

Embedded Coder®
Getting Started Guide



MATLAB® & SIMULINK®

R2022b



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Embedded Coder[®] Getting Started Guide

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Revision History

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March 2022	Online only	Revised for Version 7.8 (Release 2022a)
September 2022	Online only	Revised for Version 7.9 (Release 2022b)

Check Bug Reports for Issues and Fixes

Software is inherently complex and is not free of errors. The output of a code generator might contain bugs, some of which are not detected by a compiler. MathWorks reports critical known bugs brought to its attention on its Bug Report system at www.mathworks.com/support/bugreports/. In the search bar, type the phrase "Incorrect Code Generation" to obtain a report of known bugs that produce code that might compile and execute, but still produce wrong answers. To save a search, click Save Search.

The bug reports are an integral part of the documentation for each release. Examine periodically all bug reports for a release, as such reports may identify inconsistencies between the actual behavior of a release you are using and the behavior described in this documentation.

In addition to reviewing bug reports, you should implement a verification and validation strategy to identify potential bugs in your design, code, and tools.

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Product Overview

- “Embedded Coder Product Description” on page 1-2
- “Code Generation by Using Embedded Coder” on page 1-3
- “Validation and Verification for System Development” on page 1-6
- “Target Environments and Applications” on page 1-20

Embedded Coder Product Description

Generate C and C++ code optimized for embedded systems

Embedded Coder generates readable, compact, and fast C and C++ code for embedded processors used in mass production. It extends MATLAB® Coder™ and Simulink® Coder with advanced optimizations for precise control of the generated functions, files, and data. These optimizations improve code efficiency and facilitate integration with legacy code, data types, and calibration parameters. You can incorporate a third-party development tool to build an executable for turnkey deployment on your embedded system or rapid prototyping board.

Embedded Coder offers built-in support for AUTOSAR, MISRA C®, and ASAP2 software standards. It also provides traceability reports, code documentation, and automated software verification to support DO178, IEC 61508, and ISO 26262 software development. Embedded Coder code is portable, and can be compiled and executed on any processor. In addition, it offers support packages with advanced optimizations and device drivers for specific hardware.

Key Features

- Optimization and code configuration options extending MATLAB Coder and Simulink Coder
- Storage class, type, and alias definition using data dictionaries
- Multirate, multitask, and multicore code execution with or without an RTOS
- Code verification, including SIL and PIL testing, custom comments, and code reports with tracing of models to and from code and requirements
- Standards support, including ASAP2, AUTOSAR, DO-178, IEC 61508, ISO 26262, and MISRA C (with Simulink)
- Advanced code optimizations and device drivers for specific hardware, including ARM®, Intel®, NXP™, STMicroelectronics®, and Texas Instruments™

Code Generation by Using Embedded Coder

Code Generation Technology

MathWorks® code generation technology produces C or C++ code and executable programs for algorithms. You can write algorithms programmatically by using MATLAB or graphically in the Simulink environment. You can generate code for MATLAB functions and Simulink blocks that are useful for real-time and embedded applications. Generated source code and executable programs for floating-point algorithms match the functional behavior of MATLAB code execution and Simulink simulations to a high degree of fidelity. Using the Fixed-Point Designer product, you can generate fixed-point code that provides a bitwise match to model simulation results. Such broad support and high degree of accuracy are possible because code generation is tightly integrated with the MATLAB and Simulink execution and simulation engines. The built-in accelerated simulation modes in Simulink use code generation technology.

Code generation technology and related products provide tooling that you can apply to the V-model for system development. The V-model is a representation of system development that highlights verification and validation steps in the development process. For more information, see “Validation and Verification for System Development” on page 1-6.

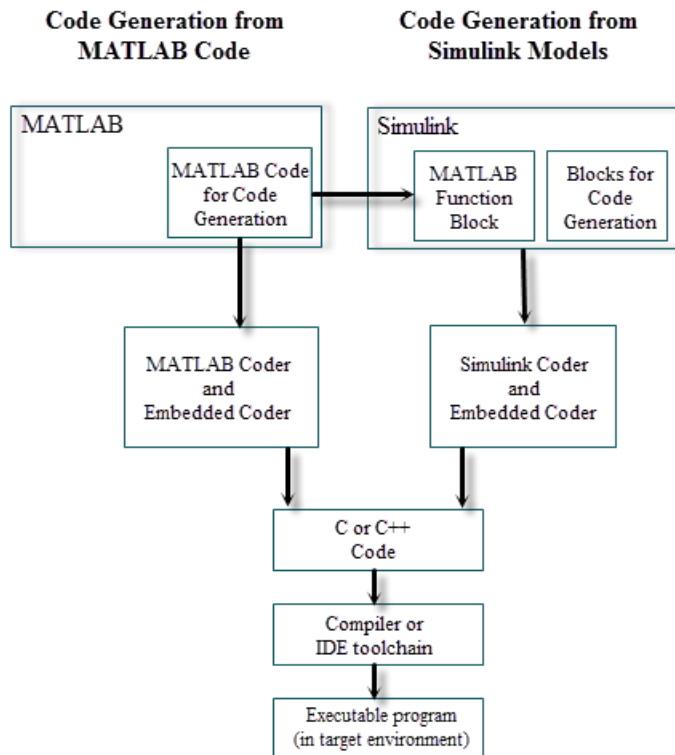
To learn about model design patterns that include Simulink blocks, Stateflow® charts, and MATLAB functions, and map to commonly used C constructs, see “Modeling Patterns for C Code Constructs”.

Code Generation Workflows with Embedded Coder

The Embedded Coder product *extends* the MATLAB Coder and Simulink Coder products with features that you can use for embedded software development. Using the Embedded Coder product, you can generate code that has the clarity and efficiency of handwritten code. For example, you can:

- Generate code that is compact and fast, which is essential for real-time simulators, rapid prototyping boards, microprocessors used in mass production, and embedded systems.
- Customize the appearance of the generated code.
- Optimize generated code for a specific target environment.
- Integrate existing applications, functions, and data.
- Enable tracing, reporting, and testing options that facilitate code verification.

The code generator supports two workflows for designing, implementing, and verifying generated C or C++ code. The following figure shows the design and deployment environment options.



Other products that support code generation, such as Stateflow software, are available.

To develop algorithms with MATLAB code for code generation, see “Code Generation from MATLAB Code” on page 1-4.

To implement algorithms as Simulink blocks and Stateflow charts in a Simulink model, and generate C or C++ code, see “Code Generation from Simulink Models” on page 1-5.

Code Generation from MATLAB Code

Code generation from the MATLAB code workflow with Embedded Coder requires the following products:

- MATLAB
- MATLAB Coder
- Embedded Coder

MATLAB Coder supports a subset of core MATLAB language features, including program control constructs, functions, and matrix operations. To generate C or C++ code, you can use MATLAB Coder projects or enter the function `codegen` in the MATLAB Command Window. Embedded Coder provides additional options and advanced optimizations for fine-grain control of generated code functions, files, and data. For more information about these options and optimizations, see “Embedded Coder Capabilities for Code Generation from MATLAB Code” on page 2-2.

For more information about generating code from MATLAB code, see “Code Generation Workflow”.

To get started generating code from MATLAB code using Embedded Coder, see “Embedded Coder Capabilities for Code Generation from MATLAB Code” on page 2-2.

Code Generation from Simulink Models

Code generation from the Simulink models workflow with Embedded Coder requires the following products:

- MATLAB
- MATLAB Coder
- Simulink
- Simulink Coder
- Embedded Coder

You can implement algorithms as Simulink blocks and Stateflow charts in a Simulink model. To generate C or C++ code from a Simulink model, Embedded Coder provides features for implementing, configuring, and verifying your model for code generation.

If you have algorithms written in MATLAB code, you can include the MATLAB code in a Simulink model or subsystem by using the MATLAB Function block. When you generate C or C++ code for a Simulink model, the MATLAB code in the MATLAB Function block is generated into C or C++ code and included in the generated source code.

To get started generating code from Simulink models using Embedded Coder, see “Generate C Code from Simulink Models” on page 3-2.

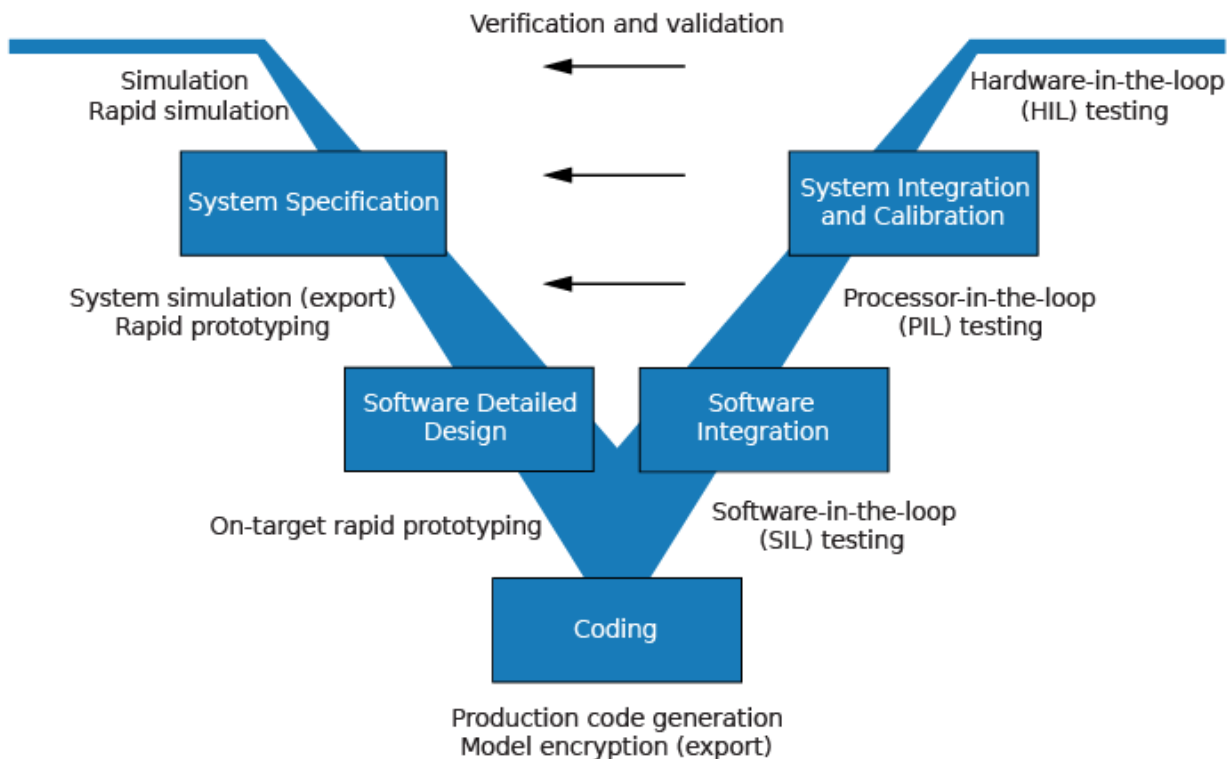
To learn how to model and generate code for commonly used C constructs using Simulink blocks, Stateflow charts, and MATLAB functions, see “Modeling Patterns for C Code Constructs”.

Validation and Verification for System Development

An approach to validating and verifying system development is the V-model.

V-Model for System Development

The V-model is a representation of system development that highlights verification and validation steps in the system development process. The left side of the 'V' identifies steps that lead to code generation, including system specification and detailed software design. The right side of the V focuses on the verification and validation of steps cited on the left side, including software and system integration.



Depending on your application and its role in the process, you might focus on one or more of the steps called out in the V-model or repeat steps at several stages of the V-model. Code generation technology and related products provide tooling that you can apply to the V-model for system development. For more information about how you can apply MathWorks code generation technology and related products to the V-model process, see:

- “Types of Simulation and Prototyping in the V-Model” on page 1-6
- “Types of In-the-Loop Testing in the V-Model” on page 1-7
- “Code Generation Goal Summary” on page 1-8

Types of Simulation and Prototyping in the V-Model

Use the V-model for system development for different types of simulation and prototyping, such as rapid simulation, system simulation, rapid prototyping, and rapid prototyping on target hardware.

This table compares the types of simulation and prototyping identified on the left side of the V-model diagram shown in “V-Model for System Development” on page 1-6.

	Simulation	Rapid Simulation	System Simulation, Rapid Prototyping	Rapid Prototyping on Target Hardware
Purpose	Test and validate functionality of concept model	Refine, test, and validate functionality of concept model in nonreal time	Test new ideas and research	Refine and calibrate design during development process
Execution hardware	Development computer	Development computer Standalone executable runs outside of MATLAB and Simulink environments	PC or nontarget hardware	Embedded computing unit (ECU) or near-production hardware
Code efficiency and I/O latency	Not applicable	Not applicable	Less emphasis on code efficiency and I/O latency	More emphasis on code efficiency and I/O latency
Ease of use and cost	Can simulate component (algorithm or controller) and environment (or plant) Normal mode simulation in Simulink enables you to access, display, and tune data during verification Can accelerate Simulink simulations	Easy to simulate models of hybrid dynamic systems that include components and environment models Ideal for batch or Monte Carlo simulations Can repeat simulations with varying data sets, interactively or programmatically by using scripts, without rebuilding the model Can connect to Simulink to monitor signals and tune parameters	Might require custom real-time simulators and hardware Might be done with inexpensive, off-the-shelf PC hardware and I/O cards	Might use existing hardware for less expense and more convenience

Types of In-the-Loop Testing in the V-Model

This table compares types of in-the-loop testing for verification identified on the right side of the V-model diagram shown in “V-Model for System Development” on page 1-6.

	SIL Simulation	PIL Simulation on Embedded Hardware	PIL Simulation on Instruction Set Simulator	HIL Simulation
Purpose	Verify component source code	Verify component object code	Verify component object code	Verify system functionality
Fidelity and accuracy	Two options: Same source code as target, but might have numerical differences Changes source code to emulate word sizes, but is bit accurate for fixed-point math	Same object code Bit accurate for fixed-point math Cycle accurate because code runs on hardware	Same object code Bit accurate for fixed-point math Might not be cycle accurate	Same executable code Bit accurate for fixed-point math Cycle accurate Use real and emulated system I/O
Execution platforms	Development computer	Target hardware	Development computer	Target hardware
Ease of use and cost	Desktop convenience Executes only in Simulink Reduces hardware cost	Executes on desktop or test bench Uses hardware — process board and cables	Desktop convenience Executes on development computer with Simulink and integrated development environment (IDE) Reduces hardware cost	Executes on test bench or in a lab Uses hardware — processor, embedded computer unit (ECU), I/O devices, and cables
Real-time capability	Not real time	Not real time (between samples)	Not real time (between samples)	Hard real time

Code Generation Goal Summary

These tables list goals that you might have, as you apply code generation technology, and where to find guidance on how to meet those goals.

- Document and Validate Requirements
- Develop System Specification
- Develop Detailed Software Design
- Generate Application Code
- Integrate and Verify Software
- Integrate, Verify, and Calibrate System Components

You can open and run the examples linked below and generate code.

Document and Validate Requirements

Goals	Related Product Information	Examples
Capture requirements in a document, spreadsheet, data base, or requirements management tool	<p>“Simulink Report Generator”</p> <p>Third-party vendor tools such as Microsoft® Word, Microsoft Excel®, raw HTML, or IBM® Rational® DOORS®</p>	
<p>Associate requirements documents with objects in concept models</p> <p>Generate a report on requirements associated with a model</p>	<p>“Requirements Management Interface” (Requirements Toolbox)</p> <p>Bidirectional tracing in Microsoft Word, Microsoft Excel, HTML, and IBM Rational DOORS</p>	slvndemo_fuelsys_docreq
Include requirements links in generated code	“Review and Maintain Requirements Links” (Requirements Toolbox)	rtwdemo_requirements
Trace model elements and subsystems to generated code and vice versa	“Code Analysis and Tracing”	rtwdemo_hyperlinks
Verify, refine, and test concept model in non real time on a development computer	<p>“Model Architecture and Design”</p> <p>“Rapid Prototyping and Real-Time Simulation”</p> <p>“Simulation”</p> <p>“Acceleration”</p>	“Air-Fuel Ratio Control System with Stateflow Charts”
<p>Run standalone rapid simulations</p> <p>Run batch or Monte-Carlo simulations</p> <p>Repeat simulations with varying data sets, interactively or programmatically with scripts, without rebuilding the model</p> <p>Tune parameters and monitor signals interactively</p> <p>Simulate models for hybrid dynamic systems that include components and an environment or plant that requires variable-step solvers and zero-crossing detection</p>	<p>“Accelerate, Refine, and Test Hybrid Dynamic System on Host Computer by Using RSim System Target File”</p> <p>“External Mode Simulations for Parameter Tuning, Signal Monitoring, and Code Execution Profiling”</p>	<p>“Run Rapid Simulations over a Range of Parameter Values”</p> <p>“Run Batch Simulations Without Recompiling Generated Code”</p> <p>“Use MAT-Files to Feed Data to Import Blocks for Rapid Simulations”</p>
Distribute simulation runs across multiple computers	<p>“Simulink Test”</p> <p>“MATLAB Parallel Server”</p> <p>“Parallel Computing Toolbox”</p>	

Develop System Specification

Goals	Related Product Information	Examples
Produce design artifacts for algorithms that you develop in MATLAB code for reviews and archiving	“MATLAB Report Generator”	
Produce design artifacts from Simulink and Stateflow models for reviews and archiving	“System Design Description” (Simulink Report Generator)	“Generate Code Generation Report”
Add one or more components to another environment for system simulation Refine a component model Refine an integrated system model Verify functionality of a model in nonreal time Test a concept model	“Deploy Algorithm Model for Real-Time Rapid Prototyping”	
Schedule generated code	“Absolute and Elapsed Time Computation” “Time-Based Scheduling and Code Generation” “Asynchronous Events”	“Time-Based Scheduling Example Models”
Specify function boundaries of system	“Subsystems”	rtwdemo_atomic rtwdemo_ssreuse rtwdemo_filepart rtwdemo_exporting_functions
Specify components and boundaries for design and incremental code generation	“Component-Based Modeling” “Application and Component Interfaces” “Simulink Modeling Components”	“File Packaging for Models (Code and Data)”
Specify function interfaces so that external software can compile, build, and invoke the generated code	“C Data and Function Interfaces” “C++ Data and Function Interfaces”	rtwdemo_configinterface rtwdemo_configdefaults rtwdemo_fcncntrl
Manage data packaging in generated code for integrating and packaging data	“C Data and Function Interfaces” “C++ Data and Function Interfaces”	rtwdemo_ssreuse rtwdemo_configinterface “File Packaging for Models (Code and Data)”
Generate and control the format of comments and identifiers in generated code	“Code Comments” “Identifiers”	rtwdemo_comments rtwdemo_symbols

Goals	Related Product Information	Examples
Create a zip file that contains generated code files, static files, and dependent data to build generated code in an environment other than your host computer	"Relocate or Share Generated Code"	rtwdemo_buildinfo
Export models for validation in a system simulator using shared libraries	"Package Generated Code as Shared Libraries"	rtwdemo_shrplib
<p>Refine component and environment model designs by rapidly iterating between algorithm design and prototyping</p> <p>Verify whether a component can adequately control a physical system in non-real time</p> <p>Evaluate system performance before laying out hardware, coding production software, or committing to a fixed design</p> <p>Test hardware</p>	<p>"Deployment"</p> <p>"Deployment, Integration, and Supported Hardware"</p>	
Generate code for rapid prototyping	"Generate Modular Function Code for Nonvirtual Subsystems"	rtwdemo_counter rtwdemo_counter_msvc rtwdemo_async
Generate code for rapid prototyping in hard real time, using PCs	"Simulink Real-Time"	"Create and Run Real-Time Application from Simulink Model" (Simulink Real-Time)
Generate code for rapid prototyping in soft real time, using PCs	"Simulink Desktop Real-Time"	sldrtext_vdp (and others)

Develop Detailed Software Design

Goals	Related Product Information	Examples
Refine a model design for representation and storage of data in generated code	<p>“Data Access for Prototyping and Debugging”</p> <p>“Data Representation”</p>	
Select code generation features for deployment	<p>“Run-Time Environment Configuration”</p> <p>“Target Platform Device Customization”</p> <p>“Shared Libraries and Utility Code”</p>	<p>rtwdemo_counter</p> <p>rtwdemo_counter_msvc</p> <p>rtwdemo_async</p> <p>“AUTOSAR Workflow Samples” (AUTOSAR Blockset)</p>
Specify target hardware settings	<p>“Run-Time Environment Configuration”</p> <p>“Target Platform Device Customization”</p>	rtwdemo_targetsettings
Design model variants	<p>“Define, Configure, and Activate Variant Choices in a Variant Subsystem Block”</p> <p>“Variant Systems”</p>	
Specify fixed-point algorithms in Simulink, Stateflow, and the MATLAB language subset for code generation	<p>“Parameter Data Types in the Generated Code”</p> <p>“Fixed-Point Code Generation Support” (Fixed-Point Designer)</p>	<p>rtwdemo_fixpt1</p> <p>“Air-Fuel Ratio Control System with Fixed-Point Data”</p>
Convert a floating-point model or subsystem to a fixed-point representation	“Iterative Fixed-Point Conversion in Simulink” (Fixed-Point Designer)	
Iterate to obtain an optimal fixed-point design, using autoscaling	“Parameter Data Types in the Generated Code”	
Create or rename data types specifically for your application	“Control Data Type Names in Generated Code”	UserDefinedDataTypes
Control the format of identifiers in generated code	“Construction of Generated Identifiers”	rtwdemo_symbols
Specify how signals, tunable parameters, block states, and data objects are declared, stored, and represented in generated code	“Organize Parameter Data into a Structure by Using Struct Storage Class”	rtwdemo_cscpredef
Create a data dictionary for a model	“What Is a Data Dictionary?”	rtwdemo_configinterface
Relocate data segments for generated functions and data using #pragmas for calibration or data access	“Control Data and Function Placement in Memory by Inserting Pragmas”	rtwdemo_memsec

Goals	Related Product Information	Examples
Assess and adjust model configuration parameters based on the application and an expected run-time environment	<p>"Model Configuration"</p> <p>"Model Configuration Set Customization"</p>	<p>"Generate Code Using Simulink Coder"</p> <p>"Generate Code Using Embedded Coder"</p>
Check a model against basic modeling guidelines	"Check Your Model Using the Model Advisor"	rtwdemo_advisor1
Add custom checks to the Simulink Model Advisor	"Create Model Advisor Checks" (Simulink Check)	"Create and Deploy a Model Advisor Custom Configuration" (Simulink Check)
Check a model against custom standards or guidelines	"Check Your Model Using the Model Advisor"	
Check a model against industry standards and guidelines (MathWorks Advisory Board (MAB), IEC 61508, IEC 62304, ISO 26262, EN 50128 and DO-178)	<p>"Standards, Guidelines, and Block Usage"</p> <p>"Check Model Compliance" (Simulink Check)</p>	rtwdemo_iec61508
Obtain model coverage for structural coverage analysis such as MCDC	"Simulink Coverage"	
Prove properties and generate test vectors for models	Simulink Design Verifier™	sldvdemo_cruise_control sldvdemo_cruise_control_verification
Generate reports of models and software designs	<p>"MATLAB Report Generator"</p> <p>"Simulink Report Generator"</p> <p>"System Design Description" (Simulink Report Generator)</p>	"Generate Code Generation Report"
Conduct reviews of your model and software designs with coworkers, customers, and suppliers who do not have Simulink available	"Create Model Web Views" (Simulink Report Generator)	"Compare and Merge Simulink Models Containing Stateflow"
<p>Refine the concept model of your component or system</p> <p>Test and validate the model functionality in real time</p> <p>Test the hardware</p> <p>Obtain real-time profiles and code metrics for analysis and sizing based on your embedded processor</p> <p>Assess the feasibility of the algorithm based on integration with the environment or plant hardware</p>	<p>"Deployment"</p> <p>"Deployment, Integration, and Supported Hardware"</p> <p>"Code Execution Profiling"</p> <p>"Static Code Metrics"</p>	

Goals	Related Product Information	Examples
Generate source code for your models, integrate the code into your production build environment, and run it on existing hardware	"Code Generation" "Source Code Generation"	rtwdemo_counter rtwdemo_counter_msvc rtwdemo_fcnprotoctrl "Configure C++ Class Interface for Rate-Based Models" rtwdemo_async "AUTOSAR Workflow Samples" (AUTOSAR Blockset)
Integrate existing externally written C or C++ code with your model for simulation and code generation	"Block Authoring and Simulation Integration" "External Code Integration"	rtwdemos, select Model Architecture and Design > External Code Integration
Generate code for on-target rapid prototyping on specific embedded microprocessors and IDEs	"Deploy Generated Component Software to Application Target Platforms"	In rtwdemo_vxworks

Generate Application Code

Goals	Related Product Information	Examples
Optimize generated ANSI® C code for production (for example, disable floating-point code, remove termination and error handling code, and combine code entry points into single functions)	“Performance” “Code Efficiency”	rtwdemos, select Performance
Optimize code for a specific run-time environment, using specialized function libraries	“Code Replacement” “Code Replacement” “Code Replacement Customization”	“Optimize Generated Code by Developing and Using Code Replacement Libraries - Simulink”
Control the format and style of generated code	“Model Configuration Parameters: Code Style”	rtwdemo_parentheses
Control comments inserted into generated code	“Model Configuration Parameters: Comments”	rtwdemo_comments
Enter special instructions or tags for postprocessing by third-party tools or processes	“Customize Post-Code-Generation Build Processing”	rtwdemo_buildinfo
Include requirements links in generated code	“Review and Maintain Requirements Links” (Requirements Toolbox)	rtwdemo_requirements
Trace model blocks and subsystems to generated code and vice versa	“Code Analysis and Tracing” “Standards, Guidelines, and Block Usage”	rtwdemo_comments rtwdemo_hyperlinks
Integrate existing externally written code with code generated for a model	“Block Authoring and Simulation Integration” “Deployment, Integration, and Supported Hardware”	rtwdemos, select Model Architecture and Design > External Code Integration
Verify generated code for MISRA C ^a and other run-time violations	“Verification, Testing, and Certification” “Polyspace Bug Finder” “Polyspace Code Prover”	
Protect the intellectual property of component model design and generated code Generate a binary file (shared library)	“Reference Protected Models from Third Parties” “Package Generated Code as Shared Libraries”	
Generate a shared library for a model or subsystem so that it can be shared with a third-party vendor	“Package Generated Code as Shared Libraries”	

Goals	Related Product Information	Examples
Test generated production code with an environment or plant model to verify a conversion of the model to code	“Software-in-the-Loop Simulation”	“Test Generated Code with SIL and PIL Simulations”
Create an S-function wrapper for calling your generated source code from a model running in Simulink	“Write Wrapper S-Function and TLC Files”	
Set up and run SIL tests on your host computer	“Software-in-the-Loop Simulation”	“Test Generated Code with SIL and PIL Simulations”

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Integrate and Verify Software

Goals	Related Product Information	Examples
Integrate existing externally written C or C++ code with a model for simulation and code generation	“Block Authoring and Simulation Integration” “Deployment, Integration, and Supported Hardware”	rtwdemos, select Model Architecture and Design > External Code Integration
Connect to data interfaces for generated C code data structures	“Calibration and Measurement” “Generated Code Interfacing”	rtwdemo_capi rtwdemo_asap2
Control the generation of code interfaces so that external software can compile, build, and invoke the generated code	“Code Interface Configuration”	rtwdemo_fcnprotoctrl
Export virtual and function-call subsystems	“Generate Component Source Code for Export to External Code Base”	rtwdemo_exporting_functions
Include target-specific code	“Code Replacement” “Code Replacement” “Code Replacement Customization”	“Optimize Generated Code by Developing and Using Code Replacement Libraries - Simulink”
Customize and control the build process	“Build Process Customization”	rtwdemo_buildinfo
Create a zip file that contains generated code files, static files, and dependent data to build the generated code in an environment other than your host computer	“Relocate or Share Generated Code”	rtwdemo_buildinfo
Integrate software components as a complete system for testing in the target environment	“Verification, Testing, and Certification”	
Generate source code for integration with specific production environments	“Code Generation” “Source Code Generation”	rtwdemo_async “AUTOSAR Workflow Samples” (AUTOSAR Blockset)
Integrate code for a specific run-time environment, using specialized function libraries	“Code Replacement” “Code Replacement” “Code Replacement Customization”	“Optimize Generated Code by Developing and Using Code Replacement Libraries - Simulink”
Enter special instructions or tags for postprocessing by third-party tools or processes	“Customize Post-Code-Generation Build Processing”	rtwdemo_buildinfo
Integrate existing externally written code with code generated for a model	“Block Authoring and Simulation Integration” “External Code Integration”	rtwdemos, select Model Architecture and Design > External Code Integration

Goals	Related Product Information	Examples
Connect to data interfaces for the generated C code data structures	<p>“Calibration and Measurement”</p> <p>“Generated Code Interfacing”</p>	<p>rtwdemo_capi</p> <p>rtwdemo_asap2</p>
Schedule the generated code	<p>“Timers”</p> <p>“Time-Based Scheduling”</p> <p>“Event-Based Scheduling”</p>	<p>“Time-Based Scheduling Example Models”</p>
Verify object code files in a target environment	<p>“Software-in-the-Loop Simulation”</p>	<p>“Test Generated Code with SIL and PIL Simulations”</p>
Set up and run PIL tests on your target system	<p>“Processor-in-the-Loop Simulation”</p>	<p>“Test Generated Code with SIL and PIL Simulations”</p> <p>“Configure Processor-In-The-Loop (PIL) for a Custom Target”</p> <p>“Create a Target Communication Channel for Processor-in-the-Loop (PIL) Simulation”</p> <p>See the list of supported hardware for the Embedded Coder product on the MathWorks Web site, and then find an example for the related product of interest</p>

Integrate, Verify, and Calibrate System Components

Goals	Related Product Information	Examples
<p>Integrate the software and its microprocessor with the hardware environment for the final embedded system product</p> <p>Add the complexity of the environment (or plant) under control to the test platform</p> <p>Test and verify the embedded system or control unit by using a real-time target environment</p>	<p>“Deploy Algorithm Model for Real-Time Rapid Prototyping”</p> <p>“Deploy Environment Model for Real-Time Hardware-In-the-Loop (HIL) Simulation”</p> <p>“Deploy Applications to Target Hardware”</p> <p>“Deploy Generated Component Software to Application Target Platforms”</p>	
<p>Generate source code for HIL testing</p>	<p>“Code Generation”</p> <p>“Code Generation”</p> <p>“Deploy Environment Model for Real-Time Hardware-In-the-Loop (HIL) Simulation”</p>	
<p>Conduct hard real-time HIL testing using PCs</p>	<p>“Simulink Real-Time”</p>	<p>“Create and Run Real-Time Application from Simulink Model” (Simulink Real-Time)</p> <p>“Real-Time Simulation and Testing” (Simulink Real-Time)</p>
<p>Tune ECU properly for its intended use</p>	<p>“Calibration and Measurement”</p> <p>“Generated Code Interfacing”</p>	<p>rtwdemo_capi</p> <p>rtwdemo_asap2</p>
<p>Generate ASAP2 data files</p>	<p>“Export ASAP2 File for Data Measurement and Calibration”</p>	<p>rtwdemo_asap2</p>
<p>Generate C API data interface files</p>	<p>“Exchange Data Between Generated and External Code Using C API”</p>	<p>rtwdemo_capi</p>

Target Environments and Applications

In this section...

“About Target Environments” on page 1-20

“Types of Target Environments” on page 1-20

“Applications of Supported Target Environments” on page 1-21

About Target Environments

The code generator produces make or project files to build an executable program for a specific target environment. The generated make or project files are optional. If you prefer, you can build an executable program for the generated source files by using an existing target build environment, such as a third-party integrated development environment (IDE). Applications of generated code range from calling a few exported C or C++ functions on a development computer to generating a complete executable program that uses a custom build process for custom hardware, in an environment completely separate from the development computer running MATLAB and Simulink.

The code generator provides built-in system target files that generate, build, and execute code for specific target environments. These system target files offer varying degrees of support for interacting with the generated code to log data, tune parameters, and experiment with or without Simulink as the external interface to your generated code.

Types of Target Environments

Before you select a system target file, identify the target environment on which you expect to execute your generated code. The most common target environments include environments listed in this table.

Target Environment	Description
Development computer	The computer that runs MATLAB and Simulink. A development computer is a PC or UNIX ^{®a} environment that uses a non-real-time operating system, such as Microsoft Windows [®] or Linux ^{®b} . Non-real-time (general purpose) operating systems are nondeterministic. For example, those operating systems might suspend code execution to run an operating system service and then, after providing the service, continue code execution. Therefore, the executable for your generated code might run faster or slower than the sample rates that you specified in your model.

Target Environment	Description
Real-time simulator	<p>A different computer from the development computer. A real-time simulator can be a PC or UNIX environment that uses a real-time operating system (RTOS), such as:</p> <ul style="list-style-type: none"> • Simulink Real-Time system • A real-time Linux system • A Versa Module Eurocard (VME) chassis with PowerPC® processors running a commercial RTOS <p>The generated code runs in real time. The exact nature of execution varies based on the particular behavior of the system hardware and RTOS.</p> <p>A real-time simulator connects to a development computer for data logging, interactive parameter tuning, and Monte Carlo batch execution studies.</p>
Embedded microprocessor	<p>A computer that you eventually disconnect from a development computer and run as a standalone computer as part of an electronics-based product. Embedded microprocessors range in price and performance, from high-end digital signal processors (DSPs) to process communication signals to inexpensive 8-bit fixed-point microcontrollers in mass production (for example, electronic parts produced in the millions of units). Embedded microprocessors can:</p> <ul style="list-style-type: none"> • Use a full-featured RTOS • Be driven by basic interrupts • Use rate monotonic scheduling provided with code generation

a UNIX is a registered trademark of The Open Group in the United States and other countries.

b Linux is a registered trademark of Linus Torvalds.

A target environment can:

- Have single- or multiple-core CPUs
- Be a standalone computer or communicate as part of a computer network

You can deploy different parts of a Simulink model on different target environments. For example, it is common to separate the component (algorithm or controller) portion of a model from the environment (or plant). Using Simulink to model an entire system (plant and controller) is often referred to as closed-loop simulation and can provide many benefits, such as early verification of a component.

The following figure shows example target environments for code generated for a model.

Applications of Supported Target Environments

This table lists ways that you can apply code generation technology in the context of the different target environments.

Application	Description
Development Computer	

Application	Description
"Acceleration"	Techniques to speed up the execution of model simulation in the context of the MATLAB and Simulink environments. Accelerated simulations are especially useful when run time is long compared to the time associated with compilation and checking whether the target is up to date.
Rapid Simulation	Execute code generated for a model in non-real-time on the development computer, but outside the context of the MATLAB and Simulink environments.
Shared Object Libraries	Integrate components into a larger system. You provide generated source code and related dependencies for building a system in another environment or in a shared library to which other code can dynamically link.
"Protect Models to Conceal Contents"	Generate a protected model for use by a third-party vendor in another Simulink simulation environment.
Real-Time Simulator	
Real-Time Rapid Prototyping	Generate, deploy, and tune code on a real-time simulator connected to the system hardware, for example, physical plant or vehicle. being controlled. Crucial for validating whether a component can control the physical system.
Shared Object Libraries	Integrate generated source code and dependencies for components into a larger system that is built in another environment. You can use shared library files for intellectual property protection.
Hardware-in-the-Loop (HIL) Simulation	Run a simulation that pairs physical hardware, such as a controller, with a virtual real-time implementation of physical components on a real-time target computer, including a plant, sensors, actuators, and the environment. Use HIL simulations to test and validate physical hardware and a controller algorithm by including the effects of component response in real time to realistic stimuli. Testing commonly compares the HIL simulation results to system requirements. Validation compares HIL simulation results to user requirements. Often HIL simulations are referred to as closed-loop simulations due to the component response to the physical environment stimuli.

Application	Description
Embedded Microprocessor	
"Code Generation"	From a model, generate code that is optimized for speed, memory usage, simplicity, and compliance with industry standards and guidelines.
"Software-in-the-Loop Simulation"	Compile generated or external source code intended for production and execute the code as a separate process from the rest of the Simulink model on your development computer. Goals include initial source code testing and verification by comparing SIL and model simulation results or comparing SIL results to requirements by using back-to-back testing. Commonly used with external code integration, bit-accurate fixed-point math, and coverage analysis.
"Processor-in-the-Loop Simulation"	Cross-compile generated or external source code intended for production on a development computer, and then download and run the object code on a target processor or an equivalent instruction set simulator. Goals include verification by comparing PIL simulation results against model or SIL simulation results and collecting execution time profiling data. Commonly used with external code integration, bit-accurate fixed-point math, and coverage analysis.
Hardware-in-the-loop (HIL) Simulation	Run a simulation that pairs physical hardware, such as a controller, with a virtual real-time implementation of physical components on a real-time target computer, including a plant, sensors, actuators, and the environment. Use HIL simulations to test and validate physical hardware and a controller algorithm by including the effects of component response in real time to realistic stimuli. Testing commonly compares the HIL simulation results to system requirements. Validation compares HIL simulation results to user requirements. Often HIL simulations are referred to as closed-loop simulations due to the component response to the physical environment stimuli.

MATLAB Tutorials

- “Embedded Coder Capabilities for Code Generation from MATLAB Code” on page 2-2
- “Controlling C Code Style” on page 2-7
- “Include Comments in Generated C/C++ Code” on page 2-12

Embedded Coder Capabilities for Code Generation from MATLAB Code

The Embedded Coder product extends the MATLAB Coder product with capabilities that you can use for embedded software development. You can generate code that has the clarity and efficiency of professional handwritten code. For example, you can:

- Generate code that is compact and fast, which is essential for real-time simulators, on-target rapid prototyping boards, microprocessors used in mass production, and embedded systems.
- Customize the appearance of generated code.
- Optimize generated code for application-specific requirements.
- Enable tracing options that help you to verify the generated code.

The Embedded Coder product extends the MATLAB Coder product with the following options and optimizations for C/C++ code generation.

Goal	Project Setting	Code Configuration Object Property	More Information
Execution Time			
Control generation of floating-point data and operations	Support only purely-integer numbers	PurelyIntegerCode	N/A
Simplify array indexing in loops in the generated code	Simplify array indexing	EnableStrengthReduction	“Simplify Multiply Operations for Array Indexing in Loops”
Replace functions and operators in the generated code to meet application-specific code requirements	Code replacement library on the Custom Code tab	CodeReplacementLibrary	Embedded Coder offers additional libraries and the ability to create and use custom code. See “Code Replacement Customization”.
Create and register application-specific implementations of functions and operators	N/A	N/A	“Code Replacement Customization”
Code Appearance			
Specify use of single-line or multiline comments in the generated code	Comment Style	CommentStyle	“Specify Comment Style for C/C++ Code”
Include MATLAB source code as comments with traceability tags. In the code generation report, the traceability tags link to the corresponding MATLAB source code	MATLAB source code as comments	MATLABSourceComments	“Include Comments in Generated C/C++ Code” on page 2-12

Goal	Project Setting	Code Configuration Object Property	More Information
Generate MATLAB function help text in the function banner	MATLAB function help text	MATLABFcnDesc	"Include Comments in Generated C/C++ Code" on page 2-12
Include comments in the generated code that contain summaries for requirements linked to MATLAB code. In the code generation report, the comments are hyperlinks that to the requirements in the Requirements Editor	Requirement summaries as comments	ReqsInCode	"Requirements Traceability for Code Generated from MATLAB Code" (Requirements Toolbox)
Convert if-elseif-else patterns to switch-case statements	Convert if-elseif-else patterns to switch-case statements	ConvertIfToSwitch	"Controlling C Code Style" on page 2-7
Specify that the extern keyword is included in declarations of generated external functions	Preserve extern keyword in function declarations	PreserveExtern-InFcnDecls	N/A
Specify the level of parenthesization in the generated code	Parentheses	ParenthesesLevel	N/A
Specify whether to replace multiplications by powers of two with signed left bitwise shifts in the generated code	Use signed shift left for fixed-point operations and multiplication by powers of 2	EnableSignedLeftShifts	"Control Signed Left Shifts in Generated Code"
Specify whether to allow signed right bitwise shifts in the generated code	Allow right shifts on signed integers	EnableSignedRightShifts	N/A
Control data type casts in the generated code	Casting mode on the All Settings tab	CastingMode	"Control Data Type Casts in Generated Code"
Specify the indent style for the generated code	Indent style on the All Settings tab Indent size on the All Settings tab	IndentStyle IndentSize	"Specify Indent Style for C/C++ Code"
Specify the maximum number of columns before a line break in the generated code	Column limit on the All Settings tab	ColumnLimit	N/A
Specify custom names for MATLAB data types in generated code	Enable custom data type replacement	EnableCustomReplacementTypes ReplacementTypes	"Customize Data Type Replacement"

Goal	Project Setting	Code Configuration Object Property	More Information
Import custom data type definitions from external header files	Import custom types from external header files	IsExtern HeaderFiles	"Import Custom Data Type Definitions from External Header Files"
Customize generated C/C++ file names	Generated source and header file name format	CustomFileNameStr	"Customize C/C++ File Names Generated from MATLAB Code"
Customize generated global variable identifiers	Global variables	CustomSymbolStr- GlobalVar	"Customize Generated Identifiers"
Customize generated global type identifiers	Global types	CustomSymbolStrType	"Customize Generated Identifiers"
Customize generated field names in global type identifiers	Field name of global types	CustomSymbolStrField	"Customize Generated Identifiers"
Customize generated local functions identifiers	Local functions	CustomSymbolStrFcn	"Customize Generated Identifiers"
Customize generated identifiers for local temporary variables	Local temporary variables	CustomSymbolStrTmpVar	"Customize Generated Identifiers"
Customize generated identifiers for constant macros	Constant macros	CustomSymbolStrMacro	"Customize Generated Identifiers"
Customize generated identifiers for EMX Array types (Embeddable mxArray types)	EMX Array Types	CustomSymbolStr- EMXArray	"Customize Generated Identifiers"
Customize generated identifiers for EMX Array (Embeddable mxArray) utility functions	EMX Array Utility Functions	CustomSymbolStrEMX- ArrayFcn	"Customize Generated Identifiers"
Customize function interface in the generated code	Initialize function required on the All Settings tab Terminate function required on the All Settings tab	IncludeInitializeFcn IncludeTerminateFcn	N/A
Customize file and function banners	N/A	CodeTemplate	<ul style="list-style-type: none"> "Generate Custom File and Function Banners for C/C++ Code" "Code Generation Template Files for MATLAB Code"

Goal	Project Setting	Code Configuration Object Property	More Information
Control declarations and definitions of global variables in the generated code	N/A	N/A	<ul style="list-style-type: none"> “Storage Classes for Code Generation from MATLAB Code” “Control Declarations and Definitions of Global Variables in Code Generated from MATLAB Code”
Debugging			
Generate a static code metrics report including generated file information, number of lines, and memory usage	Static code metrics	GenerateCodeMetrics-Report	“Generating a Static Code Metrics Report for Code Generated from MATLAB Code”
Generate a code replacement report that summarizes the replacements used from the selected code replacement library	Code replacements	GenerateCode-ReplacementReport	<ul style="list-style-type: none"> “Verify Code Replacement Library”
Highlight single-precision, double-precision, and expensive fixed-point operations in the code generation report	Highlight potential data type issues	HighlightPotential-DataTypeIssues	“Highlight Potential Data Type Issues in a Report”
Custom Code			
Replace functions and operators in the generated code to meet application-specific code requirements	Code replacement library	CodeReplacementLibrary	Embedded Coder offers additional libraries and the ability to create and use custom code. See “Code Replacement Customization”.
Create and register application-specific implementations of functions and operators	N/A	N/A	“Code Replacement Customization”
Verification			
Interactively trace between MATLAB source code and generated C/C++ code	Enable Code Traceability	EnableTraceability	“Interactively Trace Between MATLAB Code and Generated C/C++ Code”
Verify generated code using software-in-the-loop and processor-in-the-loop execution	N/A	VerificationMode	“Code Verification Through Software-in-the-Loop and Processor-in-the-Loop Execution”

Goal	Project Setting	Code Configuration Object Property	More Information
Debug code during software-in-the-loop execution	Enable source-level debugging for SIL on the Debugging pane	SILDebugging	“Debug Generated Code During SIL Execution”
Profile execution times during software-in-the-loop and processor-in-the-loop execution	Enable entry point execution profiling for SIL/PIL on the Debugging pane	CodeExecutionProfiling	“Execution Time Profiling for SIL and PIL”
Verify and profile ARM optimized code	Hardware Board on the Hardware pane	Hardware	<ul style="list-style-type: none"> • “PIL Execution with ARM Cortex-A at the Command Line” • “PIL Execution with ARM Cortex-A by Using the MATLAB Coder App”
Run Polyspace® verification on generated C/C++ code by using the integrated workflow	N/A	N/A	“Polyspace Verification of C/C++ Code Generated by MATLAB Coder”

Controlling C Code Style

In this section...

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 “Copy File to a Local Working Folder” on page 2-8
 “Open the MATLAB Coder App” on page 2-8
 “Specify Source Files” on page 2-8
 “Define Input Types” on page 2-8
 “Check for Run-Time Issues” on page 2-8
 “Configure Code Generation Parameters” on page 2-9
 “Generate C Code” on page 2-9
 “View the Generated Code” on page 2-9
 “Finish the Workflow” on page 2-10
 “Key Points to Remember” on page 2-10

About This Tutorial

Learning Objectives

This tutorial shows you how to:

- Generate code for `if-elseif-else` decision logic as `switch-case` statements.
- Generate C code from your MATLAB code using the MATLAB Coder app.
- Configure code generation configuration parameters in the MATLAB Coder project.
- Generate a code generation report that you can use to trace between the original MATLAB code and the generated C code.

Required Products

This tutorial requires the following products:

- MATLAB
- MATLAB Coder
- C compiler

MATLAB Coder locates and uses a supported installed compiler. See Supported and Compatible Compilers on the MathWorks website.

You can use `mex -setup` to change the default compiler. See “Change Default Compiler”.

Required Files

Type	Name	Description
Function code	<code>test_code_style.m</code>	MATLAB example that uses <code>if-elseif-else</code> .

Copy File to a Local Working Folder

- 1 Create a local working folder, for example, `c:\ecoder\work`.
- 2 Change to the `matlabroot\help\toolbox\ecoder\examples` folder. At the MATLAB command prompt, enter:

```
cd(fullfile(docroot, 'toolbox', 'ecoder', 'examples'))
```

- 3 Copy the file `test_code_style.m` to your local working folder.

Open the MATLAB Coder App

On the MATLAB Toolstrip **Apps** tab, under **Code Generation**, click the MATLAB Coder app icon.

The app opens the **Select Source Files** page.

Specify Source Files

- 1 On the **Select Source Files** page, type or select the name of the entry-point function `test_code_style.m`.
- 2 In the **Project location** field, change the project name to `code_style.prj`.
- 3 Click **Next** to go to the **Define Input Types** step. The app analyzes the function for coding issues and code generation readiness. If the app identifies issues, it opens the **Review Code Generation Readiness** page where you can review and fix issues. In this example, because the app does not detect issues, it opens the **Define Input Types** page.

Define Input Types


Because C uses static typing, at compile time, the code generator must determine the properties of all variables in the MATLAB files. Therefore, you must specify the properties of all function inputs. To define the properties of the input `x`:

- 1 Click **Let me enter input or global types directly**.
- 2 Click the field to the right of `x`.
- 3 From the list of options, select `int16`. Then, select `scalar`.
- 4 Click **Next** to go to the **Check for Run-Time Issues** step.

Note The **Convert if-elseif-else patterns to switch-case statements** optimization works only for integer and enumerated type inputs.

Check for Run-Time Issues


The **Check for Run-Time Issues** step generates a MEX file from your entry-point functions, runs the MEX function, and reports issues. This step is optional. However, it is a best practice to perform this step. Using this step, you can detect and fix run-time errors that are harder to diagnose in the generated C code. By default, the MEX function includes memory integrity checks. These checks perform array bounds and dimension checking. The checks detect violations of memory integrity in code generated for MATLAB functions. For more information, see “Control Run-Time Checks”.

- 1 To open the **Check for Run-Time Issues** dialog box, click the **Check for Issues** arrow .
- 2 In the **Check for Run-Time Issues** dialog box, enter code that calls `test_code_style` with an example input. For this example, enter `test_code_style(int16(4))`.
- 3 Click **Check for Issues**.

The app generates a MEX function. It runs the MEX function with the example input. If the app detects issues during the MEX function generation or execution, it provides warning and error messages. Click these messages to navigate to the problematic code and fix the issue. In this example, the app does not detect issues.

- 4 Click **Next** to go to the **Generate Code** step.

Configure Code Generation Parameters

- 1 To open the **Generate** dialog box, click the **Generate** arrow .
- 2 Set the **Build type** to `Static Library (.lib)`.
- 3 Click **More settings** and set these settings:
 - On the **Code Appearance** tab, select the **Convert if-elseif-else patterns to switch-case statements** check box.
 - On the **Debugging** tab, make sure that **Always create a report** is selected.
 - On the **All Settings** tab, make sure that **Enable code traceability** is selected.

Generate C Code

Click **Generate**.

When code generation is complete, the code generator produces a C static library, `test_code_style.lib`, and C code in the `/codegen/lib/test_code_style` subfolder. The code generator provides a link to the report.

View the Generated Code

- 1 To open the code generation report, click the **View Report** link.
The `test_code_style` function is displayed in the code pane.
- 2 To view the MATLAB code and the C code next to each other, click **Trace Code**.
- 3 In the MATLAB code, place your cursor over the statement `if (x == 1)`.

The report traces `if (x == 1)` to a switch statement.

```

Code
test_code_style.m test_code_style.m - [4-4] | 1 trace found
1 function y = test_code_style(x)
2 %#codegen
3
4 if (x == 1)
5     y = 1;
6 elseif (x == 2)
7     y = 2;
8 elseif (x == 3)
9     y = 3;
10 else
11     y = 4;
12 end
9
10 /* Include Files */
11 #include "rt_nonfinite.h"
12 #include "test_code_style.h"
13
14 /* Function Definitions */
15
16 /*
17  * Arguments      : short x
18  * Return Type    : double
19  */
20 double test_code_style(short x)
21 {
22     double y;
23     switch (x) {
24     case 1:
25         y = 1.0;
26         break;
27
28     case 2:
29         y = 2.0;
30         break;
31
32     case 3:
33         y = 3.0;
34         break;
35
36     default:
37         y = 4.0;
38         break;
39     }

```

Finish the Workflow

Click **Next** to open the **Finish Workflow** page.

The **Finish Workflow** page indicates that code generation succeeded. It provides a project summary and links to the generated output.

Key Points to Remember

- To check for run-time issues before code generation, perform the **Check for Run-Time Issues** step.
- To access build configuration settings, on the **Generate Code** page, open the **Generate** dialog box, and then click **More Settings**.

See Also

More About

- [“Generate C Code by Using the MATLAB Coder App”](#)
- [“Generate C Code at the Command Line”](#)
- [“Interactively Trace Between MATLAB Code and Generated C/C++ Code”](#)

Include Comments in Generated C/C++ Code

In this section...

“About This Tutorial” on page 2-12
“Creating the MATLAB Source File” on page 2-12
“Configuring Build Parameters” on page 2-12
“Generating the C Code” on page 2-13
“Viewing the Generated C Code” on page 2-13
“Tracing the Generated Code to the MATLAB Code” on page 2-14

About This Tutorial

Learning Objectives

This tutorial shows you how to generate code that includes:

- The function signature and function help text in the function banner.
- MATLAB source code as comments with traceability tags. In the code generation report, the traceability tags link to the corresponding MATLAB source code.

Prerequisites

To complete this tutorial, you must have these products:

- MATLAB
- MATLAB Coder
- Embedded Coder
- C compiler

For a list of supported compilers, see https://www.mathworks.com/support/compilers/current_release/.

Creating the MATLAB Source File

In a writable folder, create a copy of the tutorial file.

```
copyfile(fullfile(docroot, 'toolbox', 'ecoder', 'examples', 'polar2cartesian.m'))
```

polar2cartesian

```
function [x y] = polar2cartesian(r,theta)
%#codegen
% Convert polar to Cartesian
x = r * cos(theta);
y = r * sin(theta);
```

Configuring Build Parameters

Create a `coder.EmbeddedCodeConfig` code generation configuration object and set these properties to `true`:

- `GenerateComments` to allow comments in the generated code.
- `MATLABSourceComments` to generate MATLAB source code as comments with traceability tags. In the code generation report, the tags link to the corresponding MATLAB code. When this property is `true`, the code generator also produces the function signature in the function banner.
- `MATLABFcnDesc` to generate the function help text in the function banner.

```
cfg = coder.config('lib', 'ecoder', true);
cfg.GenerateComments = true;
cfg.MATLABSourceComments = true;
cfg.MATLABFcnDesc = true;
```

Generating the C Code

To generate C code, call the `codegen` function. Use these options:

- `-config` to pass in the code generation configuration object `cfg`.
- `-report` to create a code generation report.
- `-args` to specify the class, size, and complexity of the input parameters.

```
codegen -config cfg -report polar2cartesian -args {0, 0}
```

`codegen` generates a C static library, `polar2cartesian.lib`, and C code in the `/codegen/lib/polar2cartesian` subfolder. Because you selected report generation, `codegen` provides a link to the report.

Viewing the Generated C Code

View the generated code in the code generation report.

- 1 To open the code generation report, click `View report`.
- 2 In the **Generated Code** pane, click `polar2cartesian.c`.

The generated code includes:

- The function signature and function help text in the function banner.
- Comments containing the MATLAB source code that corresponds to the generated C/C++ code. The comment includes a traceability tag that links to the original MATLAB code.

```
/*
 * function [x y] = polar2cartesian(r,theta)
 * Convert polar to Cartesian
 * Arguments    : double r
 *               double theta
 *               double *x
 *               double *y
 * Return Type  : void
 */
void polar2cartesian(double r, double theta, double *x, double *y)
{
    /* 'polar2cartesian:4' x = r * cos(theta); */
    *x = r * cos(theta);

    /* 'polar2cartesian:5' y = r * sin(theta); */
    *y = r * sin(theta);
}
```

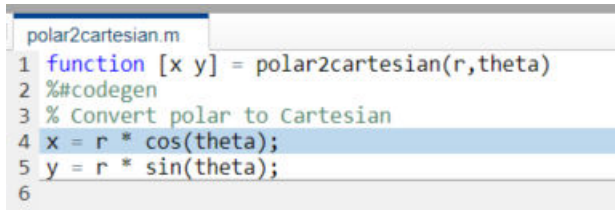
The generated function banner also depends on the code generation template (CGT) file. With the default CGT, the code generator places information about the arguments in the function banner. You can customize the function banner by modifying the CGT. See “Generate Custom File and Function Banners for C/C++ Code”.

Tracing the Generated Code to the MATLAB Code

Traceability tags provide information and links that help you to trace the generated code back to the original MATLAB code. For example, click the traceability tag that precedes the code `x = r * cos(theta);`.

```
/* polar2cartesian:4 x = r * cos(theta); */
```

The report opens `polar2cartesian.m` and highlights line 4.



```
polar2cartesian.m  
1 function [x y] = polar2cartesian(r,theta)  
2 %#codegen  
3 % Convert polar to Cartesian  
4 x = r * cos(theta);  
5 y = r * sin(theta);  
6
```

To view the MATLAB source code and generated C/C++ code next to each other and to interactively trace between them, in the report, click **Trace Code**. See “Interactively Trace Between MATLAB Code and Generated C/C++ Code”.

See Also

More About

- “Specify Comment Style for C/C++ Code”
- “Tracing Generated C/C++ Code to MATLAB Source Code”
- “Interactively Trace Between MATLAB Code and Generated C/C++ Code”
- “Code Generation Template Files for MATLAB Code”
- “Generate Custom File and Function Banners for C/C++ Code”

Simulink Code Generation Tutorials

- “Generate C Code from Simulink Models” on page 3-2
- “Generate Code by Using Embedded Coder Quick Start” on page 3-5
- “Configure Data Interface” on page 3-9
- “Configure a Model Parameter as a Global Variable for Tuning During Run Time” on page 3-14
- “Compare Model Simulation and Generated Code Results” on page 3-16
- “Deploy the Generated Code” on page 3-20
- “Generate C++ Code from Simulink Models” on page 3-23
- “Generate C++ Code by Using Embedded Coder Quick Start” on page 3-24
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Generate C Code from Simulink Models

In this section...
“Prerequisites” on page 3-2
“Example Models” on page 3-2

Use the Embedded Coder product to generate C or C++ code that is optimized for deployment on rapid-prototyping boards, embedded processors, or microprocessors. If you are new to Embedded Coder or your application code customization requirements are minimal, you can use graphical tools and default code configuration settings to quickly generate production-quality code. If you need to produce customized code for integration with existing external code or you want to meet code guidelines and standards, tooling is available to configure the code generator to meet requirements for interfacing, code appearance, packaging, and optimizations.

Generating and reviewing code for deployment to an embedded system can be as simple as preparing the model for code generation with the Quick Start tool. Then, with code tools accessible from the Simulink Editor, you can configure code interfaces, initiate code generation, and review the generated code.

Prerequisites

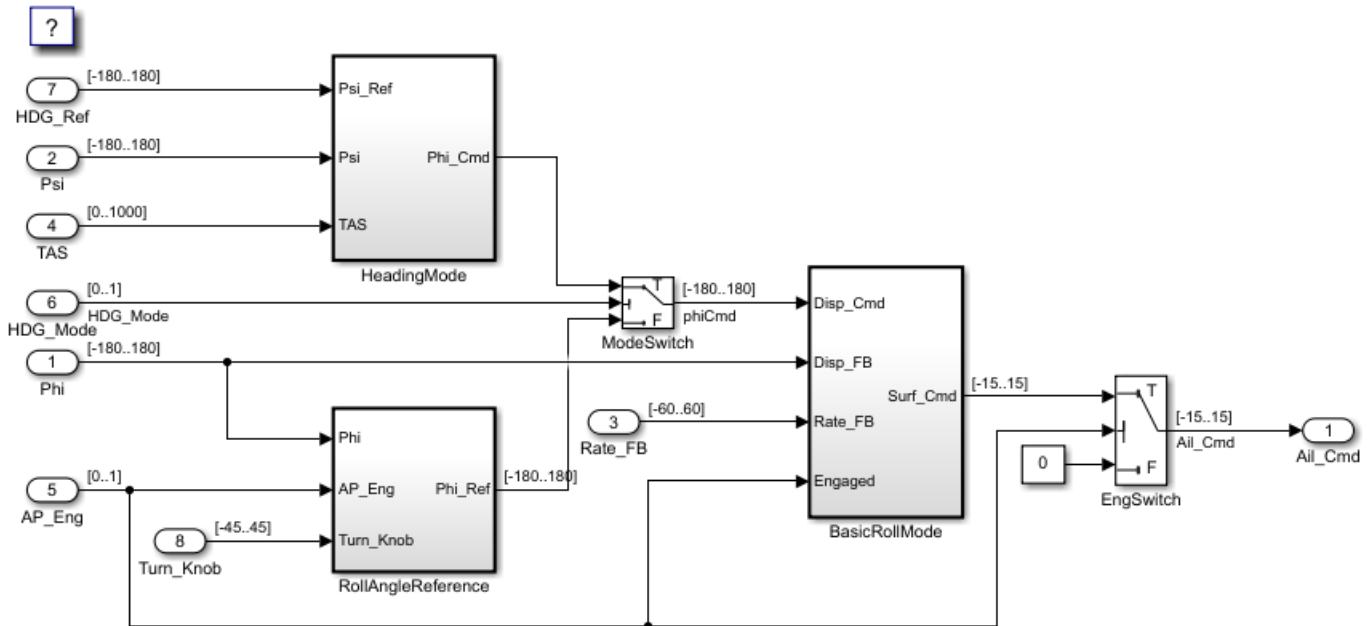
To complete this tutorial, you must have:

- MATLAB
- MATLAB Coder
- Simulink
- Simulink Coder
- Embedded Coder

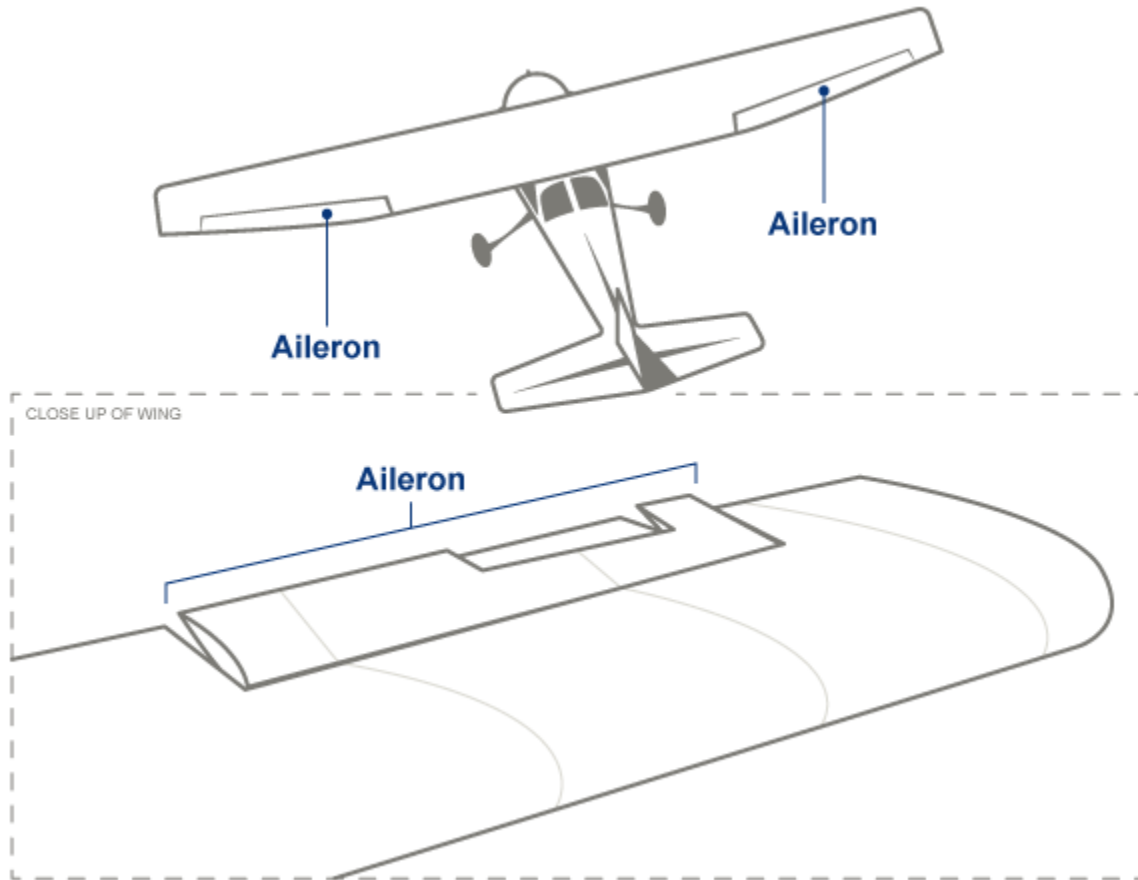
Example Models

The tutorial uses example models `rtwdemo_roll` and `rtwdemo_roll_harness`. The models have been verified for simulation.

Open model `rtwdemo_roll`.



This model implements a basic roll axis autopilot algorithm, which controls the aileron position of an aircraft.



The model represents one component in the greater control system of an aircraft. Through the `HDG_Mode` signal, the control system places the model in one of two operating modes: roll attitude hold or heading hold. The `RollAngleReference` and `HeadingMode` subsystems calculate a roll attitude setpoint that supports one of the operating modes. Then, the `BasicRollMode` subsystem, a PID controller, calculates an aileron position command based on the setpoint and on feedback that indicates the measured roll attitude and rate of change. The model is designed to operate at 40 Hz.

The tutorial uses model `rtwdemo_roll_harness` to test `rtwdemo_roll`.

You will learn how to:

- 1 Generate code by using the Embedded Coder Quick Start tool.
- 2 Configure the data interface.
- 3 Configure a model parameter as a global variable for tuning during run time.
- 4 Compare model simulation and generated code results for numeric equivalency.
- 5 Deploy the generated code.

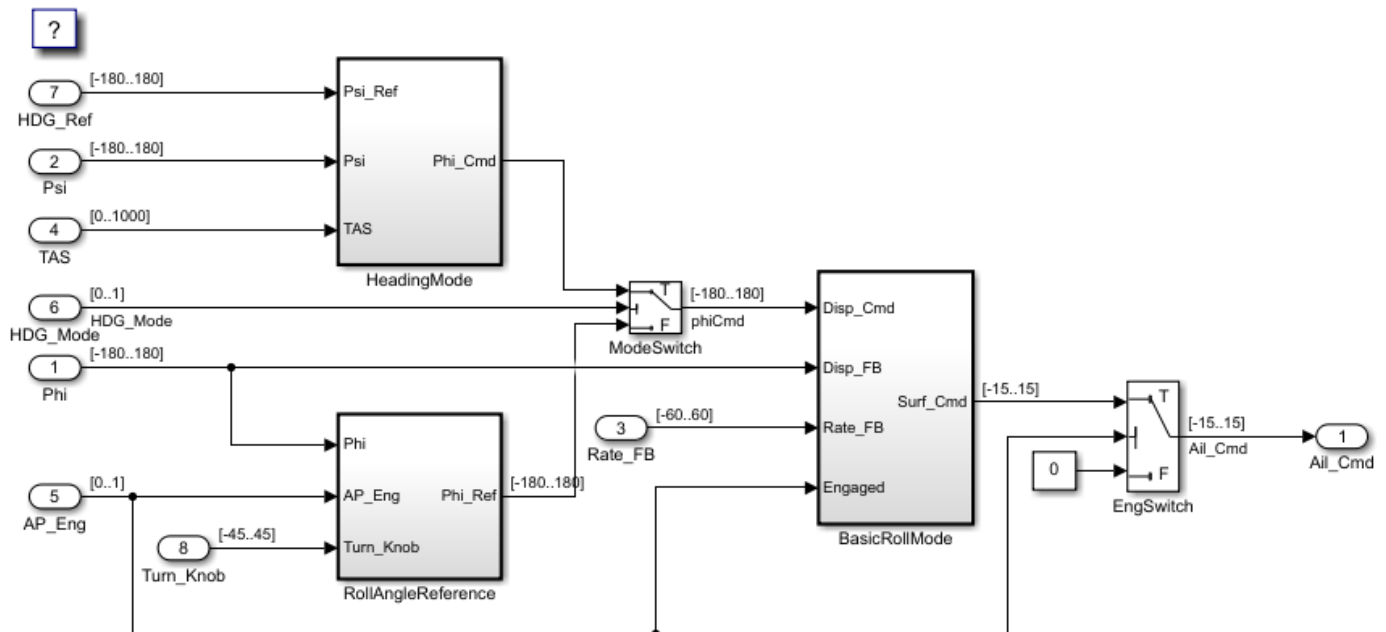
To start the tutorial, see “Generate Code by Using Embedded Coder Quick Start” on page 3-5.

Generate Code by Using Embedded Coder Quick Start

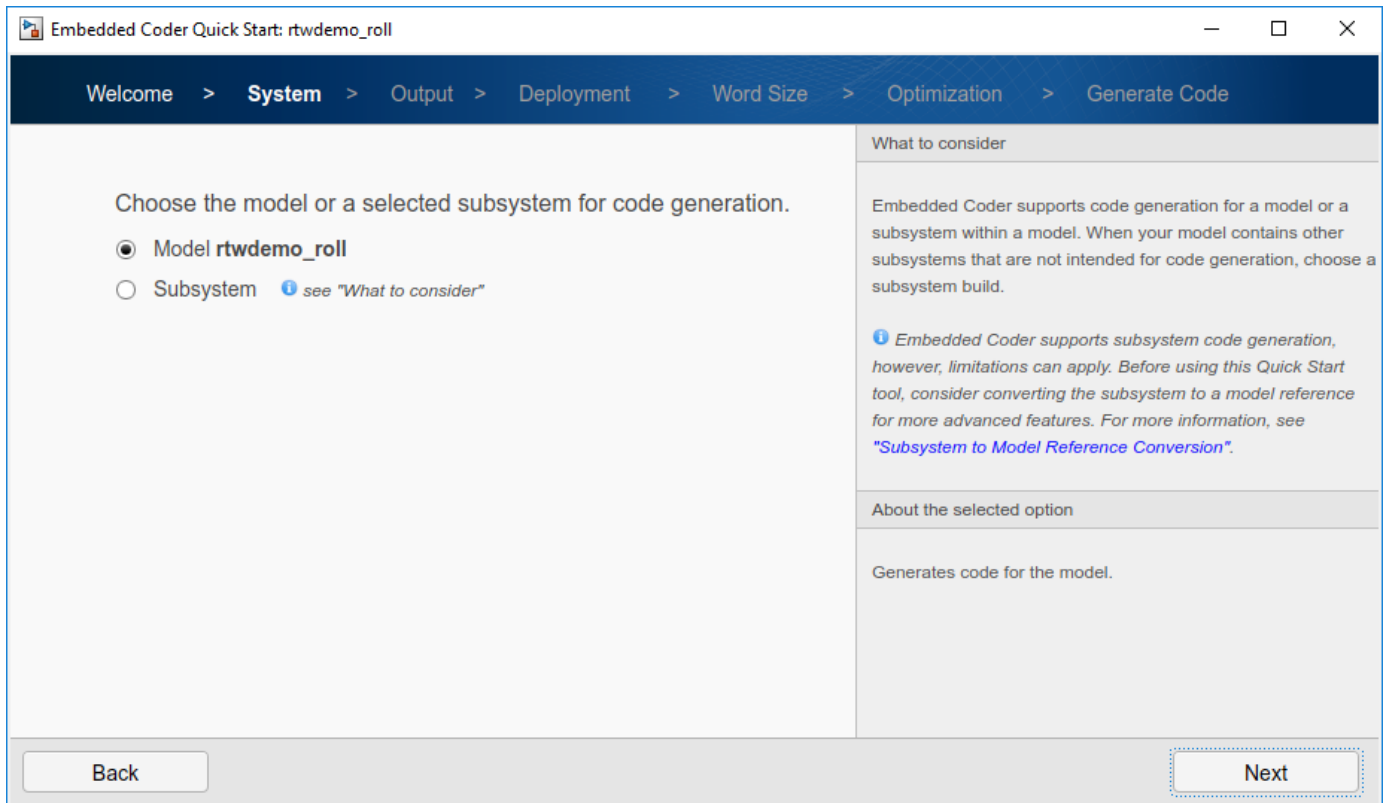
Model `rtwdemo_roll` represents an autopilot control system for an aircraft. You prepare `rtwdemo_roll` for embedded code generation by using Embedded Coder Quick Start, which chooses fundamental code generation settings based on your goals and application.

Generate Code with Quick Start Tool

- 1 Open model `rtwdemo_roll`.



- 2 Save a copy of the model to a writable location on the MATLAB search path.
- 3 If the **C Code** tab is not already open, in the Apps gallery, under **Code Generation**, click **Embedded Coder**.
- 4 On the **C Code** tab, click **Quick Start**.



- 5 Advance through the steps of the Quick Start tool, stopping at the **Generate Code** step. Each step asks questions about the code that you want to generate. For this tutorial, use the defaults that are already selected. The tool validates your selections against the model and presents the parameter changes required to generate code.
- 6 In the **Generate Code** step, apply the proposed changes and generate code from `rtwdemo_roll` by clicking **Next**.
- 7 Click **Finish**, then return to the **C Code** tab. From this tab you can configure code generation customizations, and then check the results in the Code view next to the model.

The screenshot displays the MATLAB Embedded Coder environment. On the left, a Simulink model named 'rtwdemo_roll' is shown. The model includes several blocks: 'HeadingMode', 'RollAngleReference', 'BasicRollMode', and 'EngSwitch'. Inputs include HDG_Ref, Psi, TAS, HDG_Mode, Phi, AP_Eng, and Turn_Knob. Outputs include All_Cmd. The model is annotated with numbered callouts (1-8) corresponding to the code snippets on the right.

On the right, the 'Code' window shows the generated C code for 'rtwdemo_roll.c'. The code includes headers, comments, and preprocessor directives. The visible code is as follows:

```

5  * File: rtwdemo_roll.c
6  *
7  * Code generated for Simulink model 'rtwdemo_r
8  *
9  * Model version           : 6.0
10 * Simulink Coder version  : 9.8 (R2022b
11 * C/C++ source code generated on : Wed Jul 13
12 *
13 * Target selection: ert.tlc
14 * Embedded hardware selection: Intel->x86-64 (
15 * Code generation objectives:
16 *   1. Execution efficiency
17 *   2. Traceability
18 *   3. Safety precaution
19 *   4. RAM efficiency
20 * Validation result: Not run
21 */
22
23 #include "rtwdemo_roll.h"
24 #include <math.h>
25 #include "rtwtypes.h"
26
27 /* Block signals and states (default storage) */
28 DW rtDW;
29
30 /* External inputs (root inport signals with de
31 Extu rtu;

```

Inspect the Generated Code

The generated code appears in two primary files: `rtwdemo_roll.c` and `rtwdemo_roll.h`. In your MATLAB current folder, the `rtwdemo_roll_ert_rtw` folder contains these primary files.

In your current folder, the code generator creates the `slprj` folder. This folder contains the `rtwtypes.h` file, which defines standard data types that the generated code uses by default. In general, this sibling folder contains generated files that can or must be shared between multiple models.

The code that you generate from a model includes entry-point functions, which you call from your application code. For a rate-based model, these functions include an initialization function, an execution function, and, optionally, terminate and reset functions. The functions exchange data with your application code through a data interface that you control.

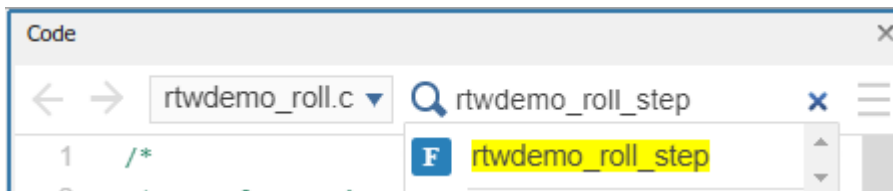
Open the Code Mappings editor by clicking **Code Mappings - Component Interface** below the model diagram. On the **Functions** tab, you can see the individual entry-point functions that the code generator produces. You call these generated functions from external code or from a version of a generated main function that you modify. For the base-rate step function of a rate-based model and for step functions for export function models, you can customize the function name and arguments.

Review the list of entry-point functions that the code generator produces for the model. Use this view to selectively specify for each function a function customization template (code definition) and name. For this tutorial, the code generator uses default (shipped) settings for the customization template and entry-point function names. The code generator names the initialize function `rtwdemo_roll_initialize` and the execution (step) function `rtwdemo_roll_step`. Both entry-point functions have a `void-void` interface (they pass no arguments). The functions gain access to data through shared data structures. Examples of such data include system-level input and output that the functions exchange with application code.

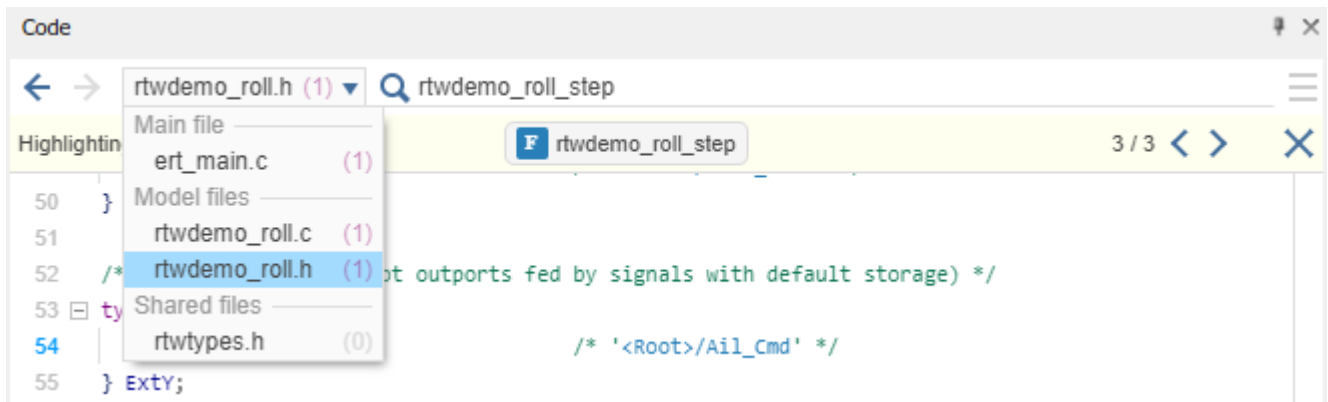
Code Mappings - Component Interface				
Data Defaults				
Function Defaults				
Functions				
Inports				
Outports				
Parameters				
Data Stores				
Signals/States				
Filter contents				
Source	Function Customization Template	Function Name	Function Preview	...
<i>fx</i> Initialize	Model default		<code>void rtwdemo_roll_initialize(void)</code>	
<i>fx</i> Periodic:D1 [Sample Time...	Model default		<code>void rtwdemo_roll_step(void)</code>	

To see these entry-point functions in the generated code:

- 1 On the right side of the Simulink Editor window, in the Code view pane, locate the search bar.
- 2 In the search bar, type `rtwdemo_roll_step`. To find each instance of the step function name across the generated code files, click the search suggestion.



- 3 Use the arrows on the right to step through each instance, including the step function definition in `rtwdemo_roll.c` and the declaration in `rtwdemo_roll.h`. You can also see the number of search hits in each file from the file menu in the upper left corner.



- 4 Repeat these search steps to locate the initialize function, `rtwdemo_roll_initialize` in the generated code.

Next, configure the data interface for code generation and review the generated code.

Configure Data Interface

Embedded Coder reduces the effort for configuring data and function interfaces by providing a way to specify default configurations for categories of data elements and functions across a model. Applying default configurations can save time and reduce the risk of introducing errors in code, especially for larger models and models from which you generate multi-instance code. After applying default configurations, you can selectively override the default settings for individual data elements and functions.

Customize the data interface of model `rtwdemo_roll` by configuring function `roll_control_step` to:

- Read input data from global variables that are declared and defined in external files `roll_input_data.h` and `roll_input_data.c`.
- Write output data to global variables that the code generator declares in `output_data.h` and defines in `output_data.c`.

To make these changes, in the MATLAB Command Window, copy these external code files to your current MATLAB working folder.

```
copyfile(fullfile(matlabroot,'toolbox','rtw','rtwdemos','roll_input_data.c'));
copyfile(fullfile(matlabroot,'toolbox','rtw','rtwdemos','roll_input_data.h'));
copyfile(fullfile(matlabroot,'toolbox','rtw','rtwdemos','roll_heading_mode.c'));
copyfile(fullfile(matlabroot,'toolbox','rtw','rtwdemos','roll_heading_mode.h'));
```

The data interface configuration changes that you make depend on these files being accessible for code generation and the build process. The build process compiles the generated code with the code that is in these files.

Configure Default Code Generation for Data

Configure default code generation configurations for model inports and outports.

- 1 In the **C Code** tab, select **Code Interface > Default Code Mappings**.
- 2 Configure Inport blocks at the root level of the model to appear in the generated code as separate global variables defined by external code. In the Code Mappings editor, under **Inports and Outports**, select category **Inports**. Set the default storage class to `ImportFromFile`.

Model Element Category	Storage Class	
Inports and Outports		
Inports	ImportFromFile	
Outports	Default	
Signals		
Signals, states, and internal data	Default	
Shared local data stores	Default	
Global data stores	Default	
Parameters		
Model parameter arguments	Default	
Model parameters	'Auto' will be inlined	Default
External parameters	'Auto' will be inlined	Default
Constants	Default	


With this setting, the generated code does not define global variables that represent the inport data. Instead, a `#include` statement includes a header file that declares the input variables. You specify the name of the header file with the Property Inspector.

- 3 Click the icon and set **HeaderFile** to `roll_input_data.h`.
- 4 To see how the `extern` declarations in external header file `roll_input_data.h` name the input variables, in the MATLAB Command Window, open `roll_input_data.h` located in your current working folder.

```
extern boolean_T AP_Eng;
extern real32_T HDG_Ref;
extern real32_T Rate_FB;
extern real32_T Phi;
extern real32_T Psi;
extern real32_T TAS;
extern real32_T Turn_Knob;
```

- 5 Configure the code generation naming rule for global variables. By default, the code generator names global variables with the prefix `rt`. For the code generator to produce code that matches the external variable declarations in `roll_input_data.h`, configure the code generation naming rule for global variables accordingly.
 - a Open the Model Configuration Parameters dialog box. In the toolbar, on the **C Code** tab, click **Settings**.
 - b Navigate to the **Code Generation > Identifiers** pane.
 - c Set parameter **Global variables** to the naming rule `NM` (remove the `rt` prefix). Token `$N` represents the name of a data element in the model, for example, the name of an Inport or Outport block. Token `$M` represents name-mangling text that the code generator inserts, if necessary, to avoid name collisions with other global variables in the code.
 - d Apply the change.
- 6 Configure Outport blocks at the root level of the model to appear in the generated code as separate global variables. In the Code Mappings editor, on the **Data Defaults** tab, for category **Outports**, set **Storage Class** to `ExportToFile`.

The generated code declares and defines the output variables in header and definition files that you specify with the Property Inspector.

- 7 Click the  icon and set **HeaderFile** to `roll_output_data.h` and **DefinitionFile** to `roll_output_data.c`.
- 8 Configure code generation for the model to include the external source files `roll_input_data.c` and `roll_heading_mode.c`. In the Configuration Parameters dialog box, set **Code Generation > Custom Code > Code information > Source files** to `roll_input_data.c` `roll_heading_mode.c`. Then, click **Apply** and **OK**.
- 9 Save the model. Regenerate the code by clicking **Build**.

A compiler error indicates that variable `HDG_Mode` is not declared. That variable is not declared in header file `roll_input_data.h`, which you declared as the default header file for imports. You fix this error in the next section of this tutorial.

The model is configured to open the code generation report after code generation is complete. Minimize this report window for exploration later in this tutorial.

- 10 You configured Import blocks to use an external header file to declare and define input variables. In the Code view, confirm that the generated code includes this external header file by searching for `roll_input_data.h`.
- 11 Search for the root level Import block name, `HDG_Ref`. As you type, choose the search suggestion with the green V icon. This search suggestion finds instances of `HDG_Ref` used as a variable in the generated code. Confirm that `HDG_Ref` is defined as a separate global variable.



- 12 In the model, `rtwdemo_roll`, click the Outport block `Ail_Cmd`. Place your cursor over the ellipsis menu above the block and click **Navigate To Code**. The Code view highlights code in `rtwdemo_roll.c` that corresponds to the block. In the code, place your cursor over the output variable `Ail_Cmd`. The traceability dialog box displays variable definitions. The dialog box confirms that `Ail_Cmd` is defined as a separate global variable. Click the definition code to see the definition in `roll_output_data.c`.

```

172  if (AP_Eng) {
173      /* Outputs for Atomic SubSystem: '<Root>/BasicRollMode' */
174      Limit' */
175      0F) {
176      Ail_Cmd' */
177      Ail_Cmd = 15.0F;
178  } else if (rtb_TKSwitch < -15.0F) {
179      /* Output: '<Root>/Ail_Cmd' */
180      Ail_Cmd = -15.0F;
181  } else {
182      /* Output: '<Root>/Ail_Cmd' */
183      Ail_Cmd = rtb_TKSwitch;
184  }

```

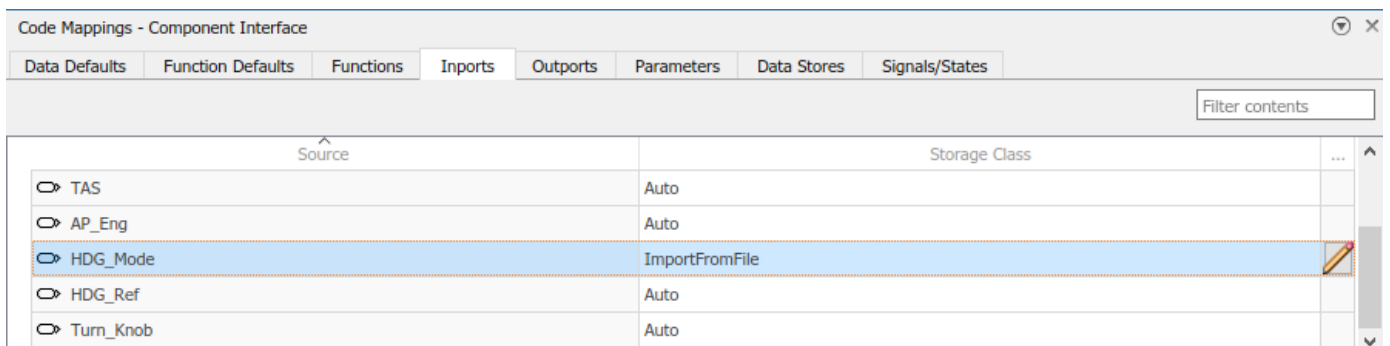
Definition
Variable defined in roll_output_data.c
29 real32_T Ail_Cmd;

Override Default Settings for Individual Data Elements

The settings that you choose for a category under **Data Defaults** apply to elements in that category across a model. To override the default settings for an individual data element, use the Code Mappings editor.

When you generated code after configuring default settings for inports and outports, a compiler error indicated that variable HDG_Mode is not declared. You can fix that error by overriding the default configuration for Inport block HDG_Mode.

- 1 In the Code Mappings editor, on the **Inports** tab, select source HDG_Mode.
- 2 Set **Storage Class** to ImportFromFile.



- 3 Click the  icon and set **Identifier** to HDG_Mode and **Header File** to roll_heading_mode.h.

Based on these settings, the code generator imports the declaration for external variable HDG_Mode from header file roll_heading_mode.h.

```
extern boolean_T HDG_Mode;
```

- 4 Save the model and regenerate the code.

Minimize the code generation report window for exploration later in this tutorial.

- 5 In the Code view, search for roll_heading_mode.h and confirm that it is included in the generated code with the default configuration file roll_input_data.h.

- 6 Search for HDG_Mode and confirm that it is defined as a separate global variable.

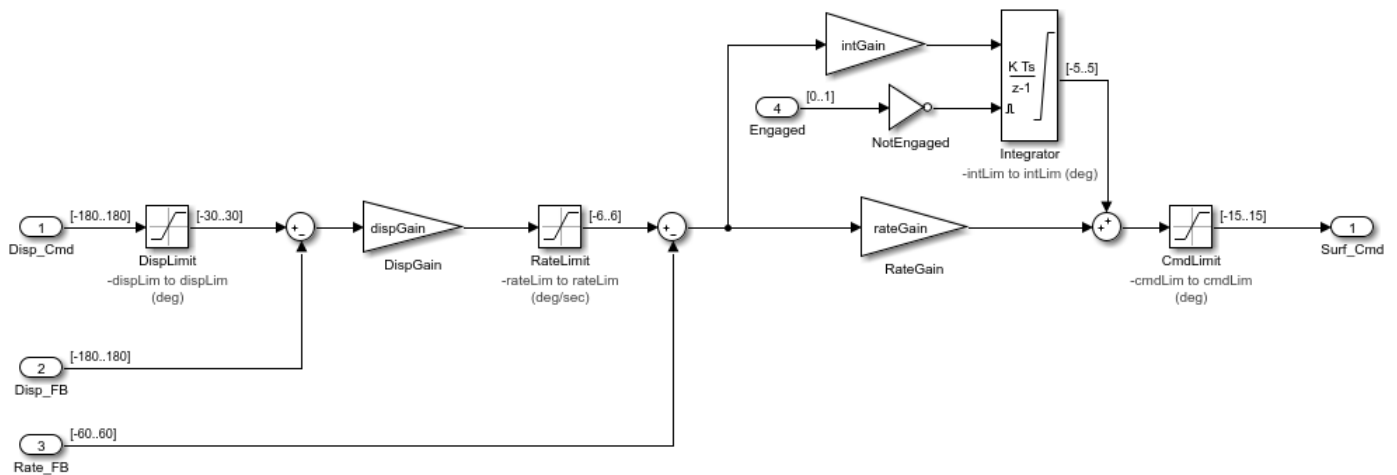
Next, configure a model parameter to be a global variable in the generated code. As a global variable, you can tune the parameter value at run time.

Configure a Model Parameter as a Global Variable for Tuning During Run Time

By default, code generation optimizations eliminate storage for model parameters and most signals that do not participate in the entry-point function interface. To make parameters tunable and related signals accessible, identify them by configuring them explicitly.

In the `BasicRollMode` subsystem of model `rtwdemo_roll`, configure a PID control parameter to appear in the code as a global variable whose value you can tune.

- 1 Open the `BasicRollMode` subsystem.



- 2 Open the Model Data Editor. On the **Modeling** tab, click **Model Data Editor**.
- 3 In the Model Data Editor, select the **Parameters** tab.
- 4 In the filter field, type `IntGain`. The Model Data Editor shows a row that corresponds to the **Gain** parameter and a row that corresponds to a workspace variable.

Model Data Editor								
Parameters								
Source	Name	Value	Data Type	Min	Max	Dimensions	Unit	Argument
IntGain	Gain	intGain	Inherit: Same as input					
Model W...	intGain	0.5	double (auto)			[1 1]		<input type="checkbox"/>

- 5 In the **Source** column, click `IntGain`. That `Gain` block appears highlighted in the model diagram.
- 6 In the **Value** column, next to `intGain`, click the action button (button with three vertical dots) and select **Explore**.
- 7 Convert the model workspace variable to a parameter object. In the Model Explorer, right-click `intGain` and select **Convert to parameter object**.

- 8 In the **Dialog** pane, on the **Code Generation** tab, click **Configure in Coder App**.
- 9 In the Code Mappings editor, on the **Parameters** tab, change the **Storage Class** setting for `intGain` to `Model default`, which indicates that the parameter object prevents code generation optimizations from eliminating storage for the variable. With this setting, the object uses the storage class specified in the Code Mappings editor as the data default for category **Model parameters**.
- 10 Save the model and regenerate the code.

Minimize the code generation report window for exploration later in this tutorial.

- 11 In the Code view:
 - a Search for `intGain`.
 - b In `rtwdemo_roll.c`, place your cursor over the `P` in the highlighted code `P.intGain`.

```

153   rtb_TKSwitc
154
155   /* Update
156    * Gain:
157    */
158   DW_1.Integrator_DSTATE += P.intGain * rtb_Xnew * 0.025F;
159   if (DW_1.Integrator_DSTATE > 5.0F) {
160     DW_1.Integrator_DSTATE = 5.0F;
161   } else if (DW_1.Integrator_DSTATE <= -5.0F) {
162     DW_1.Integrator_DSTATE = -5.0F;
163   }
  
```

Definition
Variable defined in `rtwdemo_roll_data.c`
26 `P_e P = {`
Code metrics
size: 4 byte

- c To see the parameter object definition for `intGain` in `rtwdemo_roll_data.c`, click the definition code in the dialog box.

```

25  /* Block parameters (default storage) */
26  P_e P = {
27    /* Variable: intGain
28     * Referenced by: '<S1>/IntGain'
29     */
30    0.5F
31  };
  
```

The code that you generate from the model stores the parameter object in memory. Because you left the default storage class settings in the Code Mapping Editor for category **Model parameters** set to `Default`, the code generator determines the storage format, for example, as fields of structures.

Next, use a test harness model and software-in-the-loop (SIL) simulation to compare results of model simulation and generated code.

Compare Model Simulation and Generated Code Results

In this section...

“Inspect and Configure Test Harness Model” on page 3-16

“Simulate the Model in Normal Mode” on page 3-17

“Simulate the Model in SIL Mode” on page 3-18

“Compare Simulation Results” on page 3-18

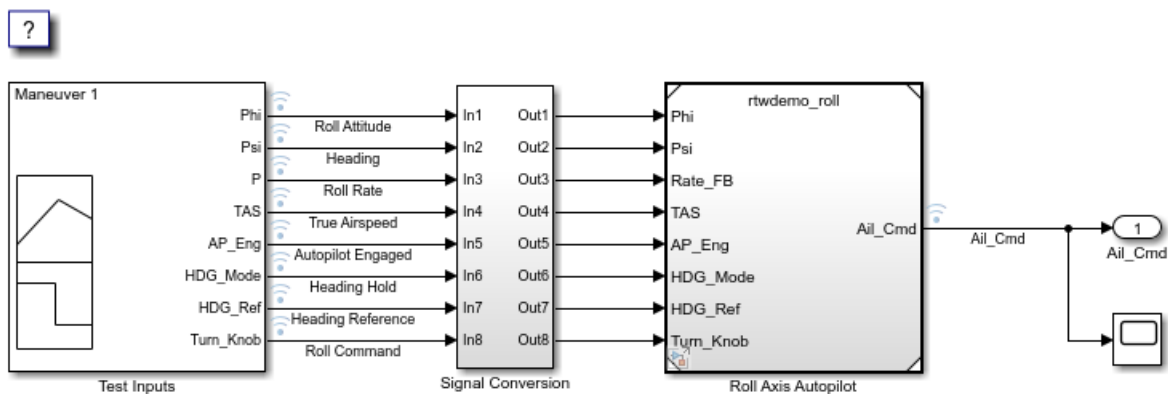
In this step of the tutorial, you verify that when executed, the code is numerically equivalent to the algorithm modeled in Simulink. You use a test harness model to simulate `rtwdemo_roll` in normal mode and in SIL mode, then compare the simulations by using the Simulation Data Inspector.

To test generated code, you can run software-in-the-loop (SIL) and processor-in-the-loop (PIL) simulations. A SIL simulation compiles and runs the generated code on your development computer. A PIL simulation cross-compile source code on your development computer. The PIL simulation then downloads and runs the object code on a target processor or an equivalent instruction set simulator. You can use SIL and PIL simulations to:

- Verify the numeric behavior of your code.
- Collect code coverage and execution-time metrics.
- Optimize your code.
- Progress toward achieving IEC 61508, IEC 62304, ISO 26262, EN 50128, or DO-178 certification.

Inspect and Configure Test Harness Model

Model `rtwdemo_roll_harness` references the model-under-test, `rtwdemo_roll`, through a Model block. The harness model generates test inputs for the referenced model. You can easily switch the Model block between the normal, SIL, or PIL simulation modes.



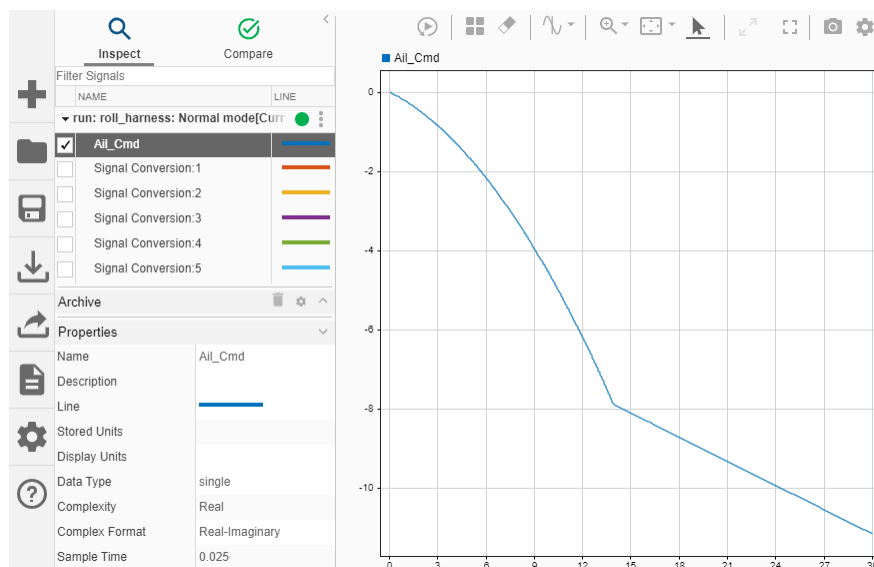
- 1 Open model `rtwdemo_roll_harness`. If you closed your copy of model `rtwdemo_roll`, reopen it.
- 2 In the `rtwdemo_roll_harness` model, right-click the Model block and select **Subsystem & Model Reference > Refresh Selected Model Block**.
- 3 Save a copy of `rtwdemo_roll_harness` in the current working folder.

- 4 Open the Configuration Parameters dialog boxes for `rtwdemo_roll_harness` and `rtwdemo_roll`.
- 5 To run SIL and PIL simulations, on the **Code Generation** pane, verify that parameter **Generate code only** is cleared. Do this for both models.
- 6 For both models, on the **Hardware Implementation** pane, expand **Device details**. Verify that **Support long long** is selected.
- 7 Click **OK**. Then, save the models.

Simulate the Model in Normal Mode

Run the harness model in normal mode and capture the results in the Simulation Data Inspector.

- 1 In the `rtwdemo_roll_harness` model, open the Model Data Editor. On the **Modeling** tab, click **Model Data Editor**.
- 2 In the Model Data Editor, select the **Signals** tab.
- 3 Set the **Change view** list to Instrumentation.
- 4 In the data table, select all rows.
- 5 To configure signals to log simulation data to the Simulation Data Inspector, select a cleared check box in the **Log Data** column. When you are finished, make sure that all of the check boxes in the column are selected.
- 6 Right-click the Model block, `Roll Axis Autopilot`. From the context menu, select **Block Parameters**.
- 7 In the Block Parameters dialog box, for **Simulation mode**, verify that the `Normal` option is selected. Click **OK**.
- 8 Simulate `rtwdemo_roll_harness`.
- 9 When the simulation is done, view the simulation results in the Simulation Data Inspector. If the Simulation Data Inspector is not already open, on the **Simulation** tab, click **Data Inspector**.
- 10 For the most recent (current) run, double-click the run name field and rename the run: `roll_harness: Normal mode`.
- 11 Select `Ail_Cmd` to plot the signal.



Simulate the Model in SIL Mode

The SIL simulation generates, compiles, and executes code on your development computer. The Simulation Data Inspector logs results.

- 1 In the `rtwdemo_roll_harness` model window, right-click the Roll Axis Autopilot model block and select **Block Parameters**.
- 2 In the Block Parameters dialog box, set **Simulation mode** to Software-in-the-loop (SIL) and **Code Interface** to Top model. Click **OK**.
- 3 Exclude external code files from the build process. In the Configuration Parameters dialog box for model `rtwdemo_roll`, set **Code Generation > Custom Code > Code information > Source files** to the default value, which is empty. Save the model.
- 4 Simulate the `rtwdemo_roll_harness` model.

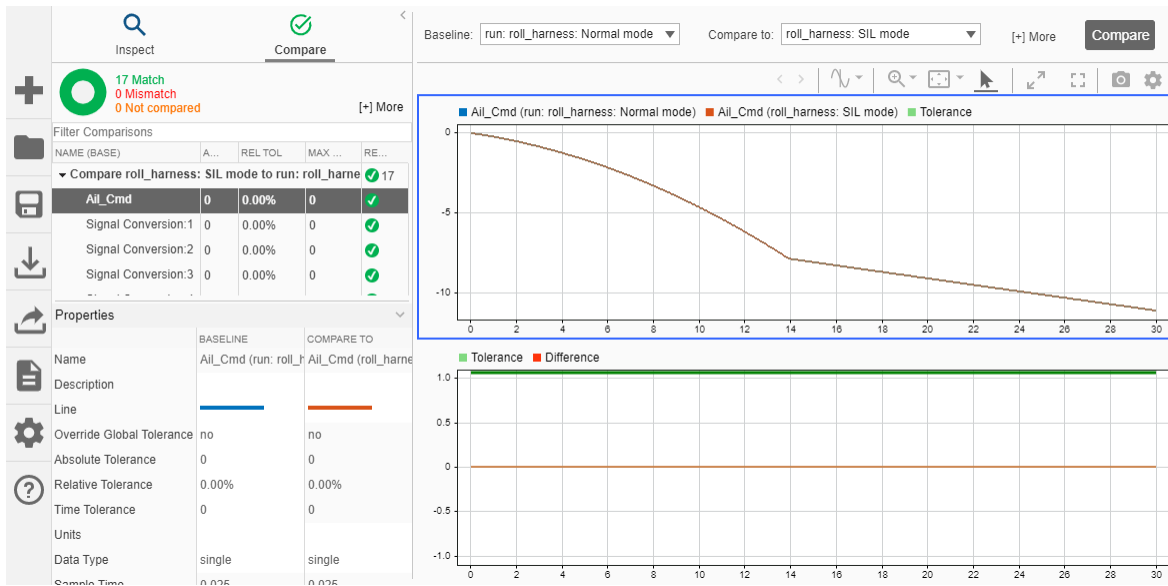
Minimize the code generation report window for exploration later in this tutorial.

- 5 In the Simulation Data Inspector, double-click the run name field and rename the new run as `roll_harness: SIL mode`.
- 6 Select `Ail_Cmd` to plot the signal.
- 7 Reconfigure the build process for model `rtwdemo_roll` to include the external source files `roll_input_data.c` and `roll_heading_mode.c`. In the Model Configuration Parameters dialog box, set **Code Generation > Custom Code > Code information > Source files** to `roll_input_data.c roll_heading_mode.c`. Click **Apply**, close the dialog box, and save the model.

Compare Simulation Results

In the Simulation Data Inspector:

- 1 Click the **Compare** tab.
- 2 In the **Baseline** field, select `roll_harness: Normal mode`.
- 3 In the **Compare To** field, select `roll_harness: SIL mode`.
- 4 Click **Compare**.



The Simulation Data Inspector shows that the normal mode and SIL mode results match. Comparing the results of normal mode simulation with SIL and PIL simulations can help you verify that the generated application performs as expected.

Next, explore ways that you can deploy generated code.

Deploy the Generated Code

In this step of the tutorial, you explore mechanisms for deploying the generated code.

Example Main Program

To facilitate deployment of the generated code, the code generator produces an example `main` program that you can use to get started. The example `main` program is in the file `ert_main.c`. To use the algorithmic code (the model entry-point functions) generated for your application, you can copy the incomplete functions defined in `ert_main.c`, and then complete the functions by inserting your custom scheduling code.

Explore the example `main` program generated for model `rtwdemo_roll`.

- 1 If not already open, open your copy of the model `rtwdemo_roll`.
- 2 In the Apps gallery, click **Embedded Coder**.
- 3 Regenerate the code.
- 4 In the Code view, select file `ert_main.c`.
- 5 Click in the **Search** field and select function `rt_OneStep`.
- 6 Explore the incomplete wrapper function `rt_OneStep`. This function calls the model execution entry-point function, `rtwdemo_roll_step`. Your application code can call `rt_OneStep` to run the model algorithm during each execution cycle.
- 7 Click in the **Search** field and select function `main`.
- 8 Explore the incomplete example `main` function. This function outlines the order and context in which your application code can call `rt_OneStep` and other model entry-point functions.

For more information, see “Deploy Applications to Target Hardware”.

Relocate Generated Code Files

Embedded Coder provides a pack-n-go utility for relocating static and generated code files for a model to another development environment. File relocation is necessary when your system or integrated development environment (IDE) does not include MATLAB and Simulink products. The utility packages the files in a compressed file that you can relocate and unpack by using a standard zip utility. You can apply the pack-n-go utility from graphical and programming interfaces. For more information, see “Relocate or Share Generated Code”.

Share and Archive Code Generation Report

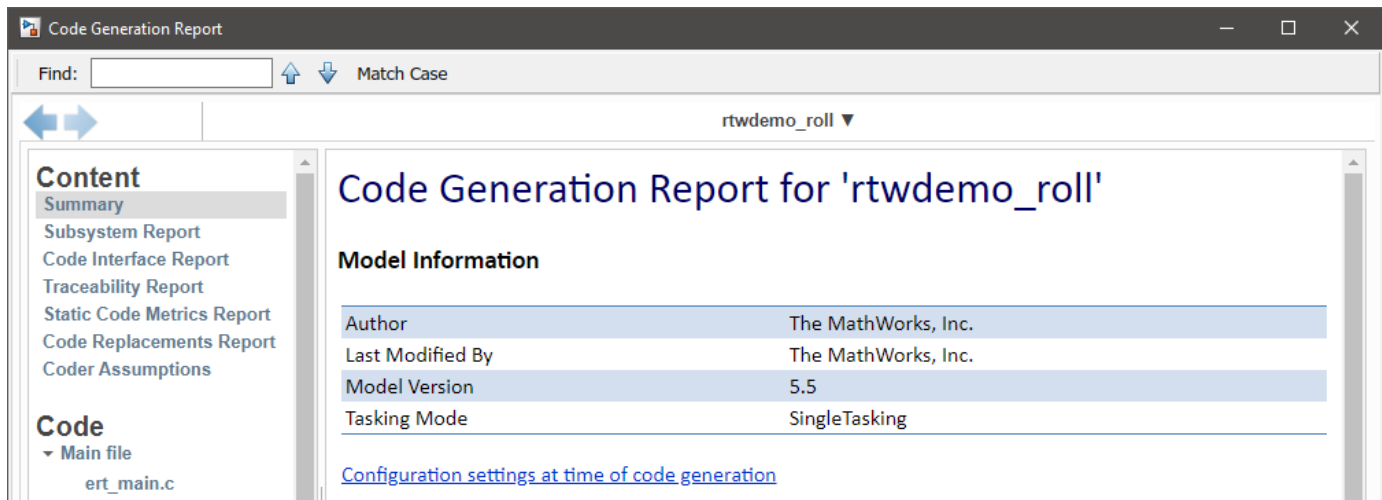
The Quick Start tool configures a model to produce an HTML code generation report. In addition to a summary of model and code information, the report includes:

- A subsystem report
- Generated code files
- A code interface report
- A traceability report
- A static code metrics report

- A code replacements report
- A coder assumptions report
- Optionally, a model web view

You can use this report outside of the Simulink environment, so it is suitable for sharing or for archival purposes. You can open the report from the tool or, on the **C Code** tab, click **Open Report**.

The default location for the code generation report files is in the `html` subfolder of the build folder, `model_target_rtw/html/`. In this case, `target` is the name of the **System target file** specified on the **Code Generation** pane. The default name for the top-level HTML report file is `index.html`.



Explore Other Options

Use these links to explore more ways to customize, verify, and deploy generated production code.

Task	Reference
Quickly generate readable, efficient code from your model	“Generate Code by Using the Quick Start Tool”
Consider model design and configuration for code generation	“Architecture and Component Design”
Learn about generated entry-point functions	“Configure Generated C Function Interface for Model Entry-Point Functions”
Achieve code reuse	“Choose a Componentization Technique for Code Reuse”
Specify default configurations for categories of data elements and functions across a model	“Configure Default C Code Generation for Categories of Data Elements and Functions”
Override default configurations for individual entry-point functions	“Configure Names for Individual C Entry-Point Functions” and “Configure Name and Arguments for Individual Step Functions”

Task	Reference
Override default configurations for individual data elements	"C Code Generation Configuration for Model Interface Elements" and "Organize Parameter Data into a Structure by Using Struct Storage Class"
Compare normal mode simulation results against software-in-the-loop (SIL) or processor-in-the-loop (PIL) simulation results for numerical equivalency	"SIL and PIL Simulations" and "Choose a SIL or PIL Approach"
Collect code coverage metrics for generated code during SIL or PIL simulation	"Code Coverage"
Use generated example main code as a starting point to deploy generated executable programs	"Deploy Applications to Target Hardware"

Generate C++ Code from Simulink Models

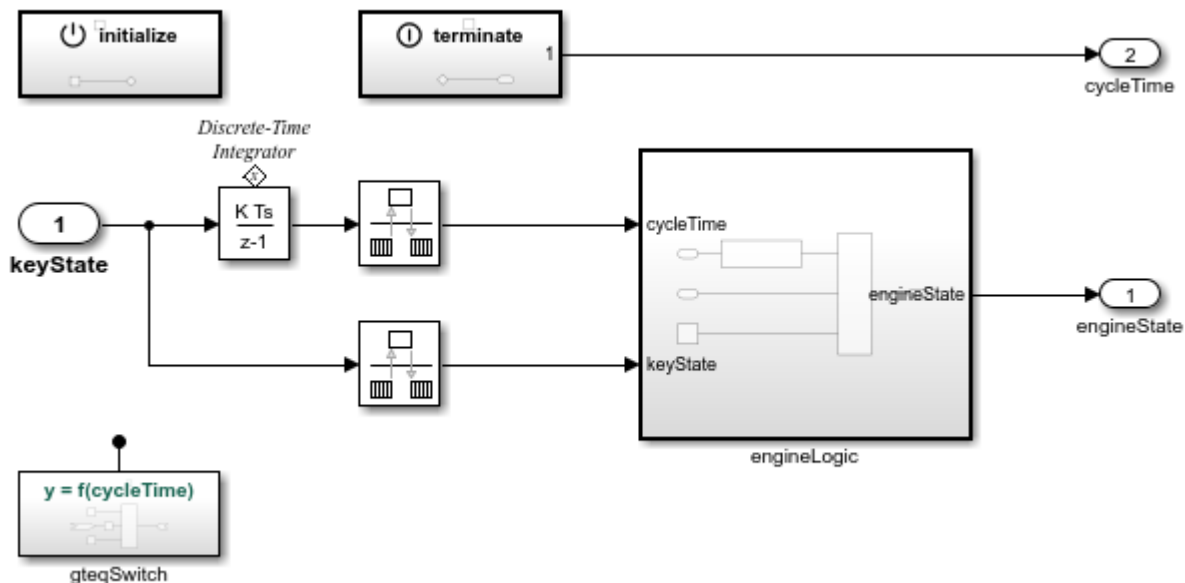
This example shows you how to generate C++ code from a Simulink® model of a key ignition system by using the Embedded Coder® product.

To generate and review code for deployment to an embedded system, you can prepare your model for code generation by using the Embedded Coder Quick Start tool. Then, using code tools accessible from the Simulink Editor, you configure code interfaces, initiate code generation, and review the generated code.

Example model

This tutorial uses the CppClassWorkflowKeyIgnition example model.

The CppClassWorkflowKeyIgnition model represents a key ignition system in the greater control system of a vehicle engine. When the ignition is turned on, the `keyState` input signal changes state and the control system waits a delay before switching the output `engineState`.



By using this tutorial, you learn how to:

- Generate C++ code by using the Embedded Coder Quick Start tool.
- Configure the C++ class interface.
- Deploy the generated C++ code.

For the first task, see “Generate C++ Code by Using Embedded Coder Quick Start” on page 3-24.

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Generate C++ Code by Using Embedded Coder Quick Start

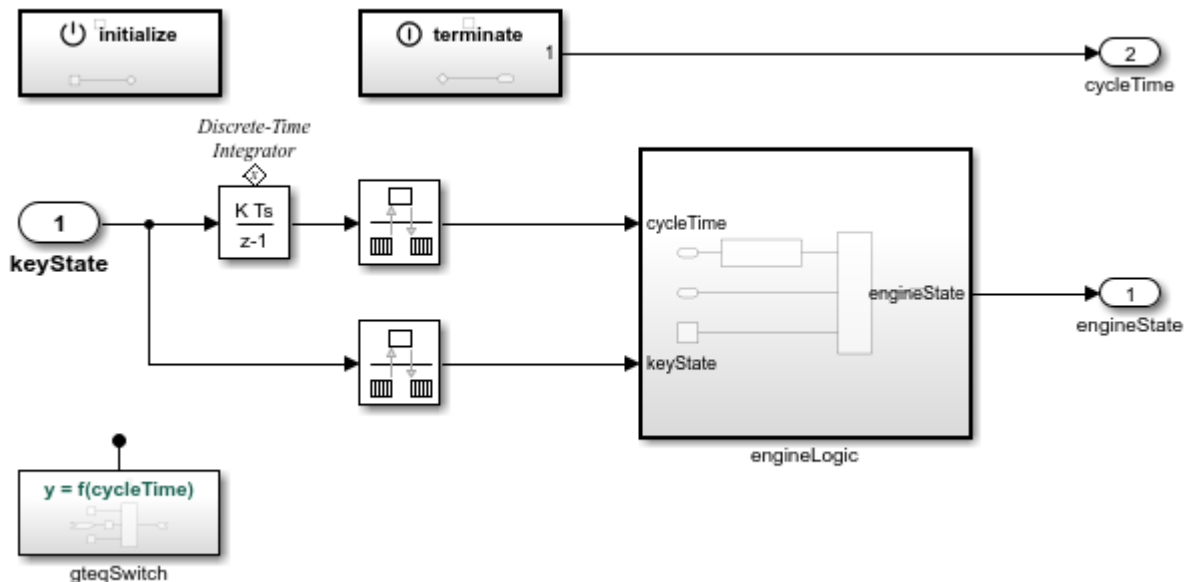
Prepare the CppClassWorkflowKeyIgnition model for embedded code generation by using the Embedded Coder Quick Start tool. The Quick Start tool chooses fundamental code generation settings based on your goals and application.

For this step of the tutorial, you generate code for the CppClassWorkflowKeyIgnition model, and then inspect the generated files. The CppClassWorkflowKeyIgnition model represents an ignition system for a vehicle.

Generate C++ Code by Using Quick Start Tool

- 1 Open the model CppClassWorkflowKeyIgnition.

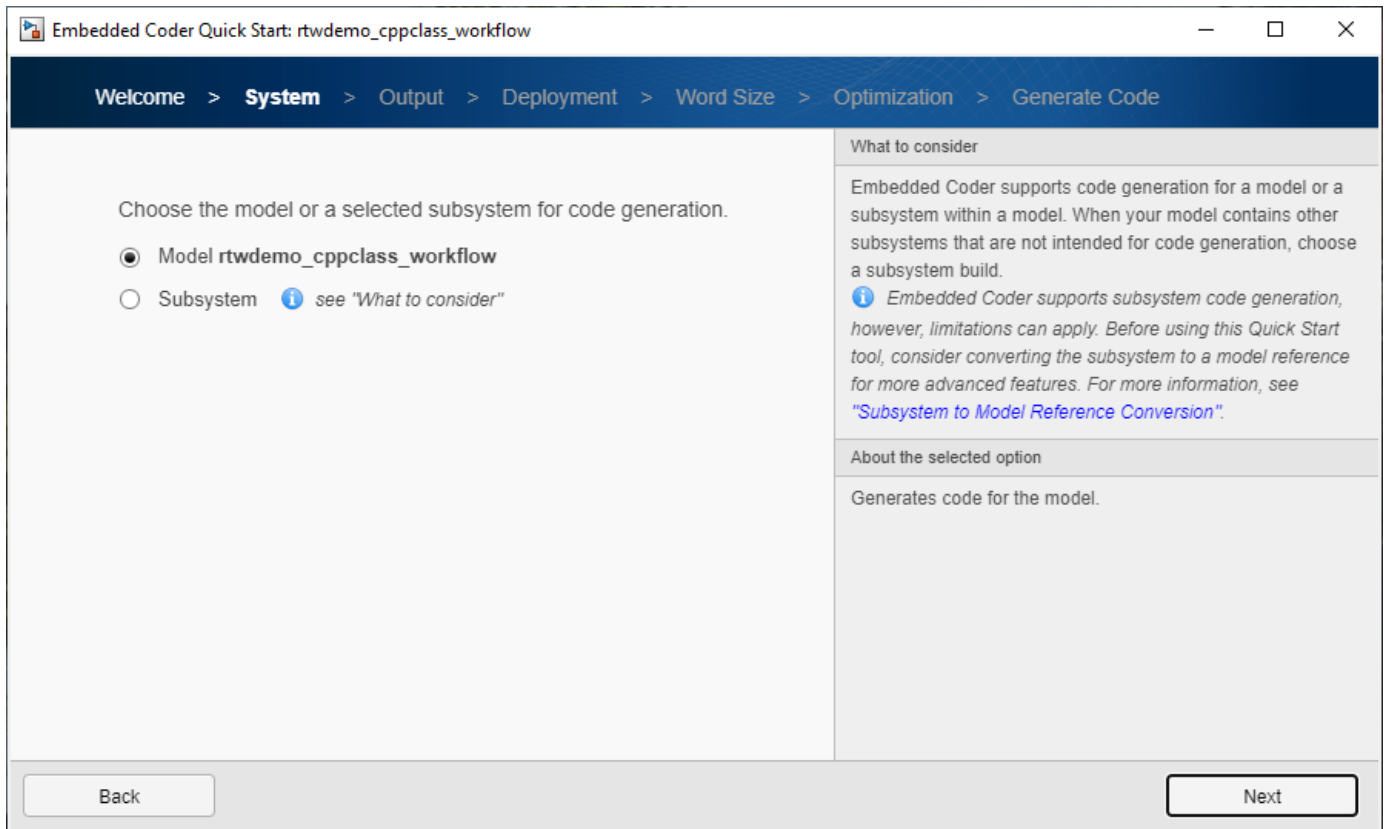
```
openExample('ecoder/CppCodeGenerationWorkflowForKeyIgnitionSystemExample', ...
    supportingFile='CppClassWorkflowKeyIgnition.slx')
```



- 2 Save a copy of the model to a writable location on the MATLAB search path.
- 3 If the **C++ Code** tab is not already open, on the **Apps** tab, in the Apps gallery, under **Code Generation**, click **Embedded Coder**.
- 4 On the **C++ Code** tab, click **Settings** and select **C/C++ Code generation settings**.

The Configuration Parameters dialog box opens.

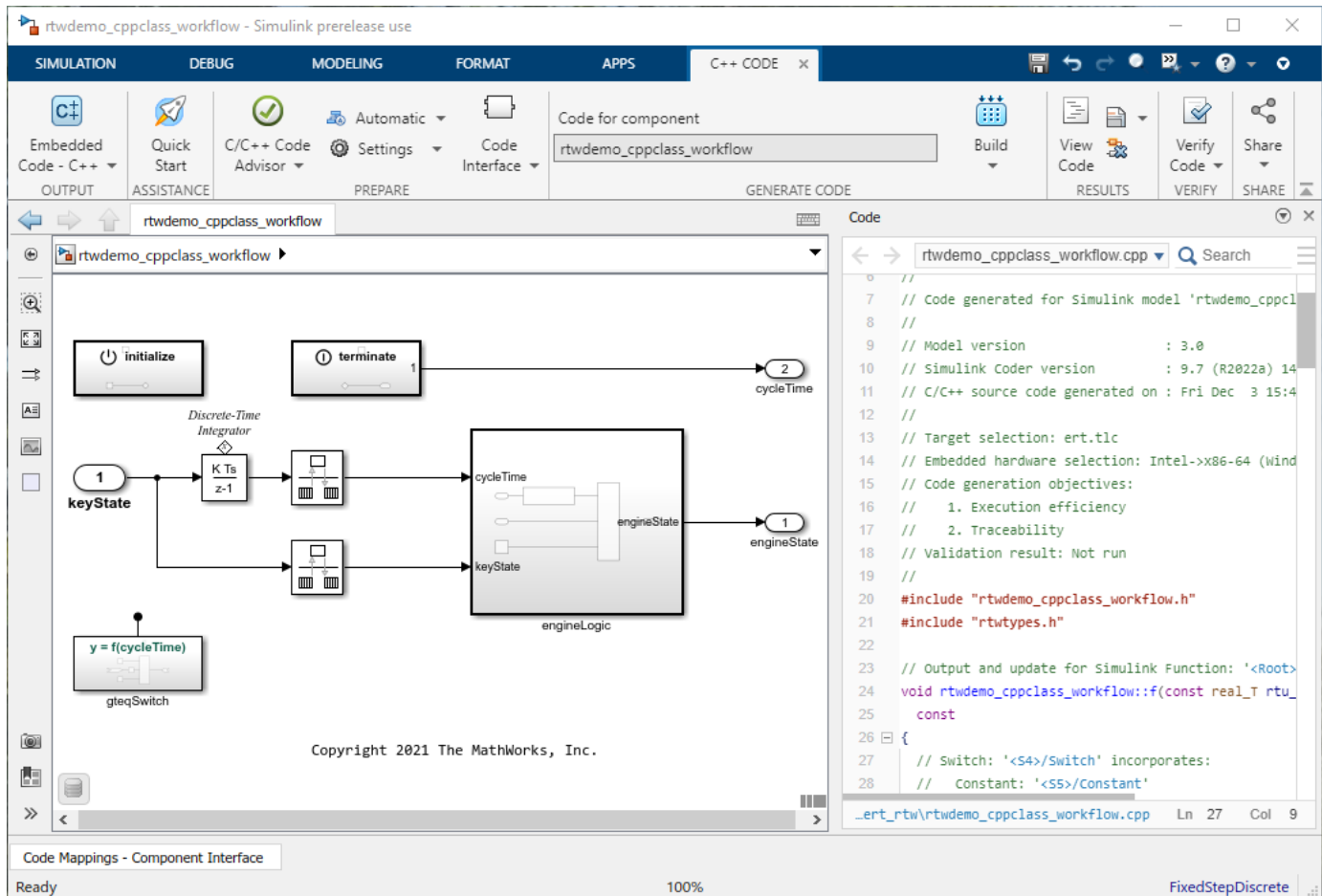
- 5 On the Configuration Parameters dialog box, open the **Code Generation** pane, and under **Target selection**, verify the parameter **Language** is set to C++. Click **OK** to close the dialog box.
- 6 On the **C++ Code** tab, click **Quick Start**.



- 7 Advance through the Quick Start tool by clicking **Next** in each step.

Each step asks questions about the code that you want to generate. For this tutorial, use the defaults. The tool validates your selections against the model and presents the parameter changes required to generate code.

- 8 In the **Generate Code** step, apply the proposed changes and generate code from `CppClassWorkflowKeyIgnition` by clicking **Next**.
- 9 Click **Finish**, then return to the **C++ Code** tab.



Inspect Generated C++ Code

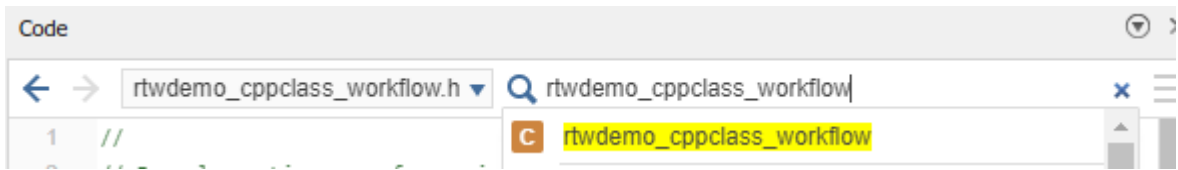
The code generator converts the CppClassWorkflowKeyIgnition model into a C++ class, which you access from your application code. The model data elements appear as class members. The Simulink functions appear as class methods.

The CppClassWorkflowKeyIgnition model incorporates elements of rate-based and export-function modeling. For rate-based modeling, the entry-point class methods, which you call from your application code, include an initialization method, an execution method, a terminate method, and, optionally, a reset method. To integrate with external code or interface requirements, you can customize the generated class interface.

For this tutorial, the code generated by using the Quick Start tool uses default settings for the class elements. The default name for the C++ class is the model name CppClassWorkflowKeyIgnition.

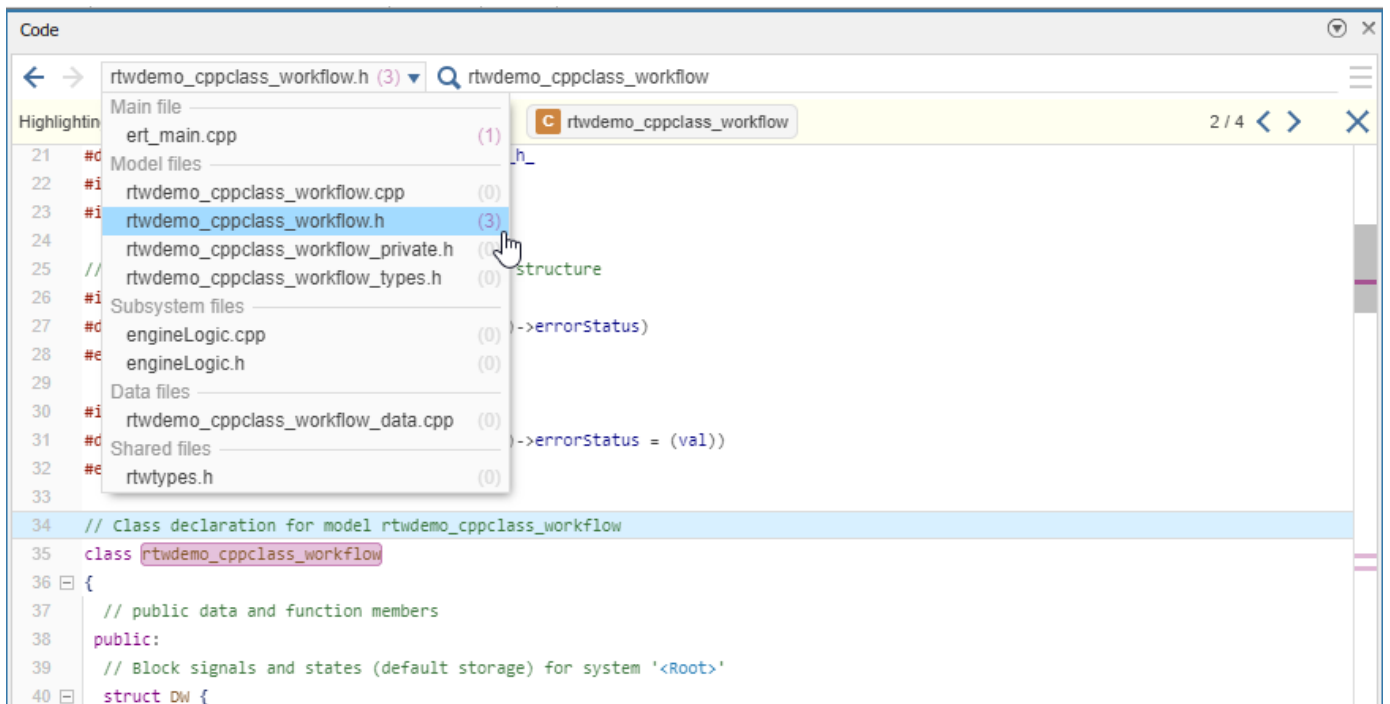
To inspect the C++ class information generated for the model:

- 1 On the right side of the Simulink Editor window, in the Code view pane, locate the search bar.
- 2 In the search bar, type the model class name CppClassWorkflowKeyIgnition to find each instance of the class name across the generated code, and then click the highlighted search suggestion.



- Use the arrows on the right under the search bar to step through each instance, including the class definition in `CppClassWorkflowKeyIgnition.h` and the class instantiation in `ert_main.cpp`.

You can also see the number of search results in each file from the file menu in the upper-left corner.



- Review the data and function code mappings.

In the Simulink Editor window, click **Code Interface**, and select **Code Mappings** to open the Code Mappings editor.

The screenshot displays the Simulink C++ Code Generation environment. The top menu bar includes SIMULATION, DEBUG, MODELING, FORMAT, APPS, and C++ CODE. The main workspace shows a Simulink model with blocks like 'Initialize', 'terminate', 'Discrete-Time Integrator', 'K Ts z-1', 'ZOH', 'engineLogic', and 'gteeqSwitch'. The 'Code Mappings - Component Interface' window is open, showing a table with columns for Model Element Category, Data Visibility, and Member Access Method. The 'Data' tab is selected, and the 'Functions' tab is also visible. The 'Code' window on the right shows the generated C++ code for the component, including class declarations and member functions.

Model Element Category	Data Visibility	Member Access Method
Inports	public	None
Outports	public	None
Model parameter arguments	private	None
Model parameters	public	None
Signals, states, and internal data	public	None

```

33
34 // Class declaration for model rtwdemo_cppclass_work
35 class rtwdemo_cppclass_workflow
36 {
37 // public data and function members
38 public:
39 // Block signals and states (default storage) for
40 struct DW {
41 real_T DiscreteTimeIntegrator_DSTATE; // '<Root>'
42 real_T RateTransition_Buffer; // '<Root>/R
43 real_T RateTransition1_Buffer; // '<Root>/R
44 };
45
46 // instance parameters, for system '<Root>'
47 struct InstP {
48 real_T conditionCalibration[3]; // Variable:
49 // Refer
50
51 };
52
53 // External inputs (root inport signals with defa
54 struct ExtU {
55 real_T keyState; // '<Root>/K
56 };
57
58 // External outputs (root outports fed by signals
59 struct ExtY {

```

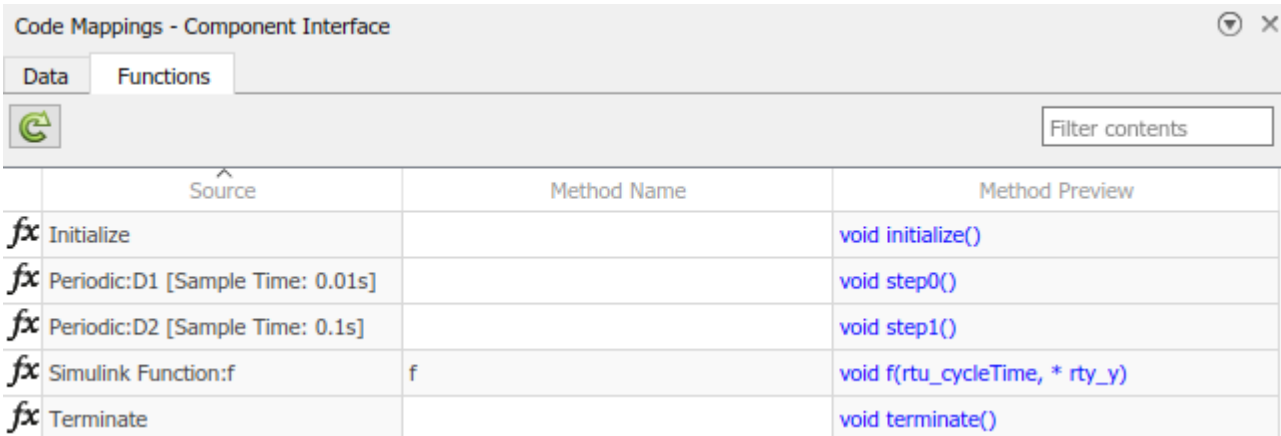
- 5 Click the **Data** tab to view class member visibility and access methods.

Simulink data elements are grouped into categories of modeling elements:

- **Inports:** Root-level data input ports of a model.
- **Outports:** Root-level data output ports of a model.
- **Model parameter arguments:** Workspace variables that appear as instance (nonstatic) class data members.
- **Model parameters:** Workspace variables that are shared across instances of the model class that are generated as static class data members.
- **Signals, states, and internal data:** Data elements that are internal to a model, such as block output signals, discrete block states, data stores, and zero-crossing signals.

- 6 Click the **Functions** tab to view class methods.

The generated class methods are entry-point methods and are locations in code where a transfer of program control occurs.



The screenshot shows a window titled "Code Mappings - Component Interface" with two tabs: "Data" and "Functions". The "Functions" tab is active. Below the tabs is a search bar labeled "Filter contents" and a refresh icon. The main area contains a table with three columns: "Source", "Method Name", and "Method Preview".

	Source	Method Name	Method Preview
<i>fx</i>	Initialize		<code>void initialize()</code>
<i>fx</i>	Periodic:D1 [Sample Time: 0.01s]		<code>void step0()</code>
<i>fx</i>	Periodic:D2 [Sample Time: 0.1s]		<code>void step1()</code>
<i>fx</i>	Simulink Function:f	f	<code>void f(rtu_cycleTime, * rty_y)</code>
<i>fx</i>	Terminate		<code>void terminate()</code>

The default name for the initialize class method is `initialize`, the execution (step) method is `step0`, and the terminate method is `terminate`.

- 7 Repeat the search steps to locate class methods `initialize`, `step0`, and `terminate` in the generated code.

Next, configure a customized class interface for code generation and review the generated code.

Configure Class Interface

In this step of the tutorial, you configure the C++ class interface. A customized C++ class interface enables the generated classes to meet specific code standards or interface requirements so that the generated code can compile and integrate into larger architectures requiring minimal post-generation customization.

To customize the class interface of model CppClassWorkflowKeyIgnition:

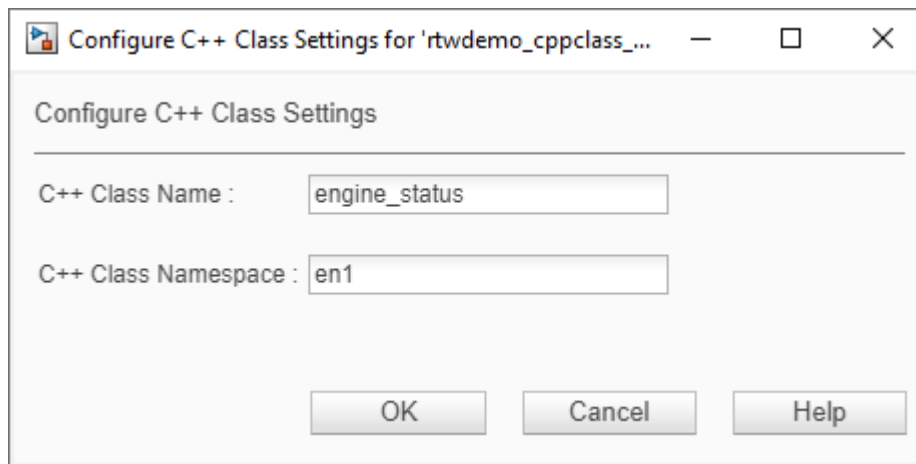
- Change the class name to `engine_status`.
- Set the class namespace to `en1`.
- Configure the inports of the model as public with a set method for access.
- Configure the outports of the model as public with an aggregate structure-based get method to access all output ports.
- Update the names of the initialize and terminate entry-point methods.

Configure Model Class Name and Namespace

- 1 If the model CppClassWorkflowKeyIgnition is not open, open the model.

```
openExample('ecoder/CppCodeGenerationWorkflowForKeyIgnitionSystemExample', ...
    supportingFile='CppClassWorkflowKeyIgnition.slx')
```

- 2 On the **C++ Code** tab, click **Code Interface** and select **Class Name & Namespace**.
- 3 Edit the **C++ Class Name** field to `engine_status`.
- 4 Enter `en1` in the **C++ Class Namespace** field.



- 5 Click **OK**. Validation is performed interactively with field warnings that alert you if you enter an invalid name or namespace.
- 6 Save the model, and then click **Build** to build and regenerate the code.
- 7 In the Code view pane, search for `engine_status` to view the change in the generated code.

```

33
34 // Class declaration for model rtwdemo_cppclass_workflow
35 namespace en1
36 {
37     class engine_status
38     {
39         // public data and function members
40     public:
41         // Block signals and states (default storage) for sy

```

Configure Visibility and Access of Class Members

- 1 Open the Code Mappings editor.

To open the Code Mappings editor, on the **C++ Code** tab, click **Code Interface** and select **Code Mappings**.

- 2 Click the **Data** tab to open the **Data** pane.

The Code Mappings spreadsheet displays visibility and access information for each category of model element.

- 3 Configure **Inports**.

- In the **Data Visibility** column, select public.
- In the **Member Access Method** column, select Inlined method.

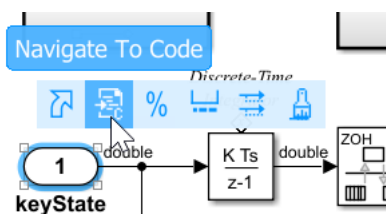
- 4 Configure **Outports**.

- In the **Data Visibility** column, select public.
- In the **Member Access Method** column, select Structure-based method.

- 5 Save the model, and click **Build** to build and regenerate the code.

- 6 In the model CppClassWorkflowKeyIgnition, click the Inport block keyState.

- 7 Place your cursor over the ellipsis menu above the block and click **Navigate To Code**.



The Code view highlights code that corresponds to the block.

- 8 In the Code view, click the search arrows to locate the public declaration and definition of the set method setkeyState for the root inport keyState.

```

Code
rtwdemo_cppclass_workflow.h (2) Search
Highlighting: <Root>/keyState 4 / 4
118
119 // Root inport: '<Root>/keyState' set method
120 void setkeyState(real_T localArgInput)
121 {
122     rtU.keyState = localArgInput;
123 }
124
125 // Root outports get method
126 const ExtY &getExternalOutputs() const;
127
128 // model initialize function

```

The get method for the aggregated root outports, `getExternalOutputs`, is declared directly beneath the inport set method.

- Place your cursor over the identifier `ExtY` in the `getExternalOutputs` method declaration.

A traceability dialog box displays definitions that correspond to the code.

```

122     rtU.keyState = localArgInput;
Definition
Type defined in rtwdemo_cppclass_workflow.h
52 struct ExtY {
126     const ExtY &getExternalOutputs() const;

```

- In the traceability dialog box, click `struct ExtY` to locate the structure.

```

// External outputs (root outports fed by signals with default storage)
struct ExtY {
    real_T engineState[3];           // '<Root>/engineState'
    real_T cycleTime;               // '<Root>/cycleTime'
};

```

- In the search bar, type `getExternalOutputs` and press **Enter** to locate the method definition in `CppClassWorkflowKeyIgnition.cpp`.

Configure Model Functions

Configure the class method names. When you generate C++ code from a model, model entry-point functions appear as class methods in the generated code. To integrate with external code or interface requirements, you can customize the name of the generated methods.

- In the Code Mappings editor, click the **Functions** tab to view the class methods.
- Configure the **Initialize** function name.

In the **Method Name** column, click and edit the spreadsheet to change the name to `initIntegrator`.

- 3 Configure the **Terminate** function name.

In the **Method Name** column, click and edit the spreadsheet to change the name to `terminateIntegrator`.

- 4 Verify the updated names in the **Method Preview** column.

The screenshot displays the MATLAB/Simulink environment. The top toolbar includes tabs for SIMULATION, DEBUG, MODELING, FORMAT, APPS, and C++ CODE. The main workspace shows a Simulink model for 'rtwdemo_cppclass_workflow'. The model consists of several blocks: 'Initialize', 'terminate' (with a '1' in a circle), 'Discrete-Time Integrator' (containing a 'K Ts / z-1' block), two 'ZOH' blocks, 'engineLogic' (containing 'engineState'), 'keyState', 'cycleTime', and 'gteqSwitch' (containing 'y = f(cycleTime)'). Data flow is indicated by arrows and labels like 'double'. The 'terminate' block is connected to a 'cycleTime' output block with a '2' in a circle.

Below the model is the 'Code Mappings - Component Interface' window, which shows a table mapping source functions to method names and their previews.

Source	Method Name	Method Preview
<code>fx Initialize</code>	<code>initIntegrator</code>	<code>void initIntegrator()</code>
<code>fx Periodic:D1 [Sample Time: 0.01s]</code>		<code>void step0()</code>
<code>fx Periodic:D2 [Sample Time: 0.1s]</code>		<code>void step1()</code>
<code>fx Simulink Function:f</code>	<code>f</code>	<code>void f(rtu_cycleTime, * rty_y)</code>
<code>fx Terminate</code>	<code>terminateIntegrator</code>	<code>void terminateIntegrator()</code>

- 5 Save the model, and then click **Build** to build and regenerate code.
- 6 In the Code view, search for the updated method names for the entry-point functions to view the generated code.

Next, deploy the C++ generated code.

Deploy the C++ Generated Code

In this step of the tutorial, you explore mechanisms for deploying the generated code.

Example Main Program

To facilitate deployment of the generated code, the code generator produces an example `main` program that you can use to get started. The example `main` program is in the file `ert_main.cpp`. To use the C++ class and model entry-point functions generated for your application, you can copy the incomplete functions defined in `ert_main.cpp`, and then complete the functions by inserting your custom scheduling code.

Explore the example `main` program generated for model `CppClassWorkflowKeyIgnition`.

- 1 If not already open, open your copy of the model `CppClassWorkflowKeyIgnition`.
- 2 In the Apps gallery, click **Embedded Coder**.
- 3 Regenerate the code.
- 4 In the Code view, select file `ert_main.cpp`.
- 5 Click in the **Search** field and select function `rt_OneStep`.
- 6 Explore the incomplete wrapper function `rt_OneStep`. This function calls the model execution entry-point function, `step0`. Your application code can call `rt_OneStep` to run the model algorithm during each execution cycle.
- 7 Click in the **Search** field and select function `main`.
- 8 Explore the incomplete example `main` function. This function outlines the order and context in which your application code can call `rt_OneStep` and other model entry-point functions.

Overview of Generated Code Files

The code generator creates two folders in your MATLAB current folder for the generated code files:

- `slprj`
- `CppClassWorkflowKeyIgnition_ert_rtw`

The `slprj/ert/_sharedutils` folder contains generated files that are shared between multiple models. This folder contains the file `rtwtypes.h`, which defines standard data types that the generated code uses by default.

The `CppClassWorkflowKeyIgnition_ert_rtw` folder contains the model-specific files of your generated code, including the two primary files `CppClassWorkflowKeyIgnition.cpp` and `CppClassWorkflowKeyIgnition.h`.

Relocate Generated Code Files

Embedded Coder provides a `packNGo` utility for relocating static and generated code files for a model to another development environment. The utility packages the files in a compressed file that you can relocate and unpack by using a standard `zip` utility. You can apply the `packNGo` utility from graphical and programming interfaces.

For more information, see “Relocate or Share Generated Code”.

Share and Archive a Code Generation Report

The Quick Start tool configures a model to produce an HTML code generation report. In addition to a summary of model and code information, the report includes:

- A subsystem report
- A code interface report
- A traceability report
- A static code metrics report
- A code replacements report
- Coder assumptions
- Generated code files
- Optionally, a model web view

You can use this report outside of the Simulink environment, so it is suitable for sharing or for archival purposes. You can open the report from the tool or, on the **C++ Code** tab, click **Open Report**.

The default location for the code generation report files is in the `html` subfolder of the build folder, `model_target_rtw/html/`. `target` is the name of the **System target file** specified on the **Code Generation** pane. The default name for the top-level HTML report file is `index.html`.

Code Generation Report

Find: Match Case

rtwdemo_cppclass_workflow

Code Generation Report for 'rtwdemo_cppclass_workflow'

Model Information

Author	The MathWorks, Inc.
Last Modified By	
Model Version	3.1
Tasking Mode	MultiTasking

[Configuration settings at time of code generation](#)

Code Information

System Target File	ert.tlc
Hardware Device Type	Intel->x86-64 (Windows64)
Simulink Coder Version	9.7 (R2022a) 14-Oct-2021
Timestamp of Generated Source Code	Mon Nov 29 17:13:14 2021

Explore Other Options

To explore more ways to customize, verify, and deploy generated production code, use the links listed in the table.

Task	Reference
Consider model design and configuration for code generation	"Architecture and Component Design"
Learn about generated entry-point functions	"Configure Generated C Function Interface for Model Entry-Point Functions"
Learn about configuring C++ code interfaces for code generation	"Interactively Configure C++ Interface"
Achieve code reuse	"Choose a Componentization Technique for Code Reuse"
Compare normal mode simulation results against software-in-the-loop (SIL) or processor-in-the-loop (PIL) simulation results for numeric equivalency	"SIL and PIL Simulations" and "Choose a SIL or PIL Approach"
Collect code coverage metrics for generated code during SIL or PIL simulation	"Code Coverage"
Use generated example main code as a starting point to deploy generated executable programs	"Deploy Applications to Target Hardware"

See Also

Related Examples

- "Interactively Configure C++ Interface"
- "Programmatically Configure C++ Interface"
- "Configure C++ Class Interface for Rate-Based Models"
- "Configure C++ Class Interface for Export-Function Models"

Get Started with Embedded Coder

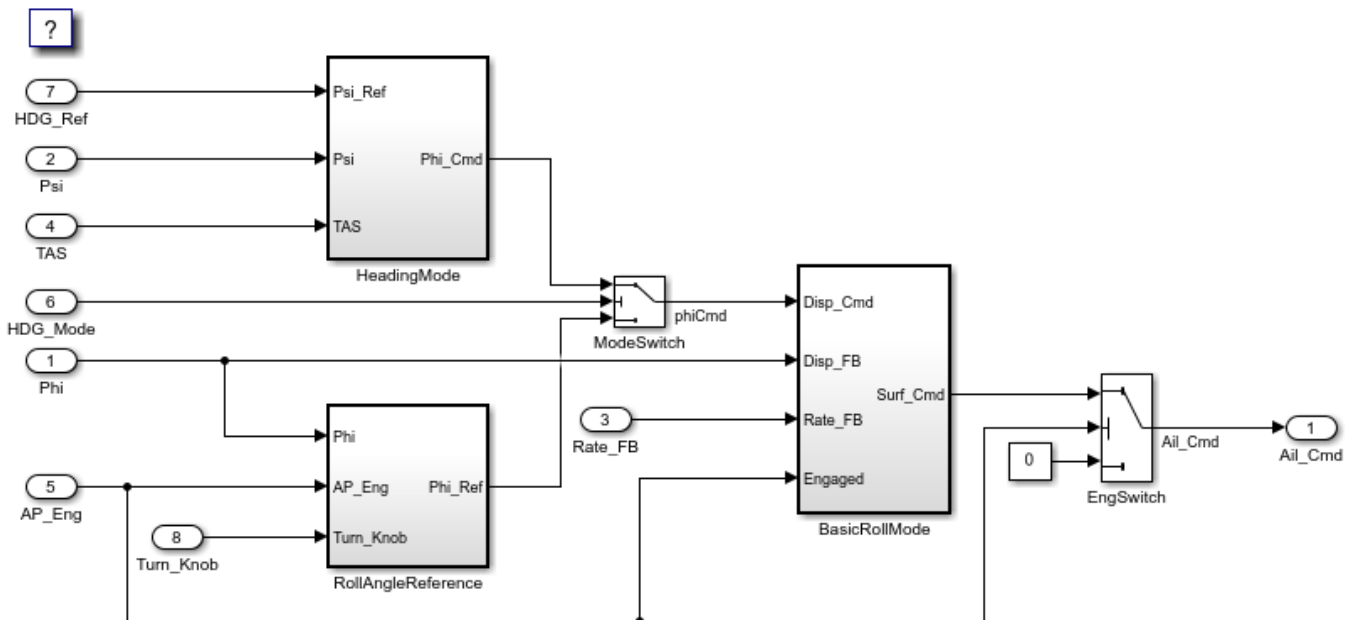
This model shows an implementation of a roll axis autopilot control system, that is designed for code generation.

About the Model

This model represents a basic roll axis autopilot with two operating modes: roll attitude hold and heading hold. The mode logic for these modes is external to this model. The model architecture represents the heading hold mode and basic roll attitude function as atomic subsystems.

The roll attitude control function is a PID controller that uses roll attitude and roll rate feedback to produce an aileron command. The input to the controller is either a basic roll angle reference or a roll command to track the desired heading. The model is as follows:

```
open_system('rtwdemo_roll');
```

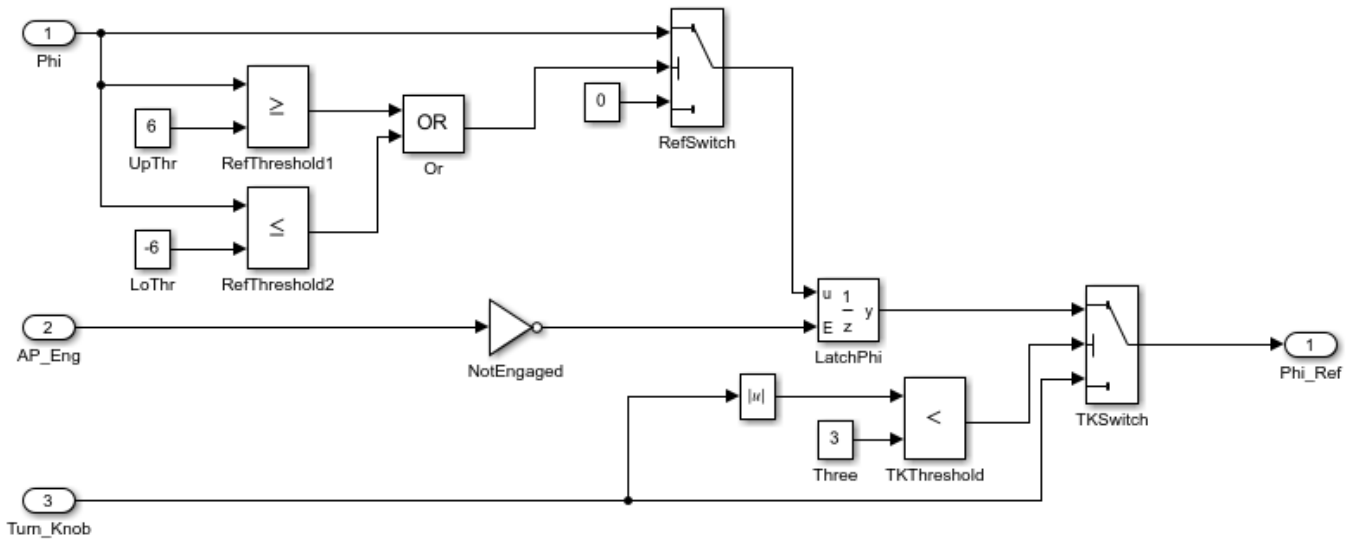


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Subsystem RollAngleReference

The basic roll angle reference calculation is implemented as the subsystem `RollAngleReference`. Embedded Coder® inlines this calculation directly into the main function for `rtwdemo_roll`.

```
open_system('rtwdemo_roll/RollAngleReference');
```

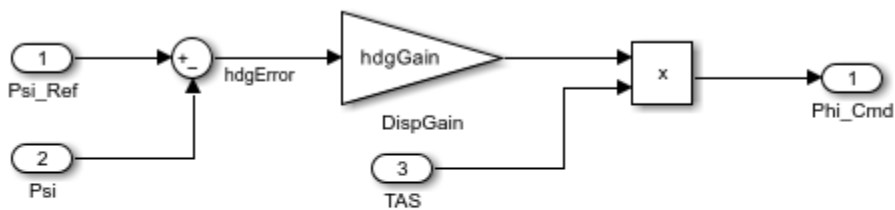


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Subsystem HeadingMode

The subsystem HeadingMode computes the roll command to track the desired heading.

```
close_system('rtwdemo_roll/RollAngleReference');
open_system('rtwdemo_heading');
```



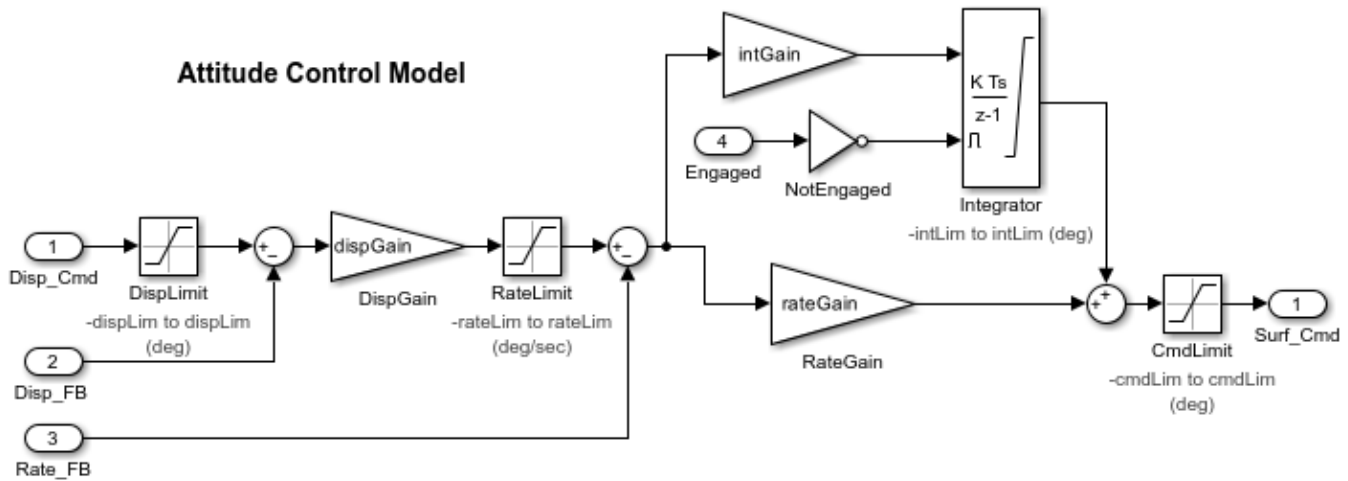
Roll Command to Track Desired Heading

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Subsystem BasicRollMode

The subsystem BasicRollMode computes the roll attitude control function (PID).

```
close_system('rtwdemo_heading');
open_system('rtwdemo_attitude');
```



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Generate Code for the Model

The model is preconfigured to generate code using Embedded Coder. To generate code using Simulink® Coder™ only, reconfigure the model or at the command prompt type `rtwconfiguredemo('rtwdemo_roll','GRT')`

In your system temporary folder, create a temporary folder for the build process.

```
currentDir = pwd;
[~,cgDir] = rtwmodedir();
```

Generate code.

```
slbuild('rtwdemo_roll');
```

```
### Starting build procedure for: rtwdemo_roll
### Successful completion of build procedure for: rtwdemo_roll
```

Build Summary

Top model targets built:

Model	Action	Rebuild Reason
rtwdemo_roll	Code generated and compiled.	Code generation information file does not exist.

```
1 of 1 models built (0 models already up to date)
Build duration: 0h 0m 30.493s
```

You can view the entire generated code in a detailed HTML report, with bi-directional traceability between model and code.

```
web(fullfile(cgDir,'rtwdemo_roll_ert_rtw','html','index.html'))
```

Close models and return to previous working folder.

```
close_system('rtwdemo_roll',0)
close_system('rtwdemo_attitude',0)
close_system('rtwdemo_heading',0)
```

```
cd(currentDir);
rtwdemoclean;
```

Embedded Coder Get Started Tutorials

For more information on generating code with Embedded Coder, see “Generate C Code from Simulink Models” on page 3-2 in the *Get Started with Embedded Coder* documentation.