

MATLAB EXPO 2019

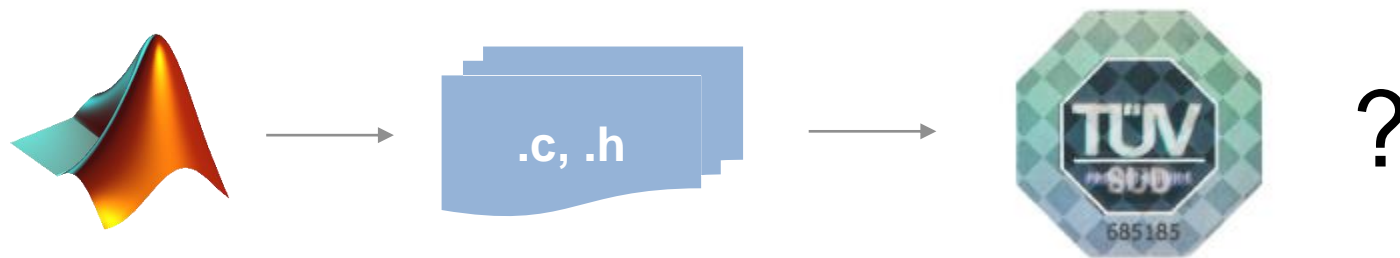
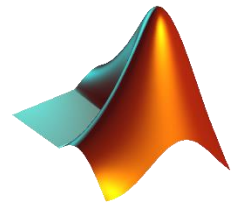
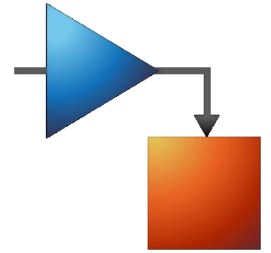
Toolchain Definition and Integration
for ISO 26262-Compliant
Development

Dave Hoadley



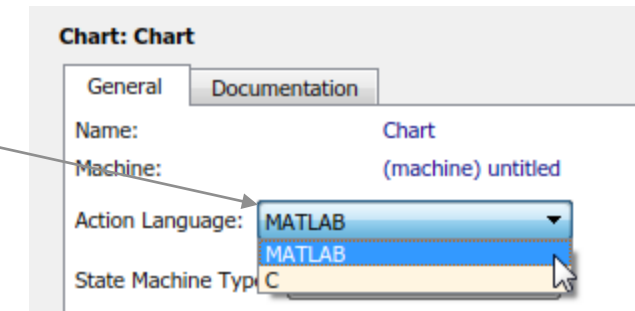
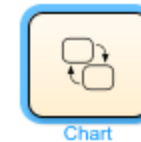
Introduction

- We've seen how MathWorks tools like Simulink and Stateflow are suitable for generating code for ISO 26262 QM to ASIL-D applications
- MATLAB has emerged for AD/ADAS algorithm prototyping
 - A natural language for matrices, image processing, deep learning
 - MATLAB source (text) is also seamless to integrate with Agile workflow tools
- How to generate certifiable code from MATLAB?



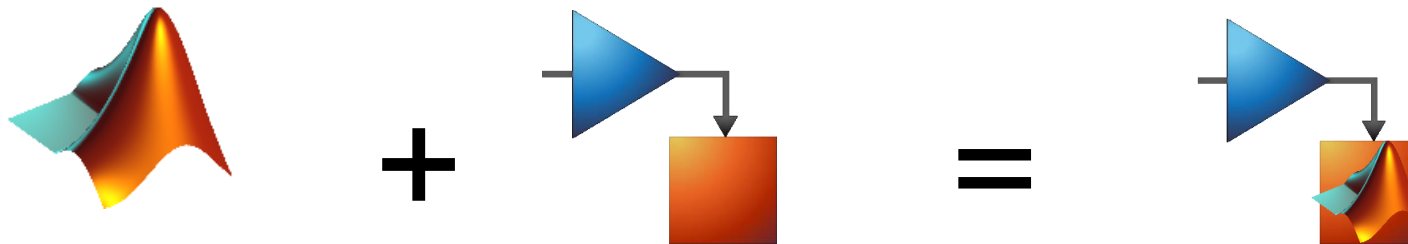
Yes! MATLAB and Simulink Integration

- Called by the MATLAB Function block and/or Stateflow
 - Inlined MATLAB operators
 - External functions
 - Long list of language [features](#) that support code generation
 - And [functions](#), including toolboxes like Sensor Fusion, Stats and Machine Learning, Automated Driving, Deep Learning
- MATLAB code generation is supported by our IEC Certification Kit



Best practice

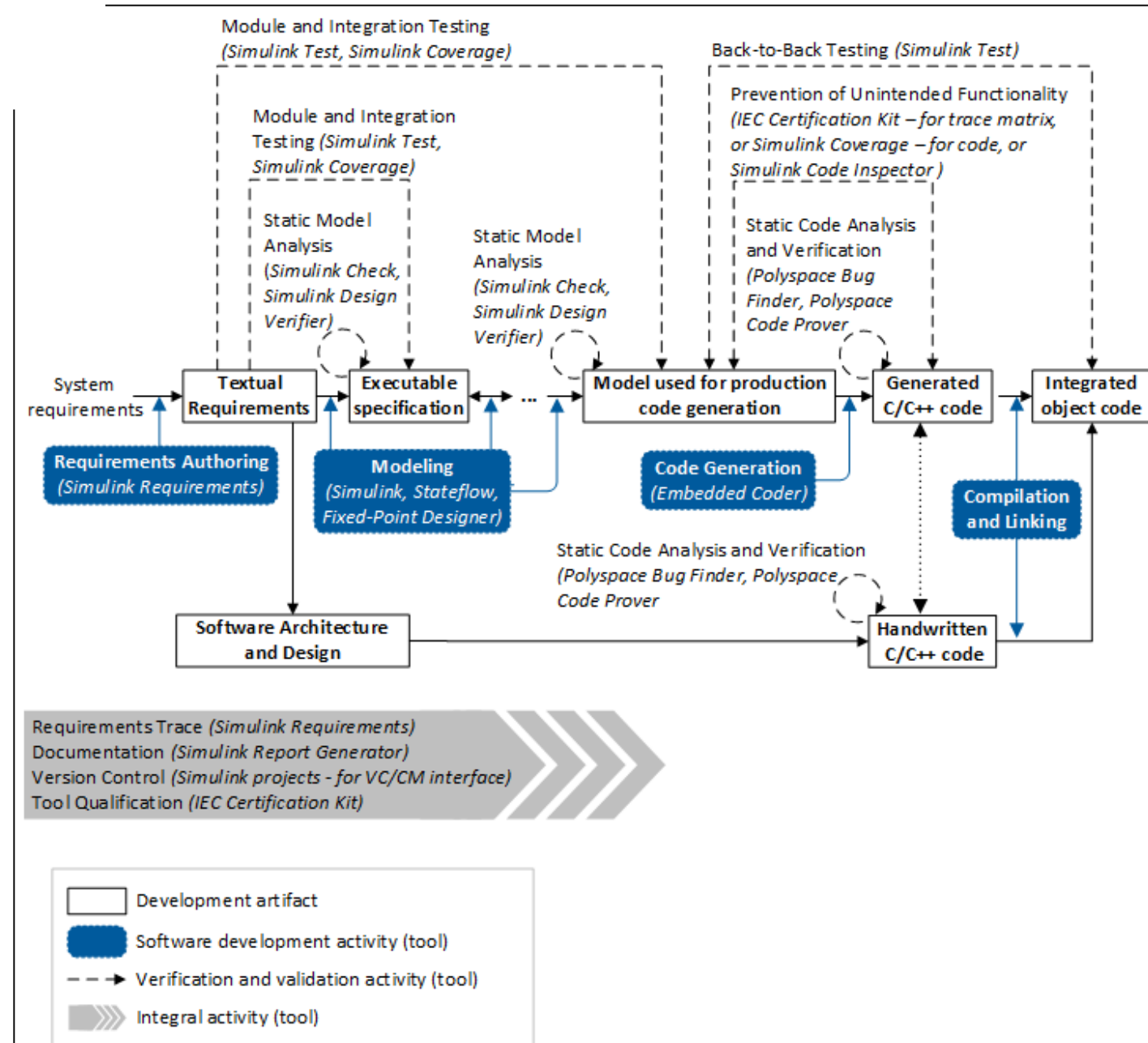
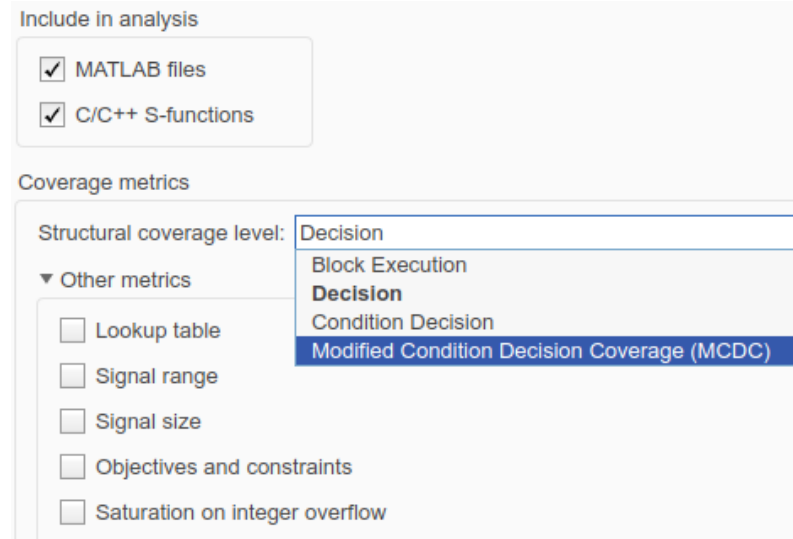
- We can combine these and have the best of both worlds
 - + Richness of the MATLAB language
 - + Rigor of the Simulink family of verification tools



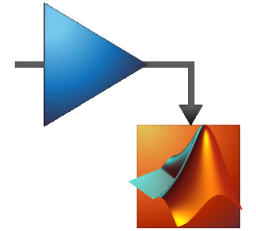
- “I’m a MATLAB user, is Simulink for me?”
 - ➔ If you need to provide **evidence of conformance**
 - ➔ To define **architecture** around MATLAB algorithms

Verification workflow

- Trace requirements \Leftrightarrow design \Leftrightarrow implementation \Leftrightarrow validation
- Meet design & implementation standards
- Show intended and no unintended functionality
 - Coverage is key evidence



MATLAB + Simulink ISO 26262 Workflow



- Our ISO verification activities now support this combined language
 - + Requirements traceability
 - + Design standards
 - + Prove correct functionality
 - + Prove absence of unintended functionality



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Traceability

Simulink Requirements

- + Simulink Requirements supports authoring, importing/exporting, and linking requirements to **model elements**, test cases (Simulink Test)
 - + Blocks, Charts, lines of MATLAB code
- + Requirements Traceability report for evidence
- + MATLAB source and user comments can be included as generated comments

Requirements Traceability sample

Requirements Editor

File Edit Display Analysis Report Help

View: Requirements Search

Index	ID	Summary
tracker		
1	#1	Track object path with extended Kalm...
1.1	#3	Compute Phi, Q, and R
1.2	#4	Propagate the covariance matrix
1.3	#5	Propagate the track estimate
1.4	#6	Compute results
1.4.1	#7	Observation estimate
1.4.2	#8	linearize measurement matrix
1.4.3	#9	Estimate error
1.5	#10	Compute Kalman gain
1.6	#11	Update estimate
1.7	#12	Update covariance matrix

Type: Functional

Index: 1.4.3

Custom ID: #9

Summary: Estimate error

Description Rationale

Keywords:

Revision information:

Links

Implemented by:

[residual = meas - yhat;](#)

Editor - Block: sldemo_radar_eml/MATLAB Function

EDITOR VIEW

FILE NAVIGATE BREAKPOINTS RUN SIMULINK

MATLAB Function

```

33
34 % 4 a). Compute observation estimates:
35 Rangehat = sqrt(xhat(1)^2+xhat(3)^2);
36 Bearinghat = atan2(xhat(3),xhat(1));
37
38 % 4 b). Compute observation vector y and linearized measur
39 yhat = [Rangehat;
40         Bearinghat];
41 M = [ cos(Bearinghat)      0 sin(Bearinghat)
42      -sin(Bearinghat)/Rangehat 0 cos(Bearinghat)/Rangehat 0
43
44 % 4 c). Compute residual (Estimation Error)
45 residual = meas - yhat;
46
47 % 5. Compute Kalman Gain:
48 W = P*M'*inv(M*P*M' + R);

```

EXTKALMAN

Code Generation Report

Find: Match Case

Highlight code for block: '<S1>:1:45'

Contents

- Summary
- Subsystem Report
- Code Interface Report
- Traceability Report
- Static Code Metrics Report
- Code Replacements Report
- Coder Assumptions

Generated Code

```

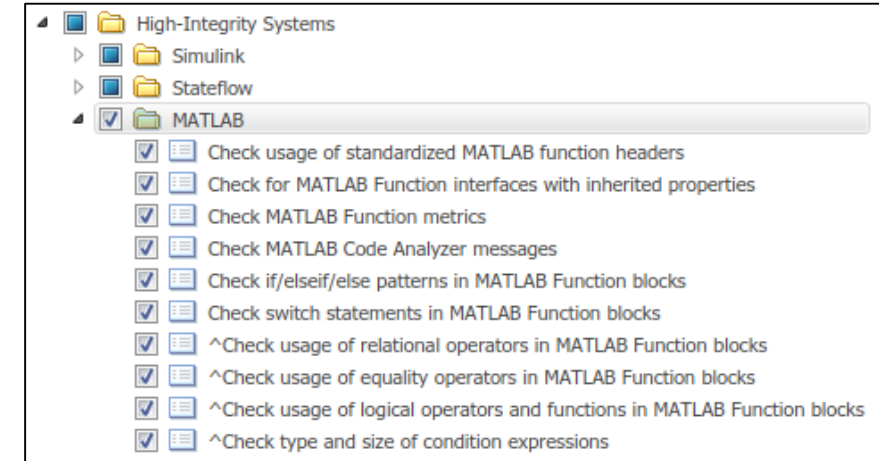
460 M[0] = M_tmp_0;
461 M[2] = 0.0;
462 M[4] = M_tmp;
463 M[6] = 0.0;
464 M[1] = -M_tmp / rtb_range;
465 M[3] = 0.0;
466 M[5] = M_tmp_0 / rtb_range;
467 M[7] = 0.0;
468
469 /* 4 c). Compute residual (Estimation Error) */
470 /* '<S1>:1:45' residual = meas - yhat; */
471 /* Requirements for MATLAB Function: '<S1>|737719.842.6' Line 45:
472 * 1. Estimate error (tracker#9)
473 */
474 sldemo_radar_eml_B.residual[0] = sldemo_radar_eml_B.PolarCoords[0] -
475 rtb_range;
476 sldemo_radar_eml_B.residual[1] = sldemo_radar_eml_B.PolarCoords[1] -
477 rtb_WhiteNoise_idx_0;
478
479 /* 5. Compute Kalman Gain: */
480 /* '<S1>:1:48' W = P*M'*inv(M*P*M' + R); */
481 for (i = 0; i < 2; i++) {
482     for (iU = 0; iU < 4; iU++) {
483         Phi_tmp_tmp = (iU < 1) + i;
484         x_tmp[iU + (i < 2)] = M[Phi_tmp_tmp];

```


Design and Code Standards

Simulink Check

- + Simulink Check has checks for good MATLAB style and improving code compliance
 - + Enforcement of low complexity
 - + Enforcement of comment density
 - + Strong data typing between MATLAB and Simulink
 - + Find logical operators with mixed data types
- + Some MATLAB & Embedded Coder settings for MISRA-C
- MATLAB style guides are limited in scope (MAAB, NASA)



Demonstrate correct functionality

Simulink Requirements

Simulink Test

Simulink Design Verifier

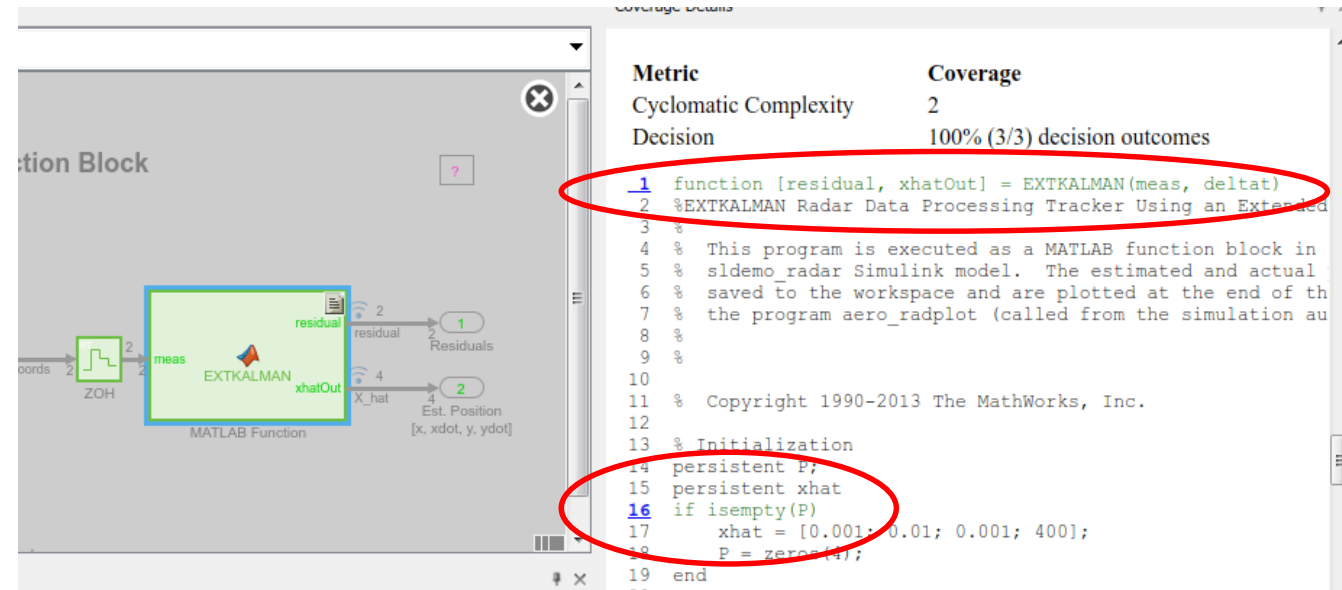
- + Requirements-based test authoring, execution via Simulink Test
- + Simulink Design Verifier (SLDV) property proving
- + SLDV design error detection
- + Back to back testing for model to code for Software-in-the-Loop (SIL), Processor-in-the-Loop (PIL)

Demonstrate no unintended functionality

Simulink Coverage

Simulink Design Verifier

- + Simulink Coverage to show completeness of test cases
 - + Model coverage
 - + Code coverage for SIL/PIL
- + SLDV can generate missing tests

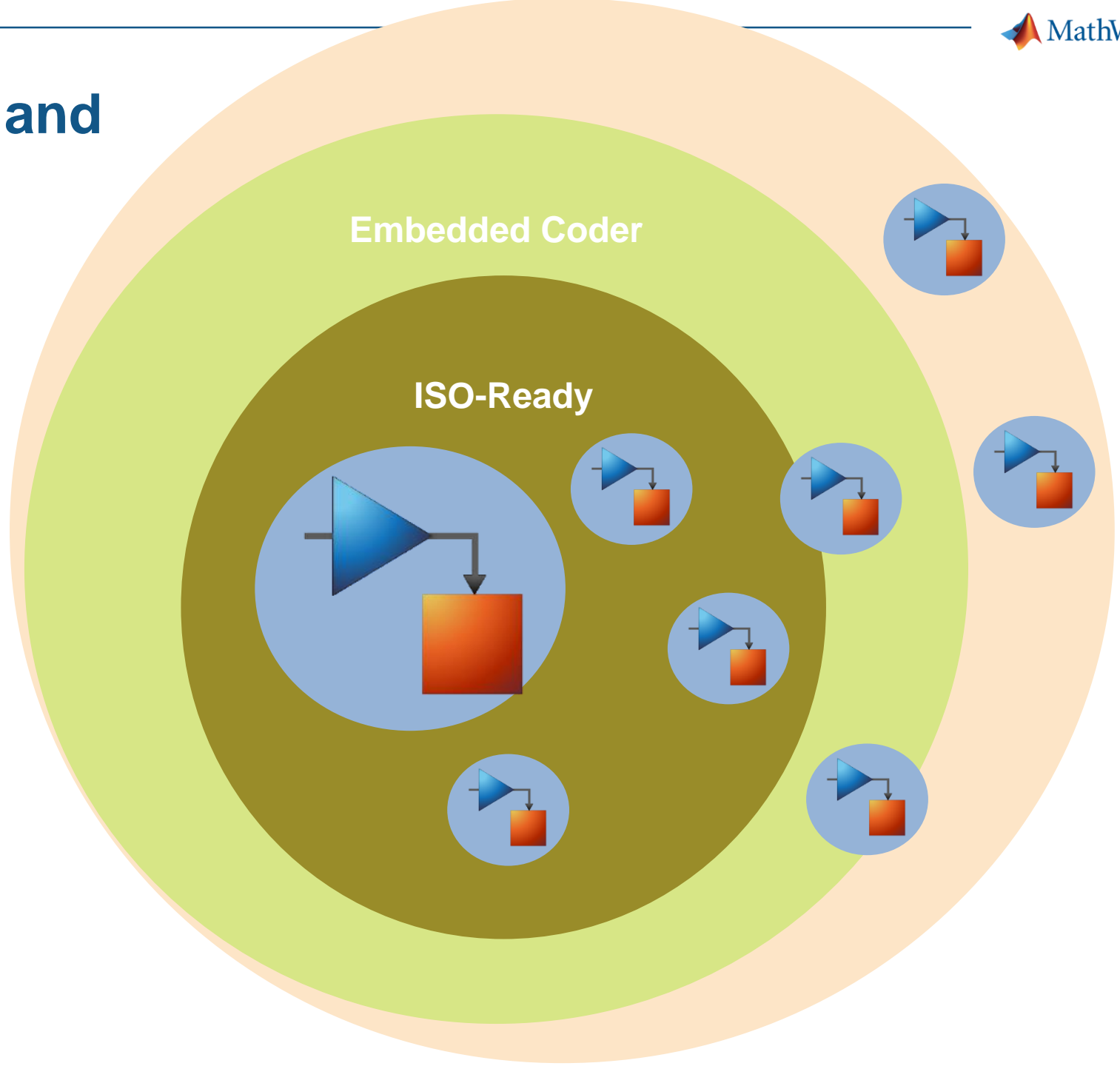


Summary so far

- Customers are successfully using MATLAB in ISO 26262-compliant products today
- Our verification workflow and tools support MATLAB called by Simulink
- But... there are some gaps remaining
 - Potential issues with MISRA-C compliance of code generated from MATLAB
 - Achieving MATLAB vs C code coverage
 - Simplifying Simulink model comparison reviews

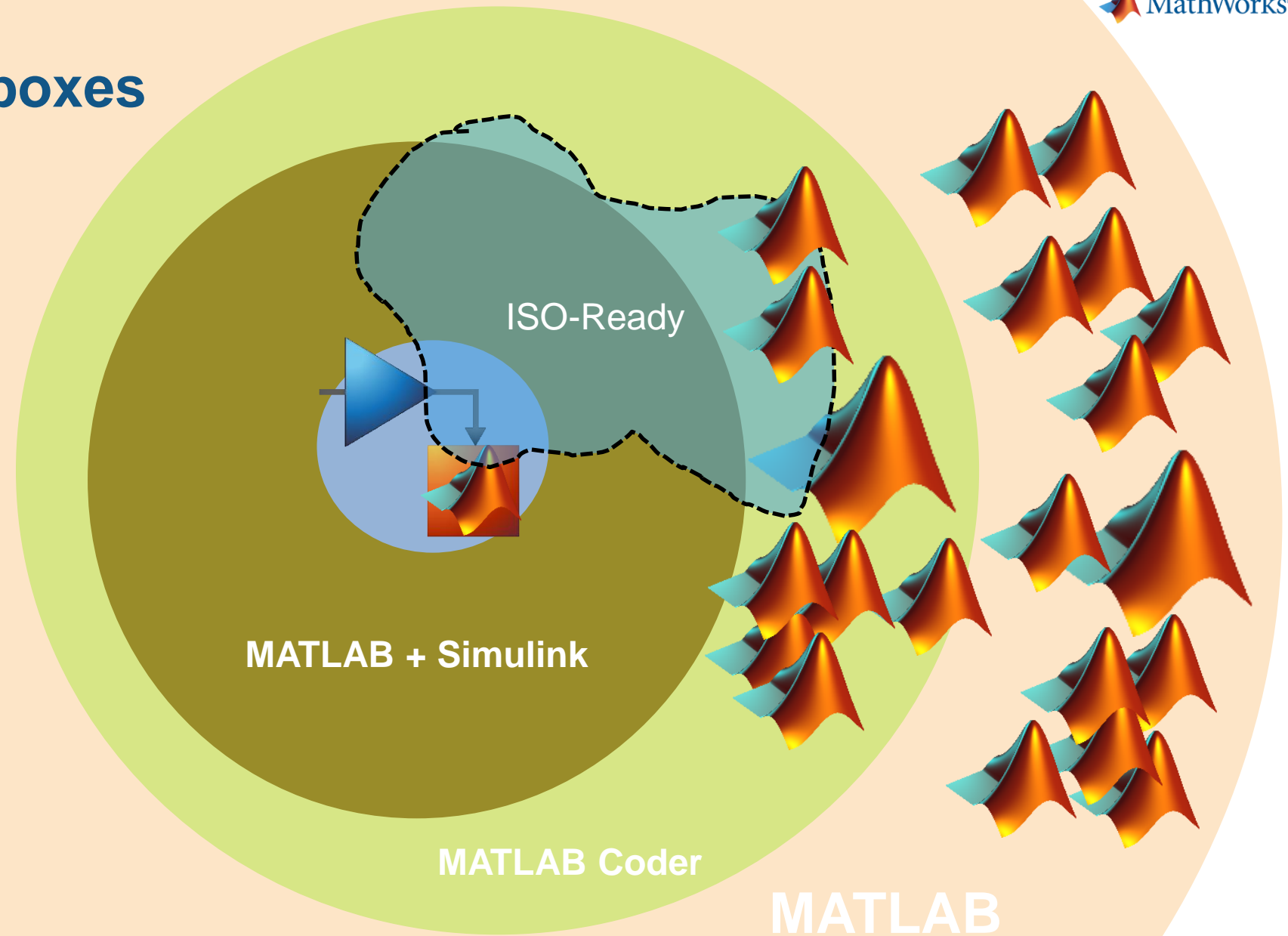
Simulink core blocks and toolboxes

- Well-understood
- Up-front tools to help
- Few surprises



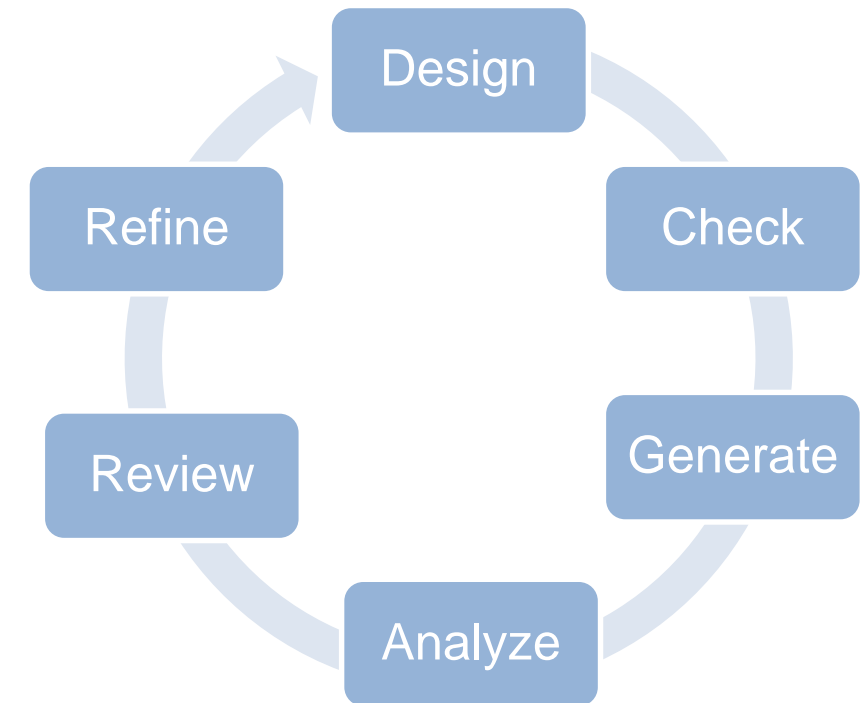
MATLAB and toolboxes

- Emerging usage
- Less up-front advice
- Iterative process today



Code standards compliance

- Practice is to
 - run model checks **Simulink Check**
 - generate code
 - analyze compliance **Polyspace Bug Finder**
- Issues discovered?
 - document and proceed
 - rework the algorithm
 - rewrite a compliant function (toolboxes)
- Result is an allowed function list (language subset)
- Process gets more efficient over time



Code coverage

- MATLAB functions can be complex in C/C++

```
% 5. Compute Kalman Gain:
W = P*M'*inv(M*P*M'+ R);
```

- One test case gets coverage in MATLAB, but more required to show no unintended functionality in the generated C

- Strategies include
 - Develop unit tests for feature/function
 - Implement a simpler replacement

```
480 /* 5. Compute Kalman Gain: */
481 /* '<S1>:1:48' W = P*M'*inv(M*P*M'+ R); */
482 for (i = 0; i < 2; i++) {
483     for (iU = 0; iU < 4; iU++) {
484         Phi_tmp_tmp = (int32_T)((int32_T)(iU << 1) + i);
485         x_tmp[(int32_T)(iU + (int32_T)(i << 2))] = M[Phi_tmp_tmp];
486         M_0[Phi_tmp_tmp] = 0.0;
487         Phi_tmp = (int32_T)(iU << 2);
488         M_0[Phi_tmp_tmp] += sldemo_radar_eml_DWork.P[Phi_tmp] * M[i];
489         M_0[Phi_tmp_tmp] += sldemo_radar_eml_DWork.P[(int32_T)(Phi_tmp + 1)] *
490             0.0;
491         M_0[Phi_tmp_tmp] += sldemo_radar_eml_DWork.P[(int32_T)(Phi_tmp + 2)] *
492             M[(int32_T)(i + 4)];
493         M_0[Phi_tmp_tmp] += sldemo_radar_eml_DWork.P[(int32_T)(Phi_tmp + 3)] *
494             0.0;
495     }
496 }
497
498 for (i = 0; i < 2; i++) {
499     for (iU = 0; iU < 2; iU++) {
500         Phi_tmp_tmp = (int32_T)(i << 2);
501         Phi_tmp = (int32_T)((int32_T)(i << 1) + iU);
502         Phi_1[Phi_tmp] = ((x_tmp[(int32_T)(Phi_tmp_tmp + 1)] * M_0[(int32_T)(iU
503             + 2)] + x_tmp[Phi_tmp_tmp] * M_0[iU]) + x_tmp[(int32_T)(Phi_tmp_tmp +
504             2)] * M_0[(int32_T)(iU + 4)]) + x_tmp[(int32_T)(Phi_tmp_tmp + 3)] *
505             M_0[(int32_T)(iU + 6)]) + R[Phi_tmp];
506     }
507 }
508
509 if (fabs(Phi_1[1]) > fabs(Phi_1[0])) {
510     rtb_range = Phi_1[0] / Phi_1[1];
511     rtb_WhiteNoise_idx_0 = 1.0 / (rtb_range * Phi_1[3] - Phi_1[2]);
512     M_tmp = Phi_1[3] / Phi_1[1] * rtb_WhiteNoise_idx_0;
513     M_tmp_0 = -rtb_WhiteNoise_idx_0;
514     y_idx_2 = -Phi_1[2] / Phi_1[1] * rtb_WhiteNoise_idx_0;
515     rtb_WhiteNoise_idx_0 *= rtb_range;
516 } else {
517     rtb_range = Phi_1[1] / Phi_1[0];
518     rtb_WhiteNoise_idx_0 = 1.0 / (Phi_1[3] - rtb_range * Phi_1[2]);
519     M_tmp = Phi_1[3] / Phi_1[0] * rtb_WhiteNoise_idx_0;
520     M_tmp_0 = -rtb_range * rtb_WhiteNoise_idx_0;
521     y_idx_2 = -Phi_1[2] / Phi_1[0] * rtb_WhiteNoise_idx_0;
522 }
523 }
```


Reviewing Simulink models

- Are you reviewing Simulink models?
 - 1-1 or 1-many at desk or in conference rooms?
 - Screen sharing apps?
- Modern workforces are often distributed and busy, making this a challenge
- Tools to manage the review process, such as Gerrit Code Review, are becoming a popular approach



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Text-based differences + review comments

Gerrit Code Review

Gerrit implements a web-based review and approval workflow for git patch revisions

Review comments are shared in the **context** of the source

But, binary formats not supported (.slx)

The screenshot shows the Gerrit Code Review interface in a Mozilla Firefox browser. The page displays a code diff for 'ModelReview.m' in a 'demo-project'. The diff shows changes between two versions of the file, with line numbers 197-207 on the left and 191-201 on the right. A red arrow points from the review comment on the right to the corresponding code lines in the diff. The review comment is from David Hoadley, dated Jan 8, 2019, and asks: 'Why did we need ~master~, etc. in the endpoint?'. Below the comment are buttons for 'Reply', 'Quote', 'Done', and 'Fix'. The comment also includes a response from David Hoadley: 'Customer testing reported it'.

```

197     elseif numPatches > 0
198         prompt = ['Found ' num2str(numPatches) ' patch sets. Which one?
199             num2str(numPatches) ']:'];
200
201     +10↑ ... skipped 497 common lines ... +10↓
202     % or Id!
203     % GET
204     % /changes/myProject-master~changeID/revisions/revisionID/comments/
205
206     if ~obj.reviewReady
207         error('First use ModelReview.review to establish a review session
208
209     end
210
211     base = ['https://' obj.gerrit_server '/a/'];
212     % base = ['http://' obj.gerrit_server ':8080/a/']; % Dave only
213     endpoint = [base 'changes/' obj.change_id ...
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Extending this concept to Simulink

- Custom add-on to Simulink context menu
- Block badge indicates comment attached
- Publish to Gerrit when ready to share

The screenshot displays the Simulink Model Review UI. The main window shows a Simulink model titled "patch_refs_changes_68_168_1_sl_aircraft" with a block diagram of an "Aircraft Longitudinal Flight Control" system. A red arrow points from the "Block badge" in the list to the "Publish" button in the comment panel.

The Simulink model diagram includes the following components and signals:

- Pilot** block with input **Stick** and output **u**.
- Controller** block with input **u** and output **Stick, in**.
- Actuator Model** block with input **Stick, in** and output **num(s)/den(s)**.
- Aircraft Dynamics Model** block with inputs **q, rad/sec** and **alpha, rad**, and outputs **wdot, ft/sec²**, **qdot, rad/sec²**, **q, rad/sec**, and **alpha, rad**.
- Dryden Wind Gust Models** block with inputs **wGust** and **qGust**, and outputs **wGust** and **qGust**.
- Mw** and **Mq** blocks representing transfer functions.
- Zw** block representing a zero-pole cancellation.
- Gain** block with value **2**.

The Model Review UI panel on the right shows the following details:

- Path:** patch_refs_changes_68_168_1_sl_aircraft/Gain/2
- Highlight object** button.
- All Comments** section with a list of comments.
- Selected Comment** dropdown showing **1**.
- Draft** section with the text: "Is Zw the right gain?"
- Buttons:** Reply, Add, Edit, Delete, Revert, and Publish (circled in red).

Ubu [Running] - Oracle VM VirtualBox

File Machine View Input Devices Help

MATLAB R2019b

patch_refs_changes_68_168_1_sl_aircraft.slx vs. patch_refs_changes_68_168_2_sl_aircraft.slx

COMPARISON

Previous Next Swap Find Highlight Now Show Hide Lines Nonfunctional Chan... Block Defaults New Filter PUBLISH MERGE

Left: patch_refs_changes_68_168_1_sl_aircraft.slx

Simulink

- Aircraft Dynamics Model
 - Gain3
 - Sum1
 - Controller
 - Gain
- Dryden Wind Gust Models:1 -> Branch
- Gain:1 -> Aircraft Dynamics Model:2

Model Configuration Sets

- Configuration
 - Data Import/Export
 - Diagnostics
 - Solver

ModelReviewUI

Previous Next

Path

patch_refs_changes_68_168_1_sl_aircraft/Gain

Highlight object

All Comments

*1: Draft new 21-Oct-2019 10:49
Which requirement changed to lead to deletion of this block?

Selected Comment 1

Draft new 21-Oct-2019 10:49
Which requirement changed to lead to deletion of this block?

Draft

Which requirement changed to lead to deletion of this block?

Reply Add Edit Delete

Revert Publish

patch_refs_changes_68_168_1_sl_aircraft - Simulink

SIMULATION DEBUG MODELING FORMAT APPS BLOCK

Open Save Library Browser Log Signals Add Viewer Stop Time 60 Normal Fast Restart Step Back Run Step Forward Stop Data Inspector

patch_refs_changes_68_168_1_sl_aircraft

Aircraft Longitudinal Flight Control

This example models a flight control algorithm for the longitudinal motion of an aircraft.

Pilot Stick u

1

Stick, in q, rad/sec δcmd, deg α, rad

Controller

num(s) den(s)

Actuator Model

δ_e, deg wdot, ft/sec²

qdot, rad/sec²

wGust, ft/sec q, rad/sec

qGust, rad/sec α, rad

wg wGust Mw

100%

ode45

patch_refs_changes_68_168_2_sl_aircraft - Simulink

SIMULATION DEBUG MODELING FORMAT APPS BLOCK

Open Save Library Browser Log Signals Add Viewer Stop Time 5 Normal Fast Restart Step Back Run Step Forward Stop Data Inspector

patch_refs_changes_68_168_2_sl_aircraft

Aircraft Longitudinal Flight Control

This example models a flight control algorithm for the longitudinal motion of an aircraft.

Pilot Stick u

1

Stick, in q, rad/sec δcmd, deg α, rad

Controller

num(s) den(s)

Actuator Model

δ_e, deg wdot, ft/sec²

qdot, rad/sec²

wGust, ft/sec q, rad/sec

qGust, rad/sec α, rad

wg wGust Mw

100%

ode45

Summary redux

- Customers are successfully using Simulink **AND MATLAB** in ISO 26262-compliant products today
- Our verification workflow and tools support MATLAB called by Simulink
- There are some gaps remaining
 - Potential issues with MISRA-C compliance of code generated from MATLAB
 - Achieving MATLAB to C code coverage
 - Simplifying Simulink model reviews
- Contact me dhoadley@mathworks.com and at the ISO 26262 table

