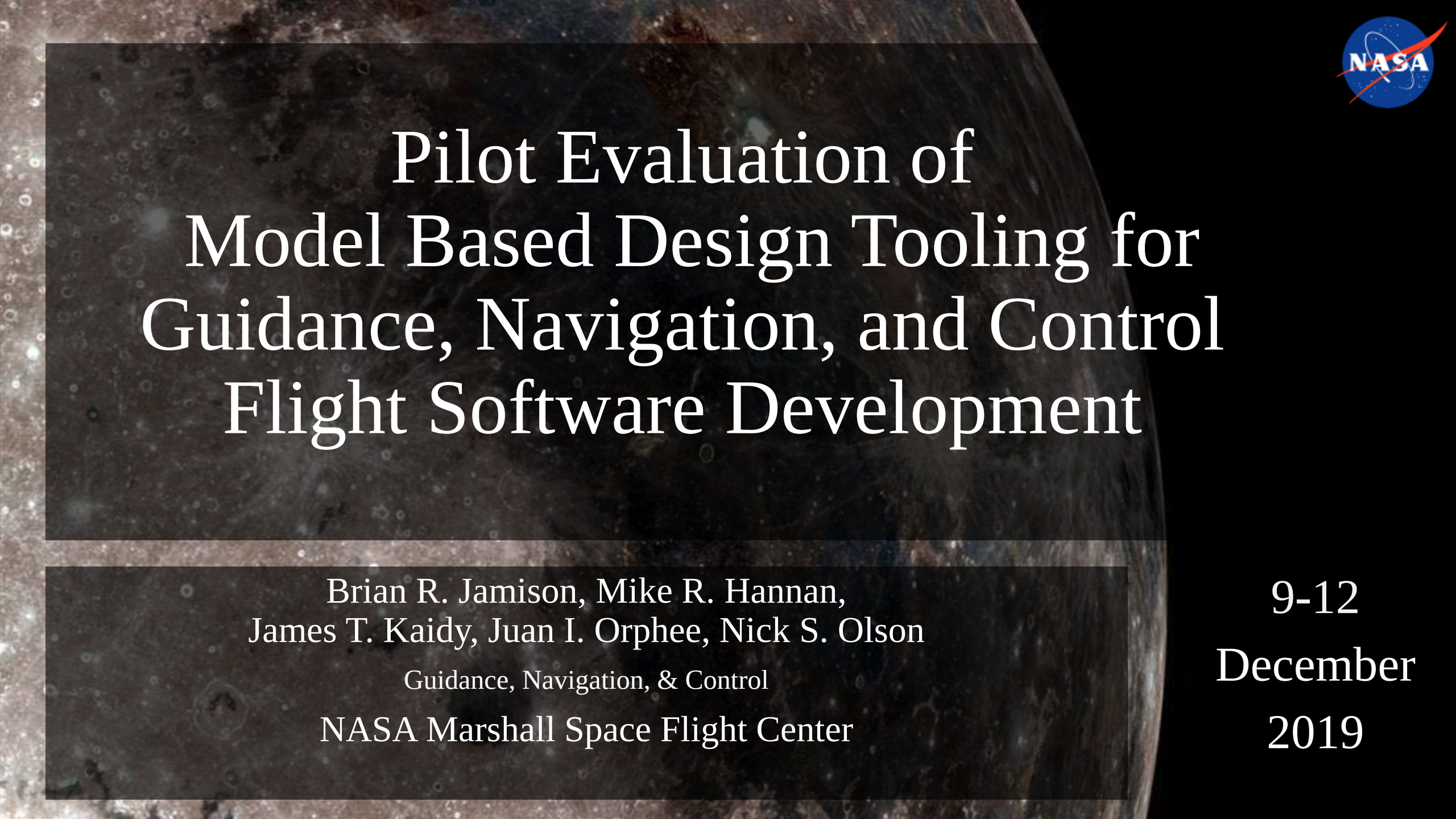


Pilot Evaluation of Model Based Design Tooling for Guidance, Navigation, and Control Flight Software Development

Brian R. Jamison, Mike R. Hannan,
James T. Kaidy, Juan I. Orphee, Nick S. Olson

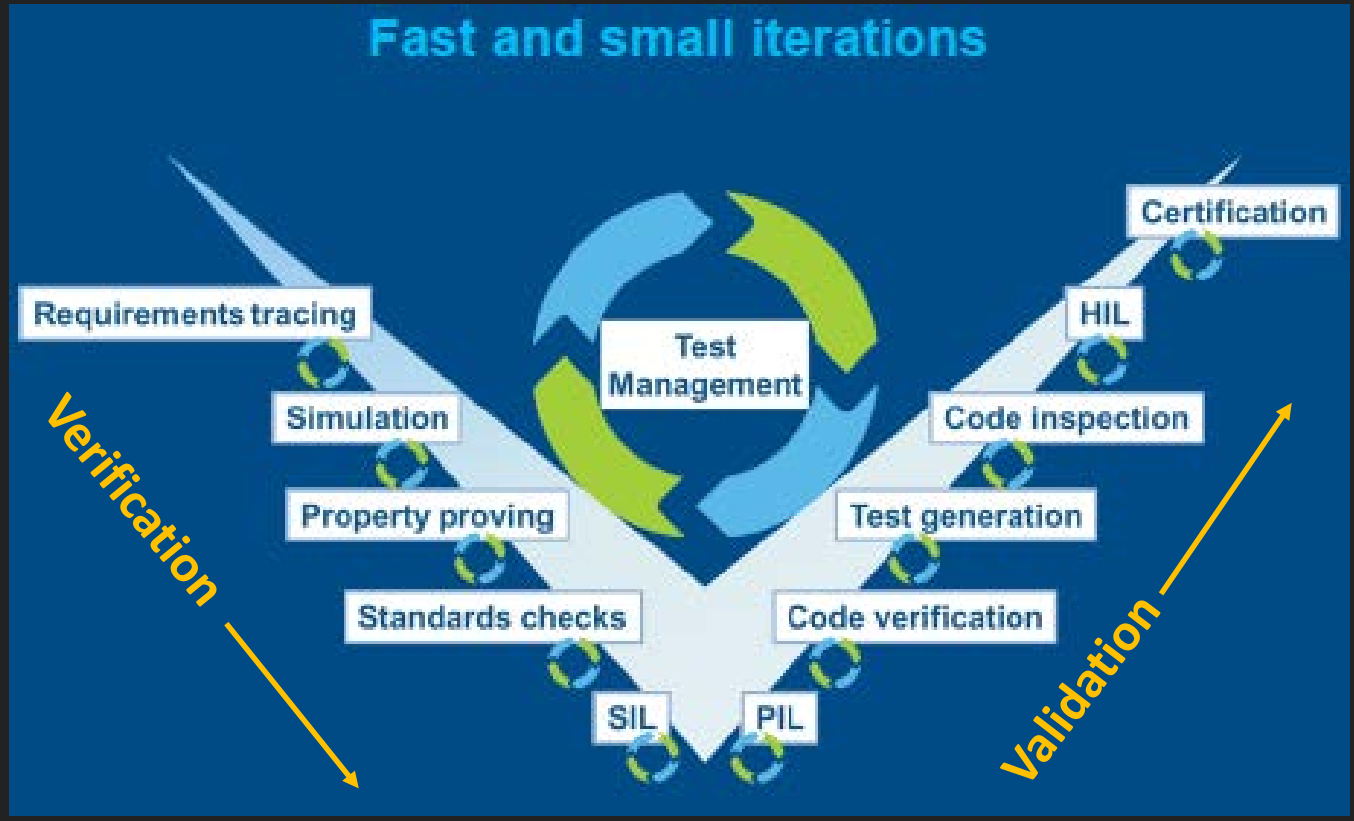
Guidance, Navigation, & Control

NASA Marshall Space Flight Center

9-12 December 2019

What & Why Model Based Design (MBD)

- MBD systematically uses models throughout the development process for requirements, design, analysis, simulation, verification and validation, and documentation
- An MBD approach seeks to incorporate models into an automated, concurrent design process intended to minimize potential for human error
- Improvements offered by an MBD approach include efficiency improvements by automating aspects of requirements testing and documentation
- An advantage of MathWorks MBD tooling is the model visualization Simulink naturally incorporates into the design process



NASA LADEE MBD Experience

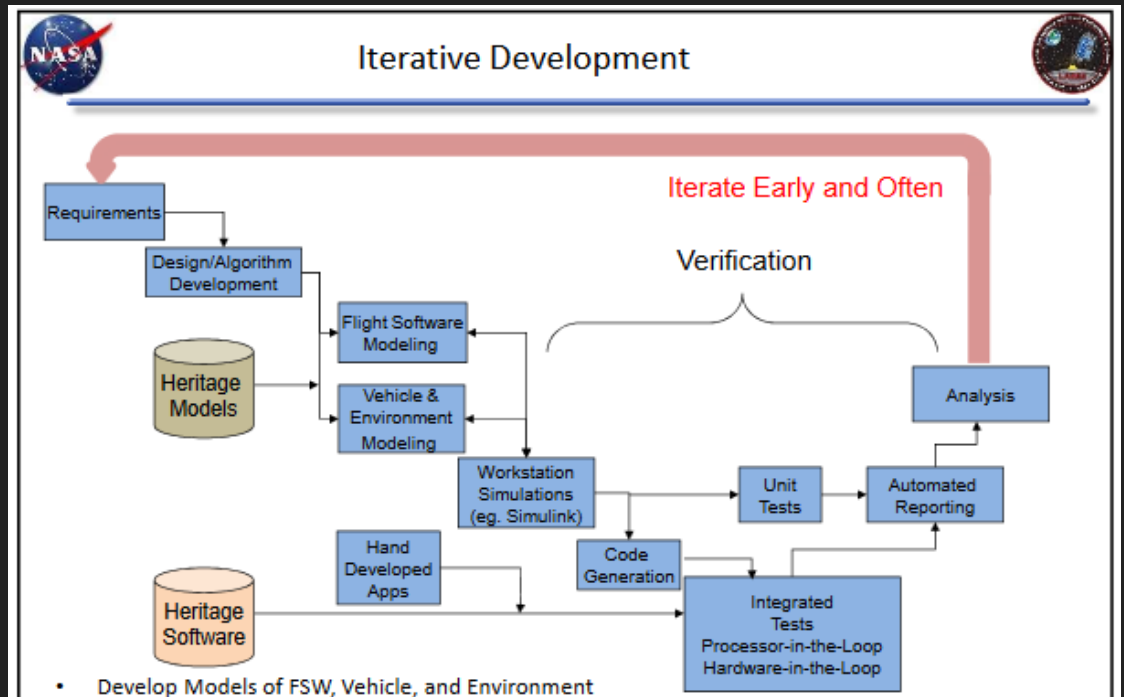
- "Compared with using Model-Based Design, hand-coding the flight software would have taken longer and made collaboration more difficult. Managers and hardware system engineers understand Simulink models, making it easy to achieve consensus because everyone knows what's going on in the software."

  - *Dr. Karen Gundy-Burlet, NASA Ames Research Center*

Model Based Development

- Issues:
  - Low Cost Mission and fixed schedule demanded rapid, low cost flight software development process
  - Simulations needed for FSW Verification and Mission Operations development, training, and command verification.
- Solution:
  - Use model based development approach
    - Automatic conversion of Models to FSW allows development and testing of algorithms which then becomes Software. Avoids "throwing it over the fence to be coded".
  - Developed multiple simulators of varying degrees of fidelity (WSIM, PIL, HIL)
  - Developed Simulink Interface Layer
    - Allows immediate translation from models to Code allowing rapid turnaround
  - Developed an automated test harness for rapid turnaround of verification results
- Result:
  - Model Based Development coupled with "push button" code generation and testing was highly effective for rapid software development.
  - Models and Simulations used extensively in Mission Operations.
    - WSIM provided faster than real time capability for rapid command verification.
    - Processor in the Loop and Hardware in the Loop simulations provided high fidelity simulations for critical maneuver verification, Ops training, and debugging anomalies
    - Fully Coupled Simulations (Power, Thermal, Propulsion, Attitude Control) provided better insight for coupled problems.

Iterative Development



- Develop Models of FSW, Vehicle, and Environment
- Automatically generate High-Level Control Software
- Integrate with hand-written and heritage software.
- Iterate while increasing fidelity of tests – Workstation Sim (WSIM), Processor-In-The-Loop (PIL), Hardware-in-the-Loop (HIL)
- Automated self-documenting tests providing traceability to requirements

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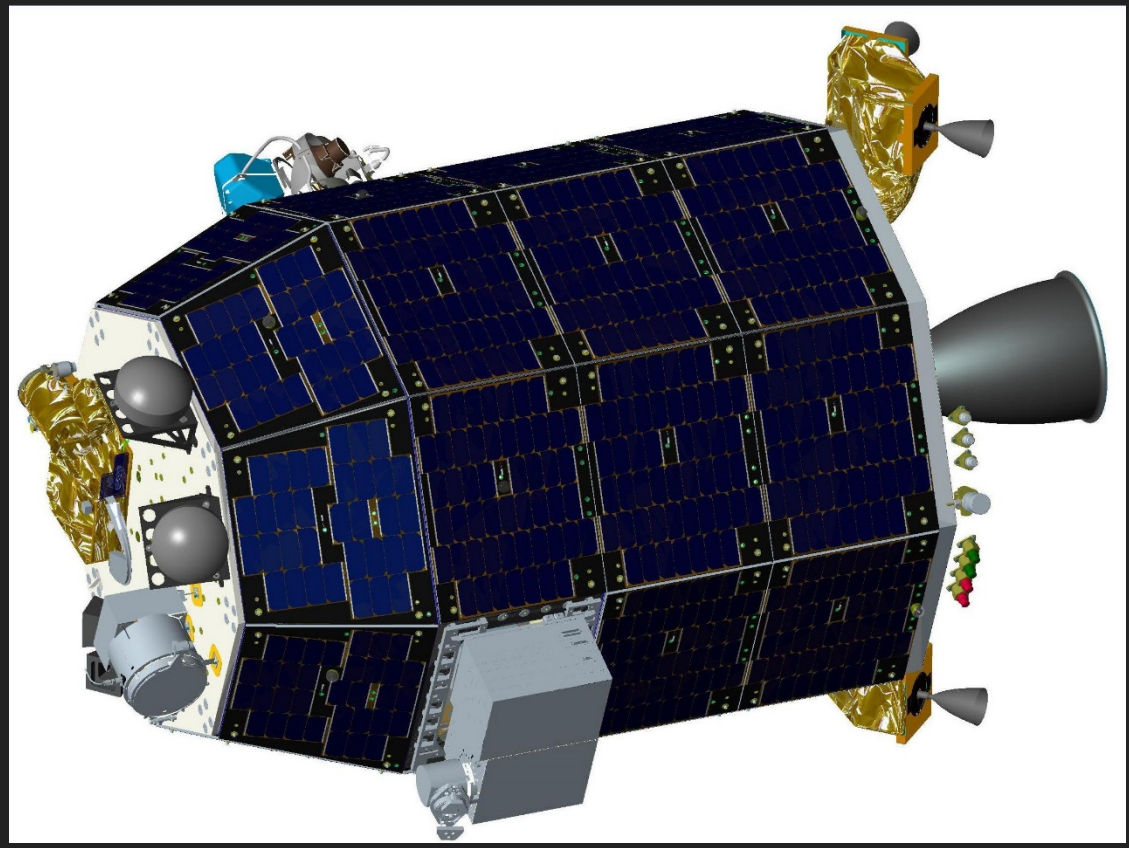
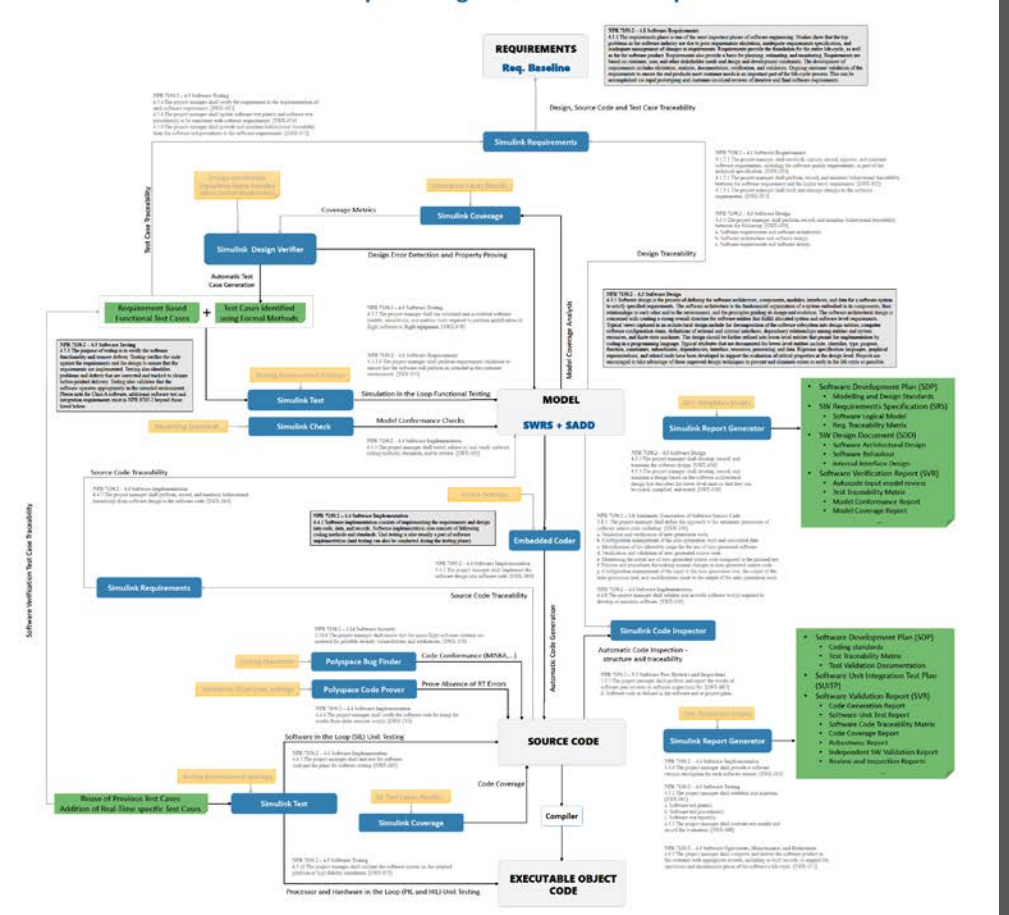
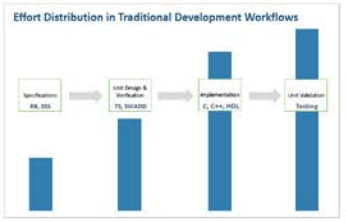
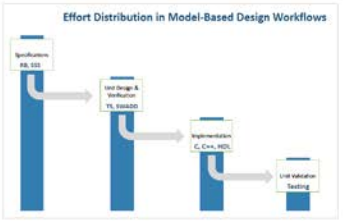
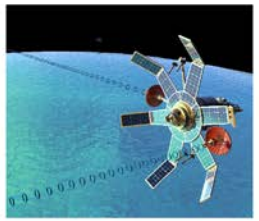


MathWorks MBD Tooling









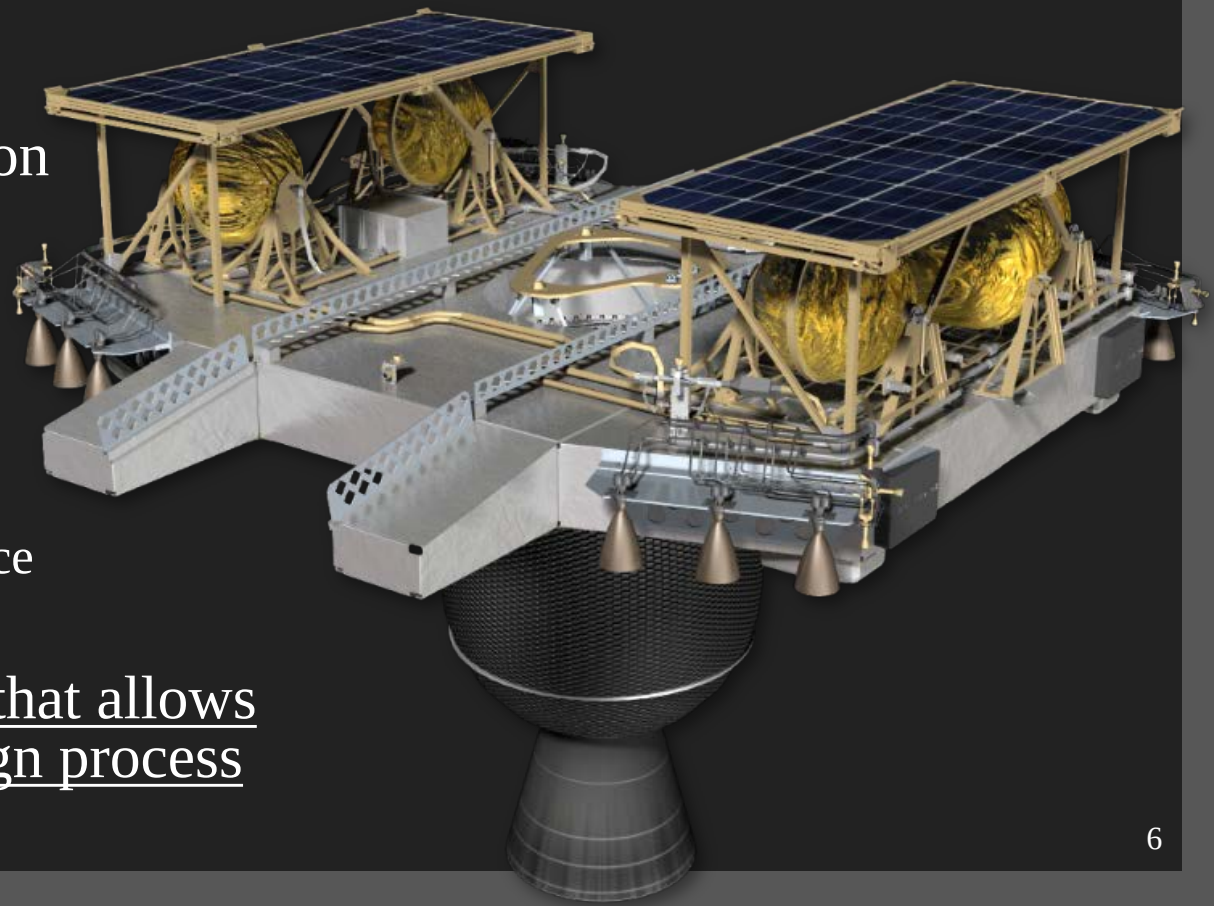
- MathWorks worked with the NASA Engineering & Safety Center (NESC) to develop tooling that addresses about 80% of NPR 7150.2 requirements, including:
  - Software requirements
  - Software design
  - Software implementation
  - Software testing
- NPR 7150.2 Requirements outside of the MathWorks workflow include:
  - Software architecture requirements
  - Project management requirements
- Consultation ongoing with the Marshall Space Flight Center (MSFC) software division to ensure they concur with our MBD approach

VIPER Lunar Lander Pilot Program

- MSFC Guidance, Navigation, & Control (GNC) group used the VIPER Lander as a pilot program to use of MathWorks MBD tools for GNC FSW development
- Goal: Apply an MBD approach and tooling to condense schedule, reduce needed resources, and improve quality

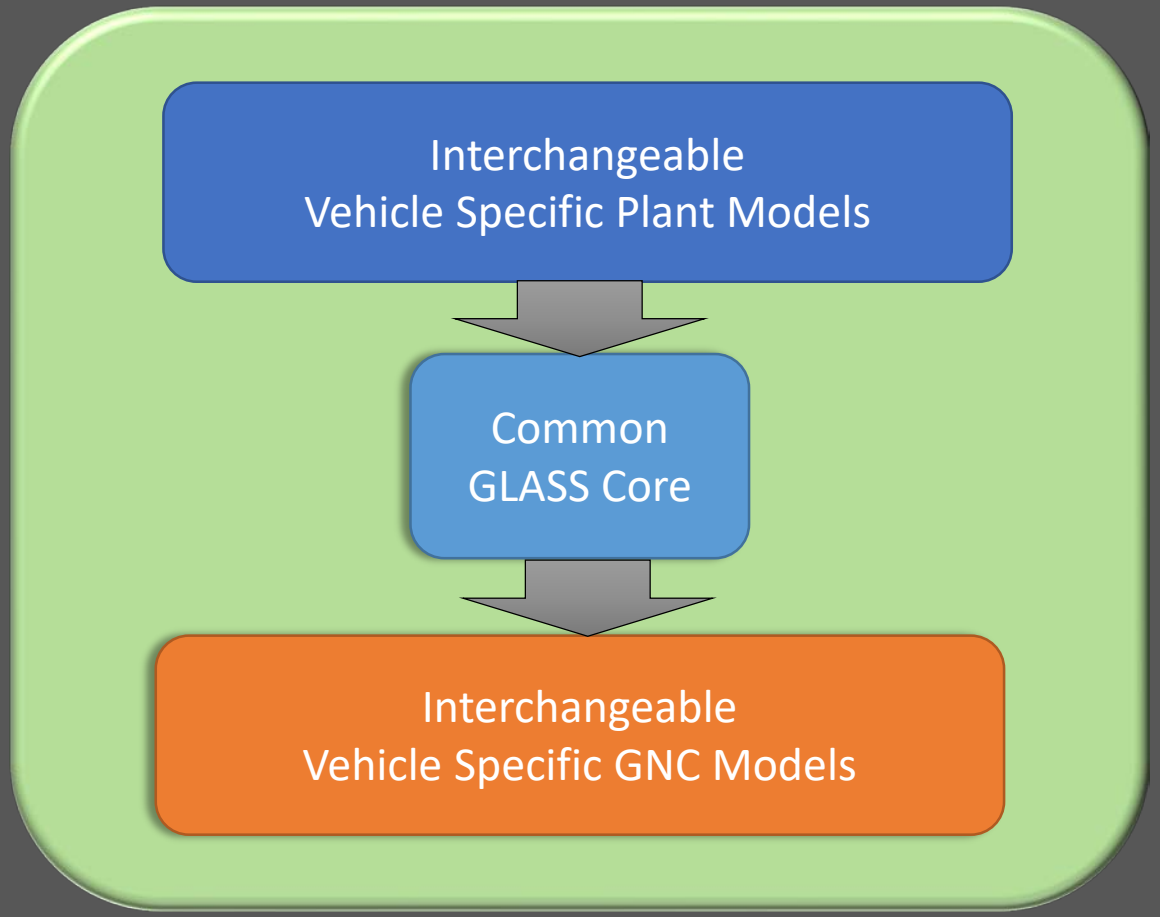
Expected MBD approach benefits:

- Facilitates requirements implementation verification
- Automates:
  - Requirements verification testing
  - Continuous model and flight code testing
  - Modeling standards (DO-178C) enforcement
  - Code-generation from the Simulink model
  - Static code analysis to ensure coding standard compliance
  - Report generation
- Establish a highly automated, disciplined process that allows repeated testing of the system throughout the design process



Generalized Lander Simulation in Simulink (GLASS)

- 6-DoF aerospace vehicle simulation environment designed to be:
  - Modern
  - Flexible
  - User-friendly
- Features
  - Simulink Framework
    - Interfaces with MathWorks MBD products
    - Supports auto-coding to C/C++
  - Dynamics constructed using Simscape Multibody
    - Provides flexible & modular physics engine for simulation
    - GLASS Core is common to all simulations
  - Modular GNC algorithms
    - Mirror FSW functions in generated code



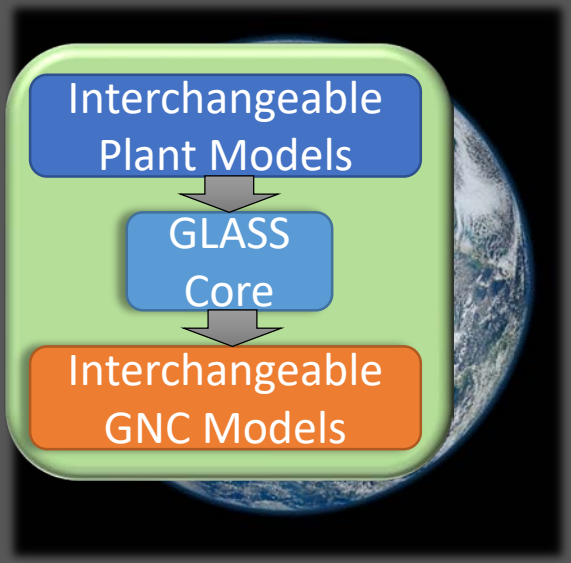
MBD for GNC FSW Development

Check Requirements: Simulink Requirements & Simulink Test

- ✓ Ensure code satisfies requirements

Model & GNC Code Development: Simulink & Model Advisor

- ✓ Highly modular software development
- ✓ Enforce DO178 and custom standards




```
1  // NASA MSFC GNC
2  Quality
3  Autocode
4  GNC
5  FSW
```

Static Code Check: Polyspace

- ✓ Catch run time errors,
- ✓ Enforce MISRA, JSF, etc.

Auto-code GNC Software: Simulink Embedded Coder

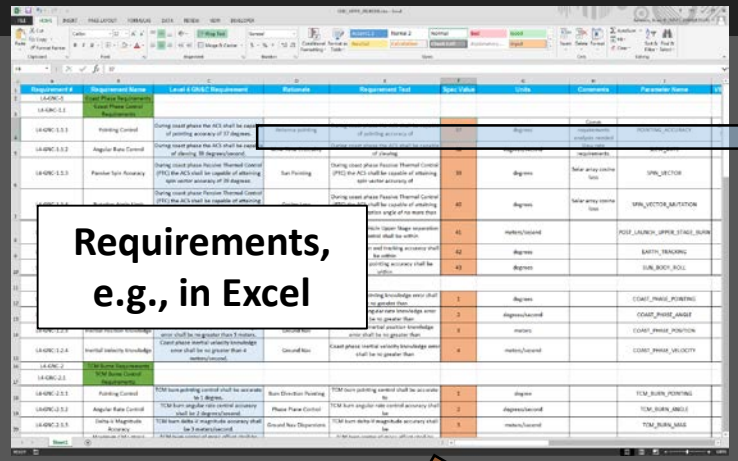
- ✓ Customize auto-code to meet FSW standards
- ✓ Enforce selected standards
- ✓ cFS compatible (optional)

Generate Automated Reports: Report Generator

Software Unit Testing: Simulink Model & Code Coverage

- ✓ Ensure software modules perform as expected
- ✓ Ensure all code is exercised

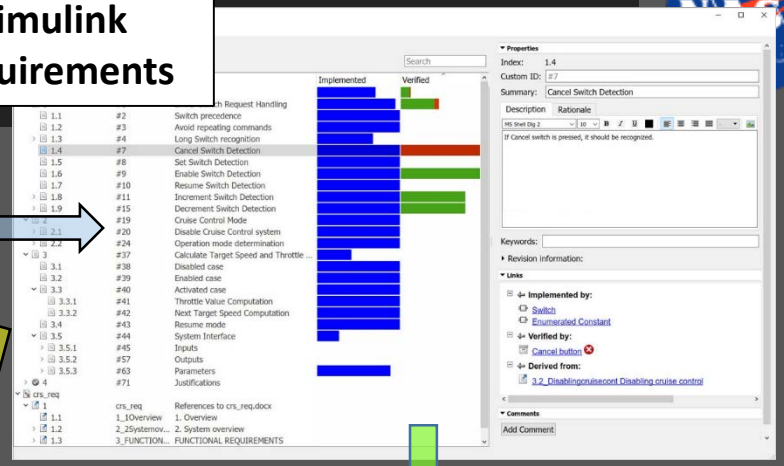
MBD Workflow



Requirements, e.g., in Excel

Requirement Statements

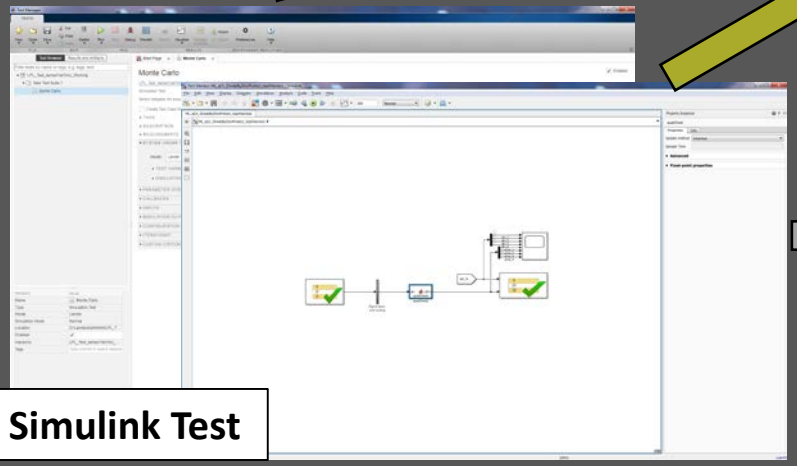
Simulink Requirements



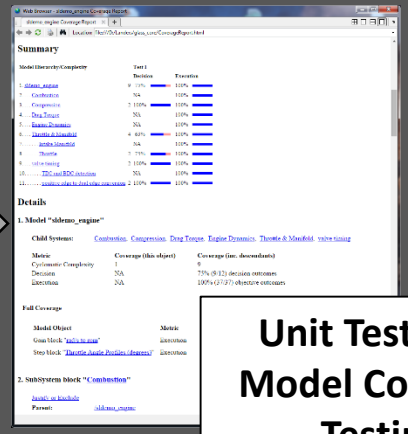
Iteration Updates Synchronized via Script

Data Dictionary

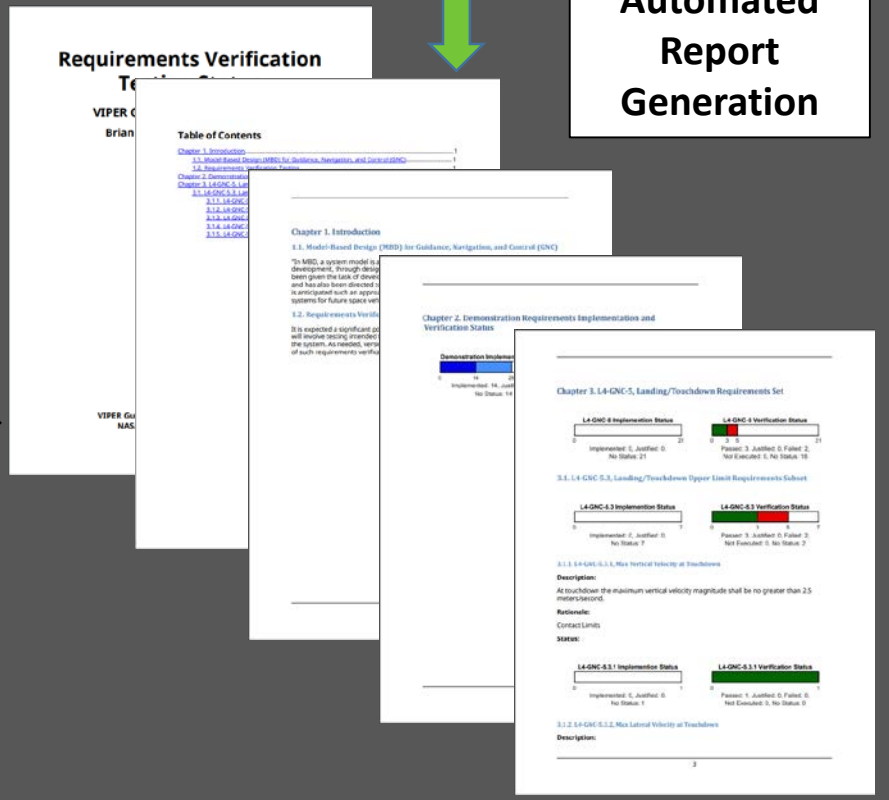
Test Parameters



Simulink Test



Unit Testing & Model Coverage Testing



Automated Report Generation

I64 | 0.5

	D	E	F	G	H	I	J
1	Requirement ID	Requirement Name	Level 4 GN&C Requirement	Rationale	Level 4 GN&C Requirement Text	Spec Value	Units
62	L4-GNC-5.3	Landing/Touchdown Upper Limit Requirements					
63	L4-GNC-5.3.1	Maximum Vertical Velocity at Touchdown	At touchdown, the maximum vertical velocity magnitude shall be no greater than 2.5 meters/second.	Contact Limits	At touchdown, the maximum vertical velocity magnitude shall be no greater than	2.5	meters/second
64	L4-GNC-5.3.2	Maximum Lateral Velocity at Touchdown	At touchdown, the maximum lateral velocity magnitude shall be no greater than 0.5 meters/second.	Contact Limits	At touchdown, the maximum lateral velocity magnitude shall be no greater than	0.5	meters/second
65	L4-GNC-5.3.3	Maximum Pitch Angle at Touchdown	At touchdown, the maximum pitch angle with respect to local vertical shall be no greater than 3 degrees.	Tip Over Limits	At touchdown, the maximum pitch angle with respect to local vertical shall be no greater than	3	degrees
66	L4-GNC-5.3.4	Maximum Angular Rate at Touchdown	At touchdown, the maximum magnitude of the inertial angular rate shall be no greater than 0.1 degrees/second.	Tip Over Limits	At touchdown, the maximum magnitude of the inertial angular rate shall be no greater than	0.1	degrees/second
67	L4-GNC-5.3.5	Maximum Position Error	At touchdown, the maximum position error from the nominal landing site shall be no greater than 100 meters.	Landed Payload Limits	At touchdown, the maximum position error from the nominal landing site shall be no greater than	100	meters
68	L4-GNC-5.3.6	Maximum Lateral CM Offset	At touchdown the lateral CM offset shall be no greater than 77 millimeters.	Control Stability Margin	At touchdown the lateral CM offset shall be no greater than	77	millimeters
69							
70							
71							
72							
73							
74							

Requirements Editor

File Edit Display Analysis Report Help

View: Requirements

Search

Update completed. Refer to Comments on Import1.

Index	ID	Summary	Implemented	Verified
Requireme...				
Import1	Requirements!Sheet1	References to Requirements.xls (Shee...		
1	L4-GNC-1	Coast Phase Requirements		
2	L4-GNC-2	TCM Burns Requirements		
3	L4-GNC-3	SRM Burn Phase Requirements		
4	L4-GNC-4	Liquid Descent Requirement		
5	L4-GNC-5	Landing/Touchdown Requirements		
5...	L4-GNC-5.1	Landing/Touchdown Control Require...		
5...	L4-GNC-5.2	Landing/Touchdown Knowledge Requ...		
5...	L4-GNC-5.3	Landing/Touchdown Upper Limit Req...		
	L4-GNC-5.3.1	Maximum Vertical Velocity at Touchd...		
	L4-GNC-5.3.2	Maximum Lateral Velocity at Touchdo...		
	L4-GNC-5.3.3	Maximum Pitch Angle at Touchdown		
	L4-GNC-5.3.4	Maximum Angular Rate at Touchdown		
	L4-GNC-5.3.5	Maximum Position Error		
	L4-GNC-5.3.6	Maximum Lateral CM Offset		

Properties

Type: Functional

Index: 5.3.2

Custom ID: L4-GNC-5.3.2

Summary: Maximum Lateral Velocity at Touchdown

Description | Rationale

At touchdown, the maximum lateral velocity magnitude shall be no greater than 0.5 meters/second.

Keywords:

Revision information:

SID: 64

Revision: 42

Updated on: 15-Nov-2019 10:27:24

Created by:

Created on: 07-Aug-2019 13:19:11

Modified by:

Modified on: 15-Nov-2019 10:27:21

Show in document | Unlock

Links

Verified by:

L4-GNC-5.3.2

Comments

Test Manager

TESTS

New Open Save | Cut Copy Paste Delete | Run Stop Debug Parallel | Report Visualize Highlight in Model Import Export | Preferences | Help

FILE EDIT RUN RESULTS ENVIRONMENT RESOURCES

Test Browser | Results and Artifacts

Filter results by name or tags, e.g. tags: test

NAME	STATUS
Results: 2019-Nov-15 10:27:27	199 1
Results: 2019-Nov-15 10:33:25	197 3
Results: 2019-Nov-15 10:39:15	199 1
Results: 2019-Nov-15 10:45:14	200
Results: 2019-Nov-15 10:51:10	200

PROPERTY	VALUE

L4-GNC-5.3.2

L4-GNC-5.3.2

Enabled

Tests » L4-GNC-5 » L4-GNC-5.3 » L4-GNC-5.3.2

Simulation Test

Select releases for simulation: Current

Create Test Case from External File

- TAGS
- DESCRIPTION
- REQUIREMENTS*
- SYSTEM UNDER TEST*
  - Model: readIn3x1Vector
  - TEST HARNESS
  - SIMULATION SETTINGS OVERRIDES*
- PARAMETER OVERRIDES
- CALLBACKS
- INPUTS
- SIMULATION OUTPUTS
- CONFIGURATION SETTINGS OVERRIDES
- ITERATIONS*
- LOGICAL AND TEMPORAL ASSESSMENTS
- CUSTOM CRITERIA*
- COVERAGE SETTINGS

Test Manager

TESTS

New Open Save | Cut Copy Paste Delete | Run Stop Debug Parallel | Report Visualize Highlight in Model Import Export | Preferences | Help

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Filter results by name or tags, e.g. tags: test

NAME	STATUS
Results: 2019-Nov-15 10:27:27	199 1
Results: 2019-Nov-15 10:33:25	197 3
L4-GNC-5.3.2	197 3
Scripted_Iteration1	
Scripted_Iteration10	
Scripted_Iteration100	
Scripted_Iteration101	
Scripted_Iteration102	
Scripted_Iteration103	
Scripted_Iteration104	
Scripted_Iteration105	
Scripted_Iteration106	
Scripted_Iteration107	
Scripted_Iteration108	
Scripted_Iteration109	
Scripted_Iteration11	
Scripted_Iteration110	
Scripted_Iteration111	
Scripted_Iteration112	
Scripted_Iteration113	

PROPERTY	VALUE

L4-GNC-5.3.2

L4-GNC-5.3.2

Enabled

Tests » L4-GNC-5 » L4-GNC-5.3 » L4-GNC-5.3.2

Simulation Test

Select releases for simulation: Current

Create Test Case from External File

- TAGS
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- ITERATIONS*
- LOGICAL AND TEMPORAL ASSESSMENTS
- CUSTOM CRITERIA*
- COVERAGE SETTINGS

Test Manager

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New Open Save | Cut Copy Paste Delete | Run Stop Debug Parallel | Report Visualize Highlight in Model Import Export | Preferences | Help

FILE EDIT RUN RESULTS ENVIRONMENT RESOURCES

Test Browser | Results and Artifacts

Filter results by name or tags, e.g. tags: test

NAME	STATUS
Scripted_Iteration136	✓
Scripted_Iteration137	✓
Scripted_Iteration138	✓
Scripted_Iteration139	✓
Scripted_Iteration14	✓
Scripted_Iteration140	✓
Scripted_Iteration141	✓
Scripted_Iteration142	✓
Scripted_Iteration143	✓
Scripted_Iteration144	✓
Scripted_Iteration145	✗
Sim Output (readIn3x1Vecto	
Custom Criteria Result	✗
Landing Lateral Speed: 0.5	✗
Scripted_Iteration146	✓
Scripted_Iteration147	✓
Scripted_Iteration148	✓
Scripted_Iteration149	✓
Scripted_Iteration15	✓
Scripted_Iteration150	✓

PROPERTY	VALUE
Diagnostic Result	Landing Lateral Speed: 0.517...
Status	✗

Scripted_Iteration145 | L4-GNC-5.3.2

SUMMARY

Name	Scripted_Iteration145
Outcome	1 ✗
Start Time	11/15/2019 10:38:44
End Time	11/15/2019 10:38:44
Type	Simulation Test
Test File Location	D:\Landers_20190214\lpl\MAIN\MBD\Tests.mldatx
Test Case Definition	
Rerun Test Iteration	
Cause of Failure	Failed criteria: Custom
Simulation Metadata	

TEST REQUIREMENTS

ITERATION SETTINGS

ERRORS

LOGS

DESCRIPTION

Double-click to edit

CUSTOM CRITERIA LOGS

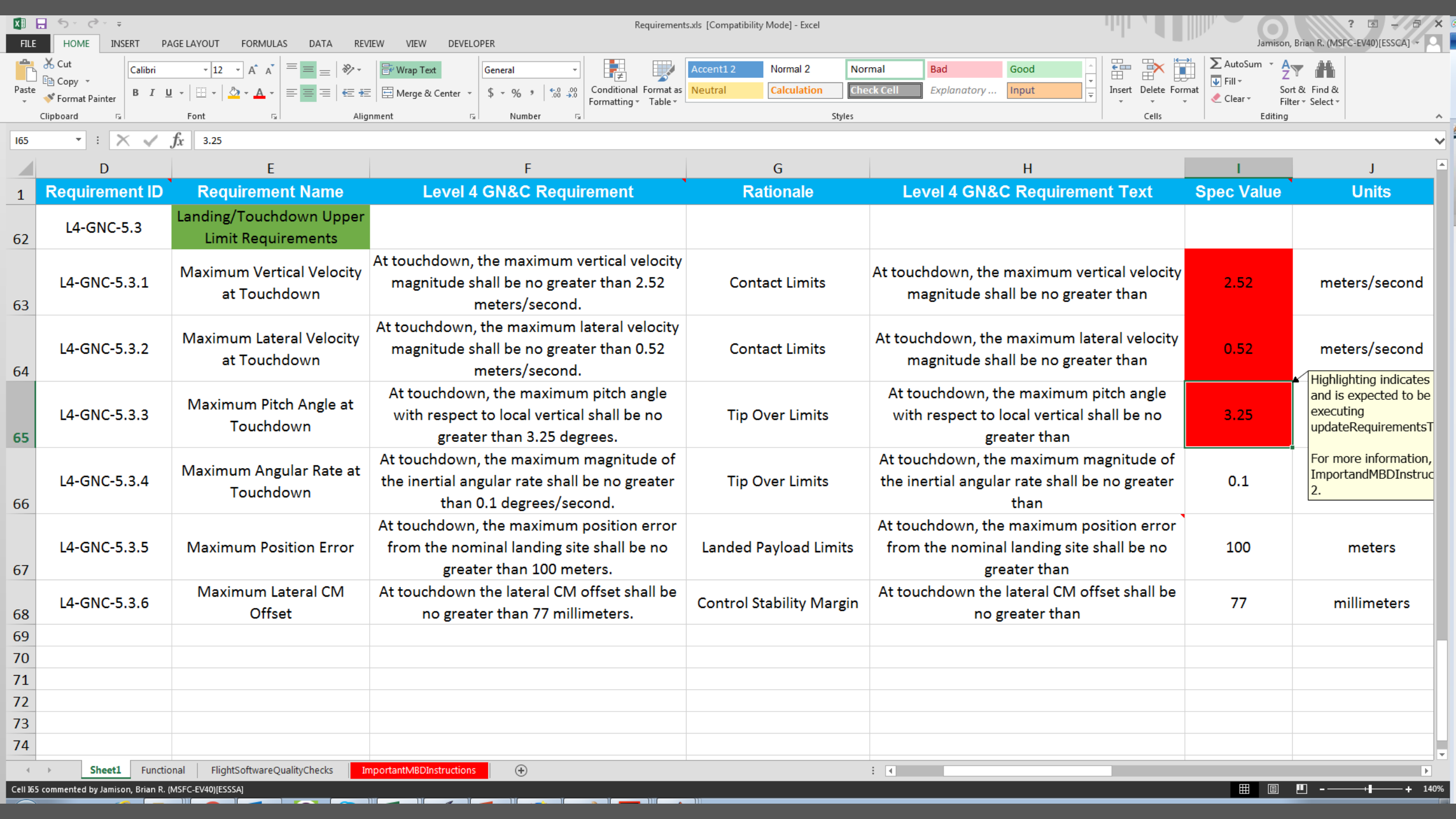
```
------------------------------------------------------------------
VerificationFailed in custom criteria of sltest.testmanager.TestCase.

    ----------------
    Test Diagnostic:
    ----------------
    Landing Lateral Speed: 0.51722 meters/second.

    --------------------
    Framework Diagnostic:
    --------------------
    verifyLessThanOrEqual failed.
    --> The value must be less than or equal to the maximum value.

    Actual Value:
       0.517217612807295
    Maximum Value (Inclusive):
       0.500000000000000

------------------------------------------------------------------
```



	D	E	F	G	H	I	J
1	Requirement ID	Requirement Name	Level 4 GN&C Requirement	Rationale	Level 4 GN&C Requirement Text	Spec Value	Units
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63	L4-GNC-5.3.1	Maximum Vertical Velocity at Touchdown	At touchdown, the maximum vertical velocity magnitude shall be no greater than 2.52 meters/second.	Contact Limits	At touchdown, the maximum vertical velocity magnitude shall be no greater than	2.52	meters/second
64	L4-GNC-5.3.2	Maximum Lateral Velocity at Touchdown	At touchdown, the maximum lateral velocity magnitude shall be no greater than 0.52 meters/second.	Contact Limits	At touchdown, the maximum lateral velocity magnitude shall be no greater than	0.52	meters/second
65	L4-GNC-5.3.3	Maximum Pitch Angle at Touchdown	At touchdown, the maximum pitch angle with respect to local vertical shall be no greater than 3.25 degrees.	Tip Over Limits	At touchdown, the maximum pitch angle with respect to local vertical shall be no greater than	3.25	
66	L4-GNC-5.3.4	Maximum Angular Rate at Touchdown	At touchdown, the maximum magnitude of the inertial angular rate shall be no greater than 0.1 degrees/second.	Tip Over Limits	At touchdown, the maximum magnitude of the inertial angular rate shall be no greater than	0.1	
67	L4-GNC-5.3.5	Maximum Position Error	At touchdown, the maximum position error from the nominal landing site shall be no greater than 100 meters.	Landed Payload Limits	At touchdown, the maximum position error from the nominal landing site shall be no greater than	100	meters
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69							
70							
71							
72							
73							
74							

Editor - D:\Landers_20190214\lpl\MAIN\MBD\updateRequirementsTesting.m

EDITOR | PUBLISH | VIEW

New | Open | Save | Find Files | Compare | Print | Go To | Find | Insert | Comment | Indent | Breakpoints | Run | Run and Advance | Run Section | Advance | Run and Time

```
%% Beginning from an Excel spreadsheet, as determined necessary, this script creates or
% updates a Simulink Data Dictionary and the corresponding Simulink Requirements file, and
% loads and reruns the associated Simulink Test files.

clearvars
clc

%% display a pop-up indicating the need to now close open Excel requirements window to avoid the possiblity of errors when clearing highlighting in the .xls requirement file
uifig = figure;  %  Create and then hide the UI as it is being constructed.
h = uicontrol('Position',[180 20 200 40],'String','Continue','Callback','uiresume(gcbf)','FontSize',16);
uidirections1 = 'To prevent errors during execution of updateRequirementsTesting.m, ensure ';
uidirections2 = 'the Excel Requirements.xls window is closed, and then select Continue.';
htext  = uicontrol('Style','text','String',[uidirections1 uidirections2],'Position',[40,100,480,300],'FontSize',23);
uiwait(gcf);
close(uifig);

%% Open the MAIN project
open('..\MAIN.prj')   % among other things, sets up needed path(s), including to readDict and editDict
cd('MBD')  % change directory back to MBD directory since previous command went back to MAIN directory

%% Setup filenames and ensure they are valid
xlsFilename = 'Requirements.xls';
slreqxFilename = 'Requirements.slreqx';
slddFilename = 'Dictionary.sldd';
testsFilename = 'Tests.mldatx';
testsResultsFilename = 'TestsResults_20190807_1434.mldatx';
if ~strcmp(xlsFilename(1:end-3),slreqxFilename(1:end-6))
    error('The filenames of the .xls and .slreqx files should match.')  % e.g., relative to importing materials from the .xls for creation of the .slreqx file if necessary
end

%% Create the data dictionary if necessary
if ~exist(slddFilename,'file')  % if the data dictionary does not exist, ...
    Simulink.data.dictionary.create(slddFilename);  % create it
end

%% specify the number of Monte Carlo iterations, and, as necessary, define or update a corresponding data dictionary parameter
NUM_MONTE_CARLO_ITERATIONS_ThisTime = 200;%0;
try  % if the data dictionary has a NUM_MONTE_CARLO_ITERATIONS parameter such that the following line doesn't result in an error, ...
    NUM_MONTE_CARLO_ITERATIONS = readDict(slddFilename,'NUM_MONTE_CARLO_ITERATIONS');  % get it's value (which is expected to be an integer) to see if it needs to be updated
    if (NUM_MONTE_CARLO_ITERATIONS ~= NUM_MONTE_CARLO_ITERATIONS_ThisTime)  % if the NUM_MONTE_CARLO_ITERATIONS parameter does not match the one already in the data dictionary, ...
        editDict(slddFilename,'NUM_MONTE_CARLO_ITERATIONS',NUM_MONTE_CARLO_ITERATIONS_ThisTime);  % update the NUM_MONTE_CARLO_ITERATIONS parameter in the data dictionary
    end
catch  % otherwise, ...
    editDict(slddFilename,'NUM_MONTE_CARLO_ITERATIONS',NUM_MONTE_CARLO_ITERATIONS_ThisTime);  % add the NUM_MONTE_CARLO_ITERATIONS parameter to the data dictionary
end

%% Check the xls file to see if it has been modified, and if so, set the flag to update the data dictionary and the requirements file
xls_file_obj = dir(xlsFilename);  % expected to contain 'name' (filename), 'folder' (folder location and name), 'date' (string), 'isdir' (boolean), and 'datenum' (float) fields
```

Initialization.mlx
oldLandedTests.m
setupCallback.m
RefineFinalDescentTimeEstimate.m
compareGLASSResults.m
MBDReqsImplStatusColorbarImagePath.m
MBDReqsVerifStatusColorbarImagePath.m
addMBDReqsStatusImages.m
datenum.m
updateRequirementsTesting.m
loadMCIterationsLandingVelocities.m
loadMCIterationsLandingAngularVelocities.m
loadMCIterationsLandingQuaternions.m
loadMCIterationsLandingPositions.m
testTouchdownVerticalVelocityResult.m
testTouchdownLateralSpeedResult.m
testTouchdownPitchResult.m
testTouchdownAngularRateResult.m
testTouchdownDistanceResult.m
GNC_MBD_RptGen.m

script | Ln 63 | Col 50

I66 0.1

	D	E	F	G	H	I	J
1	Requirement ID	Requirement Name	Level 4 GN&C Requirement	Rationale	Level 4 GN&C Requirement Text	Spec Value	Units
62	L4-GNC-5.3	Landing/Touchdown Upper Limit Requirements					
63	L4-GNC-5.3.1	Maximum Vertical Velocity at Touchdown	At touchdown, the maximum vertical velocity magnitude shall be no greater than 2.52 meters/second.	Contact Limits	At touchdown, the maximum vertical velocity magnitude shall be no greater than	2.52	meters/second
64	L4-GNC-5.3.2	Maximum Lateral Velocity at Touchdown	At touchdown, the maximum lateral velocity magnitude shall be no greater than 0.52 meters/second.	Contact Limits	At touchdown, the maximum lateral velocity magnitude shall be no greater than	0.52	meters/second
65	L4-GNC-5.3.3	Maximum Pitch Angle at Touchdown	At touchdown, the maximum pitch angle with respect to local vertical shall be no greater than 3.25 degrees.	Tip Over Limits	At touchdown, the maximum pitch angle with respect to local vertical shall be no greater than	3.25	degrees
66	L4-GNC-5.3.4	Maximum Angular Rate at Touchdown	At touchdown, the maximum magnitude of the inertial angular rate shall be no greater than 0.1 degrees/second.	Tip Over Limits	At touchdown, the maximum magnitude of the inertial angular rate shall be no greater than	0.1	degrees/second
67	L4-GNC-5.3.5	Maximum Position Error	At touchdown, the maximum position error from the nominal landing site shall be no greater than 100 meters.	Landed Payload Limits	At touchdown, the maximum position error from the nominal landing site shall be no greater than	100	meters
68	L4-GNC-5.3.6	Maximum Lateral CM Offset	At touchdown the lateral CM offset shall be no greater than 77 millimeters.	Control Stability Margin	At touchdown the lateral CM offset shall be no greater than	77	millimeters
69							
70							
71							
72							
73							
74							

Test Manager

TESTS

New Open Save | Cut Copy Paste Delete | Run Stop Debug Parallel | Report Visualize Highlight in Model Import Export | Preferences | Help

FILE EDIT RUN RESULTS ENVIRONMENT RESOURCES

Test Browser | Results and Artifacts

Filter results by name or tags, e.g. tags: test

NAME	STATUS
Results: 2019-Nov-15 10:27:27	199 1
Results: 2019-Nov-15 10:33:25	197 3
Results: 2019-Nov-15 10:39:15	199 1
Results: 2019-Nov-15 10:45:14	200
Results: 2019-Nov-15 10:51:10	200
Results: 2019-Nov-15 12:25:46	200
Results: 2019-Nov-15 12:30:54	200
Results: 2019-Nov-15 12:36:06	197 2 1

PROPERTY	VALUE

Scripted_Iteration145 | L4-GNC-5.3.2

SUMMARY

Name	Scripted_Iteration145
Outcome	1
Start Time	11/15/2019 10:38:44
End Time	11/15/2019 10:38:44
Type	Simulation Test
Test File Location	D:\Landers_20190214\pl\MAIN\MBD\Tests.mldatx
Test Case Definition	
Rerun Test Iteration	
Cause of Failure	Failed criteria: Custom
Simulation Metadata	

TEST REQUIREMENTS

ITERATION SETTINGS

ERRORS

LOGS

DESCRIPTION

Double-click to edit

CUSTOM CRITERIA LOGS

```
------------------------------------------------------------------
VerificationFailed in custom criteria of sltest.testmanager.TestCase.

    ----------------
    Test Diagnostic:
    ----------------
    Landing Lateral Speed: 0.51722 meters/second.

    --------------------
    Framework Diagnostic:
    --------------------
    verifyLessThanOrEqual failed.
    --> The value must be less than or equal to the maximum value.

    Actual Value:
       0.517217612807295
    Maximum Value (Inclusive):
       0.500000000000000

------------------------------------------------------------------
```

Requirements Editor

File Edit Display Analysis Report Help

View: Requirements

Search

Update completed. Refer to Comments on Import1.

Index	ID	Summary	Implemented	Verified
Requireme...				
Import1	Requirements!Sheet1	References to Requirements.xls (Shee...		
1	L4-GNC-1	Coast Phase Requirements		
2	L4-GNC-2	TCM Burns Requirements		
3	L4-GNC-3	SRM Burn Phase Requirements		
4	L4-GNC-4	Liquid Descent Requirement		
5	L4-GNC-5	Landing/Touchdown Requirements		
5...	L4-GNC-5.1	Landing/Touchdown Control Require...		
5...	L4-GNC-5.2	Landing/Touchdown Knowledge Requ...		
5...	L4-GNC-5.3	Landing/Touchdown Upper Limit Req...		
	L4-GNC-5.3.1	Maximum Vertical Velocity at Touchd...		
	L4-GNC-5.3.2	Maximum Lateral Velocity at Touchdo...		
	L4-GNC-5.3.3	Maximum Pitch Angle at Touchdown		
	L4-GNC-5.3.4	Maximum Angular Rate at Touchdown		
	L4-GNC-5.3.5	Maximum Position Error		
	L4-GNC-5.3.6	Maximum Lateral CM Offset		

Requirement Interchange

Update Export Unlock all

Properties

Attribute Mapping

Links

Comments

Report Generation

Requirements Verification Testing Status

VIPER GN&C Model Based Desig

Brian R. Jamison, James T. Kaidy

22-May-2019

VIPER Guidance, Navigation & Control Group
NASA, Marshall Space Flight Center

Table of Contents

Chapter 1. Introduction

1.1. Model-Based Design (MBD) for Guidance, Navigation, and Control (

"In MBD, a system model is at the center of the development process, from requi
development, through design, implementation, and testing" [1]. The VIPER GNC T
been given the task of developing the GNC system for the VIPER Lunar Lander act
and has also been directed to implement an MBD approach to the design process
is anticipated such an approach will become a fundamental aspect of designing G
systems for future space vehicles developed at the Marshall Space Flight Center (M

1.2. Requirements Verification Testing

It is expected a significant portion of the MBD approach to the design of the GNC
will involve testing intended to verify the design satisfies the requirements impos
the system. As needed, versions of this document will be produced to summarize
of such requirements verification testing.

Chapter 2. Demonstration Requirements Implementation and Verification Status

Demonstration Implemention Status

0 14 28 42

Implemented: 14, Justified: 14,
No Status: 14

Demonstration Verification Status

0 12 18 24 34

Passed: 12, Justified: 6, Failed: 6,
Not Executed: 10, No Status: 8

Chapter 3. L4-GNC-5, Landing/Touchdown Requirements Set

L4-GNC-5 Implemention Status

0 21

Implemented: 0, Justified: 0,
No Status: 21

L4-GNC-5 Verification Status

0 3 5 21

Passed: 3, Justified: 0, Failed: 2,
Not Executed: 0, No Status: 16

3.1. L4-GNC-5.3, Landing/Touchdown Upper Limit Requirements Subset

L4-GNC-5.3 Implemention Status

0 7

Implemented: 0, Justified: 0,
No Status: 7

L4-GNC-5.3 Verification Status

0 3 5 7

Passed: 3, Justified: 0, Failed: 2,
Not Executed: 0, No Status: 2

3.1.1. L4-GNC-5.3.1, Max Vertical Velocity at Touchdown

Description:

At touchdown the maximum vertical velocity magnitude shall be no greater than 2.5 meters/second.

Rationale:

Contact Limits

Status:

L4-GNC-5.3.1 Implemention Status

0 1

Implemented: 0, Justified: 0,
No Status: 1

L4-GNC-5.3.1 Verification Status

0 1

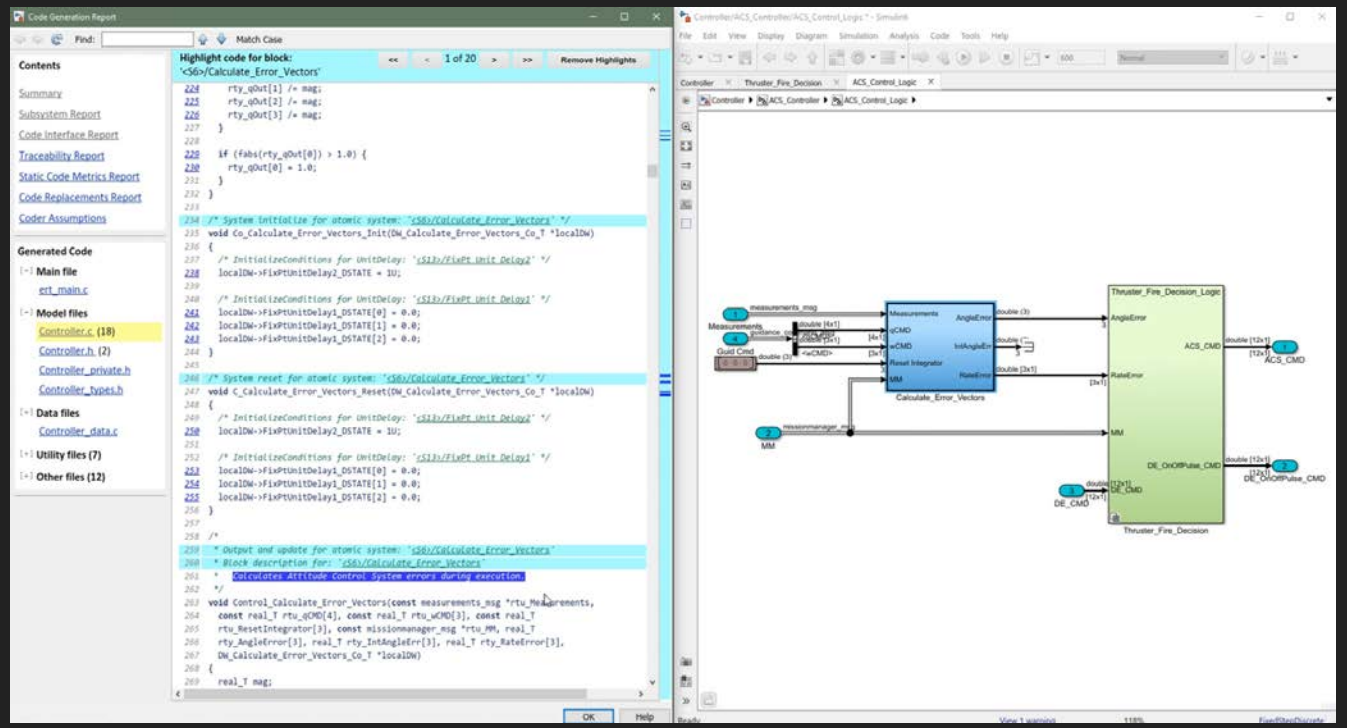
Passed: 1, Justified: 0, Failed: 0,
Not Executed: 0, No Status: 0

3.1.2. L4-GNC-5.3.2, Max Lateral Velocity at Touchdown

Description:

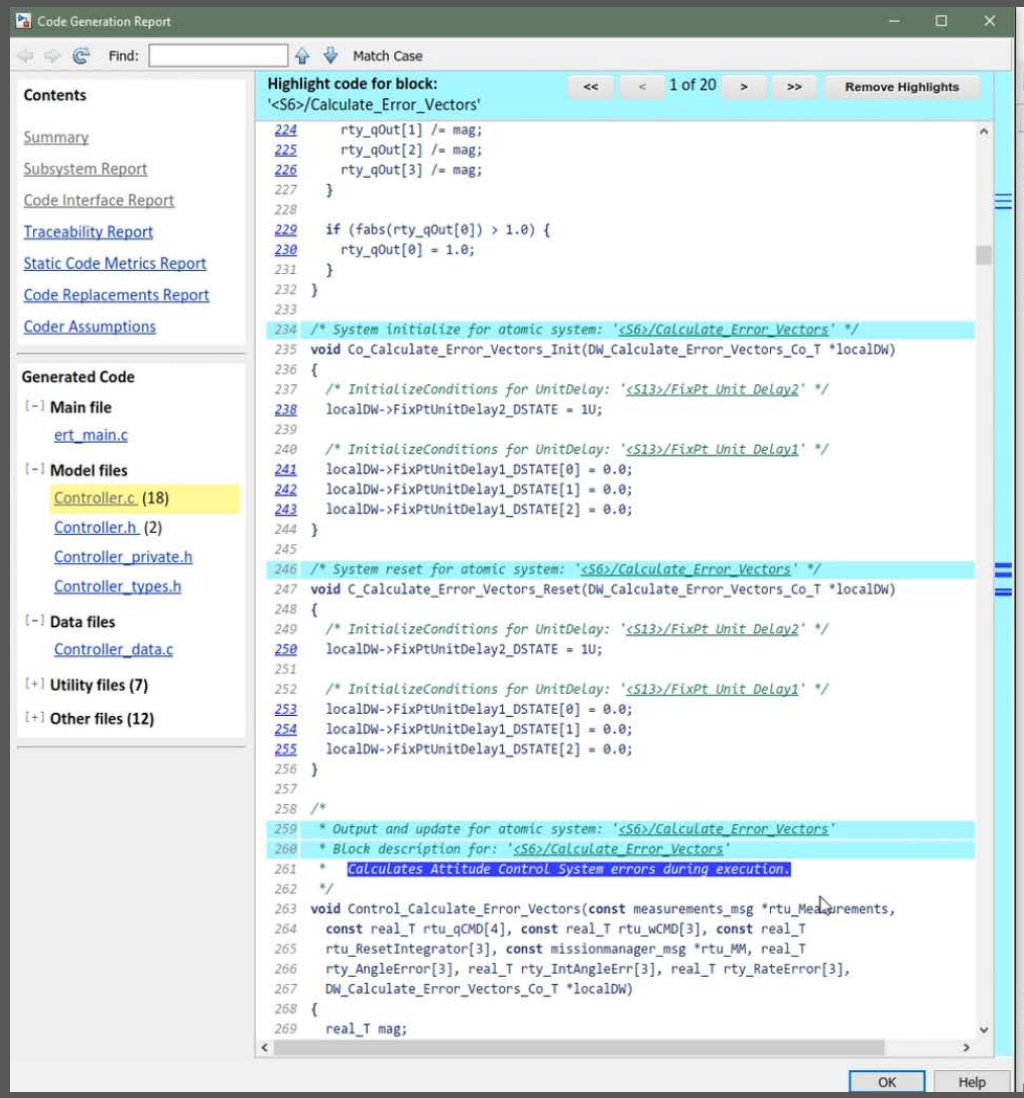
Simulink Auto-Coding for MBD

- Auto-coding enforces coding standards automatically and consistently
- Utilizes Simulink Coder & Embedded Coder to generate C/C++ code directly from Simulink models
  - One interface for plant modeling, algorithm development, & code deployment
  - Access to MathWorks control toolboxes and other analysis tools
- Used by:
  - NASA
    - GLASS
    - NEA-Scout
    - Orion GN&C
    - Goddard programs – PACE, JEDI
  - APL
  - Lockheed Martin
  - Automotive Industry



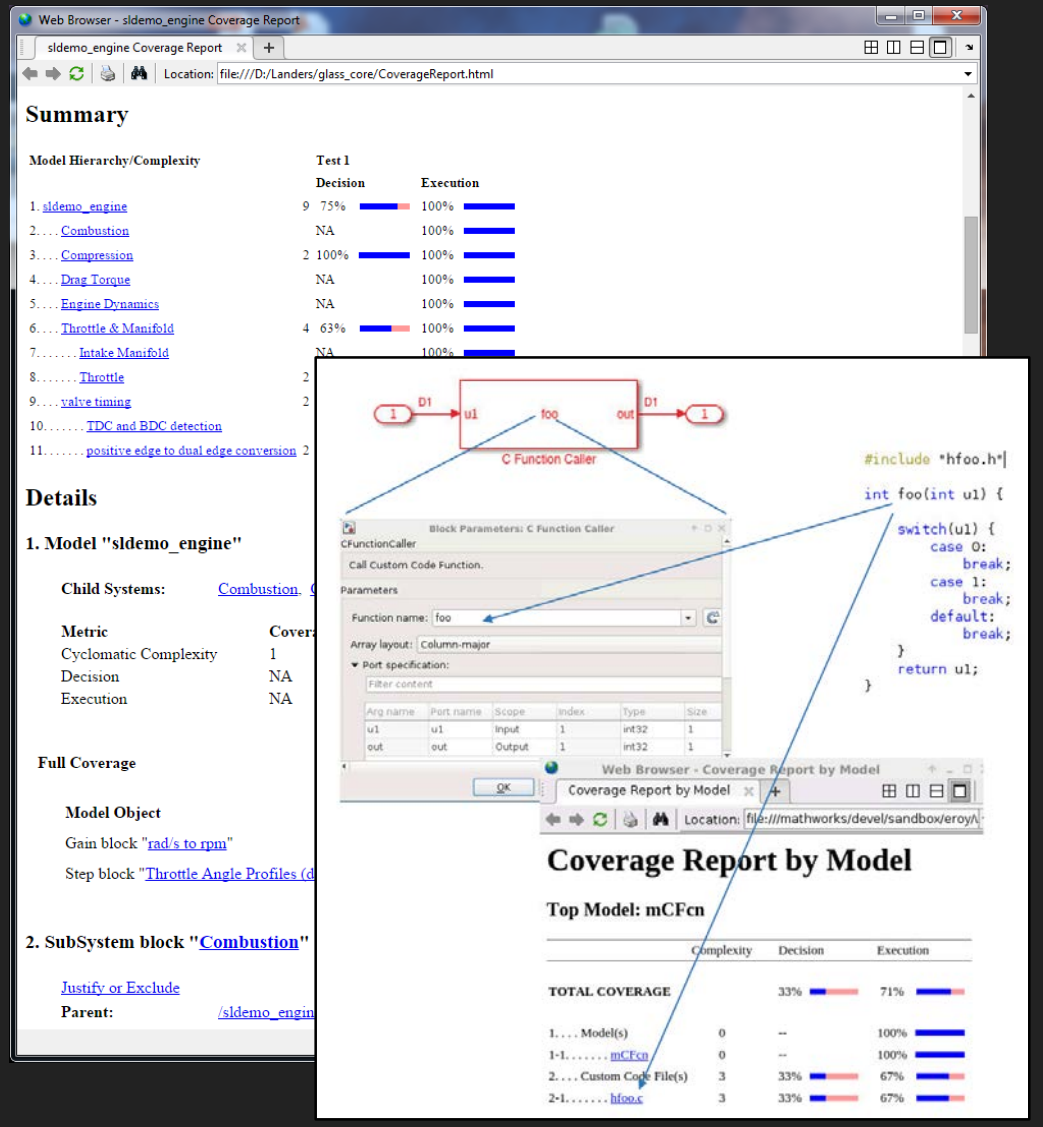
Simulink Auto-Coding for MBD – Example

- Code & model linking
- Code comments
- Improved readability



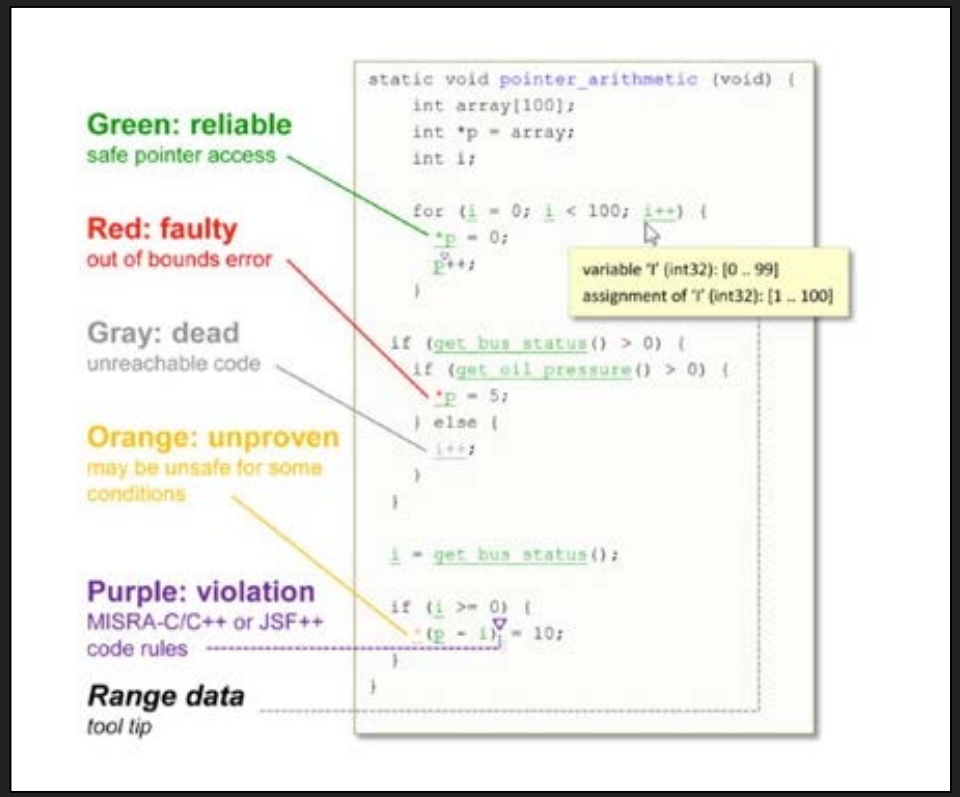
Coverage Testing

- Ensures model/code are fully exercised
  - Used during unit testing
- Checked in the Simulink model and generated code
- Report links un-executed portions of the model and code
  - Simplifies repair/justification
- Report provides metric about work remaining



MBD Static Code Checking

- Static Code Check – Polyspace
  - Integrated with Simulink for traceability from the source code back to the original model
  - Looks for concurrency issues, security vulnerabilities, & runtime errors, including arithmetic overflow, buffer overrun, division by zero, out-of-bounds array access, and others
    - Ariane 5 failed (4 June 1996) due to overflow
  - Enforces coding guidelines
    - MISRA C, MISRA C++, JSF++, CERT® C, CERT® C++, etc.
  - Static code checks are typically required for FSW



MBD Static Code Checking

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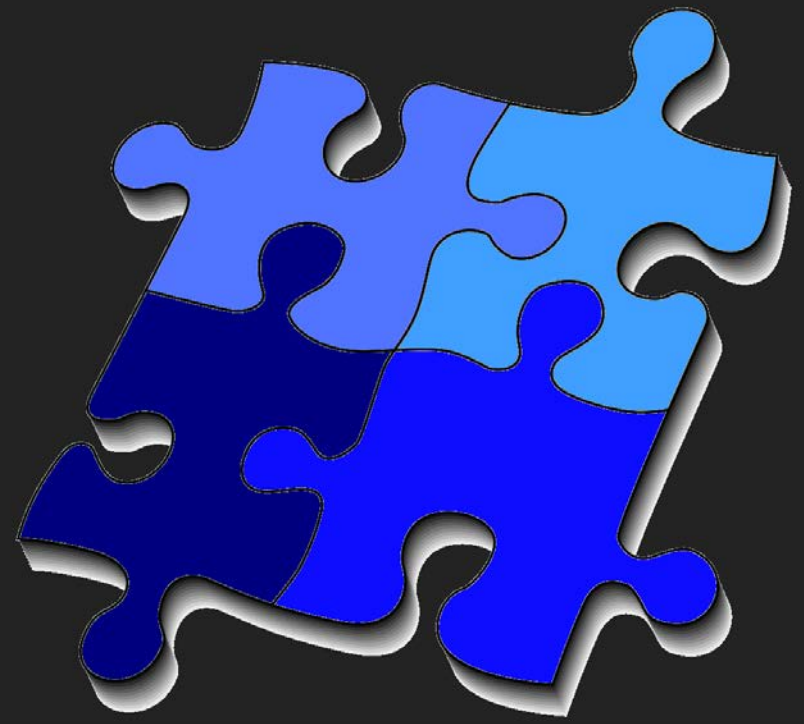
Example: Traditional vs. MBD

- Traditional (manual, labor intensive, error prone):
  - Near Earth Asteroid Scout (NEA-Scout) Project had ~33 GNC L4 requirements, verified through 4 major analysis packages
  - When changes were introduced, analyses and documentation were (manually) repeated to assess impacts to requirements
  - NEA-Scout relied on the FSW integrator (JPL) to run static code checks, involving manual trace-backs from the code to the model
- MBD (largely automated):
  - L4 requirements are checked within the model, and impacts to the design changes can be assessed with every execution of the model
  - When change is introduced, automated testing confirms requirements are satisfied
  - Static code checks are done by code developer prior to delivery to FSW integrator using Polyspace, which seamlessly links code violations with the source code and the model

A Synergistic Environment

- Automated processes
  - Testing, Auto-coding, report generation
- Testing
  - Tools such as Simulink Test are capable of exercising both the Simulink model and the generated code for requirements validation
- Auto-coding
- Reporting is part of the process
- All pieces work together to produce a highly automated, disciplined process



Summary

- A preliminary process has been established to generate quality GNC code using MBD tools from MathWorks (and Microsoft Excel)
- Initial discussions with the NASA MSFC Flight Software group have taken place to ensure processes work together
- Goals:
  - Increase development speed
  - Reduce manual tasks (e.g., testing, hand coding, report writing)
  - Traceability from requirements to model/code verification
  - Consistent quality

Image Sources

- NASA logo: https://commons.wikimedia.org/wiki/File:NASA_logo.svg
- LADEE image: https://www.nasa.gov/mission_pages/ladee/multimedia
- Dictionary image: https://commons.wikimedia.org/wiki/File:Gnome-dictionary.svg
- Simulink Requirements Editor: https://www.mathworks.com/products/simulink-requirements/features.html#author-and-organize-requirements-in-simulink
- Puzzle pieces image, modified from: https://commons.wikimedia.org/wiki/Jigsaw_puzzle#/media/File:Jigsaw.svg