Satellite Co-Orbital Engagement Engineering with System Composer

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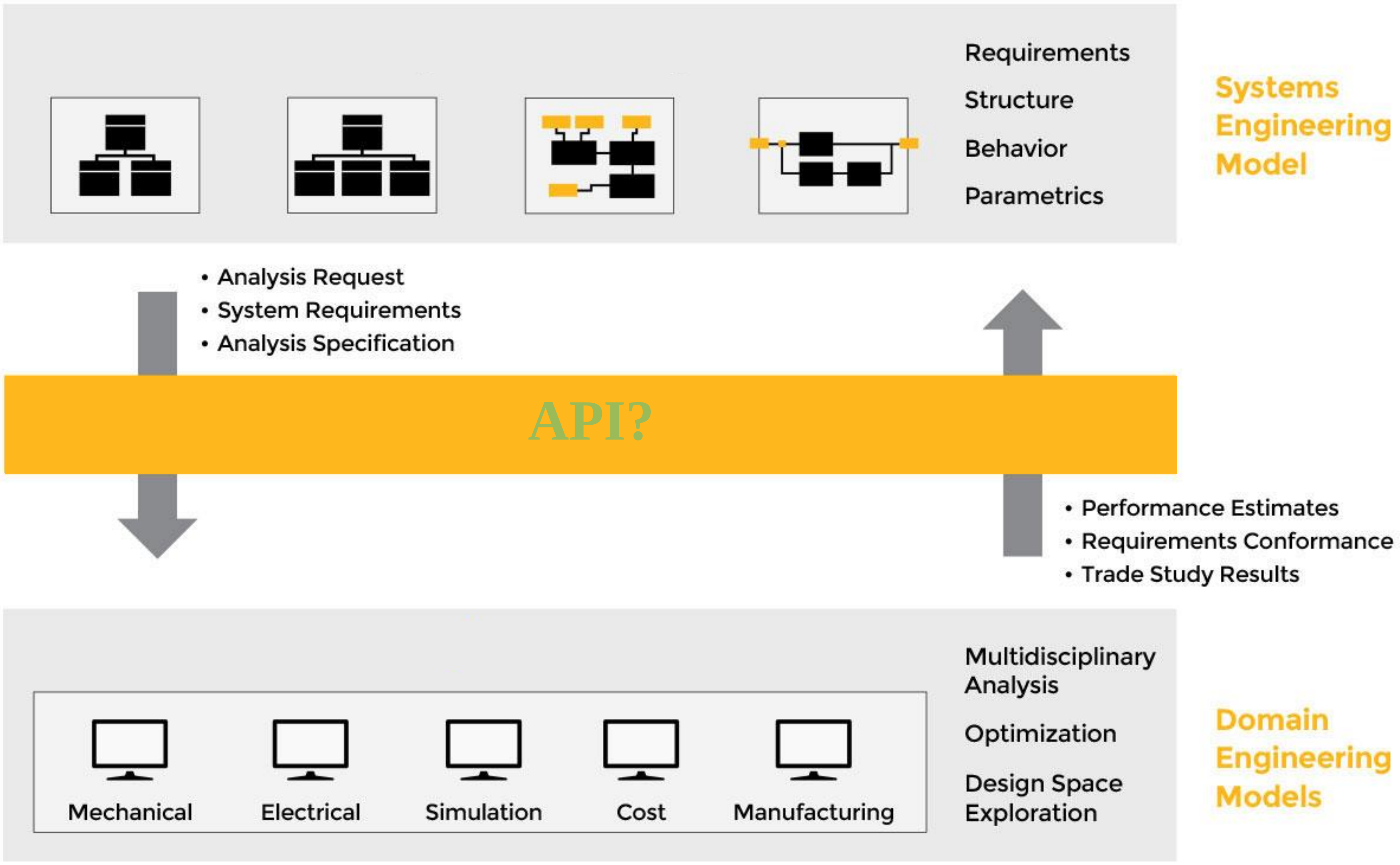
OUTLINE

- **Background**
- **Representative Mission to be Modeled**
- **Mission Modeling Domain**
- **Integration with Cameo System Modeler**
- **Integration with MathWorks' System Composer**
- **Demonstration of Model Execution**
- **Conclusions**

Section Header

BACKGROUND

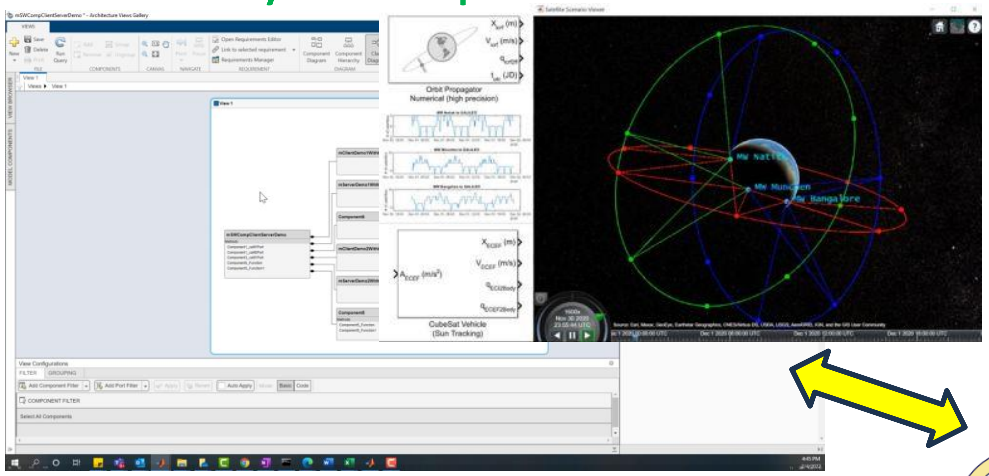
CONNECTING SYSTEMS ENGINEERING DOMAIN WITH DOMAIN ENGINEERING MODELS



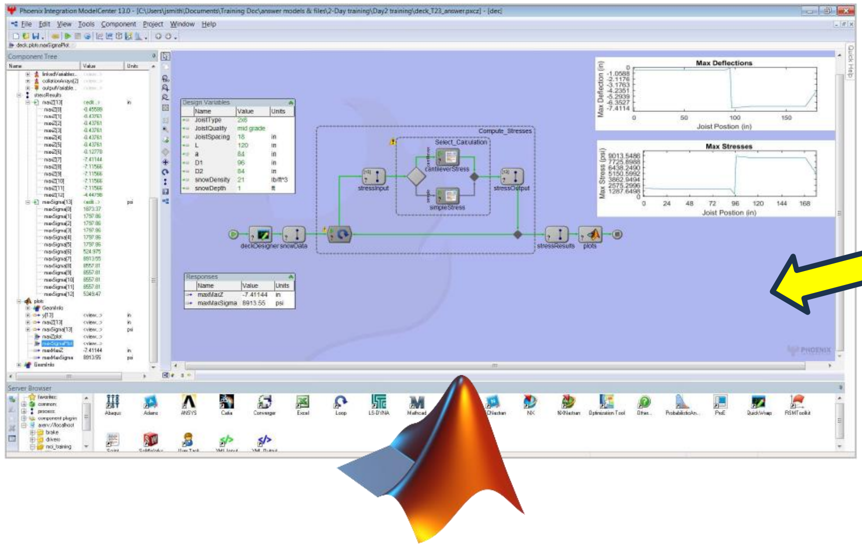
DIGITAL ECOSYSTEMS ERA

NDIA

MathWorks System Composer

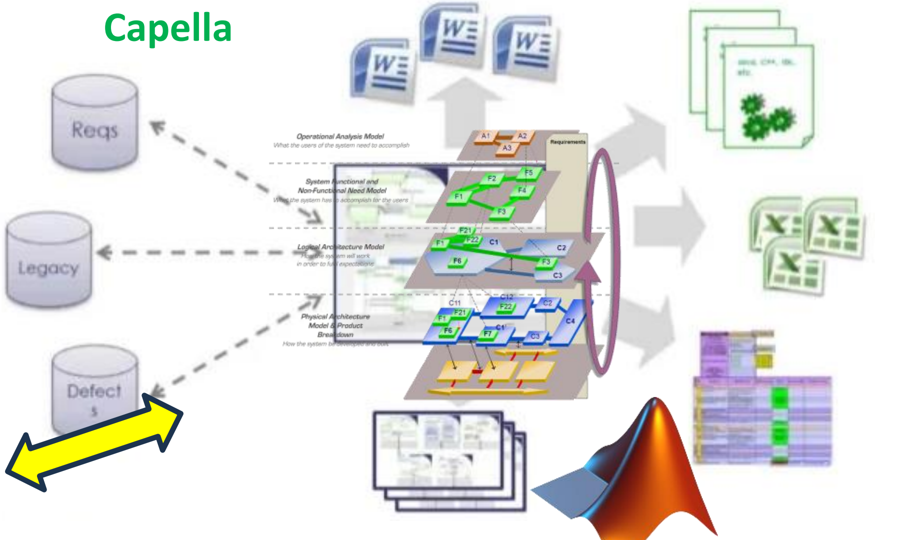


Ansys ModelCenter

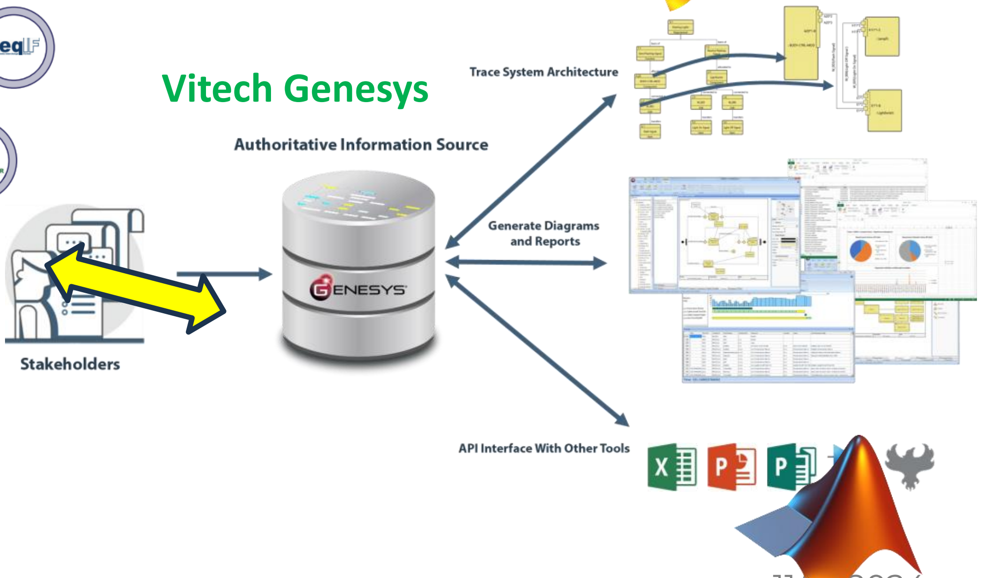


Cameo Systems Modeler

Capella



Vitech Genesys



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REPRESENTATIVE MISSION TO BE MODELED

BACKGROUND ON MODELED MISSION

- Threats that originate from an on-orbit platform
- Aim to conduct RPO w/ targets to create wide variety of effects
- Commercial spacecraft vulnerable
  - Predictable orbits
  - Minimal hardening
  - Industry-standard interfaces?

Co-Orbital ASAT effects and methods

Effect	Method
Deception	Attacker feeds incorrect information directly into system or interface with payload via ground service ports to replicate effect
Disruption	Numerous methods, such as blocking target satellite's solar array
Denial	Obstructing or jamming payload systems
Degradation	Damage external components of target spacecraft
Destruction	Disassembly of key components; kinetic impacts; directed-energy weapons

Global Counter Space 2024 global assessment

	US	Russia	China	India	Aus.	France	Iran	Israel	Japan	North Korea	South Korea	UK
LEO Co-Orbital	■	▲	■	●	●	●	●	●	●	●	●	●
MEO/GEO Co-Orbital	■	■	■	●	●	●	●	●	●	●	●	●
LEO Direct Ascent	■	■	▲	■	●	●	●	●	●	●	●	●
MEO/GEO Direct Ascent	■	■	■	●	●	●	●	●	●	●	●	●
Directed Energy	■	■	■	●	●	■	●	●	●	●	●	●
Electronic Warfare	▲	▲	▲	■	■	■	■	▲	■	■	●	●
Space Situational Awareness	▲	▲	▲	■	■	■	■	■	■	■	■	■

Legend: none ● some ■ significant ▲

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MISSION MODELING DOMAIN

CO-ORBITAL ENGAGEMENT MODEL USING SIMULINK

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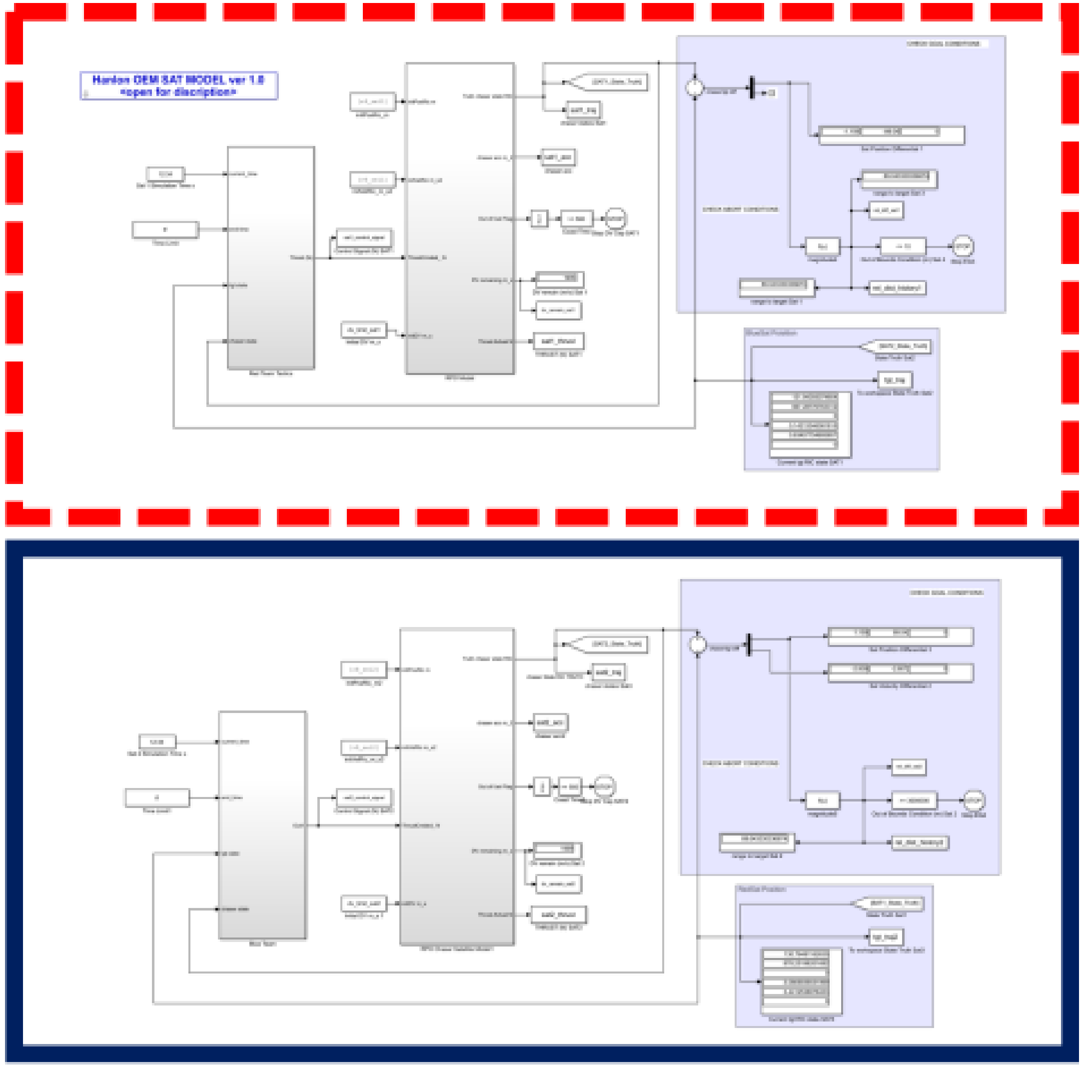

Attacker (Red) Defender (Blue)

Hanlon, N., and Yakimenko, O.A., "Introduction to Space Dogfighting – What Matters in Space Engagements," Proceedings of the IEEE Aerospace Conference, Big Sky, MT, March 7-14, 2019.

Yakimenko, O., and Hanlon, E., "System and Method for Automated Intercept Avoidance for Spacecraft," Patent # 11,667,407 B2, June 6, 2023.

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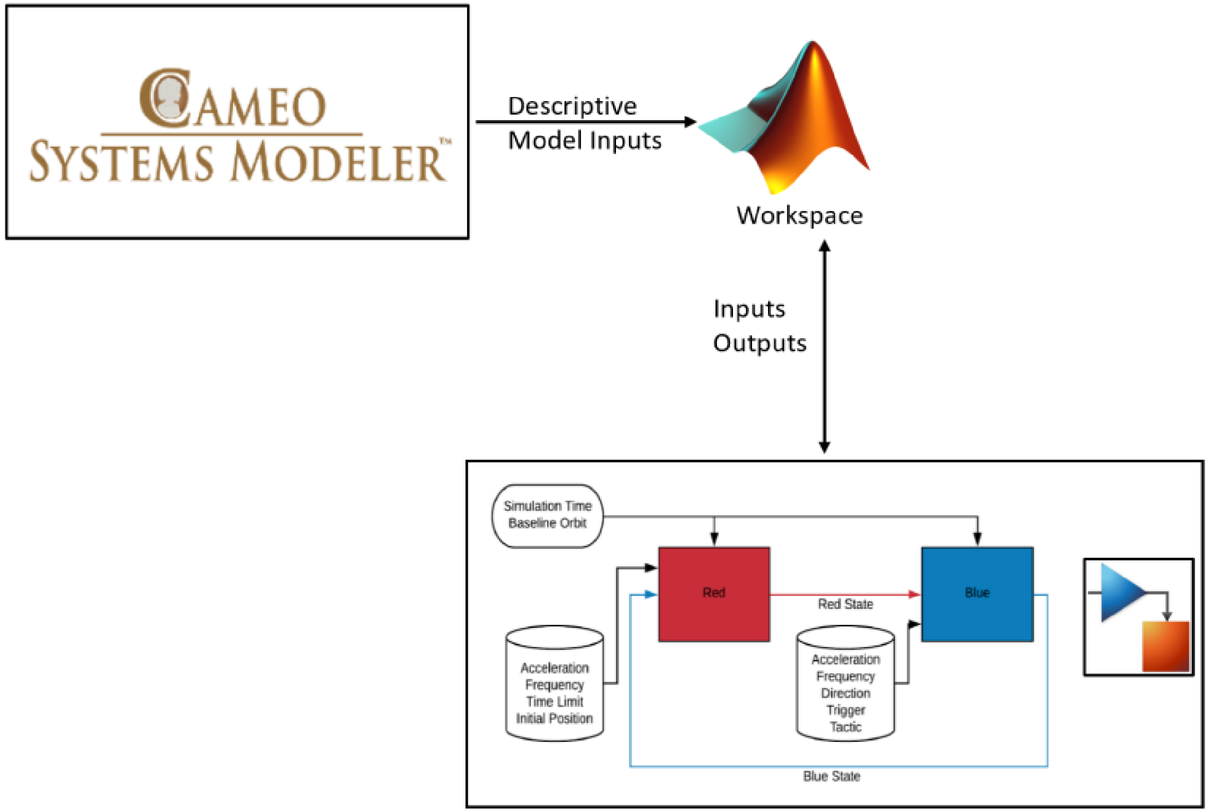
INTEGRATION WITH CAMEO SYSTEM MODELER

PREVIOUS INTEGRATION ATTEMPTS

- Simulink high-fidelity simulation was integrated with the descriptive model of the spacecraft engagement mission developed in Cameo System Modeler (CSM)
- The value of MBSE approach was clearly demonstrated via
  - enabling enhanced mission analysis
  - facilitating tactics assessments
  - validating operational requirements
  - providing outputs to derive new requirements
- Full integration was not achieved cased by application programming interface incompatibility
  - Incompatible value properties between CSM/Simulink
  - GUI limitations
  - Manual requirements in execution
- Another attempt included integrating Cameo System Modeler mission model with rewriting spacecraft engagement mission model with high-fidelity satellite engagement model converted to Python



Rangel, D., Pavalkis, S., and Yakimenko, O. "Incorporation of a High-Fidelity Simulink Model into the Cameo Systems Modeler Environment for a Conceptual Design of Satellite Engagement Missions," Proceedings of the 33rd Annual INCOSE International Symposium (IS2023), Honolulu, HI, July 15-20, 2023.

Hanlon, N., and Yakimenko, O.A., "Hardening Civilian Spacecraft Against Kinetic Attack through Model-Based Systems Engineering," Proceedings of the IEEE Aerospace Conference, Big Sky, MT, March 5-10, 2023.

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INTEGRATION WITH MATHWORKS' SYSTEM COMPOSER

MATHWORKS' MBSE TOOLS (R2021A)

System Composer allows users to:

- Create architectures and requirements, allocate between them, and define metadata
- Create custom viewpoints of an architecture model
- Specify and simulate model behaviors using activity diagrams, sequence diagrams, Simulink, Simscape™, and Stateflow®
- Write analyses based on element properties and verify system requirements
- Import and export models using MATLAB® tables, generate reports using Simulink Report Generator™
- Organize System Composer architectural data using Simulink projects, data dictionaries, and model comparison
- Author, simulate, and deploy software architectures and generate code

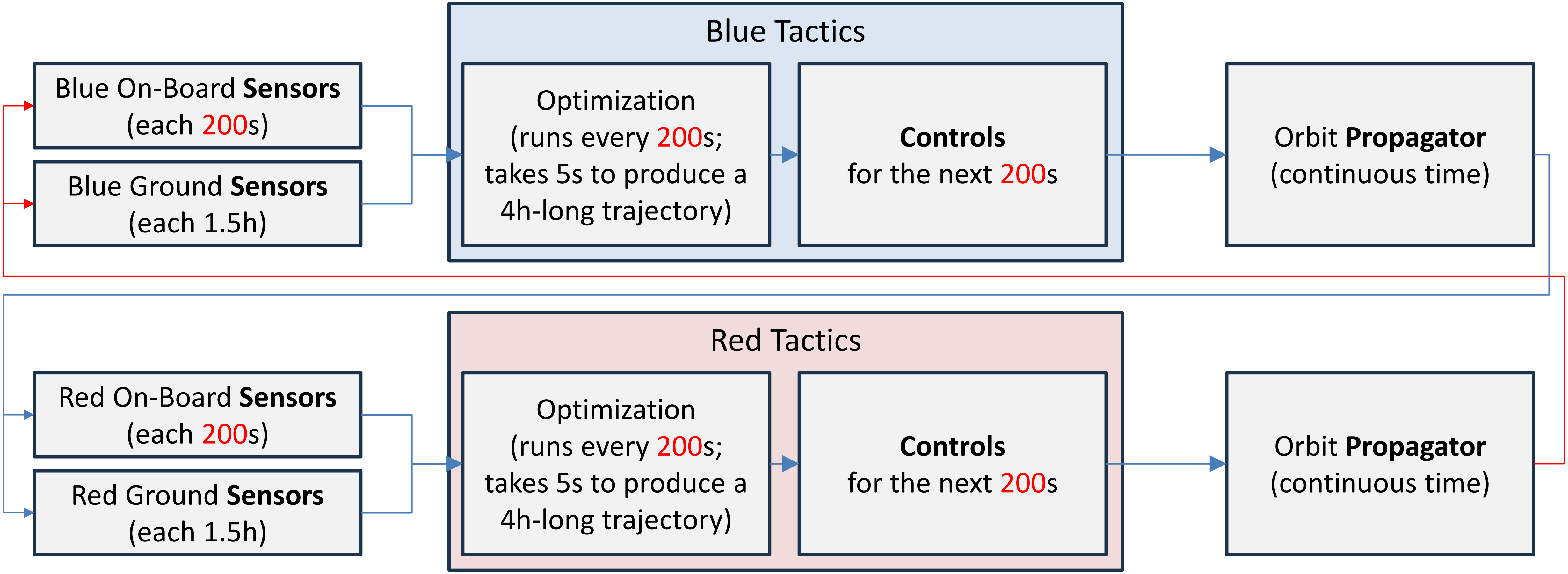
Requirements Toolbox allows users to:

- Author requirements, import, export, and formalize requirements
- Link requirements to designs, code, and tests, specify relationships, add markup, review traceability to models and code, check consistency
- Requirements-based model verification, interpreting and reporting test results
- Requirements review and comparison, track changes and provide justification, generate reports for sign-off and approval
- Requirements traceability supported by the legacy RMI interface
- Qualify Requirements Toolbox for DO and IEC certification

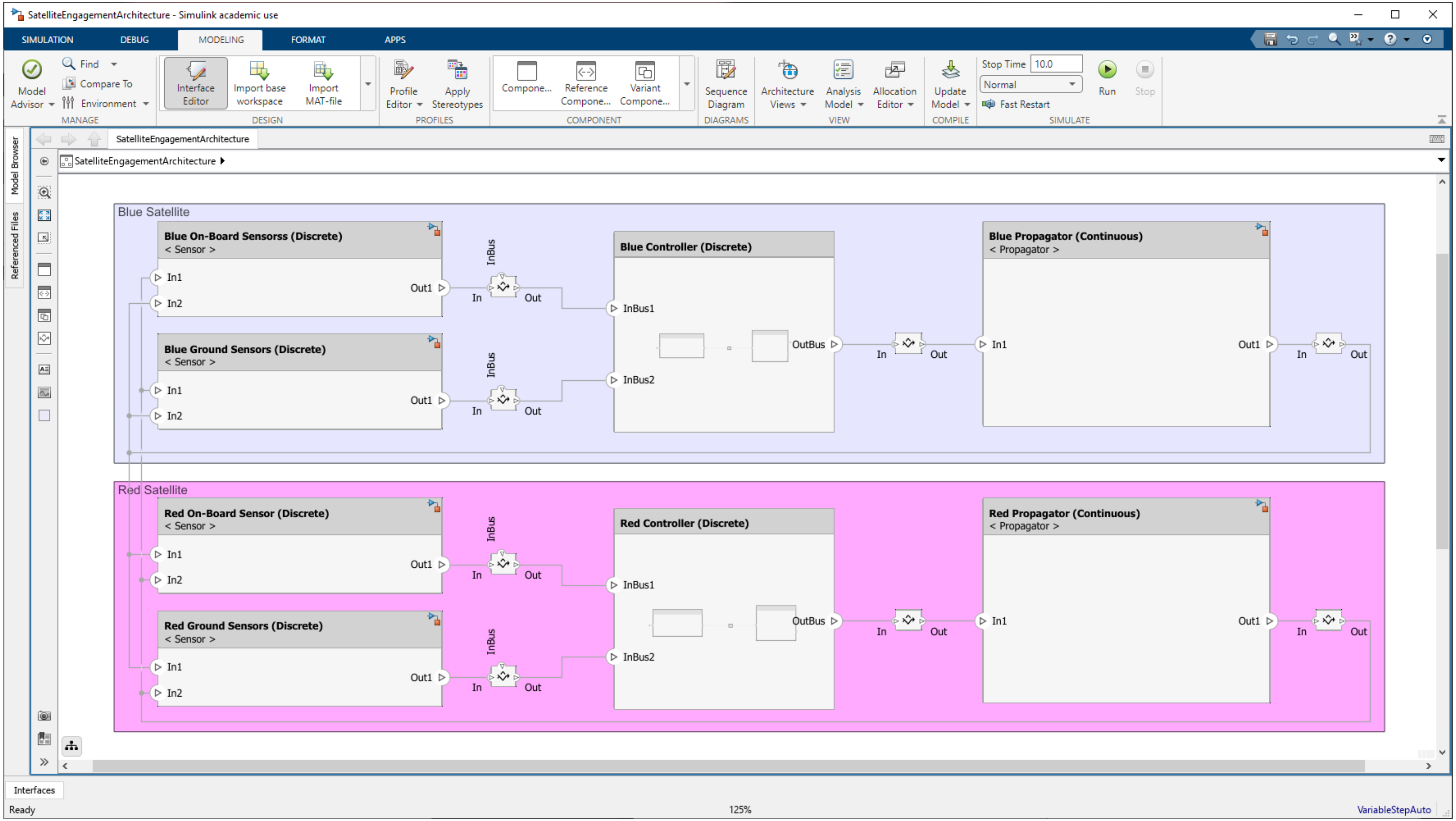
Simulink Test allows users to:

- Create and import data, develop test sequences, log signals, assess simulation and output
- Run tests, view and interpret test results, debug tests, and check test coverage
- Report and archive test specifications and test results, package test files, work with change management systems
- Create and run tests using command-line functions and scripts, set test preferences

SIMPLIFIED MISSION ARCHITECTURE

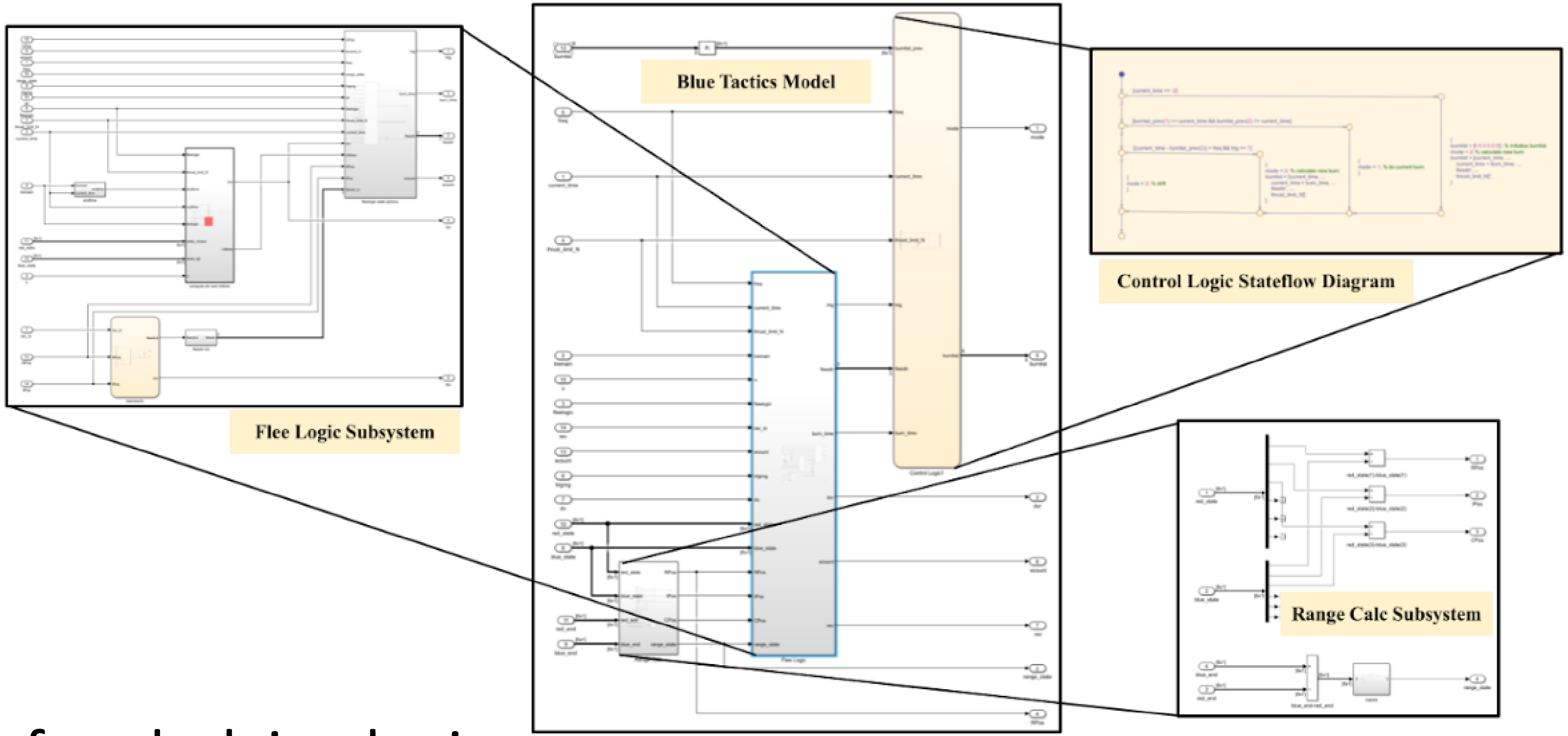


MISSION ARCHITECTURE IN SYSTEM COMPOSER



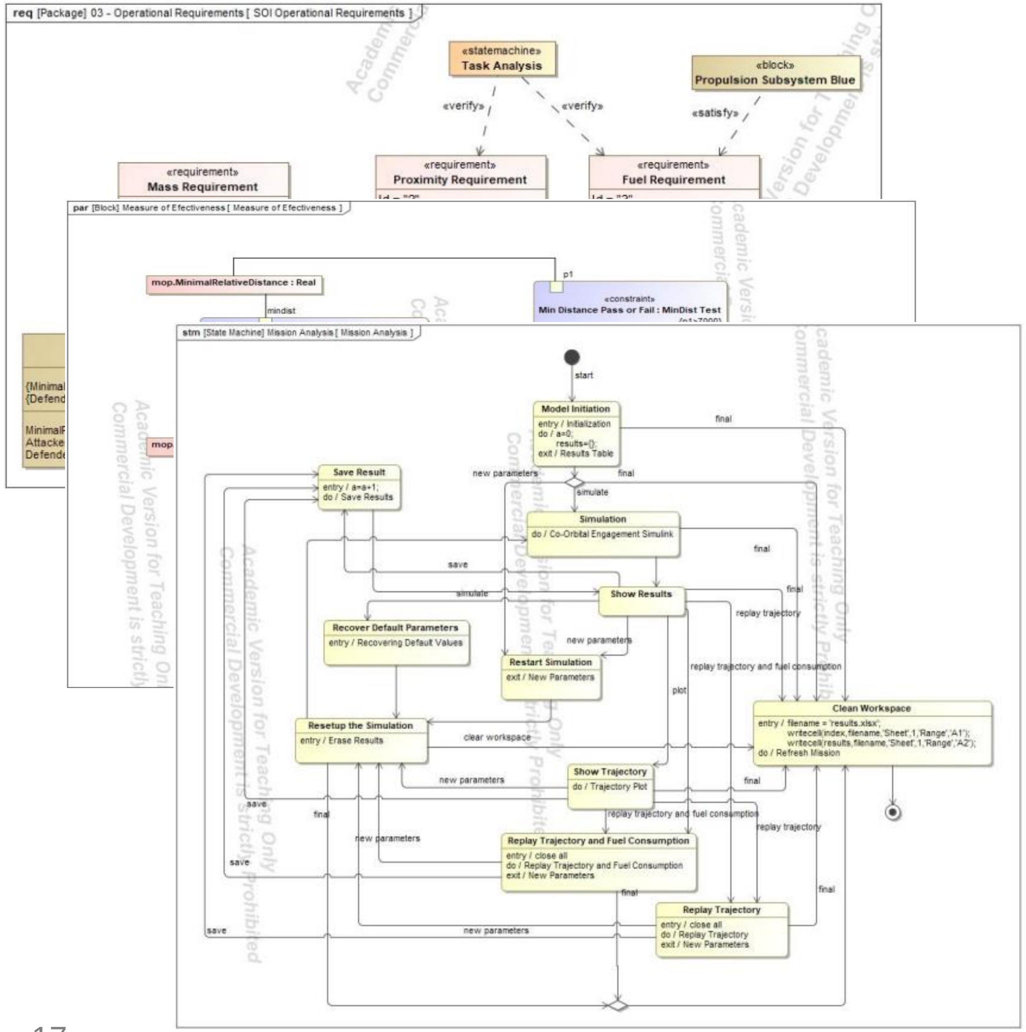
Distribution Statement A. Distribution Unlimited

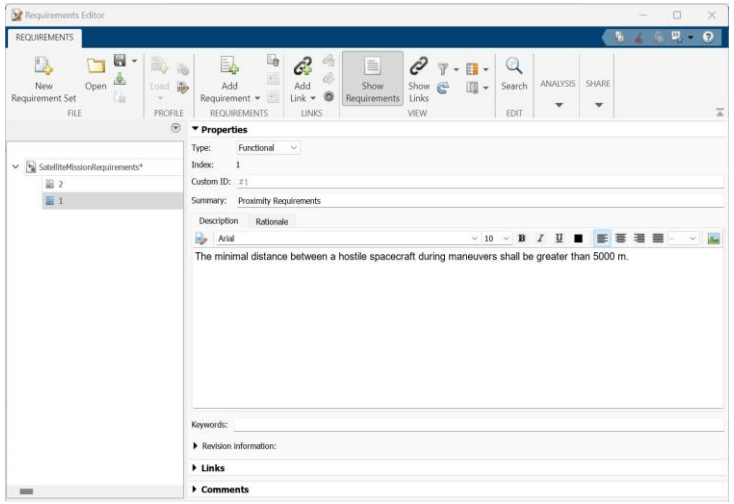
SIMULINK SUBSYSTEMS AND STATEFLOW DIAGRAMS WITHIN TACTICS COMPONENT



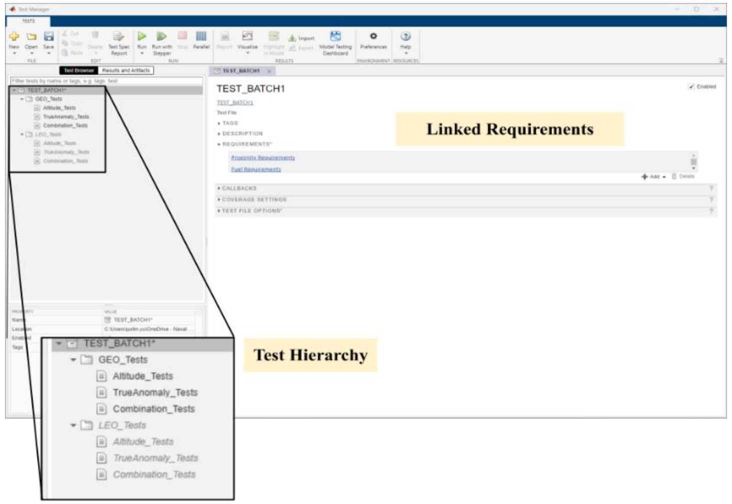
- Visual representation of underlying logic
- Simulation performance improvements
- Requirements traceability and verification
- Increased modularity to adapt to changing requirements and model updates

SIMPLIFICATION OF REQUIREMENTS AND ASSESSMENTS GUI





Requirements Editor

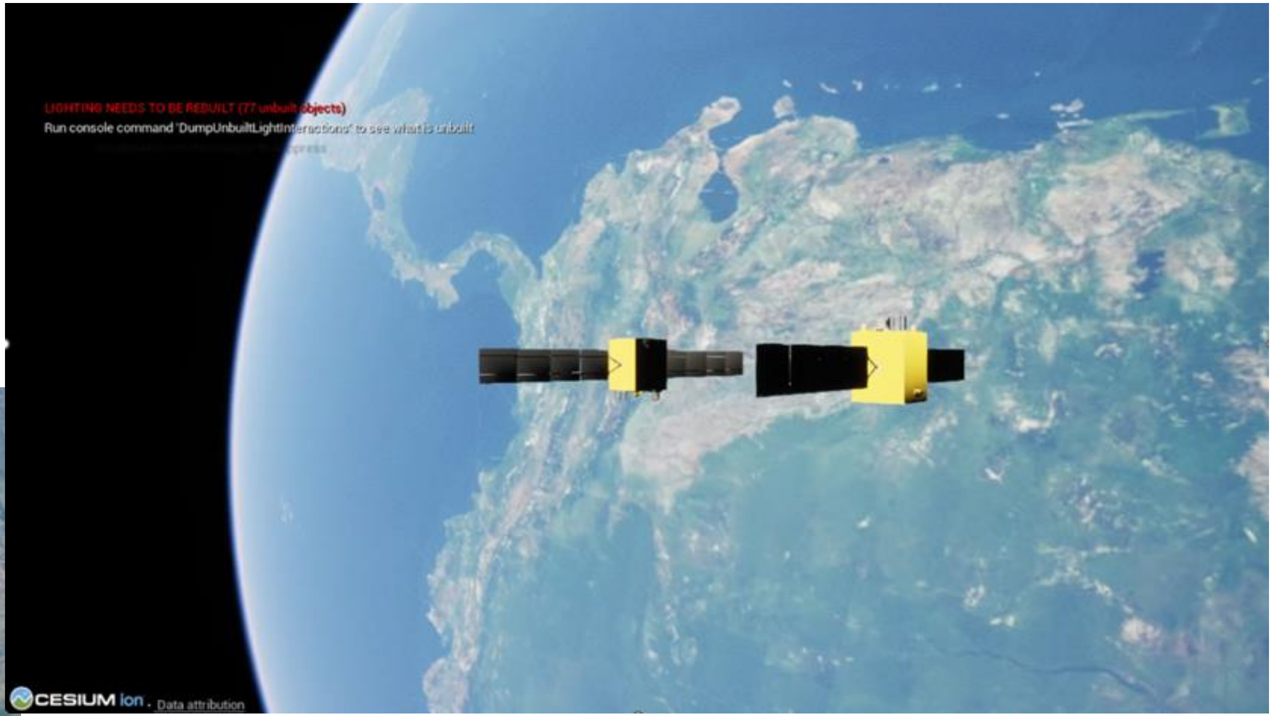


Test Manager

ADDITIONAL CAPABILITIES / ADVANTAGES

- Natural seamless integration of multiple products within the same development environment, integrated by design
- Base workspace -> Data Dictionary (source control)
- Higher fidelity representation of system components and real-world interfaces (e.g., rates transition)
- Taking advantage of rich modeling libraries (e.g., of high-precision orbit propagator)
- Advanced visualization capabilities
- Model reusability
- Usage of projects
- Advanced GUI capabilities
- Generation and deployment of standalone applications

SIMULATION 3D VIEWER



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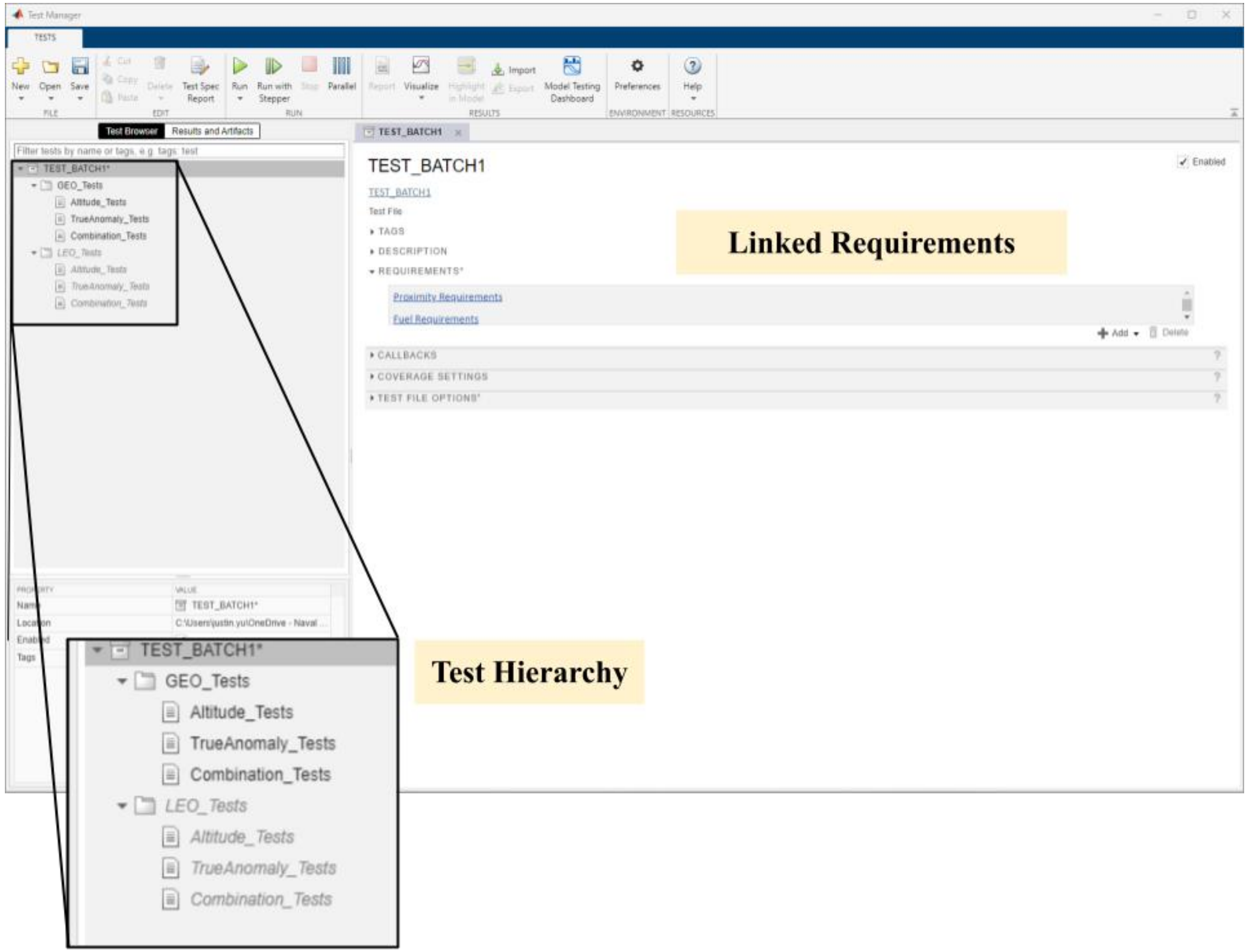
DEMONSTRATION OF MODEL FEATURES/EXECUTION

TEST MANAGER GUI FOR MANAGING BATCH TESTS



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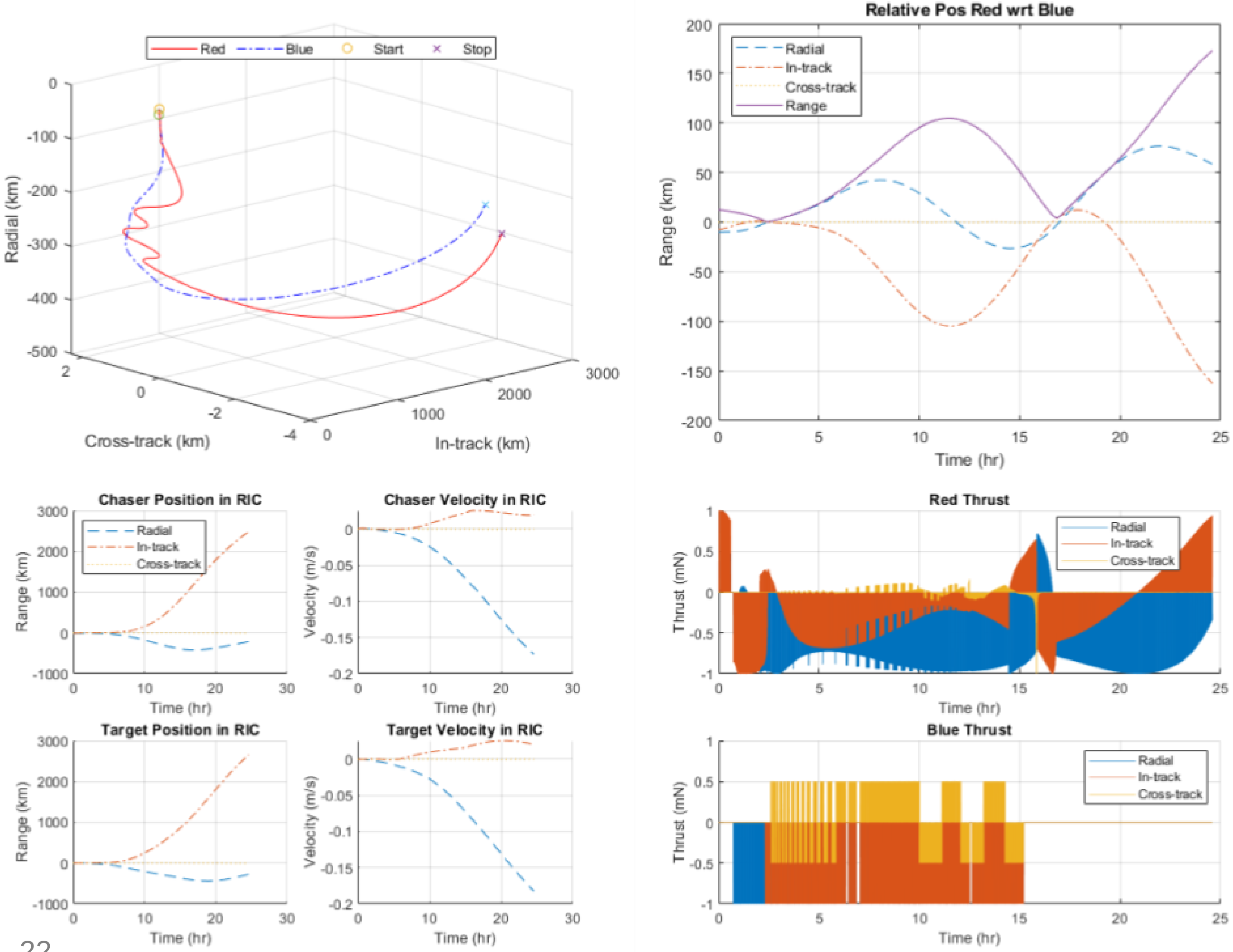
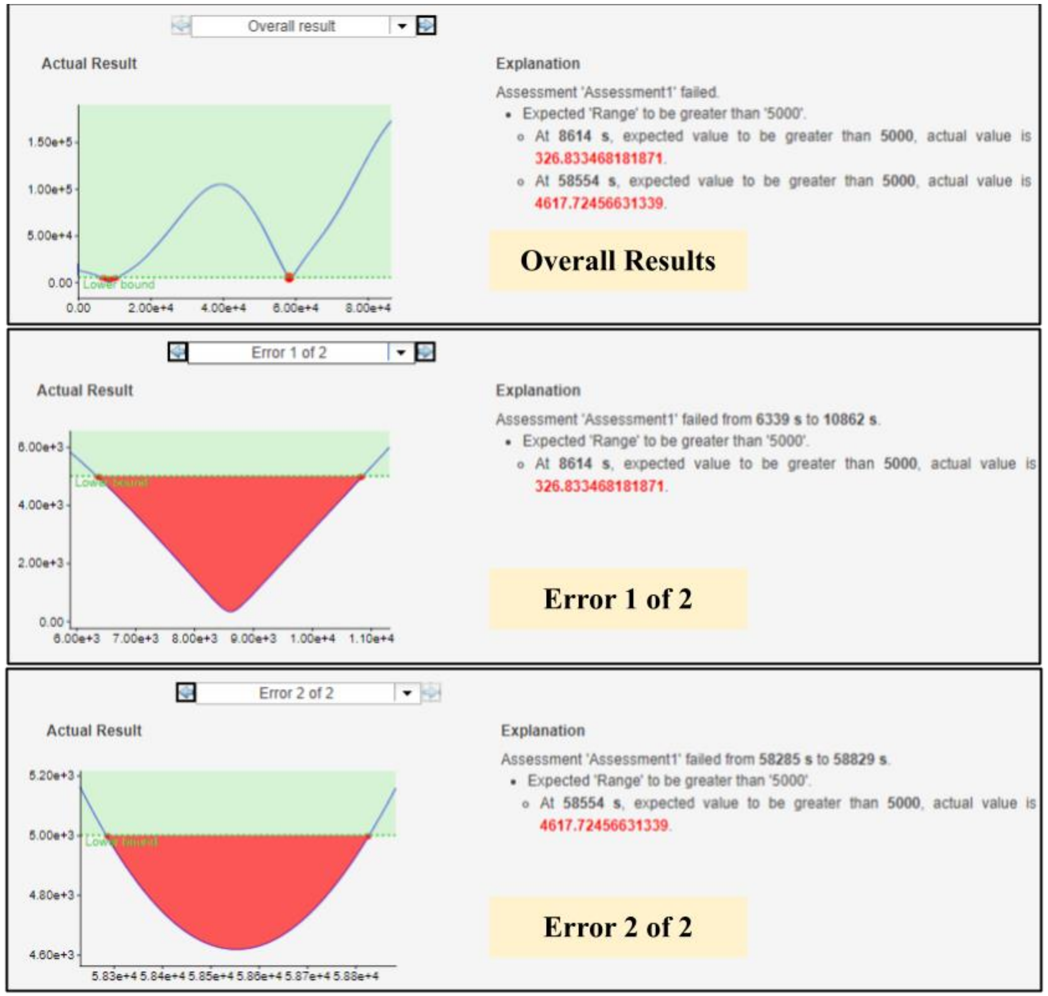
IN-DEPTH REQUIREMENT VERIFICATION

NDIA

GEO chaser trajectory starting 10 km below and 0.01° true anomaly behind target



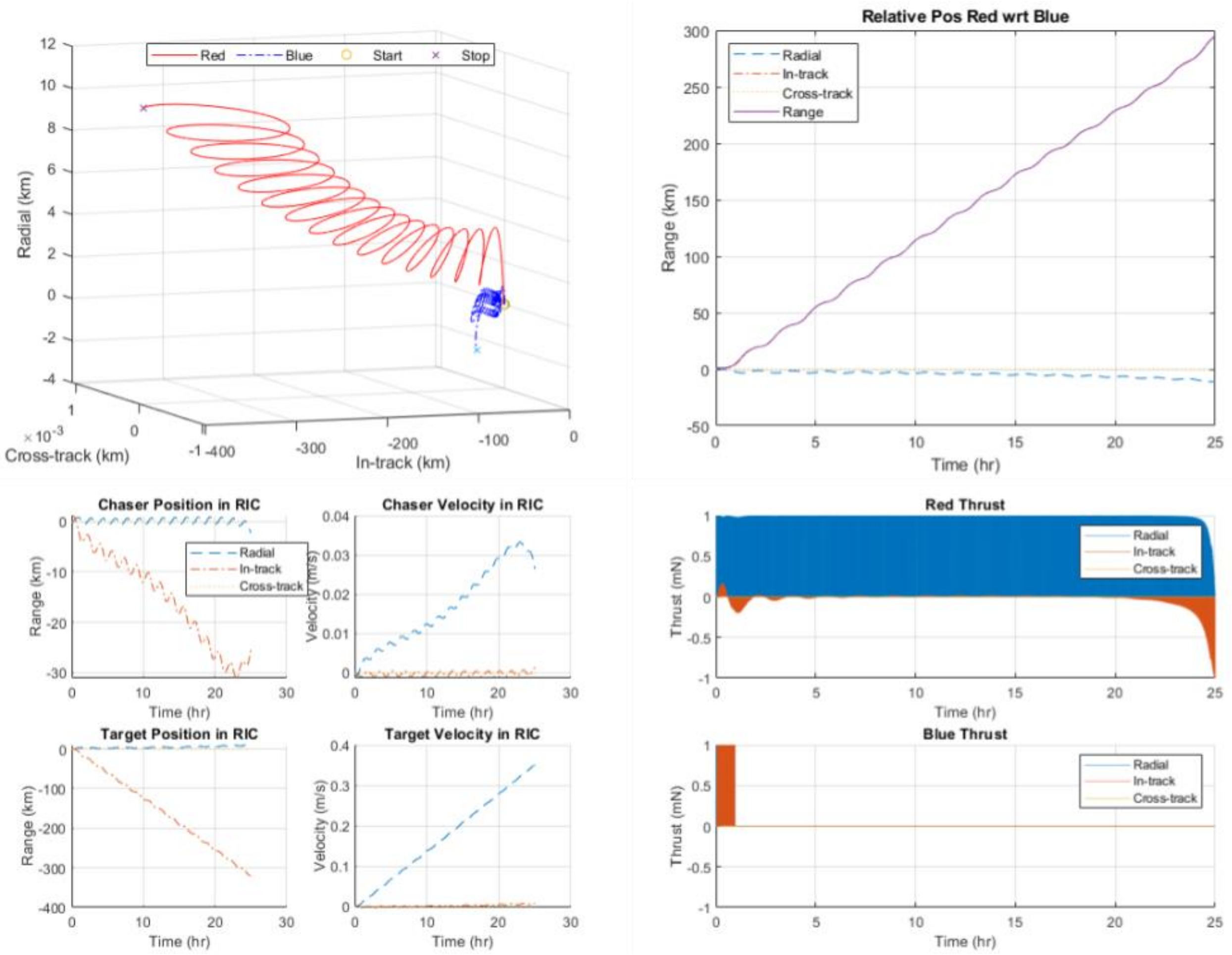
Automatic assessment conducted by Test Manager (proximity requirement)



11/12/2024

IN-DEPTH REQUIREMENT VERIFICATION, CONT'D

GEO chaser trajectory starting 10 km below and 0.05° true anomaly behind target



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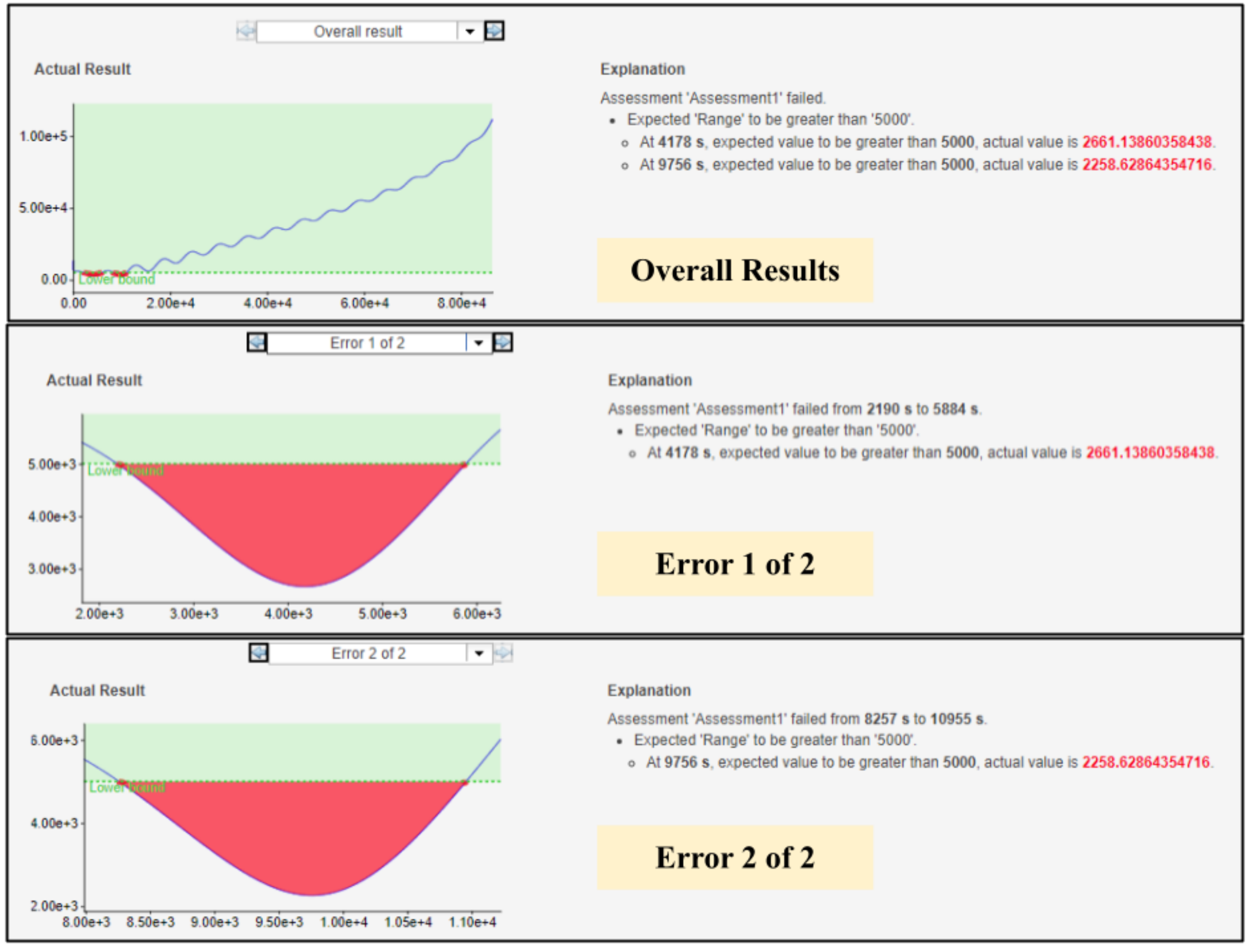

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CONCLUSIONS

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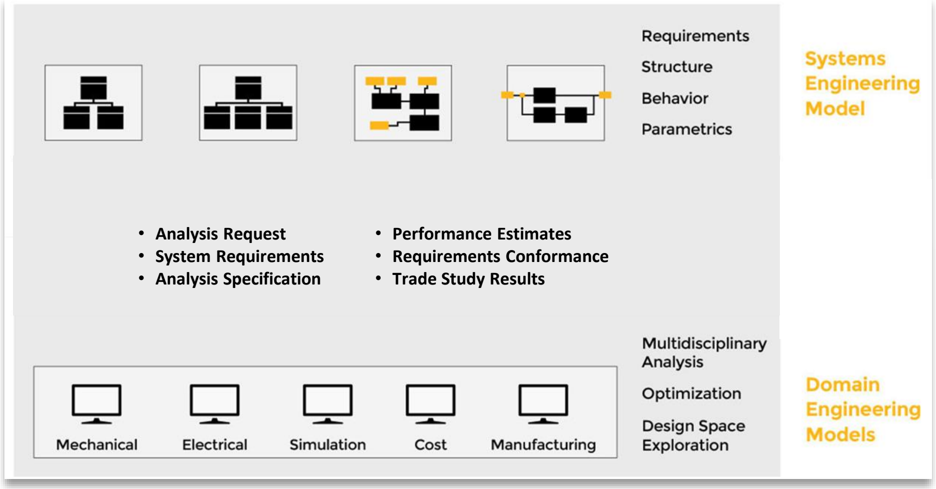
- Potential to close the gap between System Engineers and SMEs with a different background

- Advantages of a Unified Development Environment
  - Unified UI for Architecture and Design/Analysis
  - Significant added verification capability
  - Advanced visualization capability
  - Single source control tool
  - No value compatibility issues
  - Capability to use well-proven legacy models
  - Reusability
  - Varied complexity
  - Usage of a wide variety of existing Toolboxes and Blocksets
  - Collaborative environment



- Challenges
  - Initial effort to migrate analysis from legacy MATLAB scripts into Simulink/Stateflow models*

(*This could have been avoided by planning for Analysis and Simulation from project start)