



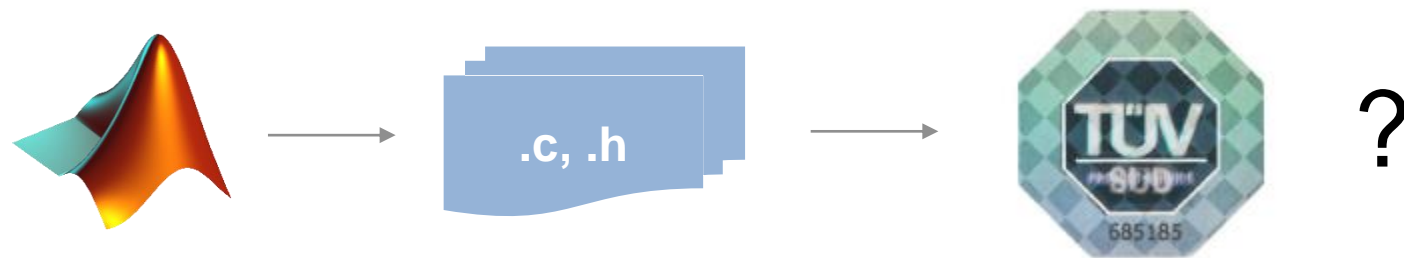
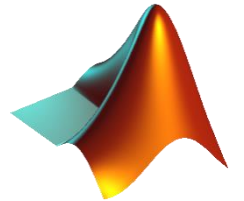
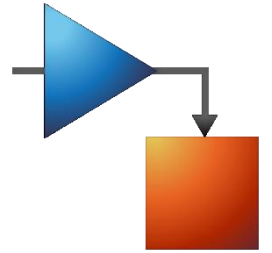
# Toolchain Definition and Integration for ISO 26262-Compliant Development

July 1

MathWorks  
**AUTOMOTIVE  
CONFERENCE 2020**

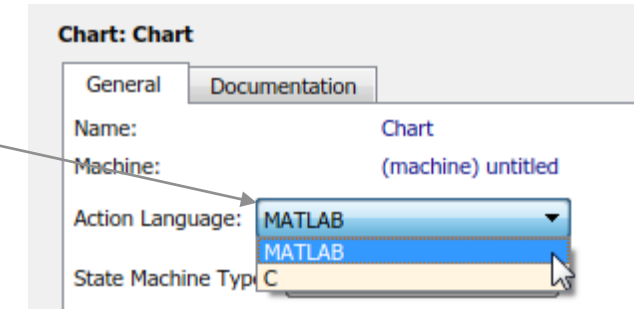
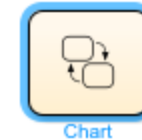
# Introduction

- 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
- Can we generate certifiable code from MATLAB?



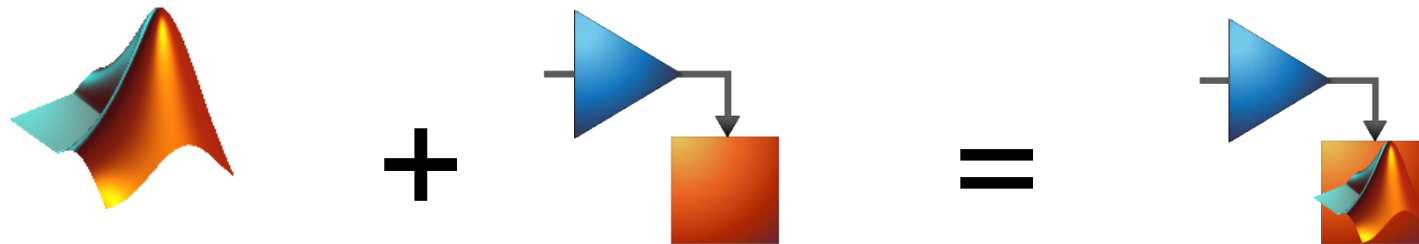
# Yes! Through Simulink Integration

- 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 and reference workflow



## 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 ↔ design ↔ implementation ↔ validation
- Meet design & implementation standards
- Show intended and no unintended functionality
  - Coverage is key evidence

Include in analysis

- MATLAB files
- C/C++ S-functions

Coverage metrics

Structural coverage level: Decision

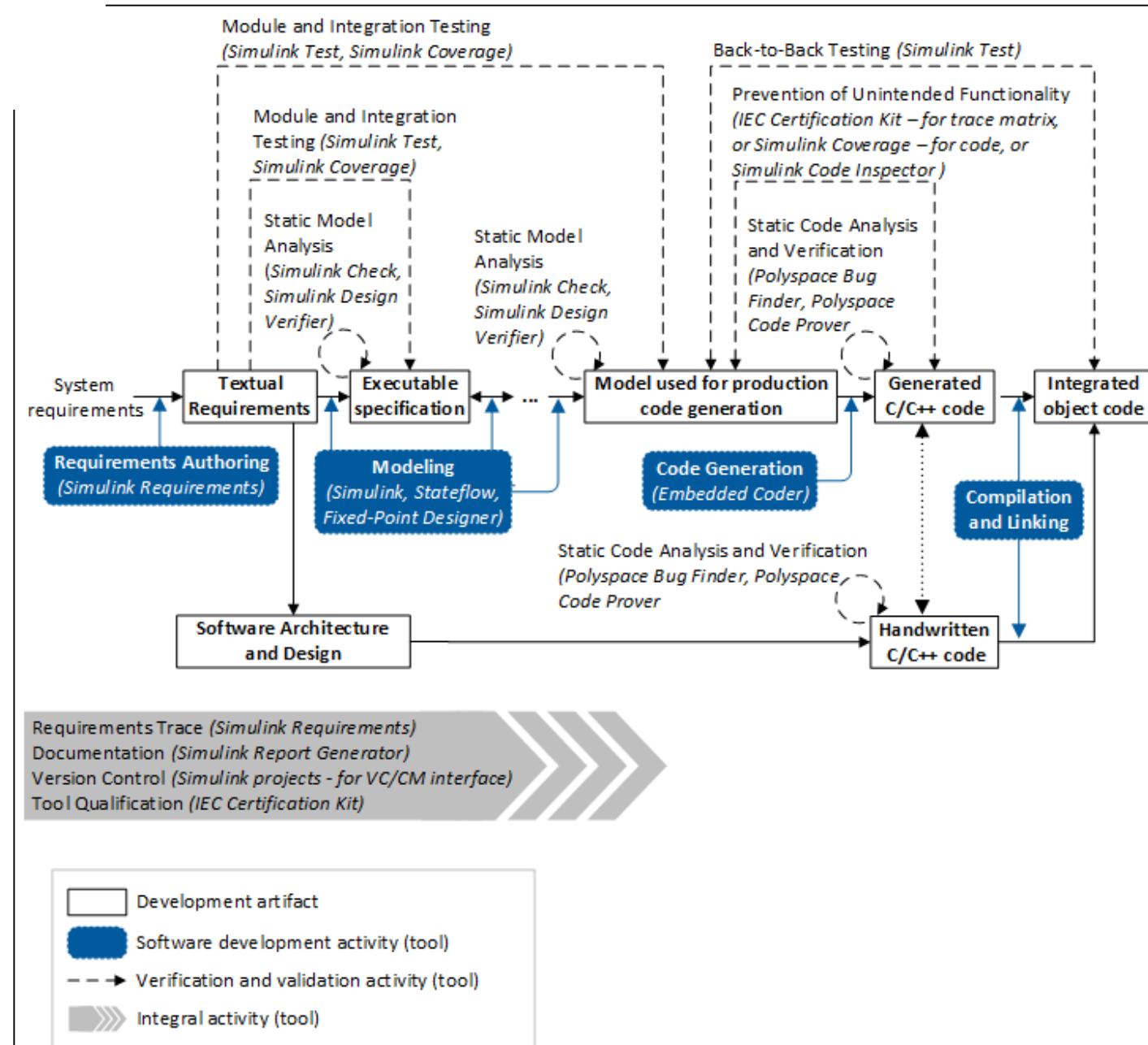
Other metrics

- Lookup table
- Signal range
- Signal size
- Objectives and constraints
- Saturation on integer overflow

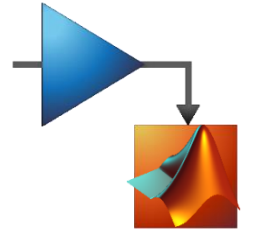
Decision

Condition Decision

Modified Condition Decision Coverage (MCDC)



# 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

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

```

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);
49

```

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];

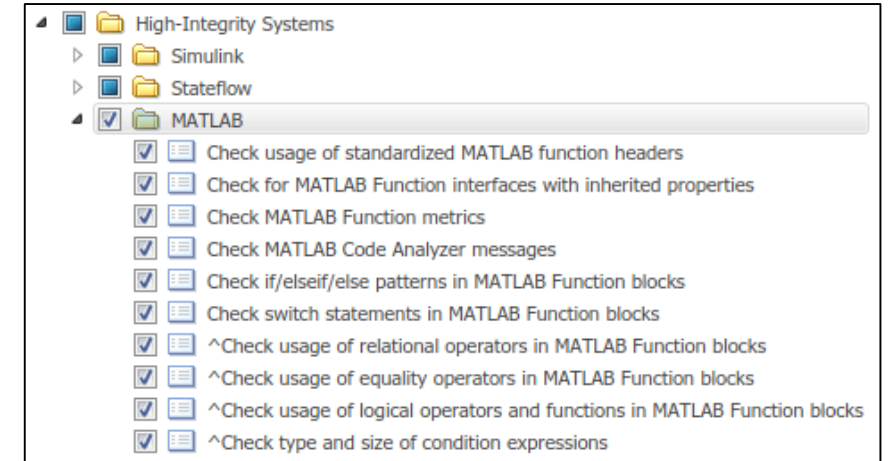
```



# 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

The screenshot displays the Simulink Coverage tool interface. On the left, a Simulink model is shown with a 'MATLAB Function' block highlighted in green. The right pane shows the 'Coverage Details' for the selected block, including a table of metrics and the corresponding MATLAB code with line numbers.

Metric	Coverage
Cyclomatic Complexity	2
Decision	100% (3/3) decision outcomes

```

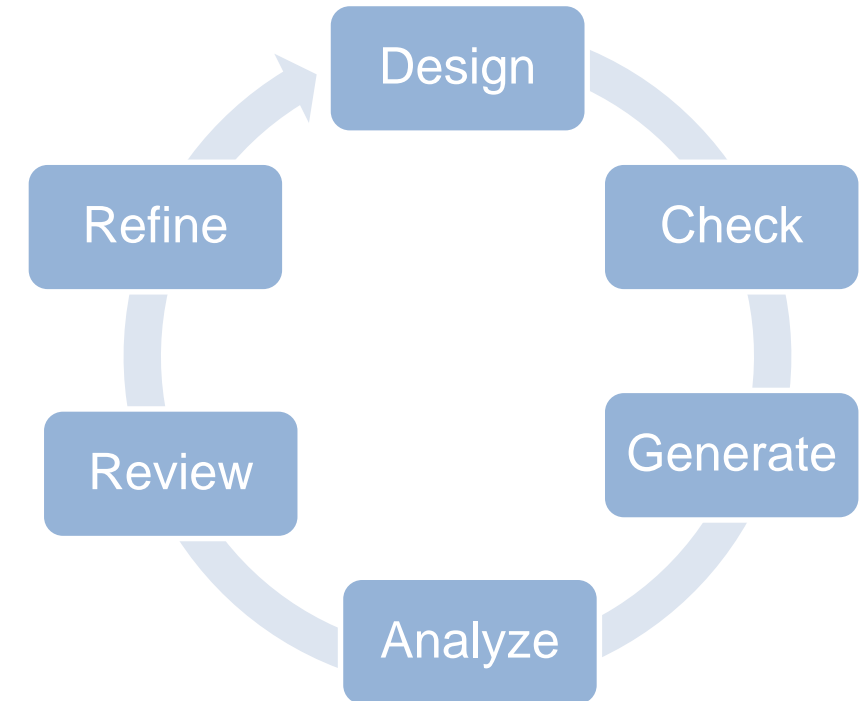
1 function [residual, xhatOut] = EXTKALMAN(meas, deltat)
2 %EXTKALMAN Radar Data Processing Tracker Using an Extended
3 %
4 % This program is executed as a MATLAB function block in
5 % sldemo_radar Simulink model. The estimated and actual
6 % saved to the workspace and are plotted at the end of th
7 % the program aero_radplot (called from the simulation au
8 %
9 %
10
11 % Copyright 1990-2013 The MathWorks, Inc.
12
13 % Initialization
14 persistent P;
15 persistent xhat
16 if isempty(P)
17     xhat = [0.001; 0.01; 0.001; 400];
18     P = zeros(4);
19 end
20
  
```

## 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 reviews

# 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  }
  
```

# 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 browser address bar shows the URL: `dave-virtualbox:8080/#/c/132/4..5/ModelReview.m`. The page title is "ModelReview.m | dave-virtualbox Code Review - Mozilla Firefox".

The interface displays a code diff for the file "ModelReview.m". The diff shows changes between two versions of the code. The left side shows the original code, and the right side shows the proposed changes. A red box highlights a change in the `endpoint` variable definition on line 707:

```

707 endpoint = [base 'changes/' obj.change_id ...

```

A review comment is displayed on the right side of the diff, associated with the highlighted change. The 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". A second comment from David Hoadley, dated Jan 8, 2019, replies: "Customer testing reported it".



# Model reviews with built-in features

- Configure SCM with external diff tool for MATLAB files
  - E.g., "C:\Program Files\MATLAB\R2019a\bin\win64\mlDiff.exe" %LOCAL %PWD %REMOTE
  - Note this will reuse a running MATLAB not start a new instance
- Publish model comparison to MS Word format
- Annotate and share Word document with comments/replies

<b>Gain3</b>	<b>Gain3</b>
Gain : Uo	Gain : -Uo
<b>Sum1</b>	<b>Sum1</b>

**Dave Hoadley** 4 minutes ago  
Was there a requirement change to support this?

Reply   Resolve

# Extending this concept *into* 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 ModelReviewUI interface. The main window shows a Simulink model titled 'patch\_refs\_changes\_68\_168\_1\_sl\_aircraft'. A red arrow points from the text 'Block badge indicates comment attached' to a small badge on the 'Zw' block in the 'Controller' subsystem. The right-hand panel, titled 'ModelReviewUI', shows a comment for the selected block: 'patch\_refs\_changes\_68\_168\_1\_sl\_aircraft/Gain 2'. The comment text reads: 'Is Zw the right gain?'. The 'Publish' button at the bottom right of the comment panel is circled in red.

# Summary redux

- Customers are successfully using Simulink **AND MATLAB** in ISO 26262-compliant products today

- 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



- [Best Practices Technical paper](#)

## An ISO 26262 Workflow for Automated Driving Applications Using MATLAB: Guidelines and Best Practices

By Lars Rosqvist, MathWorks

The use of Simulink® and Stateflow® for ISO 26262 software development is well established for automotive ECUs. There is a growing trend, particularly in automated driving applications, toward implementing software designs using MATLAB® functions as well as Simulink blocks and Stateflow charts. This article offers best practices for using a MATLAB-centric workflow to verify compliance with ISO 26262 software standards [1]. These best practices complement the ISO 26262 Reference Workflow using Model-Based Design illustrated in IEC Certification Kit.

### Recommended Modeling Pattern

In this article we use a software development pattern in which a Simulink model incorporates a MATLAB Function block (Figure 1). The top layer Simulink model carries all the configuration settings for code generation. The MATLAB Function block calls external MATLAB functions.



```

MATLABAlgorithm = @(inputData) MATLABAlgorithm(inputData)
  
```

# Q&A

Do you use MATLAB code in your ISO 26262 components?

- Yes
- No
- No, but planning to

**Please contact us with questions**



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