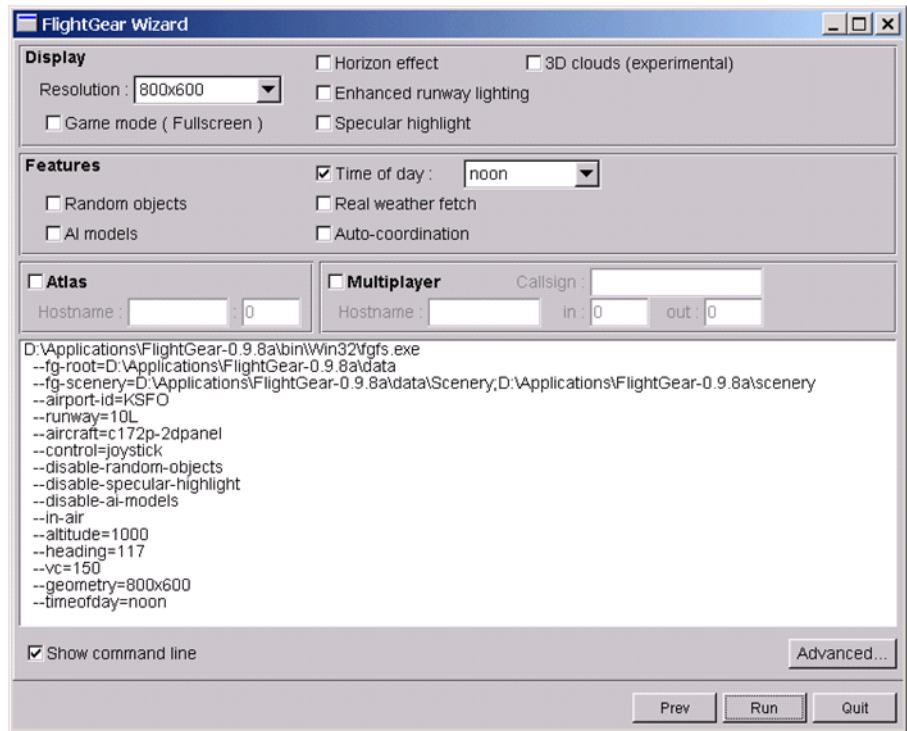
Aerospace Blockset generates the run script, clears the checkbox, and saves it in your working directory under the filename that you specified in the **Output file name** field.

- 10 Repeat Steps 5 through 9 to generate other run scripts, if needed.
- 11 Click **OK** to close the dialog box. You don't have 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 directory. The following is an example of the contents of a run script file:

```
cd D:\Applications\FlightGear-0.9.8a
SET FG_ROOT=D:\Applications\FlightGear-0.9.8a\data
.\bin\win32\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-id=KSFO
--runway=10L --altitude=7224 --heading=113 --offset-distance=4.72
--offset-azimuth=0
```

**Using the GUI provided with FlightGear.** The FlightGear launcher GUI (part of FlightGear, not Aerospace Blockset) lets you build up simple and advanced options into a visible run command:



### Starting FlightGear

If your computer has enough computational power to run both Simulink and FlightGear at the same time, the easiest way to start FlightGear is to build a MATLAB desktop button containing the following command to execute the run script created above:

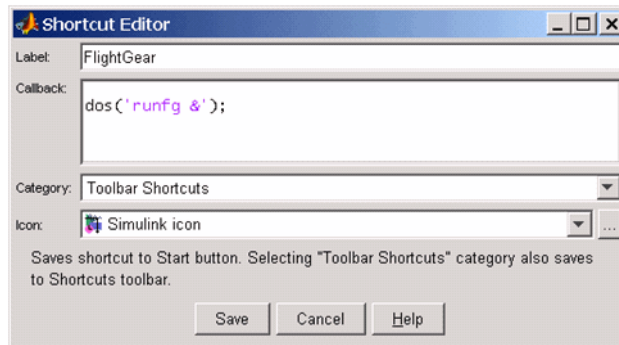
```
dos(`runfg &`)
```

Follow this procedure to create the desktop button:

- 1 In your MATLAB window, click **Start -> Shortcuts -> New Shortcut**.

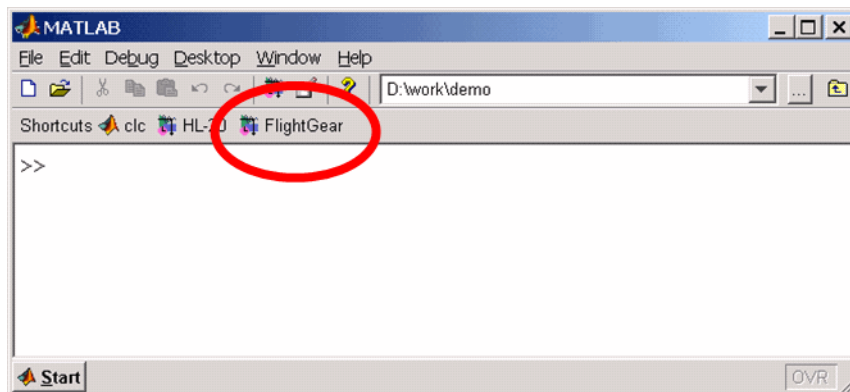
The Shortcut Editor dialog box opens.

- 2 Set the **Label**, **Callback**, **Category**, and **Icon** fields as shown in the following figure.



- 3 Click **Save**.

The **FlightGear** toolbar button appears in your MATLAB desktop, as shown below. If you click it, it runs the `runfg.bat` file in the current directory.



Once you have performed all the setup steps, follow this sequence to both start FlightGear and run your model:

- 1 Load your model and perform **Edit -> Update Diagram** to ensure the model is ready to run. The update diagram step is important because once you start FlightGear, it will use all available CPU cycles while it is in run mode.

- 2 Click the **FlightGear** button or run the FlightGear run script manually.
- 3 When FlightGear starts, it will display the initial view and at the initial coordinates specified in the run script. If you are running Simulink and FlightGear from different computers, arrange to see the two displays at the same time.
- 4 Now begin the simulation and view the animation in FlightGear.

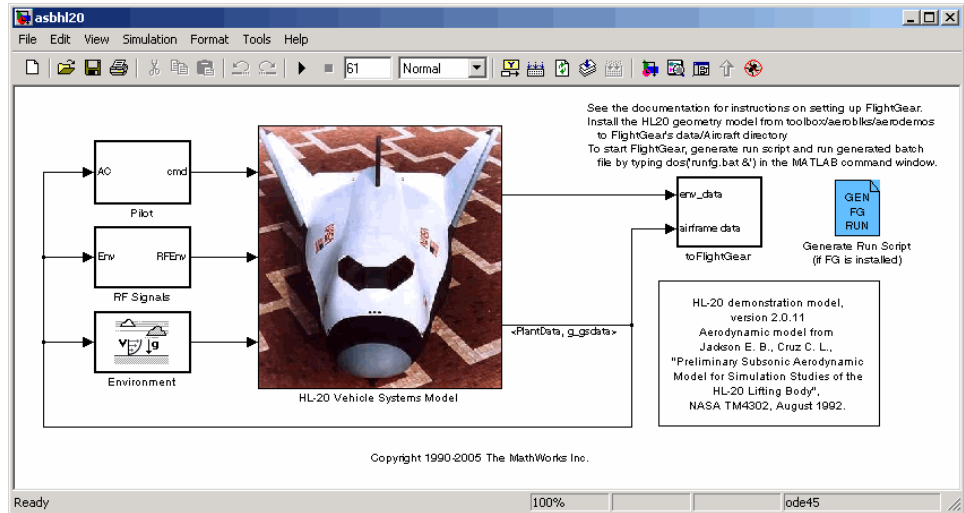
### Running the NASA HL-20 Demo with FlightGear Interface

Aerospace Blockset contains a demo of the NASA HL-20 model with FlightGear Interface. To run this demo:

- 1 Install FlightGear Flight Simulator 0.9.8a, as described in “Obtaining and Installing FlightGear” on page 2-19.
- 2 Copy the HL20 folder from `matlabroot\toolbox\ aeroblks\ aerodemos` directory to `FlightGear\data\Aircraft` directory. This folder contains all the preconfigured geometries for the HL-20 simulation and the `HL20-set.xml` file. For more information, see “Installing New Aircraft into FlightGear” on page 2-25.
- 3 Start MATLAB.
- 4 Open the demo either by typing `asbh120` in the MATLAB Command Window or by selecting **Start -> Demos -> Blocksets -> Aerospace -> Vehicle System Modeling -> NASA HL-20 with FlightGear Interface** and clicking **Open this model** on the demo page.



The demo model opens, as shown below.



- 5 If this is the first time you run the Flight Simulator for this model, double-click the Generate Run Script block to create a run script. Make sure to specify your FlightGear installation directory in the **FlightGear base directory** field. For more information, see “Creating a FlightGear Run Script” on page 2-31.
- 6 Click the **FlightGear** desktop button to execute the run script you created in the previous step and start FlightGear. For more information, see “Starting FlightGear” on page 2-34. If you did not create a desktop button, execute the script manually by typing the following in your MATLAB Command Window:
 

```
dos(`runfg &`)
```
- 7 Now begin the simulation and view the animation in FlightGear.

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



# Case Studies

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Missile Guidance System (p. 3-2)	Design and simulate a three-degrees-of-freedom missile guidance system using Simulink and the Aerospace Blockset
NASA HL-20 Lifting Body Airframe (p. 3-22)	Model the airframe of a NASA HL-20 lifting body, a low-cost complement to the Space Shuttle orbiter, using Simulink and the Aerospace Blockset
Ideal Airspeed Correction (p. 3-36)	Calculate indicated and true airspeed using Simulink and the Aerospace Blockset
1903 Wright Flyer Model (p. 3-43)	Model the airframe, environment, and pilot of the first aircraft, the Wright Flyer

## Missile Guidance System

This section explains how to design and simulate a three-degrees-of-freedom missile guidance system using Simulink and the Aerospace Blockset:

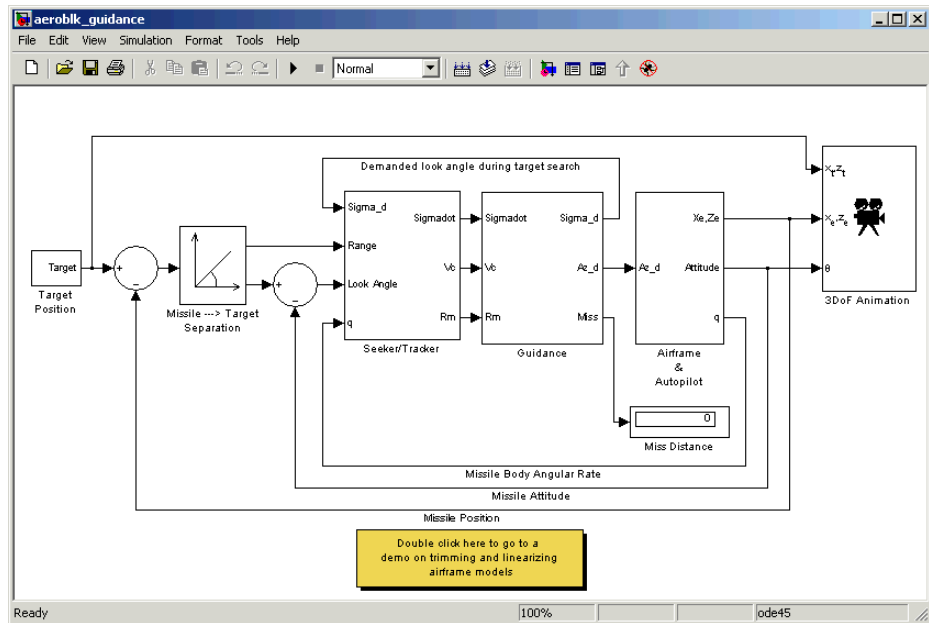
- “Missile Guidance System Model” on page 3-2 shows how to open the model used in this case study.
- “Modeling Airframe Dynamics” on page 3-3 describes how the atmospheric equations and the equations of motion in the missile airframe are implemented.
- “Modeling a Classical Three-Loop Autopilot” on page 3-10 describes how to design the missile autopilot to control the acceleration normal to the missile body.
- “Modeling the Homing Guidance Loop” on page 3-12 describes how to design the homing guidance loop to track the target and generate the demands that are passed to the autopilot.
- “Simulating the Missile Guidance System” on page 3-18 describes how to simulate the model and evaluate system performance.
- “Extending the Model” on page 3-20 examines a full six-degrees-of-freedom equations of motion representation.
- “References” on page 3-20 provides a selected bibliography.

### Missile Guidance System Model

To view the missile guidance system model, enter the following at the MATLAB command line.

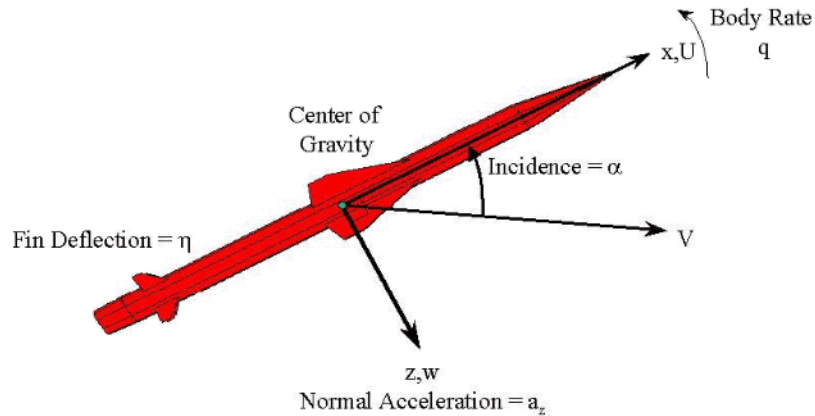
```
aeroblk_guidance
```

The missile airframe and autopilot are contained in the Airframe & Autopilot subsystem. The Seeker/Tracker and Guidance subsystems model the homing guidance loop.



## Modeling Airframe Dynamics

The model of the missile airframe in this demo uses advanced control methods applied to missile autopilot design [1], [2], [3]. The model represents a tail-controlled missile traveling between Mach 2 and Mach 4, at altitudes ranging between 3050 meters (10000 feet) and 18290 meters (60000 feet), and with typical angles of attack in the range of  $\pm 20$  degrees.



#### Missile Airframe Model

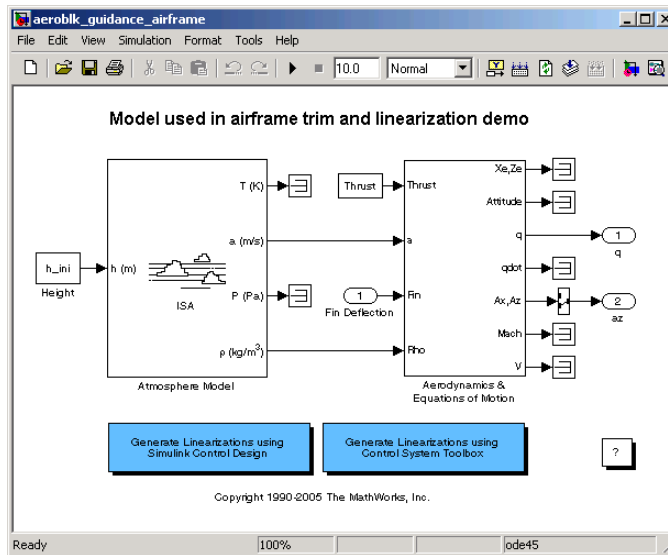
The core element of the model is a nonlinear representation of the rigid body dynamics of the airframe. The aerodynamic forces and moments acting on the missile body are generated from coefficients that are nonlinear functions of both incidence and Mach number. You can model these dynamics easily in the Simulink environment using the Aerospace Blockset.

The model of the missile airframe consists of two main components:

- “ISA Atmosphere Model Block” on page 3-5 calculates the change in atmospheric conditions with changing altitude.
- “Aerodynamics & Equations of Motion Subsystem” on page 3-8 calculates the magnitude of the forces and moments acting on the missile body and integrates the equations of motion.

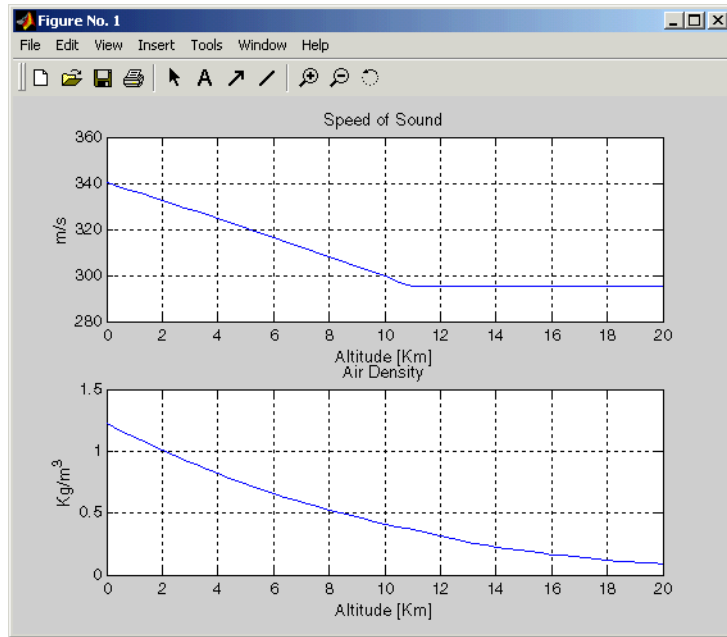
To view the missile airframe model, enter the following in the MATLAB Command Window.

```
aeroblk_guidance_airframe
```



## ISA Atmosphere Model Block

The ISA Atmosphere Model block is an approximation of the International Standard Atmosphere (ISA). This block consists of two sets of equations. One set of equations models is used for the troposphere region, and the other set of equations models is used for the lower stratosphere region. The troposphere region lies between sea level and 11000 meters (36089 feet). The ISA model assumes a linear temperature drop with increasing altitude in the troposphere region. The lower stratosphere region ranges between 11000 meters (36089 feet) and 20000 meters (65617 feet). The ISA models the stratosphere by assuming that the temperature remains constant in the lower stratosphere region. The figure below displays how the speed of sound and the air density vary with altitude.



The following equations define the troposphere.

$$T = T_o - Lh$$

$$\rho = \rho_o \cdot \left(\frac{T}{T_o}\right)^{\frac{g}{LR} - 1}$$

$$P = P_o \cdot \left(\frac{T}{T_o}\right)^{\frac{g}{LR}}$$

$$a = \sqrt{\gamma RT}$$



The following equations define the lower stratosphere.

$$T = 216.7^{\circ}K$$

$$\rho = \rho_o \cdot \left(\frac{T}{T_o}\right)^{\frac{g}{LR}} \cdot e^{\frac{g}{RT}(11000-h)}$$

$$P = P_o \cdot \left(\frac{T}{T_o}\right)^{\frac{g}{LR}-1} \cdot e^{\frac{g}{RT}(11000-h)}$$

$$a = \sqrt{\gamma RT}$$

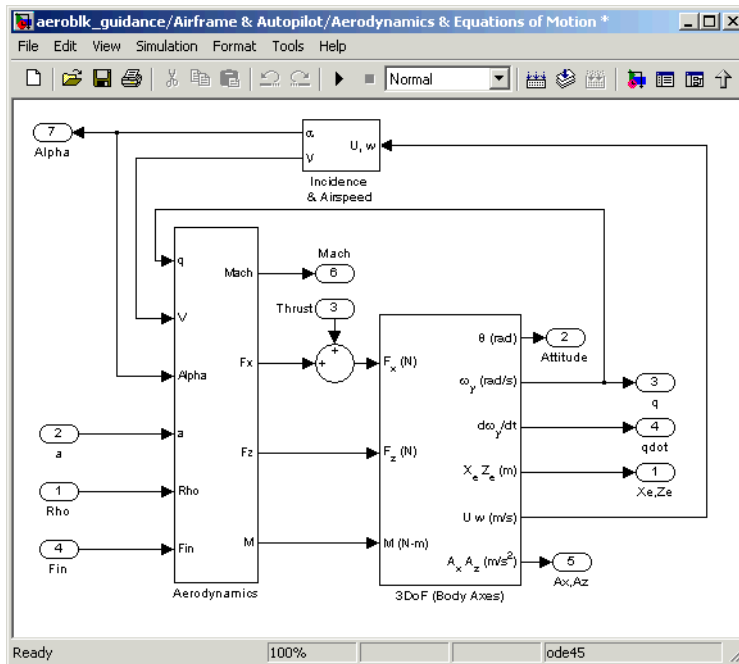
The symbols are defined as follows.

$T_0$	Absolute temperature at mean sea level in degrees Kelvin
$\rho_0$	Air density at mean sea level in kg/m <sup>3</sup>
$P_0$	Static pressure at mean sea level in N/m <sup>2</sup>
$h$	Altitude in m
$T$	Absolute temperature at altitude $h$ in degrees Kelvin
$\rho$	Air density at altitude $h$ in kg/m <sup>3</sup>
$P$	Static pressure at altitude $h$ in N/m <sup>2</sup>
$a$	Speed of sound at altitude $h$ in m/s <sup>2</sup>
$L$	Lapse rate in degrees Kelvin/m
$R$	Characteristic gas constant J/kg-degrees Kelvin
$\gamma$	Specific heat ratio
$g$	Acceleration due to gravity in m/s <sup>2</sup>

You can look under the mask of the ISA Atmosphere Model block to see how these equations are implemented in the model.

### Aerodynamics & Equations of Motion Subsystem

The Aerodynamics & Equations of Motion subsystem generates the forces and moments applied to the missile in the body axes and integrates the equations of motion that define the linear and angular motion of the airframe. The aerodynamic coefficients are stored in data sets, and, during the simulation, the value at the current operating condition is determined by interpolation using the Interpolation (n-D) using PreLook-Up blocks.



These are the three-degrees-of-freedom body axis equations of motion, which are defined in the Equations of Motion (Body Axes) block.

$$\dot{U} = (T + F_x)/m - qW - g \sin \theta$$

$$\dot{W} = F_z/m + qU + g \cos \theta$$

$$\dot{q} = M/I_{yy}$$

$$\dot{\theta} = q$$

These are the aerodynamic forces and moments equations, which are defined in the Aerodynamics subsystem.

$$F_x = \bar{q}S_{ref}C_x(Mach, \alpha)$$

$$F_z = \bar{q}S_{ref}C_z(Mach, \alpha, \eta)$$

$$M = \bar{q}S_{ref}d_{ref}C_M(Mach, \alpha, \eta, q)$$

$$\bar{q} = \frac{1}{2}\rho V^2$$

These are the stability axes variables, which are calculated in the Incidence & Airspeed block.

$$V = \sqrt{U^2 + W^2}$$

$$\alpha = \text{atan}(W/U)$$

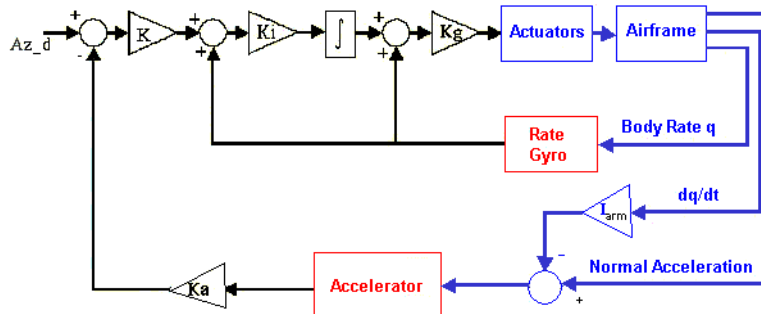
The symbols are defined as follows.

$\theta$	Attitude in radians
$q$	Body rotation rate in rad/s
$M$	Missile mass in kg
$g$	Acceleration due to gravity in m/s <sup>2</sup>
$I_{yy}$	Moment of inertia about the y axis in kg-m <sup>2</sup>
$W$	Acceleration in the Z body axis in m/s <sup>2</sup>
$\dot{q}$	Change in body rotation rate in rad/s <sup>2</sup>
$T$	Thrust in the X body axis in N
$\rho$	Air density in kg/m <sup>3</sup>
$S_{ref}$	Reference area in m <sup>2</sup>
$C_X$	Coefficient of aerodynamic force in the X axis
$C_Z$	Coefficient of aerodynamic force in the Z axis
$C_M$	Coefficient of aerodynamic moment about the Y axis

$d_{ref}$	Reference length in meters
$\eta$	Fin angle in radians
$F_X$	Aerodynamic force in the X body axis in N
$F_Z$	Aerodynamic force in the Z body axis in N
$M$	Aerodynamic moment along the Y body axis
$\bar{q}$	Dynamic pressure in Pa
$V$	Airspeed in m/s
$\alpha$	Incidence in radians
$U$	Velocity in the X body axis in m/s
$W$	Velocity in the Z body axis in m/s

### Modeling a Classical Three-Loop Autopilot

The missile autopilot controls the acceleration normal to the missile body. In this case study, the autopilot structure is a three-loop design using measurements from an accelerometer located ahead of the missile's center of gravity and from a rate gyro to provide additional damping. The following figure shows the classical configuration of an autopilot. The controller gains are scheduled on incidence and Mach number and tuned for robust performance at an altitude of 3050 meters (10000 feet).



Designing an autopilot entails the following:

- “Trimming and Linearizing an Airframe Model” on page 3-11 explains how to model the airframe pitch dynamics for a number of trimmed flight conditions.
- “Autopilot Design” on page 3-12 summarizes the autopilot design process.

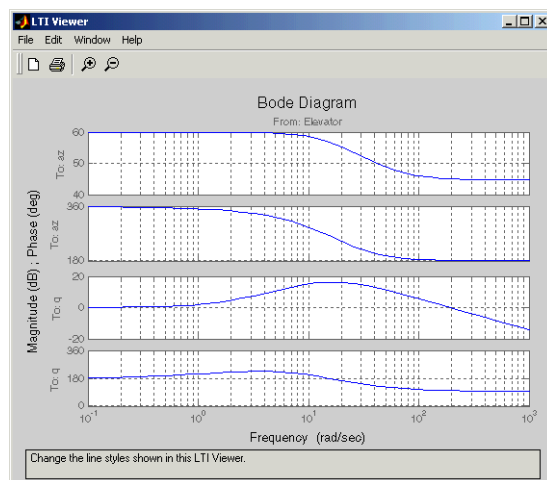
### Trimming and Linearizing an Airframe Model

Designing the autopilot using classical design techniques requires linear models of the airframe pitch dynamics for a number of trimmed flight conditions. MATLAB can determine the trim conditions and derive linear state-space models directly from the nonlinear Simulink model. This saves time and helps to validate the model. The functions provided by the Control System Toolbox allow you to visualize the behavior of the airframe in terms of open-loop frequency (or time) responses.

The airframe trim demo shows how to trim and linearize an airframe model. To run this demo, enter the following in the MATLAB Command Window.

```
aeroblk_lin_aero
```

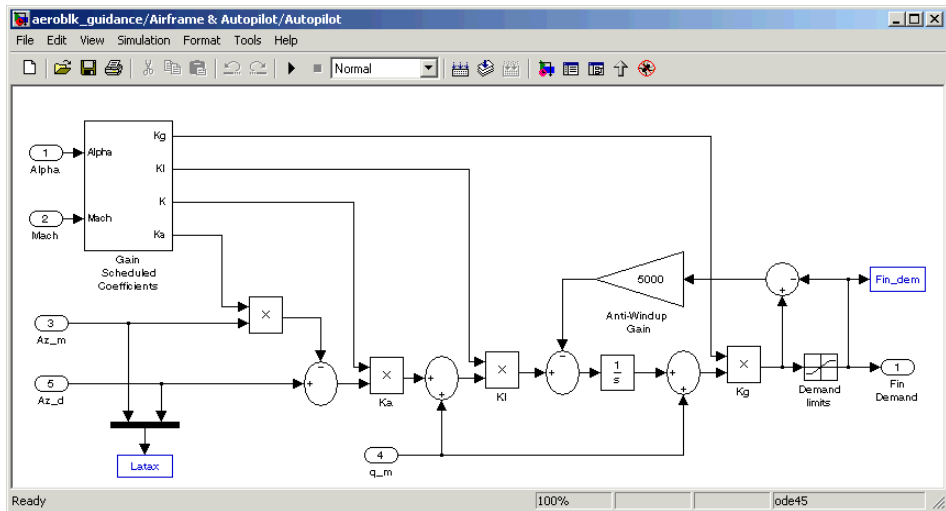
The output from this demo is a Bode diagram in the Control System Toolbox viewer.



### Autopilot Design

Autopilot design can begin after the missile airframe has been linearized at a number of flight conditions. Typically, autopilot designs are carried out on a number of linear airframe models derived at varying flight conditions across the expected flight envelope. Implementing the autopilot in the nonlinear model involves storing the autopilot gains in two-dimensional lookup tables and incorporating an antiwindup gain to prevent integrator windup when the fin demands exceed the maximum limits. Testing the autopilot in the nonlinear Simulink model is the best way to demonstrate satisfactory performance in the presence of nonlinearities, such as actuator fin and rate limits and dynamically changing gains.

The Autopilot subsystem is an implementation of the classical three-loop autopilot design within Simulink.

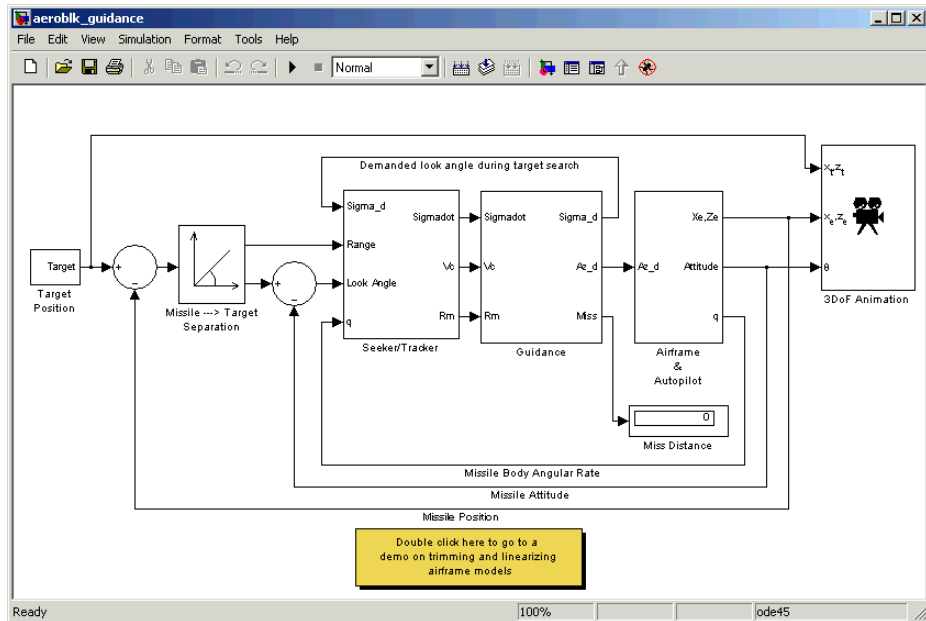


### Modeling the Homing Guidance Loop

The complete homing guidance loop consists of these two subsystems:

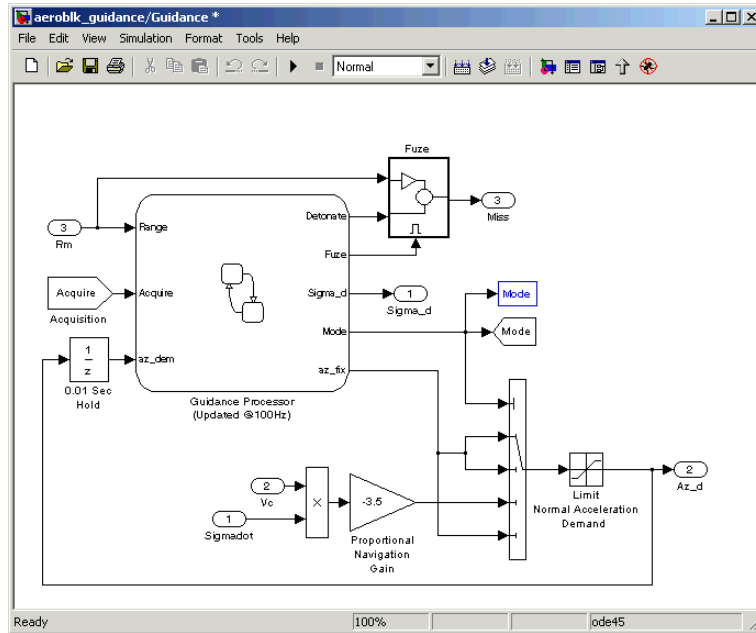
- The “Guidance Subsystem” on page 3-13 generates the normal acceleration demands that are passed to the autopilot.
- The “Seeker/Tracker Subsystem” on page 3-16 returns measurements of the relative motion between the missile and the target.

The autopilot is now part of an inner loop within the overall homing guidance system. Consult Reference [4] for information on different types of guidance systems and on the analysis techniques that are used to quantify guidance loop performance.



## Guidance Subsystem

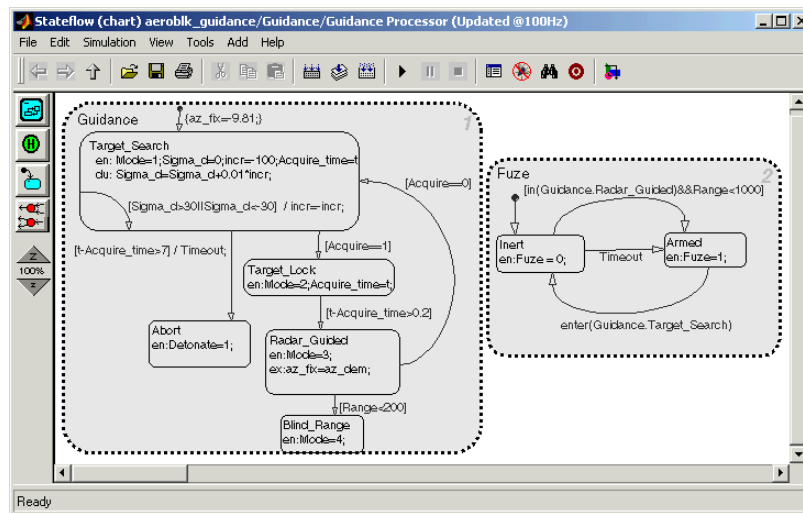
Initially, the Guidance subsystem searches to locate the target's position and then generates demands during closed-loop tracking. A Stateflow model controls the transfer between the different modes of these operations. Stateflow is the ideal tool for rapidly defining all the operational modes, both during normal operation and during unusual situations.



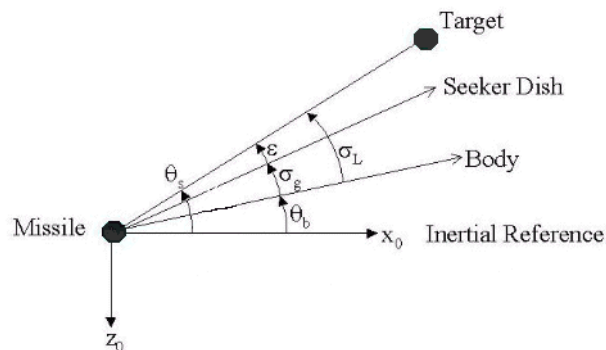
**Guidance Processor Statechart.** Mode switching is triggered by events generated in Simulink or in the Stateflow chart. The variable Mode is passed out to Simulink and is used to control the Simulink model's behavior and to determine the response of the Simulink model. For example, the Guidance Processor state chart, which is part of the Guidance subsystem, shows how the system reacts in response to either losing the target lock or failing to acquire the target's position during the target search.

During the target search, this Stateflow state chart controls the tracker directly by sending demands to the seeker gimbals (Sigma\_d). Target acquisition is flagged by the tracker once the target lies within the beam width of the seeker (Acquire) and, after a short delay, closed loop guidance begins.





**Proportional Navigation Guidance Measurements.** Once the seeker has acquired the target, a Proportional Navigation Guidance (PNG) law guides the missile until impact. This form of guidance law is the most basic, used in guided missiles since the 1950s, and can be applied to radar-, infrared-, or television-guided missiles. The navigation law requires measurements of the closing velocity between the missile and target, which for a radar-guided missile can be obtained with a Doppler tracking device, and an estimate for the rate of change of the inertial sight line angle.



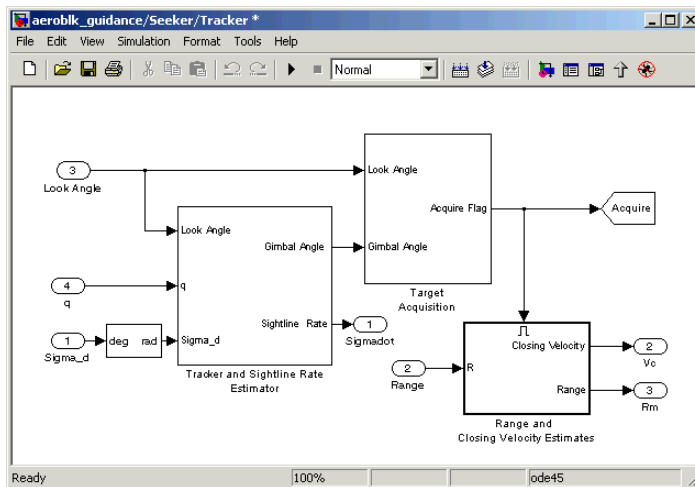
**Proportional Navigation Guidance Measurements**

The diagram symbols are defined as follows.

$\lambda$	Navigation gain ( $> 2$ )
$V_c$	Closing velocity
$\theta_b$	Body attitude
$\dot{\theta}_s$	Sight line rate
$\sigma_g$	Gimbal angle
$\sigma_L$	Look angle
$\sigma_d$	Dish angle
$a_{z\_dem} = \lambda V_c \dot{\theta}_s$	Demanded normal acceleration

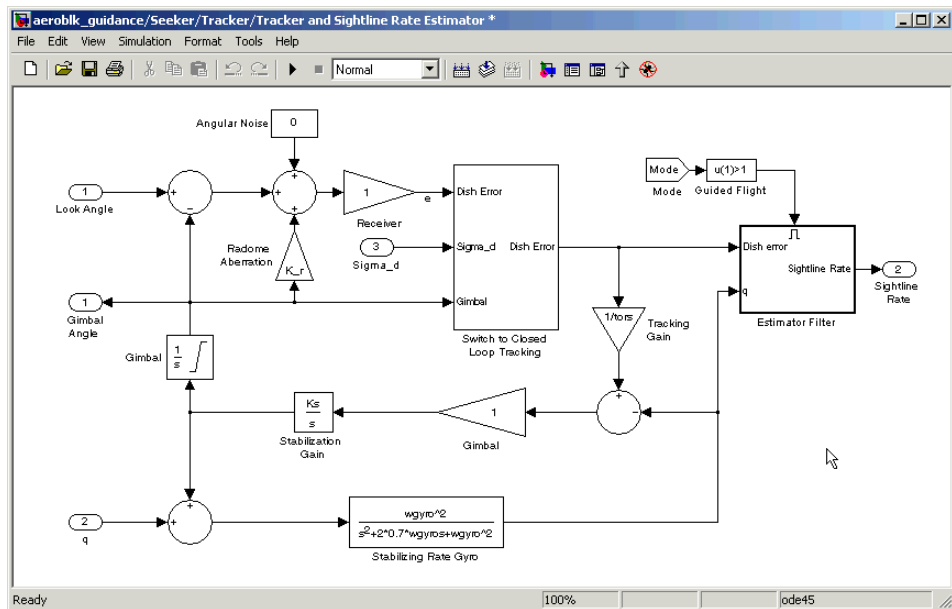
### Seeker/Tracker Subsystem

The Seeker/Tracker subsystem controls the seeker gimbals to keep the seeker dish aligned with the target and provides the guidance law with an estimate of the sight line rate.



**Tracker and Sightline Rate Estimator.** The Tracker and Sightline Rate Estimator, the most elaborate subsystem of the Seeker/Tracker subsystem because of its complex error modeling, is shown below.

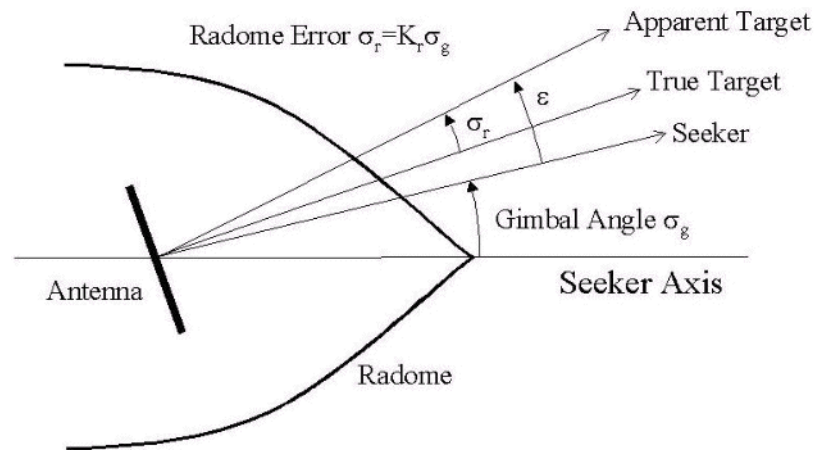
The subsystem contains a number of feedback loops, estimated parameters, and parasitic effects for the homing guidance. The tracker loop time constant  $\tau$  is set to 0.05 second, a compromise between maximizing speed of response and keeping the noise transmission within acceptable levels. The stabilization loop compensates for body rotation rates, and the gain  $K_s$ , which is the loop crossover frequency, is set as high as possible subject to the limitations of the stabilizing rate gyro's bandwidth. The sight line rate estimate is a filtered value of the sum of the rate of change of the dish angle measured by the stabilizing rate gyro and an estimated value for the rate of change of the angular tracking error ( $e$ ) measured by the receiver. In this demo, the bandwidth of the estimator filter is set to half that of the bandwidth of the autopilot.



**Radome Aberration.** Radome aberration is also modeled by the Tracker and Sightline Rate Estimator subsystem.

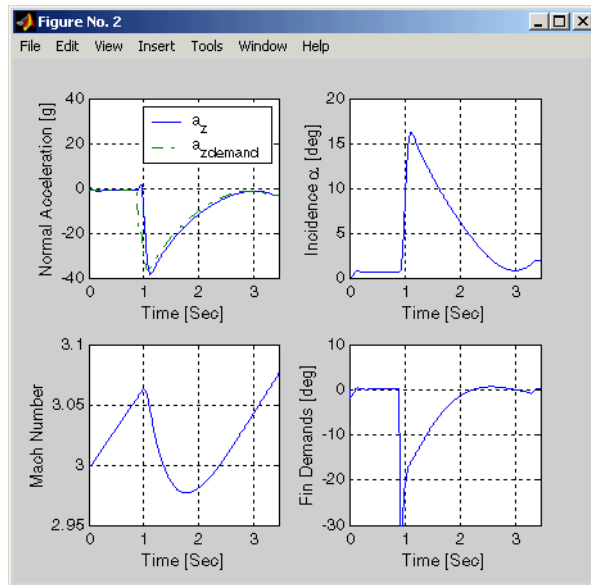
Radome aberration is a parasitic feedback effect commonly modeled in radar-guided missile designs. It occurs because the shape of the protective covering over the seeker distorts the returning signal, and it gives a false reading of the look angle to the target. The amount of distortion is, in general,

a nonlinear function of the current gimbal angle. But a commonly used approximation is to assume a linear relationship between the gimbal angle and the magnitude of the distortion. Often, other parasitic effects, such as sensitivity to normal acceleration in the rate gyros, are also modeled to test the robustness of the target tracker and estimator filters.

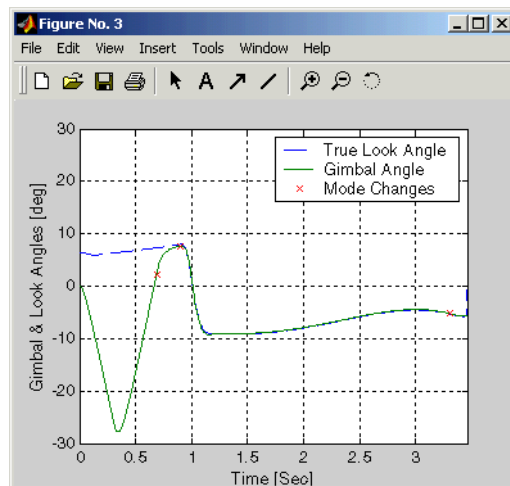


### Simulating the Missile Guidance System

Running the guidance simulation demonstrates the performance of the overall system. The target is defined to be traveling at a constant speed of 328 m/s on a reciprocal course to the initial missile heading and 500 meters above the initial missile position. The data, shown in the figure below, can be used to determine if the missile can withstand the flight demands and complete the mission to impact.



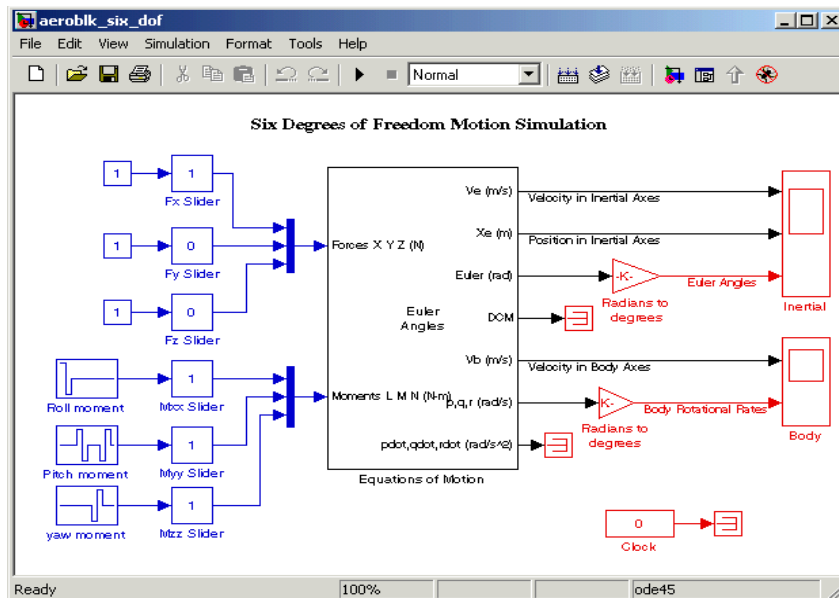
The simulation results show that target acquisition occurs 0.69 second after search initiation, with closed loop guidance starting after 0.89 second. Impact with the target occurs at 3.46 seconds, with the range to target at the point of closest approach calculated to be 0.26 meter.



## Extending the Model

Modeling the airframe and guidance loop in a single plane is only the start of the design process. Extending the model to a full six-degrees-of-freedom representation requires the implementation of the full equations of motion for a rigid body.

Six-degrees-of-freedom can be represented using quaternion or Euler Angles. The quaternion implementation uses a quaternion to represent the angular orientation of the body in space. The quaternion is appropriate when the standard Euler angle definitions become singular as the pitch attitude tends to  $\pm 90$  degrees. The Euler angle implementation uses the standard Euler angle equations of motion. Euler angles are appropriate when obtaining trim conditions and modeling linear airframes. This model contains one of the six-degrees-of-freedom equations of motion blocks.



## References

[1] Bennani, S., D. M. C. Willemsen, and C. W. Scherer, "Robust LPV control with bounded parameter rates," AIAA-97-3641, August 1997.

- [2] Mracek, C. P. and J. R. Cloutier, "Full Envelope Missile Longitudinal Autopilot Design Using the State-Dependent Riccati Equation Method," AIAA-97-3767, August 1997.
- [3] Shamma, J. S. and J. R. Cloutier, "Gain-Scheduled Missile Autopilot Design Using Linear Parameter Varying Transformations," *Journal of Guidance, Control and Dynamics*, Vol. 16, No. 2, March-April 1993.
- [4] Lin, Ching-Fang, *Modern Navigation, Guidance, and Control Processing*, Vol. 2, ISBN 0-13-596230-7, Prentice Hall, 1991.

## NASA HL-20 Lifting Body Airframe

This section shows how to model the airframe of a NASA HL-20 lifting body, a low-cost complement to the Space Shuttle orbiter, with Simulink and the Aerospace Blockset.

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 case study, the Aerospace Blockset is used to rapidly model portions of the HL-20 airframe. The remaining portions, including the calculation of the aerodynamic coefficients, are modeled with Simulink. This case study examines the construction of the Simulink model of the HL-20 airframe and touches on how the aerodynamic data are used in the model.

This section includes the following topics:

- “NASA HL-20 Lifting Body” on page 3-22 provides an overview of the history and purposes of the NASA HL-20 lifting body.
- “The HL-20 Airframe and Controller Model” on page 3-24 describes how the Aerospace Blockset and Simulink are used to model the HL-20 airframe.
- “References” on page 3-35 provides a selected bibliography.

### NASA HL-20 Lifting Body

The HL-20, also known as 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 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 an 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 runways.

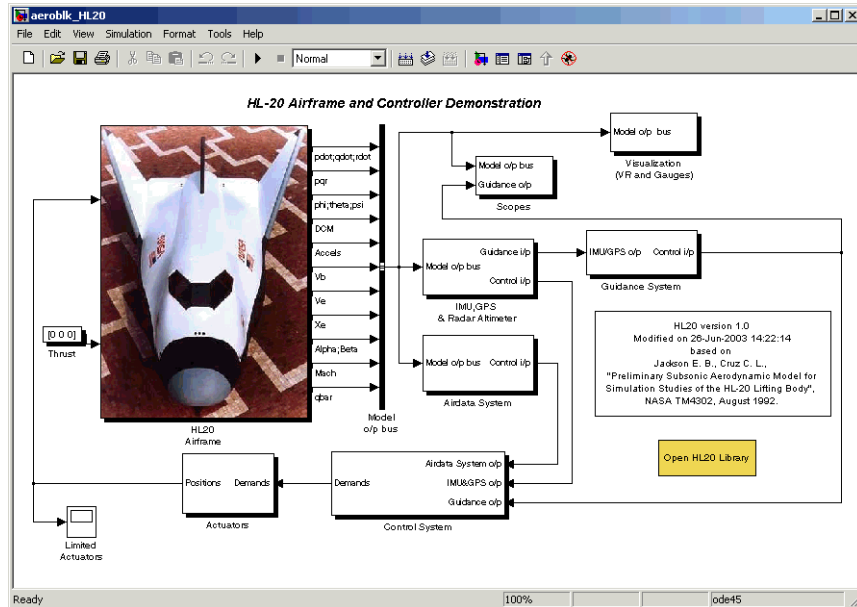
Potential uses for the HL-20 include

- Orbital rescue of stranded astronauts
- International Space Station crew exchanges, if the Space Shuttle orbiter is not available
- 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 HL20 airframe and controller model by entering `aeroblk_HL20_main` at the command line.



### HL-20 Airframe and Controller Model

#### 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 reentry portion of a mission.
- HL-20 is assumed to be a laterally symmetric vehicle.
- Compressibility (Mach) effects are assumed to be negligible.

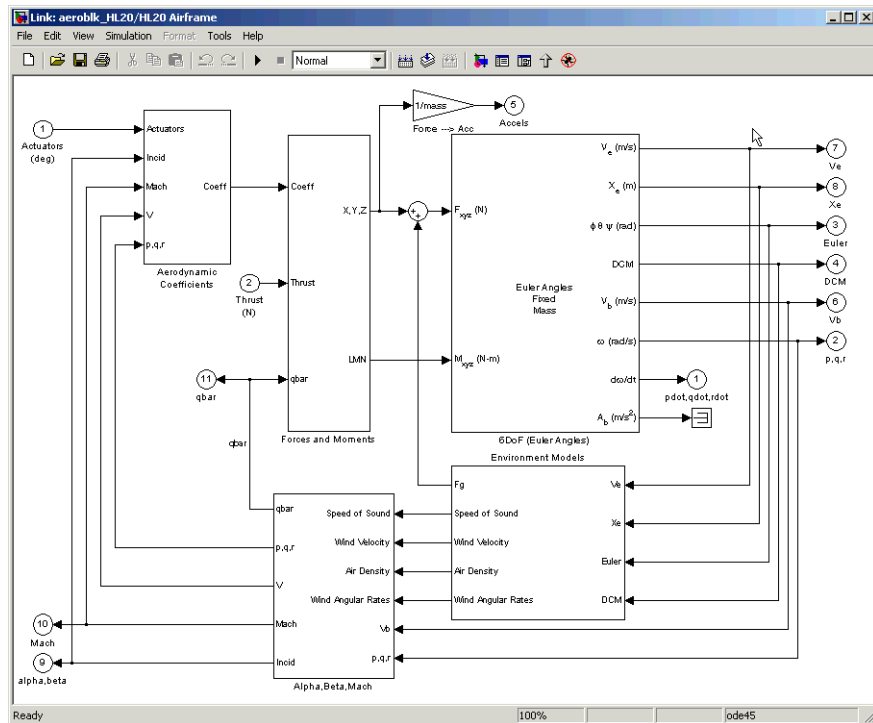
- Control effectiveness is assumed to vary nonlinearly with angle of attack and linearly with angle of deflection. Control effectiveness is not dependent on sideslip angle.
- The nonlinear six-degrees-of-freedom aerodynamic model is a representation of an early version of the HL-20. Therefore the model 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 HL-20 airframe subsystem of the HL-20 airframe model contains five subsystems, which model the typical airframe components:

- “6DoF (Euler Angles) Subsystem” on page 3-26
- “Environmental Models Subsystem” on page 3-27
- “Alpha, Beta, Mach Subsystem” on page 3-29
- “Aerodynamic Coefficients Subsystem” on page 3-30
- “Forces and Moments Subsystem” on page 3-34



## 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. 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 blocks/subsystems:

- 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 aerospace 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.

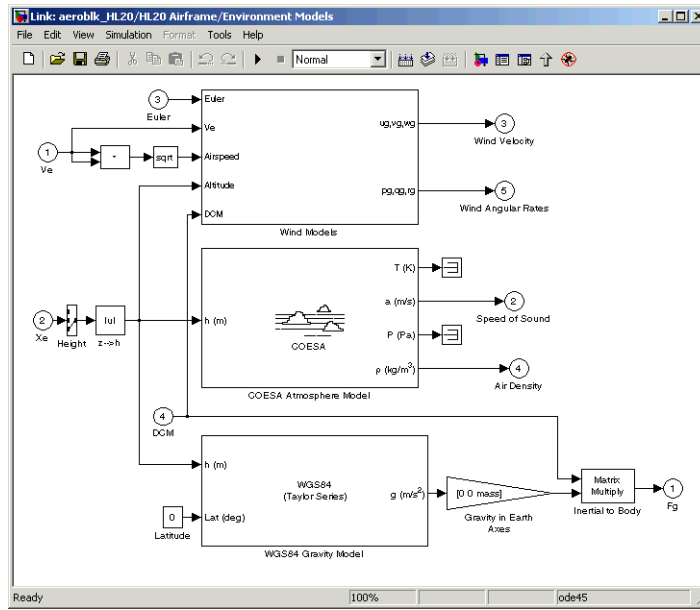
See the Discrete Wind Gust Model block reference page for more information on this block.

- 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.

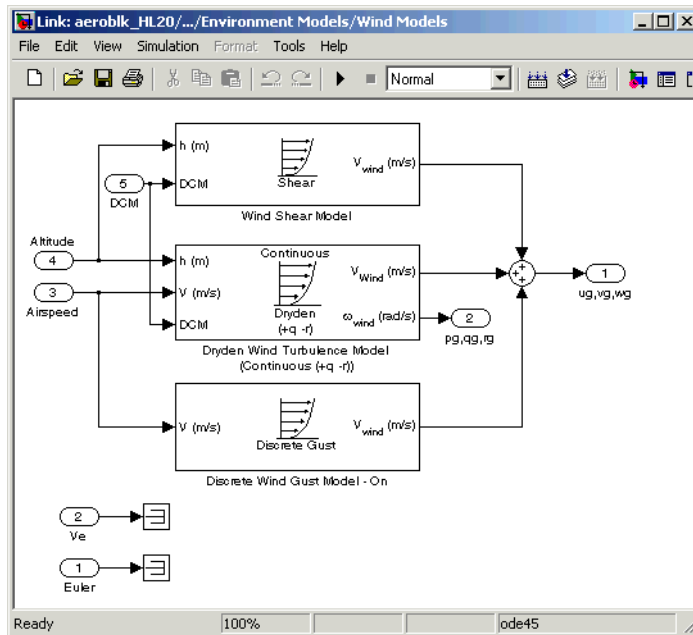
See Dryden Wind Turbulence Model (Continuous) block reference page for more information on this block.

These are some of the standard environmental blocks contained in the Aerospace Blockset. The environmental models implement mathematical representations within standard references, such as U.S. Standard Atmosphere, 1976.

The following figures show the environmental and wind turbulence models used in the model.



**Environmental Models in HL-20 Airframe Model**



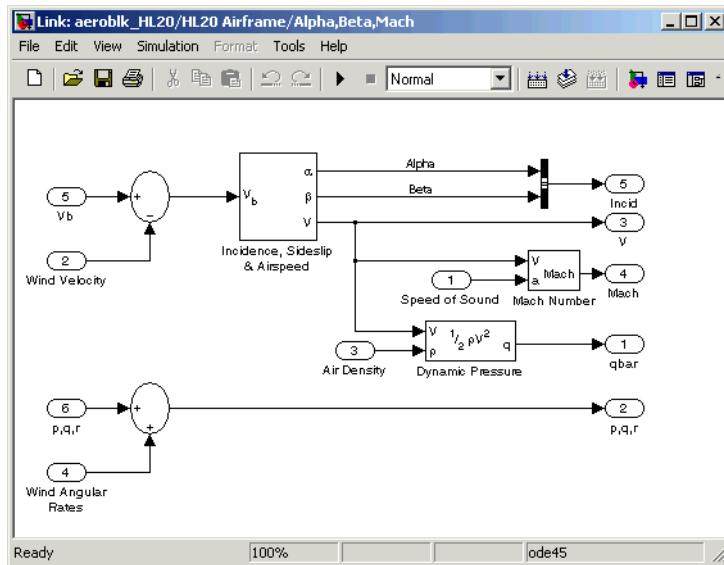
## Wind Models in HL-20 Airframe Model

### 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 ( $\alpha, \beta$ )
- 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)

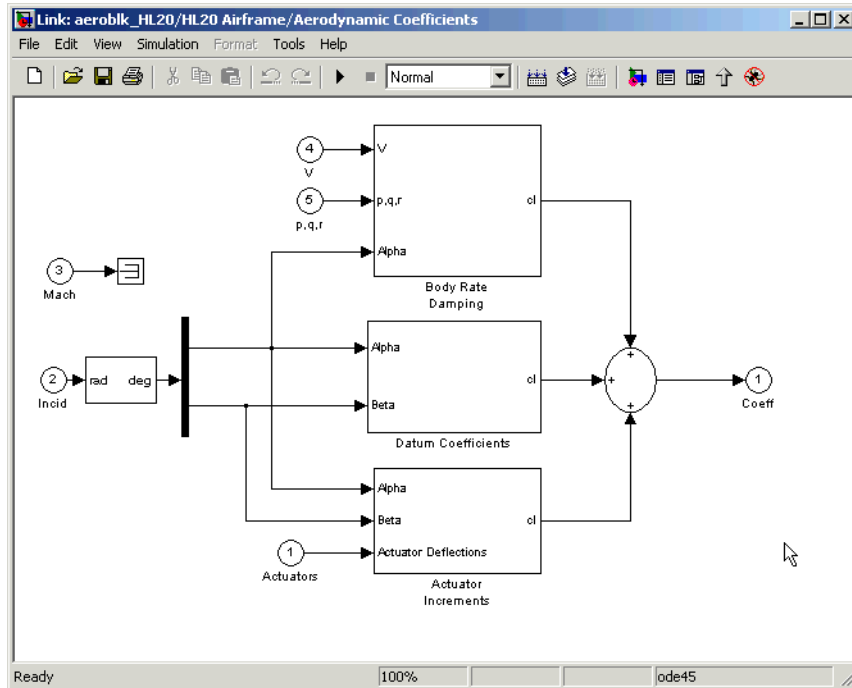
#### Aerodynamic Coefficients Subsystem

The Aerodynamic Coefficients subsystem contains aerodynamic data and equations for calculating the six aerodynamic coefficients, which are implemented as in NASA document TM4302. However, the ground and landing gear effects are not used in this aerodynamic model. The six aerodynamic coefficients are as follows.

- C<sub>x</sub> Axial-force coefficient
- C<sub>y</sub> Side-force coefficient
- C<sub>z</sub> Normal-force coefficient
- C<sub>l</sub> Rolling-moment coefficient
- C<sub>m</sub> Pitching-moment coefficient
- C<sub>n</sub> Yawing-moment coefficient



The contribution of each of these 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

**Aerodynamic Coefficient Calculation.** 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 NASA document TM4302 [1].

The polynomial functions contained in the M-file `aeroblk_init_h120.m` 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

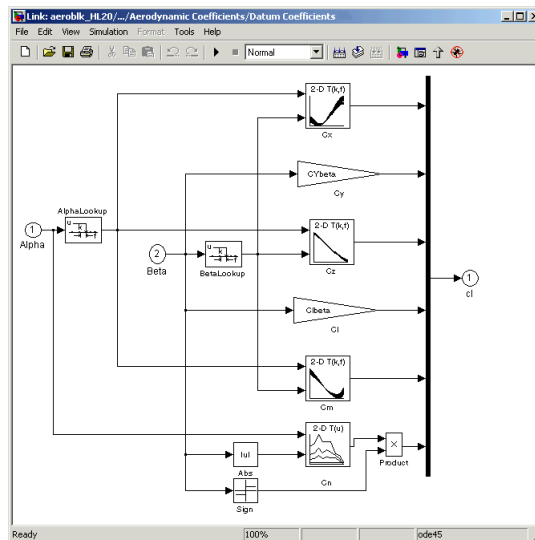
model efficiency, most tables are implemented as PreLook-up Index Search and Interpolation (n-D) using PreLook-up blocks. These blocks improve efficiency most when there are a number of tables with identical breakpoints. These blocks reduce the number of times the model has to search for a breakpoint 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 3-32
- “Body Rate Damping Subsystem” on page 3-33
- “Actuator Increment Subsystem” on page 3-33

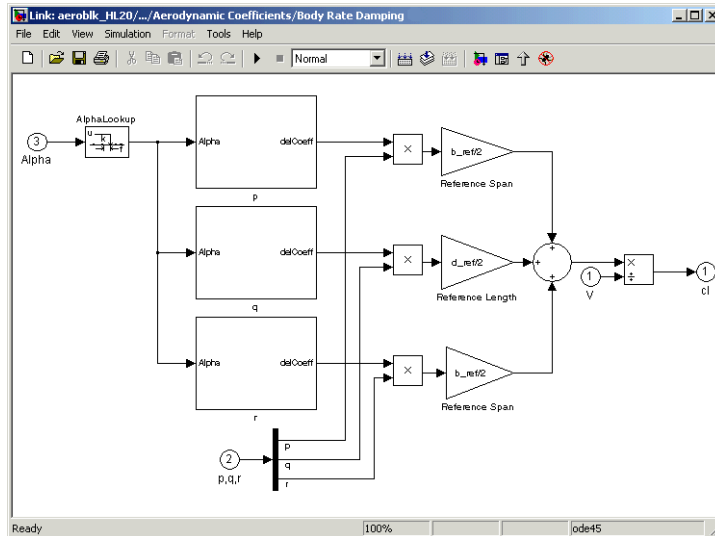
Summing the Datum Coefficients, Body Rate Damping, and Actuator Increments subsystem outputs generates the six aerodynamic coefficients used to calculate the airframe forces and moments.

**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.



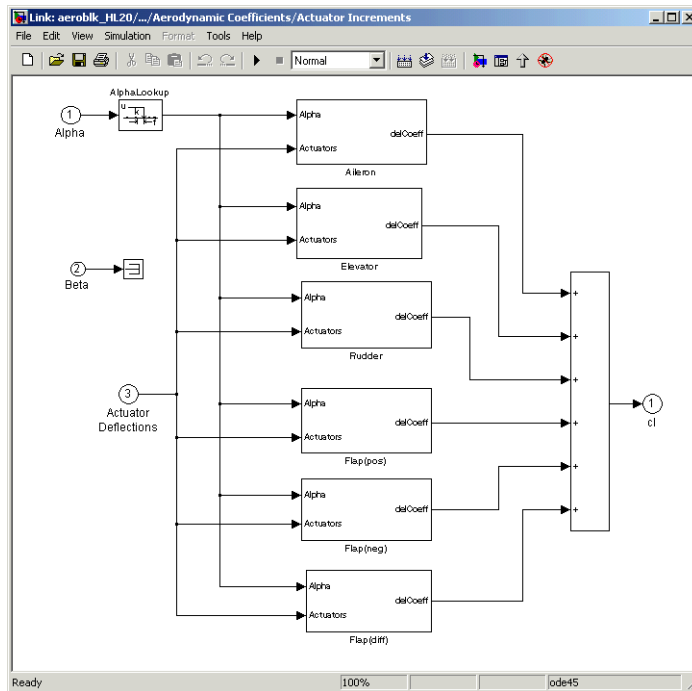
**Datum Coefficients Subsystem**

**Body Rate Damping Subsystem.** Dynamic derivatives are computed in the Body Rate Damping subsystem.



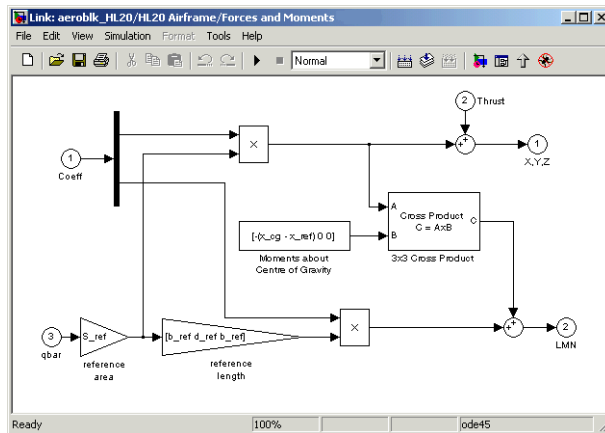
### Body Rate Damping Subsystem

**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.



### Actuator Increments Subsystem

**Forces and Moments Subsystem.** The last subsystem in the HL-20 airframe model is Forces and Moments. 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. The equations defining the body forces and body moments are found in NASA document TM4302 [1].



## Forces and Moments Subsystem

### Completing the Model

The Simulink and the Aerospace Blockset 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 by entering `aeroblk_HL20_main` in the command window.

## References

Additional information about the HL-20 lifting body can be found at <http://www.astronautix.com/craft/h120.htm>.

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

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

See also:

<http://www.aviationnow.com/content/publication/awst/20020520/aw46.htm>.

## Ideal Airspeed Correction

This case study demonstrates how to create indicated and true airspeed using Simulink and the Aerospace Blockset. To find out more, read the following sections:

- “Airspeed Correction Models” on page 3-36 shows how to open the models that are used in this case study.
- “Measuring Airspeed” on page 3-37 describes the different types of airspeed used in aerospace engineering.
- “Modeling Airspeed Correction” on page 3-38 describes how the Ideal Airspeed Correction block is implemented in the two models.
- “Simulating Airspeed Correction” on page 3-41 describes how to run the model simulation.

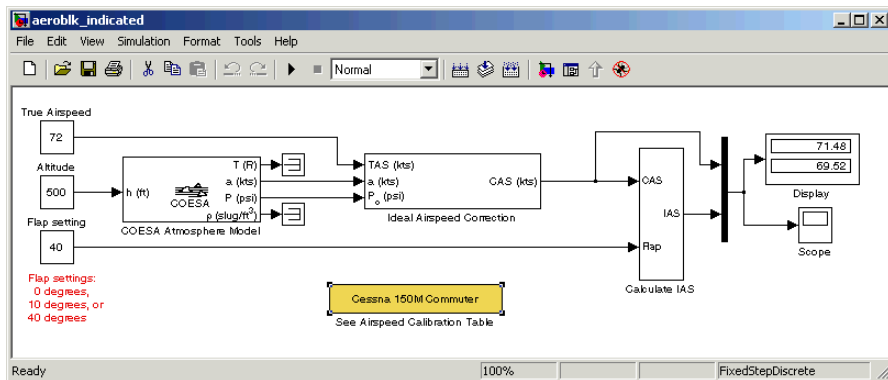
## Airspeed Correction Models

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

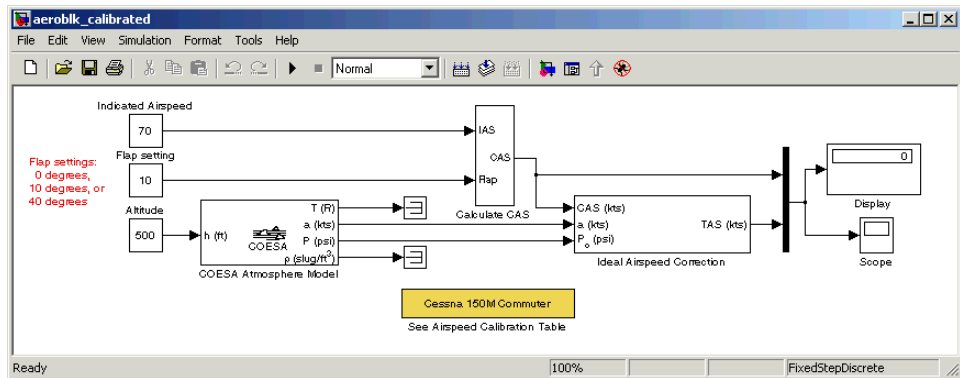
```
aeroblk_indicated
```

and

```
aeroblk_calibrated
```



**aeroblk\_indicated Model**



### aeroblk\_calibrated Model

## Measuring Airspeed

To measure airspeed, most light aircraft designs implement pilot-static airspeed indicators. Pilot-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), which denotes the airspeed that a pilot would see in the cockpit of an aircraft.

To help compensate for measurement errors, airspeed is divided into three definitions of measurement.

Airspeed Type	Description	See Also
Calibrated	Indicated airspeed that is corrected for the calibration error	“Examining the Calibration Error” on page 3-38
Equivalent	Calibrated airspeed that is corrected for the compressibility error	“Examining the Compressibility Error” on page 3-38
True	Equivalent airspeed that is corrected for the density error	“Examining the Density Error” on page 3-38

### **Examining the Calibration Error**

An airspeed indicator features a static vent 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 thereby, the amount of calibration error of the airspeed indicator. Therefore, 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.

### **Examining the Compressibility Error**

The ability of air to resist compression diminishes as altitude and airspeed increases, or when contained in a restricted volume. A restricted volume of air exists within a pilot-static airspeed indicator. When flying at high altitudes and high airspeeds, calibrated airspeed is always higher than equivalent airspeed. Equivalent airspeed can be derived by compensating the calibrated airspeed for the compressibility error.

### **Examining the Density Error**

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

## **Modeling 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 airplane. The `aeroblk_indicated` model implements a conversion to indicated airspeed, and the `aeroblk_calibrated` model implements a conversion to true airspeed.

Each model consists of two main components:

- “COESA Atmosphere Model Block” on page 3-39 calculates the change in atmospheric conditions with changing altitude.
- “Ideal Airspeed Correction Block” on page 3-39 transforms true airspeed to calibrated airspeed and vice versa.



### COESA Atmosphere Model Block

The COESA Atmosphere Model block is a 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 32000 meters (approximately 104987 feet), the U.S. Standard Atmosphere is identical with the Standard Atmosphere of the International Civil Aviation Organization (ICAO).

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 lets you compensate for the airspeed measurement errors to convert airspeed from one type to another type. The following table contains the Ideal Airspeed Correction block's airspeed 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 airspeed to calibrated airspeed. In the `aeroblk_calibrated` model, the Ideal Airspeed Correction block transforms calibrated airspeed to true airspeed.

To understand how the Ideal Airspeed Correction block implements airspeed transformations as mathematical formulas, see the following sections:

- “True Airspeed Implementation” on page 3-40
- “Calibrated Airspeed Implementation” on page 3-40
- “Equivalent Airspeed Implementation” on page 3-40

**True Airspeed Implementation.** True airspeed (TAS) is implemented as an input and as a function of equivalent airspeed (EAS), which can be expressed as

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

The symbols are defined as follows.

$a$	Speed of sound at altitude in $m/s^2$
$\delta$	Relative pressure ratio at altitude
$a_0$	Speed of sound at mean sea level in $m/s^2$

**Calibrated Airspeed Implementation.** Calibrated airspeed (CAS), which is derived using the compressible form of Bernoulli’s equation and assuming isentropic conditions, can be expressed as

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

The symbols are defined as follows:

$\rho_0$	Air density at mean sea level in $kg/m^3$
$P_0$	Static pressure at mean sea level in $N/m^2$
$\gamma$	Specific heat ratio
$q$	Dynamic pressure at mean sea level in $N/m^2$

**Equivalent Airspeed Implementation.** Equivalent airspeed (EAS), which is derived using the compressible form of Bernoulli’s equation and assuming isentropic conditions, can be expressed as:

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

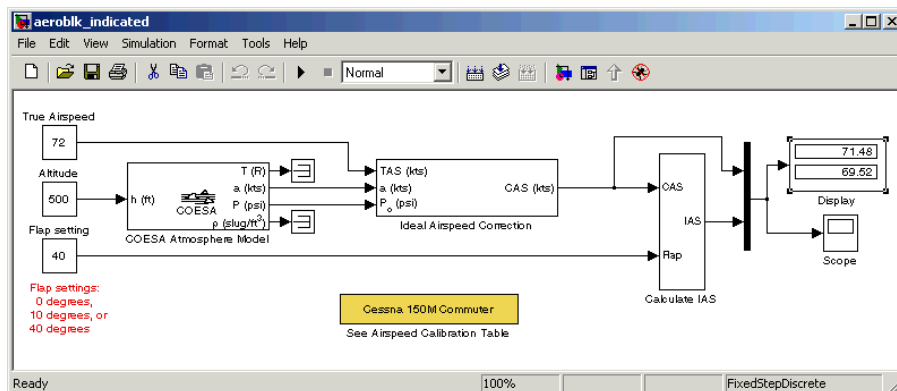
The symbols are defined as follows:

$\rho_0$	Air density at mean sea level in kg/m <sup>3</sup>
$P$	Static pressure at altitude in N/m <sup>2</sup>
$\gamma$	Specific heat ratio
$q$	Dynamic pressure at mean sea level in N/m <sup>2</sup>

## Simulating Airspeed Correction

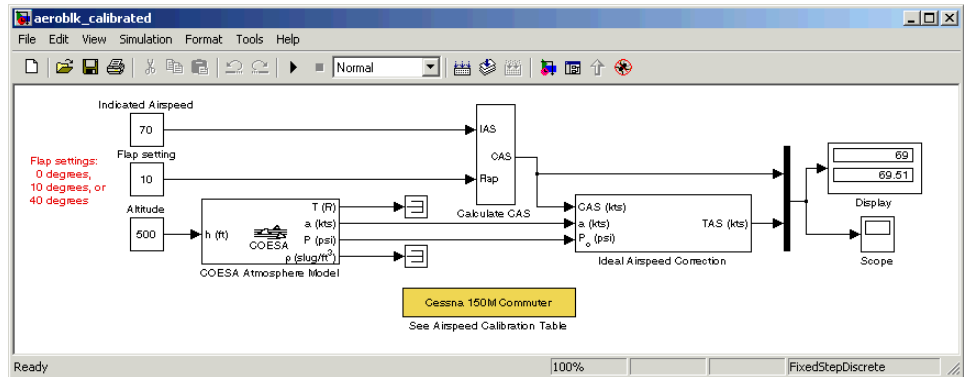
In the `aeroblk_indicated` model, the aircraft is defined to be traveling at a constant speed of 72 knots (true airspeed) and altitude of 500 feet. The flaps are set to 40 degrees. The COESA Atmosphere Model block takes the altitude as an input and outputs the speed of sound and air pressure. Taking 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.

As you can see in the following figure, the display shows both indicated airspeed and calibrated airspeed.



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 an 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.

As you can see in the following figure, the display shows both calibrated and true airspeed.



## 1903 Wright Flyer Model

This section describes the 1903 Wright Flyer model, which was built using Simulink, the Aerospace Blockset, and the Virtual Reality Toolbox. Built by Orville and Wilbur Wright, the Wright Flyer took to the skies in December 1903 and represented the dawn of the aviation age. 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 created by Frederick J. Hooven[1]. That simulation explored the longitudinal stability of the Wright Flyer, and therefore, dealt only with the 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 over turn in crosswinds and gusts, and longitudinally, the 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.

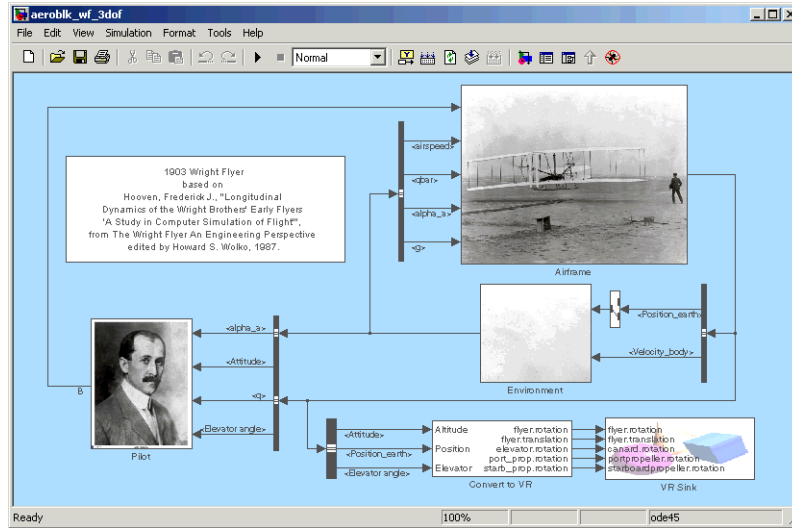
For more information, see the following sections:

- “Wright Flyer Model” on page 3-44 shows how to open the model used in this case study.
- “Airframe Subsystem” on page 3-44 describes the airframe subsystem.
- “Environment Subsystem” on page 3-49 describes the environment subsystem.
- “Pilot Subsystem” on page 3-51 describes the pilot subsystem.
- “Running the Simulation” on page 3-51 provides a demonstration of the Wright Flyer model.

## Wright Flyer Model

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

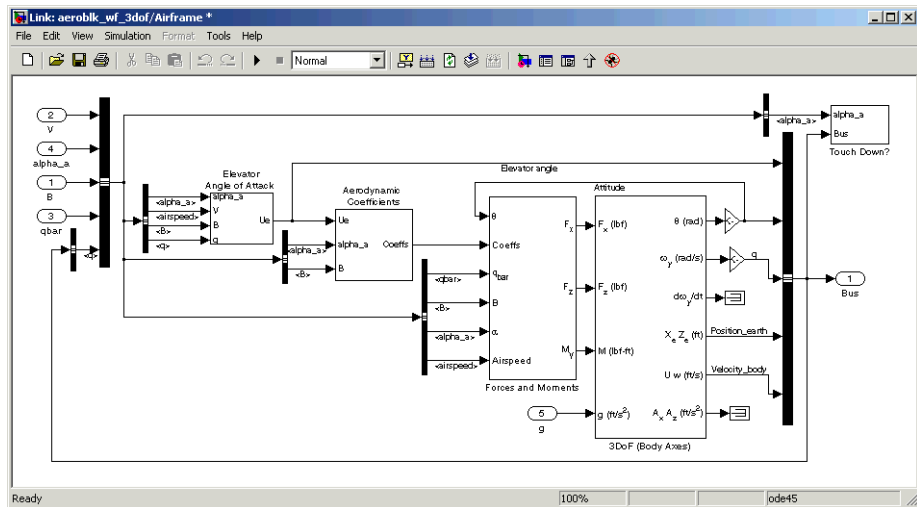
```
aeroblk_wf_3dof
```



**aeroblk\_wf\_3dof Model**

## Airframe Subsystem

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



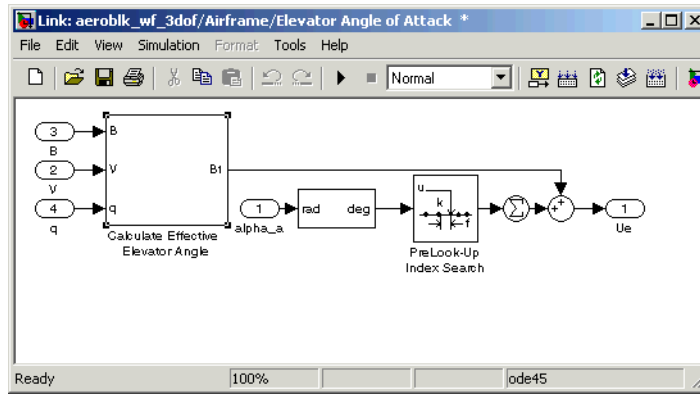
## Airframe Subsystem

The Airframe subsystem consists of the following parts:

- “Elevator Angle of Attack Subsystem” on page 3-45
- “Aerodynamic Coefficients Subsystem” on page 3-46
- “Forces and Moments Subsystem” on page 3-47
- “3DoF (Body Axes) Block” on page 3-48

## 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.

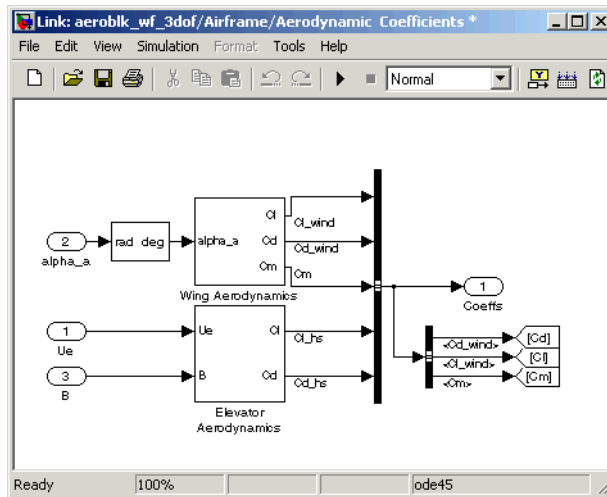


### Elevator Angle of Attack Subsystem

### 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 PreLook-Up blocks.

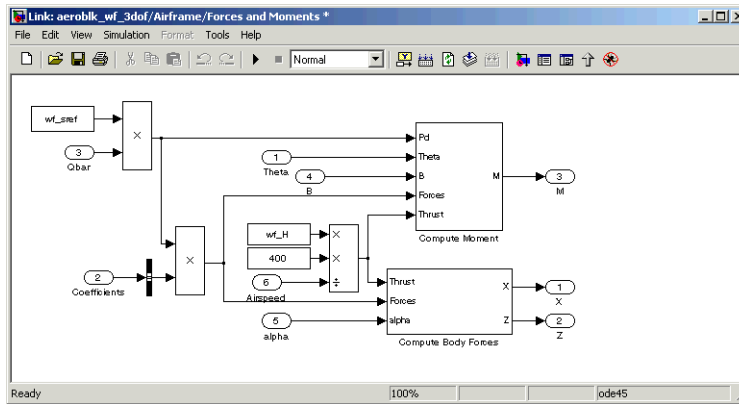




### Aerodynamic Coefficients Subsystem

### Forces and Moments Subsystem

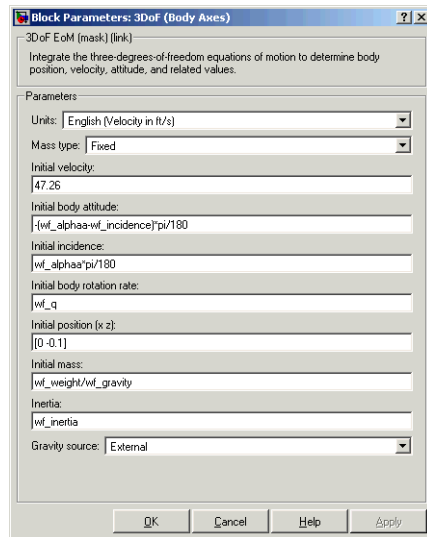
The aerodynamic forces and moments acting on the airframe are generated from aerodynamic coefficients. The Forces and Moments subsystem calculates the body forces and body moments acting on the airframe about the center of gravity. These forces and moments depend on the aerodynamic coefficients, thrust,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



## Forces and Moments Subsystem

### 3DoF (Body Axes) Block

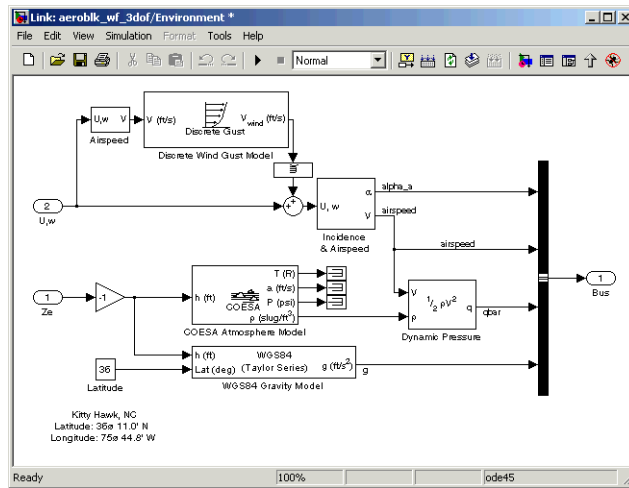
The 3DoF (Body Axes) block use equations of motion to define the linear and angular motion of the Wright Flyer airframe. Conversions from the axis system of Hooven's simulation and body axes are also performed.



### 3DoF (Body Axes) Block Mask

## Environment Subsystem

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



### 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, which is situated near the Atlantic coast. On that day, wind gusts of more than 25 m.p.h. were recorded at Kitty Hawk. Indeed, after the final flight on that blustery December day, a wind gust caught the Wright Flyer and flipped it over, damaging it beyond repair.

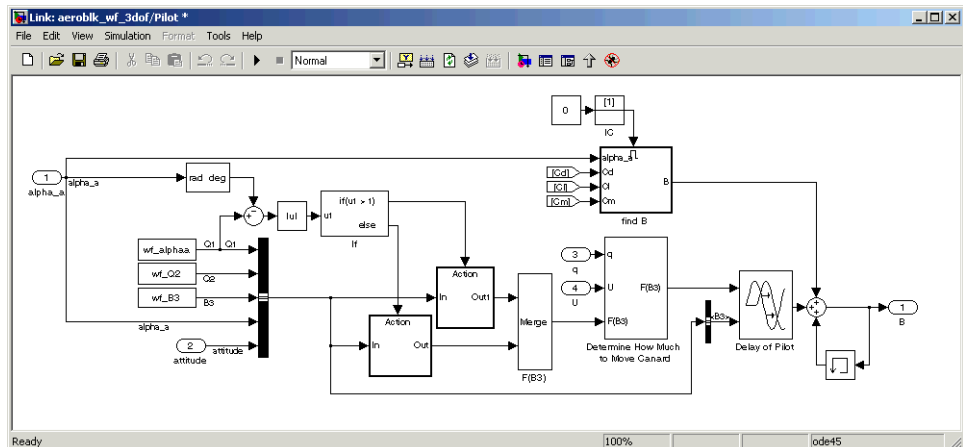
In the Wright Flyer model's Environmental subsystem, the Discrete Wind Gust Model block provides wind gusts to the simulated environment. The other blocks are

- The Incidence and Airspeed block calculates the angle of attack and airspeed.
- The COESA Atmosphere Model block calculates the air density.
- The Dynamic Pressure block takes the air density and velocity and computes the dynamic pressure.
- The WGS84 Gravity Block produces the gravity at the Wright Flyer's latitude 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 angular velocity exceeds  $\pm 0.02$  rad/s, angular velocity and angular acceleration are also taken into consideration with additional corrections to the elevator angle.

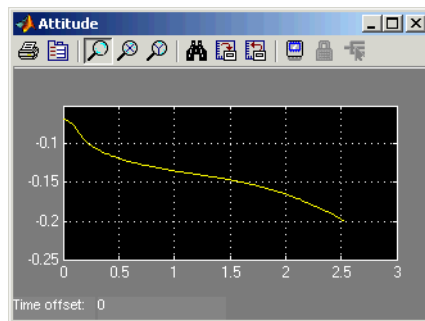
Pilot reaction time largely contributes to the success of the flights. Hooven found the reaction time of 0.06 second to be optimum for successful flights. The Delay of Pilot block recreates this effect by producing a delay of no more than 0.08 second.



## Pilot Subsystem

### Running the Simulation

Default values for this simulation are set to allow the Wright Flyer model to take off and land successfully. The pilot reaction time (wf\_B3) is set to 0.06 second, the desired angle of attack (wf\_alphaaa) 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. Examining the attitude, this model exhibits the longitudinal “undulation” of the original aircraft.

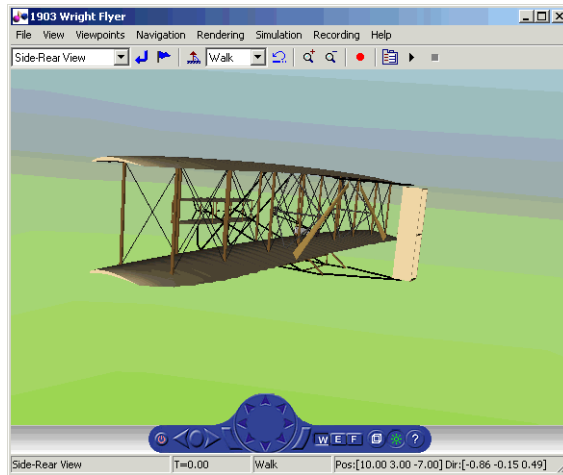


#### **Attitude Scope**

A pilot with quick reaction times and ideal flight conditions make it possible to fly the Wright Flyer successfully. The Wright Flyer model confirms that it was quite challenging to control the longitudinal motion of the Flyer. The longest recorded flight on that day lasted a mere 59 seconds and covered 852 feet.

Using the Virtual Reality Toolbox, the Wright Flyer model also provides a Virtual Reality Modeling Language (VRML) world. Thaddeus Beier created the initial Wright Flyer model in Inventor format.

The VR Sink block enables the flight motion to be viewed in three dimensions.



## 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* edited by Howard S. Wolko, 1987.
- [2] Culick, F. E. C. and Jex, H. R., "Aerodynamics, Stability, and Control of the 1903 Wright Flyer," from *The Wright Flyer An Engineering Perspective* edited by Howard S. Wolko, 1987.

Additional information about the 1903 Wright Flyer can be found at the following locations:

- <http://www.wrightexperience.com>
- <http://wright.nasa.gov>





# Block Reference

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Blocks — Categorical List (p. 4-2)

Blocks — Alphabetical List (p. 4-15)

Aerospace Blockset blocks by category

Aerospace Blockset blocks by name

## Blocks – Categorical List

The Aerospace Blockset's block library, `aerolib`, is organized into libraries according to their behavior. The **aerolib** window displays the block library icons and names.

Actuators Library	Actuator models
Aerodynamics Library	Aerodynamics models
Animation Library	3-D animation during simulation, including the MATLAB-Based Animation Sublibrary, the Flight Simulator Interfaces Sublibrary, and the Animation Support Utilities Sublibrary
Environment Library	Environmental models, including the Atmosphere Sublibrary, the Gravity Sublibrary, and the Wind Sublibrary
Flight Parameters Library	Flight parameter models
Equations of Motion Library	Equation of motion models, including the 3DoF Sublibrary, the 6DoF Sublibrary, and the Point Mass Sublibrary
GNC Library	Gain scheduling models, including the Controls Sublibrary, the Guidance Sublibrary, and the Navigation Sublibrary
Mass Properties Library	Center of gravity and tensor models
Propulsion Library	Simple propulsion system models
Utilities Library	Common mathematical operations and conversions, including the Axes Transformations Sublibrary, the Unit Conversions Sublibrary, and the Math Operations Sublibrary

## Actuators Library

Second Order Linear Actuator	Implement a second-order linear actuator
Second Order Nonlinear Actuator	Implement a second-order nonlinear actuator with rate and deflection limits

## Aerodynamics Library

Aerodynamic Forces and Moments	Compute the aerodynamic forces and moments using the aerodynamic coefficients, dynamic pressure, center of gravity, and center of pressure
--------------------------------	--

## Animation Library

The Animation Library contains the following sublibraries:

### MATLAB-Based Animation Sublibrary

3DoF Animation	Create a 3-D Handle Graphics® animation of a three-degrees-of-freedom object
6DoF Animation	Create a 3-D Handle Graphics animation of a six-degrees-of-freedom object

### Flight Simulator Interfaces Sublibrary

FlightGear Preconfigured 6DoF Animation	Connect your model to FlightGear Flight Simulator
Generate Run Script	Generate FlightGear run script on current platform
Pack net_fdm Packet for FlightGear	Generate net_fdm packet for FlightGear
Send net_fdm Packet to FlightGear	Transmit net_fdm packet to destination IP address and port for FlightGear session

### **Animation Support Utilities Sublibrary**

Pilot Joystick	Use joystick interface for Windows platform for FlightGear Flight Simulator
Simulation Pace	Set the simulation pace for FlightGear Flight Simulator

### **Environment Library**

The Environment Library contains the following sublibraries:

#### **Atmosphere Sublibrary**

COESA Atmosphere Model	Implement the 1976 Committee on Extension to the Standard Atmosphere (COESA) lower atmosphere
ISA Atmosphere Model	Implement the International Standard Atmosphere (ISA)
Lapse Rate Model	Implement Lapse Rate Model for atmosphere
Non-Standard Day 210C	Implement the MIL-STD-210C climatic data
Non-Standard Day 310	Implement the MIL-HDBK-310 climatic data
Pressure Altitude	Calculate pressure altitude based on ambient pressure

#### **Gravity Sublibrary**

WGS84 Gravity Model	Implement the 1984 World Geodetic System representation of Earth's gravity
World Magnetic Model 2000	Calculate the Earth's magnetic field at a specific location and time using the World Magnetic Model 2000 (WMM2000)
World Magnetic Model 2005	Calculate the Earth's magnetic field at a specific location and time using the World Magnetic Model 2005 (WMM2005)

**Wind Sublibrary**

Discrete Wind Gust Model	Generate discrete wind gust
Dryden Wind Turbulence Model (Continuous)	Generate wind turbulence with the Dryden velocity spectra
Dryden Wind Turbulence Model (Discrete)	Generate wind turbulence with the Dryden velocity spectra
Horizontal Wind Model	Transform horizontal wind into body-axes coordinates
Von Karman Wind Turbulence Model (Continuous)	Generate atmospheric turbulence
Wind Shear Model	Calculate wind shear conditions

**Flight Parameters Library**

Dynamic Pressure	Compute dynamic pressure using velocity and air density
Ideal Airspeed Correction	Calculate equivalent airspeed (EAS), calibrated airspeed (CAS), or true airspeed (TAS) from each other
Incidence & Airspeed	Calculate incidence and air speed
Incidence, Sideslip & Airspeed	Calculate incidence, sideslip and air speed
Mach Number	Compute Mach number using velocity and speed of sound
Radius at Geocentric Latitude	Estimate radius of ellipsoid planet at geocentric latitude
Relative Ratio	Calculate relative atmospheric ratios
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

## Equations of Motion Library

The Equations of Motion library contains the following sublibraries:

### 3DoF Sublibrary

3DoF (Body Axes)	Implement three-degrees-of-freedom equations of motion with respect to body axes
3DoF (Wind Axes)	Implement three-degrees-of-freedom equations of motion with respect to wind axes
Custom Variable Mass 3DoF (Body Axes)	Implement three-degrees-of-freedom equations of motion with respect to body axes
Custom Variable Mass 3DoF (Wind Axes)	Implement three-degrees-of-freedom equations of motion with respect to wind axes
Simple Variable Mass 3DoF (Body Axes)	Implement three-degrees-of-freedom equations of motion with respect to body axes
Simple Variable Mass 3DoF (Wind Axes)	Implement three-degrees-of-freedom equations of motion with respect to wind axes

### 6DoF Sublibrary

6DoF (Euler Angles)	Implement an Euler angle representation of six-degrees-of-freedom equations of motion
6DoF (Quaternion)	Implement a quaternion representation of six-degrees-of-freedom equations of motion with respect to body axes
6DoF ECEF (Quaternion)	Implement a quaternion representation of six-degrees-of-freedom equations of motion in Earth-Centered Earth-Fixed (ECEF) coordinates.
6DoF Wind (Quaternion)	Implement a quaternion representation of six-degrees-of-freedom equations of motion with respect to wind axes
6DoF Wind (Wind Angles)	Implement a wind angle representation of six-degrees-of-freedom equations of motion

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Custom Variable Mass 6DoF (Euler Angles)	Implement an Euler angle representation of six-degrees-of-freedom equations of motion
Custom Variable Mass 6DoF (Quaternion)	Implement a quaternion representation of six-degrees-of-freedom equations of motion with respect to body axes
Custom Variable Mass 6DoF ECEF (Quaternion)	Implement a quaternion representation of six-degrees-of-freedom equations of motion in Earth-Centered Earth-Fixed (ECEF) coordinates.
Custom Variable Mass 6DoF Wind (Quaternion)	Implement a quaternion representation of six-degrees-of-freedom equations of motion with respect to wind axes
Custom Variable Mass 6DoF Wind (Wind Angles)	Implement a wind angle representation of six-degrees-of-freedom equations of motion
Simple Variable Mass 6DoF (Euler Angles)	Implement an Euler angle representation of six-degrees-of-freedom equations of motion
Simple Variable Mass 6DoF (Quaternion)	Implement a quaternion representation of six-degrees-of-freedom equations of motion with respect to body axes
Simple Variable Mass 6DoF ECEF (Quaternion)	Implement a quaternion representation of six-degrees-of-freedom equations of motion in Earth-Centered Earth-Fixed (ECEF) coordinates.
Simple Variable Mass 6DoF Wind (Quaternion)	Implement a quaternion representation of six-degrees-of-freedom equations of motion with respect to wind axes
Simple Variable Mass 6DoF Wind (Wind Angles)	Implement a wind angle representation of six-degrees-of-freedom equations of motion

### Point Mass Sublibrary

4th Order Point Mass (Longitudinal)	Calculate fourth order point mass
4th Order Point Mass Forces (Longitudinal)	Calculate forces used by fourth order point mass
6th Order Point Mass (Coordinated Flight)	Calculate sixth order point mass in coordinated flight
6th Order Point Mass Forces (Coordinated Flight)	Calculate forces used by sixth order point mass in coordinated flight

### GNC Library

The GNC library contains the following sublibraries:

#### Controls Sublibrary

1D Controller [A(v),B(v),C(v),D(v)]	Implement a gain-scheduled state-space controller depending on one scheduling parameter
1D Controller Blend $u=(1-L).K1.y+L.K2.y$	Implement a 1-D vector of state-space controllers by linear interpolation of their outputs
1D Observer Form [A(v),B(v),C(v),F(v),H(v)]	Implement a gain-scheduled state-space controller in an observer form depending on one scheduling parameter
1D Self-Conditioned [A(v),B(v),C(v),D(v)]	Implement a gain-scheduled state-space controller in a self-conditioned form
2D Controller [A(v),B(v),C(v),D(v)]	Implement a gain-scheduled state-space controller depending on two scheduling parameters
2D Controller Blend	Implement a 2-D vector of state-space controllers by linear interpolation of their outputs



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2D Observer Form [A(v),B(v),C(v),F(v),H(v)]	Implement a gain-scheduled state-space controller in an observer form depending on two scheduling parameters
2D Self-Conditioned [A(v),B(v),C(v),D(v)]	Implement a gain-scheduled state-space controller in a self-conditioned form
3D Controller [A(v),B(v),C(v),D(v)]	Implement a gain-scheduled state-space controller depending on three scheduling parameters
3D Observer Form [A(v),B(v),C(v),F(v),H(v)]	Implement a gain-scheduled state-space controller in an observer form depending on three scheduling parameters
3D Self-Conditioned [A(v),B(v),C(v),D(v)]	Implement a gain-scheduled state-space controller in a self-conditioned form
Gain Scheduled Lead-Lag	Implement a first-order lead-lag with gain-scheduled coefficients
Interpolate Matrix(x)	Return an interpolated matrix for given input x
Interpolate Matrix(x,y)	Return an interpolated matrix for given inputs x and y
Interpolate Matrix(x,y,z)	Return an interpolated matrix for given inputs x, y, and z
Self-Conditioned [A,B,C,D]	Implement a state-space controller in a self-conditioned form

### **Guidance Sublibrary**

Calculate Range                      Calculate the range between two crafts given their respective positions

### **Navigation Sublibrary**

Three-Axis Accelerometer          Implement a three-axis accelerometer

Three-Axis Gyroscope              Implement a three-axis gyroscope

Three-Axis Inertial Measurement Unit      Implement a three-axis inertial measurement unit (IMU)

### **Mass Properties Library**

Estimate Center of Gravity          Calculate the center of gravity location

Estimate Inertia Tensor              Calculate the inertia tensor

Moments About CG Due to Forces      Compute moments about center of gravity due to forces that are applied at point CP, not the center of gravity

Symmetric Inertia Tensor          Create an inertia tensor from moments and products of inertia

### **Propulsion Library**

Turbofan Engine System              Implement a first-order representation of a turbofan engine with controller

### **Utilities Library**

The Utilities library contains the following sublibraries:

## Axes Transformations Sublibrary

Besselian Epoch to Julian Epoch	Transform position and velocity components from the discontinued Standard Besselian Epoch (B1950) to the Standard Julian Epoch (J2000)
Direction Cosine Matrix Body to Wind	Convert angle of attack and sideslip angle to direction cosine matrix
Direction Cosine Matrix Body to Wind to Alpha and Beta	Convert direction cosine matrix to angle of attack and sideslip angle
Direction Cosine Matrix ECEF to NED	Convert geodetic latitude and longitude to direction cosine matrix
Direction Cosine Matrix ECEF to NED to Latitude and Longitude	Convert direction cosine matrix to geodetic latitude and longitude
Direction Cosine Matrix to Euler Angles	Convert direction cosine matrix to Euler angles
Direction Cosine Matrix to Quaternions	Convert direction cosine matrix to quaternion vector
Direction Cosine Matrix to Wind Angles	Convert direction cosine matrix to wind angles
ECEF Position to LLA	Calculate geodetic latitude, longitude, and altitude above mean sea-level (MSL) from Earth-centered Earth-fixed (ECEF) position
Euler Angles to Direction Cosine Matrix	Convert Euler angles to direction cosine matrix
Euler Angles to Quaternions	Convert Euler angles to quaternion vector
Flat Earth to LLA	Estimate geodetic latitude, longitude, and altitude from flat Earth position
Geocentric to Geodetic Latitude	Convert geocentric latitude to geodetic latitude

Geodetic to Geocentric Latitude	Convert geodetic latitude to geocentric latitude
Julian Epoch to Besselian Epoch	Transform position and velocity components from the Standard Julian Epoch (J2000) to the discontinued Standard Besselian Epoch (B1950)
LLA to ECEF Position	Calculate Earth-centered Earth-fixed (ECEF) position from geodetic latitude, longitude, and altitude above mean sea-level (MSL)
Quaternions to Direction Cosine Matrix	Convert quaternion vector to direction cosine matrix
Quaternions to Euler Angles	Convert quaternion vector to Euler angles
Wind Angles to Direction Cosine Matrix	Convert wind angles to direction cosine matrix

## Math Operations Sublibrary

3x3 Cross Product	Calculate the cross product of two 3-by-1 vectors
Adjoint of 3x3 Matrix	Compute the adjoint matrix for the input matrix
Create 3x3 Matrix	Create a 3-by-3 matrix from nine input values
Determinant of 3x3 Matrix	Compute the determinant for the input matrix
Invert 3x3 Matrix	Compute the inverse of 3-by-3 matrix using determinant formula
Quaternion Conjugate	Calculate the conjugate of a quaternion
Quaternion Division	Divide a quaternion by another quaternion
Quaternion Inverse	Calculate the inverse of a quaternion
Quaternion Modulus	Calculate the modulus of a quaternion
Quaternion Multiplication	Calculate the product of two quaternions
Quaternion Norm	Calculate the norm of a quaternion
Quaternion Normalize	Normalize a quaternion
Quaternion Rotation	Rotate a vector by a quaternion
SinCos	Compute the sine and cosine of input angle

## Unit Conversions Sublibrary

Acceleration Conversion	Convert from acceleration units to desired acceleration units
Angle Conversion	Convert from angle units to desired angle units
Angular Acceleration Conversion	Convert from angular acceleration units to desired angular acceleration units
Angular Velocity Conversion	Convert from angular velocity units to desired angular velocity units
Density Conversion	Convert from density units to desired density units

Force Conversion	Convert from force units to desired force units
Length Conversion	Convert from length units to desired length units
Mass Conversion	Convert from mass units to desired mass units
Pressure Conversion	Convert from pressure units to desired pressure units
Temperature Conversion	Convert from temperature units to desired temperature units
Velocity Conversion	Convert from velocity units to desired velocity units

## **Blocks — Alphabetical List**

This section contains block reference pages listed alphabetically.

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

**Purpose** Implement a gain-scheduled state-space controller depending on one scheduling parameter

**Library** GNC/Controls

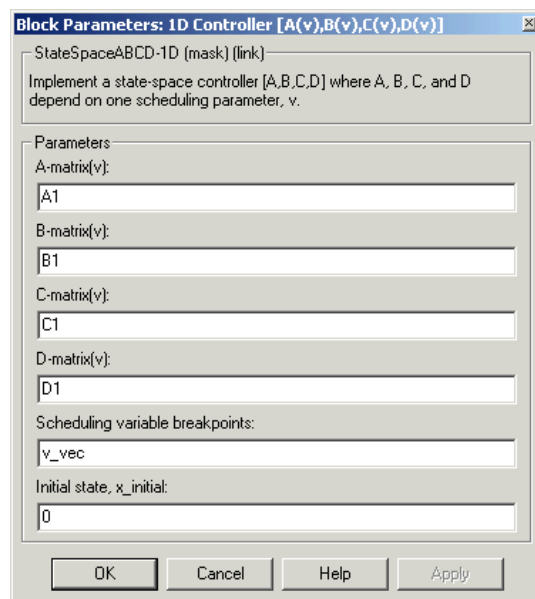
**Description** The 1D Controller [A(v),B(v),C(v),D(v)] block implements a gain-scheduled state-space controller as defined by the equations



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

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.

## Dialog Box





## **A-matrix(v)**

A-matrix of the state-space implementation. In the case of 1-D scheduling, the A-matrix should have three dimensions, the last one corresponding to the scheduling variable  $v$ . Hence, for example, if the A-matrix corresponding to the first entry of  $v$  is the identity matrix, then  $A(:, :, 1) = [1 \ 0; 0 \ 1];$ .

## **B-matrix(v)**

B-matrix of the state-space implementation. In the case of 1-D scheduling, the B-matrix should have three dimensions, the last one corresponding to the scheduling variable  $v$ . Hence, for example, if the B-matrix corresponding to the first entry of  $v$  is the identity matrix, then  $B(:, :, 1) = [1 \ 0; 0 \ 1];$ .

## **C-matrix(v)**

C-matrix of the state-space implementation. In the case of 1-D scheduling, 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  $C(:, :, 1) = [1 \ 0; 0 \ 1];$ .

## **D-matrix(v)**

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

## **Scheduling variable breakpoints**

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

## **Initial state, $x\_initial$**

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.

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

---

## Inputs and Outputs

The first input is the measurements.

The second input is the scheduling variable conforming to the dimensions of the state-space matrices.

The output is the actuator demands.

## Assumptions and Limitations

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

## Examples

See H-Infinity Controller (1 Dimensional Scheduling) in the aeroblk\_lib\_HL20 demo library for an example of this block.

## See Also

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

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)]

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

## Purpose

Implement a 1-D vector of state-space controllers by linear interpolation of their outputs

## Library

GNC/Controls

## Description



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

For example, suppose two controllers are designed at two operating points  $v=v_{min}$  and  $v=v_{max}$ . The 1D Controller Blend block implements

$$\begin{aligned}\dot{x}_1 &= A_1x_1 + B_1y \\ u_1 &= C_1x_1 + D_1y \\ \dot{x}_2 &= A_2x_2 + B_2y \\ u_2 &= C_2x_2 + D_2y \\ u &= (1-\lambda)u_1 + \lambda u_2\end{aligned}$$

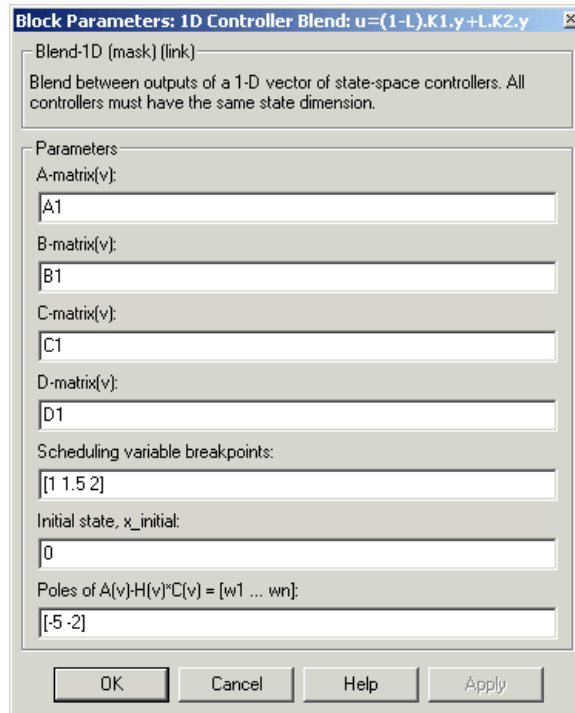
$$\lambda = \begin{cases} 0 & v < v_{min} \\ \frac{v - v_{min}}{v_{max} - v_{min}} & v_{min} \leq v \leq v_{max} \\ 1 & v > v_{max} \end{cases}$$

For longer arrays of design points, the blocks only implement nearest neighbor designs. For the 1D Controller Blend block, at any given instant in time, three controller designs are being updated. This reduces computational requirements.

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.

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

## Dialog Box



### A-matrix(v)

A-matrix of the state-space implementation. In the case of 1-D blending, the A-matrix should have three dimensions, the last one corresponding to scheduling variable  $v$ . Hence, for example, if the A-matrix corresponding to the first entry of  $v$  is the identity matrix, then  $A(:, :, 1) = [1 \ 0; 0 \ 1]$ ;

### B-matrix(v)

B-matrix of the state-space implementation.

### C-matrix(v)

C-matrix of the state-space implementation.

### D-matrix(v)

D-matrix of the state-space implementation.

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

## Scheduling variable breakpoints

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

## Initial state, $x_{initial}$

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.

## Poles of $A(v)-H(v)*C(v)$

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  $u$ .

## Inputs and Outputs

The first input is the measurements.

The second input is the scheduling variable conforming to the dimensions of the state-space matrices.

The output is the actuator demands.

## Assumptions and Limitations

This block requires the Control System Toolbox.

## References

Hyde, R. A., "H-infinity Aerospace Control Design - A VSTOL Flight Application," Springer Verlag, *Advances in Industrial Control Series*, 1995. ISBN 3-540-19960-8. See Chapter 5.

## 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)]

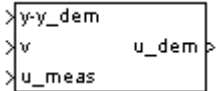
2D Controller Blend

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

**Purpose** Implement a gain-scheduled state-space controller in an observer form depending on one scheduling parameter

**Library** GNC/Controls

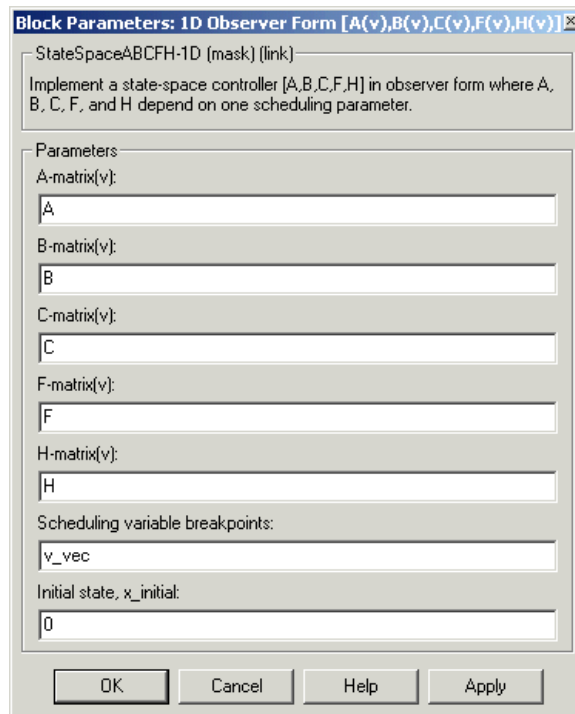
**Description** The 1D Observer Form  $[A(v),B(v),C(v),F(v),H(v)]$  block implements a gain-scheduled state-space controller defined in the following observer form



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

The main application of this blocks is to implement a controller designed using H-infinity loop-shaping, one of the design methods supported by the  $\mu$ -Analysis and Synthesis Toolbox.

## Dialog Box



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

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## **A-matrix(v)**

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

## **B-matrix(v)**

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

## **C-matrix(v)**

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  $C(:, :, 1) = [1 \ 0; 0 \ 1];$

## **F-matrix(v)**

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  $F(:, :, 1) = [1 \ 0; 0 \ 1];$

## **H-matrix(v)**

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  $H(:, :, 1) = [1 \ 0; 0 \ 1];$

## **Scheduling variable breakpoints**

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

## **Initial state, $x\_initial$**

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.

## **Inputs and Outputs**

The first input is the set-point error.

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

---

The second input is the scheduling variable.

The third input is measured actuator position.

The output is the actuator demands.

## Assumptions and Limitations

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

## Examples

See H-Infinity Controller (1 Dimensional Scheduling) in the `aeroblk_lib_HL20` demo library for an example of this block.

## References

Hyde, R. A., "H-infinity Aerospace Control Design - A VSTOL Flight Application," Springer Verlag, *Advances in Industrial Control Series*, 1995. ISBN 3-540-19960-8. See Chapter 6.

## 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  $[A(v),B(v),C(v),F(v),H(v)]$

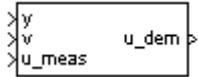


# 1D Self-Conditioned [A(v),B(v),C(v),D(v)]

**Purpose** Implement a gain-scheduled state-space controller in a self-conditioned form

**Library** GNC/Controls

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

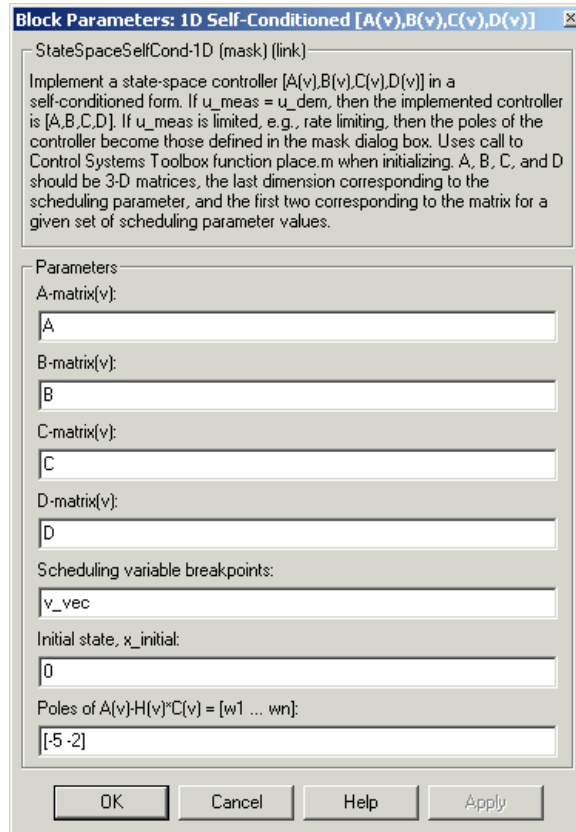
$$\dot{z} = (A(v) - H(v)C(v))z + (B(v) - H(v)D(v))e + H(v)u_{meas}$$

$$u_{dem} = C(v)z + D(v)e$$

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 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.

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

## Dialog Box



### A-matrix(v)

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

### B-matrix(v)

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

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

## C-matrix(v)

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  $C(:, :, 1) = [1 \ 0; 0 \ 1]$ ;

## D-matrix(v)

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

## Scheduling variable breakpoints

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.

## Initial state, $x\_initial$

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.

## Poles of $A(v)-H(v)*C(v)$

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.

## Inputs and Outputs

The first input is the measurements.

The second input is the scheduling variable conforming to the dimensions of the state-space matrices.

The third input is the measured actuator position.

The output is the actuator demands.

## Assumptions and Limitations

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

This block requires the Control System Toolbox.

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

---

## References

The algorithm used to determine the matrix H is defined in Kautsky, Nichols, and Van Dooren, "Robust Pole Assignment in Linear State Feedback," *International Journal of Control*, Vol. 41, No. 5, pages 1129-1155, 1985.

## 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  $[A(v),B(v),C(v),D(v)]$

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

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

**Library** GNC/Controls

**Description** The 2D Controller [A(v),B(v),C(v),D(v)] block implements a gain-scheduled state-space controller as defined by the equations



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

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.

## Dialog Box

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

StateSpaceABCD-2D (mask) (link)

Implement a state-space controller [A,B,C,D] where A, B, C, and D depend on two scheduling parameters, v1 and v2.

Parameters

A-matrix(v1,v2):  
A

B-matrix(v1,v2):  
B

C-matrix(v1,v2):  
C

D-matrix(v1,v2):  
D

First scheduling variable (v1) breakpoints:  
v1\_vec

Second scheduling variable (v2) breakpoints:  
v2\_vec

Initial state, x\_initial:  
0

OK Cancel Help Apply

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

---

### **A-matrix(v1,v2)**

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 v1 and v2. Hence, for example, if the A-matrix corresponding to the first entry of v1 and first entry of v2 is the identity matrix, then  $A(:, :, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **B-matrix(v1,v2)**

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 v1 and v2. Hence, for example, if the B-matrix corresponding to the first entry of v1 and first entry of v2 is the identity matrix, then  $B(:, :, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **C-matrix(v1,v2)**

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 v1 and v2. Hence, for example, if the C-matrix corresponding to the first entry of v1 and first entry of v2 is the identity matrix, then  $C(:, :, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **D-matrix(v1,v2)**

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 v1 and v2. Hence, for example, if the D-matrix corresponding to the first entry of v1 and first entry of v2 is the identity matrix, then  $D(:, :, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **First scheduling variable (v1) breakpoints**

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.

### **Second scheduling variable (v2) breakpoints**

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.

### **Initial state, x\_initial**

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.

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

---

## Inputs and Outputs

The first input is the measurements.

The second and third block inputs are the scheduling variables ordered conforming to the dimensions of the state-space matrices.

The output is the actuator demands.

## Assumptions and Limitations

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

## Examples

See H-Infinity Controller (Two Dimensional Scheduling) in the `aerob1k_lib_HL20` demo library for an example of this block.

## 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  $[A(v),B(v),C(v),D(v)]$

# 2D Controller Blend

---

**Purpose** Implement a 2-D vector of state-space controllers by linear interpolation of their outputs

**Library** GNC/Controls

## 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.

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.



## Dialog Box

**Block Parameters: 2D Controller Blend**

Blend-2D (mask) (link)

Blend between outputs of a 2-D vector of state-space controllers. All controllers must have the same state dimension.

Parameters

A-matrix(v1,v2):  
A

B-matrix(v1,v2):  
B

C-matrix(v1,v2):  
C

D-matrix(v1,v2):  
D

First scheduling variable (v1) breakpoints:  
v1\_vec

Second scheduling variable (v2) breakpoints:  
v2\_vec

Initial state, x\_initial:  
0

Poles of  $A(v)H(v)^*C(v) = [w1 \dots wn]$ :  
[-5 -2]

OK Cancel Help Apply

### **A-matrix(v1,v2)**

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 v1 and v2. Hence, for example, if the A-matrix corresponding to the first entry of v1 and first entry of v2 is the identity matrix, then  $A(:, :, 1, 1) = [1 \ 0; 0 \ 1];$

### **B-matrix(v1,v2)**

B-matrix of the state-space implementation.

### **C-matrix(v1,v2)**

C-matrix of the state-space implementation.

# 2D Controller Blend

---

## **D-matrix(v1,v2)**

D-matrix of the state-space implementation.

## **First scheduling variable (v1) breakpoints**

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.

## **Second scheduling variable (v2) breakpoints**

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.

## **Initial state, x\_initial**

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.

## **Poles of $A(v)-H(v)*C(v)$**

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  $u$ .

## **Inputs and Outputs**

The first input is the measurements.

The second and third inputs are the scheduling variables ordered conforming to the dimensions of the state-space matrices.

The output is the actuator demands.

## **Assumptions and Limitations**

This block requires the Control System Toolbox.

## **References**

Hyde, R. A., "H-infinity Aerospace Control Design - A VSTOL Flight Application," Springer Verlag, *Advances in Industrial Control Series*, 1995. ISBN 3-540-19960-8. See Chapter 5.

**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  $[A(v),B(v),C(v),D(v)]$

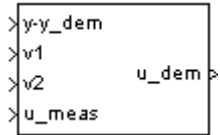
# 2D Observer Form $[A(v), B(v), C(v), F(v), H(v)]$

---

**Purpose** Implement a gain-scheduled state-space controller in an observer form depending on two scheduling parameters

**Library** GNC/Controls

**Description** The 2D Observer Form  $[A(v), B(v), C(v), F(v), H(v)]$  block implements a gain-scheduled state-space controller defined in the following observer form:



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

The main application of these blocks is to implement a controller designed using H-infinity loop-shaping, one of the design methods supported by the  $\mu$ -Analysis and Synthesis Toolbox.

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

## Dialog Box

Block Parameters: 2D Observer Form  $[A(v),B(v),C(v),F(v),H(v)]$

StateSpaceABCFH-2D (mask) (link)

Implement a state-space controller  $[A,B,C,F,H]$  in observer form where  $A$ ,  $B$ ,  $C$ ,  $F$ , and  $H$  depend on two scheduling parameters.

Parameters

A-matrix(v1,v2):  
A

B-matrix(v1,v2):  
B

C-matrix(v1,v2):  
C

F-matrix(v1,v2):  
F

H-matrix(v1,v2):  
H

First scheduling variable (v1) breakpoints:  
v1\_vec

Second scheduling variable (v2) breakpoints:  
v2\_vec

Initial state, x\_initial:  
0

OK Cancel Help Apply

### **A-matrix(v1,v2)**

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  $v1$  and  $v2$ . Hence, for example, if the A-matrix corresponding to the first entry of  $v1$  and first entry of  $v2$  is the identity matrix, then  $A(:, :, 1, 1) = [1 \ 0; 0 \ 1];$

### **B-matrix(v1,v2)**

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  $v1$  and  $v2$ . Hence, for example, if the B-matrix corresponding to the first entry of  $v1$  and first entry of  $v2$  is the identity matrix, then  $B(:, :, 1, 1) = [1 \ 0; 0 \ 1];$

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

---

### **C-matrix(v1,v2)**

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  $v_2$ . Hence, 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  $C(:, :, 1, 1) = [1 \ 0; 0 \ 1];$

### **F-matrix(v1,v2)**

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  $v_2$ . Hence, 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  $F(:, :, 1, 1) = [1 \ 0; 0 \ 1];$

### **H-matrix(v1,v2)**

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  $v_2$ . Hence, 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  $H(:, :, 1, 1) = [1 \ 0; 0 \ 1];$

### **First scheduling variable (v1) breakpoints**

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.

### **Second scheduling variable (v2) breakpoints**

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.

### **Initial state, $x_{initial}$**

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.

## **Inputs and Outputs**

The first input is the set-point error.

The second and third inputs are the scheduling variables ordered conforming to the dimensions of the state-space matrices.

The fourth input is the measured actuator position.

The output is the actuator demands.

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

---

**Assumptions and Limitations** If the scheduling parameter inputs to the block go out of range, then they are clipped; i.e., the state-space matrices are not interpolated out of range.

**Examples** See H-Infinity Controller (Two Dimensional Scheduling) in the `aeroblk_lib_HL20` demo library for an example of this block.

**References** Hyde, R. A., “H-infinity Aerospace Control Design - A VSTOL Flight Application,” Springer Verlag, *Advances in Industrial Control Series*, 1995. ISBN 3-540-19960-8. See Chapter 6.

**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  $[A(v),B(v),C(v),F(v),H(v)]$

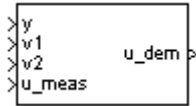
## 2D Self-Conditioned [A(v),B(v),C(v),D(v)]

---

**Purpose** Implement a gain-scheduled state-space controller in a self-conditioned form

**Library** GNC/Controls

### Description



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



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

## Dialog Box

StateSpaceSelfCond-2D (mask) (link)

Implement a state-space controller  $[A(v1,v2),B(v1,v2),C(v1,v2),D(v1,v2)]$  in a self-conditioned form. If  $u\_meas = u\_dem$ , then the implemented controller is  $[A,B,C,D]$ . If  $u\_meas$  is limited, e.g., rate limiting, then the poles of the controller become those defined in the mask dialog box. Uses call to Control Systems Toolbox function `place.m` when initializing. A, B, C, and D should be 4-D matrices, the last two dimensions corresponding to the scheduling parameters, and the first two corresponding to the matrix for a given set of scheduling parameter values.

Parameters

A-matrix(v1,v2):  
A

B-matrix(v1,v2):  
B

C-matrix(v1,v2):  
C

D-matrix(v1,v2):  
D

First scheduling variable (v1) breakpoints:  
v1\_vec

Second scheduling variable (v2) breakpoints:  
v2\_vec

Initial state, x\_initial:  
0

Poles of  $A(v)-H(v)*C(v) = [w1 \dots wn]$ :  
[-5 -2]

OK Cancel Help Apply

### A-matrix(v1,v2)

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  $v1$  and  $v2$ . Hence, for example, if the A-matrix corresponding to the first entry of  $v1$  and first entry of  $v2$  is the identity matrix, then  $A(:, :, 1, 1) = [1 \ 0; 0 \ 1]$ ;

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

---

### **B-matrix(v1,v2)**

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 v1 and v2. Hence, for example, if the B-matrix corresponding to the first entry of v1 and first entry of v2 is the identity matrix, then  $B(:, :, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **C-matrix(v1,v2)**

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 v1 and v2. Hence, for example, if the C-matrix corresponding to the first entry of v1 and first entry of v2 is the identity matrix, then  $C(:, :, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **D-matrix(v1,v2)**

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 v1 and v2. Hence, for example, if the D-matrix corresponding to the first entry of v1 and first entry of v2 is the identity matrix, then  $D(:, :, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **First scheduling variable (v1) breakpoints**

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.

### **Second scheduling variable (v2) breakpoints**

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.

### **Initial state, x\_initial**

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.

### **Poles of $A(v)-H(v)*C(v)$**

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.

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

---

### Inputs and Outputs

The first input is the measurements.

The second and third inputs are the scheduling variables ordered conforming to the dimensions of the state-space matrices.

The fourth input is the measured actuator position.

The output is the actuator demands.

### Assumptions and Limitations

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

This block requires the Control System Toolbox.

### References

The algorithm used to determine the matrix H is defined in Kautsky, Nichols, and Van Dooren, "Robust Pole Assignment in Linear State Feedback," *International Journal of Control*, Vol. 41, No. 5, pages 1129-1155, 1985.

### 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  $[A(v),B(v),C(v),D(v)]$

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

---

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

**Library** GNC/Controls

**Description** The 3D Controller [A(v),B(v),C(v),D(v)] block implements a gain-scheduled state-space controller as defined by the equations



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

$$u = C(v)x + D(v)y$$

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.

## Dialog Box

StateSpaceABCD-3D (mask) (link)

Implement a state-space controller  $[A,B,C,D]$  where A, B, C, and D depend on three scheduling parameters,  $v_1$ ,  $v_2$ , and  $v_3$ .

Parameters

A-matrix( $v_1,v_2,v_3$ ):  
A

B-matrix( $v_1,v_2,v_3$ ):  
B

C-matrix( $v_1,v_2,v_3$ ):  
C

D-matrix( $v_1,v_2,v_3$ ):  
D

First scheduling variable ( $v_1$ ) breakpoints:  
v1\_vec

Second scheduling variable ( $v_2$ ) breakpoints:  
v2\_vec

Third scheduling variable ( $v_3$ ) breakpoints:  
v3\_vec

Initial state,  $x_{initial}$ :  
0

OK Cancel Help Apply

### **A-matrix( $v_1,v_2,v_3$ )**

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  $v_3$ . Hence, 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  $A(:, :, 1, 1, 1) = [1 \ 0 \ 0; 0 \ 1 \ 0; 0 \ 0 \ 1]$ ;

### **B-matrix( $v_1,v_2,v_3$ )**

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  $v_3$ . Hence, for example, if the B-matrix

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

---

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  $B(:, :, 1, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **C-matrix( $v_1, v_2, v_3$ )**

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  $v_3$ . Hence, 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  $C(:, :, 1, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **D-matrix( $v_1, v_2, v_3$ )**

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  $v_3$ . Hence, 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  $D(:, :, 1, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **First scheduling variable ( $v_1$ ) breakpoints**

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.

### **Second scheduling variable ( $v_2$ ) breakpoints**

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.

### **Third scheduling variable ( $v_3$ ) breakpoints**

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.

### **Initial state, $x_{\text{initial}}$**

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.

## **Inputs and Outputs**

The first input is the measurements.

The second, third and fourth inputs are the scheduling variables ordered conforming to the dimensions of the state-space matrices.

The output is the actuator demands.

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

---

### **Assumptions and Limitations**

If the scheduling parameter input to the block go out of range, then they are clipped; i.e., the state-space matrices are not interpolated out of range.

### **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  $[A(v),B(v),C(v),D(v)]$

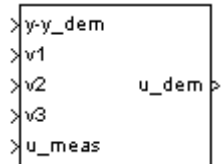
# 3D Observer Form [A(v),B(v),C(v),F(v),H(v)]

---

**Purpose** Implement a gain-scheduled state-space controller in an observer form depending on three scheduling parameters

**Library** GNC/Controls

**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 the following observer form:



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

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

The main application of this block is to implement a controller designed using H-infinity loop-shaping, one of the design methods supported by the  $\mu$ -Analysis and Synthesis Toolbox.



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

## Dialog Box

Block Parameters: 3D Observer Form  $[A(v),B(v),C(v),F(v),H(v)]$  [X]

StateSpaceABCFH-3D (mask) (link)

Implement a state-space controller  $[A,B,C,F,H]$  in observer form where  $A$ ,  $B$ ,  $C$ ,  $F$ , and  $H$  depend on three scheduling parameters.

Parameters

A-matrix  $(v1,v2,v3)$ :

B-matrix  $(v1,v2,v3)$ :

C-matrix  $(v1,v2,v3)$ :

F-matrix  $(v1,v2,v3)$ :

H-matrix  $(v1,v2,v3)$ :

First scheduling variable (v1) breakpoints:

Second scheduling variable (v2) breakpoints:

Third scheduling variable (v3) breakpoints:

Initial state,  $x_{initial}$ :

OK Cancel Help Apply

### **A-matrix $(v1,v2,v3)$**

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  $v1$ ,  $v2$ , and  $v3$ . Hence, for example, if the A-matrix corresponding to the first entry of  $v1$ , the first entry of  $v2$ , and the first entry of  $v3$  is the identity matrix, then  $A(:, :, 1, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **B-matrix $(v1,v2,v3)$**

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

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

---

scheduling variables  $v_1$ ,  $v_2$ , and  $v_3$ . Hence, 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  $B(:, :, 1, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **C-matrix( $v_1, v_2, v_3$ )**

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  $v_3$ . Hence, 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  $C(:, :, 1, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **F-matrix( $v_1, v_2, v_3$ )**

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  $v_3$ . Hence, 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  $F(:, :, 1, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **H-matrix( $v_1, v_2, v_3$ )**

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  $v_3$ . Hence, 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  $H(:, :, 1, 1, 1) = [1 \ 0; 0 \ 1]$ ;

### **First scheduling variable ( $v_1$ ) breakpoints**

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.

### **Second scheduling variable ( $v_2$ ) breakpoints**

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.

### **Third scheduling variable ( $v_3$ ) breakpoints**

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.

### **Initial state, $x_{\text{initial}}$**

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.

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

---

## Inputs and Outputs

The first input is the set-point error.

The second, third, and fourth inputs are the scheduling variables ordered conforming to the dimensions of the state-space matrices.

The fifth input is measured actuator position.

The output is the actuator demands.

## Assumptions and Limitations

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

## References

Hyde, R. A., "H-infinity Aerospace Control Design - A VSTOL Flight Application," Springer Verlag, *Advances in Industrial Control Series*, 1995. ISBN 3-540-19960-8. See Chapter 6.

## 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  $[A(v),B(v),C(v),D(v)]$

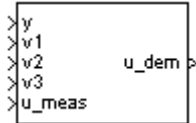
# 3D Self-Conditioned [A(v),B(v),C(v),D(v)]

---

**Purpose** Implement a gain-scheduled state-space controller in a self-conditioned form

**Library** GNC/Controls

**Description** The 3D Self-Conditioned [A(v),B(v),C(v),D(v)] 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.

## Dialog Box

StateSpaceSelfCond-3D (mask) (link)

Implement a state-space controller  $[A(v_1,v_2,v_3),B(v_1,v_2,v_3),C(v_1,v_2,v_3),D(v_1,v_2,v_3)]$  in a self-conditioned form. If  $u_{meas} = u_{dem}$ , then the implemented controller is  $[A,B,C,D]$ . If  $u_{meas}$  is limited, e.g., rate limiting, then the poles of the controller become those defined in the mask dialog box. Uses call to Control Systems Toolbox function `place.m` when initializing. A, B, C, and D should be 5-D matrices, the last three dimensions corresponding to the scheduling parameters, and the first two corresponding to the matrix for a given set of scheduling parameter values.

Parameters

A-matrix( $v_1,v_2,v_3$ ):

B-matrix( $v_1,v_2,v_3$ ):

C-matrix( $v_1,v_2,v_3$ ):

D-matrix( $v_1,v_2,v_3$ ):

First scheduling variable ( $v_1$ ) breakpoints:

Second scheduling variable ( $v_2$ ) breakpoints:

Third scheduling variable ( $v_3$ ) breakpoints:

Initial state,  $x_{initial}$ :

Poles of  $A(v) \cdot H(v) \cdot C(v) = [w_1 \dots w_n]$ :

OK Cancel Help Apply

### A-matrix( $v_1,v_2,v_3$ )

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  $v_3$ . Hence, 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  $A(:, :, 1, 1, 1) = [1 \ 0; 0 \ 1]$ ;

## 3D Self-Conditioned $[A(v), B(v), C(v), D(v)]$

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### **B-matrix(v1,v2,v3)**

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  $v_3$ . Hence, 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  $B(:, :, 1, 1, 1) = [1 \ 0 \ 0 \ 1]$ ;

### **C-matrix(v1,v2,v3)**

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  $v_3$ . Hence, 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  $C(:, :, 1, 1, 1) = [1 \ 0 \ 0 \ 1]$ ;

### **D-matrix(v1,v2,v3)**

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  $v_3$ . Hence, 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  $D(:, :, 1, 1, 1) = [1 \ 0 \ 0 \ 1]$ ;

### **First scheduling variable (v1) breakpoints**

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.

### **Second scheduling variable (v2) breakpoints**

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.

### **Third scheduling variable (v3) breakpoints**

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.

### **Initial state, $x_{initial}$**

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.

### **Poles of $A(v)-H(v)*C(v)$**

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

# 3D Self-Conditioned $[A(v),B(v),C(v),D(v)]$

---

number of pole locations defined should be equal to the length of the first dimension of the A-matrix.

## Inputs and Outputs

The first input is the measurements.

The second, third, and fourth inputs are the scheduling variables ordered conforming to the dimensions of the state-space matrices.

The fifth input is the measured actuator position.

The output is the actuator demands.

## Assumptions and Limitations

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

This block requires the Control System Toolbox.

## References

The algorithm used to determine the matrix H is defined in Kautsky, Nichols, and Van Dooren, "Robust Pole Assignment in Linear State Feedback," *International Journal of Control*, Vol. 41, No. 5, pages 1129-1155, 1985.

## 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  $[A(v),B(v),C(v),D(v)]$

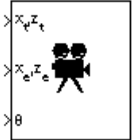
3D Observer Form  $[A(v),B(v),C(v),F(v),H(v)]$

# 3DoF Animation

**Purpose** Create a 3-D Handle Graphics animation of a three-degrees-of-freedom object

**Library** Animation

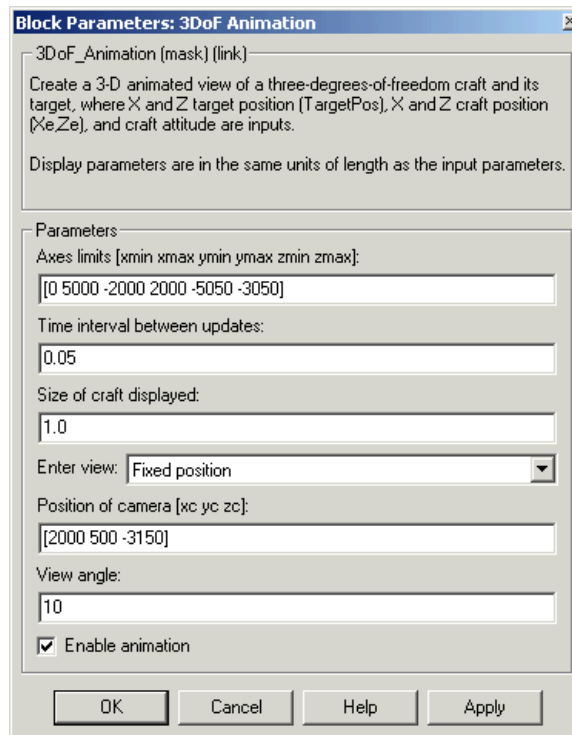
## Description



The 3DoF Animation block displays a 3-D animated view of a three-degrees-of-freedom (3DoF) craft, its trajectory, and its target using Handle Graphics.

The 3DoF Animation block uses the input values and the dialog parameters to create and display the animation.

## Dialog Box





**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 Handle 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 Handle Graphics parameter **CameraPosition** for the figure axes. Used in all cases except for the Cockpit view.

**View angle**

Specifies the Handle 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**

The first input is a vector containing the altitude and the downrange position of the target in Earth coordinates.

The second input is a vector containing the altitude and the downrange position of the craft in Earth coordinates.

The third input is the attitude of the craft.

# 3DoF Animation

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## Examples

See the `aero_guidance` demo for an example of this block.

## See Also

6DoF Animation

FlightGear Preconfigured 6DoF Animation

## Purpose

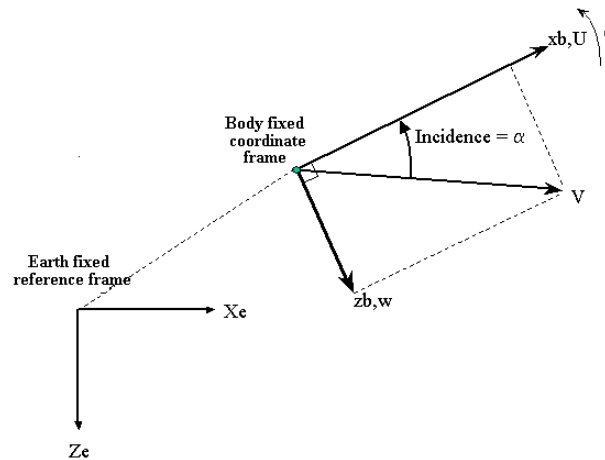
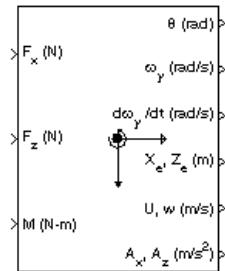
Implement three-degrees-of-freedom equations of motion with respect to body axes

## 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 an Earth-fixed reference frame.



The equations of motion are

$$\dot{u} = \frac{F_x}{m} - qw - g \sin \theta$$

$$\dot{w} = \frac{F_z}{m} + qu + g \cos \theta$$

$$\dot{q} = \frac{M}{I_{yy}}$$

$$\dot{\theta} = q$$

where the applied forces are assumed to act at the center of gravity of the body.

# 3DoF (Body Axes)

## Dialog Box

**Block Parameters: 3DoF (Body Axes)** [?] [X]

3DoF EoM (mask) (link)

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

Parameters

Units: Metric (MKS) [v]

Mass type: Fixed [v]

Initial velocity: [100]

Initial body attitude: [0]

Initial incidence: [0]

Initial body rotation rate: [0]

Initial position (x z): [0 0]

Initial mass: [1.0]

Inertia: [1.0]

Gravity source: External [v]

[OK] [Cancel] [Help] [Apply]

## 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, ( $\theta_0$ ).

## Initial incidence

A scalar value for the initial angle between the velocity vector and the body, ( $\alpha_0$ ).

## 3DoF (Body Axes)

---

### 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 Earth-fixed 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.

## Inputs and Outputs

The first input to the block is the force acting along the body x-axis, ( $F_x$ ).

The second input to the block is the force acting along the body z-axis, ( $F_z$ ).

The third input to the block is the applied pitch moment, ( $M$ ).

The fourth optional input to the block is gravity in the selected units.

The first output from the block is the pitch attitude, in radians ( $\theta$ ).

The second output is the pitch angular rate, in radians per second ( $q$ ).

The third output is the pitch angular acceleration, in radians per second squared ( $\dot{q}$ ).

The fourth output is a two-element vector containing the location of the body, in the Earth-fixed reference frame, ( $X_e, Z_e$ ).

The fifth output is a two-element vector containing the velocity of the body resolved into the body-fixed coordinate frame,  $(u,w)$ .

The sixth output is a two-element vector containing the acceleration of the body resolved into the body-fixed coordinate frame,  $(Ax,Az)$ .

### Examples

See the `aero_guidance` demo 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 \(Wind Axes\)](#)

# 3DoF (Wind Axes)

## Purpose

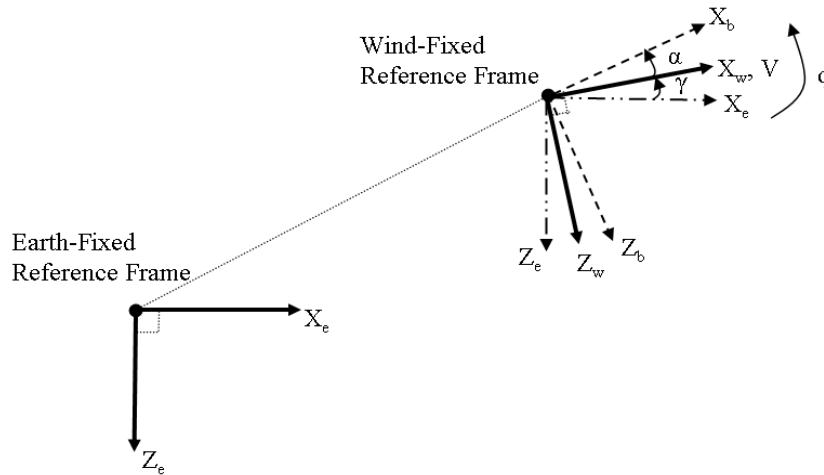
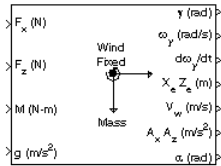
Implement three-degrees-of-freedom equations of motion with respect to wind axes

## 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 an Earth-fixed reference frame.



The equations of motion are

$$\dot{V} = \frac{F_{x_{wind}}}{m} - g \sin \gamma$$

$$\dot{\alpha} = \frac{F_{z_{wind}}}{mV \cos \beta} + q + \frac{g}{V \cos \beta} \cos \gamma$$

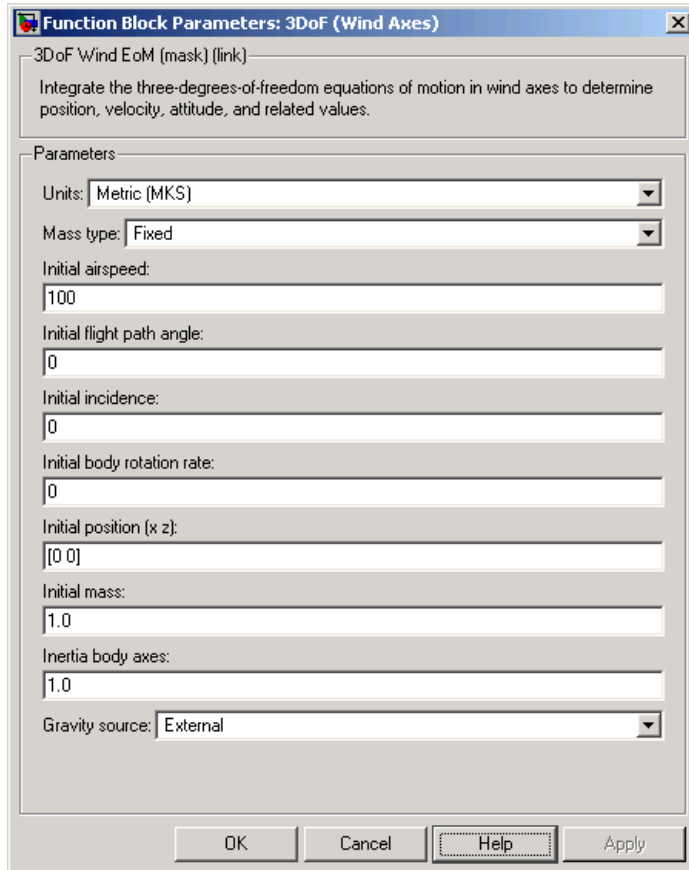
$$\dot{q} = \dot{\theta} = \frac{M_{y_{body}}}{I_{yy}} = \frac{DCM_{bw} M_{y_{wind}}}{I_{yy}}$$

$$\dot{\gamma} = q - \dot{\alpha}$$

where the applied forces are assumed to act at the center of gravity of the body.



## Dialog Box



Function Block Parameters: 3DoF (Wind Axes)

3DoF Wind EoM (mask) (link)

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

Parameters

Units: Metric (MKS)

Mass type: Fixed

Initial airspeed: 100

Initial flight path angle: 0

Initial incidence: 0

Initial body rotation rate: 0

Initial position (x z): [0 0]

Initial mass: 1.0

Inertia body axes: 1.0

Gravity source: External

OK Cancel Help Apply

# 3DoF (Wind Axes)

---

## 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 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, ( $\gamma_0$ ).

## Initial incidence

A scalar value for the initial angle between the velocity vector and the body, ( $\alpha_0$ ).

## 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 Earth-fixed 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.

## Inputs and Outputs

The first input to the block is the force acting along the wind x-axis, ( $F_x$ ).

The second input to the block is the force acting along the wind z-axis, ( $F_z$ ).

The third input to the block is the applied pitch moment in wind-axes, ( $M$ ).

The fourth optional input to the block is gravity in the selected units.

The first output from the block is the flight path angle, in radians ( $\gamma$ ).

The second output is the pitch angular rate, in radians per second ( $\omega_y$ ).

The third output is the pitch angular acceleration, in radians per second squared ( $d\omega_y/dt$ ).

The fourth output is a two-element vector containing the location of the body, in the Earth-fixed reference frame, ( $X_e, Z_e$ ).

## 3DoF (Wind Axes)

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The fifth output is a two-element vector containing the velocity of the body resolved into the wind-fixed coordinate frame,  $(V,0)$ .

The sixth output is a two-element vector containing the acceleration of the body resolved into the body-fixed coordinate frame,  $(Ax,Az)$ .

The seventh output is a scalar containing the angle of attack,  $(\alpha)$ .

### 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.

### References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 1992.

### See Also

3DoF (Body Axes)

4th Order Point Mass (Longitudinal)

Custom Variable Mass 3DoF (Body Axes)

Custom Variable Mass 3DoF (Wind Axes)

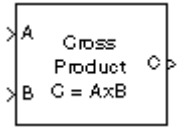
Simple Variable Mass 3DoF (Body Axes)

Simple Variable Mass 3DoF (Wind Axes)

**Purpose** Calculate the cross product of two 3-by-1 vectors

**Library** Utilities/Math Operations

## Description



The 3x3 Cross Product block computes cross (or vector) product of two vectors, A and B, by generating a third vector, C, in a direction normal to the plane containing A and B, and 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 is that in which a right-handed screw would move in turning from A to B.

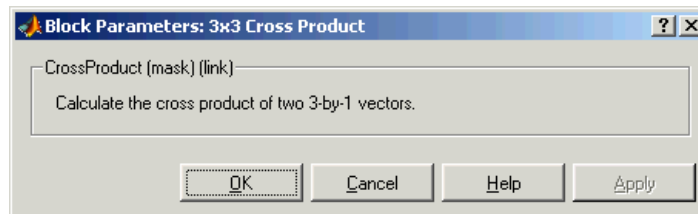
$$A = a_1\mathbf{i} + a_2\mathbf{j} + a_3\mathbf{k}$$

$$B = b_1\mathbf{i} + b_2\mathbf{j} + b_3\mathbf{k}$$

$$C = A \times B = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{vmatrix}$$

$$= (a_2b_3 - a_3b_2)\mathbf{i} + (a_3b_1 - a_1b_3)\mathbf{j} + (a_1b_2 - a_2b_1)\mathbf{k}$$

## Dialog Box



**Inputs and** The inputs are two 3-by-1 vectors.

**Outputs** The output is a 3-by-1 vector.

# 4th Order Point Mass (Longitudinal)

## Purpose

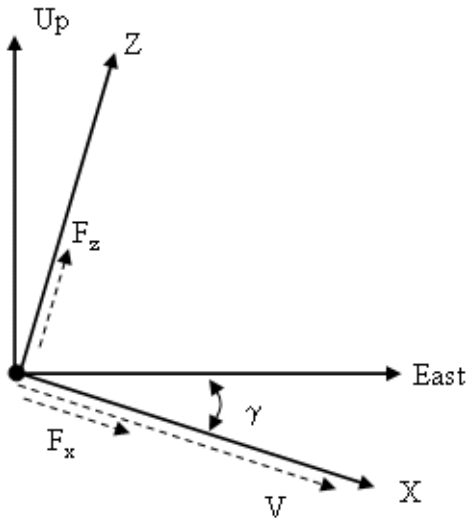
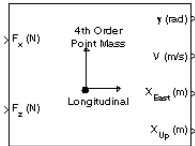
Calculate fourth order point mass

## 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  $[X_{East} X_{Up}]^T$  are functions of airspeed ( $V$ ) and flight path angle ( $\gamma$ ),

$$F_x = m\dot{V}$$

$$F_z = mV\dot{\gamma}$$

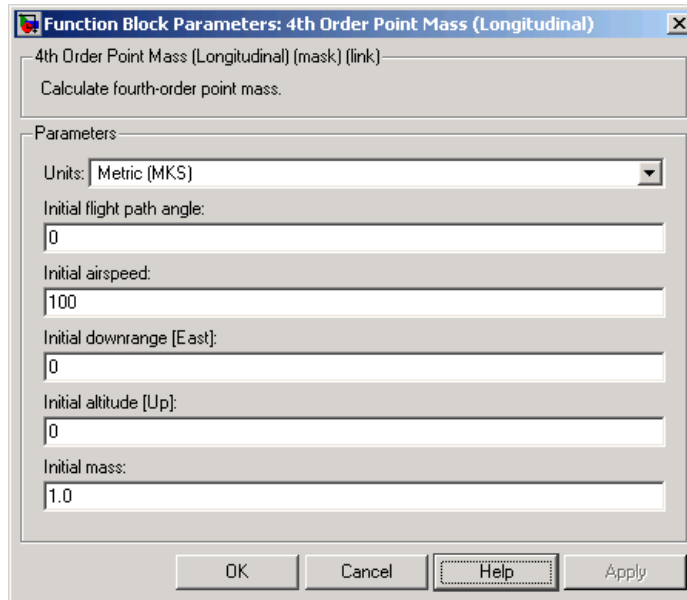
$$\dot{X}_{East} = V\cos\gamma$$

$$\dot{X}_{Up} = V\sin\gamma$$

# 4th Order Point Mass (Longitudinal)

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 upwards and  $y$ -axis completes the right hand frame. The mass of the body  $m$  is assumed constant.

## Dialog Box



## 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).

# 4th Order Point Mass (Longitudinal)

---

## **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**

The first input is force in  $x$ -axis in selected units.

The second input is force in  $z$ -axis in selected units.

The first output is flight path angle in radians.

The second output is airspeed in selected units.

The third output is the downrange or amount traveled East in selected units.

The fourth output is the altitude or amount traveled Up in selected units.

## **Assumptions and Limitations**

The flat Earth-fixed reference frame is considered inertial, a simplification that allows the forces due to the Earth's motion relative to a star-fixed reference system 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)

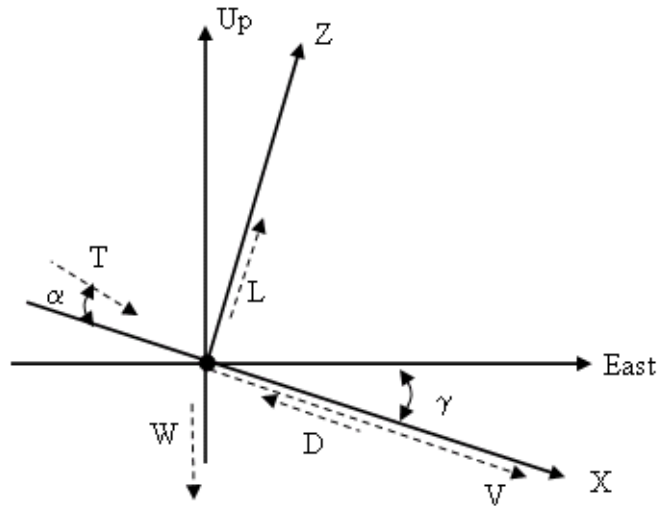
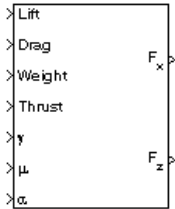


# 4th Order Point Mass Forces (Longitudinal)

**Purpose** 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 upwards and  $y$ -axis completes the right hand frame. They are functions of lift ( $L$ ), drag ( $D$ ), thrust ( $T$ ), weight ( $W$ ), flight path angle ( $\gamma$ ), angle of attack ( $\alpha$ ), and bank angle ( $\mu$ ).

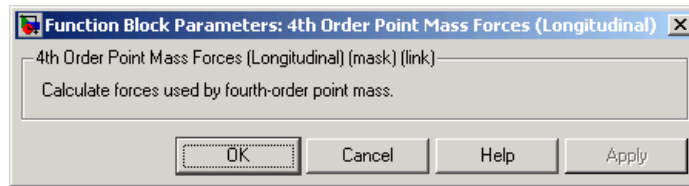
$$F_x = T \cos \alpha - D - W \sin \gamma$$

$$F_z = (L + T \sin \alpha) \cos \mu - W \cos \gamma$$

# 4th Order Point Mass Forces (Longitudinal)

---

## Dialog Box



## Inputs and Outputs

The first input is lift in units of force.

The second input is drag in units of force.

The third input is weight in units of force.

The fourth input is thrust in units of force.

The fifth input is flight path angle in radians.

The sixth input is bank angle in radians.

The seventh input is angle of attack in radians.

The first output is force in  $x$ -axis in units of force.

The second output is force in  $z$ -axis in units of force.

## Assumptions and Limitations

The flat Earth-fixed reference frame is considered inertial, a simplification that allows the forces due to the Earth's motion relative to a star-fixed reference system to be neglected.

## See Also

4th Order Point Mass (Longitudinal)

6th Order Point Mass (Coordinated Flight)

6th Order Point Mass Forces (Coordinated Flight)

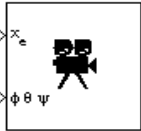
## Purpose

Create a 3-D Handle Graphics® animation of a six-degrees-of-freedom object

## Library

Animation

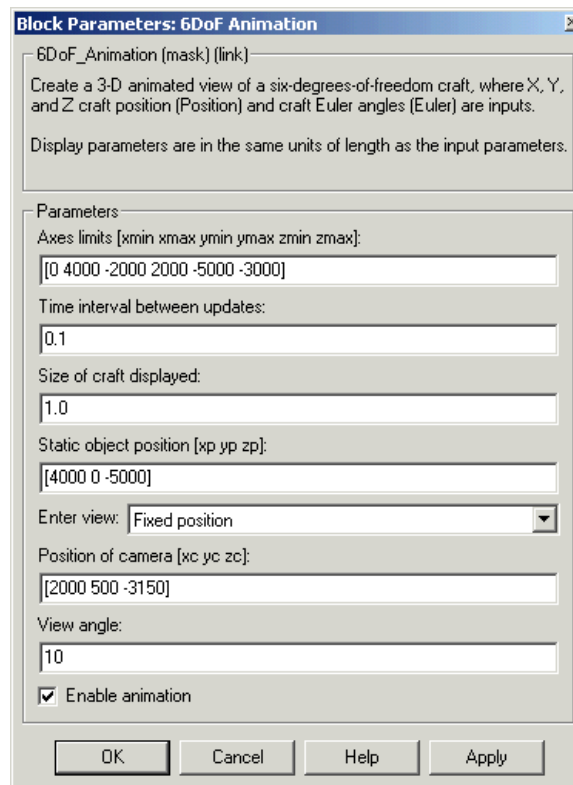
## Description



The 6DoF Animation block displays a 3-D animated view of a six-degrees-of-freedom (6DoF) craft, its trajectory, and its target using Handle Graphics.

The 6DoF Animation block uses the input values and the dialog parameters to create and display the animation.

## Dialog Box

A screenshot of a MATLAB dialog box titled "Block Parameters: 6DoF Animation". The dialog box contains the following fields and controls:

- A title bar with the text "Block Parameters: 6DoF Animation" and a close button.
- A text area with the description: "6DoF\_Animation (mask) (link) Create a 3-D animated view of a six-degrees-of-freedom craft, where X, Y, and Z craft position (Position) and craft Euler angles (Euler) are inputs. Display parameters are in the same units of length as the input parameters."
- A "Parameters" section with several input fields:
  - "Axes limits [xmin xmax ymin ymax zmin zmax]": [0 4000 -2000 2000 -5000 -3000]
  - "Time interval between updates": 0.1
  - "Size of craft displayed": 1.0
  - "Static object position [xp yp zp]": [4000 0 -5000]
  - "Enter view": Fixed position (dropdown menu)
  - "Position of camera [xc yc zc]": [2000 500 -3150]
  - "View angle": 10
- A checked checkbox labeled "Enable animation".
- Buttons for "OK", "Cancel", "Help", and "Apply" at the bottom.

# 6DoF Animation

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## **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 cross-range position, and the downrange position of the target.

## **Enter view**

Selects preset Handle 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 Handle Graphics parameter **CameraPosition** for the figure axes. Used in all cases except for the Cockpit view.

## **View angle**

Specifies the Handle 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**

The first input is a vector containing the altitude, the cross-range position, and the downrange position of the craft in Earth coordinates.

The second input is a vector containing the Euler angles of the craft.

## **Examples**

See the aeroblk\_vmm demo for an example of this block.

## **See Also**

[3DoF Animation](#)

[FlightGear Preconfigured 6DoF Animation](#)

# 6DoF (Euler Angles)

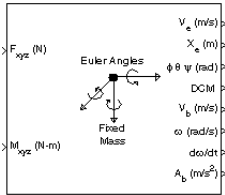
## Purpose

Implement an Euler angle representation of six-degrees-of-freedom equations of motion

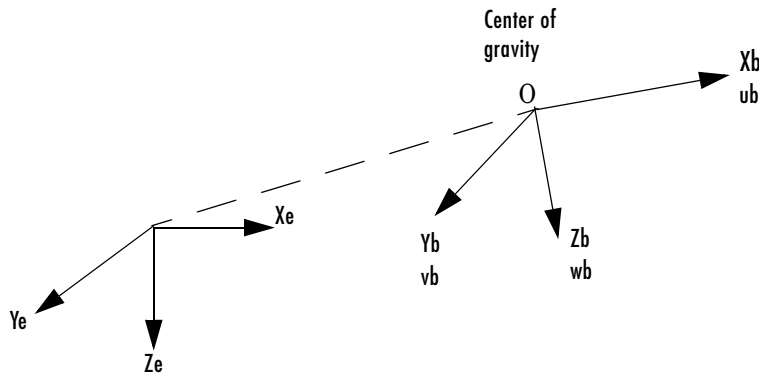
## Library

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 an Earth-fixed 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 Earth-fixed reference frame is considered inertial, a simplification that allows the forces due to the Earth's motion relative to a star-fixed reference system to be neglected.



Earth-fixed 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.

$$\underline{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\underline{V}}_b + \underline{\omega} \times \underline{V}_b)$$

$$\underline{V}_b = \begin{bmatrix} u_b \\ v_b \\ w_b \end{bmatrix}, \underline{\omega} = \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

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.

$$\underline{M}_B = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I \underline{\dot{\omega}} + \underline{\omega} \times (I \underline{\omega})$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

The relationship between the body-fixed angular velocity vector,  $[p \ q \ r]^T$ , and the rate of change of the Euler angles,  $[\dot{\phi} \ \dot{\theta} \ \dot{\psi}]^T$ , can be determined by resolving the Euler rates into the body-fixed coordinate frame.

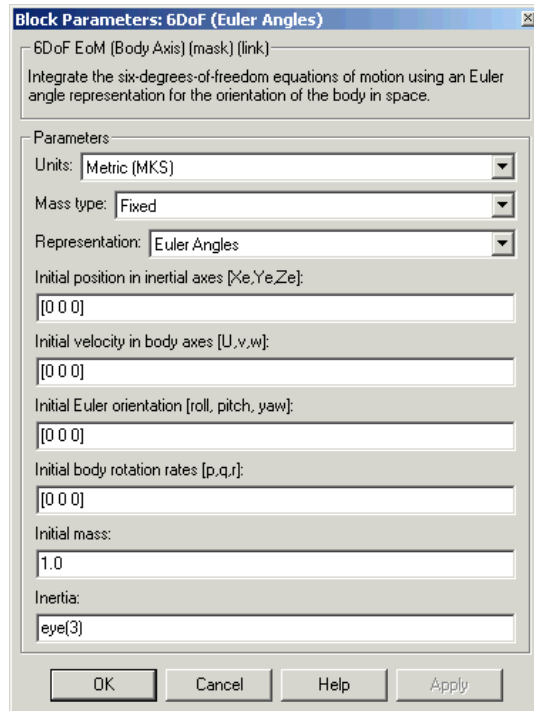
$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} \dot{\phi} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & \sin \phi \\ 0 & -\sin \phi & \cos \phi \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & \sin \phi \\ 0 & -\sin \phi & \cos \phi \end{bmatrix} \begin{bmatrix} \cos \theta & 0 & -\sin \theta \\ 0 & 1 & 0 \\ \sin \theta & 0 & \cos \theta \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix} \equiv \underline{J}^{-1} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

Inverting  $\underline{J}$  then gives the required relationship to determine the Euler rate vector.

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \underline{J} \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & (\sin \phi \tan \theta) & (\cos \phi \tan \theta) \\ 0 & \cos \phi & -\sin \phi \\ 0 & \frac{\sin \phi}{\cos \theta} & \frac{\cos \phi}{\cos \theta} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

# 6DoF (Euler Angles)

## Dialog Box



## 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 Earth-fixed 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.

# 6DoF (Euler Angles)

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## Inertia

The 3-by-3 inertia tensor matrix  $I$ .

## Inputs and Outputs

The first input to the block is a vector containing the three applied forces.

The second input is a vector containing the three applied moments.

The first output is a three-element vector containing the velocity in the Earth-fixed reference frame.

The second output is a three-element vector containing the position in the Earth-fixed reference frame.

The third output is a three-element vector containing the Euler rotation angles [roll, pitch, yaw], in radians.

The fourth output is a 3-by-3 matrix for the coordinate transformation from Earth-fixed axes to body-fixed axes.

The fifth output is a three-element vector containing the velocity in the body-fixed frame.

The sixth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The seventh output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The eighth output is a three-element vector containing the accelerations in body-fixed axes.

## 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` demo, `Airframe` in the `aeroblk_HL20` demo and `asbh120` demo for examples of this block.

## References

Mangiacasale, L., "Flight Mechanics of a u-Airplane with a MATLAB Simulink Helper," Edizioni Libreria CLUP, 1998.

## 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)

# 6DoF (Quaternion)

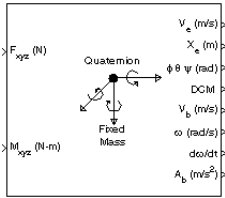
## Purpose

Implement a 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 employed 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  $\varepsilon$  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.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} q_3 & -q_2 & q_1 \\ q_2 & q_3 & -q_0 \\ -q_1 & q_0 & q_3 \\ -q_0 & -q_1 & -q_2 \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} + K\varepsilon \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

$$\varepsilon = 1 - (q_0^2 + q_1^2 + q_3^2 + q_4^2)$$

## Dialog Box

**Block Parameters: 6DoF (Quaternion)**

6DoF EoM (Body Axis) (mask) (link)

Integrate the six-degrees-of-freedom equations of motion using an Euler angle representation for the orientation of the body in space.

Parameters

Units: Metric (MKS)

Mass type: Fixed

Representation: Quaternion

Initial position in inertial axes [x<sub>e</sub>,y<sub>e</sub>,z<sub>e</sub>]:  
[0 0 0]

Initial velocity in body axes [u,v,w]:  
[0 0 0]

Initial Euler orientation [roll, pitch, yaw]:  
[0 0 0]

Initial body rotation rates [p,q,r]:  
[0 0 0]

Initial mass:  
1.0

Inertia:  
eye(3)

Gain for quaternion normalization:  
1.0

OK Cancel Help Apply

# 6DoF (Quaternion)

---

## 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 Earth-fixed 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.

**Inputs and Outputs**

The first input to the block is a vector containing the three applied forces.

The second input is a vector containing the three applied moments.

The first output is a three-element vector containing the velocity in the Earth-fixed reference frame.

The second output is a three-element vector containing the position in the Earth-fixed reference frame.

The third output is a three-element vector containing the Euler rotation angles [roll, pitch, yaw], in radians.

The fourth output is a 3-by-3 matrix for the coordinate transformation from Earth-fixed axes to body-fixed axes.

The fifth output is a three-element vector containing the velocity in the body-fixed frame.

## 6DoF (Quaternion)

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The sixth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The seventh output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The eighth output is a three-element vector containing the accelerations in body-fixed axes.

### 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.

### References

Mangiacasale, L., "Flight Mechanics of a u-Airplane with a MATLAB Simulink Helper," Edizioni Libreria CLUP, 1998.

### 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)



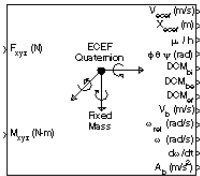
## Purpose

Implement a quaternion representation of six-degrees-of-freedom equations of motion in Earth-Centered Earth-Fixed (ECEF) coordinates

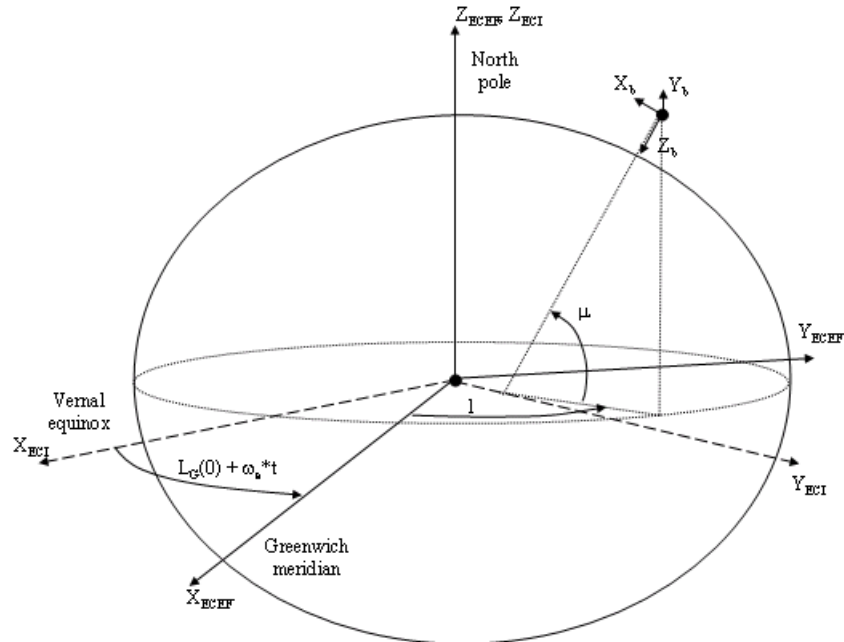
## Library

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 ( $\omega_e$ ) including an initial celestial longitude ( $L_G(0)$ ). This simplification that allows the forces due to the Earth's complex motion relative to a star-fixed reference system to be neglected.



## 6DoF ECEF (Quaternion)

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.

$$\underline{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\underline{V}}_b + \underline{\omega}_b \times \underline{V}_b + (DCM_{bi}\underline{\omega}_e \times \underline{V}_b) + DCM_{bi}(\underline{\omega}_e \times (\underline{\omega}_e \times \underline{x}_i)))$$

where the change of position in ECI ( $\dot{\underline{x}}_i$ ) is calculated by

$$\dot{\underline{x}}_i = \begin{bmatrix} \dot{x}_{ECI} \\ \dot{y}_{ECI} \\ \dot{z}_{ECI} \end{bmatrix} = DCM_{ib}\underline{V}_b + \underline{\omega}_e \times \underline{x}_i$$

and the velocity in body-axis ( $\underline{V}_b$ ), angular rates in body-axis ( $\underline{\omega}_b$ ), Earth rotation rate ( $\underline{\omega}_e$ ), and relative angular rates in body-axis ( $\underline{\omega}_{rel}$ ) are defined as

$$\underline{V}_b = \begin{bmatrix} u \\ v \\ w \end{bmatrix}, \underline{\omega}_b = \begin{bmatrix} p \\ q \\ r \end{bmatrix}, \underline{\omega}_e = \begin{bmatrix} 0 \\ 0 \\ \omega_e \end{bmatrix}, \underline{\omega}_{rel} = \underline{\omega}_b - DCM_{bi}\underline{\omega}_e$$

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.

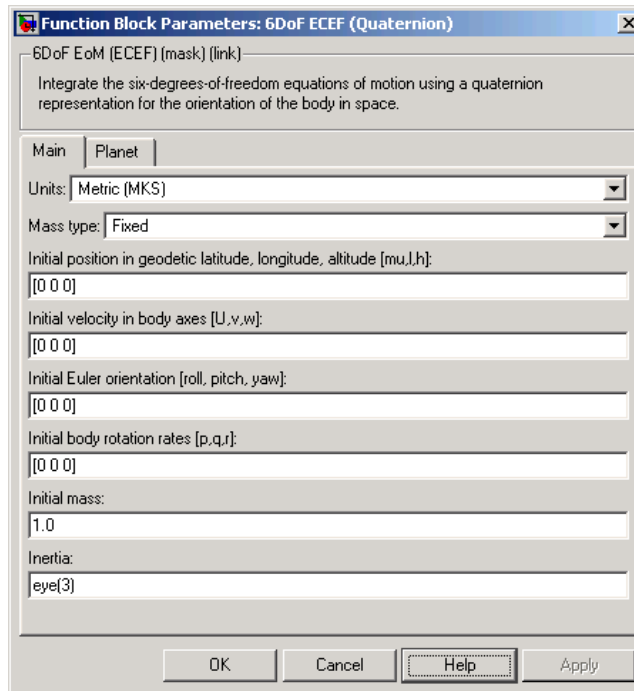
$$\underline{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I\dot{\underline{\omega}}_b + \underline{\omega}_b \times (I\underline{\omega}_b)$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

The integration of the rate of change of the quaternion vector is given below.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = -\frac{1}{2} \begin{bmatrix} 0 & p & q & r \\ -p & 0 & -r & q \\ -q & r & 0 & -p \\ -r & -q & p & 0 \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

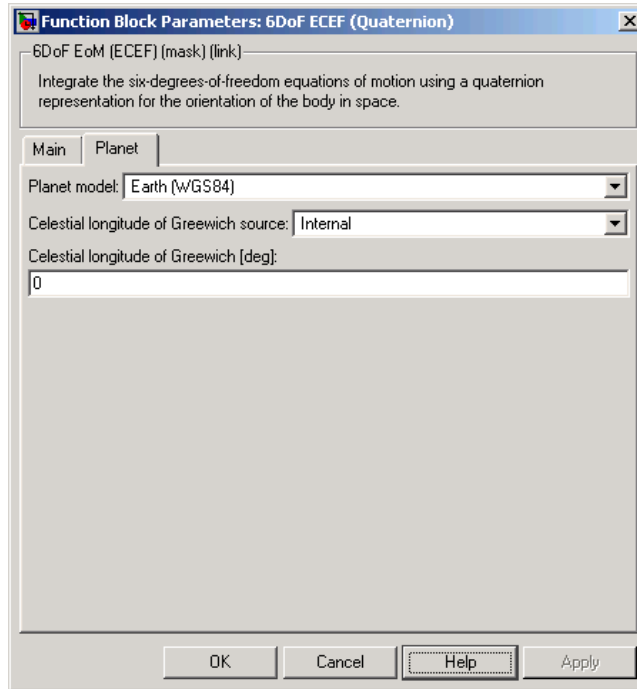
## Dialog Box



The dialog box, titled "Function Block Parameters: 6DoF ECEF (Quaternion)", contains the following fields and controls:

- 6DoF EoM (ECEF) (mask) (link) —
- Integrate the six-degrees-of-freedom equations of motion using a quaternion representation for the orientation of the body in space.
- Tabbed interface with "Main" and "Planet" tabs.
- Units: Metric (MKS)
- Mass type: Fixed
- Initial position in geodetic latitude, longitude, altitude [mu,l,h]: [0 0 0]
- Initial velocity in body axes [U,v,w]: [0 0 0]
- Initial Euler orientation [roll, pitch, yaw]: [0 0 0]
- Initial body rotation rates [p,q,r]: [0 0 0]
- Initial mass: 1.0
- Inertia: eye(3)
- Buttons: OK, Cancel, Help, Apply

# 6DoF ECEF (Quaternion)



## 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.

## Initial velocity in body axes

The three-element vector containing the initial velocity in the body-fixed coordinate frame.

## Initial Euler orientation

The three-element vector containing 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  $I$ , in body-fixed axes.

## Planet model

Specifies the planet model to use:

- Custom
- Earth (WGS84)

## 6DoF ECEF (Quaternion)

---

### 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/sec. 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.

## Inputs and Outputs

The first input to the block is a vector containing the three applied forces in body-fixed axes.

The second input is a vector containing the three applied moments in body-fixed axes.

The first output is a three-element vector containing the velocity in the ECEF reference frame.

The second output is a three-element vector containing the position in the ECEF reference frame.

The third output is a three-element vector containing the position in geodetic latitude, longitude and altitude, in degrees, degrees and selected units of length respectively.

The fourth output is a three-element vector containing the body rotation angles [roll, pitch, yaw], in radians.

The fifth output is a 3-by-3 matrix for the coordinate transformation from ECI axes to body-fixed axes.

The sixth output is a 3-by-3 matrix for the coordinate transformation from geodetic axes to body-fixed axes.

The seventh output is a 3-by-3 matrix for the coordinate transformation from ECEF axes to geodetic axes.

The eighth output is a three-element vector containing the velocity in the body-fixed frame.

The ninth output is a three-element vector containing the relative angular rates in body-fixed axes, in radians per second.

The tenth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The eleventh output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The twelfth output is a three-element vector containing the accelerations in body-fixed axes.

### **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  $\pm 90$  degrees, and longitude that lies between  $\pm 180$  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

## 6DoF ECEF (Quaternion)

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center of the Earth through the center of the Sun 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*, John Wiley & Sons, New York, NY, 1992.

Zipfel, P. H., *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA Education Series, Reston, VA, 2000.

“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)



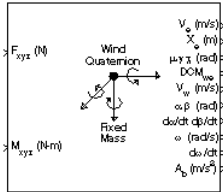
## Purpose

Implement a quaternion representation of six-degrees-of-freedom equations of motion with respect to wind axes

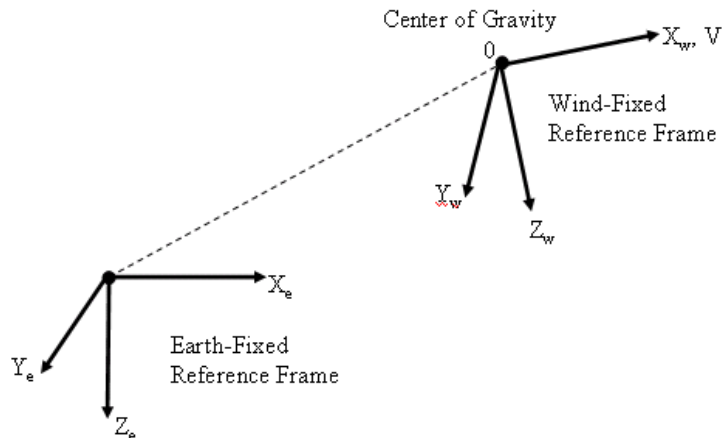
## Library

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 Earth-fixed 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 Earth-fixed reference frame is considered inertial, a simplification that allows the forces due to the Earth's motion relative to a star-fixed reference system 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.

$$\underline{F}_w = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\underline{\dot{V}}_w + \underline{\omega}_w \times \underline{V}_w)$$

## 6DoF Wind (Quaternion)

$$\underline{V}_w = \begin{bmatrix} V \\ 0 \\ 0 \end{bmatrix}, \underline{\omega}_w = \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = DMC_{wb} \begin{bmatrix} p_b - \beta \sin \alpha \\ q_b - \dot{\alpha} \\ r_b + \beta \cos \alpha \end{bmatrix}, \underline{w}_b = \begin{bmatrix} p_b \\ q_b \\ r_b \end{bmatrix}$$

The rotational dynamics of the wind-fixed frame in relation to 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.

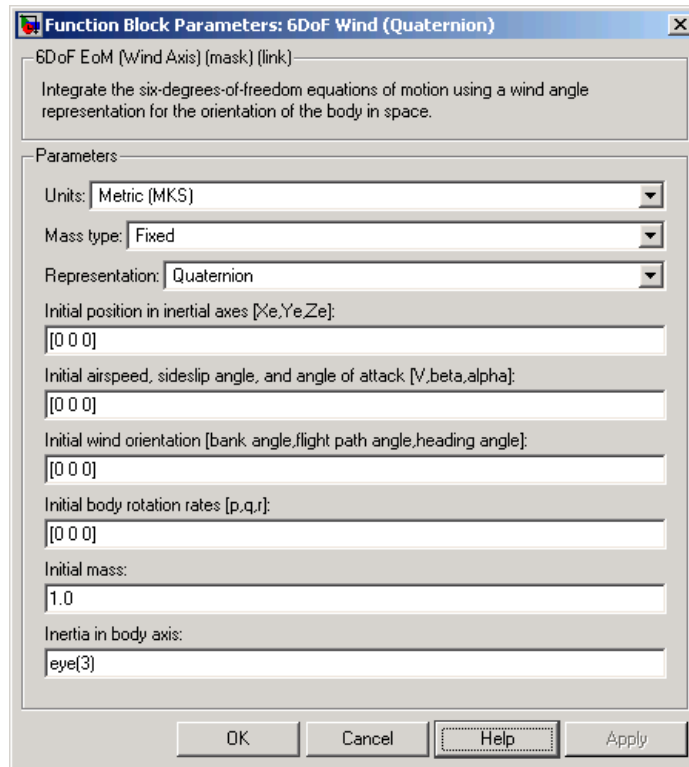
$$\underline{M}_w = DCM_{wb} \underline{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I \dot{\underline{\omega}}_b + \underline{\omega}_b \times (I \underline{\omega}_b)$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

The integration of the rate of change of the quaternion vector is given below.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = -\frac{1}{2} \begin{bmatrix} 0 & p & q & r \\ -p & 0 & -r & q \\ -q & r & 0 & -p \\ -r & -q & p & 0 \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

## Dialog Box



Function Block Parameters: 6DoF Wind (Quaternion)

6DoF EoM (Wind Axis) (mask) (link)

Integrate the six-degrees-of-freedom equations of motion using a wind angle representation for the orientation of the body in space.

Parameters

Units: Metric (MKS)

Mass type: Fixed

Representation: Quaternion

Initial position in inertial axes [Xe,Ye,Ze]:  
[0 0 0]

Initial airspeed, sideslip angle, and angle of attack [V,beta,alpha]:  
[0 0 0]

Initial wind orientation [bank angle,flight path angle,heading angle]:  
[0 0 0]

Initial body rotation rates [p,q,r]:  
[0 0 0]

Initial mass:  
1.0

Inertia in body axis:  
eye(3)

OK Cancel Help Apply

# 6DoF Wind (Quaternion)

---

## Units

Specifies the input and output units:

<b>Units</b>	<b>Forces</b>	<b>Moment</b>	<b>Acceleration</b>	<b>Velocity</b>	<b>Position</b>	<b>Mass</b>	<b>Inertia</b>
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 Earth-fixed 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.

**Inputs and Outputs**

The first input to the block is a vector containing the three applied forces in wind-fixed axes.

The second input is a vector containing the three applied moments in wind-fixed axes.

The first output is a three-element vector containing the velocity in the Earth-fixed reference frame.

The second output is a three-element vector containing the position in the Earth-fixed reference frame.

The third output is a three-element vector containing the wind rotation angles [bank, flight path, heading], in radians.

The fourth output is a 3-by-3 matrix for the coordinate transformation from Earth-fixed axes to wind-fixed axes.

The fifth output is a three-element vector containing the velocity in the wind-fixed frame.

# 6DoF Wind (Quaternion)

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The sixth output is a two-element vector containing the angle of attack and sideslip angle, in radians.

The seventh output is a two-element vector containing the rate of change of angle of attack and rate of change of sideslip angle, in radians per second.

The eighth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The ninth output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The tenth output is a three-element vector containing the accelerations in body-fixed axes.

## 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.

## References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 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)

# 6DoF Wind (Wind Angles)

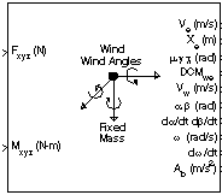
## Purpose

Implement a 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.

$$\begin{bmatrix} \dot{\mu} \\ \dot{\gamma} \\ \dot{\chi} \end{bmatrix} = J \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} 1 & (\sin \mu \tan \gamma) & (\cos \mu \tan \gamma) \\ 0 & \cos \mu & -\sin \mu \\ 0 & \frac{\sin \mu}{\cos \gamma} & \frac{\cos \mu}{\cos \gamma} \end{bmatrix} \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix}$$

The body-fixed angular rates are related to the wind-fixed angular rate by the following equation.

$$\begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = DMC_{wb} \begin{bmatrix} p_b - \beta \sin \alpha \\ q_b - \dot{\alpha} \\ r_b + \beta \cos \alpha \end{bmatrix}$$

Using this relationship in the wind rate vector equations, gives the relationship between the wind rate vector and the body-fixed angular rates.



$$\begin{bmatrix} \dot{\mu} \\ \dot{\gamma} \\ \dot{\chi} \end{bmatrix} = J \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} 1 & (\sin \mu \tan \gamma) & (\cos \mu \tan \gamma) \\ 0 & \cos \mu & -\sin \mu \\ 0 & \frac{\sin \mu}{\cos \gamma} & \frac{\cos \mu}{\cos \gamma} \end{bmatrix} DMC_{wb} \begin{bmatrix} p_b - \beta \sin \alpha \\ q_b - \dot{\alpha} \\ r_b + \beta \cos \alpha \end{bmatrix}$$

## Dialog Box

**Function Block Parameters: 6DoF Wind (Wind Angles)**

6DoF EoM (Wind Axis) (mask) (link)

Integrate the six-degrees-of-freedom equations of motion using a wind angle representation for the orientation of the body in space.

Parameters

Units: Metric (MKS)

Mass type: Fixed

Representation: Wind Angles

Initial position in inertial axes [Xe,Ye,Ze]:  
[0 0 0]

Initial airspeed, angle of attack, and sideslip angle [V,alpha,beta]:  
[0 0 0]

Initial wind orientation [bank angle,flight path angle,heading angle]:  
[0 0 0]

Initial body rotation rates [p,q,r]:  
[0 0 0]

Initial mass:  
1.0

Inertia in body axis:  
eye(3)

OK Cancel Help Apply

# 6DoF Wind (Wind Angles)

---

## Units

Specifies the input and output units:

<b>Units</b>	<b>Forces</b>	<b>Moment</b>	<b>Acceleration</b>	<b>Velocity</b>	<b>Position</b>	<b>Mass</b>	<b>Inertia</b>
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 Earth-fixed 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.

**Inputs and Outputs**

The first input to the block is a vector containing the three applied forces in wind-fixed axes.

The second input is a vector containing the three applied moments in wind-fixed axes.

The first output is a three-element vector containing the velocity in the Earth-fixed reference frame.

The second output is a three-element vector containing the position in the Earth-fixed reference frame.

The third output is a three-element vector containing the wind rotation angles [bank, flight path, heading], in radians.

The fourth output is a 3-by-3 matrix for the coordinate transformation from Earth-fixed axes to wind-fixed axes.

The fifth output is a three-element vector containing the velocity in the wind-fixed frame.

# 6DoF Wind (Wind Angles)

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The sixth output is a two-element vector containing the angle of attack and sideslip angle, in radians.

The seventh output is a two-element vector containing the rate of change of angle of attack and rate of change of sideslip angle, in radians per second.

The eighth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The ninth output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The tenth output is a three-element vector containing the accelerations in body-fixed axes.

## 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.

## References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 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)

# 6th Order Point Mass (Coordinated Flight)

## Purpose

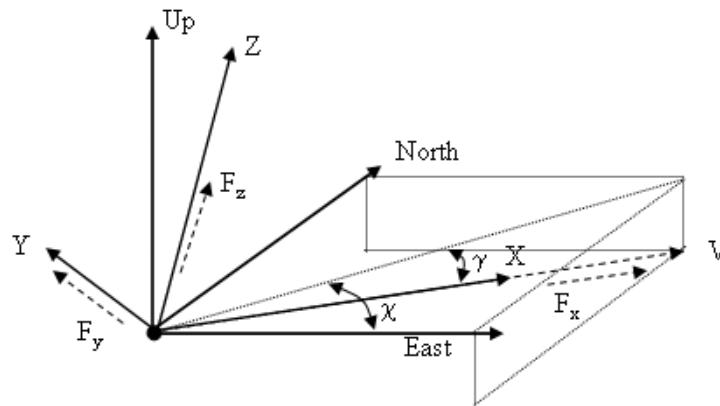
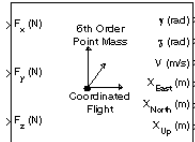
Calculate sixth order point mass in coordinated flight

## 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 ( $\gamma$ ), and heading angle ( $\chi$ ),

$$F_x = m\dot{V}$$

$$F_y = (mV \cos \gamma) \dot{\chi}$$

$$F_z = mV \dot{\gamma}$$

$$\dot{X}_{East} = V \cos \chi \cos \gamma$$

$$\dot{X}_{North} = V \sin \chi \cos \gamma$$

$$\dot{X}_{Up} = V \sin \gamma$$

# 6th Order Point Mass (Coordinated Flight)

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 upwards and y-axis completes the right hand frame, and the mass of the body  $m$  is assumed constant

## Dialog Box

Function Block Parameters: 6th Order Point Mass (Coordinated Flight) [X]

6th Order Point Mass (Coordinated Flight) (mask) (link)

Calculate sixth-order point mass in coordinated flight.

Parameters

Units: Metric (MKS) [v]

Initial flight path angle: [0]

Initial heading angle: [0]

Initial airspeed: [100]

Initial downrange [East]: [0]

Initial crossrange [North]: [0]

Initial altitude [Up]: [0]

Initial mass: [1.0]

OK Cancel Help Apply

# 6th Order Point Mass (Coordinated Flight)

---

## Units

Specifies the input and output units:

<b>Units</b>	<b>Forces</b>	<b>Velocity</b>	<b>Position</b>
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

The first input is force in x-axis in selected units.

The second input is force in y-axis in selected units.

The third input is force in z-axis in selected units.

The first output is flight path angle in radians.

The second output is heading angle in radians.

The third output is airspeed in selected units.



# 6th Order Point Mass (Coordinated Flight)

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The fourth output is the downrange or amount traveled East in selected units.

The fifth output is the crossrange or amount traveled North in selected units.

The sixth output is 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 Earth-fixed reference frame is considered inertial, a simplification that allows the forces due to the Earth's motion relative to a star-fixed reference system 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)

# 6th Order Point Mass Forces (Coordinated Flight)

## Purpose

Calculate forces used by sixth order point mass in coordinated flight

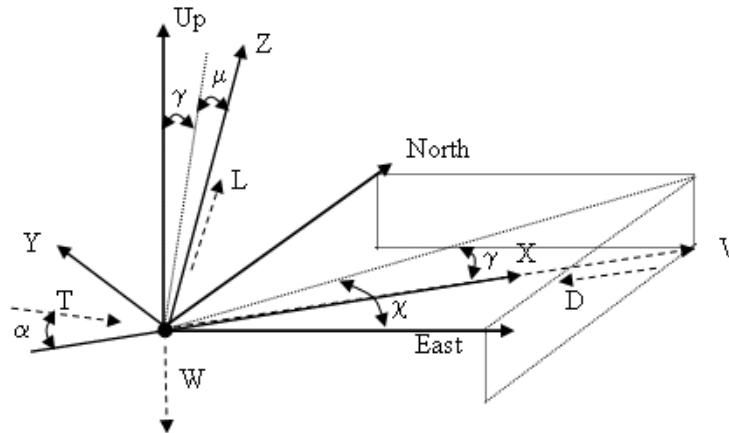
## Library

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.

> Lift	$F_x$
> Drag	
> Weight	
> Thrust	$F_y$
> $\gamma$	
> $\mu$	$F_z$
> $\alpha$	



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 hand frame and are functions of lift ( $L$ ), drag ( $D$ ), thrust ( $T$ ), weight ( $W$ ), flight path angle ( $\gamma$ ), angle of attack ( $\alpha$ ), and bank angle ( $\mu$ ).

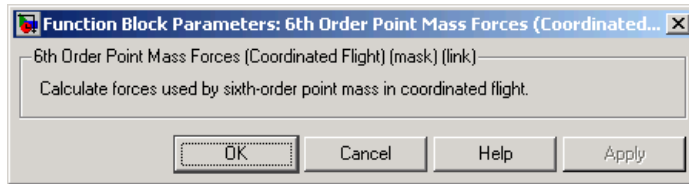
$$F_x = T \cos \alpha - D - W \sin \gamma$$

$$F_y = (L + T \sin \alpha) \sin \mu$$

$$F_z = (L + T \sin \alpha) \cos \mu - W \cos \gamma$$

# 6th Order Point Mass Forces (Coordinated Flight)

## Dialog Box



## Inputs and Outputs

The first input is lift in units of force.

The second input is drag in units of force.

The third input is weight in units of force.

The fourth input is thrust in units of force.

The fifth input is flight path angle in radians.

The sixth input is bank angle in radians.

The seventh input is angle of attack in radians.

The first output is force in x-axis in units of force.

The second output is force in y-axis in units of force.

The third output is 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-fixed reference frame is considered inertial, a simplification that allows the forces due to the Earth's motion relative to a star-fixed reference system to be neglected.

## See Also

4th Order Point Mass (Longitudinal)

4th Order Point Mass Forces (Longitudinal)

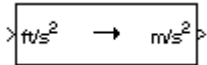
6th Order Point Mass (Coordinated Flight)

# Acceleration Conversion

**Purpose** Convert from acceleration units to desired acceleration units

**Library** Utilities/Unit Conversions

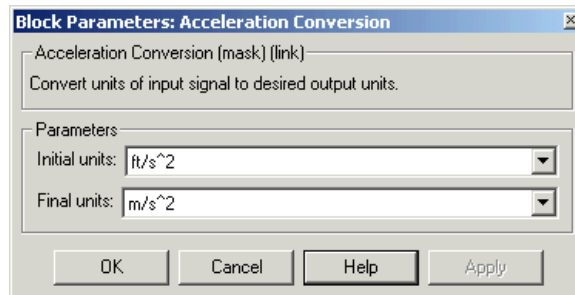
## Description



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 units** and **Final units** lists.

## Dialog Box



### Initial units

Specifies the input units.

### Final units

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**

The input is acceleration in initial acceleration units.

The output is 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

# Adjoint of 3x3 Matrix

## Purpose

Compute the adjoint matrix for the input 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

$$A = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

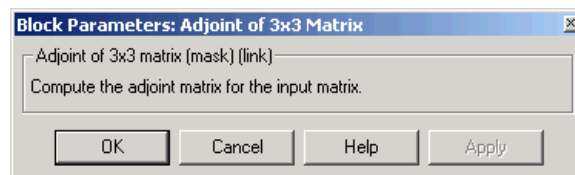
The adjoint of the matrix has the form of

$$adj(A) = \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix}$$

where

$$M_{ij} = (-1)^{i+j}$$

## Dialog Box



## Inputs and Outputs

The input is a 3-by-3 matrix.

The output of the block is 3-by-3 adjoint matrix of input matrix.

## See Also

[Create 3x3 Matrix](#)

[Determinant of 3x3 Matrix](#)

[Invert 3x3 Matrix](#)

# Aerodynamic Forces and Moments

## Purpose

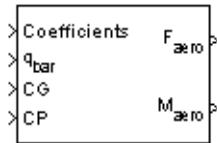
Compute the aerodynamic forces and moments using the aerodynamic coefficients, dynamic pressure, center of gravity, and center of pressure.

## Library

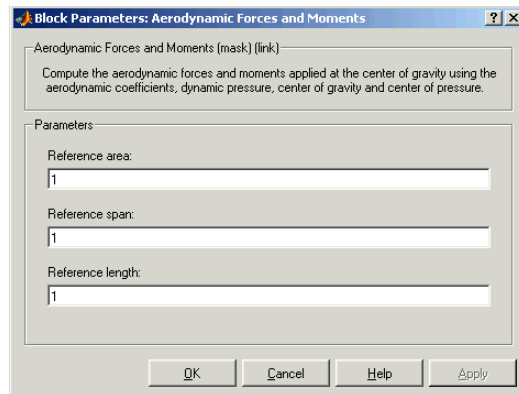
Aerodynamics

## Description

The Aerodynamic Forces and Moments block computes the aerodynamic forces and moments about the center of gravity.



## Dialog Box



### 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.



# Aerodynamic Forces and Moments

---

## Inputs and Outputs

The first input is aerodynamic coefficients (in body axes) for forces and moments.

The second input is the dynamic pressure.

The third input is the center of gravity.

The fourth input is the center of pressure.

The first output of the block is aerodynamic forces at the center of gravity in x-axes, y-axes and z-axes.

The second output of the block is aerodynamic moments at the center of gravity in x-axes, y-axes and z-axes.

## Examples

See Airframe in the aeroblk\_HL20 demo for an example of this block.

## See Also

Dynamic Pressure

Estimate Center of Gravity

Moments About CG Due to Forces

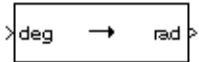
# Angle Conversion

---

**Purpose** Convert from angle units to desired angle units

**Library** Utilities/Unit Conversions

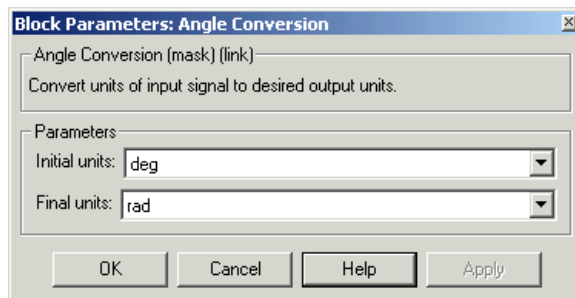
## Description



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 units** and the **Final units** lists.

## Dialog Box



### Initial units

Specifies the input units.

### Final units

Specifies the output units.

The following conversion units are available:

deg	Degrees
rad	Radians
rev	Revolutions

## Inputs and Outputs

The input is angle in initial angle units.

The output is 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

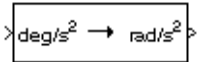
Velocity Conversion

# Angular Acceleration Conversion

**Purpose** Convert from angular acceleration units to desired angular acceleration units

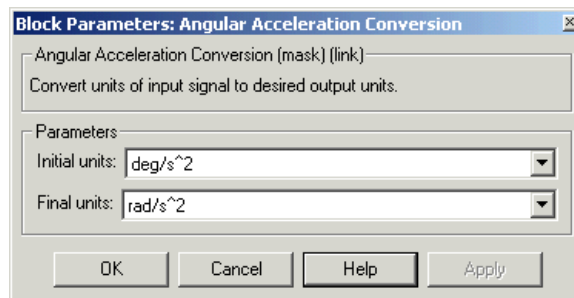
**Library** Utilities/Unit Conversions

**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 units** and the **Final units** lists.

## Dialog Box



### Initial units

Specifies the input units.

### Final units

Specifies the output units.

The following conversion units are available:

deg/s <sup>2</sup>	Degrees per second squared
rad/s <sup>2</sup>	Radians per second squared
rpm/s	Revolutions per minute per second

## Inputs and Outputs

The input is angular acceleration in initial angular acceleration units.

The output is 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

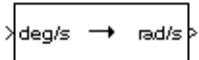
Velocity Conversion

# Angular Velocity Conversion

**Purpose** Convert from angular velocity units to desired angular velocity units

**Library** Utilities/Unit Conversions

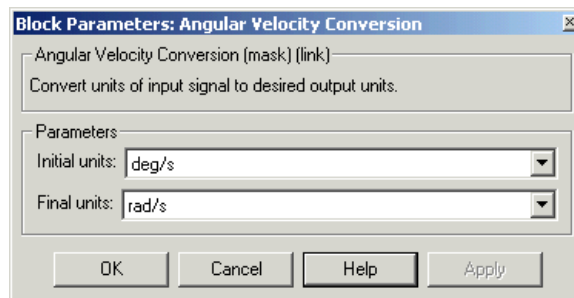
## Description



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 units** and the **Final units** lists.

## Dialog Box



### Initial units

Specifies the input units.

### Final units

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

The input is angular velocity in initial angular velocity units.

The output is angular velocity in final angular velocity units.

**See Also**

Acceleration Conversion

Angle Conversion

Angular Acceleration Conversion

Density Conversion

Force Conversion

Length Conversion

Mass Conversion

Pressure Conversion

Temperature Conversion

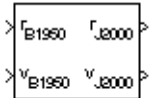
Velocity Conversion

# Besselian Epoch to Julian Epoch

**Purpose** Transform position and velocity components from the discontinued Standard Besselian Epoch (B1950) to the 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 ( $r_{B1950}$ ), and Besselian Epoch velocity ( $v_{B1950}$ ) into Julian Epoch position ( $r_{J2000}$ ), and Julian Epoch velocity ( $v_{J2000}$ ). The transformation is calculated using:



$$\begin{bmatrix} r_{J2000} \\ v_{J2000} \end{bmatrix} = \begin{bmatrix} \underline{M}_{rr} & \underline{M}_{vr} \\ \underline{M}_{rv} & \underline{M}_{vv} \end{bmatrix} \begin{bmatrix} r_{B1950} \\ v_{B1950} \end{bmatrix}$$

where ( $\underline{M}_{rr}$ ,  $\underline{M}_{vr}$ ,  $\underline{M}_{rv}$ ,  $\underline{M}_{vv}$ ) are defined as:

$$\underline{M}_{rr} = \begin{bmatrix} 0.9999256782 & -0.0111820611 & -0.0048579477 \\ 0.0111820610 & 0.9999374784 & -0.0000271765 \\ 0.0048579479 & -0.0000271474 & 0.9999881997 \end{bmatrix}$$

$$\underline{M}_{vr} = \begin{bmatrix} 0.00000242395018 & -0.00000002710663 & -0.00000001177656 \\ 0.00000002710663 & 0.00000242397878 & -0.00000000006587 \\ 0.00000001177656 & -0.00000000006582 & 0.00000242410173 \end{bmatrix}$$

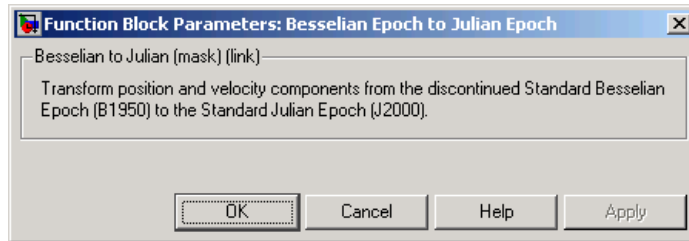
$$\underline{M}_{rv} = \begin{bmatrix} -0.000551 & -0.238565 & 0.435739 \\ 0.238514 & -0.002667 & -0.008541 \\ -0.435623 & 0.012254 & 0.002117 \end{bmatrix}$$

$$\underline{M}_{vv} = \begin{bmatrix} 0.99994704 & -0.01118251 & -0.00485767 \\ 0.01118251 & 0.99995883 & -0.00002718 \\ 0.00485767 & -0.00002714 & 1.00000956 \end{bmatrix}$$



# Besselian Epoch to Julian Epoch

## Dialog Box



## Inputs and Outputs

The first input is a 3-by-1 vector containing the position in Standard Besselian Epoch (B1950).

The second input is a 3-by-1 vector containing the velocity in Standard Besselian Epoch (B1950).

The first output is a 3-by-1 vector containing the position in Standard Julian Epoch (J2000).

The second output is a 3-by-1 vector containing the velocity in Standard Julian Epoch (J2000).

## References

“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

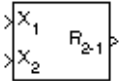
Julian Epoch to Besselian Epoch

# Calculate Range

**Purpose** Calculate the range between two crafts given their respective positions.

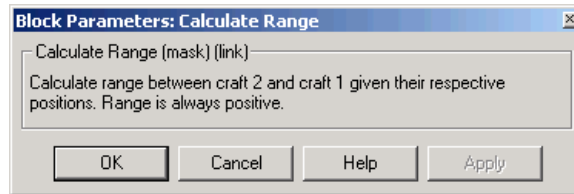
**Library** GNC/Guidance

**Description** The Calculate Range block computes the range between two crafts. The equation used for the range calculation is



$$Range = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$

**Dialog Box**



**Inputs and Outputs**

The first input is the (x, y and z) position of craft 1.

The second input is the (x, y and z) position of craft 2.

The output is the range from craft 2 and craft 1.

**Limitation**

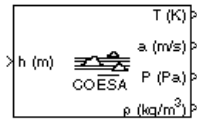
The calculated range is give the magnitude of the distance but not the direction therefore it is always positive.

Craft positions are real values.

**Purpose** Implement the 1976 COESA lower atmosphere

**Library** Environment/Atmosphere

## Description

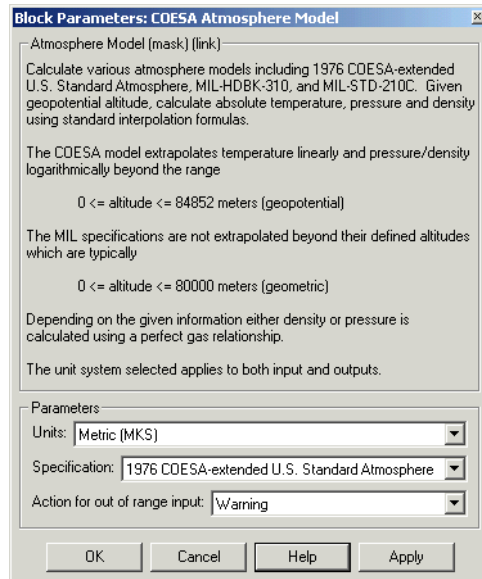


The COESA Atmosphere Model block implements the mathematical representation of the 1976 Committee on Extension to the Standard Atmosphere (COESA) United States standard lower atmospheric values for absolute temperature, pressure, density, and speed of sound for the input geopotential altitude.

Below 32000 meters (approximately 104987 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.

## Dialog Box



# COESA Atmosphere Model

---

## Units

Specifies the input and output units:

<b>Units</b>	<b>Height</b>	<b>Temperature</b>	<b>Speed of Sound</b>	<b>Air Pressure</b>	<b>Air Density</b>
Metric (MKS)	Meters	Degrees 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.

MIL-STD-210C

This selection is linked to the Non-Standard Day 210C block. See the block reference for more information.

## Action for out of range input

Specify if out of range input invokes a warning, error, or no action.

## Inputs and Outputs

The input is geopotential height.

The four outputs are temperature, speed of sound, air pressure, and air density.

## Assumptions and Limitations

Below the geopotential altitude of 0 m (0 feet) and above the geopotential altitude of 84852 m (approximately 278386 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 Airframe in the `aeroblk_HL20` demo for examples of this block.

**References**

*U.S. Standard Atmosphere*, 1976, U.S. Government Printing Office, Washington, D.C.

**See Also**

ISA Atmosphere Model

Non-Standard Day 210C

Non-Standard Day 310

# Create 3x3 Matrix

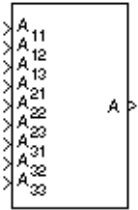
## Purpose

Create a 3-by-3 matrix from nine input values.

## Library

Utilities/Math Operations

## Description

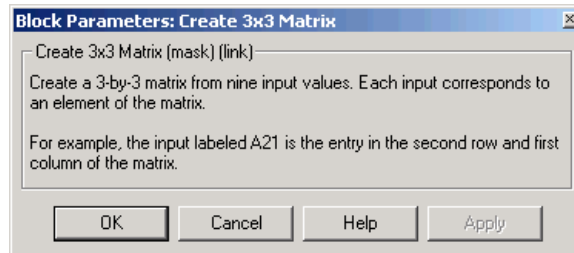


The Create 3x3 Matrix block creates a 3-by-3 matrix from nine input values where each input corresponds to an element of the matrix.

The output matrix has the form of

$$A = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

## Dialog Box



## Inputs and Outputs

The first input is the entry of the first row and first column of the matrix.

The second input is the entry of the first row and second column of the matrix.

The third input is the entry of the first row and third column of the matrix.

The fourth input is the entry of the second row and first column of the matrix.

The fifth input is the entry of the second row and second column of the matrix.

The sixth input is the entry of the second row and third column of the matrix.

The seventh input is the entry of the third row and first column of the matrix.

The eighth input is the entry of the third row and second column of the matrix.

The ninth input is the entry of the third row and third column of the matrix.

The output of the block is a 3-by-3 matrix.

## See Also

[Adjoint of 3x3 Matrix](#)

[Determinant of 3x3 Matrix](#)

[Invert 3x3 Matrix](#)

[Symmetric Inertia Tensor](#)

# Custom Variable Mass 3DoF (Body Axes)

## Purpose

Implement three-degrees-of-freedom equations of motion with respect to body axes

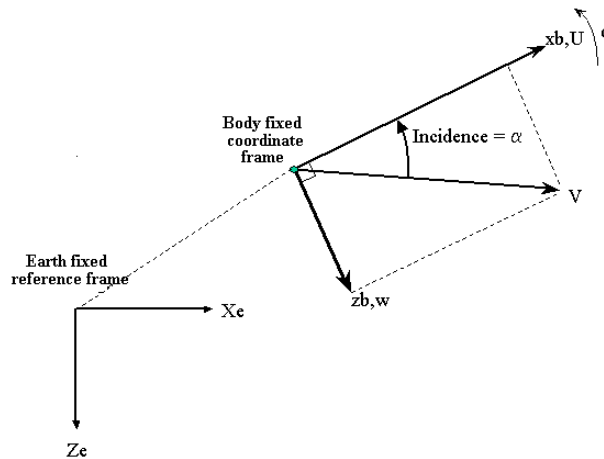
## Library

Equations of Motion/3DoF

## Description

> $F_x$ (N)	$\theta$ (rad)
> $F_z$ (N)	
> $M$ (N-m)	Custom Variable $\omega_y$ (rad/s)
> $dm/dt$ (kg/s)	$d\omega_y/dt$
> $m$ (kg)	$X_c, Z_c$ (m)
> $dI/dt$ (kg-m <sup>2</sup> /s)	Mass $U, w$ (m/s)
> $I$ (kg-m <sup>2</sup> )	$A_x, A_z$ (m/s <sup>2</sup> )
> $g$ (m/s <sup>2</sup> )	

The Custom Variable Mass 3DoF (Body Axes) block considers the rotation in the vertical plane of a body-fixed coordinate frame about an Earth-fixed reference frame.



The equations of motion are

$$\dot{u} = \frac{F_x}{m} - \frac{\dot{m}U}{m} - qw - g \sin \theta$$

$$\dot{w} = \frac{F_z}{m} - \frac{\dot{m}w}{m} + qu + g \cos \theta$$

$$\dot{q} = \frac{M - I_{yy}q}{I_{yy}}$$

$$\dot{\theta} = q$$



# Custom Variable Mass 3DoF (Body Axes)

where the applied forces are assumed to act at the center of gravity of the body.

## Dialog Box

**Block Parameters: Custom Variable Mass 3DoF (Body Axes)** ? X

3DoF EoM (mask) (link)  
Integrate the three-degrees-of-freedom equations of motion to determine body position, velocity, attitude, and related values.

Parameters

Units: Metric (MKS)

Mass type: Custom Variable

Initial velocity:  
100

Initial body attitude:  
0

Initial incidence:  
0

Initial body rotation rate:  
0

Initial position (x z):  
[0 0]

Gravity source: External

OK Cancel Help Apply

# Custom Variable Mass 3DoF (Body Axes)

## 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, ( $\theta_0$ ).

## Initial incidence

A scalar value for the initial angle between the velocity vector and the body, ( $\alpha_0$ ).

## Initial body rotation rate

A scalar value for the initial body rotation rate, ( $q_0$ ).

# Custom Variable Mass 3DoF (Body Axes)

## Initial position (x,z)

A two-element vector containing the initial location of the body in the Earth-fixed reference frame.

## 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.

## Inputs and Outputs

The first input to the block is the force acting along the body  $x$ -axis, ( $F_x$ ).

The second input to the block is the force acting along the body  $z$ -axis, ( $F_z$ ).

The third input to the block is the applied pitch moment, ( $M$ ).

The fourth input to the block is the rate of change of mass, ( $\dot{m}$ ).

The fifth input to the block is the mass, ( $m$ ).

The sixth input to the block is the rate of change of inertia tensor matrix, ( $\dot{I}_{yy}$ ).

The seventh input to the block is the inertia tensor matrix, ( $I_{yy}$ ).

The eighth optional input to the block is gravity in the selected units.

The first output from the block is the pitch attitude, in radians ( $\theta$ ).

The second output is the pitch angular rate, in radians per second ( $q$ ).

The third output is the pitch angular acceleration, in radians per second squared ( $\dot{q}$ ).

The fourth output is a two-element vector containing the location of the body, in the Earth-fixed reference frame, ( $X_e, Z_e$ ).

The fifth output is a two-element vector containing the velocity of the body resolved into the body-fixed coordinate frame, ( $u, w$ ).

## Custom Variable Mass 3DoF (Body Axes)

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The sixth output is a two-element vector containing the acceleration of the body resolved into the body-fixed coordinate frame,  $(A_x, A_z)$ .

### See Also

[3DoF \(Body Axes\)](#)

[Incidence & Airspeed](#)

[Simple Variable Mass 3DoF \(Body Axes\)](#)

# Custom Variable Mass 3DoF (Wind Axes)

## Purpose

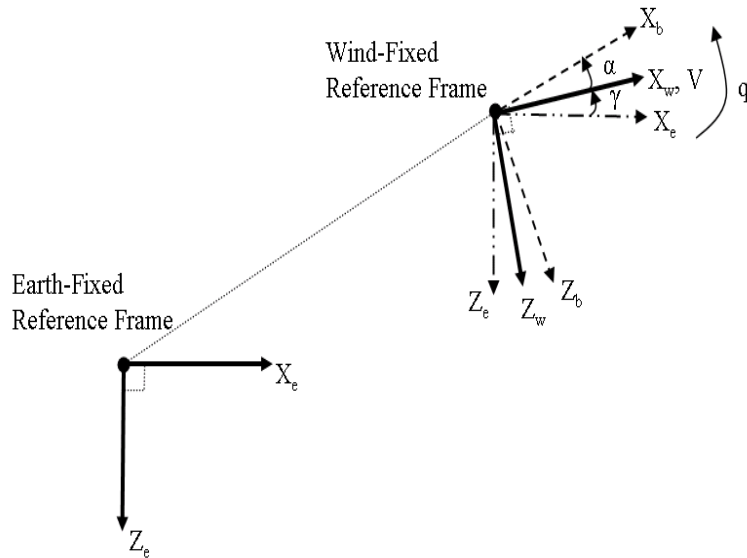
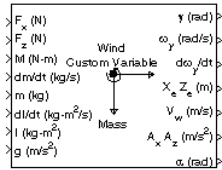
Implement three-degrees-of-freedom equations of motion with respect to wind axes

## 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 an Earth-fixed reference frame.



The equations of motion are

# Custom Variable Mass 3DoF (Wind Axes)

$$\dot{V} = \frac{F_{x_{wind}}}{m} - \frac{\dot{m}V}{m} - g \sin \gamma$$

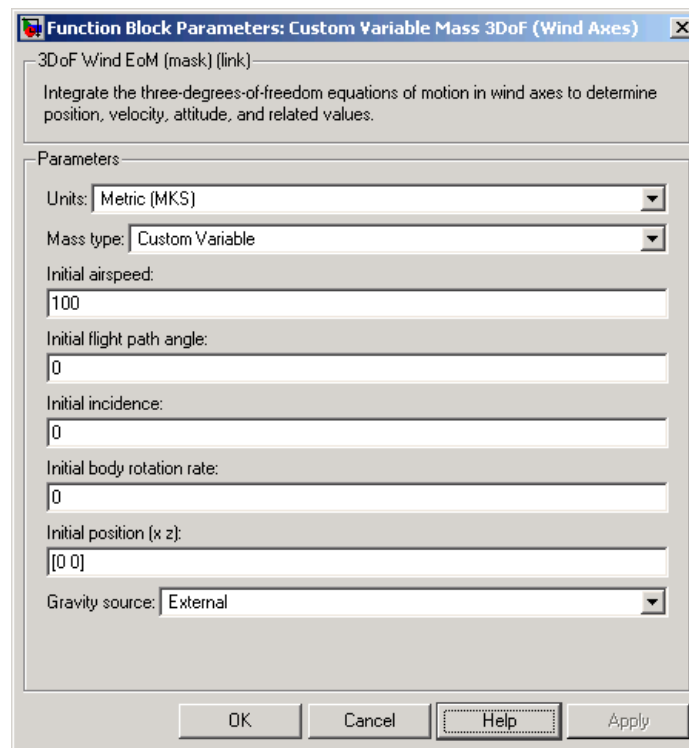
$$\dot{\alpha} = \frac{F_{z_{wind}}}{mV} + q + \frac{g}{V} \cos \gamma$$

$$\dot{q} = \dot{\theta} = \frac{M_{y_{body}} - I_{yy}\dot{q}}{I_{yy}} = \frac{DCM_{bw}M_{y_{wind}} - I_{yy}\dot{q}}{I_{yy}}$$

$$\dot{\gamma} = q - \dot{\alpha}$$

where the applied forces are assumed to act at the center of gravity of the body.

## Dialog Box



**Function Block Parameters: Custom Variable Mass 3DoF (Wind Axes)**

3DoF Wind EoM (mask) (link)

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

Parameters

Units: Metric (MKS)

Mass type: Custom Variable

Initial airspeed: 100

Initial flight path angle: 0

Initial incidence: 0

Initial body rotation rate: 0

Initial position (x z): [0 0]

Gravity source: External

OK Cancel Help Apply

# Custom Variable Mass 3DoF (Wind Axes)

## 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 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, ( $\gamma_0$ ).

## Initial incidence

A scalar value for the initial angle between the velocity vector and the body, ( $\alpha_0$ ).

## Initial body rotation rate

A scalar value for the initial body rotation rate, ( $q_0$ ).

# Custom Variable Mass 3DoF (Wind Axes)

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## Initial position ( $x,z$ )

A two-element vector containing the initial location of the body in the Earth-fixed reference frame.

## 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.

## Inputs and Outputs

The first input to the block is the force acting along the wind  $x$ -axis, ( $F_x$ ).

The second input to the block is the force acting along the wind  $z$ -axis, ( $F_z$ ).

The third input to the block is the applied pitch moment in wind-axes, ( $M$ ).

The fourth input to the block is the rate of change of mass, ( $\dot{m}$ ).

The fifth input to the block is the mass, ( $m$ ).

The sixth input to the block is the rate of change of inertia tensor matrix, ( $\dot{I}_{yy}$ ).

The seventh input to the block is the inertia tensor matrix, ( $I_{yy}$ ).

The eighth optional input to the block is gravity in the selected units.

The first output from the block is the flight path angle, in radians ( $\gamma$ ).

The second output is the pitch angular rate, in radians per second ( $\omega_y$ ).

The third output is the pitch angular acceleration, in radians per second squared ( $d\omega_y/dt$ ).

The fourth output is a two-element vector containing the location of the body, in the Earth-fixed reference frame, ( $X_e, Z_e$ ).

The fifth output is a two-element vector containing the velocity of the body resolved into the wind-fixed coordinate frame, ( $V, \theta$ ).



# Custom Variable Mass 3DoF (Wind Axes)

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The sixth output is a two-element vector containing the acceleration of the body resolved into the body-fixed coordinate frame,  $(A_x, A_z)$ .

The seventh output is a scalar containing the angle of attack,  $(\alpha)$ .

## References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 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)

# Custom Variable Mass 6DoF (Euler Angles)

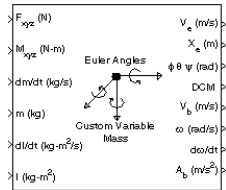
## Purpose

Implement an Euler angle representation of six-degrees-of-freedom equations of motion

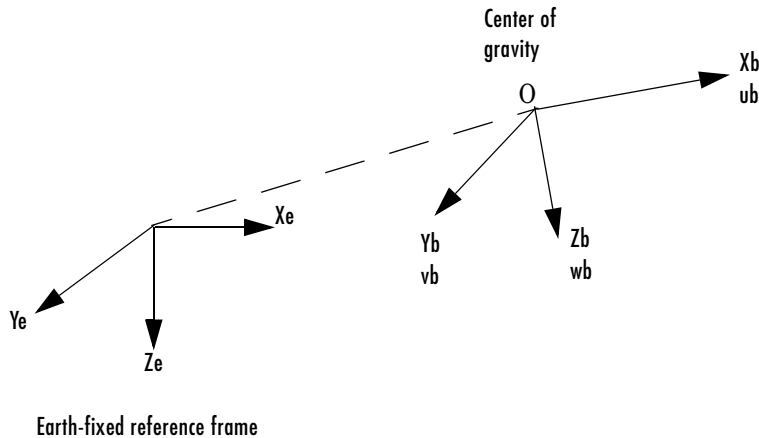
## Library

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 an Earth-fixed 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 Earth-fixed reference frame is considered inertial, a simplification that allows the forces due to the Earth's motion relative to a star-fixed reference system to be neglected.



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.

$$\underline{E}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\underline{V}}_b + \underline{\omega} \times \underline{V}_b) + \dot{m} \underline{V}_b$$

# Custom Variable Mass 6DoF (Euler Angles)

$$\underline{V}_b = \begin{bmatrix} u_b \\ v_b \\ w_b \end{bmatrix}, \underline{\omega} = \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

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.

$$\underline{M}_B = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I \dot{\underline{\omega}} + \underline{\omega} \times (I \underline{\omega}) + \dot{I} \underline{\omega}$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

$$\dot{I} = \begin{bmatrix} \dot{I}_{xx} & -\dot{I}_{xy} & -\dot{I}_{xz} \\ -\dot{I}_{yx} & \dot{I}_{yy} & -\dot{I}_{yz} \\ -\dot{I}_{zx} & -\dot{I}_{zy} & \dot{I}_{zz} \end{bmatrix}$$

The relationship between the body-fixed angular velocity vector,  $[p \ q \ r]^T$ , 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.

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} \dot{\phi} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & \sin \phi \\ 0 & -\sin \phi & \cos \phi \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & \sin \phi \\ 0 & -\sin \phi & \cos \phi \end{bmatrix} \begin{bmatrix} \cos \theta & 0 & -\sin \theta \\ 0 & 1 & 0 \\ \sin \theta & 0 & \cos \theta \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix} \equiv \mathcal{J}^{-1} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

Inverting  $\mathcal{J}$  then gives the required relationship to determine the Euler rate vector.

# Custom Variable Mass 6DoF (Euler Angles)

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = J \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & (\sin \phi \tan \theta) & (\cos \phi \tan \theta) \\ 0 & \cos \phi & -\sin \phi \\ 0 & \frac{\sin \phi}{\cos \theta} & \frac{\cos \phi}{\cos \theta} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

## Dialog Box

**Block Parameters: Custom Variable Mass 6DoF (Euler Angles)**

6DoF EoM (Body Axis) (mask) (link)  
Integrate the six-degrees-of-freedom equations of motion using an Euler angle representation for the orientation of the body in space.

Parameters

Units: Metric (MKS)

Mass type: Custom Variable

Representation: Euler Angles

Initial position in inertial axes [Xe,Ye,Ze]:  
[0 0 0]

Initial velocity in body axes [U,v,w]:  
[0 0 0]

Initial Euler orientation [roll, pitch, yaw]:  
[0 0 0]

Initial body rotation rates [p,q,r]:  
[0 0 0]

OK Cancel Help Apply

# Custom Variable Mass 6DoF (Euler Angles)

## Units

Specifies the input and output units:

<b>Units</b>	<b>Forces</b>	<b>Moment</b>	<b>Acceleration</b>	<b>Velocity</b>	<b>Position</b>	<b>Mass</b>	<b>Inertia</b>
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.

# Custom Variable Mass 6DoF (Euler Angles)

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## **Initial position in inertial axes**

The three-element vector for the initial location of the body in the Earth-fixed 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.

## **Inputs and Outputs**

The first input to the block is a vector containing the three applied forces.

The second input is a vector containing the three applied moments.

The third input is a scalar containing the rate of change of mass.

The fourth input is a scalar containing the mass

The fifth input is a 3-by-3 matrix for the rate of change of inertia tensor matrix.

The sixth input is a 3-by-3 matrix for the inertia tensor matrix.

The first output is a three-element vector containing the velocity in the Earth-fixed reference frame.

The second output is a three-element vector containing the position in the Earth-fixed reference frame.

The third output is a three-element vector containing the Euler rotation angles [roll, pitch, yaw], in radians.

The fourth output is a 3-by-3 matrix for the coordinate transformation from Earth-fixed axes to body-fixed axes.

The fifth output is a three-element vector containing the velocity in the body-fixed frame.

# Custom Variable Mass 6DoF (Euler Angles)

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The sixth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The seventh output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The eighth output is a three-element vector containing the accelerations in body-fixed axes.

## Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

## References

Mangiacasale, L., *Flight Mechanics of a u-Airplane with a MATLAB Simulink Helper*, Edizioni Libreria CLUP, 1998.

## 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)

# Custom Variable Mass 6DoF (Quaternion)

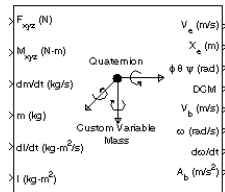
## Purpose

Implement a 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 employed 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  $\varepsilon$  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.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} q_3 & -q_2 & q_1 \\ q_2 & q_3 & -q_0 \\ -q_1 & q_0 & q_3 \\ -q_0 & -q_1 & -q_2 \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} + K\varepsilon \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

$$\varepsilon = 1 - (q_0^2 + q_1^2 + q_2^2 + q_3^2)$$



# Custom Variable Mass 6DoF (Quaternion)

## Dialog Box

Block Parameters: Custom Variable Mass 6DoF (Quaternion)

6DoF EoM (Body Axis) (mask) (link)

Integrate the six-degrees-of-freedom equations of motion using an Euler angle representation for the orientation of the body in space.

Parameters

Units: Metric (MKS)

Mass type: Custom Variable

Representation: Quaternion

Initial position in inertial axes [Xe,Ye,Ze]:  
[0 0 0]

Initial velocity in body axes [U,v,w]:  
[0 0 0]

Initial Euler orientation [roll, pitch, yaw]:  
[0 0 0]

Initial body rotation rates [p,q,r]:  
[0 0 0]

Gain for quaternion normalization:  
1.0

OK Cancel Help Apply

## 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

# Custom Variable Mass 6DoF (Quaternion)

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## 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 Earth-fixed 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.

# Custom Variable Mass 6DoF (Quaternion)

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## Inputs and Outputs

The first input to the block is a vector containing the three applied forces.

The second input is a vector containing the three applied moments.

The third input is a scalar containing the rate of change of mass.

The fourth input is a scalar containing the mass

The fifth input is a 3-by-3 matrix for the rate of change of inertia tensor matrix.

The sixth input is a 3-by-3 matrix for the inertia tensor matrix.

The first output is a three-element vector containing the velocity in the Earth-fixed reference frame.

The second output is a three-element vector containing the position in the Earth-fixed reference frame.

The third output is a three-element vector containing the Euler rotation angles [roll, pitch, yaw], in radians.

The fourth output is a 3-by-3 matrix for the coordinate transformation from Earth-fixed axes to body-fixed axes.

The fifth output is a three-element vector containing the velocity in the body-fixed frame.

The sixth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The seventh output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The eighth output is a three-element vector containing the accelerations in body-fixed axes.

## Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

## References

Mangiacasale, L., *Flight Mechanics of a u-Airplane with a MATLAB Simulink Helper*, Edizioni Libreria CLUP, 1998.

## See Also

6DoF (Euler Angles)

6DoF (Quaternion)

# Custom Variable Mass 6DoF (Quaternion)

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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)

# Custom Variable Mass 6DoF ECEF (Quaternion)

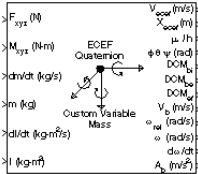
## Purpose

Implement a quaternion representation of six-degrees-of-freedom equations of motion in Earth-Centered Earth-Fixed (ECEF) coordinates

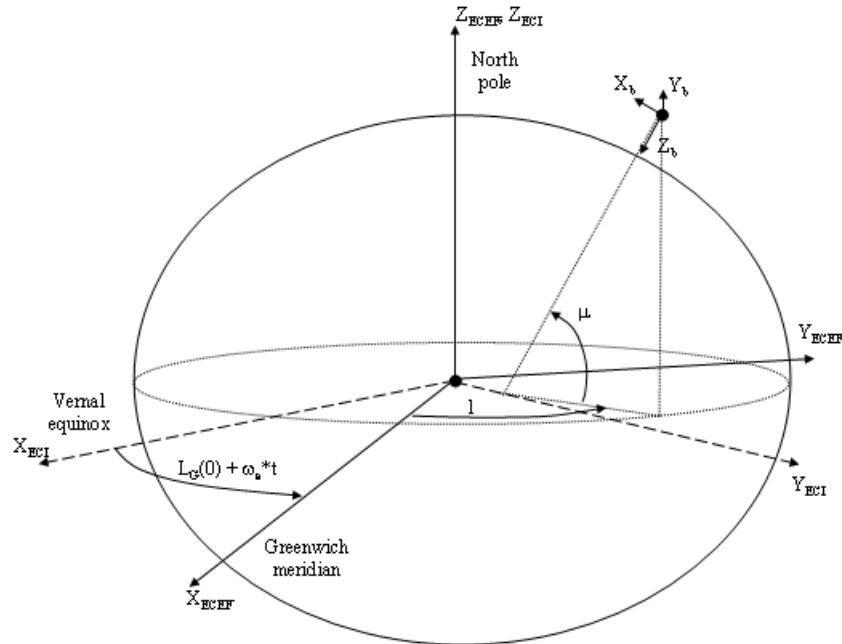
## Library

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 ( $\omega_e$ ) including an initial celestial longitude ( $L_G(0)$ ). This simplification allows the forces due to the Earth's complex motion relative to a star-fixed reference system to be neglected.



# Custom Variable Mass 6DoF ECEF (Quaternion)

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.

$$\underline{\omega}_b \times \underline{V}_b + (DCM_{bi} \underline{\omega}_e \times \underline{V}_b) + DCM_{bi} (\underline{\omega}_e \times (\underline{\omega}_e \times \underline{x}_i)) + \dot{m} (\underline{V}_b + DC$$

where the change of position in ECI ( $\dot{\underline{x}}_i$ ) is calculated by

$$\dot{\underline{x}}_i = \begin{bmatrix} \dot{x}_{ECI} \\ \dot{y}_{ECI} \\ \dot{z}_{ECI} \end{bmatrix} = DCM_{ib} \underline{V}_b + \underline{\omega}_e \times \underline{x}_i$$

and the velocity in body-axis ( $\underline{V}_b$ ), angular rates in body-axis ( $\underline{\omega}_b$ ), Earth rotation rate ( $\underline{\omega}_e$ ), and relative angular rates in body-axis ( $\underline{\omega}_{rel}$ ) are defined as

$$\underline{V}_b = \begin{bmatrix} u \\ v \\ w \end{bmatrix}, \underline{\omega}_b = \begin{bmatrix} p \\ q \\ r \end{bmatrix}, \underline{\omega}_e = \begin{bmatrix} 0 \\ 0 \\ \omega_e \end{bmatrix}, \underline{\omega}_{rel} = \underline{\omega}_b - DCM_{bi} \underline{\omega}_e$$

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.

$$\underline{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I \dot{\underline{\omega}}_b + \underline{\omega}_b \times (I \underline{\omega}_b)$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

# Custom Variable Mass 6DoF ECEF (Quaternion)

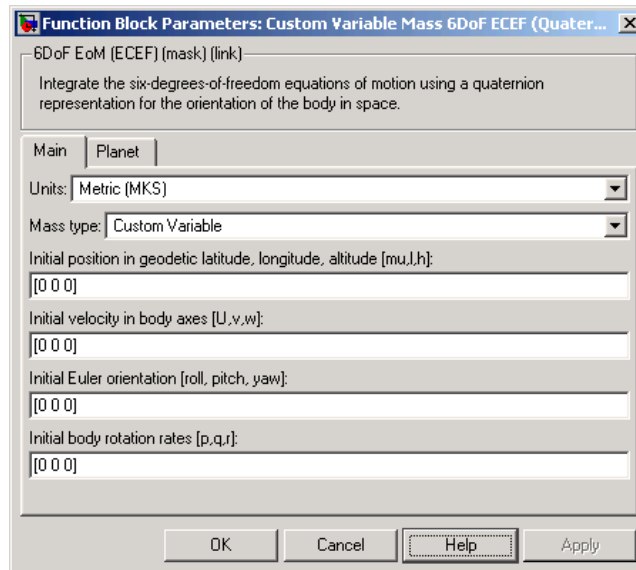
The rate of change of the inertia tensor is defined by the following equation.

$$\dot{I} = \begin{bmatrix} \dot{I}_{xx} & -\dot{I}_{xy} & -\dot{I}_{xz} \\ -\dot{I}_{yx} & \dot{I}_{yy} & -\dot{I}_{yz} \\ -\dot{I}_{zx} & -\dot{I}_{zy} & \dot{I}_{zz} \end{bmatrix}$$

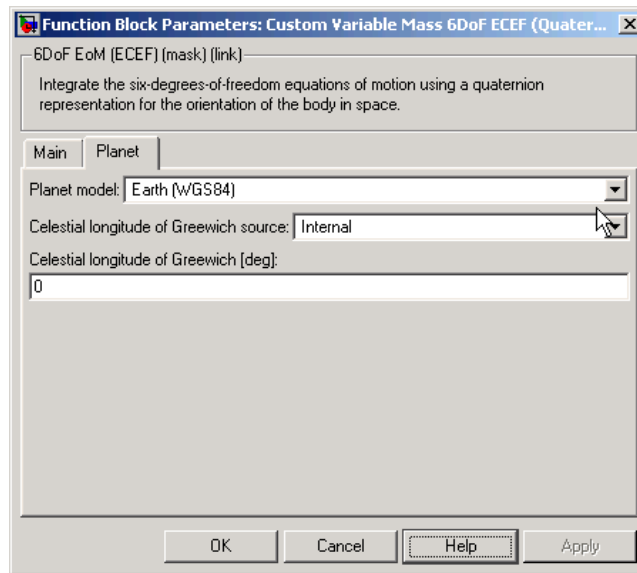
The integration of the rate of change of the quaternion vector is given below.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = -\frac{1}{2} \begin{bmatrix} 0 & p & q & r \\ -p & 0 & -r & q \\ -q & r & 0 & -p \\ -r & -q & p & 0 \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

## Dialog Box



# Custom Variable Mass 6DoF ECEF (Quaternion)



## 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



# Custom Variable Mass 6DoF ECEF (Quaternion)

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## 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 position in geodetic latitude, longitude and altitude

The three-element vector for the initial location of the body in the geodetic reference frame.

## Initial velocity in body-axis

The three-element vector containing the initial velocity in the body-fixed coordinate frame.

## Initial Euler orientation

The three-element vector containing 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.

## Planet model

Specifies the planet model to use:

- Custom
- Earth (WGS84)

## Flattening

Specifies the flattening of the planet. This option is only available when **Planet model** is set to Custom.

# Custom Variable Mass 6DoF ECEF (Quaternion)

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## 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/sec. 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.

## Inputs and Outputs

The first input to the block is a vector containing the three applied forces in body-fixed axes.

The second input is a vector containing the three applied moments in body-fixed axes.

The third input is a scalar containing the rate of change of mass.

The fourth input is a scalar containing the mass

The fifth input is a 3-by-3 matrix for the rate of change of inertia tensor matrix.

The sixth input is a 3-by-3 matrix for the inertia tensor matrix.

The first output is a three-element vector containing the velocity in the ECEF reference frame.

The second output is a three-element vector containing the position in the ECEF reference frame.

The third output is a three-element vector containing the position in geodetic latitude, longitude and altitude, in degrees, degrees and selected units of length respectively.

# Custom Variable Mass 6DoF ECEF (Quaternion)

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The fourth output is a three-element vector containing the body rotation angles [roll, pitch, yaw], in radians.

The fifth output is a 3-by-3 matrix for the coordinate transformation from ECI axes to body-fixed axes.

The sixth output is a 3-by-3 matrix for the coordinate transformation from geodetic axes to body-fixed axes.

The seventh output is a 3-by-3 matrix for the coordinate transformation from ECEF axes to geodetic axes.

The eighth output is a three-element vector containing the velocity in the body-fixed frame.

The ninth output is a three-element vector containing the relative angular rates in body-fixed axes, in radians per second.

The tenth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The eleventh output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The twelfth output is a three-element vector containing the accelerations in body-fixed axes.

## 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  $\pm 90$  degrees, and longitude that lies between  $\pm 180$  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.

# Custom Variable Mass 6DoF ECEF (Quaternion)

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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 through the center of the Sun 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*, John Wiley & Sons, New York, NY, 1992.

Zipfel, P. H., *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA Education Series, Reston, VA, 2000.

“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)

# Custom Variable Mass 6DoF Wind (Quaternion)

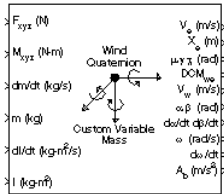
## Purpose

Implement a quaternion representation of six-degrees-of-freedom equations of motion with respect to wind axes

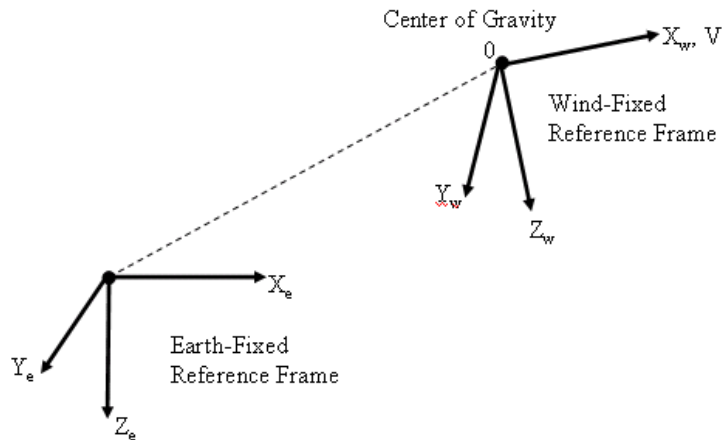
## Library

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 Earth-fixed 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 Earth-fixed reference frame is considered inertial, a simplification that allows the forces due to the Earth's motion relative to a star-fixed reference system 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.

$$\underline{F}_w = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\underline{V}}_w + \underline{\omega}_w \times \underline{V}_w) + m \underline{V}_w$$

## Custom Variable Mass 6DoF Wind (Quaternion)

$$\underline{V}_w = \begin{bmatrix} V \\ 0 \\ 0 \end{bmatrix}, \underline{\omega}_w = \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = DMC_{wb} \begin{bmatrix} p_b - \beta \sin \alpha \\ q_b - \dot{\alpha} \\ r_b + \beta \cos \alpha \end{bmatrix}, \underline{\omega}_b = \begin{bmatrix} p_b \\ q_b \\ r_b \end{bmatrix}$$

The rotational dynamics of the wind-fixed frame in relation to 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.

$$\underline{M}_w = DCM_{wb} \underline{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I \dot{\underline{\omega}}_b + \underline{\omega}_b \times (I \underline{\omega}_b) + \dot{I} \underline{\omega}_b$$

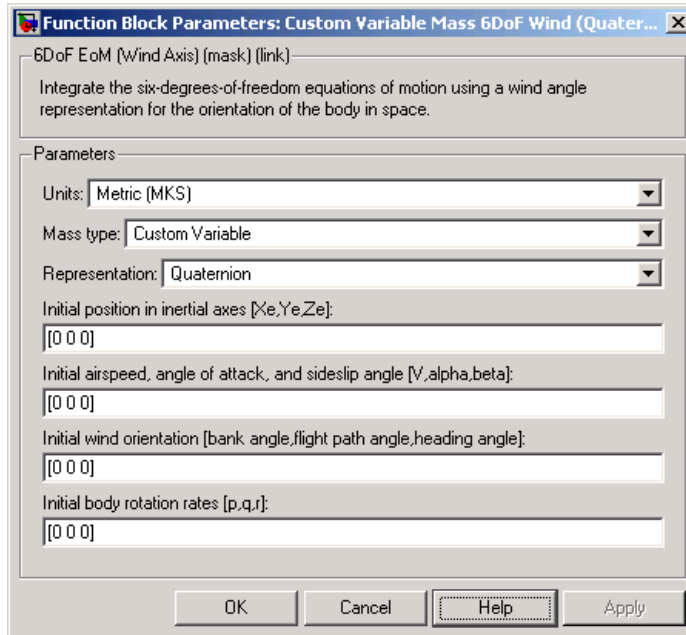
$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

The integration of the rate of change of the quaternion vector is given below.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 0 & p & q & r \\ -p & 0 & -r & q \\ -q & r & 0 & -p \\ -r & -q & p & 0 \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

# Custom Variable Mass 6DoF Wind (Quaternion)

## Dialog Box



## 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

# Custom Variable Mass 6DoF Wind (Quaternion)

---

## 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 Earth-fixed 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.

## Inputs and Outputs

The first input to the block is a vector containing the three applied forces in wind-fixed axes.



# Custom Variable Mass 6DoF Wind (Quaternion)

---

The second input is a vector containing the three applied moments in wind-fixed axes.

The third input is a scalar containing the rate of change of mass.

The fourth input is a scalar containing the mass

The fifth input is a 3-by-3 matrix for the rate of change of inertia tensor matrix in body-fixed axes.

The sixth input is a 3-by-3 matrix for the inertia tensor matrix in body-fixed axes.

The first output is a three-element vector containing the velocity in the Earth-fixed reference frame.

The second output is a three-element vector containing the position in the Earth-fixed reference frame.

The third output is a three-element vector containing the wind rotation angles [bank, flight path, heading], in radians.

The fourth output is a 3-by-3 matrix for the coordinate transformation from Earth-fixed axes to wind-fixed axes.

The fifth output is a three-element vector containing the velocity in the wind-fixed frame.

The sixth output is a two-element vector containing the angle of attack and sideslip angle, in radians.

The seventh output is a two-element vector containing the rate of change of angle of attack and rate of change of sideslip angle, in radians per second.

The eighth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The ninth output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The tenth output is a three-element vector containing the accelerations in body-fixed axes.

## Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

# Custom Variable Mass 6DoF Wind (Quaternion)

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## References

Mangiacasale, L., *Flight Mechanics of a u-Airplane with a MATLAB Simulink Helper*, Edizioni Libreria CLUP, 1998.

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 1992.

## 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)

# Custom Variable Mass 6DoF Wind (Wind Angles)

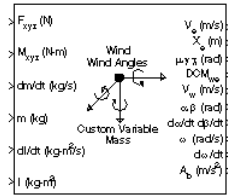
## Purpose

Implement a 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 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.

$$\begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} \dot{\mu} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \mu & \sin \mu \\ 0 & -\sin \mu & \cos \mu \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\gamma} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \mu & \sin \mu \\ 0 & -\sin \mu & \cos \mu \end{bmatrix} \begin{bmatrix} \cos \gamma & 0 & -\sin \gamma \\ 0 & 1 & 0 \\ \sin \gamma & 0 & \cos \gamma \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\chi} \end{bmatrix} \equiv \mathcal{J}^{-1} \begin{bmatrix} \dot{\mu} \\ \dot{\gamma} \\ \dot{\chi} \end{bmatrix}$$

Inverting  $\mathcal{J}$  then gives the required relationship to determine the wind rate vector.

$$\begin{bmatrix} \dot{\mu} \\ \dot{\gamma} \\ \dot{\chi} \end{bmatrix} = \mathcal{J} \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} 1 & (\sin \mu \tan \gamma) & (\cos \mu \tan \gamma) \\ 0 & \cos \mu & -\sin \mu \\ 0 & \frac{\sin \mu}{\cos \gamma} & \frac{\cos \mu}{\cos \gamma} \end{bmatrix} \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix}$$

The body-fixed angular rates are related to the wind-fixed angular rate by the following equation.

$$\begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = DMC_{wb} \begin{bmatrix} p_b - \beta \sin \alpha \\ q_b - \dot{\alpha} \\ r_b + \beta \cos \alpha \end{bmatrix}$$

Using this relationship in the wind rate vector equations, gives the relationship between the wind rate vector and the body-fixed angular rates.

# Custom Variable Mass 6DoF Wind (Wind Angles)

$$\begin{bmatrix} \dot{\mu} \\ \dot{\gamma} \\ \dot{\chi} \end{bmatrix} = J \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} 1 & (\sin\mu \tan\gamma) & (\cos\mu \tan\gamma) \\ 0 & \cos\mu & -\sin\mu \\ 0 & \frac{\sin\mu}{\cos\gamma} & \frac{\cos\mu}{\cos\gamma} \end{bmatrix} DMC_{wb} \begin{bmatrix} p_b - \beta \sin\alpha \\ q_b - \dot{\alpha} \\ r_b + \beta \cos\alpha \end{bmatrix}$$

## Dialog Box

**Function Block Parameters: Custom Variable Mass 6DoF Wind (Wind A...)**

6DoF EoM (Wind Axis) (mask) (link)

Integrate the six-degrees-of-freedom equations of motion using a wind angle representation for the orientation of the body in space.

Parameters

Units: Metric (MKS)

Mass type: Custom Variable

Representation: Wind Angles

Initial position in inertial axes [Xe,Ye,Ze]:  
[0 0 0]

Initial airspeed, angle of attack, and sideslip angle [V,alpha,beta]:  
[0 0 0]

Initial wind orientation [bank angle,flight path angle,heading angle]:  
[0 0 0]

Initial body rotation rates [p,q,r]:  
[0 0 0]

OK Cancel Help Apply

# Custom Variable Mass 6DoF Wind (Wind Angles)

## Units

Specifies the input and output units:

<b>Units</b>	<b>Forces</b>	<b>Moment</b>	<b>Acceleration</b>	<b>Velocity</b>	<b>Position</b>	<b>Mass</b>	<b>Inertia</b>
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:

- 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.

# Custom Variable Mass 6DoF Wind (Wind Angles)

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## **Initial position in inertial axes**

The three-element vector for the initial location of the body in the Earth-fixed 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.

## **Inputs and Outputs**

The first input to the block is a vector containing the three applied forces in wind-fixed axes.

The second input is a vector containing the three applied moments in wind-fixed axes.

The third input is a scalar containing the rate of change of mass.

The fourth input is a scalar containing the mass

The fifth input is a 3-by-3 matrix for the rate of change of inertia tensor matrix in body-fixed axes.

The sixth input is a 3-by-3 matrix for the inertia tensor matrix in body-fixed axes.

The first output is a three-element vector containing the velocity in the Earth-fixed reference frame.

The second output is a three-element vector containing the position in the Earth-fixed reference frame.

The third output is a three-element vector containing the wind rotation angles [bank, flight path, heading], in radians.

The fourth output is a 3-by-3 matrix for the coordinate transformation from Earth-fixed axes to wind-fixed axes.

# Custom Variable Mass 6DoF Wind (Wind Angles)

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The fifth output is a three-element vector containing the velocity in the wind-fixed frame.

The sixth output is a two-element vector containing the angle of attack and sideslip angle, in radians.

The seventh output is a two-element vector containing the rate of change of angle of attack and rate of change of sideslip angle, in radians per second.

The eighth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The ninth output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The tenth output is a three-element vector containing the accelerations in body-fixed axes.

## Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

## References

Mangiaccasale, L., *Flight Mechanics of a u-Airplane with a MATLAB Simulink Helper*, Edizioni Libreria CLUP, 1998.

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 1992.

## 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)

---

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)

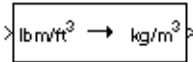
Simple Variable Mass 6DoF Wind (Wind Angles)



**Purpose** Convert from density units to desired density units

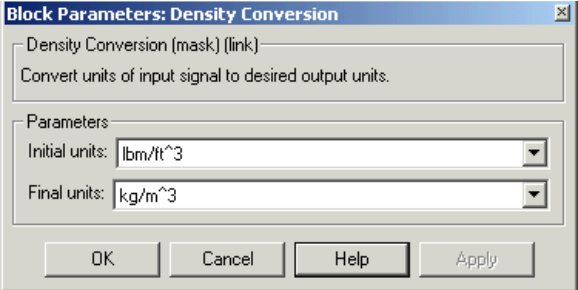
**Library** Utilities/Unit Conversions

**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 units** and the **Final units** lists.

### Dialog Box



**Initial units**  
Specifies the input units.

**Final units**  
Specifies the output units.

The following conversion units are available:

- lbm/ft<sup>3</sup>      Pound mass per cubic foot
- kg/m<sup>3</sup>      Kilograms per cubic meter
- slug/ft<sup>3</sup>      Slugs per cubic foot
- lbm/in<sup>3</sup>      Pound mass per cubic inch

**Inputs and Outputs** The input is density in initial density units.  
The output is density in final density units.

# Density Conversion

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## See Also

Acceleration Conversion

Angle Conversion

Angular Acceleration Conversion

Angular Velocity Conversion

Force Conversion

Length Conversion

Mass Conversion

Pressure Conversion

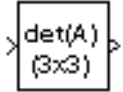
Temperature Conversion

Velocity Conversion

**Purpose** Compute the determinant for the input matrix

**Library** Utilities/Math Operations

**Description** The Determinant of 3x3 Matrix block computes the determinant for the input matrix.



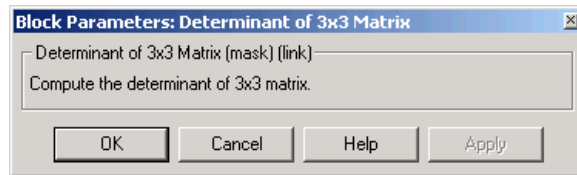
The input matrix has the form of

$$A = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

The determinant of the matrix has the form of

$$\det(A) = A_{11}(A_{22}A_{33} - A_{23}A_{32}) - A_{12}(A_{21}A_{33} - A_{23}A_{31}) + A_{13}(A_{21}A_{32} - A_{22}A_{31})$$

**Dialog Box**



**Inputs and Outputs** The input is a 3-by-3 matrix.

The output of the block is the determinant of input matrix.

**See Also** Adjoint of 3x3 Matrix

Create 3x3 Matrix

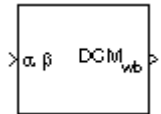
Invert 3x3 Matrix

# Direction Cosine Matrix Body to Wind

**Purpose** 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 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  $(ox_2, oy_2, oz_2)$  into coincidence with  $(ox_0, oy_0, oz_0)$  is first, a rotation about  $oz_2$  through the sideslip angle  $(\beta)$  to axes  $(ox_1, oy_1, oz_1)$ , second, a rotation about  $oy_1$  through the angle of attack  $(\alpha)$  to axes  $(ox_0, oy_0, oz_0)$ .

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = DCM_{wb} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

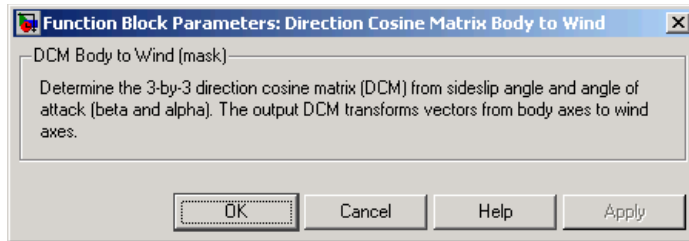
$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = \begin{bmatrix} \cos\beta & \sin\beta & 0 \\ -\sin\beta & \cos\beta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\alpha & 0 & \sin\alpha \\ 0 & 1 & 0 \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

Combining the two axis transformation matrices defines the following DCM.

$$DCM_{wb} = \begin{bmatrix} \cos\alpha\cos\beta & \sin\beta & \sin\alpha\cos\beta \\ -\cos\alpha\sin\beta & \cos\beta & -\sin\alpha\sin\beta \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix}$$

# Direction Cosine Matrix Body to Wind

## Dialog Box



## Inputs and Outputs

The input is a 2-by-1 vector containing angle of attack and sideslip angle, in radians.

The output is a 3-by-3 direction cosine matrix which transforms body-fixed vectors to wind-fixed vectors.

## References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 1992.

## See Also

Direction Cosine Matrix Body to Wind to Alpha and Beta

Direction Cosine Matrix to Euler Angles

Direction Cosine Matrix to Wind Angles

Euler Angles to Direction Cosine Matrix

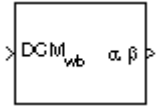
Wind Angles to Direction Cosine Matrix

# Direction Cosine Matrix Body to Wind to Alpha and Beta

**Purpose** 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  $(ox_2, oy_2, oz_2)$  into coincidence with  $(ox_0, oy_0, oz_0)$  is first, a rotation about  $oz_2$  through the sideslip angle ( $\beta$ ) to axes  $(ox_1, oy_1, oz_1)$ , second, a rotation about  $oy_1$  through the angle of attack ( $\alpha$ ) to axes  $(ox_0, oy_0, oz_0)$ .

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = DCM_{wb} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = \begin{bmatrix} \cos\beta & \sin\beta & 0 \\ -\sin\beta & \cos\beta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\alpha & 0 & \sin\alpha \\ 0 & 1 & 0 \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

Combining the two axis transformation matrices defines the following DCM.

$$DCM_{wb} = \begin{bmatrix} \cos\alpha\cos\beta & \sin\beta & \sin\alpha\cos\beta \\ -\cos\alpha\sin\beta & \cos\beta & -\sin\alpha\sin\beta \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix}$$

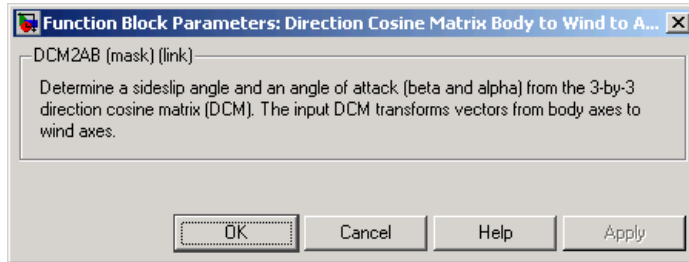
To determine angles from the DCM, the following equations are used:

$$\alpha = \text{asin}(-DCM(3, 1))$$

$$\beta = \text{asin}(DCM(1, 2))$$

# Direction Cosine Matrix Body to Wind to Alpha and Beta

## Dialog Box



## Inputs and Outputs

The input is a 3-by-3 direction cosine matrix which transforms body-fixed vectors to wind-fixed vectors.

The output is a 2-by-1 vector containing angle of attack and sideslip angle, in radians.

## Assumptions and Limitations

This implementation generates angles that lies between  $\pm 90$  degrees.

## References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 1992.

## See Also

Direction Cosine Matrix Body to Wind  
Direction Cosine Matrix to Euler Angles  
Direction Cosine Matrix to Wind Angles  
Euler Angles to Direction Cosine Matrix  
Wind Angles to Direction Cosine Matrix

# Direction Cosine Matrix ECEF to NED

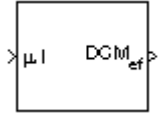
## Purpose

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  $(ox_2, oy_2, oz_2)$  into coincidence with  $(ox_0, oy_0, oz_0)$  is first, a left-handed rotation about  $oy_2$  through the geodetic latitude ( $\mu$ ) to axes  $(ox_1, oy_1, oz_1)$ , second, a rotation about  $oz_1$  through the longitude ( $\lambda$ ) to axes  $(ox_0, oy_0, oz_0)$ .

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = DCM_{ef} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

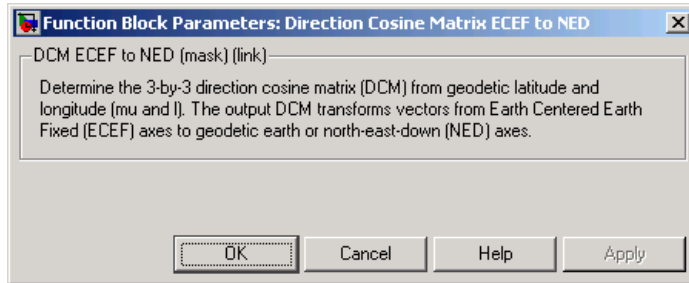
$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = \begin{bmatrix} -\sin\mu & 0 & \cos\mu \\ 0 & 1 & 0 \\ -\cos\mu & 0 & -\sin\mu \end{bmatrix} \begin{bmatrix} \cos\lambda & \sin\lambda & 0 \\ -\sin\lambda & \cos\lambda & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

Combining the two axis transformation matrices defines the following DCM.

$$DCM_{ef} = \begin{bmatrix} -\sin\mu \cos\lambda & -\sin\mu \sin\lambda & \cos\mu \\ -\sin\lambda & \cos\lambda & 0 \\ -\cos\mu \cos\lambda & -\cos\mu \sin\lambda & -\sin\mu \end{bmatrix}$$



## Dialog Box



## Inputs and Outputs

The input is a 2-by-1 vector containing geodetic latitude and longitude, in degrees.

The output is a 3-by-3 direction cosine matrix which 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, NY, 1992.

Zipfel, P. H., *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA Education Series, Reston, VA, 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 Euler Angles

Direction Cosine Matrix to Wind Angles

ECEF Position to LLA

Euler Angles to Direction Cosine Matrix

LLA to ECEF Position

# Direction Cosine Matrix ECEF to NED

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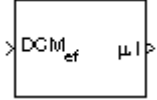
Wind Angles to Direction Cosine Matrix

# Direction Cosine Matrix ECEF to NED to Latitude and Longitude

**Purpose** 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  $(ox_2, oy_2, oz_2)$  into coincidence with  $(ox_0, oy_0, oz_0)$  is first, a left-handed rotation about  $oy_2$  through the geodetic latitude ( $\mu$ ) to axes  $(ox_1, oy_1, oz_1)$ , second, a rotation about  $oz_1$  through the longitude ( $\iota$ ) to axes  $(ox_0, oy_0, oz_0)$ .

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = DCM_{ef} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

$$\begin{bmatrix} ox_2 \\ oy_2 \\ oz_2 \end{bmatrix} = \begin{bmatrix} -\sin\mu & 0 & \cos\mu \\ 0 & 1 & 0 \\ -\cos\mu & 0 & -\sin\mu \end{bmatrix} \begin{bmatrix} \cos\iota & \sin\iota & 0 \\ -\sin\iota & \cos\iota & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

Combining the two axis transformation matrices defines the following DCM.

$$DCM_{ef} = \begin{bmatrix} -\sin\mu \cos\iota & -\sin\mu \sin\iota & \cos\mu \\ -\sin\iota & \cos\iota & 0 \\ -\cos\mu \cos\iota & -\cos\mu \sin\iota & -\sin\mu \end{bmatrix}$$

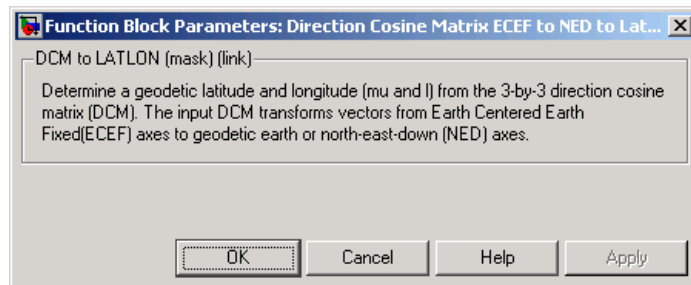
To determine geodetic latitude and longitude from the DCM, the following equations are used:

$$\mu = \text{asin}(-DCM(3, 3))$$

$$\iota = \text{atan}\left(\frac{-DCM(2, 1)}{DCM(2, 2)}\right)$$

# Direction Cosine Matrix ECEF to NED to Latitude and Longitude

## Dialog Box



## Inputs and Outputs

The input is a 3-by-3 direction cosine matrix which transforms ECEF vectors to NED vectors.

The output is a 2-by-1 vector containing geodetic latitude and longitude, in degrees.

## Assumptions and Limitations

This implementation generates a geodetic latitude that lies between  $\pm 90$  degrees, and longitude that lies between  $\pm 180$  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, NY, 1992.

Zipfel, P. H., *Modeling and Simulation of Aerospace Vehicle Dynamics*, "AIAA Education Series, Reston, VA, 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 Euler Angles

Direction Cosine Matrix to Wind Angles

ECEF Position to LLA

Euler Angles to Direction Cosine Matrix

# Direction Cosine Matrix ECEF to NED to Latitude and Longitude

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LLA to ECEF Position

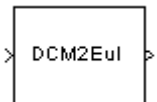
Wind Angles to Direction Cosine Matrix

# Direction Cosine Matrix to Euler Angles

**Purpose** Convert direction cosine matrix to Euler angles

**Library** Utilities/Axes Transformations

## Description



The Direction Cosine Matrix to Euler Angles block converts a 3-by-3 direction cosine matrix (DCM) into three Euler rotation angles. The DCM matrix performs the coordinate transformation of a vector in inertial axes  $(ox_0, oy_0, oz_0)$  into a vector in body axes  $(ox_3, oy_3, oz_3)$ . The order of the axis rotations required to bring  $(ox_3, oy_3, oz_3)$  into coincidence with  $(ox_0, oy_0, oz_0)$  is first, a rotation about  $ox_3$  through the roll angle ( $\phi$ ) to axes  $(ox_2, oy_2, oz_2)$ , second, a rotation about  $oy_2$  through the pitch angle ( $\theta$ ) to axes  $(ox_1, oy_1, oz_1)$ , and finally a rotation about  $oz_1$  through the yaw angle ( $\psi$ ) to axes  $(ox_0, oy_0, oz_0)$ .

$$\begin{bmatrix} ox_3 \\ oy_3 \\ oz_3 \end{bmatrix} = DCM \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

$$\begin{bmatrix} ox_3 \\ oy_3 \\ oz_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & \sin \phi \\ 0 & -\sin \phi & \cos \phi \end{bmatrix} \begin{bmatrix} \cos \theta & 0 & -\sin \theta \\ 0 & 1 & 0 \\ \sin \theta & 0 & \cos \theta \end{bmatrix} \begin{bmatrix} \cos \psi & \sin \psi & 0 \\ -\sin \psi & \cos \psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

Combining the three axis transformation matrices defines the following DCM.

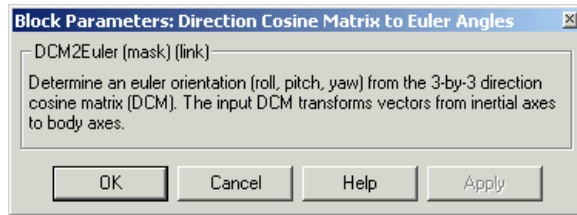
$$DCM = \begin{bmatrix} \cos \theta \cos \psi & \cos \theta \sin \psi & -\sin \theta \\ (\sin \phi \sin \theta \cos \psi - \cos \phi \sin \psi) & (\sin \phi \sin \theta \sin \psi + \cos \phi \cos \psi) & \sin \phi \cos \theta \\ (\cos \phi \sin \theta \cos \psi + \sin \phi \sin \psi) & (\cos \phi \sin \theta \sin \psi - \sin \phi \cos \psi) & \cos \phi \cos \theta \end{bmatrix}$$

To determine Euler angles from the DCM, the following equations are used:

$$\begin{aligned} \phi &= \operatorname{atan}\left(\frac{DCM(2, 3)}{DCM(3, 3)}\right) \\ \theta &= \operatorname{asin}(-DCM(1, 3)) \\ \psi &= \operatorname{atan}\left(\frac{DCM(1, 2)}{DCM(1, 1)}\right) \end{aligned}$$

# Direction Cosine Matrix to Euler Angles

## Dialog Box



## Inputs and Outputs

The input is a 3-by-3 direction cosine matrix.

The output is a 3-by-1 vector of Euler angles.

## Assumptions and Limitations

This implementation generates a pitch angle that lies between  $\pm 90$  degrees, and roll and yaw angles that lie between  $\pm 180$  degrees.

## See Also

Direction Cosine Matrix to Quaternions

Euler Angles to Direction Cosine Matrix

Euler Angles to Quaternions

Quaternions to Direction Cosine Matrix

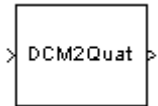
Quaternions to Euler Angles

# Direction Cosine Matrix to Quaternions

**Purpose** Convert direction cosine matrix to quaternion vector

**Library** Utilities/Axes Transformations

## Description



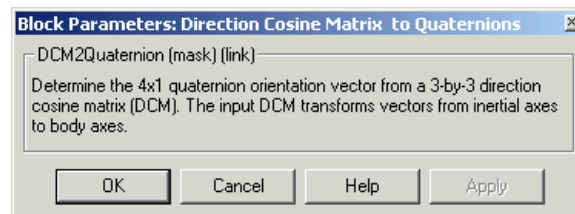
The Direction Cosine Matrix to Quaternions block transforms a 3-by-3 direction cosine matrix (DCM) into a four-element unit quaternion vector  $(q_0, q_1, q_2, q_3)$ . The DCM performs the coordinate transformation of a vector in inertial axes to a vector in body axes.

The DCM is defined as a function of a unit quaternion vector by the following:

$$DCM = \begin{bmatrix} (q_0^2 + q_1^2 - q_2^2 - q_3^2) & 2(q_1q_2 + q_0q_3) & 2(q_1q_3 - q_0q_2) \\ 2(q_1q_2 - q_0q_3) & (q_0^2 - q_1^2 + q_2^2 - q_3^2) & 2(q_2q_3 + q_0q_1) \\ 2(q_1q_3 + q_0q_2) & 2(q_2q_3 - q_0q_1) & (q_0^2 - q_1^2 - q_2^2 + q_3^2) \end{bmatrix}$$

Using this representation of the DCM, there is 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 than 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.

## Dialog Box



## Inputs and Outputs

The input is a 3-by-3 direction cosine matrix.

The output is a 4-by-1 quaternion vector.



**See Also**

[Direction Cosine Matrix to Euler Angles](#)

[Euler Angles to Direction Cosine Matrix](#)

[Euler Angles to Quaternions](#)

[Quaternions to Direction Cosine Matrix](#)

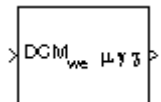
[Quaternions to Euler Angles](#)

# Direction Cosine Matrix to Wind Angles

**Purpose** 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  $(ox_3, oy_3, oz_3)$  into coincidence with  $(ox_0, oy_0, oz_0)$  is first, a rotation about  $ox_3$  through the bank angle ( $\mu$ ) to axes  $(ox_2, oy_2, oz_2)$ , second, a rotation about  $oy_2$  through the flight path angle ( $\gamma$ ) to axes  $(ox_1, oy_1, oz_1)$ , and finally, a rotation about  $oz_1$  through the heading angle ( $\chi$ ) to axes  $(ox_0, oy_0, oz_0)$ .

$$\begin{bmatrix} ox_3 \\ oy_3 \\ oz_3 \end{bmatrix} = DCM_{we} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

$$\begin{bmatrix} ox_3 \\ oy_3 \\ oz_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\mu & \sin\mu \\ 0 & -\sin\mu & \cos\mu \end{bmatrix} \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix} \begin{bmatrix} \cos\chi & \sin\chi & 0 \\ -\sin\chi & \cos\chi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

Combining the three axis transformation matrices defines the following DCM.

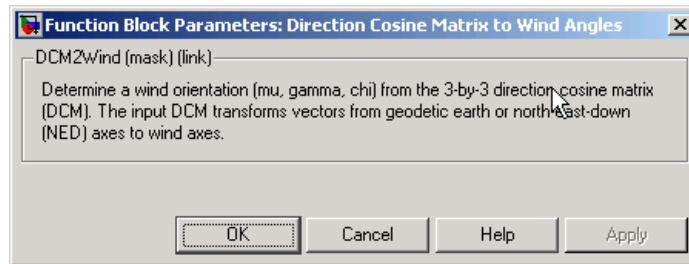
$$DCM_{we} = \begin{bmatrix} \cos\gamma\cos\chi & \cos\gamma\sin\chi & -\sin\gamma \\ (\sin\mu\sin\gamma\cos\chi - \cos\mu\sin\chi) & (\sin\mu\sin\gamma\sin\chi + \cos\mu\cos\chi) & \sin\mu\cos\gamma \\ (\cos\mu\sin\gamma\cos\chi + \sin\mu\sin\chi) & (\cos\mu\sin\gamma\sin\chi - \sin\mu\cos\chi) & \cos\mu\cos\gamma \end{bmatrix}$$

To determine wind angles from the DCM, the following equations are used:

$$\begin{aligned} \mu &= \text{atan}\left(\frac{DCM(2, 3)}{DCM(3, 3)}\right) \\ \gamma &= \text{asin}(-DCM(1, 3)) \\ \chi &= \text{atan}\left(\frac{DCM(1, 2)}{DCM(1, 1)}\right) \end{aligned}$$

# Direction Cosine Matrix to Wind Angles

## Dialog Box



## Inputs and Outputs

The input is a 3-by-3 direction cosine matrix which transforms earth vectors to wind vectors.

The output is a 3-by-1 vector of wind angles, in radians.

## Assumptions and Limitations

This implementation generates a flight path angle that lies between  $\pm 90$  degrees, and bank and heading angles that lie between  $\pm 180$  degrees.

## See Also

[Direction Cosine Matrix Body to Wind](#)

[Direction Cosine Matrix Body to Wind to Alpha and Beta](#)

[Direction Cosine Matrix to Euler Angles](#)

[Euler Angles to Direction Cosine Matrix](#)

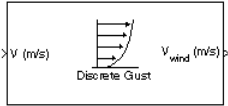
[Wind Angles to Direction Cosine Matrix](#)

# Discrete Wind Gust Model

**Purpose** Generate discrete wind gust

**Library** Environment/Wind

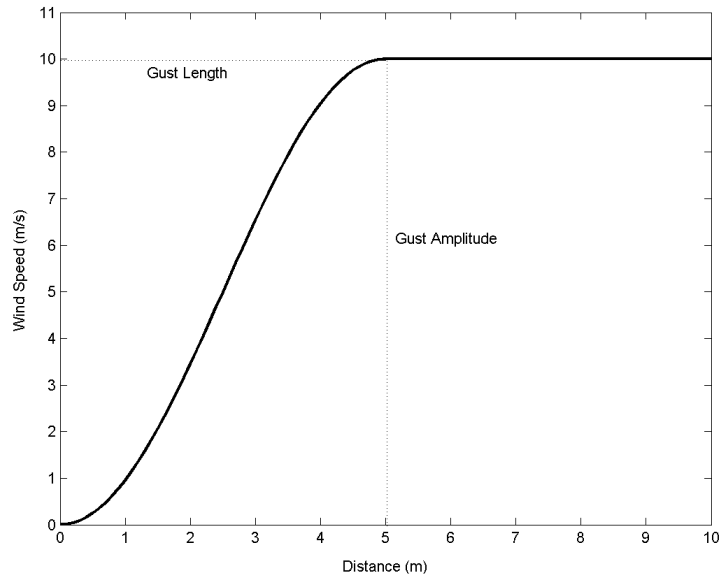
## Description



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. The user specifies 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

$$V_{wind} = \begin{cases} 0 & x < 0 \\ \frac{V_m}{2} \left( 1 - \cos\left(\frac{\pi x}{d_m}\right) \right) & 0 \leq x \leq d_m \\ V_m & x > d_m \end{cases}$$

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.

## Dialog Box

Block Parameters: Discrete Wind Gust Model

Discrete Wind Gust Model (mask) (link)

Generate a discrete wind gust. The gust profile takes the '1-cosine' form.

Parameters

Units: Metric (MKS)

Gust in u-axis

Gust in v-axis

Gust in w-axis

Gust start time (sec):

5

Gust length [dx dy dz] (m):

[120 120 80]

Gust amplitude [ug vg wg] (m/s):

[3.5 3.5 3.0]

OK Cancel Help Apply

# Discrete Wind Gust Model

---

## Units

Define the units of wind gust.

<b>Units</b>	<b>Wind</b>	<b>Altitude</b>
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

The input is airspeed in units selected.

The output is wind speed in units selected.

## Examples

See Airframe in the aeroblk\_HL20 demo for an example of this block.

## References

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)

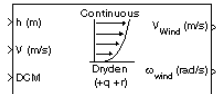
Wind Shear Model

# Dryden Wind Turbulence Model (Continuous)

**Purpose** Generate continuous wind turbulence with the 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 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  $\Omega$  radians per meter, the circular frequency  $\omega$  is calculated by multiplying  $V$  by  $\Omega$ . The following table displays the component spectra functions:

	<b>MIL-F-8785C</b>	<b>MIL-HDBK-1797</b>
Longitudinal		
$\Phi_u(\omega)$	$\frac{2\sigma_u^2 L_u}{\pi V} \cdot \frac{1}{1 + (L_u \frac{\omega}{V})^2}$	$\frac{2\sigma_u^2 L_u}{\pi V} \cdot \frac{1}{1 + (L_u \frac{\omega}{V})^2}$
$\Phi_{p_g}(\omega)$	$\frac{\sigma_w^2}{VL_w} \cdot \frac{0.8 \left( \frac{\pi L_w}{4b} \right)^{\frac{1}{3}}}{1 + \left( \frac{4b\omega}{\pi V} \right)^2}$	$\frac{\sigma_w^2}{2VL_w} \cdot \frac{0.8 \left( \frac{2\pi L_w}{4b} \right)^{\frac{1}{3}}}{1 + \left( \frac{4b\omega}{\pi V} \right)^2}$



# Dryden Wind Turbulence Model (Continuous)

	<b>MIL-F-8785C</b>	<b>MIL-HDBK-1797</b>
Lateral		
$\Phi_v(\omega)$	$\frac{\sigma_v^2 L_v}{\pi V} \cdot \frac{1 + 3(L_v \frac{\omega}{V})^2}{[1 + (L_v \frac{\omega}{V})^2]^2}$	$\frac{2\sigma_v^2 L_v}{\pi V} \cdot \frac{1 + 12(L_v \frac{\omega}{V})^2}{[1 + 4(L_v \frac{\omega}{V})^2]^2}$
$\Phi_r(\omega)$	$\frac{\mp(\frac{\omega}{V})^2}{1 + (\frac{3b\omega}{\pi V})^2} \cdot \Phi_v(\omega)$	$\frac{\mp(\frac{\omega}{V})^2}{1 + (\frac{3b\omega}{\pi V})^2} \cdot \Phi_v(\omega)$
Vertical		
$\Phi_w(\omega)$	$\frac{\sigma_w^2 L_w}{\pi V} \cdot \frac{1 + 3(L_w \frac{\omega}{V})^2}{[1 + (L_w \frac{\omega}{V})^2]^2}$	$\frac{2\sigma_w^2 L_w}{\pi V} \cdot \frac{1 + 12(L_w \frac{\omega}{V})^2}{[1 + 4(L_w \frac{\omega}{V})^2]^2}$
$\Phi_q(\omega)$	$\frac{\pm(\frac{\omega}{V})^2}{1 + (\frac{4b\omega}{\pi V})^2} \cdot \Phi_w(\omega)$	$\frac{\pm(\frac{\omega}{V})^2}{1 + (\frac{4b\omega}{\pi V})^2} \cdot \Phi_w(\omega)$

The variable  $b$  represents the aircraft wingspan. The variables  $L_u, L_v, L_w$  represent the turbulence scale lengths. The variables  $\sigma_u, \sigma_v, \sigma_w$  represent the turbulence intensities.

# Dryden Wind Turbulence Model (Continuous)

The spectral density definitions of turbulence angular rates are defined in the specifications as three variations, which are displayed in the following table:

$$p_g = \frac{\partial w_g}{\partial y} \quad q_g = \frac{\partial w_g}{\partial x} \quad r_g = -\frac{\partial v_g}{\partial x}$$

$$p_g = \frac{\partial w_g}{\partial y} \quad q_g = \frac{\partial w_g}{\partial x} \quad r_g = \frac{\partial v_g}{\partial x}$$

$$p_g = -\frac{\partial w_g}{\partial y} \quad q_g = -\frac{\partial w_g}{\partial x} \quad r_g = \frac{\partial v_g}{\partial x}$$

The variations affect only the vertical ( $q_g$ ) and lateral ( $r_q$ ) turbulence angular rates.

Keep in mind that 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. 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:

<b>Vertical</b>	<b>Lateral</b>
$\Phi_q(\omega)$	$-\Phi_r(\omega)$
$\Phi_q(\omega)$	$\Phi_r(\omega)$
$-\Phi_q(\omega)$	$\Phi_r(\omega)$

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 derived from the spectral square roots of the spectrum equations.

# Dryden Wind Turbulence Model (Continuous)

The following table displays the transfer functions:

	<b>MIL-F-8785C</b>	<b>MIL-HDBK-1797</b>
Longitudinal		
$H_u(s)$	$\sigma_u \sqrt{\frac{2L_u}{\pi V}} \frac{1}{1 + \frac{L_u}{V}s}$	$\sigma_u \sqrt{\frac{2L_u}{\pi V}} \frac{1}{1 + \frac{L_u}{V}s}$
$H_p(s)$	$\sigma_w \sqrt{\frac{0.8}{V}} \frac{\left(\frac{\pi}{4b}\right)^{1/6}}{L_w^{1/3} \left(1 + \left(\frac{4b}{\pi V}\right)s\right)}$	$\sigma_w \sqrt{\frac{0.8}{V}} \frac{\left(\frac{\pi}{4b}\right)^{1/6}}{(2L_w)^{1/3} \left(1 + \left(\frac{4b}{\pi V}\right)s\right)}$
Lateral		
$H_v(s)$	$\sigma_v \sqrt{\frac{L_v}{\pi V}} \frac{1 + \frac{\sqrt{3}L_v}{V}s}{\left(1 + \frac{L_v}{V}s\right)^2}$	$\sigma_v \sqrt{\frac{2L_v}{\pi V}} \frac{1 + \frac{2\sqrt{3}L_v}{V}s}{\left(1 + \frac{2L_v}{V}s\right)^2}$
$H_r(s)$	$\frac{\mp \frac{s}{V}}{\left(1 + \left(\frac{3b}{\pi V}\right)s\right)} \cdot H_v(s)$	$\frac{\mp \frac{s}{V}}{\left(1 + \left(\frac{3b}{\pi V}\right)s\right)} \cdot H_v(s)$
Vertical		
$H_w(s)$	$\sigma_w \sqrt{\frac{L_w}{\pi V}} \frac{1 + \frac{\sqrt{3}L_w}{V}s}{\left(1 + \frac{L_w}{V}s\right)^2}$	$\sigma_w \sqrt{\frac{2L_w}{\pi V}} \frac{1 + \frac{2\sqrt{3}L_w}{V}s}{\left(1 + \frac{2L_w}{V}s\right)^2}$
$H_q(s)$	$\frac{\pm \frac{s}{V}}{\left(1 + \left(\frac{4b}{\pi V}\right)s\right)} \cdot H_w(s)$	$\frac{\pm \frac{s}{V}}{\left(1 + \left(\frac{4b}{\pi V}\right)s\right)} \cdot H_w(s)$

# Dryden Wind Turbulence Model (Continuous)

Divided into two distinct regions, the turbulence scale lengths and intensities are functions of altitude.

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**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.

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## 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

$$L_w = h$$

$$L_u = L_v = \frac{h}{(0.177 + 0.000823h)^{1.2}}$$

### MIL-HDBK-1797

$$2L_w = h$$

$$L_u = 2L_v = \frac{h}{(0.177 + 0.000823h)^{1.2}}$$

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

# Dryden Wind Turbulence Model (Continuous)

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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

$$L_u = L_v = L_w = 1750 \text{ ft}$$

### MIL-HDBK-1797

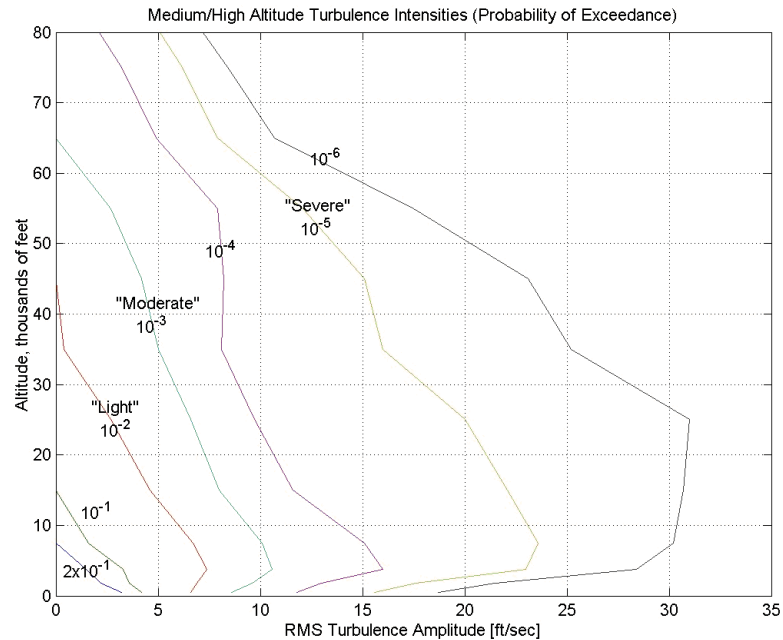
$$L_u = 2L_v = 2L_w = 1750 \text{ ft}$$

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.

$$\sigma_u = \sigma_v = \sigma_w$$

# Dryden Wind Turbulence Model (Continuous)

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.

# Dryden Wind Turbulence Model (Continuous)

## Dialog Box

**Block Parameters: Dryden Wind Turbulence Model (Continuous (+q +r))** [?] [X]

Wind Turbulence Model (mask) (link)  
Generate atmospheric turbulence. White noise is passed through a filter to give the turbulence the specified velocity spectra.  
Medium/high altitude scale lengths from the specifications are 762 m (2500 ft) for Von Karman turbulence and 533.4 m (1750 ft) for Dryden turbulence.

Parameters

Units: Metric (MKS)

Specification: MIL-F-8785C

Model type: Continuous Dryden (+q +r)

Wind speed at 6 m defines the low-altitude intensity (m/s):  
15

Wind direction at 6 m (degrees clockwise from north):  
0

Probability of exceedance of high-altitude intensity:  $10^{-2}$  · Light

Scale length at medium/high altitudes (m):  
533.4

Wingspan (m):  
10

Band limited noise sample time (sec):  
0.1

Noise seeds [ug vg wg pg]:  
[23341 23342 23343 23344]

Turbulence on

OK Cancel Help Apply

# Dryden Wind Turbulence Model (Continuous)

---

## Units

Define the units of wind speed due to the turbulence.

<b>Units</b>	<b>Wind Velocity</b>	<b>Altitude</b>	<b>Air Speed</b>
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 Kármán (+q -r) Use continuous representation of Von Kármán velocity spectra with positive vertical and negative lateral angular rates spectra.
- Continuous Von Kármán (+q +r) Use continuous representation of Von Kármán velocity spectra with positive vertical and lateral angular rates spectra.
- Continuous Von Kármán (-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.



# Dryden Wind Turbulence Model (Continuous)

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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**

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.

# Dryden Wind Turbulence Model (Continuous)

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## Scale length at medium/high altitudes (m)

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.

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**Note** An alternate scale length value changes the power spectral density asymptote and gust load.

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## Wingspan

The wingspan is 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

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

The first input is altitude, in units selected.

The second input is aircraft speed, in units selected.

The third input is a direction cosine matrix.

The first output is a three-element signal containing the turbulence velocities, in the selected units.

The second output is a three-element signal containing the turbulence angular rates, in radians per second.

# Dryden Wind Turbulence Model (Continuous)

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## 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 factors (except altitude)

## Examples

See the Airframe subsystem in the aeroblk\_HL20 demo for an example of this block.

## 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.

# Dryden Wind Turbulence Model (Continuous)

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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 (Discrete)

Discrete Wind Gust Model

Wind Shear Model

Von Karman Wind Turbulence Model (Continuous)

# Dryden Wind Turbulence Model (Discrete)

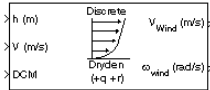
## Purpose

Generate continuous wind turbulence with the 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 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  $\Omega$  radians per meter, the circular frequency  $\omega$  is calculated by multiplying  $V$  by  $\Omega$ . The following table displays the component spectra functions:

	<b>MIL-F-8785C</b>	<b>MIL-HDBK-1797</b>
Longitudinal		
$\Phi_u(\omega)$	$\frac{2\sigma_u^2 L_u}{\pi V} \cdot \frac{1}{1 + (L_u \frac{\omega}{V})^2}$	$\frac{2\sigma_u^2 L_u}{\pi V} \cdot \frac{1}{1 + (L_u \frac{\omega}{V})^2}$
$\Phi_p(\omega)$	$\frac{\sigma_w^2}{VL_w} \cdot \frac{0.8 \left( \frac{\pi L_w}{4b} \right)^{\frac{1}{3}}}{1 + \left( \frac{4b\omega}{\pi V} \right)^2}$	$\frac{\sigma_w^2}{2VL_w} \cdot \frac{0.8 \left( \frac{2\pi L_w}{4b} \right)^{\frac{1}{3}}}{1 + \left( \frac{4b\omega}{\pi V} \right)^2}$

# Dryden Wind Turbulence Model (Discrete)

	<b>MIL-F-8785C</b>	<b>MIL-HDBK-1797</b>
Lateral		
$\Phi_v(\omega)$	$\frac{\sigma_v^2 L_v}{\pi V} \cdot \frac{1 + 3(L_v \frac{\omega}{V})^2}{[1 + (L_v \frac{\omega}{V})^2]^2}$	$\frac{2\sigma_v^2 L_v}{\pi V} \cdot \frac{1 + 12(L_v \frac{\omega}{V})^2}{[1 + 4(L_v \frac{\omega}{V})^2]^2}$
$\Phi_r(\omega)$	$\frac{\mp(\frac{\omega}{V})^2}{1 + (\frac{3b\omega}{\pi V})^2} \cdot \Phi_v(\omega)$	$\frac{\mp(\frac{\omega}{V})^2}{1 + (\frac{3b\omega}{\pi V})^2} \cdot \Phi_v(\omega)$
Vertical		
$\Phi_w(\omega)$	$\frac{\sigma_w^2 L_w}{\pi V} \cdot \frac{1 + 3(L_w \frac{\omega}{V})^2}{[1 + (L_w \frac{\omega}{V})^2]^2}$	$\frac{2\sigma_w^2 L_w}{\pi V} \cdot \frac{1 + 12(L_w \frac{\omega}{V})^2}{[1 + 4(L_w \frac{\omega}{V})^2]^2}$
$\Phi_q(\omega)$	$\frac{\pm(\frac{\omega}{V})^2}{1 + (\frac{4b\omega}{\pi V})^2} \cdot \Phi_w(\omega)$	$\frac{\pm(\frac{\omega}{V})^2}{1 + (\frac{4b\omega}{\pi V})^2} \cdot \Phi_w(\omega)$

The variable  $b$  represents the aircraft wingspan. The variables  $L_u, L_v, L_w$  represent the turbulence scale lengths. The variables  $\sigma_u, \sigma_v, \sigma_w$  represent the turbulence intensities.

# Dryden Wind Turbulence Model (Discrete)

The spectral density definitions of turbulence angular rates are defined in the references as three variations, which are displayed in the following table:

$$p_g = \frac{\partial w_g}{\partial y} \quad q_g = \frac{\partial w_g}{\partial x} \quad r_g = -\frac{\partial v_g}{\partial x}$$

$$p_g = \frac{\partial w_g}{\partial y} \quad q_g = \frac{\partial w_g}{\partial x} \quad r_g = \frac{\partial v_g}{\partial x}$$

$$p_g = -\frac{\partial w_g}{\partial y} \quad q_g = -\frac{\partial w_g}{\partial x} \quad r_g = \frac{\partial v_g}{\partial x}$$

The variations affect only the vertical ( $q_g$ ) and lateral ( $r_q$ ) 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

$$\Phi_q(\omega) \quad -\Phi_r(\omega)$$

$$\Phi_q(\omega) \quad \Phi_r(\omega)$$

$$-\Phi_q(\omega) \quad \Phi_r(\omega)$$

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.

# Dryden Wind Turbulence Model (Discrete)

The following table displays the digital filter finite difference equations:

	<b>MIL-F-8785C</b>	<b>MIL-HDBK-1797</b>
Longitudinal		
$u_g$	$\left(1 - \frac{V}{L_u}T\right)u_g + \sqrt{2\frac{V}{L_u}T\frac{\sigma_u}{\sigma_\eta}}\eta_1$	$\left(1 - \frac{V}{L_u}T\right)u_g + \sqrt{2\frac{V}{L_u}T\frac{\sigma_u}{\sigma_\eta}}\eta_1$
$p_g$	$\left(1 - \frac{2.6}{\sqrt{L_w b}}T\right)p_g + \frac{0.95}{\sqrt{2\frac{2.6}{\sqrt{L_w b}}T\sqrt[3]{2L_w b^2}\frac{\sigma_w}{\sigma_\eta}}}\eta_4$	$\left(1 - \frac{2.6}{\sqrt{2L_w b}}T\right)p_g + \frac{1.9}{\sqrt{2\frac{2.6}{\sqrt{2L_w b}}T\sqrt[3]{2L_w b^2}\frac{\sigma_w}{\sigma_\eta}}}\eta_4$
Lateral		
$v_g$	$\left(1 - \frac{V}{L_u}T\right)v_g + \sqrt{2\frac{V}{L_u}T\frac{\sigma_v}{\sigma_\eta}}\eta_2$	$\left(1 - \frac{V}{L_u}T\right)v_g + \sqrt{2\frac{V}{L_u}T\frac{\sigma_v}{\sigma_\eta}}\eta_2$
$r_g$	$\left(1 - \frac{\pi V}{3b}T\right)r_g \mp \frac{\pi}{3b}(v_g - v_{g_{past}})$	$\left(1 - \frac{\pi V}{3b}T\right)r_g \mp \frac{\pi}{3b}(v_g - v_{g_{past}})$
Vertical		
$w_g$	$\left(1 - \frac{V}{L_u}T\right)w_g + \sqrt{2\frac{V}{L_u}T\frac{\sigma_w}{\sigma_\eta}}\eta_3$	$\left(1 - \frac{V}{L_u}T\right)w_g + \sqrt{2\frac{V}{L_u}T\frac{\sigma_w}{\sigma_\eta}}\eta_3$
$q_g$	$\left(1 - \frac{\pi V}{4b}T\right)q_g \pm \frac{\pi}{4b}(w_g - w_{g_{past}})$	$\left(1 - \frac{\pi V}{4b}T\right)q_g \pm \frac{\pi}{4b}(w_g - w_{g_{past}})$

Divided into two distinct regions, the turbulence scale lengths and intensities are functions of altitude.



# Dryden Wind Turbulence Model (Discrete)

## 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

$$L_w = h$$

$$L_u = L_v = \frac{h}{(0.177 + 0.000823h)^{1.2}}$$

### MIL-HDBK-1797

$$2L_w = h$$

$$L_u = 2L_v = \frac{h}{(0.177 + 0.000823h)^{1.2}}$$

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.

# Dryden Wind Turbulence Model (Discrete)

## 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**

$$L_u = L_v = L_w = 1750 \text{ ft}$$

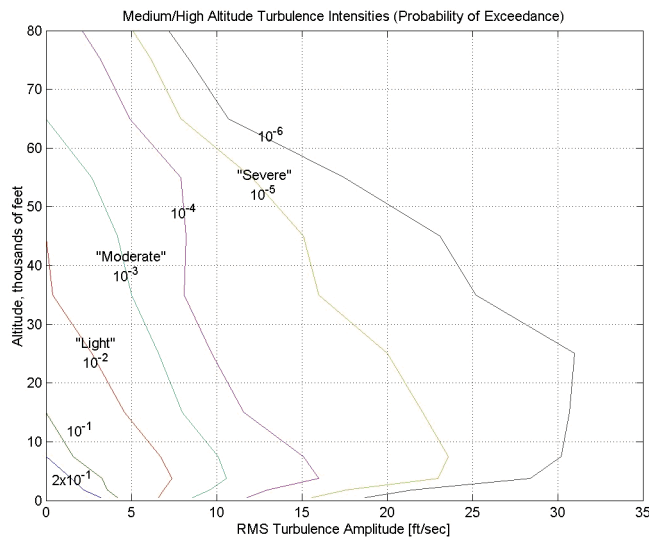
**MIL-HDBK-1797**

$$L_u = 2L_v = 2L_w = 1750 \text{ ft}$$

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.



# Dryden Wind Turbulence Model (Discrete)

## 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.

### Dialog Box

Block Parameters: Dryden Wind Turbulence Model (Discrete (+q +r))

Wind Turbulence Model (mask) (link)

Generate atmospheric turbulence. White noise is passed through a filter to give the turbulence the specified velocity spectra.

Medium/high altitude scale lengths from the specifications are 762 m (2500 ft) for Von Karman turbulence and 533.4 m (1750 ft) for Dryden turbulence.

Parameters

Units: Metric (MKS)

Specification: MIL-F-8785C

Model type: Discrete Dryden (+q +r)

Wind speed at 6 m defines the low-altitude intensity (m/s): 15

Wind direction at 6 m (degrees clockwise from north): 0

Probability of exceedance of high-altitude intensity:  $10^{-2}$  · Light

Scale length at medium/high altitudes (m): 533.4

Wingspan (m): 10

Band limited noise and discrete filter sample time (sec): 0.1

Noise seeds [ug vg wg pg]: [23341 23342 23343 23344]

Turbulence on

OK Cancel Help Apply

# Dryden Wind Turbulence Model (Discrete)

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## Units

Define the units of wind speed due to the turbulence.

<b>Units</b>	<b>Wind Velocity</b>	<b>Altitude</b>	<b>Air Speed</b>
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 Kármán (+q -r) Use continuous representation of Von Kármán velocity spectra with positive vertical and negative lateral angular rates spectra.
- Continuous Von Kármán (+q +r) Use continuous representation of Von Kármán velocity spectra with positive vertical and lateral angular rates spectra.
- Continuous Von Kármán (-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.

# Dryden Wind Turbulence Model (Discrete)

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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.

# Dryden Wind Turbulence Model (Discrete)

---

## 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

The first input is altitude, in units selected.

The second input is aircraft speed, in units selected.

The third input is a direction cosine matrix.

The first output is a three-element signal containing the turbulence velocities, in the selected units.

The second output is a three-element signal containing the turbulence angular rates, in radians per second.

# Dryden Wind Turbulence Model (Discrete)

---

## 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 factors (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.

# Dryden Wind Turbulence Model (Discrete)

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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)

Von Karman Wind Turbulence Model (Continuous)

Discrete Wind Gust Model

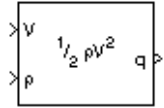
Wind Shear Model



**Purpose** Compute dynamic pressure using velocity and air density

**Library** Flight Parameters

**Description** The Dynamic Pressure block computes dynamic pressure.

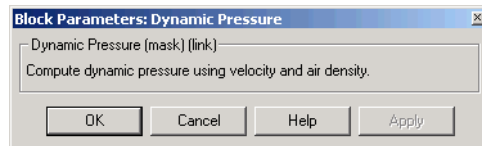


Dynamic pressure is defined as

$$\bar{q} = \frac{1}{2} \rho V^2$$

where  $\rho$  is air density and  $V$  is velocity.

**Dialog Box**



**Inputs and** The first input is velocity vector.

**Outputs** The second input is air density.

The output of the block is dynamic pressure.

**Examples** See the Airframe subsystem in the aeroblk\_HL20 demo for an example of this block.

**See Also** Aerodynamic Forces and Moments

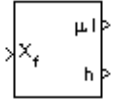
Mach Number

# ECEF Position to LLA

**Purpose** Calculate geodetic latitude, longitude, and altitude above mean sea-level (MSL) 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 ( $\underline{p}$ ) into geodetic latitude ( $\underline{\mu}$ ), longitude ( $\underline{\iota}$ ), and MSL altitude ( $\underline{h}$ ). Geocentric latitude ( $\underline{\lambda}$ ) and longitude are calculated from the ECEF position using:



$$\lambda = \text{asin}\left(\frac{p_z}{\sqrt{p_x^2 + p_y^2 + p_z^2}}\right)$$

$$\iota = \text{atan}\left(\frac{p_y}{p_x}\right)$$

where ECEF position is defined as:

$$\underline{p} = \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix}$$

Geodetic latitude ( $\underline{\mu}$ ) is determined from geocentric latitude ( $\underline{\lambda}$ ) using the block. See Geocentric to Geodetic Latitude reference page for details on calculation.

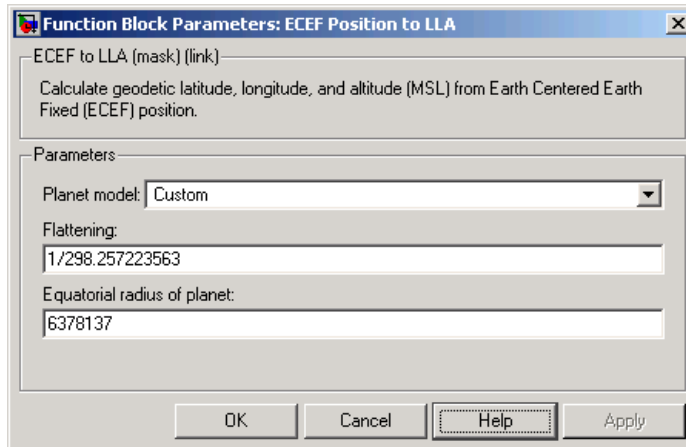
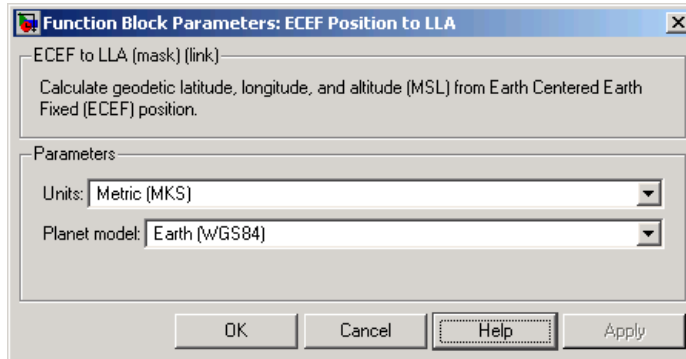
The MSL altitude ( $\underline{h}$ ) is approximated by

$$h \approx (\|\underline{p}\| - r)$$

where the radius at a surface point ( $r$ ) is defined by flattening ( $f$ ), geocentric latitude ( $\underline{\lambda}$ ), and equatorial radius ( $\underline{R}$ ) in the following relationship.

$$r = \sqrt{\frac{R^2}{1 + [1/(1-f)^2 - 1]\sin^2\lambda}}$$

## Dialog Box



## 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).

# ECEF Position to LLA

---

## **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. The units of the equatorial radius parameter should be the same as the units for ECEF position. This option is only available with **Planet model** set to Custom.

## **Inputs and Outputs**

The input is a 3-by-1 vector containing the position in ECEF frame.

The first output is a 2-by-1 vector containing geodetic latitude and longitude, in degrees.

The second output is a scalar value of altitude above mean sea-level (MSL), in same units as ECEF position.

## **Assumptions and Limitations**

This implementation generates a geodetic latitude that lies between  $\pm 90$  degrees, and longitude that lies between  $\pm 180$  degrees. The planet is assumed to be ellipsoidal by setting flattening to 0.0 a spherical planet can be achieved. Additionally, the MSL altitude is approximate.

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 hand system.

## **References**

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 1992.

Zipfel, P. H., *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA Education Series, Reston, VA, 2000.

“Atmospheric and Space Flight Vehicle Coordinate Systems,” ANSI/AIAA R-004-1992.

**See Also**

Direction Cosine Matrix ECEF to NED

Direction Cosine Matrix ECEF to NED to Latitude and Longitude

Geocentric to Geodetic Latitude

LLA to ECEF Position

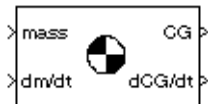
Radius at Geocentric Latitude

# Estimate Center of Gravity

**Purpose** Calculate the center of gravity location

**Library** Mass Properties

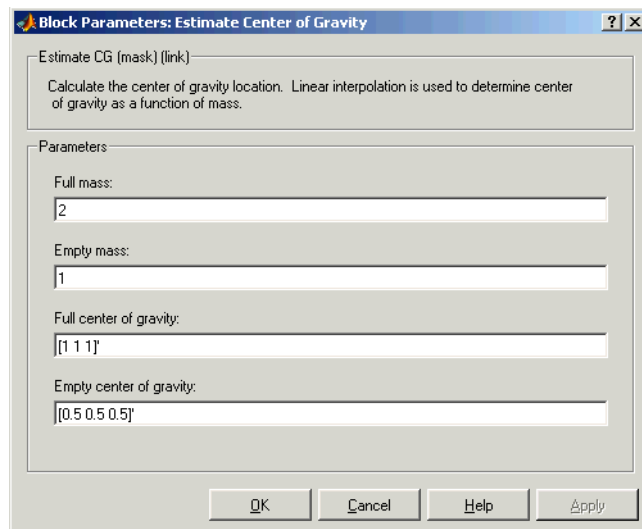
## Description



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.

## Dialog Box



### 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**

The first input is the mass.

The second input is the rate of change of mass.

The first output is the center of gravity location.

The second output is the rate of change of center of gravity location.

## **Examples**

See the `aeroblk_vmm` demo for an example of this block.

## **See Also**

Aerodynamic Forces and Moments

Estimate Inertia Tensor

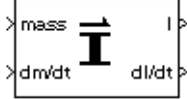
Moments About CG Due to Forces

# Estimate Inertia Tensor

**Purpose** Calculate the inertia tensor

**Library** Mass Properties

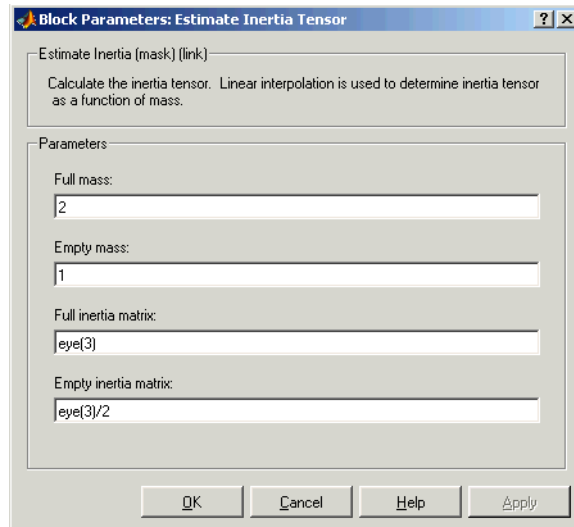
## Description



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.

## Dialog Box



### 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**

The first input is mass.

The second input is rate of change of mass.

The first output is inertia tensor.

The second output is rate of change of inertia tensor.

**See Also**

Estimate Center of Gravity

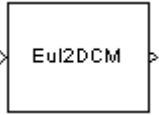
Symmetric Inertia Tensor

# Euler Angles to Direction Cosine Matrix

**Purpose** Convert Euler angles to direction cosine matrix

**Library** Utilities/Axes Transformations

**Description**



The Euler Angles to Direction Cosine Matrix block converts the three Euler rotation angles into a 3-by-3 direction cosine matrix (DCM). The DCM matrix performs the coordinate transformation of a vector in inertial axes  $(ox_0, oy_0, oz_0)$  into a vector in body axes  $(ox_3, oy_3, oz_3)$ . The order of the axis rotations required to bring  $(ox_3, oy_3, oz_3)$  into coincidence with  $(ox_0, oy_0, oz_0)$  is first a rotation about  $ox_3$  through the roll angle ( $\phi$ ) to axes  $(ox_2, oy_2, oz_2)$ . Second a rotation about  $oy_2$  through the pitch angle ( $\theta$ ) to axes  $(ox_1, oy_1, oz_1)$ , and finally a rotation about  $oz_1$  through the yaw angle ( $\psi$ ) to axes  $(ox_0, oy_0, oz_0)$ .

$$\begin{bmatrix} ox_3 \\ oy_3 \\ oz_3 \end{bmatrix} = DCM \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

$$\begin{bmatrix} ox_3 \\ oy_3 \\ oz_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & \sin \phi \\ 0 & -\sin \phi & \cos \phi \end{bmatrix} \begin{bmatrix} \cos \theta & 0 & -\sin \theta \\ 0 & 1 & 0 \\ \sin \theta & 0 & \cos \theta \end{bmatrix} \begin{bmatrix} \cos \psi & \sin \psi & 0 \\ -\sin \psi & \cos \psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

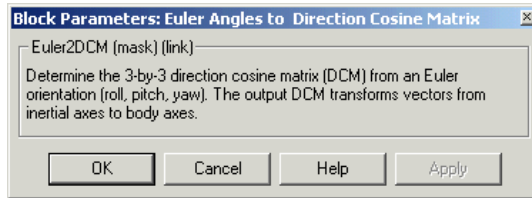
Combining the three axis transformation matrices defines the following DCM.

$$DCM = \begin{bmatrix} \cos \theta \cos \psi & \cos \theta \sin \psi & -\sin \theta \\ (\sin \phi \sin \theta \cos \psi - \cos \phi \sin \psi) & (\sin \phi \sin \theta \sin \psi + \cos \phi \cos \psi) & \sin \phi \cos \theta \\ (\cos \phi \sin \theta \cos \psi + \sin \phi \sin \psi) & (\cos \phi \sin \theta \sin \psi - \sin \phi \cos \psi) & \cos \phi \cos \theta \end{bmatrix}$$

# Euler Angles to Direction Cosine Matrix

---

## Dialog Box



## Inputs and Outputs

The input is a 3-by-1 vector of Euler angles.

The output is a 3-by-3 direction cosine matrix.

## See Also

[Direction Cosine Matrix to Euler Angles](#)

[Direction Cosine Matrix to Quaternions](#)

[Euler Angles to Quaternions](#)

[Quaternions to Direction Cosine Matrix](#)

[Quaternions to Euler Angles](#)

# Euler Angles to Quaternions

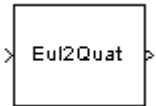
## Purpose

Convert Euler angles to a quaternion vector

## Library

Utilities/Axes Transformations

## Description



The Euler Angles to Quaternions block converts the rotation described by the three Euler angles (roll, pitch, yaw) into the four-element quaternion vector  $(q_0, q_1, q_2, q_3)$ .

A quaternion vector represents a rotation about a unit vector  $(\mu_x, \mu_y, \mu_z)$  through an angle  $\theta$ . 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,

$$\mathbf{i}^2 = \mathbf{j}^2 = \mathbf{k}^2 = -1$$

$$\mathbf{i}\mathbf{j} = -\mathbf{j}\mathbf{i} = \mathbf{k}$$

$$\mathbf{j}\mathbf{k} = -\mathbf{k}\mathbf{j} = \mathbf{i},$$

$$\mathbf{k}\mathbf{i} = -\mathbf{i}\mathbf{k} = \mathbf{j}$$

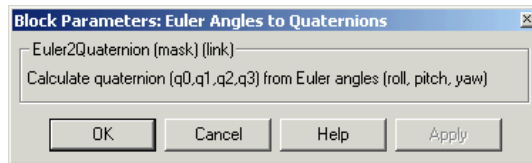
The benefit of representing the quaternion in this way is the ease with which the quaternion product can represent the resulting transformation after two or more rotations. The quaternion to represent the rotation through the three Euler angles is given below.

$$q = q_\phi q_\theta q_\psi = \left( \cos\left(\frac{\phi}{2}\right) - \mathbf{i} \sin\left(\frac{\phi}{2}\right) \right) \left( \cos\left(\frac{\theta}{2}\right) - \mathbf{j} \sin\left(\frac{\theta}{2}\right) \right) \left( \cos\left(\frac{\psi}{2}\right) - \mathbf{k} \sin\left(\frac{\psi}{2}\right) \right)$$

Expanding the preceding representation gives the four quaternion elements following.

$$\begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix} = \begin{bmatrix} \cos\left(\frac{\phi}{2}\right) \cos\left(\frac{\theta}{2}\right) \cos\left(\frac{\psi}{2}\right) + \sin\left(\frac{\phi}{2}\right) \sin\left(\frac{\theta}{2}\right) \sin\left(\frac{\psi}{2}\right) \\ \sin\left(\frac{\phi}{2}\right) \cos\left(\frac{\theta}{2}\right) \cos\left(\frac{\psi}{2}\right) - \cos\left(\frac{\phi}{2}\right) \sin\left(\frac{\theta}{2}\right) \sin\left(\frac{\psi}{2}\right) \\ \cos\left(\frac{\phi}{2}\right) \sin\left(\frac{\theta}{2}\right) \cos\left(\frac{\psi}{2}\right) + \sin\left(\frac{\phi}{2}\right) \cos\left(\frac{\theta}{2}\right) \sin\left(\frac{\psi}{2}\right) \\ \cos\left(\frac{\phi}{2}\right) \cos\left(\frac{\theta}{2}\right) \sin\left(\frac{\psi}{2}\right) - \sin\left(\frac{\phi}{2}\right) \sin\left(\frac{\theta}{2}\right) \cos\left(\frac{\psi}{2}\right) \end{bmatrix}$$

## Dialog Box



## Inputs and Outputs

The input is a 3-by-1 vector of Euler angles.

The output is a 4-by-1 quaternion vector.

## See Also

[Direction Cosine Matrix to Euler Angles](#)

[Direction Cosine Matrix to Quaternions](#)

[Euler Angles to Direction Cosine Matrix](#)

[Quaternions to Direction Cosine Matrix](#)

[Quaternions to Euler Angles](#)

# Flat Earth to LLA

**Purpose** Estimate geodetic latitude, longitude, and altitude from flat Earth position

**Library** Utilities/Axes Transformations

## Description

$$\begin{array}{|c|c|} \hline x_e & \mu l \\ \hline h_{ref} & h \\ \hline \end{array}$$

The Flat Earth to LLA block converts a 3-by-1 vector of Flat Earth position ( $\underline{p}$ ) into geodetic latitude ( $\underline{\mu}$ ), longitude ( $\underline{l}$ ), and altitude ( $h$ ). The flat Earth coordinate system assumes the z-axis is downwards 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 ( $\psi$ ) 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:

$$R_N = \frac{R}{\sqrt{1 - (2f - f^2) \sin^2 \mu}}$$

$$R_M = R_N \frac{1 - (2f - f^2)}{1 - (2f - f^2) \sin^2 \mu}$$

where ( $R$ ) is the equatorial radius of the planet and ( $f$ ) 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

$$d\mu = \text{atan}\left(\frac{1}{R_M}\right) dN$$

$$dl = \text{atan}\left(\frac{1}{R_N \cos \mu}\right) dE$$

The output latitude and longitude are simply the initial latitude and longitude plus the small changes in latitude and longitude.

$$\mu = \mu_o + d\mu$$

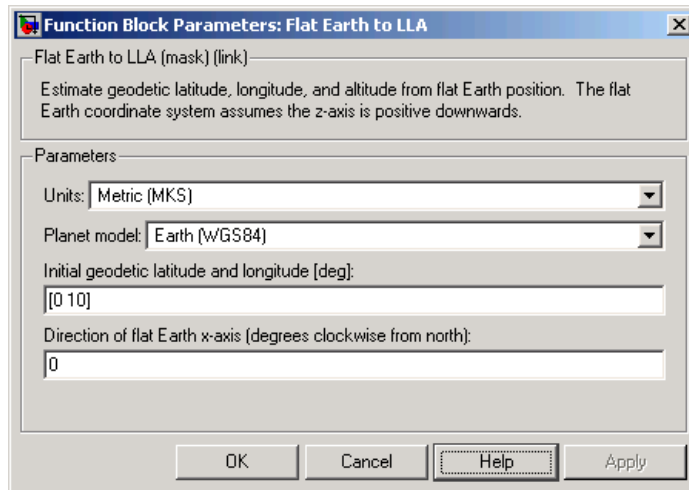
$$\iota = \iota_o + d\iota$$

The altitude is the negative flat Earth z-axis value minus the reference height ( $h_{ref}$ ).

$$h = -p_z - h_{ref}$$

# Flat Earth to LLA

## Dialog Box



Function Block Parameters: Flat Earth to LLA

Flat Earth to LLA (mask) (link)

Estimate geodetic latitude, longitude, and altitude from flat Earth position. The flat Earth coordinate system assumes the z-axis is positive downwards.

Parameters

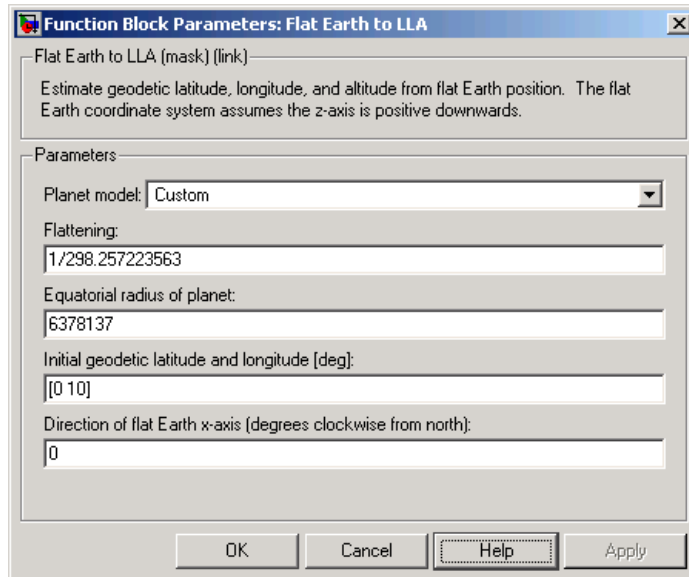
Units: Metric (MKS)

Planet model: Earth (WGS84)

Initial geodetic latitude and longitude [deg]:  
[0 10]

Direction of flat Earth x-axis (degrees clockwise from north):  
0

OK Cancel Help Apply



Function Block Parameters: Flat Earth to LLA

Flat Earth to LLA (mask) (link)

Estimate geodetic latitude, longitude, and altitude from flat Earth position. The flat Earth coordinate system assumes the z-axis is positive downwards.

Parameters

Planet model: Custom

Flattening:  
1/298.257223563

Equatorial radius of planet:  
6378137

Initial geodetic latitude and longitude [deg]:  
[0 10]

Direction of flat Earth x-axis (degrees clockwise from north):  
0

OK Cancel Help Apply



## 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

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

The first input is a 3-by-1 vector containing the position in flat Earth frame.

The second input is a scalar value of reference altitude in the same units for flat Earth position.

The first output is a 2-by-1 vector containing geodetic latitude and longitude, in degrees.

# Flat Earth to LLA

---

The second output is a scalar value of 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.

## Example

See the asbh120 demo for an example of this block.

## References

Etkin, B., *Dynamics of Atmospheric Flight*, John Wiley & Sons, New York, NY, 1972.

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, Second Edition, John Wiley & Sons, New York, NY, 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

# FlightGear Preconfigured 6DoF Animation

**Purpose** Connect your model to FlightGear Flight Simulator

**Library** 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 ( $\lambda$ ), latitude ( $L$ ), altitude ( $h$ ), roll ( $\phi$ ), pitch ( $\theta$ ), and yaw ( $\psi$ ) respectively. Units are degrees west/north for longitude and latitude, meters above mean sea level for altitude, and radians for attitude values.

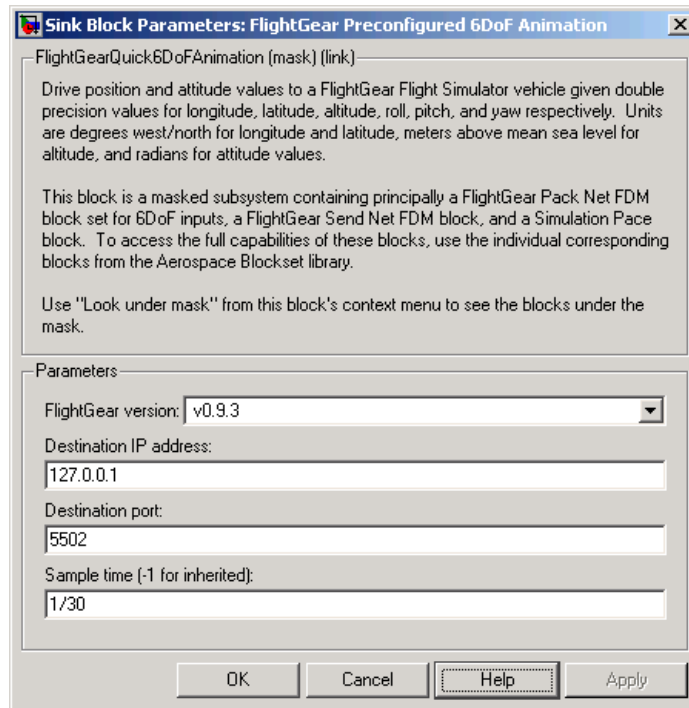
The block is a masked subsystem containing principally a Pack net\_fdm Packet for FlightGear block set for 6DoF inputs, a Send net\_fdm Packet to FlightGear block, and a Simulation Pace block. To access the full capabilities of these blocks, use the individual corresponding blocks from the Aerospace Blockset library.

The block is additionally configured as a SimViewingDevice, so that if you generate code for your model using Real-Time Workshop and connect to the running target code using the Real-Time Workshop External Mode available from the model's toolbar, then Simulink can obtain the data from the target on the fly and transmit position and attitude data to FlightGear. The SimViewingDevice facility is described in the Simulink documentation.

Use **Look under mask** from this block's context menu to see the blocks under the mask. For additional information on the operations of this block, see the reference pages for Pack net\_fdm Packet for FlightGear, Send net\_fdm Packet to FlightGear, and Simulation Pace blocks.

# FlightGear Preconfigured 6DoF Animation

## Dialog Box



### FlightGear version

Select your FlightGear software version: v0.9.3 or v0.9.8.

### Destination IP address

Specify your destination IP address.

### Destination port

Specify your destination port.

### Sample time

Specify the sample time (-1 for inherited).

## Inputs and Outputs

The input is a vector containing longitude, latitude, altitude, roll, pitch, and yaw, in double precision.

# FlightGear Preconfigured 6DoF Animation

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**Examples** See the asbh120 demo for an example of this block.

**References** Dr. Nathaniel Bowditch, *American Practical Navigator, An Epitome of Navigation*, US Navy Hydrographic Office, 1802.

**See Also**

- Generate Run Script
- Pack net\_fdm Packet for FlightGear
- Send net\_fdm Packet to FlightGear
- Simulation Pace

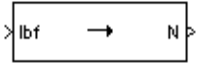
# Force Conversion

---

**Purpose** Convert from force units to desired force units

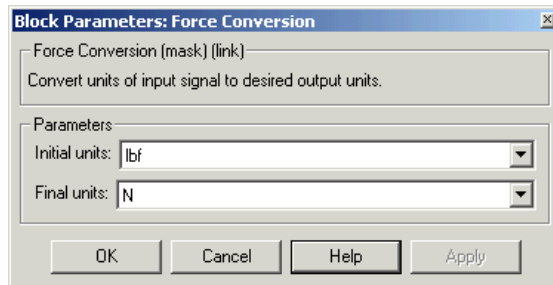
**Library** Utilities/Axes Transformations

**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 units** and the **Final units** lists.

## Dialog Box



### Initial units

Specifies the input units.

### Final units

Specifies the output units.

The following conversion units are available:

lbf	Pound force
N	Newtons

## Inputs and Outputs

The input is force in initial force units.

The output is 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

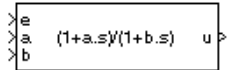
Velocity Conversion

# Gain Scheduled Lead-Lag

**Purpose** Implement a first-order lead-lag with gain-scheduled coefficients

**Library** GNC/Controls

**Description** The Gain Scheduled Lead-Lag block implements a first-order lag of the form

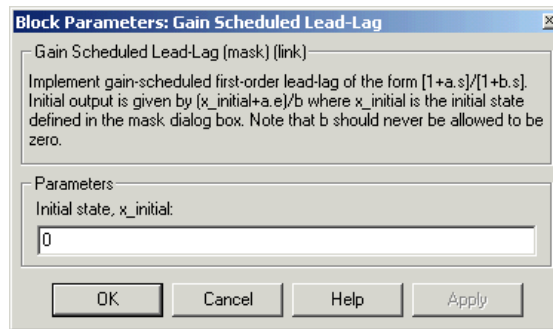


$$u = \frac{1 + as}{1 + bs}e$$

where  $e$  is the filter input, and  $u$  the filter output.

The coefficients  $a$  and  $b$  are inputs to the block, and hence can be made dependent on flight condition or operating point. For example, they could be produced from the Look-Up Table (n-D) Simulink block.

## Dialog Box



### Initial state, $x_{initial}$

The initial internal state for the filter  $x_{initial}$ . Given this initial state, the initial output is given by

$$u|_{t=0} = \frac{x_{initial} + ae}{b}$$

## Inputs and Outputs

The first input is the filter input.

The second input is the numerator coefficient.

The third input is the denominator coefficient.

The output is the filter output



**Purpose** Generate FlightGear run script on current platform

**Library** Animation/Flight Simulator Interfaces

**Description** The Generate Run Script block generates a customized FlightGear run script on the current platform.



To generate the file, fill in the information, then select the checkbox. The checkbox clears automatically once the script is generated.

Items marked with an asterisk (\*) are evaluated as MATLAB expressions, the rest of the fields are literal text.

# Generate Run Script

## Dialog Box

**Block Parameters: Generate Run Script** [X]

Generate FlightGear Run Script (mask) (link)  
Generate a custom FlightGear run script file on the current platform.

To generate the file, fill in the information then check the checkbox. The checkbox unchecks automatically. Items marked with an asterisk (\*) are evaluated as MATLAB expressions, the rest of the fields are literal text.

Parameters

Output file name:  
runfg.bat

FlightGear base directory:  
D:\Applications\FlightGear-0.9.8a

FlightGear geometry model name:  
HL20

Destination port:  
5502

Airport ID:  
KSFO

Runway ID:  
10L

Initial altitude (ft)\*:  
7224

Initial heading (deg)\*:  
113

Offset distance (miles)\*:  
4.72

Offset azimuth (deg)\*:  
0

Click checkbox to generate file (unchecks automatically)

OK Cancel Help Apply

### Output file name

Specify the name of the output file. The file name is the name of the command you will use to start FlightGear with these initial parameters. The file must have the .bat extension.

### FlightGear base directory

Specify the name of your FlightGear installation directory.

**FlightGear geometry model name**

Specify the name of the folder containing the desired model geometry in the *FlightGear\data\Aircraft* directory.

**Destination port**

Specify your network flight dynamics model (fdm) port. For more information, see the Send net\_fdm Packet to FlightGear block reference page.

**Airport ID**

Specify the airport ID. The list of supported airports is available in FlightGear under Location.

**Runway ID**

Specify the runway ID.

**Initial altitude**

Specify the initial altitude of the aircraft, in feet.

**Initial heading**

Specify the initial heading of the aircraft, in degrees.

**Offset distance**

Specify the offset distance of the aircraft from the airport, in miles.

**Offset azimuth**

Specify the offset azimuth of the aircraft, in degrees.

For more information, see “Creating a FlightGear Run Script” on page 2-31.

**Examples**

See the asbh120 demo for an example of this block.

**See Also**

FlightGear Preconfigured 6DoF Animation

Pack net\_fdm Packet for FlightGear

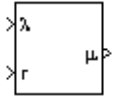
Send net\_fdm Packet to FlightGear

# Geocentric to Geodetic Latitude

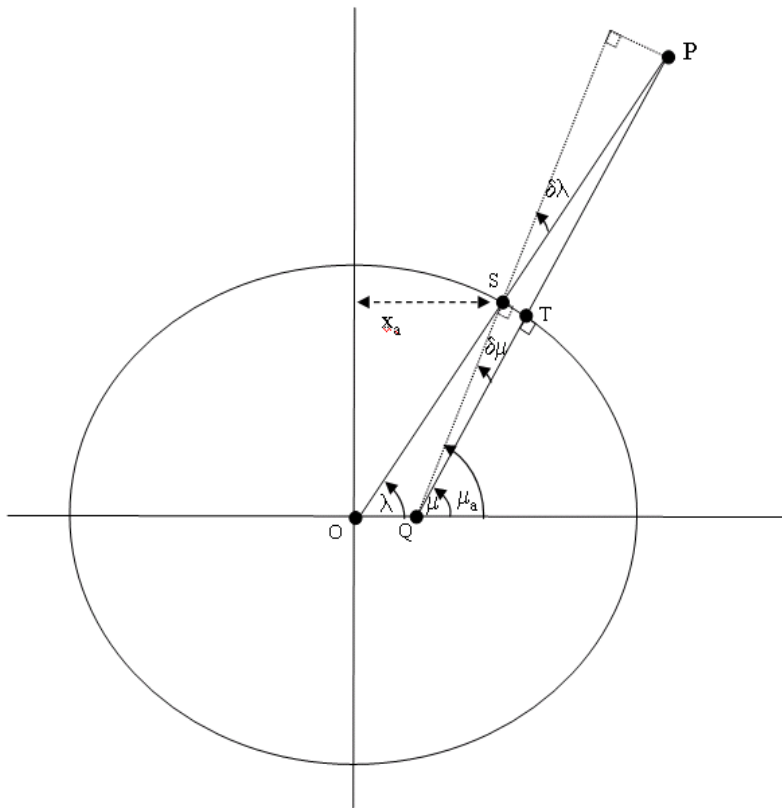
**Purpose** Convert geocentric latitude to geodetic latitude

**Library** Utilities/Axes Transformations

**Description**



The Geocentric to Geodetic Latitude block converts a geocentric latitude ( $\lambda$ ) into geodetic latitude ( $\mu$ ). There are a number of geometric relationships that are used to calculate the geodetic latitude in this non-iterative method. There are a number of angles and points involved in the calculation which are shown in following figure.



Given geocentric latitude ( $\lambda$ ) and the radius ( $r$ ) from the center of the planet ( $O$ ) to the center of gravity ( $P$ ), this non-iterative 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 S  $\mu_a$ , 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.

$$\mu_a = \text{atan}\left(\frac{\tan \lambda}{(1-f)^2}\right)$$

Using the relationship  $\tan \lambda = y_a/x_a$  and the two equations above, the resulting equation for  $\mu_a$  is obtained.

$$\mu_a = \text{atan}\left(\frac{\sqrt{R^2 - x_a^2}}{(1-f)x_a}\right)$$

The correct sign of  $\mu_a$  is determined by testing  $\lambda$  and if  $\lambda$  is less than zero  $\mu_a$  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.

$$r_a = \frac{x_a}{\cos \lambda}$$

# Geocentric to Geodetic Latitude

---

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 mean sea-level altitude ( $h$ ) is estimated.

$$h = l \cos \delta\lambda$$

The equation for the radius of curvature in the Meridian ( $\rho_a$ ) at  $\mu_a$  is

$$\rho_a = \frac{R(1-f)^2}{(1 - (2f-f^2) \sin^2 \mu_a)^{3/2}}$$

Using  $l$ ,  $\delta\lambda$ ,  $h$ , and  $\rho_a$ , the angular difference between geodetic latitude at S ( $\mu$ ) and geodetic latitude at P ( $\mu_a$ ) is defined as:

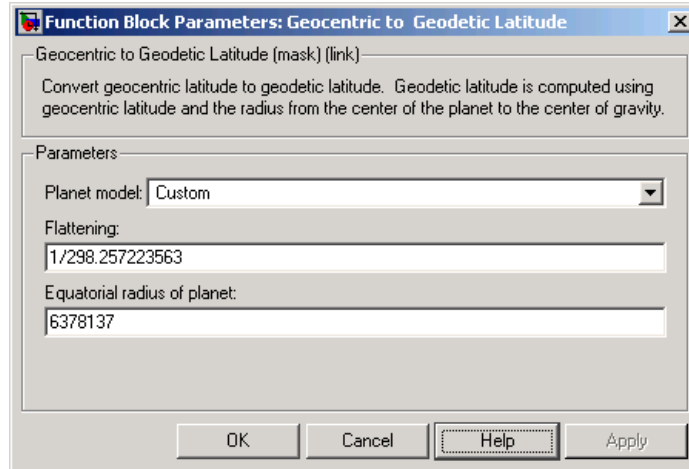
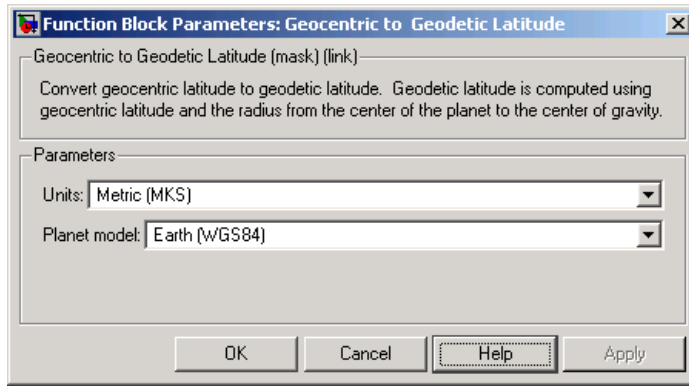
$$\delta\mu = \text{atan}\left(\frac{l \sin \delta\lambda}{\rho_a + h}\right)$$

Subtracting  $\delta\mu$  from  $\mu_a$  then gives  $\mu$ .

$$\mu = \mu_a - \delta\mu$$

# Geocentric to Geodetic Latitude

## Dialog Box



## 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).

# Geocentric to Geodetic Latitude

---

## **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. 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**

The first input is a scalar value of geocentric latitude, in degrees.

The second input is a scalar value of radius from center of the planet to the center of gravity.

The output is a scalar value of geodetic latitude, in degrees.

## **Assumptions and Limitations**

This implementation generates a geodetic latitude that lies between  $\pm 90$  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.navy.mil/oc2902w/geodesy/radiigeo.pdf>.

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 1992.

Edwards, C. H., and D. E. Penny, *Calculus and Analytical Geometry 2nd Edition*, Prentice-Hall, Englewood Cliffs, NJ, 1986.



**See Also**

[ECEF Position to LLA](#)

[Flat Earth to LLA](#)

[Geodetic to Geocentric Latitude](#)

[LLA to ECEF Position](#)

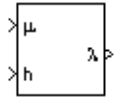
# Geodetic to Geocentric Latitude

---

**Purpose** Convert geodetic latitude to geocentric latitude

**Library** Utilities/Axes Transformations

**Description**



The Geodetic to Geocentric Latitude block converts a geodetic latitude ( $\mu$ ) into geocentric latitude ( $\lambda$ ). Geocentric latitude at the planet surface ( $\lambda_s$ ) is defined by flattening ( $f$ ), and geodetic latitude in the following relationship.

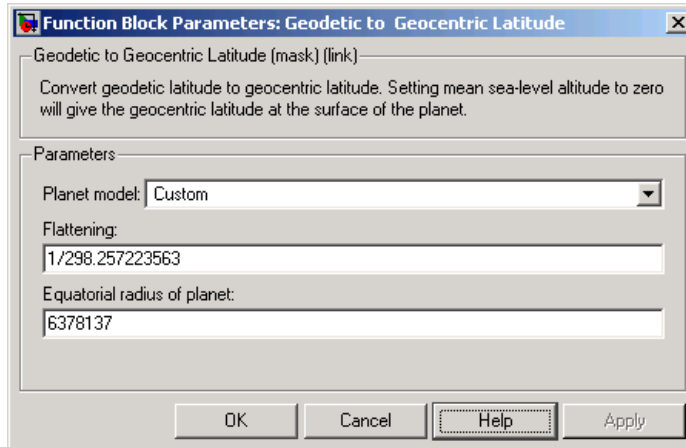
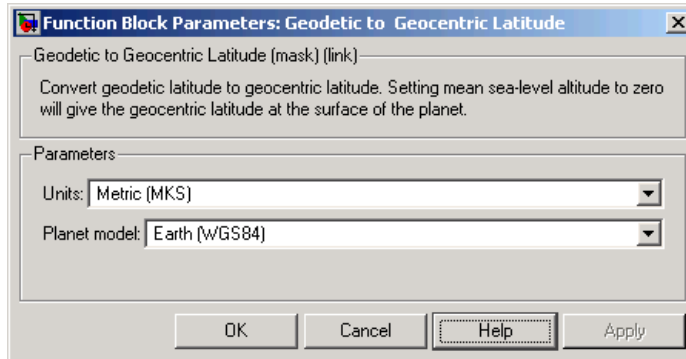
$$\lambda_s = \text{atan}((1-f)^2 \tan \mu)$$

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.

$$\lambda = \text{atan}\left(\frac{h \sin \mu + r_s \sin \lambda_s}{h \cos \mu + r_s \cos \lambda_s}\right)$$

# Geodetic to Geocentric Latitude

## Dialog Box



## Units

Specifies the parameter and output units:

<b>Units</b>	<b>Altitude</b>	<b>Equatorial Radius</b>
Metric (MKS)	Meters	Meters
English	Feet	Feet

This option is only available when **Planet model** is set to Earth (WGS84).

# Geodetic to Geocentric Latitude

---

## **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. 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**

The first input is a scalar value of geodetic latitude, in degrees.

The second input is a scalar value of mean sea-level altitude (MSL).

The output is a scalar value of geocentric latitude, in degrees.

## **Assumptions and Limitations**

This implementation generates a geocentric latitude that lies between  $\pm 90$  degrees.

## **References**

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 1992.

## **See Also**

ECEF Position to LLA

Flat Earth to LLA

Geocentric to Geodetic Latitude

LLA to ECEF Position

Radius at Geocentric Latitude

**Purpose** Transform horizontal wind into body-axes coordinates

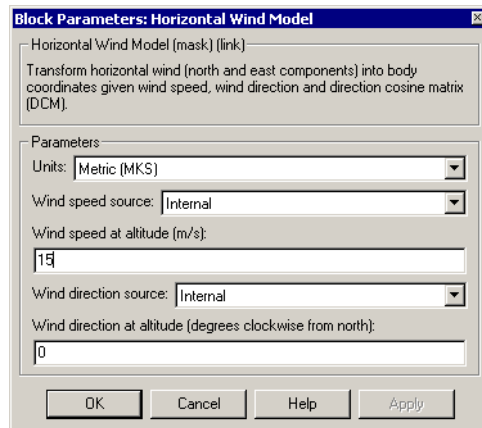
**Library** Environment/Wind

**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.

## Dialog Box



## 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

# Horizontal Wind Model

---

## 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

The first input is direction cosine matrix.

The second optional input is the wind speed in selected units.

The third optional input is the wind direction in degrees.

The output of the block is 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

Von Karman Wind Turbulence Model (Continuous)

Wind Shear Model

## Purpose

Calculate equivalent airspeed (EAS), calibrated airspeed (CAS), or true airspeed (TAS) from each other

## Library

Flight Parameters

## Description

> TAS (m/s)	
> a (m/s)	CAS (m/s)
> P <sub>o</sub> (Pa)	

The Ideal Airspeed Correction block calculates one of the following airspeeds: equivalent airspeed (EAS), calibrated airspeed (CAS), or true airspeed (TAS), from one of the other two airspeeds.

Three equations are used to implement the Ideal Airspeed Correction block. The first equation shows TAS as a function of EAS, relative pressure ratio at altitude ( $\delta$ ), and speed of sound at altitude ( $a$ ).

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

Using the compressible form of Bernoulli's equation and assuming isentropic conditions, the last two equations for EAS and CAS are derived.

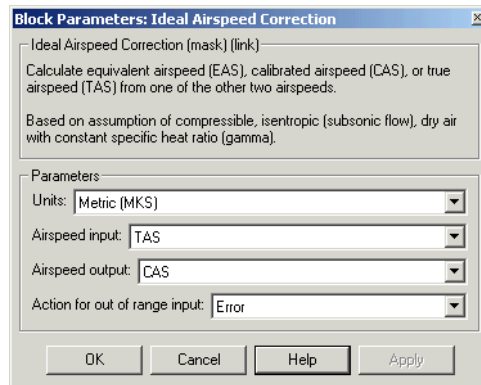
$$EAS = \sqrt{\frac{2\gamma P}{(\gamma-1)\rho_0} \left[ \left( \frac{q}{P} + 1 \right)^{(\gamma-1)/\gamma} - 1 \right]}$$

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

In order to generate a correction table and its approximate inverse, these two equations were solved for dynamic pressure ( $q$ ). Having values of  $q$  by a function of  $EAS$  and ambient pressure at altitude ( $P$ ) or by a function of  $CAS$ , allows the two equations to be solved using the other's solution for  $q$ , thus creating a solution for  $EAS$  that depends on  $P$  and  $CAS$  and a solution for  $CAS$  that depends on  $P$  and  $EAS$ .

# Ideal Airspeed Correction

## Dialog Box



### 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
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:

<b>Velocity Input</b>	<b>Velocity Output</b>
TAS	EAS (Equivalent airspeed) CAS (Calibrated airspeed)
EAS	TAS (True airspeed) CAS (Calibrated airspeed)
CAS	TAS (True airspeed) EAS (Equivalent airspeed)

## Action for out of range input

Specify if an out of range input (supersonic airspeeds) invokes a warning, an error, or no action.

## Inputs and Outputs

The first input is the selected airspeed in the selected units.

The second input is the speed of sound in the selected units.

The third input is the static pressure in the selected units.

The output of the block is the selected airspeed in the selected units.

## Assumptions and Limitations

This block assumes that the air flow is compressible, isentropic (subsonic flow), dry air with constant specific heat ratio,  $\gamma$ .

## 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.

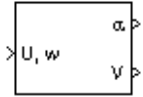
*Aeronautical Vestpocket Handbook*, United Technologies Pratt & Whitney, August, 1986.

# Incidence & Airspeed

**Purpose** Calculate incidence and air speed

**Library** Flight Parameters

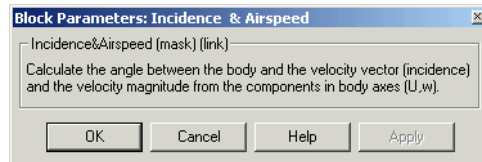
## Description



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 air speed from the velocity components in the body-fixed coordinate frame.

$$\alpha = \text{atan}\left(\frac{w}{u}\right)$$
$$V = \sqrt{u^2 + w^2}$$

## Dialog Box



## Inputs and Outputs

The input to the block is the two-element vector containing the velocity of the body resolved into the body-fixed coordinate frame.

The first output of the block is the incidence angle, in radians.

The second output is the air speed of the body.

## Examples

See the `aeroblk_guidance` model and the `aero_guidance_airframe` model for examples of this block.

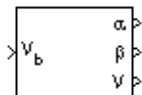
## See Also

Incidence, Sideslip & Airspeed

**Purpose** Calculate incidence, sideslip, and air speed

**Library** Flight Parameters

## Description



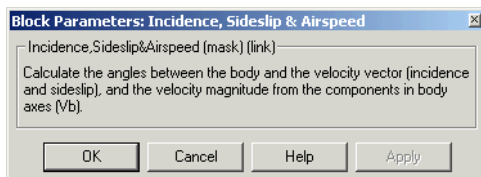
The Incidence, Sideslip & Airspeed block supports the 6DoF (Euler Angles) and 6DoF (Quaternion) models by calculating the angles between the velocity vector and the body, and also the total air speed from the velocity components in the body-fixed coordinate frame.

$$\alpha = \operatorname{atan}\left(\frac{w}{u}\right)$$

$$\beta = \operatorname{asin}\left(\frac{v}{V}\right)$$

$$V = \sqrt{u^2 + v^2 + w^2}$$

## Dialog Box



## Inputs and Outputs

The input to the block is the three-element vector containing the velocity of the body resolved into the body-fixed coordinate frame.

The first output of the block is the incidence angle in radians.

The second output of the block is the sideslip angle in radians.

The third output is the air speed of the body.

## Examples

See Airframe in the aeroblk\_HL20 model for an example of this block.

## See Also

Incidence & Airspeed

# Interpolate Matrix(x)

**Purpose** Return an interpolated matrix for given input  $x$

**Library** GNC/Controls

**Description** The Interpolate Matrix(x) block interpolates a one-dimensional array of matrices.



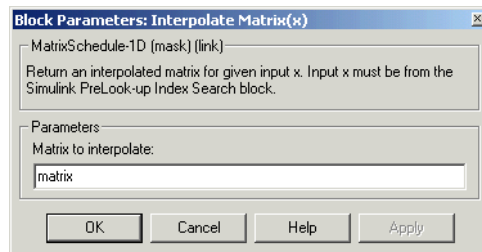
This one-dimensional case assumes a matrix  $M$  is defined at a discrete number of values of an independent variable  $\mathbf{x} = [x_1 \ x_2 \ x_3 \ \dots \ x_i \ x_{i+1} \ \dots \ x_n]$ . Then for  $x_i < x < x_{i+1}$ , the block output is given by

$$(1 - \lambda)M(x_i) + \lambda M(x_{i+1})$$

where the interpolation fraction is defined as

$$\lambda = (x - x_i) / (x_{i+1} - x_i)$$

## Dialog Box



## Matrix to interpolate

Matrix to be interpolated. It should 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;
```

## Inputs and Outputs

The first input is the first independent variable.

The output is the interpolated matrix.

**Assumptions and Limitations**

This block must be driven from the Simulink PreLook-up Index Search block.

**Examples**

See the following Aerospace Blockset blocks: 1D Controller [A(v),B(v),C(v),D(v)], 1D Observer Form [A(v),B(v),C(v),F(v),H(v)], and 1D Self-Conditioned [A(v),B(v),C(v),D(v)].

**See Also**

Interpolate Matrix(x,y)

Interpolate Matrix(x,y,z)

# Interpolate Matrix(x,y)

**Purpose** Return an interpolated matrix for given inputs x and y

**Library** GNC/Controls

## Description



The Interpolate Matrix(x,y) block interpolates a two-dimensional array of matrices.

This two-dimensional case assumes the matrix is defined as a function of two independent variables,  $\mathbf{x} = [x_1 x_2 x_3 \dots x_i x_{i+1} \dots x_n]$  and  $\mathbf{y} = [y_1 y_2 y_3 \dots y_j y_{j+1} \dots y_m]$ . 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

$$(1 - \lambda_y)[(1 - \lambda_x)M(x_i, y_j) + \lambda_x M(x_{i+1}, y_j)] + \lambda_y[(1 - \lambda_x)M(x_i, y_{j+1}) + \lambda_x M(x_{i+1}, y_{j+1})]$$

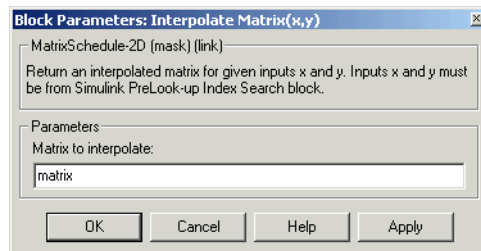
where the two interpolation fractions are denoted by

$$\lambda_x = (x - x_i)/(x_{i+1} - x_i)$$

and

$$\lambda_y = (y - y_j)/(y_{j+1} - y_j)$$

## Dialog Box



## Matrix to interpolate

Matrix to be interpolated. It should 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;
```

## Inputs and Outputs

The first input is the first independent variable.

The second input is the second independent variable.

The output is the interpolated matrix.

## Assumptions and Limitations

This block must be driven from the Simulink PreLookup Index Search block.

## Examples

See the following Aerospace Blockset blocks: 2D Controller [A(v),B(v),C(v),D(v)], 2D Observer Form [A(v),B(v),C(v),F(v),H(v)], and 2D Self-Conditioned [A(v),B(v),C(v),D(v)].

## See Also

Interpolate Matrix(x)

Interpolate Matrix(x,y,z)

# Interpolate Matrix(x,y,z)

## Purpose

Return an interpolated matrix for given inputs x, y, and z

## Library

GNC/Controls

## Description

```
>x  
>y Matrix(x,y,z) >  
>z
```

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

$$\mathbf{x} = [x_1 \ x_2 \ x_3 \ \dots \ x_i \ x_{i+1} \ \dots \ x_n], \mathbf{y} = [y_1 \ y_2 \ y_3 \ \dots \ y_j \ y_{j+1} \ \dots \ y_m]$$
$$\mathbf{z} = [z_1 \ z_2 \ z_3 \ \dots \ z_k \ z_{k+1} \ \dots \ z_p]$$

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

$$(1-\lambda_z) \{ (1-\lambda_y) [ (1-\lambda_x)M(x_i, y_j, z_k) + \lambda_x M(x_{i+1}, y_j, z_k) ] +$$
$$\lambda_y [ (1-\lambda_x)M(x_i, y_{j+1}, z_k) + \lambda_x M(x_{i+1}, y_{j+1}, z_k) ] \}$$
$$+ \lambda_z \{ (1-\lambda_y) [ (1-\lambda_x)M(x_i, y_j, z_{k+1}) + \lambda_x M(x_{i+1}, y_j, z_{k+1}) ] +$$
$$\lambda_y [ (1-\lambda_x)M(x_i, y_{j+1}, z_{k+1}) + \lambda_x M(x_{i+1}, y_{j+1}, z_{k+1}) ] \}$$

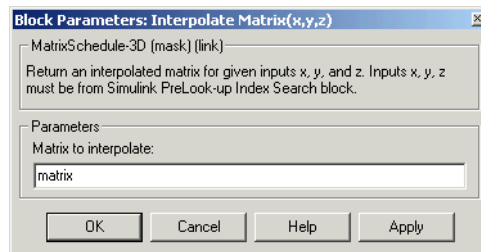
where the three interpolation fractions are denoted by

$$\lambda_x = (x - x_i) / (x_{i+1} - x_i)$$
$$\lambda_y = (y - y_j) / (y_{j+1} - y_j)$$
$$\lambda_z = (z - z_k) / (z_{k+1} - z_k)$$

In the three-dimensional case, the interpolation is carried out first on x, then y, and finally z.



## Dialog Box



## Matrix to interpolate

Matrix to be interpolated. It 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;

## Inputs and Outputs

The first input is the first independent variable.

The second input is the second independent variable.

The third input is the third independent variable.

The output is the interpolated matrix.

## Assumptions and Limitations

This block must be driven from the Simulink PreLookup Index Search block.

# Interpolate Matrix( $\mathbf{x}, \mathbf{y}, \mathbf{z}$ )

---

## Examples

See the following Aerospace Blockset blocks: 3D Controller [A(v),B(v),C(v),D(v)], 3D Observer Form [A(v),B(v),C(v),F(v),H(v)], and 3D Self-Conditioned [A(v),B(v),C(v),D(v)].

## See Also

Interpolate Matrix(x)

Interpolate Matrix(x,y)

**Purpose** Compute the inverse of 3-by-3 matrix using determinant formula

**Library** Utilities/Math Operations

**Description** The Invert 3x3 Matrix block computes the inverse of 3-by-3 matrix using determinant formula.

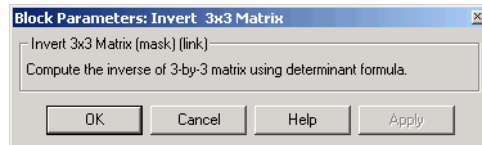


The inverse of the matrix is calculated by

$$\text{inv}(A) = \frac{\text{adj}(A)}{\text{det}(A)}$$

If the  $\text{det}(A) = 0$ , an error is thrown and the simulation will stop.

**Dialog Box**



**Inputs and** The input is a 3-by-3 matrix.

**Outputs**

The output of the block is 3-by-3 matrix inverse of input matrix.

**See Also**

Adjoint of 3x3 Matrix

Create 3x3 Matrix

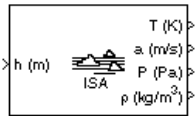
Determinant of 3x3 Matrix

# ISA Atmosphere Model

**Purpose** Implement the International Standard Atmosphere (ISA)

**Library** Environment/Atmosphere

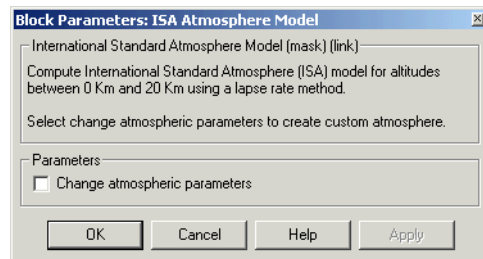
## Description



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.

## Dialog Box



## Change atmospheric parameters

Select to customize various atmospheric parameters to be different from the ISA values.

## Inputs and Outputs

The input is geopotential height.

The four outputs are temperature, speed of sound, air pressure, and 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.

## References

[1] U.S. Standard Atmosphere, 1976, U.S. Government Printing Office, Washington, D.C.

## See Also

COESA Atmosphere Model, Lapse Rate Model

# Julian Epoch to Besselian Epoch

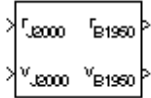
## Purpose

Transform position and velocity components from the Standard Julian Epoch (J2000) to the 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 ( $r_{J2000}$ ), and Julian Epoch velocity ( $v_{J2000}$ ) into Besselian Epoch position ( $r_{B1950}$ ), and Besselian Epoch velocity ( $v_{B1950}$ ). The transformation is calculated using:

$$\begin{bmatrix} r_{B1950} \\ v_{B1950} \end{bmatrix} = \begin{bmatrix} \underline{M}_{rr} & \underline{M}_{vr} \\ \underline{M}_{rv} & \underline{M}_{vv} \end{bmatrix}^T \begin{bmatrix} r_{J2000} \\ v_{J2000} \end{bmatrix}$$

where ( $\underline{M}_{rr}$ ,  $\underline{M}_{vr}$ ,  $\underline{M}_{rv}$ ,  $\underline{M}_{vv}$ ) are defined as:

$$\underline{M}_{rr} = \begin{bmatrix} 0.9999256782 & -0.0111820611 & -0.0048579477 \\ 0.0111820610 & 0.9999374784 & -0.0000271765 \\ 0.0048579479 & -0.0000271474 & 0.9999881997 \end{bmatrix}$$

$$\underline{M}_{vr} = \begin{bmatrix} 0.00000242395018 & -0.00000002710663 & -0.00000001177656 \\ 0.00000002710663 & 0.00000242397878 & -0.00000000006587 \\ 0.00000001177656 & -0.00000000006582 & 0.00000242410173 \end{bmatrix}$$

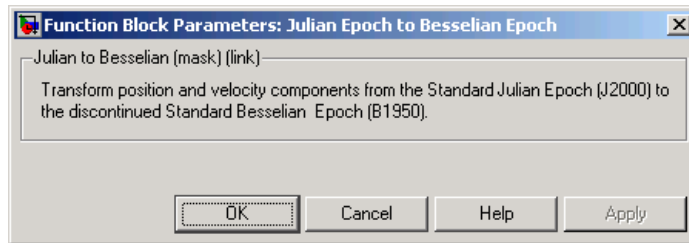
$$\underline{M}_{rv} = \begin{bmatrix} -0.000551 & -0.238565 & 0.435739 \\ 0.238514 & -0.002667 & -0.008541 \\ -0.435623 & 0.012254 & 0.002117 \end{bmatrix}$$

$$\underline{M}_{vv} = \begin{bmatrix} 0.99994704 & -0.01118251 & -0.00485767 \\ 0.01118251 & 0.99995883 & -0.00002718 \\ 0.00485767 & -0.00002714 & 1.00000956 \end{bmatrix}$$

# Julian Epoch to Besselian Epoch

---

## Dialog Box



## Inputs and Outputs

The first input is a 3-by-1 vector containing the position in Standard Julian Epoch (J2000).

The second input is a 3-by-1 vector containing the velocity in Standard Julian Epoch (J2000).

The first output is a 3-by-1 vector containing the position in Standard Besselian Epoch (B1950).

The second output is a 3-by-1 vector containing the velocity in Standard Besselian Epoch (B1950).

## References

“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.

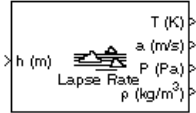
## See Also

Besselian Epoch to Julian Epoch

**Purpose** 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

$$T = T_o - Lh$$

$$P = P_o \cdot \left(\frac{T}{T_o}\right)^{\frac{g}{LR}}$$

$$\rho = \rho_o \cdot \left(\frac{T}{T_o}\right)^{\frac{g}{LR} - 1}$$

$$a = \sqrt{\gamma RT}$$

The following equations define the tropopause (lower stratosphere)

$$T = 216.7^\circ K$$

$$P = P_o \cdot \left(\frac{T}{T_o}\right)^{\frac{g}{LR} - 1} \cdot e^{\frac{g}{RT}(11000 - h)}$$

$$\rho = \rho_o \cdot \left(\frac{T}{T_o}\right)^{\frac{g}{LR}} \cdot e^{\frac{g}{RT}(11000 - h)}$$

$$a = \sqrt{\gamma RT}$$

# Lapse Rate Model

---

where:

$T_0$	Absolute temperature at mean sea level in degrees Kelvin
$\rho_0$	Air density at mean sea level in $\text{kg/m}^3$
$P_0$	Static pressure at mean sea level in $\text{N/m}^2$
$h$	Altitude in m
$T$	Absolute temperature at altitude $h$ in degrees Kelvin
$\rho$	Air density at altitude $h$ in $\text{kg/m}^3$
$P$	Static pressure at altitude $h$ in $\text{N/m}^2$
$a$	Speed of sound at altitude $h$ in $\text{m/s}^2$
$L$	Lapse rate in degrees Kelvin/m
$R$	Characteristic gas constant $\text{J/kg-degrees Kelvin}$
$\gamma$	Specific heat ratio
$g$	Acceleration due to gravity in $\text{m/s}^2$

The Lapse Rate Model block icon displays the input and output metric units.



## Dialog Box

**Block Parameters: Lapse Rate Model** [X]

International Standard Atmosphere Model (mask) (link)

Compute International Standard Atmosphere (ISA) model for altitudes between 0 Km and 20 Km using a lapse rate method.

Select change atmospheric parameters to create custom atmosphere.

Parameters

Change atmospheric parameters

Acceleration due to gravity (m/s<sup>2</sup>):  
9.80665

Ratio of specific heats:  
1.4

Characteristic gas constant (J/Kg/K):  
287.0531

Lapse rate (K/m):  
0.0065

Height of troposphere (m):  
11000

Height of tropopause (m):  
20000

Air density at mean sea level (Kg/m<sup>3</sup>):  
1.225

Ambient pressure at mean sea level (N/m<sup>2</sup>):  
101325

Ambient temperature at mean sea level (K):  
288.15

OK Cancel Help Apply

### 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 ( $\gamma$ ).

### Characteristic gas constant

Specify the characteristic gas constant (R).

# Lapse Rate Model

---

## **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 ( $\rho_0$ ).

## **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 ( $T_0$ ).

## **Inputs and Outputs**

The input is geopotential height.

The four outputs are temperature, speed of sound, air pressure, and 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.

## **References**

[1] U.S. Standard Atmosphere, 1976, U.S. Government Printing Office, Washington, D.C.

## **See Also**

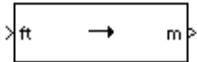
COESA Atmosphere Model

ISA Atmosphere Model

**Purpose** Convert from length units to desired length units

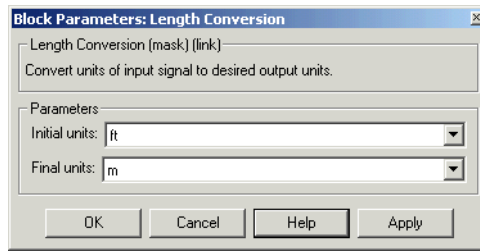
**Library** Utilities/Unit Conversions

**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 units** and the **Final units** lists.

## Dialog Box



### Initial units

Specifies the input units.

### Final units

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

The input is length in initial length units.

# Length Conversion

---

The output is 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

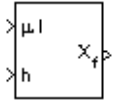
## Purpose

Calculate Earth-centered Earth-fixed (ECEF) position from geodetic latitude, longitude, and altitude above mean sea-level (MSL)

## Library

Utilities/Axes Transformations

## Description



The LLA to ECEF Position block converts geodetic latitude ( $\underline{\mu}$ ), longitude ( $\underline{l}$ ), and MSL altitude ( $\underline{h}$ ) into a 3-by-1 vector of ECEF position ( $\underline{p}$ ). The ECEF position is calculated from geocentric latitude at mean sea-level ( $\lambda_s$ ) and longitude using:

$$\underline{p} = \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} = \begin{bmatrix} r_s \cos \lambda_s \cos \iota + h \cos \mu \cos \iota \\ r_s \cos \lambda_s \sin \iota + h \cos \mu \sin \iota \\ r_s \sin \lambda_s + h \sin \mu \end{bmatrix}$$

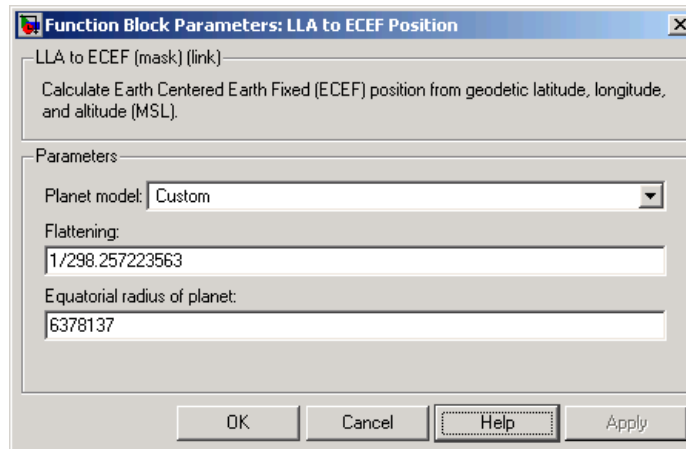
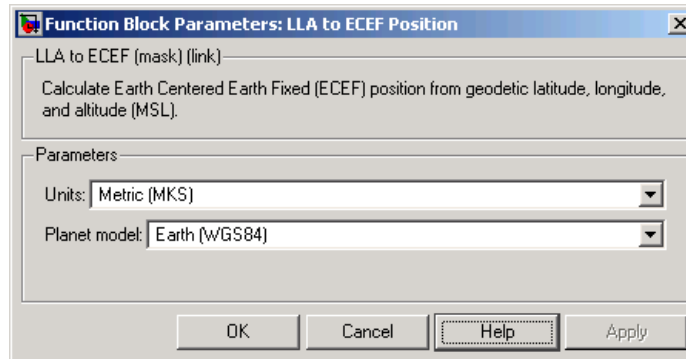
where geocentric latitude at mean sea-level and the radius at a surface point ( $r_s$ ) are defined by flattening ( $f$ ), and equatorial radius ( $R$ ) in the following relationships.

$$\lambda_s = \text{atan}((1-f)^2 \tan \mu)$$

$$r_s = \sqrt{\frac{R^2}{1 + [1/(1-f)^2 - 1] \sin^2 \lambda_s}}$$

# LLA to ECEF Position

## Dialog Box



## Units

Specifies the parameter and output units:

<b>Units</b>	<b>Altitude</b>	<b>Equatorial Radius</b>	<b>Position</b>
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

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**

The first input is a 2-by-1 vector containing geodetic latitude and longitude, in degrees.

The second input is a scalar value of altitude above mean sea-level (MSL).

The output is a 3-by-1 vector containing the position in ECEF frame, in same units as altitude.

## **Assumptions and Limitations**

The planet is assumed to be ellipsoidal by setting flattening to 0.0 a spherical planet can be achieved.

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 hand system.

## **References**

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 1992.

Zipfel, P. H., *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA Education Series, Reston, VA, 2000.

“Atmospheric and Space Flight Vehicle Coordinate Systems,” ANSI/AIAA R-004-1992.

## **See Also**

Direction Cosine Matrix ECEF to NED

# LLA to ECEF Position

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Direction Cosine Matrix ECEF to NED to Latitude and Longitude

ECEF Position to LLA

Flat Earth to LLA

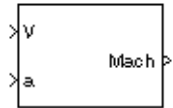
Radius at Geocentric Latitude



**Purpose** Compute Mach number using velocity and speed of sound

**Library** Flight Parameters

**Description** The Mach Number block computes Mach number.

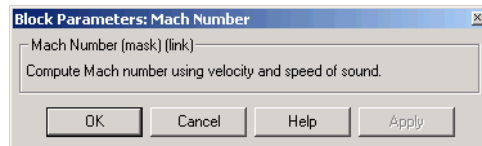


Mach number is defined as

$$Mach = \frac{\sqrt{V \cdot V}}{a}$$

where  $a$  is speed of sound and  $V$  is velocity vector.

**Dialog Box**



**Inputs and** The first input is the velocity vector.

**Outputs**

The second input is the speed of sound.

The output of the block is 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

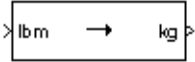
# Mass Conversion

---

**Purpose** Convert from mass units to desired mass units

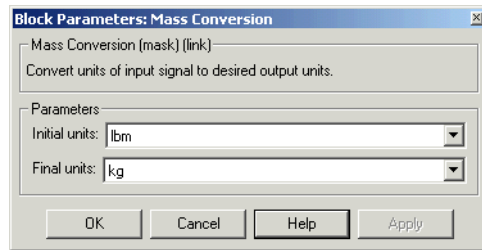
**Library** Utilities/Unit Conversions

**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 units** and the **Final units** lists.

## Dialog Box



### Initial units

Specifies the input units.

### Final units

Specifies the output units.

The following conversion units are available:

lbm	Pound mass
kg	Kilograms
slug	Slugs

## Inputs and Outputs

The input is the mass in initial mass units.

The output is 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

# Moments About CG Due to Forces

---

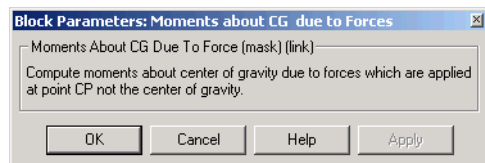
**Purpose** Compute moments about center of gravity due to forces that are applied at point CP, not the center of gravity

**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 the center of gravity.



## Dialog Box



## Inputs and Outputs

The first input is the forces applied at point CP.

The second input is the center of gravity.

The third input is the application point of forces.

The output of the block is moments at the center of gravity in  $x$ -axes,  $y$ -axes and  $z$ -axes.

## See Also

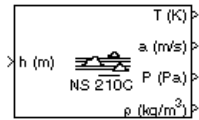
Aerodynamic Forces and Moments

Estimate Center of Gravity

**Purpose** Implement the 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 262000 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.

## Dialog Box

The dialog box is titled "Block Parameters: Non-Standard Day 210C". It contains the following text and controls:

Atmosphere Model (mask) (link)

Calculate various atmosphere models including 1976 COESA-extended U.S. Standard Atmosphere, MIL-HDBK-310, and MIL-STD-210C. Given geopotential altitude, calculate absolute temperature, pressure and density using standard interpolation formulas.

The COESA model extrapolates temperature linearly and pressure/density logarithmically beyond the range

0 <= altitude <= 84952 meters (geopotential)

The MIL specifications are not extrapolated beyond their defined altitudes which are typically

0 <= altitude <= 80000 meters (geometric)

Depending on the given information either density or pressure is calculated using a perfect gas relationship.

The unit system selected applies to both input and outputs.

Parameters

Units: Metric (MKS)

Specification: MIL-STD-210C

Atmospheric model type: Profile

Extreme parameter: High temperature

Frequency of occurrence: 1%

Altitude of extreme value: 5 km (16404 ft)

Action for out of range input: Warning

Buttons: OK, Cancel, Help, Apply

# Non-Standard Day 210C

---

## Units

Specifies the input and output units:

<b>Units</b>	<b>Height</b>	<b>Temperature</b>	<b>Speed of Sound</b>	<b>Air Pressure</b>	<b>Air Density</b>
Metric (MKS)	Meters	Degrees 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 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

## 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

Low temperature

High density

Low density

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%

5%

This option is available only when Envelope is selected for **Atmospheric model type**.

10%

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)

# Non-Standard Day 210C

---

## Action for out of range input

Specify if out of range input invokes a warning, error, or no action.

## Inputs and Outputs

The input is geopotential height.

The four outputs are temperature, speed of sound, air pressure, and air density.

## Assumptions and Limitations

All values are held below the geometric altitude of 0 m (0 feet) and above the geometric altitude of 80000 meters (approximately 262000 feet). The envelope atmospheric model has a few exceptions where values are held below the geometric altitude of 1 kilometer (approximately 3281 feet) and above the geometric altitude of 30000 meters (approximately 98425 feet). These exceptions are due to lack of data in MIL-STD-210C for these conditions.

In general, temperature values are extrapolated linearly and density values are extrapolated logarithmically. Pressure and speed of sound are calculated using a perfect gas relationship. The envelope atmospheric model has a few exceptions where the extreme value is linearly interpolated and it is the only value provided as an output. 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 are due to lack of data in MIL-STD-210C for these conditions.

A limitation is that climatic data for the region south of 60°S latitude is excluded from consideration in MIL-STD-210C.

## References

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

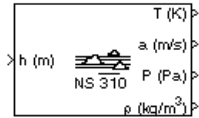
Non-Standard Day 310



**Purpose** Implement the 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 262000 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.

## Dialog Box

**Block Parameters: Non-Standard Day 310**

Atmosphere Model (mask) (link)

Calculate various atmosphere models including 1976 COESA-extended U.S. Standard Atmosphere, MIL-HDBK-310, and MIL-STD-210C. Given geopotential altitude, calculate absolute temperature, pressure and density using standard interpolation formulas.

The COESA model extrapolates temperature linearly and pressure/density logarithmically beyond the range

0 <= altitude <= 84852 meters (geopotential)

The MIL specifications are not extrapolated beyond their defined altitudes which are typically

0 <= altitude <= 80000 meters (geometric)

Depending on the given information either density or pressure is calculated using a perfect gas relationship.

The unit system selected applies to both input and outputs.

Parameters

Units: Metric (MKS)

Specification: MIL-HDBK-310

Atmospheric model type: Profile

Extreme parameter: High temperature

Frequency of occurrence: 1%

Altitude of extreme value: 5 km (16404 ft)

Action for out of range input: Warning

OK Cancel Help Apply

# Non-Standard Day 310

---

## Units

Specifies the input and output units:

<b>Units</b>	<b>Height</b>	<b>Temperature</b>	<b>Speed of Sound</b>	<b>Air Pressure</b>	<b>Air Density</b>
Metric (MKS)	Meters	Degrees 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 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

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

Low temperature

High density

Low density

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%

5%      This option is available only when Envelope is selected for **Atmospheric model type**.

10%

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)

# Non-Standard Day 310

---

## Action for out of range input

Specify if out of range input invokes a warning, error, or no action.

## Inputs and Outputs

The input is geopotential height.

The four outputs are temperature, speed of sound, air pressure, and air density.

## Assumptions and Limitations

All values are held below the geometric altitude of 0 m (0 feet) and above the geometric altitude of 80000 meters (approximately 262000 feet). The envelope atmospheric model has a few exceptions where values are held below the geometric altitude of 1 kilometer (approximately 3281 feet) and above the geometric altitude of 30000 meters (approximately 98425 feet). These exceptions are due to lack of data in MIL-HDBK-310 for these conditions.

In general, temperature values are extrapolated linearly and density values are extrapolated logarithmically. Pressure and speed of sound are calculated using a perfect gas relationship. The envelope atmospheric model has a few exceptions where the extreme value is linearly interpolated and it is the only value provided as an output. 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 are due to lack of data in MIL-HDBK-310 for these conditions.

A limitation is that climatic data for the region south of 60°S latitude is excluded from consideration in MIL-HDBK-310.

## References

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

# Pack net\_fdm Packet for FlightGear

**Purpose** Generate net\_fdm packet for FlightGear

**Library** Animation/Flight Simulator Interfaces

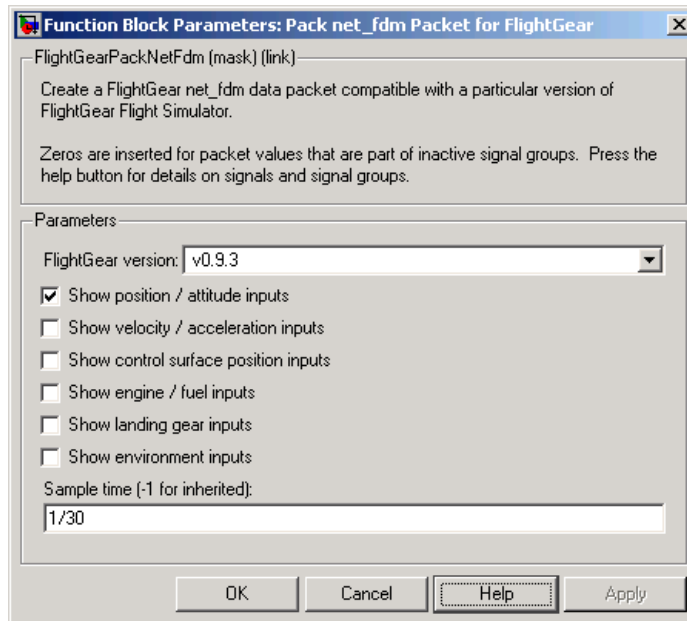
## Description



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. All the signals supported by the FlightGear net\_fdm data packet for FlightGear versions 0.9.3 and 0.9.8/0.9.8a are supported by this block. The signals are arranged into six groups. Any group can be turned on or off. Zeros are inserted for packet values that are part of inactive signal groups.

See “Inputs and Outputs” on page 4-302 for details on signals and signal groups.

## Dialog Box



### FlightGear version

Select your FlightGear software version: v0.9.3 or v0.9.8.

# Pack net\_fdm Packet for FlightGear

---

## Show position/altitude inputs

Select this check box to include the position and altitude inputs (signal group 1) into the FlightGear net\_fdm data packet.

## Show velocity/acceleration inputs

Select this check box to include the velocity and acceleration inputs (signal group 2) into the FlightGear net\_fdm data packet.

## Show control surface position inputs

Select this check box to include the control surface position inputs (signal group 3) into the FlightGear net\_fdm data packet.

## Show engine/fuel inputs

Select this check box to include the engine and fuel inputs (signal group 4) into the FlightGear net\_fdm data packet.

## Show landing gear inputs

Select this check box to include the landing gear inputs (signal group 5) into the FlightGear net\_fdm data packet.

## Show environment inputs

Select this check box to include the environment inputs (signal group 6) into the FlightGear net\_fdm data packet.

## Sample time

Specify the sample time (-1 for inherited).

## Inputs and Outputs

The following table lists all the input signals supported for FlightGear Version 0.9.3:

Name	Units	Type	Width	Description
<b>Signal Group 1: ShowPositionAttitudeInputs</b>				
longitude	rad	double	1	Geodetic longitude
latitude	rad	double	1	Geodetic attitude
altitude	m	double	1	Altitude above sea level
phi	rad	single	1	Roll
theta	rad	single	1	Pitch

# Pack net\_fdm Packet for FlightGear

Name	Units	Type	Width	Description
psi	rad	single	1	Yaw or true heading
<b>Signal Group 2: ShowVelocityAccelerationInputs</b>				
phidot	rad/sec	single	1	Roll rate
thetadot	rad/sec	single	1	Pitch rate
psidot	rad/sec	single	1	Yaw rate
vcas	kt	single	1	Calibrated airspeed
climb_rate	ft/sec	single	1	Climb rate
v_north	ft/sec	single	1	North velocity in local/body frame
v_east	ft/sec	single	1	East velocity in local/body frame
v_down	ft/sec	single	1	Down/vertical velocity in local/body frame
v_wind_body_north	ft/sec	single	1	Body north velocity relative to local airmass
v_wind_body_east	ft/sec	single	1	Body east velocity relative to local airmass
v_wind_body_down	ft/sec	single	1	Body down/vertical velocity relative to local airmass
stall_warning	-	single	1	0.0-1.0, indicating the amount of stall
A_X_pilot	ft/sec <sup>2</sup>	single	1	X acceleration in body frame
A_Y_pilot	ft/sec <sup>2</sup>	single	1	Y acceleration in body frame
A_Z_pilot	ft/sec <sup>2</sup>	single	1	Z acceleration in body frame
<b>Signal Group 3: ShowControlSurfacePositionInputs</b>				

# Pack net\_fdm Packet for FlightGear

---

<b>Name</b>	<b>Units</b>	<b>Type</b>	<b>Width</b>	<b>Description</b>
elevator	geometry-specific units	single	1	Elevator position
flaps	geometry-specific units	single	1	Flaps position
left_aileron	geometry-specific units	single	1	Left aileron position
right_aileron	geometry-specific units	single	1	Right aileron position
rudder	geometry-specific units	single	1	Rudder position
speedbrake	geometry-specific units	single	1	Speed brake position
spoilers	geometry-specific units	single	1	Spoilers position

## **Signal Group 4: ShowEngineFuelInputs**

num_engines	-	int32	1	Number of valid engines
eng_state	enum	int32	4	Engine state (0=off, 1=cranking, 2=running)
rpm	rev/min	single	4	Engine RPM
fuel_flow	gal/hr	single	4	Fuel flow
EGT	degF	single	4	Exhaust gas temp
oil_temp	degF	single	4	Oil temp
oil_px	lbf/in2	single	4	Oil pressure
num_tanks	-	int32	1	Max number of fuel tanks
fuel_quantity	-	single	4	Amount of fuel in tanks (0-1 fraction)

## **Signal Group 5: ShowLandingGearInputs**



# Pack net\_fdm Packet for FlightGear

<b>Name</b>	<b>Units</b>	<b>Type</b>	<b>Width</b>	<b>Description</b>
num_wheels	-	int32	1	Maximum number of wheels
wow	-	boolean	3	Weight on wheels signal (1=wheel is on ground)
gear_pos	-	single	3	Landing gear position (0-1, indicating amount deployed)
gear_steer	-	single	3	Landing gear steering angle
gear_compression	-	single	3	Landing gear compression

## Signal Group 6: ShowEnvironmentInputs

agl	m	single	1	Above ground level
cur_time	sec	int32	1	Current unix time
warp	sec	int32	1	Offset in seconds to unix time
visibility	m	single	1	Visibility in meters (for visual effects)

The following table lists all the input signals supported for FlightGear Versions 0.9.8/0.9.8a:

<b>Name</b>	<b>Units</b>	<b>Type</b>	<b>Width</b>	<b>Description</b>
<b>Signal Group 1: ShowPositionAttitudeInputs</b>				
longitude	rad	double	1	Geodetic longitude
latitude	rad	double	1	Geodetic attitude
altitude	m	double	1	Altitude above sea level
phi	rad	single	1	Roll
theta	rad	single	1	Pitch

# Pack net\_fdm Packet for FlightGear

---

Name	Units	Type	Width	Description
psi	rad	single	1	Yaw or true heading
<b>Signal Group 2: ShowVelocityAccelerationInputs</b>				
alpha	rad	single	1	Angle of attack
beta	rad	single	1	Side slip angle
phidot	rad/sec	single	1	Roll rate
thetadot	rad/sec	single	1	Pitch rate
psidot	rad/sec	single	1	Yaw rate
vcas	kt	single	1	Calibrated airspeed
climb_rate	ft/sec	single	1	Climb rate
v_north	ft/sec	single	1	North velocity in local/body frame
v_east	ft/sec	single	1	East velocity in local/body frame
v_down	ft/sec	single	1	Down/vertical velocity in local/body frame
v_wind_body_north	ft/sec	single	1	Body north velocity relative to local airmass
v_wind_body_east	ft/sec	single	1	Body east velocity relative to local airmass
v_wind_body_down	ft/sec	single	1	Body down/vertical velocity relative to local airmass
A_X_pilot	ft/sec <sup>2</sup>	single	1	X acceleration in body frame
A_Y_pilot	ft/sec <sup>2</sup>	single	1	Y acceleration in body frame
A_Z_pilot	ft/sec <sup>2</sup>	single	1	Z acceleration in body frame

# Pack net\_fdm Packet for FlightGear

Name	Units	Type	Width	Description
stall_warning	-	single	1	0.0-1.0, indicating the amount of stall
slip_deg	deg	single	1	Slip ball deflection
<b>Signal Group 3: ShowControlSurfacePositionInputs</b>				
elevator	geometry-specific units	single	1	Elevator position
elevator_trim_tab	geometry-specific units	single	1	Elevator trim position
left_flap	geometry-specific units	single	1	Left flap position
right_flap	geometry-specific units	single	1	Right flap position
left_aileron	geometry-specific units	single	1	Left aileron position
right_aileron	geometry-specific units	single	1	Right aileron position
rudder	geometry-specific units	single	1	Rudder position
nose_wheel	geometry-specific units	single	1	Nose wheel position
speedbrake	geometry-specific units	single	1	Speed brake position
spoilers	geometry-specific units	single	1	Spoilers position
<b>Signal Group 4: ShowEngineFuelInputs</b>				
num_engines	-	int32	1	Number of valid engines
eng_state	enum	int32	4	Engine state (0=off, 1=cranking, 2=running)

# Pack net\_fdm Packet for FlightGear

---

<b>Name</b>	<b>Units</b>	<b>Type</b>	<b>Width</b>	<b>Description</b>
rpm	rev/min	single	4	Engine RPM
fuel_flow	gal/hr	single	4	Fuel flow
EGT	degF	single	4	Exhaust gas temp
cht	degF	single	4	Cylinder head temperature
mp_osi	psi	single	4	Manifold pressure
tit	degF	single	4	Turbine inlet temperature
oil_temp	degF	single	4	Oil temp
oil_px	lbf/in2	single	4	Oil pressure
num_tanks	-	int32	1	Max number of fuel tanks
fuel_quantity	-	single	4	Amount of fuel in tanks (0-1 fraction)
<b>Signal Group 5: ShowLandingGearInputs</b>				
num_wheels	-	int32	1	Maximum number of wheels
wow	-	boolean	3	Weight on wheels signal (1=wheel is on ground)
gear_pos	-	single	3	Landing gear position (0-1, indicating amount deployed)
gear_steer	-	single	3	Landing gear steering angle
gear_compression	-	single	3	Landing gear compression
<b>Signal Group 6: ShowEnvironmentInputs</b>				
agl	m	single	1	Above ground level

# Pack net\_fdm Packet for FlightGear

---

<b>Name</b>	<b>Units</b>	<b>Type</b>	<b>Width</b>	<b>Description</b>
cur_time	sec	int32	1	Current unix time
warp	sec	int32	1	Offset in seconds to unix time
visibility	m	single	1	Visibility in meters (for visual effects)

The output signal is the FlightGear net\_fdm data packet.

## **Examples**

See the asbh120 demo for an example of this block.

## **See Also**

[FlightGear Preconfigured 6DoF Animation](#)

[Generate Run Script](#)

[Send net\\_fdm Packet to FlightGear](#)

# Pilot Joystick

**Purpose** Use joystick interface for Windows platform

**Library** Animation/Animation Support Utilities

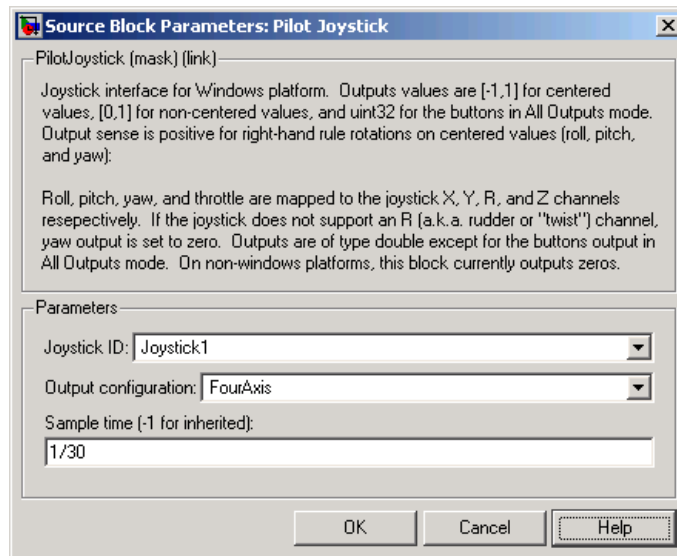
## Description



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 it to output all channels by setting the **Output configuration** parameter to AllOutputs.

## Dialog Box



### Joystick ID

Specify the joystick ID: Joystick 1, Joystick 2, or None.

### Output configuration

Specify the output configuration: FourAxis or AllOutputs.

### 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)
  - port1: [-1, 1] => [left,right] roll command
  - port2: [-1, 1] => [forward/down, back/up] pitch command
  - port3: [-1, 1] => [left, right] yaw command
  - port4: [ 0, 1] => [min, max] throttle command
- All Outputs mode (values are double precision except for buttons)
  - port1:1 - X: [-1, 1] => [left,right] roll command
  - port1:2 - Y: [-1, 1] => [forward/down, back/up] pitch command
  - port1:3 - Z: [ 0, 1] => [min, max] throttle command
  - port1:4 - R: [-1, 1] => [left, right] yaw command
  - port1:5 - U: [0, 1] => [min,max] U channel value
  - port1:6 - V: [0, 1] => [min,max] V channel value
  - port2 - buttons: uint32 flagword containing up to 32 button states. Bit 0 is button 1, etc.
  - port3 - 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 non-centered 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

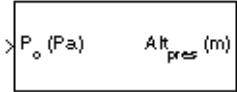
Simulation Pace

# Pressure Altitude

**Purpose** Calculate pressure altitude based on ambient pressure

**Library** Environment/Atmosphere

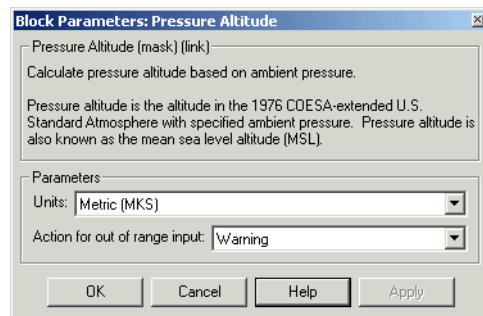
**Description** The Pressure Altitude block computes the pressure altitude based on ambient pressure. Pressure altitude is the altitude in the 1976 Committee on the Extension of the Standard Atmosphere (COESA) United States with specified ambient pressure.



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.

## Dialog Box



## 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

The input is the static pressure.

The output is 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.

**References**

U.S. Standard Atmosphere, 1976, U.S. Government Printing Office, Washington, D.C.

**See Also**

COESA Atmosphere Model

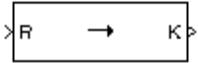
# Pressure Conversion

---

**Purpose** Convert from pressure units to desired pressure units

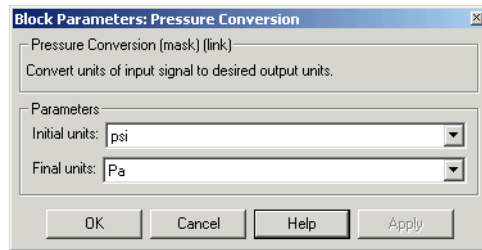
**Library** Utilities/Unit Conversions

**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 units** and the **Final units** lists.

## Dialog Box



### Initial units

Specifies the input units.

### Final units

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

The input is the pressure in initial pressure units.

The output is 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

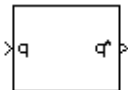
Velocity Conversion

# Quaternion Conjugate

**Purpose** Calculate the conjugate of a quaternion

**Library** Utilities/MathOperations

**Description** The Quaternion Conjugate block calculates the conjugate for a given quaternion.



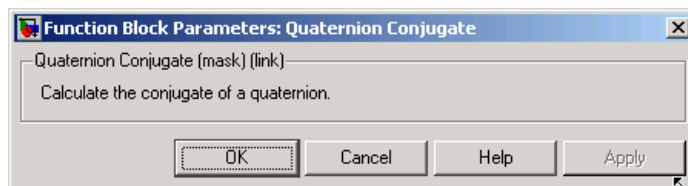
The quaternion has the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3$$

The quaternion conjugate has the form of

$$q' = q_0 - \mathbf{i}q_1 - \mathbf{j}q_2 - \mathbf{k}q_3$$

## Dialog Box



## Inputs and Outputs

The input is a quaternion or vector of quaternions in the form of  $[q_0, r_0, \dots, q_1, r_1, \dots, q_2, r_2, \dots, q_3, r_3, \dots]$ .

The output is a quaternion conjugate or vector of quaternion conjugates in the form of  $[q_0', r_0', \dots, q_1', r_1', \dots, q_2', r_2', \dots, q_3', r_3', \dots]$ .

## See Also

Quaternion Division

Quaternion Inverse

Quaternion Modulus

Quaternion Multiplication

Quaternion Norm

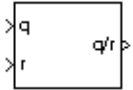
Quaternion Normalize

Quaternion Rotation

**Purpose** Divide a 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

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3 \quad \text{and}$$

$$r = r_0 + \mathbf{i}r_1 + \mathbf{j}r_2 + \mathbf{k}r_3$$

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

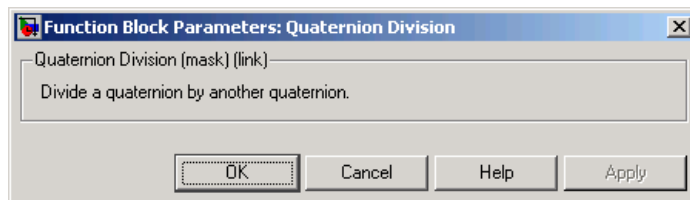
$$t_0 = \frac{(r_0q_0 + r_1q_1 + r_2q_2 + r_3q_3)}{r_0^2 + r_1^2 + r_2^2 + r_3^2}$$

$$t_1 = \frac{(r_0q_1 - r_1q_0 - r_2q_3 + r_3q_2)}{r_0^2 + r_1^2 + r_2^2 + r_3^2}$$

$$t_2 = \frac{(r_0q_2 + r_1q_3 - r_2q_0 - r_3q_1)}{r_0^2 + r_1^2 + r_2^2 + r_3^2}$$

$$t_3 = \frac{(r_0q_3 - r_1q_2 + r_2q_1 - r_3q_0)}{r_0^2 + r_1^2 + r_2^2 + r_3^2}$$

## Dialog Box



## Inputs and Outputs

The first input is a quaternion or vector of quaternions in the form of  $[q_0, p_0, \dots, q_1, p_1, \dots, q_2, p_2, \dots, q_3, p_3, \dots]$ .

# Quaternion Division

---

The second input is a quaternion or vector of quaternions in the form of  $[s_0, r_0, \dots, s_1, r_1, \dots, s_2, r_2, \dots, s_3, r_3, \dots]$ .

The output is the resulting quaternion from the division or vector of resulting quaternions from division.

## See Also

[Quaternion Conjugate](#)

[Quaternion Inverse](#)

[Quaternion Modulus](#)

[Quaternion Multiplication](#)

[Quaternion Norm](#)

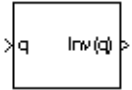
[Quaternion Normalize](#)

[Quaternion Rotation](#)

**Purpose** Calculate the inverse of a quaternion

**Library** Utilities/Math Operations

**Description** The Quaternion Inverse block calculates the inverse for a given quaternion.



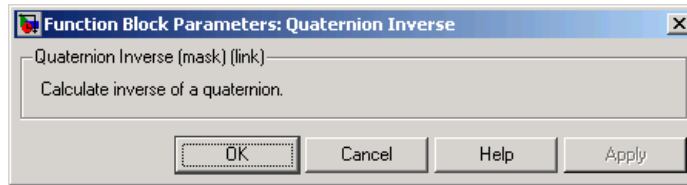
The quaternion has the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3$$

The quaternion inverse has the form of

$$q^{-1} = \frac{q_0 - \mathbf{i}q_1 - \mathbf{j}q_2 - \mathbf{k}q_3}{q_0^2 + q_1^2 + q_2^2 + q_3^2}$$

**Dialog Box**



**Inputs and Outputs** The input is a quaternion or vector of quaternions in the form of  $[q_0, r_0, \dots, q_1, r_1, \dots, q_2, r_2, \dots, q_3, r_3, \dots]$ .

The output is a quaternion inverse or vector of quaternion inverses.

**See Also**

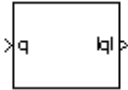
- Quaternion Conjugate
- Quaternion Division
- Quaternion Modulus
- Quaternion Multiplication
- Quaternion Norm
- Quaternion Normalize
- Quaternion Rotation

# Quaternion Modulus

**Purpose** Calculate the modulus of a quaternion

**Library** Utilities/Math Operations

**Description** The Quaternion Modulus block calculates the magnitude for a given quaternion.



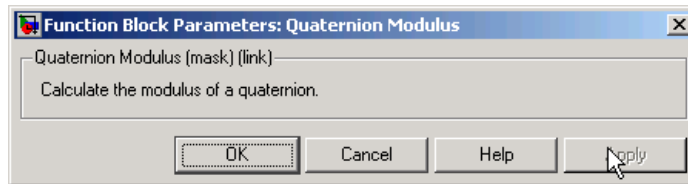
The quaternion has the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3$$

The quaternion modulus has the form of

$$|q| = \sqrt{q_0^2 + q_1^2 + q_2^2 + q_3^2}$$

## Dialog Box



## Inputs and Outputs

The input is a quaternion or vector of quaternions in the form of  $[q_0, r_0, \dots, q_1, r_1, \dots, q_2, r_2, \dots, q_3, r_3, \dots]$ .

The output is a quaternion modulus or vector of quaternion modulus in the form of  $[|q|, |r|, \dots]$ .

## See Also

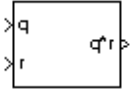
Quaternion Conjugate  
Quaternion Division  
Quaternion Inverse  
Quaternion Multiplication  
Quaternion Norm  
Quaternion Normalize  
Quaternion Rotation



**Purpose** Calculate the product of two quaternions

**Library** Utilities/Math Operations

**Description** The Quaternion Multiplication block calculates the product for two given quaternions.



The quaternions have the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3 \text{ and}$$

$$r = r_0 + \mathbf{i}r_1 + \mathbf{j}r_2 + \mathbf{k}r_3$$

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

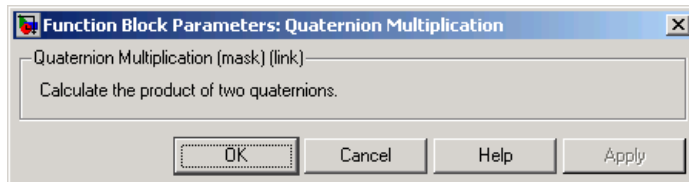
$$t_0 = (r_0q_0 - r_1q_1 - r_2q_2 - r_3q_3)$$

$$t_1 = (r_0q_1 + r_1q_0 - r_2q_3 + r_3q_2)$$

$$t_2 = (r_0q_2 + r_1q_3 + r_2q_0 - r_3q_1)$$

$$t_3 = (r_0q_3 - r_1q_2 + r_2q_1 + r_3q_0)$$

## Dialog Box



## Inputs and Outputs

The first input is a quaternion or vector of quaternions in the form of  $[q_0, p_0, \dots, q_1, p_1, \dots, q_2, p_2, \dots, q_3, p_3, \dots]$ .

The second input is a quaternion or vector of quaternions in the form of  $[s_0, r_0, \dots, s_1, r_1, \dots, s_2, r_2, \dots, s_3, r_3, \dots]$ .

The output is a quaternion product or vector of quaternion products.

# Quaternion Multiplication

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## See Also

[Quaternion Conjugate](#)

[Quaternion Division](#)

[Quaternion Inverse](#)

[Quaternion Modulus](#)

[Quaternion Norm](#)

[Quaternion Normalize](#)

[Quaternion Rotation](#)

**Purpose** Calculate the norm of a quaternion

**Library** Utilities/Math Operations

**Description** The Quaternion Norm block calculates the norm for a given quaternion.



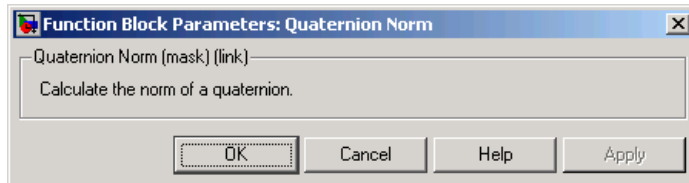
The quaternion has the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3$$

The quaternion norm has the form of

$$\text{norm}(q) = q_0^2 + q_1^2 + q_2^2 + q_3^2$$

**Dialog Box**



**Inputs and Outputs** The input is a quaternion or vector of quaternions in the form of  $[q_0, r_0, \dots, q_1, r_1, \dots, q_2, r_2, \dots, q_3, r_3, \dots]$ .

The output is a quaternion norm or vector of quaternion norms in the form of  $[\text{norm}(q), \text{norm}(r), \dots]$ .

**See Also** Quaternion Conjugate

Quaternion Division

Quaternion Inverse

Quaternion Modulus

Quaternion Multiplication

Quaternion Normalize

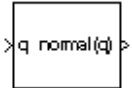
Quaternion Rotation

# Quaternion Normalize

**Purpose** Normalize a quaternion

**Library** Utilities/Math Operations

**Description** The Quaternion Normalize block calculates a normalized quaternion for a given quaternion.



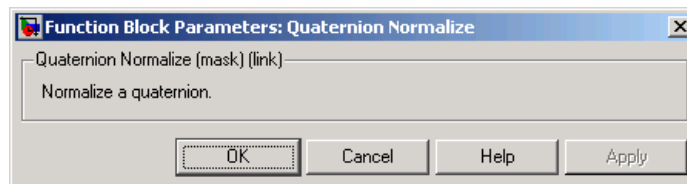
The quaternion has the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3$$

The normalized quaternion has the form of

$$\mathit{normal}(q) = \frac{q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3}{\sqrt{q_0^2 + q_1^2 + q_2^2 + q_3^2}}$$

**Dialog Box**



**Inputs and Outputs**

The input is a quaternion or vector of quaternions in the form of  $[q_0, r_0, \dots, q_1, r_1, \dots, q_2, r_2, \dots, q_3, r_3, \dots]$ .

The output is a normalized quaternion or vector of normalized quaternions.

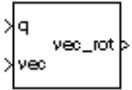
**See Also**

- Quaternion Conjugate
- Quaternion Division
- Quaternion Inverse
- Quaternion Modulus
- Quaternion Multiplication
- Quaternion Norm
- Quaternion Rotation

**Purpose** Rotate a vector by a quaternion

**Library** Utilities/Math Operations

**Description** The Quaternion Rotation block rotates a vector by a quaternion.



The quaternion has the form of

$$q = q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3$$

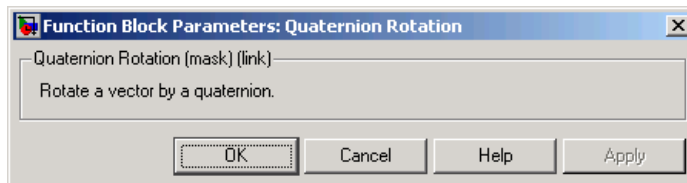
The vector has the form of

$$v = \mathbf{i}v_1 + \mathbf{j}v_2 + \mathbf{k}v_3$$

The rotated vector has the form of

$$v' = \begin{bmatrix} v_1' \\ v_2' \\ v_3' \end{bmatrix} = \begin{bmatrix} (1 - 2q_2^2 - 2q_3^2) & 2(q_1q_2 + q_0q_3) & 2(q_1q_3 - q_0q_2) \\ 2(q_1q_2 - q_0q_3) & (1 - 2q_1^2 - 2q_3^2) & 2(q_2q_3 + q_0q_1) \\ 2(q_1q_3 + q_0q_2) & 2(q_2q_3 - q_0q_1) & (1 - 2q_1^2 - 2q_2^2) \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix}$$

**Dialog Box**



**Inputs and Outputs**

The first input is a quaternion or vector of quaternions in the form of  $[q_0, r_0, \dots, q_1, r_1, \dots, q_2, r_2, \dots, q_3, r_3, \dots]$ .

The second input is a vector or vector of vectors in the form of  $[v_1, u_1, \dots, v_2, u_2, \dots, v_3, u_3, \dots]$ .

The output is a rotated vector or vector of rotated vectors.

**See Also** Quaternion Conjugate

Quaternion Division

Quaternion Inverse

# Quaternion Rotation

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Quaternion Modulus

Quaternion Multiplication

Quaternion Norm

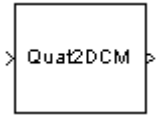
Quaternion Normalize

# Quaternions to Direction Cosine Matrix

**Purpose** 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:

$$\begin{aligned}P' &= qPq^c \\q &= q_0 + \mathbf{i}q_1 + \mathbf{j}q_2 + \mathbf{k}q_3 \\q^c &= q_0 - \mathbf{i}q_1 - \mathbf{j}q_2 - \mathbf{k}q_3 \\P &= 0 + \mathbf{i}x + \mathbf{j}y + \mathbf{k}z\end{aligned}$$

Expanding  $P'$  and collecting terms in  $x$ ,  $y$ , and  $z$  gives the following for  $P'$  in terms of  $P$  in the vector quaternion format:

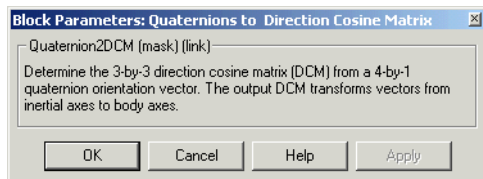
$$P' = \begin{bmatrix} 0 \\ x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} 0 \\ (q_0^2 + q_1^2 - q_2^2 - q_3^2)x + 2(q_1q_2 - q_0q_3)y + 2(q_1q_3 + q_0q_2)z \\ 2(q_0q_3 + q_1q_2)x + (q_0^2 - q_1^2 + q_2^2 - q_3^2)y + 2(q_2q_3 - q_0q_1)z \\ 2(q_1q_3 - q_0q_2)x + 2(q_0q_1 + q_2q_3)y + (q_0^2 - q_1^2 - q_2^2 + q_3^2)z \end{bmatrix}$$

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.

# Quaternions to Direction Cosine Matrix

$$DCM = \begin{bmatrix} (q_0^2 + q_1^2 - q_2^2 - q_3^2) & 2(q_1q_2 + q_0q_3) & 2(q_1q_3 - q_0q_2) \\ 2(q_1q_2 - q_0q_3) & (q_0^2 - q_1^2 + q_2^2 - q_3^2) & 2(q_2q_3 + q_0q_1) \\ 2(q_1q_3 + q_0q_2) & 2(q_2q_3 - q_0q_1) & (q_0^2 - q_1^2 - q_2^2 + q_3^2) \end{bmatrix}$$

## Dialog Box



## Inputs and Outputs

The input is a 4-by-1 quaternion vector.

The output is a 3-by-3 direction cosine matrix.

## See Also

[Direction Cosine Matrix to Euler Angles](#)

[Direction Cosine Matrix to Quaternions](#)

[Euler Angles to Direction Cosine Matrix](#)

[Euler Angles to Quaternions](#)

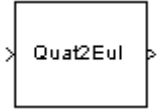
[Quaternions to Euler Angles](#)



**Purpose** Convert quaternion vector to Euler angles

**Library** Utilities/Axes Transformations

**Description**



The Quaternions to Euler Angles block converts the four-element unit quaternion  $(q_0, q_1, q_2, q_3)$  into the equivalent three Euler angle rotations (roll, pitch, yaw).

The conversion is generated by comparing elements in the direction cosine matrix (DCM), as functions of the Euler rotation angles, with elements in the DCM, as functions of a unit quaternion vector:

$$DCM = \begin{bmatrix} \cos \theta \cos \psi & \cos \theta \sin \psi & -\sin \theta \\ (\sin \phi \sin \theta \cos \psi - \cos \phi \sin \psi) & (\sin \phi \sin \theta \sin \psi + \cos \phi \cos \psi) & \sin \phi \cos \theta \\ (\cos \phi \sin \theta \cos \psi + \sin \phi \sin \psi) & (\cos \phi \sin \theta \sin \psi - \sin \phi \cos \psi) & \cos \phi \cos \theta \end{bmatrix}$$

$$DCM = \begin{bmatrix} (q_0^2 + q_1^2 - q_2^2 - q_3^2) & 2(q_1q_2 + q_0q_3) & 2(q_1q_3 - q_0q_2) \\ 2(q_1q_2 - q_0q_3) & (q_0^2 - q_1^2 + q_2^2 - q_3^2) & 2(q_2q_3 + q_0q_1) \\ 2(q_1q_3 + q_0q_2) & 2(q_2q_3 - q_0q_1) & (q_0^2 - q_1^2 - q_2^2 + q_3^2) \end{bmatrix}$$

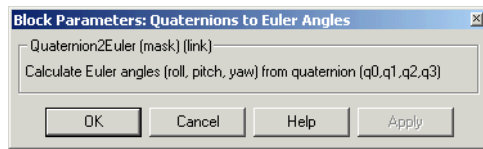
From the preceding, you can derive the following relationships between DCM elements and individual Euler angles:

$$\begin{aligned} \phi &= \text{atan}(DCM(2, 3), DCM(3, 3)) \\ &= \text{atan}(2(q_2q_3 + q_0q_1), (q_0^2 - q_1^2 - q_2^2 + q_3^2)) \\ \theta &= \text{asin}(-DCM(1, 3)) \\ &= \text{asin}(-2(q_1q_3 - q_0q_2)) \\ \psi &= \text{atan}(DCM(1, 2), DCM(1, 1)) \\ &= \text{atan}(2(q_1q_2 + q_0q_3), (q_0^2 + q_1^2 - q_2^2 - q_3^2)) \end{aligned}$$

# Quaternions to Euler Angles

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## Dialog Box



## Inputs and Outputs

The input is a 4-by-1 quaternion vector.

The output is a 3-by-1 vector of Euler angles.

## Assumptions and Limitations

This implementation generates a pitch angle that lies between  $\pm 90$  degrees, and roll and yaw angles that lie between  $\pm 180$  degrees.

The Euler angle solution is singular when the pitch angle  $\theta$  is equal to  $\pm 90$  degrees.

## Examples

See `aero_six_dof` for an example of the use of the Quaternions to Euler Angles block in an implementation of the equations of motion of a rigid body.

## See Also

Direction Cosine Matrix to Euler Angles

Direction Cosine Matrix to Quaternions

Euler Angles to Direction Cosine Matrix

Euler Angles to Quaternions

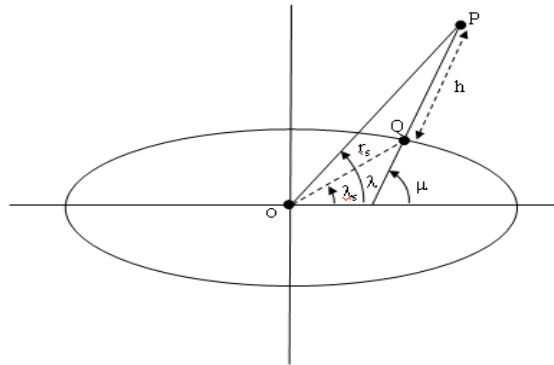
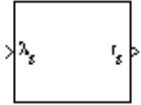
Quaternions to Direction Cosine Matrix

# Radius at Geocentric Latitude

**Purpose** 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 ( $\lambda_s$ ).

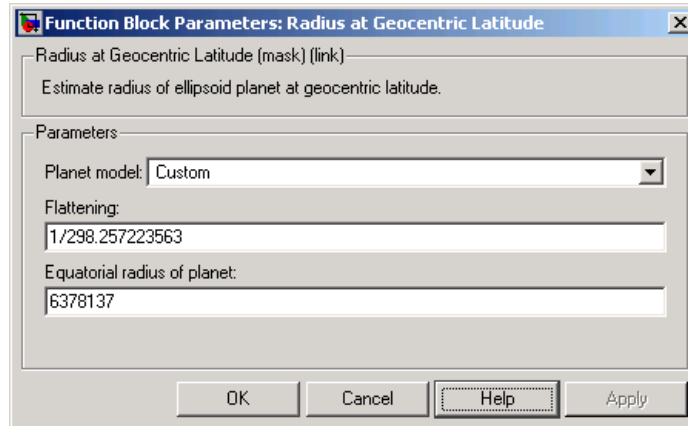
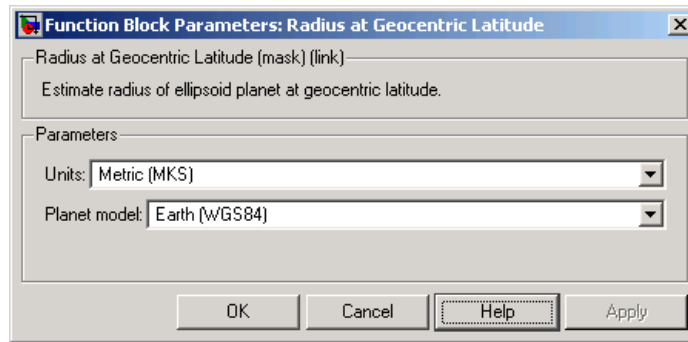


The following equation estimates the ellipsoid radius ( $r_s$ ) using flattening ( $f$ ), geocentric latitude ( $\lambda_s$ ), and equatorial radius ( $R$ ).

$$r_s = \sqrt{\frac{R^2}{1 + [1/(1-f)^2 - 1] \sin^2 \lambda_s}}$$

# Radius at Geocentric Latitude

## Dialog Box



### Units

Specifies the parameter and output units:

<b>Units</b>	<b>Equatorial Radius</b>	<b>Radius at Geocentric Latitude</b>
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**

The input is geocentric latitude, in degrees.

The output is 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, NY, 1992.

Zipfel, P. H., *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA Education Series, Reston, VA, 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

# Relative Ratio

**Purpose** Calculate relative atmospheric ratios

**Library** Flight Parameters

## Description

Mach	$\theta$
$\sqrt{\theta}$	$\sqrt{\theta}$
$T_o$ (K)	$\delta$
$P_o$ (Pa)	$\sigma$
$\rho_o$ (kg/m <sup>3</sup> )	

The Relative Ratio block computes the relative atmospheric ratios, including relative temperature ratio ( $\theta$ ),  $\sqrt{\theta}$ , relative pressure ratio ( $\delta$ ), and relative density ratio ( $\sigma$ ).

$\theta$  represents the ratio of the air stream temperature at a chosen reference station relative to sea level standard atmospheric conditions.

$$\theta = \frac{T}{T_o}$$

$\delta$  represents the ratio of the air stream pressure at a chosen reference station relative to sea level standard atmospheric conditions.

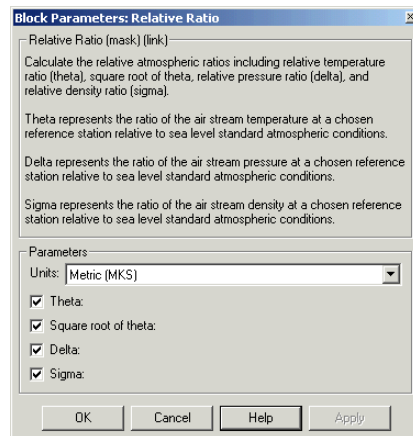
$$\delta = \frac{P}{P_o}$$

$\sigma$  represents the ratio of the air stream density at a chosen reference station relative to sea level standard atmospheric conditions.

$$\sigma = \frac{\rho}{\rho_o}$$

The Relative Ratio block icon displays the input units selected from the **Units** list.

## Dialog Box



## Units

Specifies the input units:

Units	Tstatic	Pstatic	rho_static
Metric (MKS)	Degrees Kelvin	Pascal	Kilograms per cubic meter
English	Degrees Rankine	Pound force per square inch	Slug per cubic foot

## Theta

When selected, the  $\theta$  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  $\delta$  is calculated and static pressure is a required input.

## Sigma

When selected, the  $\sigma$  is calculated and static density is a required input.

## Inputs and Outputs

The four possible inputs are Mach number, static temperature, static pressure, and static density.

The four possible outputs are  $\theta$ ,  $\sqrt{\theta}$ ,  $\delta$ , and  $\sigma$ .

## 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.

## References

*Aeronautical Vestpocket Handbook*, United Technologies Pratt & Whitney, August, 1986.

# Second Order Linear Actuator

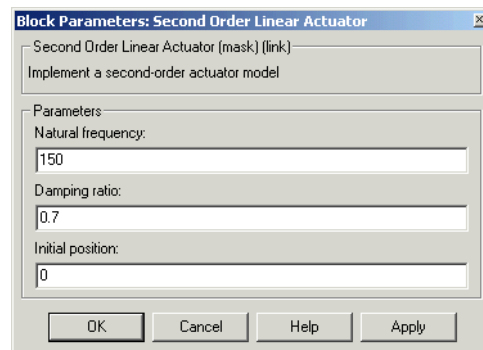
**Purpose** Implement a second-order linear actuator

**Library** Actuators

**Description** The Second Order Linear Actuator block outputs the actual actuator position using the input demanded actuator position and other dialog parameters that define the system.



## Dialog Box



### 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 should be the same as the units of demanded actuator position.

## Inputs and Outputs

The input is the demanded actuator position.

The output is the actual actuator position.

**See Also** Second Order Nonlinear Actuator



# Second Order Nonlinear Actuator

**Purpose** Implement a second-order actuator with rate and deflection limits

**Library** Actuators

**Description** The Second Order Nonlinear Actuator block outputs the actual actuator position using the input demanded actuator position and other dialog parameters that define the system.



## Dialog Box

**Block Parameters: Second Order Nonlinear Actuator**

Second Order Nonlinear Actuator (mask) (link)  
Implement a second-order actuator model with saturation and rate limits.

Parameters:

Natural frequency:  
150

Damping ratio:  
0.7

Maximum deflection:  
 $20\pi/180$

Minimum deflection:  
 $-20\pi/180$

Maximum rate:  
 $500\pi/180$

Initial position:  
0

OK Cancel Help Apply

### 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 should be the same as the units of demanded actuator position.

# Second Order Nonlinear Actuator

---

## **Minimum deflection**

The smallest actuator position allowable. The units of minimum deflection should be the same as the units of demanded actuator position.

## **Maximum rate**

The fastest speed allowable for actuator motion. The units of maximum rate should be the units of demanded actuator position per second.

## **Initial position**

The initial position of the actuator. The units of initial position should be the same as the units of demanded actuator position.

## **Inputs and Outputs**

The input is the demanded actuator position.

The output is the actual actuator position.

## **Examples**

See the `aero_guidance` model and the `Actuators` subsystem in the `aeroblk_HL20` model for an example of this block.

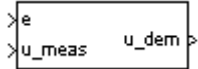
## **See Also**

Second Order Linear Actuator

**Purpose** Implement a state-space controller in a self-conditioned form

**Library** GNC/Controls

**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

$$\dot{z} = (A - HC)z + (B - HD)e + Hu_{meas}$$

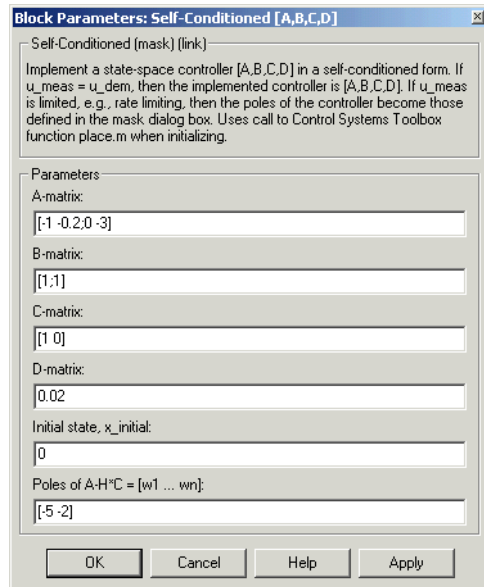
$$u_{dem} = Cz + De$$

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.

# Self-Conditioned [A,B,C,D]

## Dialog Box



### A-matrix

A-matrix of the state-space implementation.

### B-matrix

B-matrix of the state-space implementation.

### C-matrix

C-matrix of the state-space implementation.

### D-matrix

D-matrix of the state-space implementation.

### Initial state, $x_{initial}$

This is a vector of initial states for the controller, i.e., initial values for the state vector,  $z$ . It should have length equal to the size of the first dimension of  $A$ .

### Poles of $A-H^*C$

This is a vector of the desired poles of  $A-H^*C$ . Hence the number of pole locations defined should be equal to the dimension of the  $A$ -matrix.

## Inputs and Outputs

The first input is the control error.

The second input is the measured actuator position.

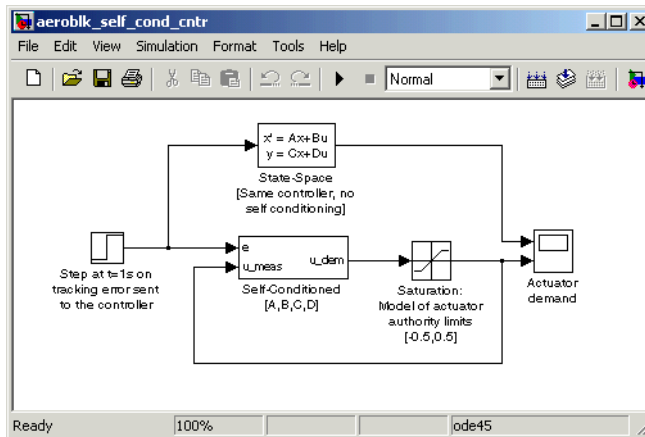
The output is the actuator demands.

## Assumptions and Limitations

This block requires the Control System Toolbox.

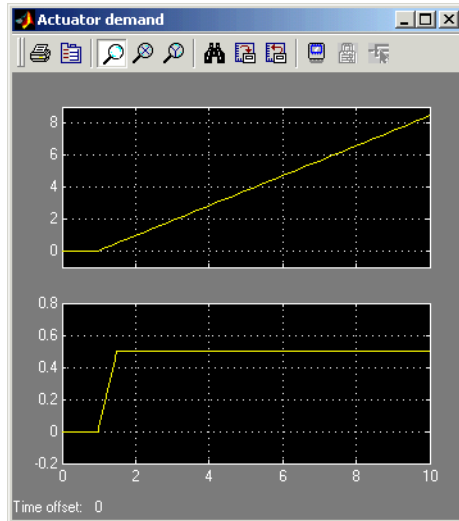
## Examples

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 [A,B,C,D]

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

The algorithm used to determine the matrix  $H$  is defined in Kautsky, Nichols, and Van Dooren, "Robust Pole Assignment in Linear State Feedback," *International Journal of Control*, Vol. 41, No. 5, pages 1129-1155, 1985.

## 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)]

# Send net\_fdm Packet to FlightGear

**Purpose** Transmit net\_fdm packet to destination IP address and port for FlightGear session

**Library** 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 (the second port in the list, 5502, is the network flight dynamics model (fdm) port). You can use one of several techniques to determine the destination IP address, such as:

- Use 127.0.0.1 for “this” 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 2000 IP Configuration
```

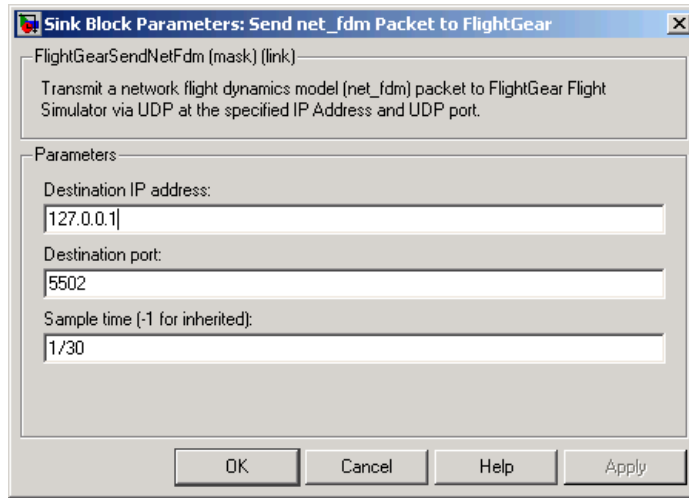
```
Ethernet adapter Local Area Connection:
```

```
Connection-specific DNS Suffix . :
IP Address. . . . . : 192.168.42.178
```

# Send net\_fdm Packet to FlightGear

Subnet Mask . . . . . : 255.255.255.0  
Default Gateway . . . . . : 192.168.42.254

## Dialog Box



### Destination IP address

Specify your destination IP address.

### Destination port

Specify your destination port.

### Sample time

Specify the sample time (-1 for inherited).

## Inputs and Outputs

The input signal is the FlightGear net\_fdm data packet.

## Examples

See the asbh120 demo for an example of this block.

## See Also

FlightGear Preconfigured 6DoF Animation

Generate Run Script

Pack net\_fdm Packet for FlightGear



# Simple Variable Mass 3DoF (Body Axes)

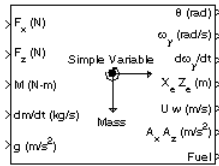
## Purpose

Implement three-degrees-of-freedom equations of motion with respect to body axes

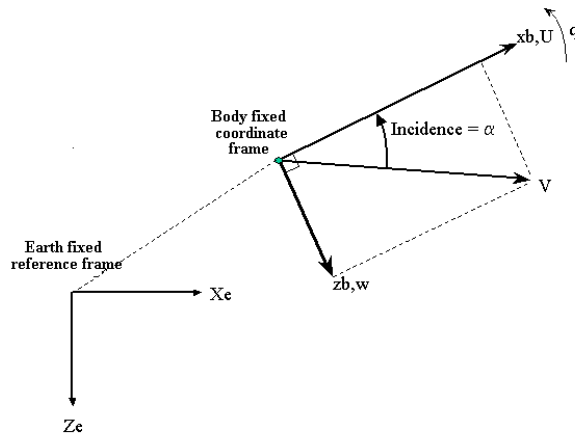
## Library

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 an Earth-fixed reference frame.



## Simple Variable Mass 3DoF (Body Axes)

---

The equations of motion are

$$\dot{u} = \frac{F_x}{m} - \frac{\dot{m}U}{m} - qw - g \sin \theta$$

$$\dot{w} = \frac{F_z}{m} - \frac{\dot{m}w}{m} + qu + g \cos \theta$$

$$q = \frac{M - I_{yy} \dot{q}}{I_{yy}}$$

$$\dot{\theta} = q$$

$$I_{yy} = \frac{I_{yyfull} - I_{yyempty}}{m_{full} - m_{empty}} \dot{m}$$

where the applied forces are assumed to act at the center of gravity of the body.

# Simple Variable Mass 3DoF (Body Axes)

## Dialog Box

**Block Parameters: Simple Variable Mass 3DoF (Body Axes)** [X]

- 3DoF EoM (mask) (link)  
Integrate the three-degrees-of-freedom equations of motion to determine body position, velocity, attitude, and related values.

Parameters

Units: Metric (MKS) [v]

Mass type: Simple Variable [v]

Initial velocity: 100 [t]

Initial body attitude: 0 [t]

Initial incidence: 0 [t]

Initial body rotation rate: 0 [t]

Initial position (x z): [0 0] [t]

Initial mass: 1.0 [t]

Empty mass: 0.5 [t]

Full mass: 3.0 [t]

Empty inertia: 0.5 [t]

Full inertia: 3.0 [t]

Gravity source: External [v]

OK Cancel Help Apply

# Simple Variable Mass 3DoF (Body Axes)

## 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, ( $\theta_0$ ).

## Initial incidence

A scalar value for the initial angle between the velocity vector and the body, ( $\alpha_0$ ).

## Initial body rotation rate

A scalar value for the initial body rotation rate, ( $q_0$ ).

# Simple Variable Mass 3DoF (Body Axes)

---

## Initial position (x,z)

A two-element vector containing the initial location of the body in the Earth-fixed reference frame.

## Initial mass

A scalar value for the initial mass 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 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.

## Inputs and Outputs

The first input to the block is the force acting along the body x-axis, ( $F_x$ ).

The second input to the block is the force acting along the body z-axis, ( $F_z$ ).

The third input to the block is the applied pitch moment, ( $M$ ).

The fourth input to the block is the rate of change of mass, ( $\dot{m}$ ).

The fifth optional input to the block is gravity in the selected units.

The first output from the block is the pitch attitude, in radians ( $\theta$ ).

# Simple Variable Mass 3DoF (Body Axes)

---

The second output is the pitch angular rate, in radians per second ( $q$ ).

The third output is the pitch angular acceleration, in radians per second squared ( $\dot{q}$ ).

The fourth output is a two-element vector containing the location of the body, in the Earth-fixed reference frame,  $(X_e, Z_e)$ .

The fifth output is a two-element vector containing the velocity of the body resolved into the body-fixed coordinate frame,  $(u, w)$ .

The sixth output is a two-element vector containing the acceleration of the body resolved into the body-fixed coordinate frame,  $(A_x, A_z)$ .

The seventh output is a scalar element containing 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.

## 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)

# Simple Variable Mass 3DoF (Wind Axes)

## Purpose

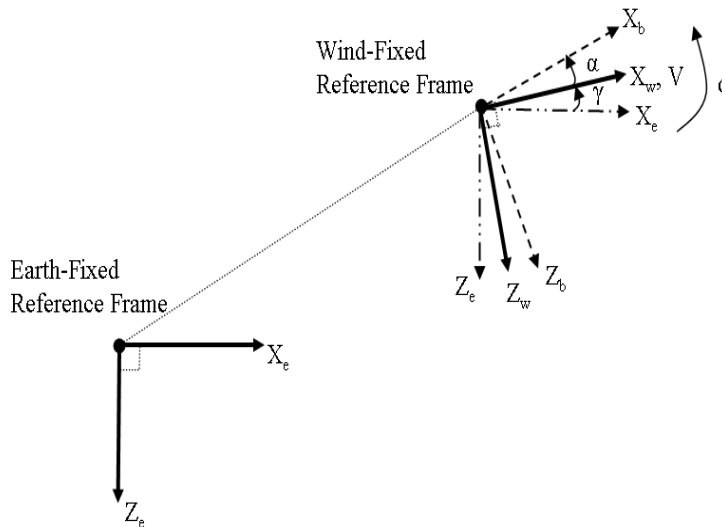
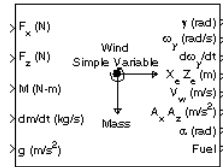
Implement three-degrees-of-freedom equations of motion with respect to wind axes

## 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 an Earth-fixed reference frame.



## Simple Variable Mass 3DoF (Wind Axes)

---

The equations of motion are

$$\dot{V} = \frac{F_{x_{wind}}}{m} - \frac{\dot{m}V}{m} - g \sin \gamma$$

$$\dot{\alpha} = \frac{F_{z_{wind}}}{mV} + q + \frac{g}{V} \cos \gamma$$

$$\dot{q} = \dot{\theta} = \frac{M_{y_{body}} - I_{yy} \dot{q}}{I_{yy}} = \frac{DCM_{bw} M_{y_{wind}} - I_{yy} \dot{q}}{I_{yy}}$$

$$\dot{\gamma} = q - \dot{\alpha}$$

$$\dot{I}_{yy} = \frac{I_{yy_{full}} - I_{yy_{empty}}}{m_{full} - m_{empty}} \dot{m}$$

where the applied forces are assumed to act at the center of gravity of the body.



# Simple Variable Mass 3DoF (Wind Axes)

## Dialog Box

Function Block Parameters: Simple Variable Mass 3DoF (Wind Axes)

3DoF Wind EoM (mask) (link)

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

Parameters

Units: Metric (MKS)

Mass type: Simple Variable

Initial airspeed: 100

Initial flight path angle: 0

Initial incidence: 0

Initial body rotation rate: 0

Initial position (x z): [0 0]

Initial mass: 1.0

Empty mass: 0.5

Full mass: 3.0

Empty inertia body axes: 0.5

Full inertia body axes: 3.0

Gravity source: External

OK Cancel Help Apply

# Simple Variable Mass 3DoF (Wind Axes)

## 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 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, ( $\gamma_0$ ).

## Initial incidence

A scalar value for the initial angle between the velocity vector and the body, ( $\alpha_0$ ).

## Initial body rotation rate

A scalar value for the initial body rotation rate, ( $q_0$ ).

# Simple Variable Mass 3DoF (Wind Axes)

---

## Initial position ( $x,z$ )

A two-element vector containing the initial location of the body in the Earth-fixed reference frame.

## Initial mass

A scalar value for the initial mass 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 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.

## Inputs and Outputs

The first input to the block is the force acting along the wind x-axis, ( $F_x$ ).

The second input to the block is the force acting along the wind z-axis, ( $F_z$ ).

The third input to the block is the applied pitch moment in wind-axes, ( $M$ ).

The fourth input to the block is the rate of change of mass, ( $\dot{m}$ ).

The fifth optional input to the block is gravity in the selected units.

The first output from the block is the flight path angle, in radians ( $\gamma$ ).

# Simple Variable Mass 3DoF (Wind Axes)

---

The second output is the pitch angular rate, in radians per second ( $\omega_y$ ).

The third output is the pitch angular acceleration, in radians per second squared ( $d\omega_y/dt$ ).

The fourth output is a two-element vector containing the location of the body, in the Earth-fixed reference frame, ( $X_e, Z_e$ ).

The fifth output is a two-element vector containing the velocity of the body resolved into the wind-fixed coordinate frame, ( $V, \theta$ ).

The sixth output is a two-element vector containing the acceleration of the body resolved into the body-fixed coordinate frame, ( $A_x, A_z$ ).

The seventh output is a scalar containing the angle of attack, ( $\alpha$ ).

The eighth output is a scalar element containing 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.

## References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 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)

# Simple Variable Mass 6DoF (Euler Angles)

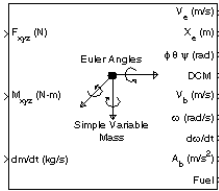
## Purpose

Implement an Euler angle representation of six-degrees-of-freedom equations of motion

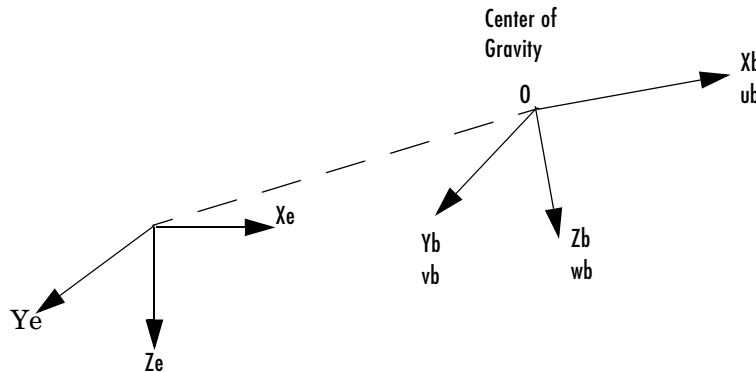
## Library

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 an Earth-fixed 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 Earth-fixed reference frame is considered inertial, a simplification that allows the forces due to the Earth's motion relative to a star-fixed reference system to be neglected.



Earth-fixed 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.

$$\mathbf{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\mathbf{V}}_b + \underline{\omega} \times \mathbf{V}_b) + \dot{m} \mathbf{V}_b$$

# Simple Variable Mass 6DoF (Euler Angles)

$$\underline{V}_b = \begin{bmatrix} u_b \\ v_b \\ w_b \end{bmatrix}, \underline{\omega} = \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

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.

$$\underline{M}_B = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I \dot{\underline{\omega}} + \underline{\omega} \times (I \underline{\omega}) + \dot{I} \underline{\omega}$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

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.

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} \dot{\phi} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & \sin \phi \\ 0 & -\sin \phi & \cos \phi \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & \sin \phi \\ 0 & -\sin \phi & \cos \phi \end{bmatrix} \begin{bmatrix} \cos \theta & 0 & -\sin \theta \\ 0 & 1 & 0 \\ \sin \theta & 0 & \cos \theta \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix} \equiv \mathcal{J}^{-1} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

Inverting  $\mathcal{J}$  then gives the required relationship to determine the Euler rate vector.

# Simple Variable Mass 6DoF (Euler Angles)

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = J \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & (\sin\phi \tan\theta) & (\cos\phi \tan\theta) \\ 0 & \cos\phi & -\sin\phi \\ 0 & \frac{\sin\phi}{\cos\theta} & \frac{\cos\phi}{\cos\theta} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

## Dialog Box

**Block Parameters: Simple Variable Mass 6DoF (Euler Angles)**

6DoF EoM (Body Axis) (mask) (link)

Integrate the six-degrees-of-freedom equations of motion using an Euler angle representation for the orientation of the body in space.

Parameters

Units: Metric (MKS)

Mass type: Simple Variable

Representation: Euler Angles

Initial position in inertial axes [Xe,Ye,Ze]:  
[0 0 0]

Initial velocity in body axes [U,v,w]:  
[0 0 0]

Initial Euler orientation [roll, pitch, yaw]:  
[0 0 0]

Initial body rotation rates [p,q,r]:  
[0 0 0]

Initial mass:  
1.0

Empty mass:  
0.5

Full mass:  
2.0

Empty inertia matrix:  
eye(3)

Full inertia matrix:  
2\*eye(3)

OK Cancel Help Apply

# Simple Variable Mass 6DoF (Euler Angles)

---

## 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.



# Simple Variable Mass 6DoF (Euler Angles)

---

## **Initial position in inertial axes**

The three-element vector for the initial location of the body in the Earth-fixed 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.

## **Inputs and Outputs**

The first input to the block is a vector containing the three applied forces.

The second input is a vector containing the three applied moments.

The third input is a scalar containing the rate of change of mass.

The first output is a three-element vector containing the velocity in the Earth-fixed reference frame.

The second output is a three-element vector containing the position in the Earth-fixed reference frame.

# Simple Variable Mass 6DoF (Euler Angles)

---

The third output is a three-element vector containing the Euler rotation angles [roll, pitch, yaw], in radians.

The fourth output is a 3-by-3 matrix for the coordinate transformation from Earth-fixed axes to body-fixed axes.

The fifth output is a three-element vector containing the velocity in the body-fixed frame.

The sixth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The seventh output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The eighth output is a three-element vector containing the accelerations in body-fixed axes.

The ninth output is a scalar 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.

## Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

## References

Mangiacasale, L., *Flight Mechanics of a u-Airplane with a MATLAB Simulink Helper*, Edizioni Libreria CLUP, 1998.

## 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)

# Simple Variable Mass 6DoF (Euler Angles)

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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)

# Simple Variable Mass 6DoF (Quaternion)

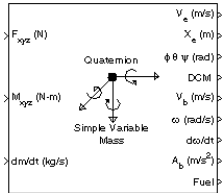
## Purpose

Implement a 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 employed 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  $\varepsilon$  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.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} q_3 & -q_2 & q_1 \\ q_2 & q_3 & -q_0 \\ -q_1 & q_0 & q_3 \\ -q_0 & -q_1 & -q_2 \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} + K\varepsilon \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

$$\varepsilon = 1 - (q_0^2 + q_1^2 + q_3^2 + q_4^2)$$

# Simple Variable Mass 6DoF (Quaternion)

## Dialog Box

**Block Parameters: Simple Variable Mass 6DoF (Quaternion)** [X]

6DoF EoM (Body Axis) (mask) (link)

Integrate the six-degrees-of-freedom equations of motion using an Euler angle representation for the orientation of the body in space.

Parameters

Units: Metric (MKS)

Mass type: Simple Variable

Representation: Quaternion

Initial position in inertial axes [Xe,Ye,Ze]:  
[0 0 0]

Initial velocity in body axes [U,v,w]:  
[0 0 0]

Initial Euler orientation [roll, pitch, yaw]:  
[0 0 0]

Initial body rotation rates [p,q,r]:  
[0 0 0]

Initial mass:  
1.0

Empty mass:  
0.5

Full mass:  
2.0

Empty inertia matrix:  
eye(3)

Full inertia matrix:  
2\*eye(3)

Gain for quaternion normalization:  
1.0

OK Cancel Help Apply

# Simple Variable Mass 6DoF (Quaternion)

## 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.

# Simple Variable Mass 6DoF (Quaternion)

---

## **Initial position in inertial axes**

The three-element vector for the initial location of the body in the Earth-fixed 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.

## **Gain for quaternion normalization**

The gain to maintain the norm of the quaternion vector equal to 1.0.

## **Inputs and Outputs**

The first input to the block is a vector containing the three applied forces.

The second input is a vector containing the three applied moments.

The third input is a scalar containing the rate of change of mass.

The first output is a three-element vector containing the velocity in the Earth-fixed reference frame.

# Simple Variable Mass 6DoF (Quaternion)

---

The second output is a three-element vector containing the position in the Earth-fixed reference frame.

The third output is a three-element vector containing the Euler rotation angles [roll, pitch, yaw], in radians.

The fourth output is a 3-by-3 matrix for the coordinate transformation from Earth-fixed axes to body-fixed axes.

The fifth output is a three-element vector containing the velocity in the body-fixed frame.

The sixth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The seventh output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The eighth output is a three-element vector containing the accelerations in body-fixed axes.

The ninth output is a scalar 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.

## Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

## References

Mangiacasale, L., *Flight Mechanics of a u-Airplane with a MATLAB Simulink Helper*, Edizioni Libreria CLUP, 1998.

## See Also

6DoF (Euler Angles)

6DoF (Quaternion)

6DoF ECEF (Quaternion)

6DoF Wind (Quaternion)

6DoF Wind (Wind Angles)

6th Order Point Mass (Coordinated Flight)



# Simple Variable Mass 6DoF (Quaternion)

---

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)

# Simple Variable Mass 6DoF ECEF (Quaternion)

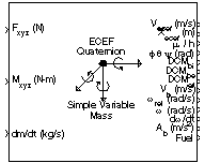
## Purpose

Implement a quaternion representation of six-degrees-of-freedom equations of motion in Earth-Centered Earth-Fixed (ECEF) coordinates

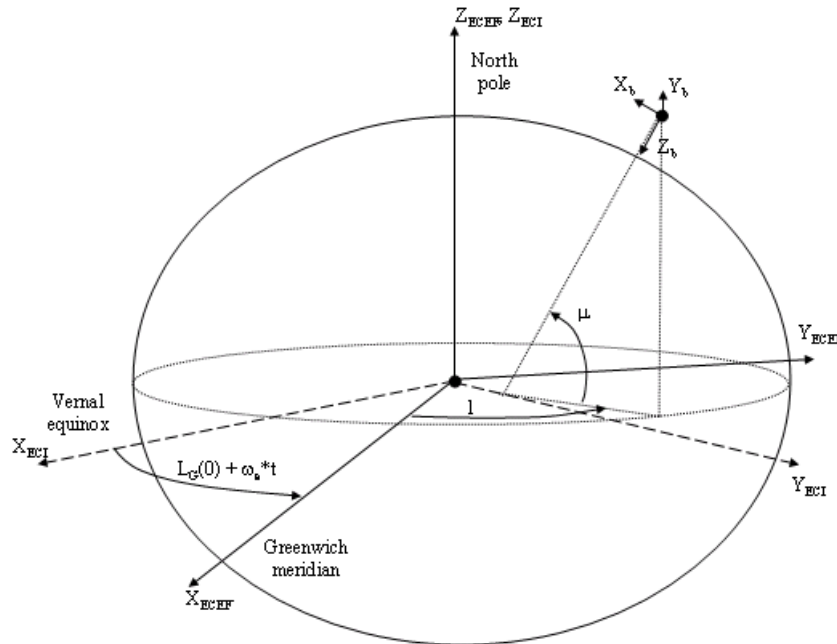
## Library

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 ( $\omega_e$ ) including an initial celestial longitude ( $L_G(0)$ ). This simplification allows the forces due to the Earth's complex motion relative to a star-fixed reference system to be neglected.



# Simple Variable Mass 6DoF ECEF (Quaternion)

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.

$$\underline{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\underline{\dot{V}}_b + \underline{\omega}_b \times \underline{V}_b + (DCM_{bi} \underline{\omega}_e \times \underline{V}_b) + DCM_{bi}(\underline{\omega}_e \times (\underline{\omega}_e \times \underline{x}_i))) + \dot{m}(\underline{V}_b + DCM_{bi}(\underline{\omega}_e \times \underline{x}_i))$$

where the change of position in ECI ( $\underline{x}_i$ ) is calculated by

$$\underline{x}_i = \begin{bmatrix} \dot{x}_{ECI} \\ \dot{y}_{ECI} \\ \dot{z}_{ECI} \end{bmatrix} = DCM_{ib} \underline{V}_b + \underline{\omega}_e \times \underline{x}_i$$

and the velocity in body-axis ( $\underline{V}_b$ ), angular rates in body-axis ( $\underline{\omega}_b$ ). Earth rotation rate ( $\underline{\omega}_e$ ), and relative angular rates in body-axis ( $\underline{\omega}_{rel}$ ) are defined as

$$\underline{V}_b = \begin{bmatrix} u \\ v \\ w \end{bmatrix}, \underline{\omega}_b = \begin{bmatrix} p \\ q \\ r \end{bmatrix}, \underline{\omega}_e = \begin{bmatrix} 0 \\ 0 \\ \omega_e \end{bmatrix}, \underline{\omega}_{rel} = \underline{\omega}_b - DCM_{bi} \underline{\omega}_e$$

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.

$$\underline{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I \underline{\dot{\omega}}_b + \underline{\omega}_b \times (I \underline{\omega}_b)$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

# Simple Variable Mass 6DoF ECEF (Quaternion)

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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.

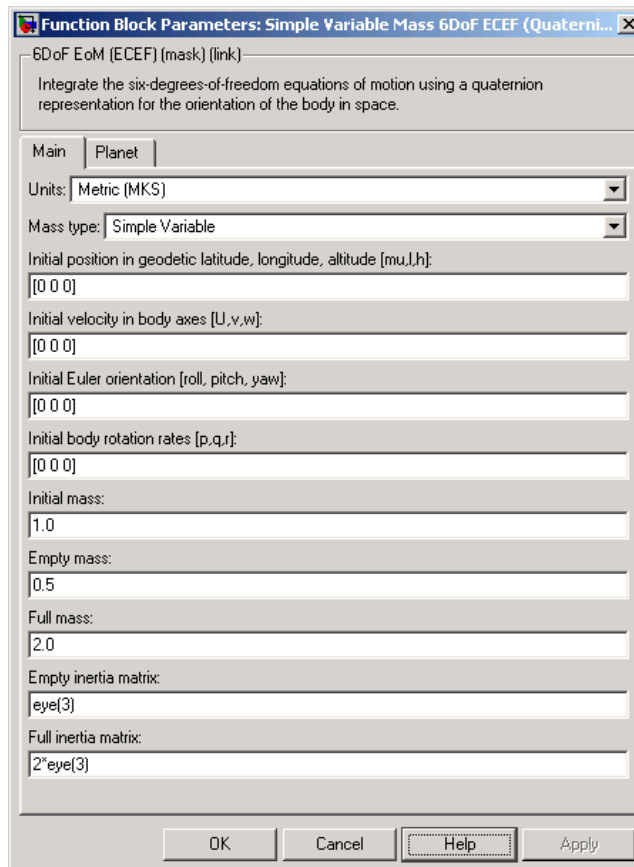
$$\dot{I} = \frac{I_{full} - I_{empty}}{m_{full} - m_{empty}} \dot{m}$$

The integration of the rate of change of the quaternion vector is given below.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = -\frac{1}{2} \begin{bmatrix} 0 & p & q & r \\ -p & 0 & -r & q \\ -q & r & 0 & -p \\ -r & -q & p & 0 \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

# Simple Variable Mass 6DoF ECEF (Quaternion)

## Dialog Box



Function Block Parameters: Simple Variable Mass 6DoF ECEF (Quaternion) [X]

6DoF EoM (ECEF) (mask) (link)  
Integrate the six-degrees-of-freedom equations of motion using a quaternion representation for the orientation of the body in space.

Main Planet

Units: Metric (MKS)

Mass type: Simple Variable

Initial position in geodetic latitude, longitude, altitude [mu,l,h]:  
[0 0 0]

Initial velocity in body axes [U,v,w]:  
[0 0 0]

Initial Euler orientation [roll, pitch, yaw]:  
[0 0 0]

Initial body rotation rates [p,q,r]:  
[0 0 0]

Initial mass:  
1.0

Empty mass:  
0.5

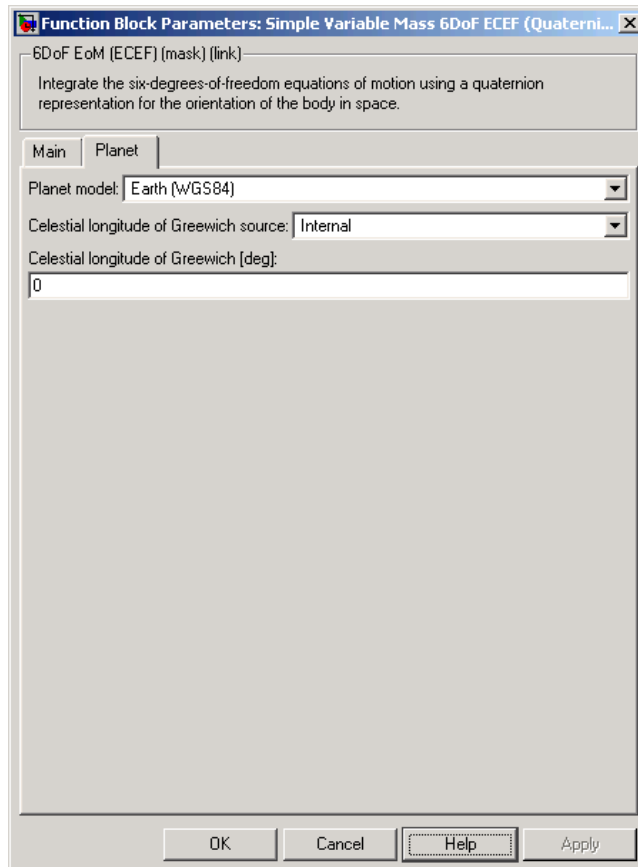
Full mass:  
2.0

Empty inertia matrix:  
eye(3)

Full inertia matrix:  
2\*eye(3)

OK Cancel Help Apply

# Simple Variable Mass 6DoF ECEF (Quaternion)



# Simple Variable Mass 6DoF ECEF (Quaternion)

## Units

Specifies the input and output units:

<b>Units</b>	<b>Forces</b>	<b>Moment</b>	<b>Acceleration</b>	<b>Velocity</b>	<b>Position</b>	<b>Mass</b>	<b>Inertia</b>
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 position in geodetic latitude, longitude and altitude

The three-element vector for the initial location of the body in the geodetic reference frame.

## Initial velocity in body axes

The three-element vector containing the initial velocity in the body-fixed coordinate frame.

## Initial Euler orientation

The three-element vector containing the initial Euler rotation angles [roll, pitch, yaw], in radians.

# Simple Variable Mass 6DoF ECEF (Quaternion)

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## **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.

## **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.

## **Planet model**

Specifies the planet model to use:

Custom

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/sec. This option is only available when **Planet model** is set to Custom.



# Simple Variable Mass 6DoF ECEF (Quaternion)

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## 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.

## Inputs and Outputs

The first input to the block is a vector containing the three applied forces in body-fixed axes.

The second input is a vector containing the three applied moments in body-fixed axes.

The third input is a scalar containing the rate of change of mass.

The first output is a three-element vector containing the velocity in the ECEF reference frame.

The second output is a three-element vector containing the position in the ECEF reference frame.

The third output is a three-element vector containing the position in geodetic latitude, longitude and altitude, in degrees, degrees and selected units of length respectively.

The fourth output is a three-element vector containing the body rotation angles [roll, pitch, yaw], in radians.

The fifth output is a 3-by-3 matrix for the coordinate transformation from ECI axes to body-fixed axes.

The sixth output is a 3-by-3 matrix for the coordinate transformation from geodetic axes to body-fixed axes.

The seventh output is a 3-by-3 matrix for the coordinate transformation from ECEF axes to geodetic axes.

The eighth output is a three-element vector containing the velocity in the body-fixed frame.

# Simple Variable Mass 6DoF ECEF (Quaternion)

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The ninth output is a three-element vector containing the relative angular rates in body-fixed axes, in radians per second.

The tenth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The eleventh output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The twelfth output is a three-element vector containing the accelerations in body-fixed axes.

The thirteenth output is a scalar 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.

## 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  $\pm 90$  degrees, and longitude that lies between  $\pm 180$  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 through the center of the Sun 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.

# Simple Variable Mass 6DoF ECEF (Quaternion)

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## References

Stevens, B. L., and F. L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, New York, NY, 1992.

Zipfel, P. H., *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA Education Series, Reston, VA, 2000.

“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)

# Simple Variable Mass 6DoF Wind (Quaternion)

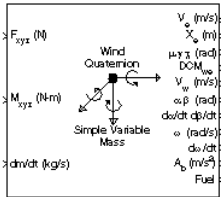
## Purpose

Implement a quaternion representation of six-degrees-of-freedom equations of motion with respect to wind axes

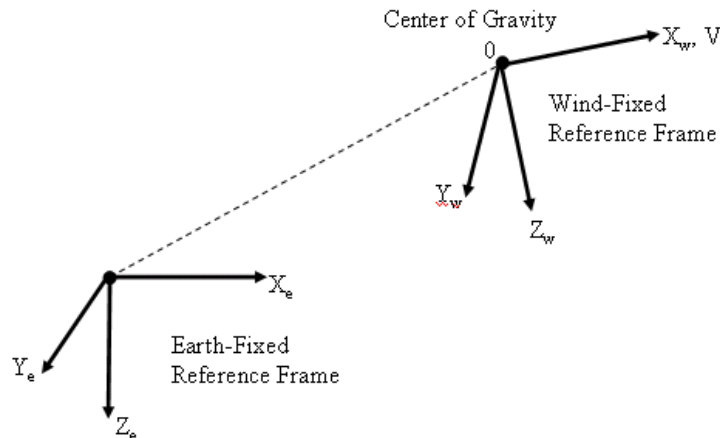
## Library

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 Earth-fixed 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 Earth-fixed reference frame is considered inertial, a simplification that allows the forces due to the Earth's motion relative to a star-fixed reference system 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.

$$\underline{F}_w = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\underline{V}}_w + \underline{\omega}_w \times \underline{V}_w) + \dot{m} \underline{V}_w$$

# Simple Variable Mass 6DoF Wind (Quaternion)

$$\underline{V}_w = \begin{bmatrix} V \\ 0 \\ 0 \end{bmatrix}, \underline{\omega}_w = \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = DMC_{wb} \begin{bmatrix} p_b - \beta \sin \alpha \\ q_b - \dot{\alpha} \\ r_b + \beta \cos \alpha \end{bmatrix}, \underline{w}_b = \begin{bmatrix} p_b \\ q_b \\ r_b \end{bmatrix}$$

The rotational dynamics of the wind-fixed frame in relation to 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.

$$\underline{M}_w = DCM_{wb} \underline{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I \dot{\underline{\omega}}_b + \underline{\omega}_b \times (I \underline{\omega}_b) + \dot{I} \underline{\omega}_b$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

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.

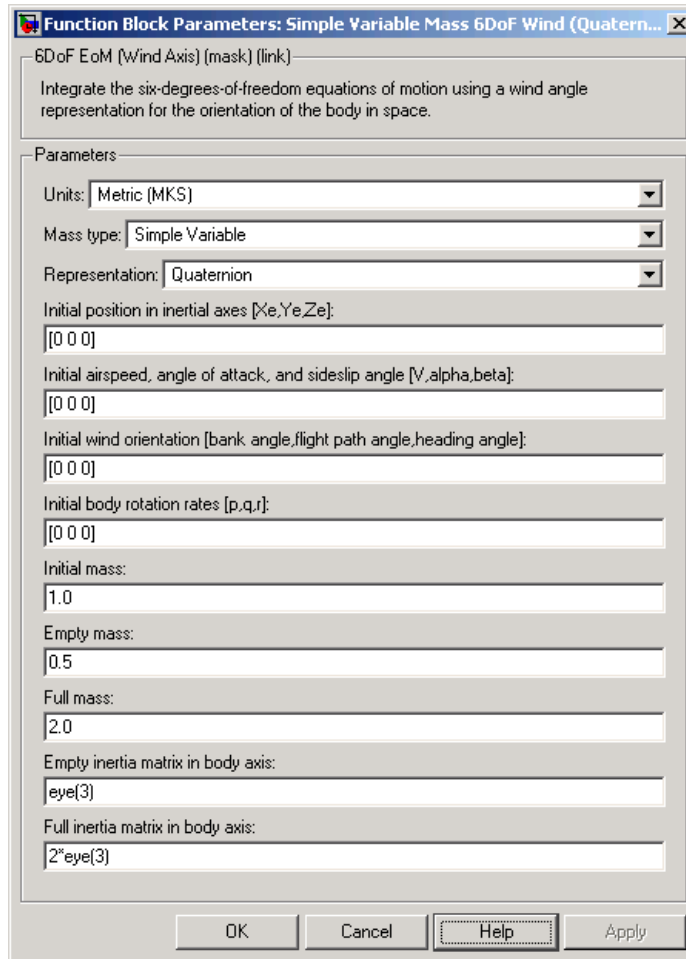
$$\dot{I} = \frac{I_{full} - I_{empty}}{m_{full} - m_{empty}} \dot{m}$$

The integration of the rate of change of the quaternion vector is given below.

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 0 & p & q & r \\ -p & 0 & -r & q \\ -q & r & 0 & -p \\ -r & -q & p & 0 \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

# Simple Variable Mass 6DoF Wind (Quaternion)

## Dialog Box



**Function Block Parameters: Simple Variable Mass 6DoF Wind (Quaternion)**

6DoF EoM (Wind Axis) (mask) (link)

Integrate the six-degrees-of-freedom equations of motion using a wind angle representation for the orientation of the body in space.

Parameters

Units: Metric (MKS)

Mass type: Simple Variable

Representation: Quaternion

Initial position in inertial axes [Xe,Ye,Ze]:  
[0 0 0]

Initial airspeed, angle of attack, and sideslip angle [V,alpha,beta]:  
[0 0 0]

Initial wind orientation [bank angle,flight path angle,heading angle]:  
[0 0 0]

Initial body rotation rates [p,q,r]:  
[0 0 0]

Initial mass:  
1.0

Empty mass:  
0.5

Full mass:  
2.0

Empty inertia matrix in body axis:  
eye(3)

Full inertia matrix in body axis:  
2\*eye(3)

OK Cancel Help Apply

# Simple Variable Mass 6DoF Wind (Quaternion)

## 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:

- 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.

# Simple Variable Mass 6DoF Wind (Quaternion)

---

## **Initial position in inertial axes**

The three-element vector for the initial location of the body in the Earth-fixed 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.

## **Inputs and Outputs**

The first input to the block is a vector containing the three applied forces in wind-fixed axes.

The second input is a vector containing the three applied moments in wind-fixed axes.

The third input is a scalar containing the rate of change of mass.



# Simple Variable Mass 6DoF Wind (Quaternion)

---

The first output is a three-element vector containing the velocity in the Earth-fixed reference frame.

The second output is a three-element vector containing the position in the Earth-fixed reference frame.

The third output is a three-element vector containing the wind rotation angles [bank, flight path, heading], in radians.

The fourth output is a 3-by-3 matrix for the coordinate transformation from Earth-fixed axes to wind-fixed axes.

The fifth output is a three-element vector containing the velocity in the wind-fixed frame.

The sixth output is a two-element vector containing the angle of attack and sideslip angle, in radians.

The seventh output is a two-element vector containing the rate of change of angle of attack and rate of change of sideslip angle, in radians per second.

The eighth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The ninth output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The tenth output is a three-element vector containing the accelerations in body-fixed axes.

The eleventh output is a scalar 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.

## Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

## References

Mangiaccasale, L., *Flight Mechanics of a u-Airplane with a MATLAB Simulink Helper*, Edizioni Libreria CLUP, 1998.

# Simple Variable Mass 6DoF Wind (Quaternion)

---

Stevens, B. L., and F. L. Lewis, "Aircraft Control and Simulation," John Wiley & Sons, New York, NY, 1992.

## 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)

# Simple Variable Mass 6DoF Wind (Wind Angles)

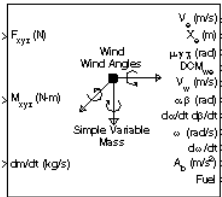
## Purpose

Implement a 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 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.

$$\begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} \dot{\mu} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \mu & \sin \mu \\ 0 & -\sin \mu & \cos \mu \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\gamma} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \mu & \sin \mu \\ 0 & -\sin \mu & \cos \mu \end{bmatrix} \begin{bmatrix} \cos \gamma & 0 & -\sin \gamma \\ 0 & 1 & 0 \\ \sin \gamma & 0 & \cos \gamma \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\chi} \end{bmatrix} \equiv \mathcal{J}^{-1} \begin{bmatrix} \dot{\mu} \\ \dot{\gamma} \\ \dot{\chi} \end{bmatrix}$$

Inverting  $\mathcal{J}$  then gives the required relationship to determine the wind rate vector.

$$\begin{bmatrix} \dot{\mu} \\ \dot{\gamma} \\ \dot{\chi} \end{bmatrix} = \mathcal{J} \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} 1 & (\sin \mu \tan \gamma) & (\cos \mu \tan \gamma) \\ 0 & \cos \mu & -\sin \mu \\ 0 & \frac{\sin \mu}{\cos \gamma} & \frac{\cos \mu}{\cos \gamma} \end{bmatrix} \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix}$$

The body-fixed angular rates are related to the wind-fixed angular rate by the following equation.

$$\begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = DMC_{wb} \begin{bmatrix} p_b - \beta \sin \alpha \\ q_b - \dot{\alpha} \\ r_b + \beta \cos \alpha \end{bmatrix}$$

Using this relationship in the wind rate vector equations, gives the relationship between the wind rate vector and the body-fixed angular rates.

# Simple Variable Mass 6DoF Wind (Wind Angles)

$$\begin{bmatrix} \dot{\mu} \\ \dot{\gamma} \\ \dot{\chi} \end{bmatrix} = J \begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} 1 & (\sin\mu \tan\gamma) & (\cos\mu \tan\gamma) \\ 0 & \cos\mu & -\sin\mu \\ 0 & \frac{\sin\mu}{\cos\gamma} & \frac{\cos\mu}{\cos\gamma} \end{bmatrix} DMC_{wb} \begin{bmatrix} p_b - \beta \sin\alpha \\ q_b - \dot{\alpha} \\ r_b + \beta \cos\alpha \end{bmatrix}$$

## Dialog Box

**Function Block Parameters: Simple Variable Mass 6DoF Wind (Wind An... X**

6DoF EoM (Wind Axis) (mask) (link)

Integrate the six-degrees-of-freedom equations of motion using a wind angle representation for the orientation of the body in space.

Parameters

Units: Metric (MKS)

Mass type: Simple Variable

Representation: Wind Angles

Initial position in inertial axes [Xe,Ye,Ze]:  
[0 0 0]

Initial airspeed, angle of attack, and sideslip angle [V,alpha,beta]:  
[0 0 0]

Initial wind orientation [bank angle,flight path angle,heading angle]:  
[0 0 0]

Initial body rotation rates [p,q,r]:  
[0 0 0]

Initial mass:  
1.0

Empty mass:  
0.5

Full mass:  
2.0

Empty inertia matrix in body axis:  
eye(3)

Full inertia matrix in body axis:  
2\*eye(3)

OK Cancel Help Apply

# Simple Variable Mass 6DoF Wind (Wind Angles)

## Units

Specifies the input and output units:

<b>Units</b>	<b>Forces</b>	<b>Moment</b>	<b>Acceleration</b>	<b>Velocity</b>	<b>Position</b>	<b>Mass</b>	<b>Inertia</b>
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:

- 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.

# Simple Variable Mass 6DoF Wind (Wind Angles)

---

## **Initial position in inertial axes**

The three-element vector for the initial location of the body in the Earth-fixed 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.

## **Inputs and Outputs**

The first input to the block is a vector containing the three applied forces in wind-fixed axes.

The second input is a vector containing the three applied moments in wind-fixed axes.

The third input is a scalar containing the rate of change of mass.

# Simple Variable Mass 6DoF Wind (Wind Angles)

---

The first output is a three-element vector containing the velocity in the Earth-fixed reference frame.

The second output is a three-element vector containing the position in the Earth-fixed reference frame.

The third output is a three-element vector containing the wind rotation angles [bank, flight path, heading], in radians.

The fourth output is a 3-by-3 matrix for the coordinate transformation from Earth-fixed axes to wind-fixed axes.

The fifth output is a three-element vector containing the velocity in the wind-fixed frame.

The sixth output is a two-element vector containing the angle of attack and sideslip angle, in radians.

The seventh output is a two-element vector containing the rate of change of angle of attack and rate of change of sideslip angle, in radians per second.

The eighth output is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The ninth output is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second.

The tenth output is a three-element vector containing the accelerations in body-fixed axes.

The eleventh output is a scalar 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.

## Assumptions and Limitations

The block assumes that the applied forces are acting at the center of gravity of the body.

## References

Mangiacasale, L., *Flight Mechanics of a u-Airplane with a MATLAB Simulink Helper*, Edizioni Libreria CLUP, 1998.

# Simple Variable Mass 6DoF Wind (Wind Angles)

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Stevens, B. L., and F. L. Lewis, "Aircraft Control and Simulation," John Wiley & Sons, New York, NY, 1992.

## See Also

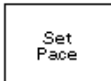
6DoF (Euler Angles)  
6DoF (Quaternion)  
6DoF ECEF (Quaternion)  
6DoF Wind (Quaternion)  
6DoF Wind (Wind Angles)  
6th Order Point Mass (Coordinated Flight)  
Custom Variable Mass 6DoF (Euler Angles)  
Custom Variable Mass 6DoF (Quaternion)  
Custom Variable Mass 6DoF ECEF (Quaternion)  
Custom Variable 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)



**Purpose** Set the simulation pace for FlightGear Flight Simulator

**Library** Animation/Animation Support Utilities

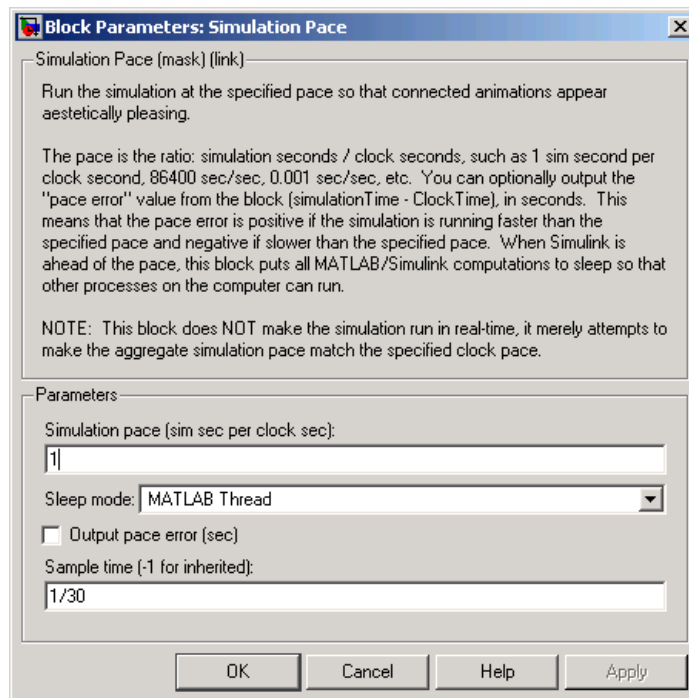
**Description** The Simulation Pace block lets you run the simulation at the specified pace so that connected animations appear aesthetically pleasing.



Use the **Sample time** parameter to set how often Simulink synchronizes with the wall clock.

The sample time of this block should be considered for human interaction with visualizations. The default is 1/30 sec, chosen to correspond to a 30 frames-per-second visualization rate (typical for common systems). Choose as slow of a sample time as needed for smooth animation, since oversampling has little benefit and undersampling can cause “jumpiness” in animations and potentially problematic blocking of MATLAB’s main thread.

## Dialog Box



# Simulation Pace

---

## Simulation pace

Specifies the ratio of simulation time to clock time. The default is 1 second of simulation time per second of clock time.

## Sleep mode

Setting the **Sleep mode** parameter to `off` lets you disable the pace functionality and run as fast as possible.

## Output pace error

If you select this check box, the block 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.

## Sample time

Specify the sample time (-1 for inherited). Larger sample times result in more efficient simulations, but less “smoothness” in output pace when there are multiple Simulink time steps between pacer block samples. If the **Sample time** is too large, MATLAB may become less responsive as MATLAB and Simulink calculations are blocked from running when the block puts MATLAB to sleep.

## Inputs and Outputs

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 make decisions about the simulation if the simulation is too slow to keep up with the specified pace.

## Assumptions and Limitations

The simulation pace is implemented by putting the entire MATLAB thread to sleep until it needs to run again to keep up the pace. Simulink is single threaded and runs on the one MATLAB thread, so only one Simulation Pace block can be active at a time.

## Examples

See the `asbh120` demo for an example of this block.

## See Also

Pilot Joystick

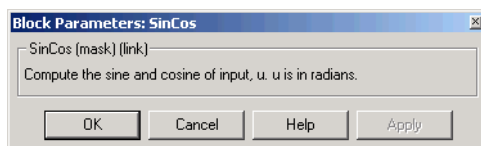
**Purpose** Compute the sine and cosine of the input angle

**Library** Utilities/Math Operations

**Description** The SinCos block computes the sine and cosine of the input angle, theta.



**Dialog Box**



**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.

# Symmetric Inertia Tensor

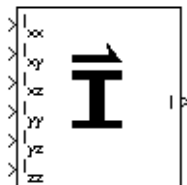
## Purpose

Create an inertia tensor from moments and products of inertia

## Library

Mass Properties

## Description

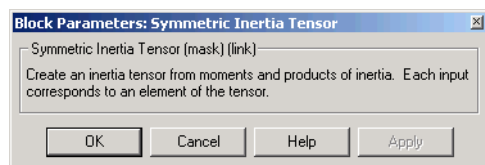


The Symmetric Inertia Tensor block creates an inertia tensor from moments and products of inertia. Each input corresponds to an element of the tensor.

The inertia tensor has the form of

$$Inertia = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{yz} \\ -I_{xy} & I_{yy} & -I_{xz} \\ -I_{yz} & -I_{xz} & I_{zz} \end{bmatrix}$$

## Dialog Box



## Inputs and Outputs

The first input is the moment of inertia about the *x-axis*.

The second input is the product of inertia in the *xy* plane.

The third input is the product of inertia in the *xz* plane.

The fourth input is the moment of inertia about the *y-axis*.

The fifth input is the product of inertia in the *yz* plane.

The sixth input is the moment of inertia about the *z-axis*.

The output of the block is a symmetric 3-by-3 inertia tensor.

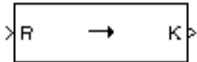
## See Also

Create 3x3 Matrix

**Purpose** Convert from temperature units to desired temperature units

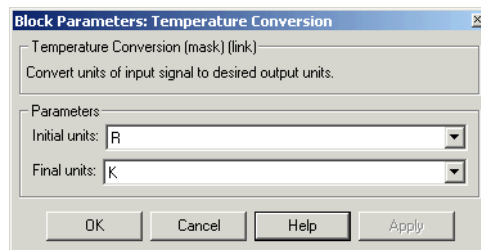
**Library** Utilities/Unit Conversions

**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 units** and the **Final units** lists.

## Dialog Box



### Initial units

Specifies the input units.

### Final units

Specifies the output units.

The following conversion units are available:

K	Degrees Kelvin
F	Degrees Fahrenheit
C	Degrees Celsius
R	Degrees Rankine

## Inputs and Outputs

The input is the temperature in initial temperature units.

The output is the temperature in final temperature units.

# Temperature Conversion

---

## **See Also**

Acceleration Conversion

Angle Conversion

Angular Acceleration Conversion

Angular Velocity Conversion

Density Conversion

Force Conversion

Length Conversion

Mass Conversion

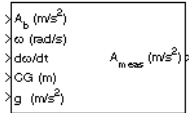
Pressure Conversion

Velocity Conversion

**Purpose** Implement a 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 ( $\underline{A}_{imeas}$ ) include the acceleration in body axes at the center of gravity ( $\underline{A}_b$ ), lever arm effects due to the accelerometer not being at the center of gravity, and, optionally, gravity in body axes can be removed.

$$\underline{A}_{imeas} = \underline{A}_b + \underline{\omega}_b \times (\underline{\omega}_b \times \underline{d}) + \dot{\underline{\omega}}_b \times \underline{d} - \underline{g}$$

where  $\underline{\omega}_b$  are body-fixed angular rates,  $\dot{\underline{\omega}}_b$  are body-fixed angular accelerations and  $\underline{d}$  is the lever arm. The lever arm ( $\underline{d}$ ) is defined as the distances that the accelerometer group is forward, right and below the center of gravity.

$$\underline{d} = \begin{bmatrix} d_x \\ d_y \\ d_z \end{bmatrix} = \begin{bmatrix} -(x_{acc} - x_{CG}) \\ y_{acc} - y_{CG} \\ -(z_{acc} - z_{CG}) \end{bmatrix}$$

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 ( $\underline{A}_{meas}$ ) output by this block contain error sources and are defined as

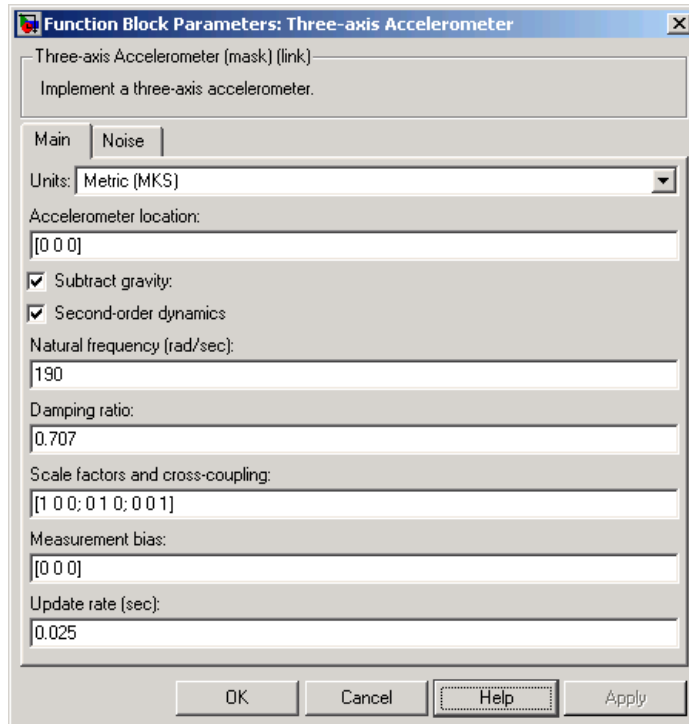
$$\underline{A}_{meas} = \underline{A}_{imeas} \cdot \underline{A}_{SFCC} + \underline{A}_{bias} + noise$$

where  $\underline{A}_{SFCC}$  is a 3-by-3 matrix of scaling factors on the diagonal and misalignment terms in the nondiagonal, and  $\underline{A}_{bias}$  are the biases.

# Three-Axis Accelerometer

Optionally discretizations can be applied to the block inputs and dynamics along with nonlinearizations of the measured accelerations via a Saturation block.

## Dialog Box



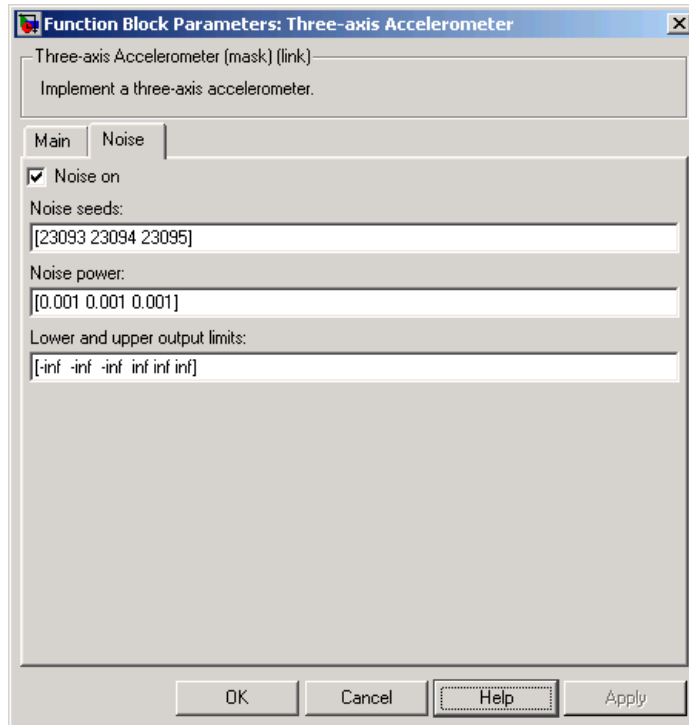
The dialog box, titled "Function Block Parameters: Three-axis Accelerometer", contains the following fields and options:

- Three-axis Accelerometer (mask) (link): Implement a three-axis accelerometer.
- Units: Metric (MKS)
- Accelerometer location: [0 0 0]
- Subtract gravity:
- Second-order dynamics
- Natural frequency (rad/sec): 190
- Damping ratio: 0.707
- Scale factors and cross-coupling: [1 0 0; 0 1 0; 0 0 1]
- Measurement bias: [0 0 0]
- Update rate (sec): 0.025

Buttons: OK, Cancel, Help, Apply



# Three-Axis Accelerometer



## 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.

# Three-Axis Accelerometer

---

## **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.

## **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.

## **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

The first input is a three-element vector containing the actual accelerations in body-fixed axes, in selected units.

The second input is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The third input is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second squared.

The fourth input is a three-element vector containing the location of the center of gravity, in selected units.

The optional fifth input is a three-element vector containing the gravity, in selected units.

The output is a three-element vector containing the measured accelerations from the accelerometer, in selected units.

## Assumptions and Limitations

Vibro-pendulous error and hysteresis effects are not accounted for in this block. Additionally, it is not the intention of this block to model the internal dynamics of differing forms of instrument.

This block requires the Control System Toolbox.

## References

Rogers, R. M., *Applied Mathematics in Integrated Navigation Systems*, AIAA Education Series, 2000.

## See Also

Three-Axis Gyroscope

Three-Axis Inertial Measurement Unit

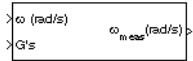
# Three-Axis Gyroscope

---

**Purpose** Implement a three-axis gyroscope

**Library** GNC/Navigation

## Description



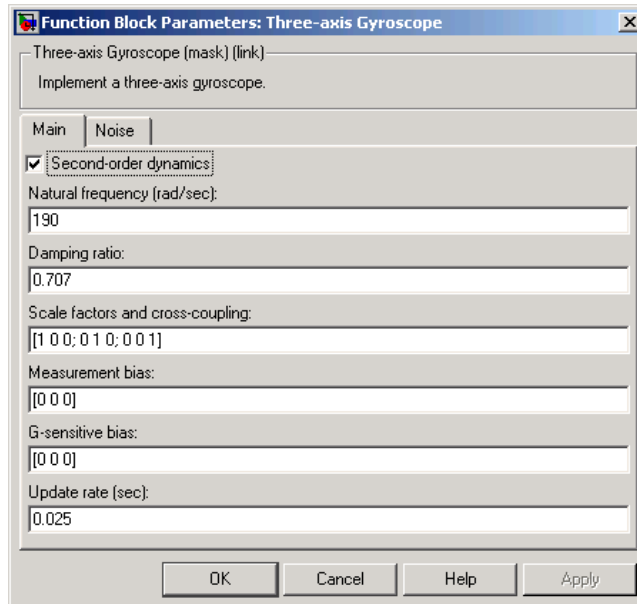
The Three-Axis Gyroscope block implements a gyroscope on each of the three axes. The measured body angular rates ( $\underline{\omega}_{meas}$ ) include the body angular rates ( $\underline{\omega}_b$ ), errors, and optionally discretizations and nonlinearizations of the signals.

$$\underline{\omega}_{meas} = \underline{\omega}_b \cdot \underline{\omega}_{SFCC} + \underline{\omega}_{bias} + Gs \cdot \underline{\omega}_{gsens} + noise$$

where  $\underline{\omega}_{SFCC}$  is a 3-by-3 matrix of scaling factors on the diagonal and misalignment terms in the nondiagonal,  $\underline{\omega}_{bias}$  are the biases, ( $Gs$ ) are the Gs on the gyroscope, and  $\underline{\omega}_{gsens}$  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.

## Dialog Box



Function Block Parameters: Three-axis Gyroscope

Three-axis Gyroscope (mask) (link)  
Implement a three-axis gyroscope.

Main | Noise

Second-order dynamics

Natural frequency (rad/sec):  
190

Damping ratio:  
0.707

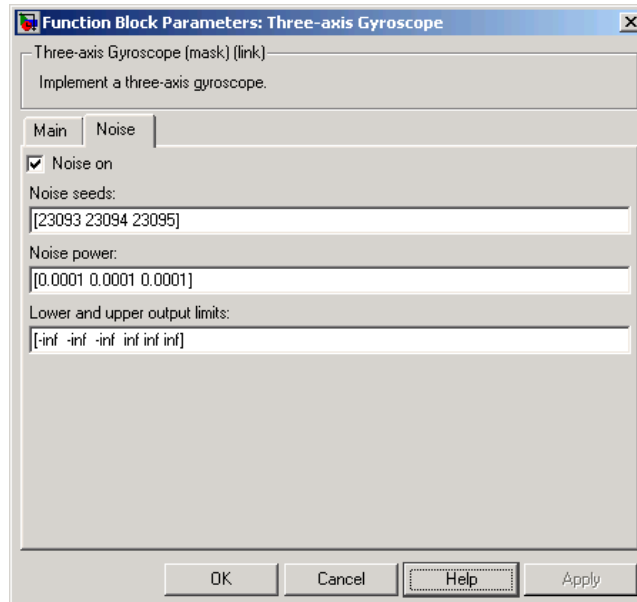
Scale factors and cross-coupling:  
[1 0 0; 0 1 0; 0 0 1]

Measurement bias:  
[0 0 0]

G-sensitive bias:  
[0 0 0]

Update rate (sec):  
0.025

OK Cancel Help Apply



Function Block Parameters: Three-axis Gyroscope

Three-axis Gyroscope (mask) (link)  
Implement a three-axis gyroscope.

Main | Noise

Noise on

Noise seeds:  
[23093 23094 23095]

Noise power:  
[0.0001 0.0001 0.0001]

Lower and upper output limits:  
[-inf -inf -inf inf inf inf]

OK Cancel Help Apply

# Three-Axis Gyroscope

---

## **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's.

## **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.

## **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.

## 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

The first input is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The second input is a three-element vector containing the accelerations in body-fixed axes, in G's.

The output is a three-element vector containing the measured angular rates from the gyroscope, in radians per second.

## Assumptions and Limitations

Anisoelastic bias and aniso inertial bias effects are not accounted for in this block. Additionally, it is not the intention of this block to model the internal dynamics of differing forms of instrument.

This block requires the Control System Toolbox.

## References

Rogers, R. M., *Applied Mathematics in Integrated Navigation Systems*, AIAA Education Series, 2000.

## See Also

Three-Axis Accelerometer

Three-Axis Inertial Measurement Unit

# Three-Axis Inertial Measurement Unit

**Purpose** Implement a three-axis inertial measurement unit (IMU)

**Library** GNC/Navigation

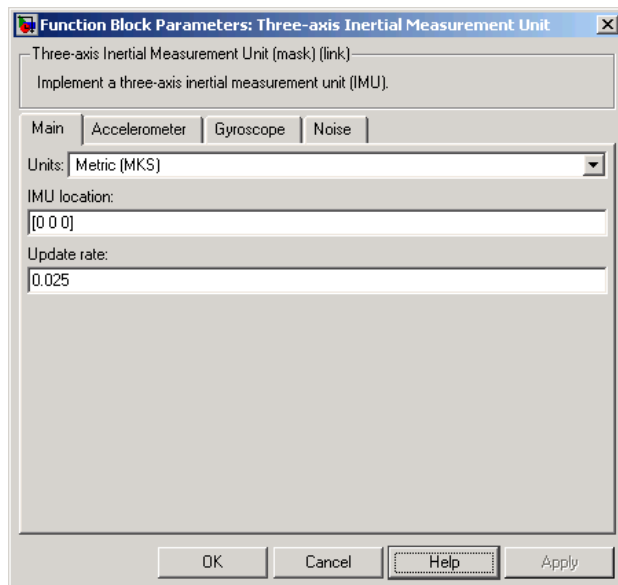
## Description

$A_b$ ( $m/s^2$ )	$A_{mass}$ ( $m/s^2$ )
$\omega$ (rad/s)	
$d\omega/dt$	
$CG$ (m)	$\omega_{mass}$ (rad/s)
$g$ ( $m/s^2$ )	

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.

## Dialog Box





# Three-Axis Inertial Measurement Unit

Function Block Parameters: Three-axis Inertial Measurement Unit

Three-axis Inertial Measurement Unit (mask) (link)  
Implement a three-axis inertial measurement unit (IMU).

Main Accelerometer Gyroscope Noise

Second-order dynamics for accelerometer

Accelerometer natural frequency (rad/sec):  
190

Accelerometer damping ratio:  
0.707

Accelerometer scale factor and cross-coupling:  
[1 0 0; 0 1 0; 0 0 1]

Accelerometer measurement bias:  
[0 0 0]

Accelerometer upper and lower limits:  
[-inf -inf -inf inf inf inf]

OK Cancel Help Apply

Function Block Parameters: Three-axis Inertial Measurement Unit

Three-axis Inertial Measurement Unit (mask) (link)  
Implement a three-axis inertial measurement unit (IMU).

Main Accelerometer Gyroscope Noise

Second-order dynamics for gyro

Gyro natural frequency (rad/sec):  
190

Gyro damping ratio:  
0.707

Gyro scale factors and cross-coupling:  
[1 0 0; 0 1 0; 0 0 1]

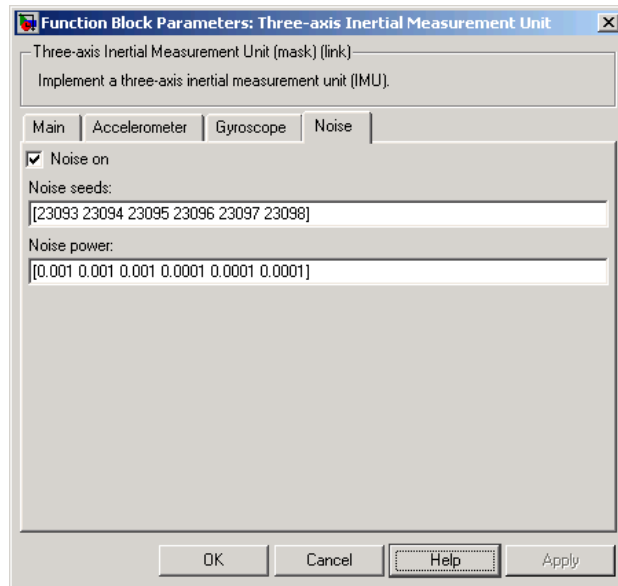
Gyro measurement bias:  
[0 0 0]

G-sensitive bias:  
[0 0 0]

Gyro upper and lower limits:  
[-inf -inf -inf inf inf inf]

OK Cancel Help Apply

# Three-Axis Inertial Measurement Unit



## 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

# Three-Axis Inertial Measurement Unit

---

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.

## **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.

# Three-Axis Inertial Measurement Unit

---

## **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's.

## **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**

The first input is a three-element vector containing the actual accelerations in body-fixed axes, in selected units.

The second input is a three-element vector containing the angular rates in body-fixed axes, in radians per second.

The third input is a three-element vector containing the angular accelerations in body-fixed axes, in radians per second squared.

The fourth input is a three-element vector containing the location of the center of gravity, in selected units.

The fifth input is a three-element vector containing the gravity, in selected units.

The first output is a three-element vector containing the measured accelerations from the accelerometer, in selected units.

# Three-Axis Inertial Measurement Unit

---

The second output is a three-element vector containing the measured angular rates from the gyroscope, in radians per second.

## **Assumptions and Limitations**

Vibro-pendulous error, hysteresis affects, anisoelastic bias and anisoinertial bias are not accounted for in this block. Additionally, it is not the intention of this block to model the internal dynamics of differing forms of instrument.

This block requires the Control System Toolbox.

## **Examples**

See the asbh120 demo for an example of this block.

## **References**

Rogers, R. M., *Applied Mathematics in Integrated Navigation Systems*, AIAA Education Series, 2000.

## **See Also**

Three-Axis Accelerometer

Three-Axis Gyroscope

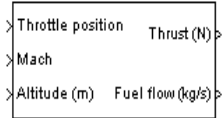
# Turbofan Engine System

---

**Purpose** Implement a first-order representation of a 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  $\delta$  and relative temperature ratio  $\theta$ , 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.

## Dialog Box

**Block Parameters: Turbofan Engine System**

Turbofan Engine System (mask) (link)

Implement a turbofan engine system. The turbofan engine system includes both engine and controller.

Throttle position can vary from zero to one, corresponding to no to full throttle. Altitude, initial thrust, and maximum thrust are entered in the same unit system as selected from the block for thrust and fuel flow output.

Parameters

Units: Metric (MKS)

Initial thrust source: Internal

Initial thrust: 0

Maximum sea-level static thrust: 45000

Fastest engine time constant at sea-level static (sec): 1

Sea-level static thrust specific fuel consumption: 0.35

Ratio of installed thrust to uninstalled thrust: 0.9

OK Cancel Help Apply

## 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.

# Turbofan Engine System

---

## **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**

The first input is the throttle position. Throttle position can vary from zero to one, corresponding to no to full throttle.

The second input is the Mach number.

The third input is the altitude in specified length units.

The first output is the thrust in specified force units.

The second output is 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.

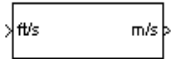
Hill, P. G., and C. R. Peterson, *Mechanics and Thermodynamics of Propulsion*, Addison-Wesley Publishing Company, Reading, MA, 1970.



**Purpose** Convert from velocity units to desired velocity units

**Library** Utilities/Unit Conversions

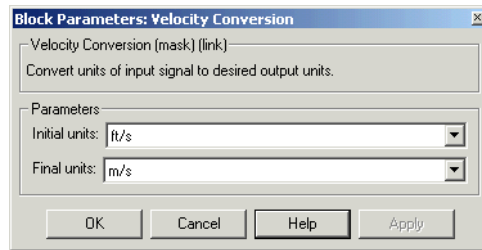
## Description



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 units** and the **Final units** lists.

## Dialog Box



### Initial units

Specifies the input units.

### Final units

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

# Velocity Conversion

---

## **Inputs and Outputs**

The input is the velocity in initial velocity units.

The output is 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

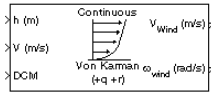
Temperature Conversion

# Von Karman Wind Turbulence Model (Continuous)

**Purpose** Generate continuous wind turbulence with the 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  $\Omega$  radians per meter, the circular frequency  $\omega$  is calculated by multiplying  $V$  by  $\Omega$ . The following table displays the component spectra functions:

	<b>MIL-F-8785C</b>	<b>MIL-HDBK-1797</b>
Longitudinal	$\Phi_u(\omega) = \frac{2\sigma_u^2 L_u}{\pi V} \cdot \frac{1}{[1 + (1.339 L_u \frac{\omega}{V})^2]^{5/6}}$	$\frac{2\sigma_u^2 L_u}{\pi V} \cdot \frac{1}{[1 + (1.339 L_u \frac{\omega}{V})^2]^{5/6}}$
	$\Phi_p(\omega) = \frac{\sigma_w^2}{V L_w} \cdot \frac{0.8 \left(\frac{\pi L_w}{4b}\right)^{\frac{1}{3}}}{1 + \left(\frac{4b\omega}{\pi V}\right)^2}$	$\frac{\sigma_w^2}{2V L_w} \cdot \frac{0.8 \left(\frac{2\pi L_w}{4b}\right)^{\frac{1}{3}}}{1 + \left(\frac{4b\omega}{\pi V}\right)^2}$

# Von Karman Wind Turbulence Model (Continuous)

	<b>MIL-F-8785C</b>	<b>MIL-HDBK-1797</b>
Lateral		
$\Phi_v(\omega)$	$\frac{\sigma_v^2 L_v}{\pi V} \cdot \frac{1 + \frac{8}{3}(1.339L_v \frac{\omega}{V})^2}{[1 + (1.339L_v \frac{\omega}{V})^2]^{11/6}}$	$\frac{2\sigma_v^2 L_v}{\pi V} \cdot \frac{1 + \frac{8}{3}(2.678L_v \frac{\omega}{V})^2}{[1 + (2.678L_v \frac{\omega}{V})^2]^{11/6}}$
$\Phi_r(\omega)$	$\frac{\mp \left(\frac{\omega}{V}\right)^2}{1 + \left(\frac{3b\omega}{\pi V}\right)^2} \cdot \Phi_v(\omega)$	$\frac{\mp \left(\frac{\omega}{V}\right)^2}{1 + \left(\frac{3b\omega}{\pi V}\right)^2} \cdot \Phi_v(\omega)$
Vertical		
$\Phi_w(\omega)$	$\frac{\sigma_w^2 L_w}{\pi V} \cdot \frac{1 + \frac{8}{3}(1.339L_w \frac{\omega}{V})^2}{[1 + (1.339L_w \frac{\omega}{V})^2]^{11/6}}$	$\frac{2\sigma_w^2 L_w}{\pi V} \cdot \frac{1 + \frac{8}{3}(2.678L_w \frac{\omega}{V})^2}{[1 + (2.678L_w \frac{\omega}{V})^2]^{11/6}}$
$\Phi_q(\omega)$	$\frac{\pm \left(\frac{\omega}{V}\right)^2}{1 + \left(\frac{4b\omega}{\pi V}\right)^2} \cdot \Phi_w(\omega)$	$\frac{\pm \left(\frac{\omega}{V}\right)^2}{1 + \left(\frac{4b\omega}{\pi V}\right)^2} \cdot \Phi_w(\omega)$

The variable  $b$  represents the aircraft wingspan. The variables  $L_u, L_v, L_w$  represent the turbulence scale lengths. The variables  $\sigma_u, \sigma_v, \sigma_w$  represent the turbulence intensities:

# Von Karman Wind Turbulence Model (Continuous)

The spectral density definitions of turbulence angular rates are defined in the references as three variations, which are displayed in the following table:

$$p_g = \frac{\partial w_g}{\partial y} \quad q_g = \frac{\partial w_g}{\partial x} \quad r_g = -\frac{\partial v_g}{\partial x}$$

$$p_g = \frac{\partial w_g}{\partial y} \quad r_g = \frac{\partial v_g}{\partial x}$$

$$q_g = \frac{\partial w_g}{\partial x}$$

$$p_g = -\frac{\partial w_g}{\partial y} \quad q_g = -\frac{\partial w_g}{\partial x} \quad r_g = \frac{\partial v_g}{\partial x}$$

The variations affect only the vertical ( $q_g$ ) and lateral ( $r_q$ ) 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

$$\Phi_q(\omega) \quad -\Phi_r(\omega)$$

$$\Phi_q(\omega) \quad \Phi_r(\omega)$$

$$-\Phi_q(\omega) \quad \Phi_r(\omega)$$

# Von Karman Wind Turbulence Model (Continuous)

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

$$H_u(s) = \frac{\sigma_u \sqrt{\frac{2}{\pi}} \cdot \frac{L_u}{V} (1 + 0.25 \frac{L_u}{V} s)}{1 + 1.357 \frac{L_u}{V} s + 0.1987 (\frac{L_u}{V})^2 s^2}$$

$$H_p(s) = \sigma_w \sqrt{\frac{0.8}{V}} \frac{\left(\frac{\pi}{4b}\right)^{1/6}}{L_w^{1/3} \left(1 + \left(\frac{4b}{\pi V}\right) s\right)}$$

Lateral

$$H_v(s) = \frac{\sigma_v \sqrt{\frac{1}{\pi}} \cdot \frac{L_v}{V} (1 + 2.7478 \frac{L_v}{V} s + 0.3398 (\frac{L_v}{V})^2 s^2)}{1 + 2.9958 \frac{L_v}{V} s + 1.9754 (\frac{L_v}{V})^2 s^2 + 0.1539 (\frac{L_v}{V})^3 s^3}$$

$$H_r(s) = \frac{\mp \frac{s}{V}}{\left(1 + \left(\frac{3b}{\pi V}\right) s\right)} \cdot H_v(s)$$

# Von Karman Wind Turbulence Model (Continuous)

## MIL-F-8785C

Vertical

$$H_w(s) = \frac{\sigma_w \sqrt{\frac{1}{\pi}} \cdot \frac{L_w}{V} (1 + 2.7478 \frac{L_w}{V} s + 0.3398 (\frac{L_w}{V})^2 s^2)}{1 + 2.9958 \frac{L_w}{V} s + 1.9754 (\frac{L_w}{V})^2 s^2 + 0.1539 (\frac{L_w}{V})^3 s^3}$$

$$H_q(s) = \frac{\pm \frac{s}{V}}{(1 + (\frac{4b}{\pi V})s)} \cdot H_w(s)$$

## MIL-HDBK-1797

Longitudinal

$$H_u(s) = \frac{\sigma_u \sqrt{\frac{2}{\pi}} \cdot \frac{L_u}{V} (1 + 0.25 \frac{L_u}{V} s)}{1 + 1.357 \frac{L_u}{V} s + 0.1987 (\frac{L_u}{V})^2 s^2}$$

$$H_p(s) = \sigma_w \sqrt{\frac{0.8}{V}} \frac{\left(\frac{\pi}{4b}\right)^{1/6}}{(2L_w)^{1/3} \left(1 + \left(\frac{4b}{\pi V}\right)s\right)}$$

# Von Karman Wind Turbulence Model (Continuous)

---

## MIL-HDBK-1797

Lateral

$$H_v(s) = \frac{\sigma_v \sqrt{\frac{1}{\pi}} \cdot \frac{2L_v}{V} \left( 1 + 2.7478 \frac{2L_v}{V} s + 0.3398 \left( \frac{2L_v}{V} \right)^2 s^2 \right)}{1 + 2.9958 \frac{2L_v}{V} s + 1.9754 \left( \frac{2L_v}{V} \right)^2 s^2 + 0.1539 \left( \frac{2L_v}{V} \right)^3 s^3}$$

$$H_r(s) = \frac{\mp \frac{s}{V}}{\left( 1 + \left( \frac{3b}{\pi V} \right) s \right)} \cdot H_v(s)$$

Vertical

$$H_w(s) = \frac{\sigma_w \sqrt{\frac{1}{\pi}} \cdot \frac{2L_w}{V} \left( 1 + 2.7478 \frac{2L_w}{V} s + 0.3398 \left( \frac{2L_w}{V} \right)^2 s^2 \right)}{1 + 2.9958 \frac{2L_w}{V} s + 1.9754 \left( \frac{2L_w}{V} \right)^2 s^2 + 0.1539 \left( \frac{2L_w}{V} \right)^3 s^3}$$

$$H_q(s) = \frac{\pm \frac{s}{V}}{\left( 1 + \left( \frac{4b}{\pi V} \right) s \right)} \cdot H_w(s)$$

Divided into two distinct regions, the turbulence scale lengths and intensities are functions of altitude.

---

**Note** The same transfer functions result after evaluating the turbulence scale lengths. The differences in turbulence scale lengths and turbulence transfer functions balance offset.

---



# Von Karman Wind Turbulence Model (Continuous)

## 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

$$L_w = h$$

$$2L_w = h$$

$$L_u = L_v = \frac{h}{(0.177 + 0.000823h)^{1.2}}$$

$$L_u = 2L_v = \frac{h}{(0.177 + 0.000823h)^{1.2}}$$

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.

# Von Karman Wind Turbulence Model (Continuous)

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## 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

$$L_u = L_v = L_w = 2500 \text{ ft}$$

### MIL-HDBK-1797

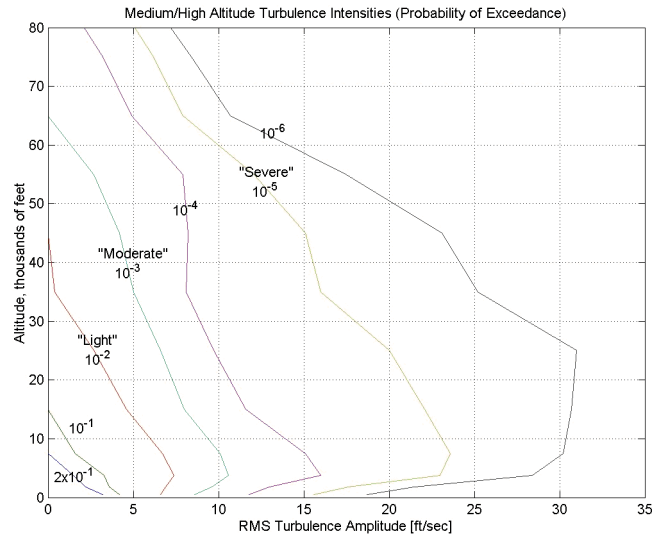
$$L_u = 2L_v = 2L_w = 2500 \text{ ft}$$

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.

$$\sigma_u = \sigma_v = \sigma_w$$

# Von Karman Wind Turbulence Model (Continuous)

The turbulence axes orientation in this region is defined as being aligned with the body coordinates:

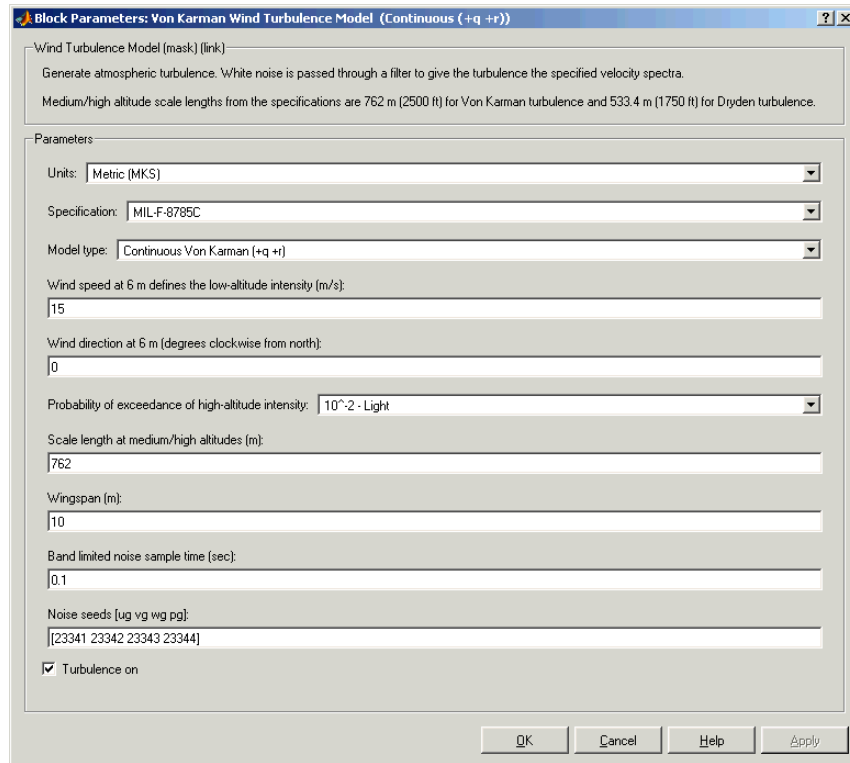


## Between Low and Medium/High Altitudes (1000 feet < Altitude < 2000 feet)

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.

# Von Karman Wind Turbulence Model (Continuous)

## Dialog Box



## Units

Define the units of wind speed due to the turbulence.

Units	Wind Velocity	Altitude	Air Speed
Metric (MKS)	Meters/second	Meters	Meters/second
English (Velocity in ft/s)	Feet/second	Feet	Feet/second
English (Velocity in kts)	Knots	Feet	Knots

# Von Karman Wind Turbulence Model (Continuous)

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## 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 Kármán (+q -r) Use continuous representation of Von Kármán velocity spectra with positive vertical and negative lateral angular rates spectra.

Continuous Von Kármán (+q +r) Use continuous representation of Von Kármán velocity spectra with positive vertical and lateral angular rates spectra.

Continuous Von Kármán (-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.

# Von Karman Wind Turbulence Model (Continuous)

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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.

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## **Wingspan**

The wingspan is required in the calculation of the turbulence on the angular rates.

# Von Karman Wind Turbulence Model (Continuous)

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## **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**

The first input is the altitude in units selected.

The second input is the aircraft speed in units selected.

The third input is a direction cosine matrix.

The first output is a three-element signal containing the turbulence velocities, in the selected units.

The second output is a three-element signal containing 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.

# Von Karman Wind Turbulence Model (Continuous)

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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 factors (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.

Hoblitt, 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.



# Von Karman Wind Turbulence Model (Continuous)

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## **See Also**

Dryden Wind Turbulence Model (Continuous)

Dryden Wind Turbulence Model (Discrete)

Discrete Wind Gust Model

Wind Shear Model

# WGS84 Gravity Model

**Purpose** Implement the 1984 World Geodetic System (WGS84) representation of Earth's gravity

**Library** Environment/Gravity

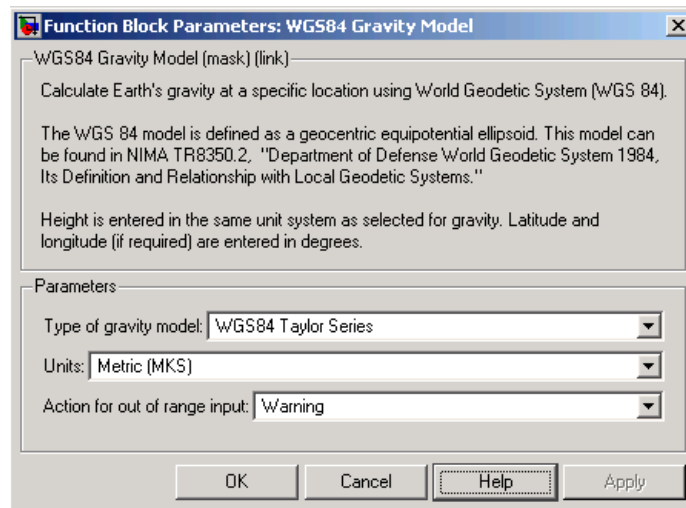
## Description



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.

## Dialog Box



### 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:

<b>Units</b>	<b>Height</b>	<b>Gravity</b>
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 only available 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. In order 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 only available with **Type of gravity model WGS84 Close Approximation** or **WGS84 Exact**.

## Month

Specifies the month used to calculate Julian Centuries from Epoch J2000.0.

This option is only available with **Type of gravity model WGS84 Close Approximation** or **WGS84 Exact** and only when Precessing reference frame is selected.

## Day

Specifies the day used to calculate Julian Centuries from Epoch J2000.0.

# WGS84 Gravity Model

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This option is only available with **Type of gravity model WGS84 Close Approximation** or **WGS84 Exact** and only when Precessing reference frame is selected.

## **Year**

Specifies the year used to calculate Julian Centuries from Epoch J2000.0. The year must be 2000 or greater.

This option is only available with **Type of gravity model WGS84 Close Approximation** or **WGS84 Exact** and only when Precessing reference frame is selected.

## **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 only available 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**

The first input is a scalar containing the altitude in specified length units.

The second input is a scalar containing the latitude in degrees.

The third input is a scalar containing the longitude in degrees. This input is only available with **Type of Gravity Model WGS84 Close Approximation** or **WGS84 Exact**.

The output is a scalar value of gravity with the direction normal to the Earth's surface.

## **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.

Use of the WGS84 Close Approximation model should be limited to a geodetic height of 20000.0 m (approximately 65620.0 feet). Below this height, it gives results with submicrogal precision.

## **Examples**

See the Airframe subsystem in the `aerob1k_HL20` model for an example of this block.

## **References**

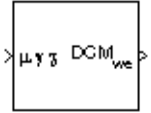
[1] NIMA TR8350.2: “Department of Defense World Geodetic System 1984, Its Definition and Relationship with Local Geodetic Systems.”

# Wind Angles to Direction Cosine Matrix

**Purpose** 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  $(ox_3, oy_3, oz_3)$  into coincidence with  $(ox_0, oy_0, oz_0)$  is first a rotation about  $ox_3$  through the bank angle ( $\mu$ ) to axes  $(ox_2, oy_2, oz_2)$ . Second a rotation about  $oy_2$  through the flight path angle ( $\gamma$ ) to axes  $(ox_1, oy_1, oz_1)$ , and finally a rotation about  $oz_1$  through the heading angle ( $\chi$ ) to axes  $(ox_0, oy_0, oz_0)$ .

$$\begin{bmatrix} ox_3 \\ oy_3 \\ oz_3 \end{bmatrix} = DCM_{we} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

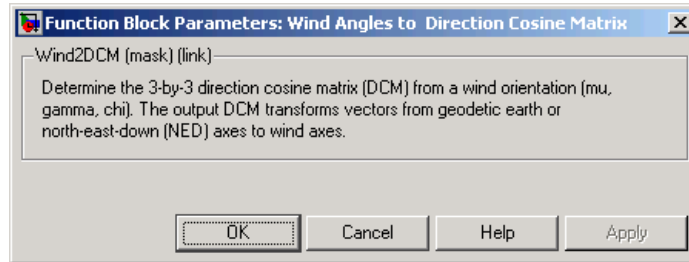
$$\begin{bmatrix} ox_3 \\ oy_3 \\ oz_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\mu & \sin\mu \\ 0 & -\sin\mu & \cos\mu \end{bmatrix} \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix} \begin{bmatrix} \cos\chi & \sin\chi & 0 \\ -\sin\chi & \cos\chi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} ox_0 \\ oy_0 \\ oz_0 \end{bmatrix}$$

Combining the three axis transformation matrices defines the following DCM.

$$DCM_{we} = \begin{bmatrix} \cos\gamma\cos\chi & \cos\gamma\sin\chi & -\sin\gamma \\ (\sin\mu\sin\gamma\cos\chi - \cos\mu\sin\chi) & (\sin\mu\sin\gamma\sin\chi + \cos\mu\cos\chi) & \sin\mu\cos\gamma \\ (\cos\mu\sin\gamma\cos\chi + \sin\mu\sin\chi) & (\cos\mu\sin\gamma\sin\chi - \sin\mu\cos\chi) & \cos\mu\cos\gamma \end{bmatrix}$$

# Wind Angles to Direction Cosine Matrix

## Dialog Box



## Inputs and Outputs

The input is a 3-by-1 vector of wind angles, in radians.

The output is a 3-by-3 direction cosine matrix which transforms earth vectors to wind vectors.

## Assumptions and Limitations

This implementation generates a flight path angle that lies between  $\pm 90$  degrees, and bank and heading angles that lie between  $\pm 180$  degrees.

## See Also

Direction Cosine Matrix Body to Wind

Direction Cosine Matrix to Euler Angles

Direction Cosine Matrix to Wind Angles

Euler Angles to Direction Cosine Matrix

# Wind Angular Rates

## Purpose

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

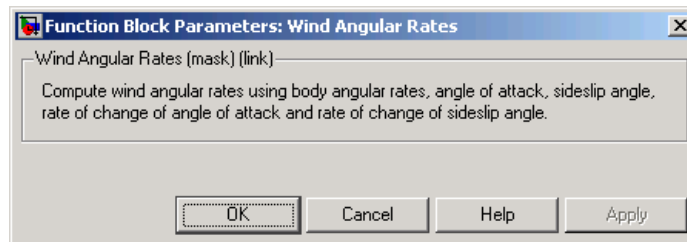
## Description



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  $(\alpha)$ , sideslip angle  $(\beta)$ , 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.

$$\begin{bmatrix} p_w \\ q_w \\ r_w \end{bmatrix} = \begin{bmatrix} \cos \alpha \cos \beta & \sin \beta & \sin \alpha \cos \beta \\ -\cos \alpha \sin \beta & \cos \beta & -\sin \alpha \sin \beta \\ -\sin \alpha & 0 & \cos \alpha \end{bmatrix} \begin{bmatrix} p_b - \dot{\beta} \sin \alpha \\ q_b - \dot{\alpha} \\ r_b + \dot{\beta} \cos \alpha \end{bmatrix}$$

## Dialog Box



## Inputs and Outputs

The first input is the 2-by-1 vector containing angle of attack and sideslip, in radians.

The second input is the 2-by-1 vector containing rate of change of angle of attack and rate of change of sideslip, in radians per second.

The third input is the body angular rates, in radians per second.

The output is 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)

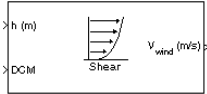
Simple Variable Mass 6DoF Wind (Wind Angles)

# Wind Shear Model

**Purpose** Calculate wind shear conditions

**Library** Environment/Wind

## Description



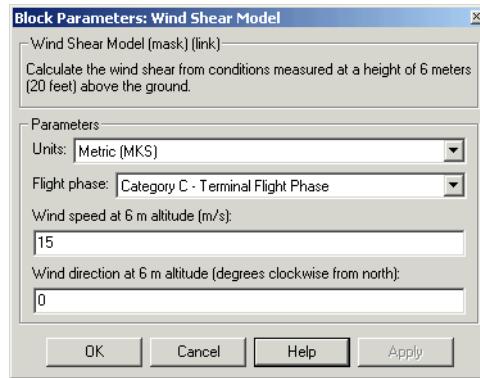
The Wind Shear Model block adds wind shear to the aerospace model. This implementation is based on the mathematical representation in the Military Specification MIL-F-8785C [1]. The magnitude of the wind shear is given by the following equation for the mean wind profile as a function of altitude and the measured wind speed at 20 feet (6 m) above the ground.

$$u_w = W_{20} \frac{\ln\left(\frac{h}{z_0}\right)}{\ln\left(\frac{20}{z_0}\right)}, \quad 3ft < h < 1000ft$$

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 Earth-fixed 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.

## Dialog Box



### Units

Define the units of wind shear.

<b>Units</b>	<b>Wind</b>	<b>Altitude</b>
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 Shear Model

---

## **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**

The first input is the altitude in units selected.

The second input is a 3-by-3 direction cosine matrix.

The output is a 3-by-1 vector of the mean wind speed in the body axes frame, in the selected units.

### **Examples**

See the Airframe subsystem in the aerob1k\_HL20 model for an example of this block.

### **References**

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)

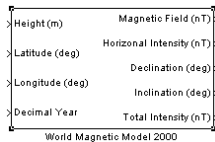
## Purpose

Calculate the Earth's magnetic field at a specific location and time using the 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.

## Dialog Box

The dialog box is titled "Block Parameters: World Magnetic Model 2000". It contains the following text and controls:

- Link: [World Magnetic Model 2000 \(mask\) \(link\)](#)
- Description: Calculate the Earth's magnetic field at a specific location and time using the World Magnetic Model (WMM). This model is valid for the year 2000 through the year 2005.
- Source information: The WMM-2000 can be found on the web at <http://wmm.ngdc.noaa.gov/DoD/WMM.shtml> and in "British Geological Survey, Technical Report 'WM/00/17R, Geomagnetism Series'".
- Units: Metric (MKS) (dropdown menu)
- Input decimal year
- Month: January (dropdown menu)
- Day: 1 (dropdown menu)
- Year: 2000 (dropdown menu)
- Action for out of range input: Error (dropdown menu)
- Output horizontal intensity
- Output declination
- Output inclination
- Output total intensity

Buttons: OK, Cancel, Help, Apply

# World Magnetic Model 2000

---

## Units

Specifies the input and output units:

<b>Units</b>	<b>Height</b>	<b>Magnetic Field</b>	<b>Horizontal Intensity</b>	<b>Total Intensity</b>
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

The first input is the height, in selected units.

The second input is the latitude in degrees.

The third input is the longitude in degrees.

The fourth optional input is 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%%%
year = '2005';
year_selected = str2num(year);
month = 'March';
day = '21';

if (mod(year_selected,400)&&~mod(year_selected,100))
% leapyear = false;
ndays = 365;
elseif ~mod(year_selected,4)
% leapyear = true;
ndays = 366;
else
% leapyear = false;
ndays = 365;
end

day_of_year = datenum([day '-' month '-'
year])-datenum(['1-january-' year]);
dyear = year_selected + day_of_year/ndays;
%%%END CODE%%%
```

The first output is the magnetic field vector in selected units.

The second optional output is the horizontal intensity in selected units.

The third optional output is the declination in degrees.

The fourth optional output is the inclination in degrees.

The fifth optional output is the total intensity in selected units.

# World Magnetic Model 2000

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## 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.

## References

Macmillian, S. and J. M. Quinn, 2000. "The Derivation of the World Magnetic Model 2000," *British Geological Survey Technical Report WM/00/17R*.

<http://www.ngdc.noaa.gov/seg/WMM/DoDWMM.shtml>

## See Also

World Magnetic Model 2005



## Purpose

Calculate the Earth's magnetic field at a specific location and time using the World Magnetic Model 2005 (WMM2005)

## Library

Environment/Gravity

## Description

> Height (m)	Magnetic Field (nT)
> Latitude (deg)	Horizontal Intensity (nT)
> Longitude (deg)	Declination (deg)
> Decimal Year	Inclination (deg)
	Total Intensity (nT)

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.

## Dialog Box

**Function Block Parameters: World Magnetic Model 2005**

World Magnetic Model 2005 (mask) (link)

Calculate the Earth's magnetic field at a specific location and time using the World Magnetic Model (WMM). This model is valid for the year 2005 through the year 2010.

The WMM-2005 can be found on the web at <http://www.ngdc.noaa.gov/seg/DoDWMM.shtml> and in "NOAA Technical Report: The US/UK World Magnetic Model for 2005-2010".

Height is entered in length units of selected unit system. Latitude and longitude are entered in degrees.

Parameters

Units: Metric [MKS]

Input decimal year

Month: January

Day: 1

Year: 2005

Action for out of range input: Error

Output horizontal intensity

Output declination

Output inclination

Output total intensity

OK Cancel Help Apply

# World Magnetic Model 2005

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## Units

Specifies the input and output units:

<b>Units</b>	<b>Height</b>	<b>Magnetic Field</b>	<b>Horizontal Intensity</b>	<b>Total Intensity</b>
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

The first input is the height, in selected units.

The second input is the latitude in degrees.

The third input is the longitude in degrees.

The fourth optional input is 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%%%
year = '2005';
year_selected = str2num(year);
month = 'March';
day = '21';

if (mod(year_selected,400)&&~mod(year_selected,100))
% leapyear = false;
ndays = 365;
elseif ~mod(year_selected,4)
% leapyear = true;
ndays = 366;
else
% leapyear = false;
ndays = 365;
end

day_of_year = datenum([day '-' month '-'
year])-datenum(['1-january-' year]);
dyear = year_selected + day_of_year/ndays;
%%%END CODE%%%
```

The first output is the magnetic field vector in selected units.

The second optional output is the horizontal intensity in selected units.

The third optional output is the declination in degrees.

The fourth optional output is the inclination in degrees.

The fifth optional output is the total intensity in selected units.

# World Magnetic Model 2005

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## 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.

## References

<http://www.ngdc.noaa.gov/seg/WMM/DoDWMM.shtml>

## See Also

World Magnetic Model 2000

# Aerospace Units

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The main blocks of the Aerospace Blockset support standard measurement systems. The Unit Conversion blocks support all units listed in the following table.

<b>Quantity</b>	<b>Metric (MKS)</b>	<b>English</b>
Acceleration	meters/second <sup>2</sup> (m/s <sup>2</sup> ), kilometers/second <sup>2</sup> (km/s <sup>2</sup> ), (kilometers/hour)/second (km/h*s), g-unit (G's)	inches/second <sup>2</sup> (in/s <sup>2</sup> ), feet/second <sup>2</sup> (ft/s <sup>2</sup> ), (miles/hour)/second (mph/s), g-unit (G's)
Angle	radian (rad), degree (deg), revolution	radian (rad), degree (deg), revolution
Angular acceleration	radians/second <sup>2</sup> (rad/s <sup>2</sup> ), degrees/second <sup>2</sup> (deg/s <sup>2</sup> ), revolutions/minute (rpm), revolutions/second (rps)	radians/second <sup>2</sup> (rad/s <sup>2</sup> ), degrees/second <sup>2</sup> (deg/s <sup>2</sup> ), 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 <sup>3</sup> (kg/m <sup>3</sup> )	pound mass/foot <sup>3</sup> (lbm/ft <sup>3</sup> ), slug/foot <sup>3</sup> (slug/ft <sup>3</sup> ), pound mass/inch <sup>3</sup> (lbm/in <sup>3</sup> )
Force	Newton (N)	pound (lb)
Inertia	kilogram-meter <sup>2</sup> (kg-m <sup>2</sup> )	slug-foot <sup>2</sup> (slug-ft <sup>2</sup> )
Length	meter (m)	inch (in), foot (ft), mile (mi), nautical mile (nm)
Mass	kilogram (kg)	slug (slug), pound mass (lbm)

---

<b>Quantity</b>	<b>Metric (MKS)</b>	<b>English</b>
Pressure	Pascal	pound/inch <sup>2</sup> (psi), pound/foot <sup>2</sup> (psf), atmosphere (atm)
Temperature	Kelvin, Celsius	Fahrenheit, Rankine
Velocity	meters/second (m/s), kilometers/second (km/s), kilometers/hour (km/h)	inches/second (in/sec), feet/second (ft/sec), feet/minute (ft/min), miles/hour (mph), knots





## A

- Acceleration Conversion block 4-116
- Actuators library 2-2
- Adjoint of 3x3 Matrix block 4-118
- Aerodynamic Forces and Moments block 4-120
- Aerodynamics library 2-2
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