National Aeronautics and Space Administration

Model-Based Systems Engineering in System Integration, Verification and Validation

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Outline

1. What is Model-Based Systems Engineering and why JPL is using it
2. Objectives and Section 314's Motivation
3. Early Progress
4. Significant Product Developments in FY12
5. The Value Proposition
6. Product Development Strategy
7. Next Steps
8. What we propose for SLO

1. What is Model-Based Systems Engineering?

"Model-based systems engineering (MBSE) is the *formalized application of modeling* to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases."

INCOSE International Council on Systems Engineering

INCOSE SE Vision 2020 (INCOSE-TP-2004-004-02, Sep 2007)

"Model-Based Engineering (MBE): An approach to engineering that *uses models as an integral part of the technical baseline* that includes the requirements, analysis, design, implementation, and verification of a capability, system, and/or product throughout the acquisition life cycle."

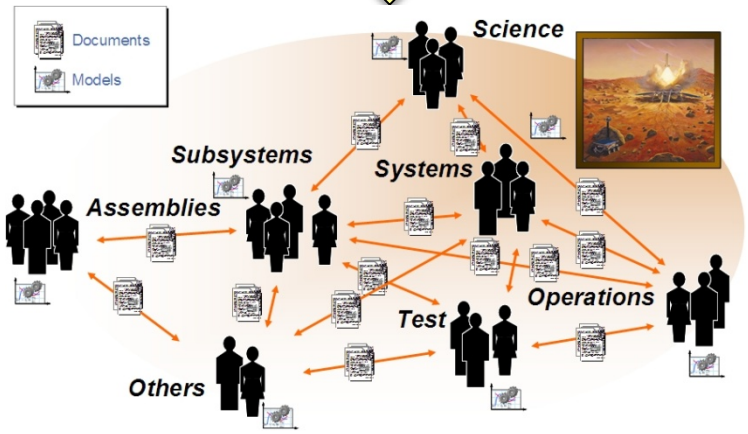
NDIA National Defense Industrial Association

Strength through Industry & Technology

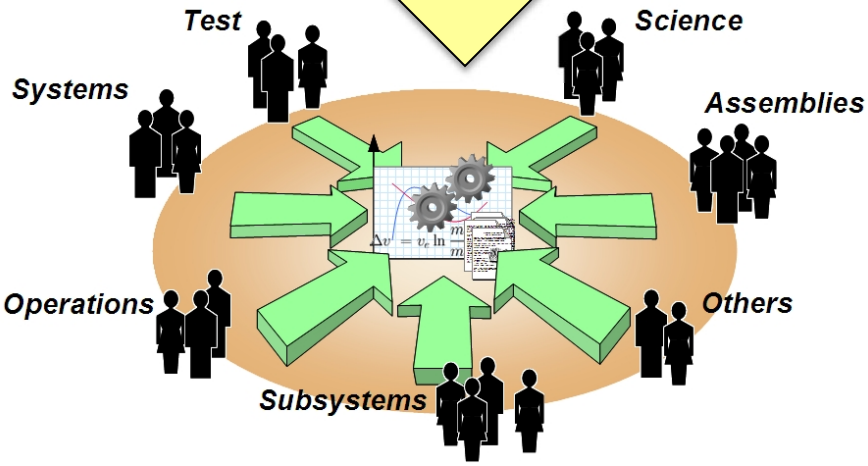
Final Report, Model-Based Engineering Subcommittee, NDIA, Feb. 2011

MBSE and the "System Model"

- Systems Engineering requires structural, behavioral, physics and simulation-based models representing the technical designs
- Current practice tends to rely on standalone (discipline-specific) models
- MBSE moves toward a **shared system model**. All disciplines, including discipline-specific models, "view" a consistent **system model**.

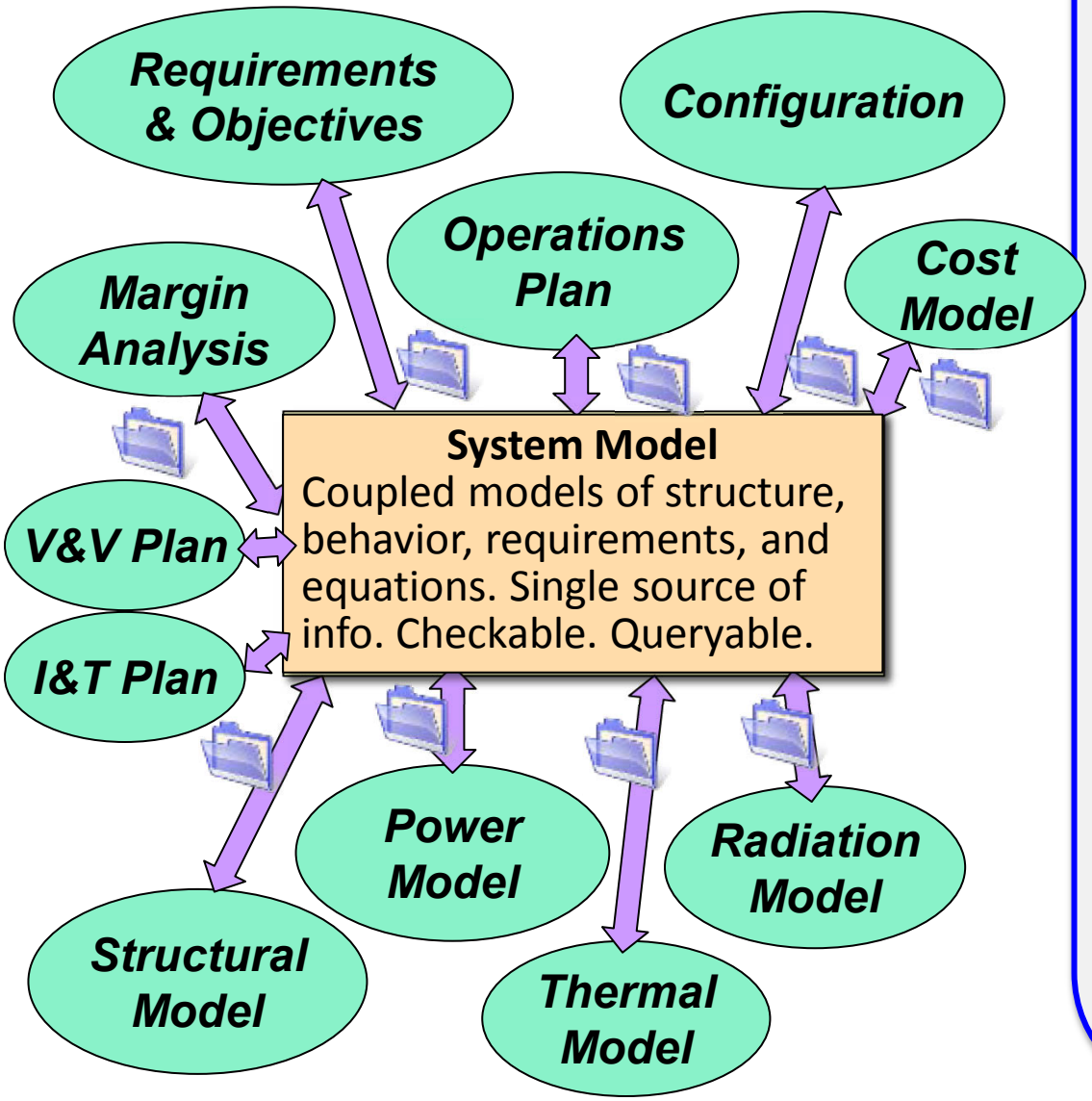


Today: Standalone models related through documents



Future: Shared system model with multiple views, and connected to discipline models

Current State



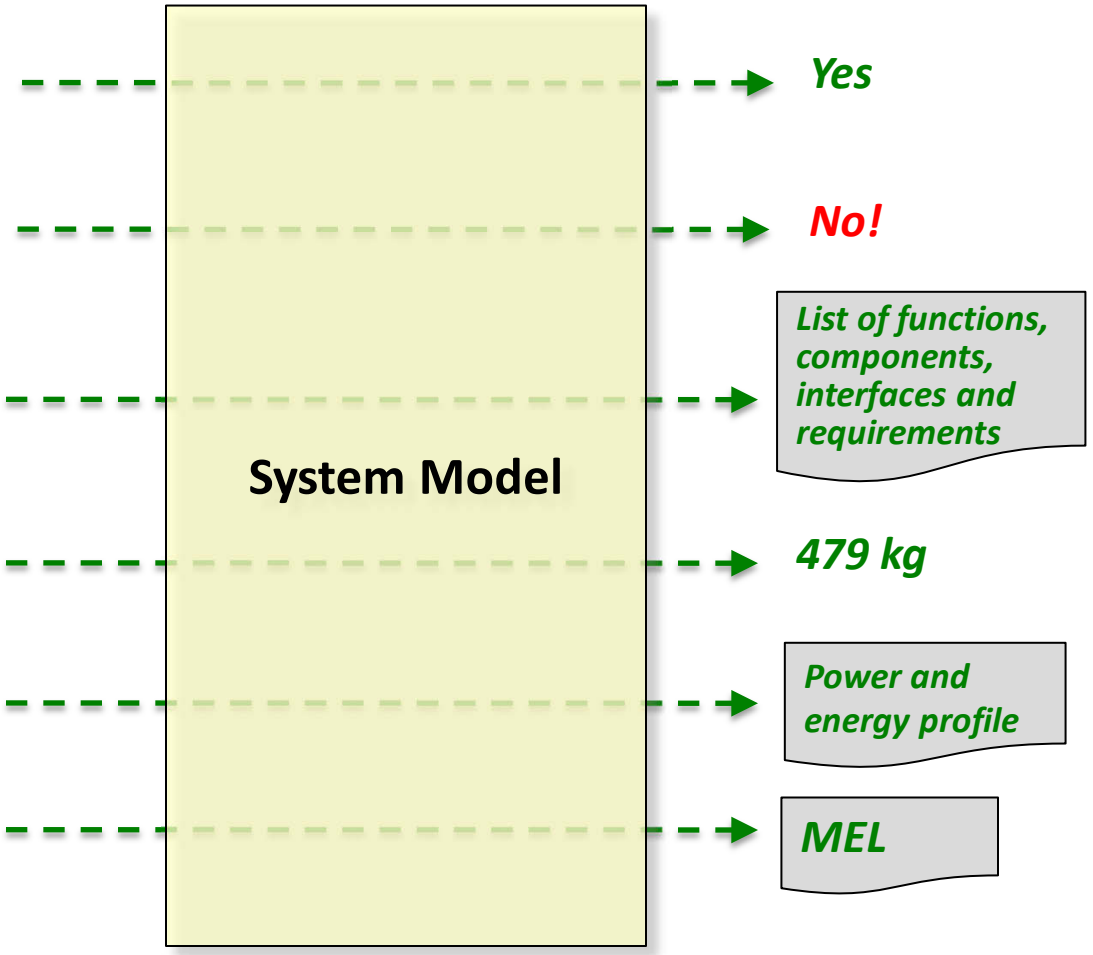
Desired State

- Architecture and designs captured in a formalized and repeatable system model
- Design reviews consist largely of model inspection & validation
- System model evolves from formulation through operations
- System test activities focus on model validation
- Models and modeling tools are integrated across life-cycle
- Behavioral, physical, cost and risk models are integrated, allowing for an integrated fully-informed approach to system optimization

How a System Model Helps

A well-structured system model can be analyzed to answer a variety of questions

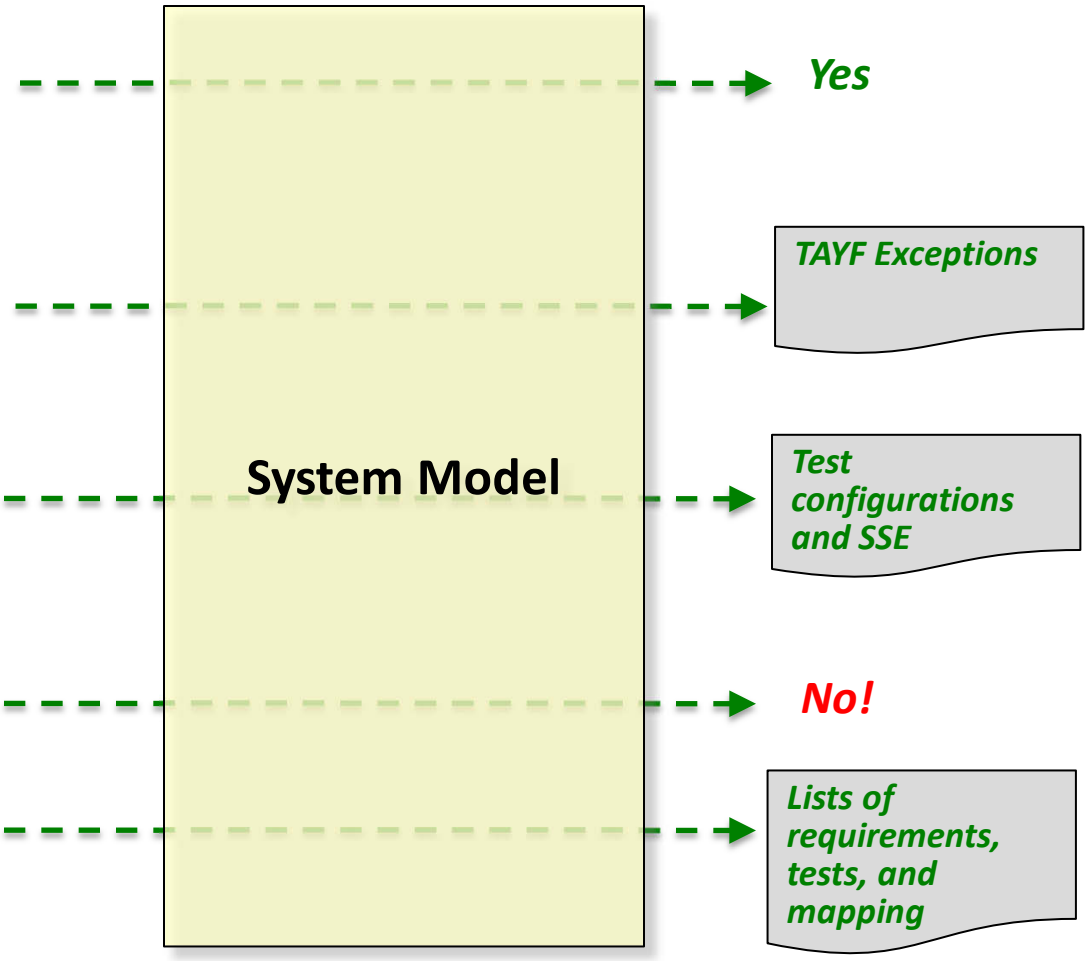
- Does every component trace to a requirement?
- Have both sides of every interface been specified?
- If this requirement changes, what is potentially affected?
- What is the dry mass of the flight system?
- Show power and energy used for mission scenario x
- What is the mass rollup?



How a System Model Helps I&T / V&V

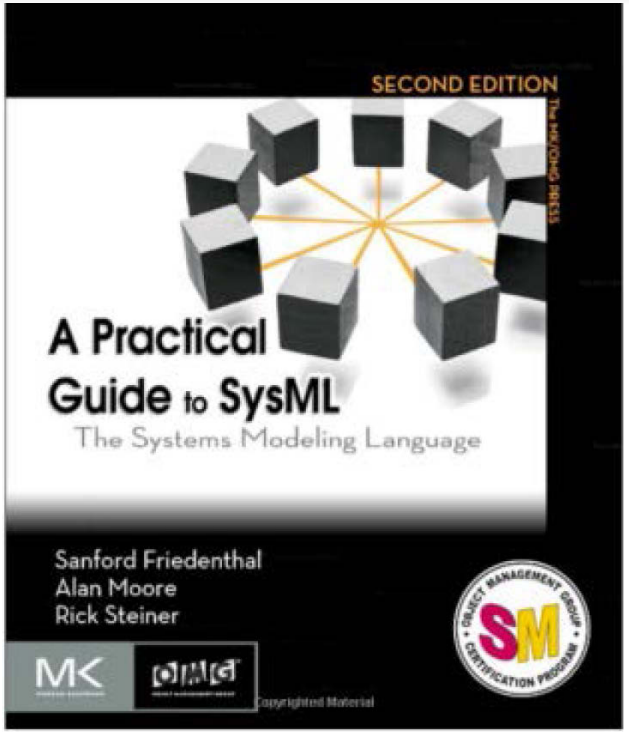
A well-structured system model can be analyzed to answer a variety of questions

- Does my current design meet the mission needs for these scenarios?
- How does my planned test configuration differ from the flight configuration?
- What support equipment do I need for this test?
- Does my current requirements set adequately describe the system?
- What testbed resources will I need for my planned test set?

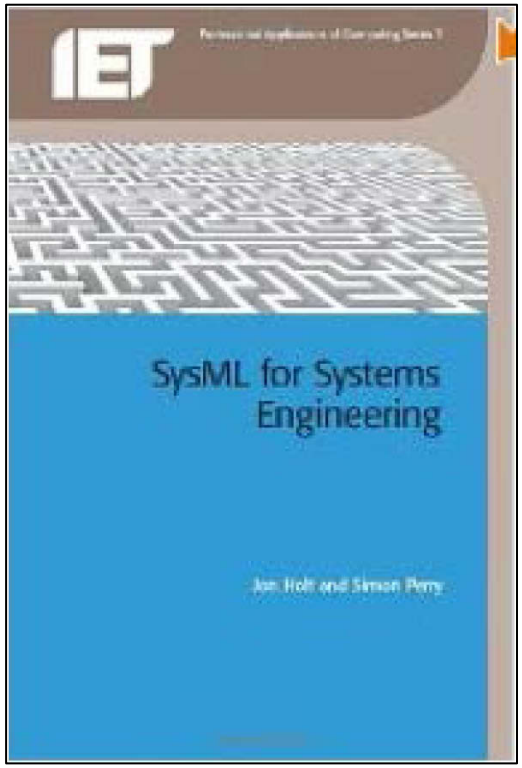


SysML: A language for system modeling

SysML is a visual modeling language that is both human- and computer-understandable, *and* extensible



(2008)

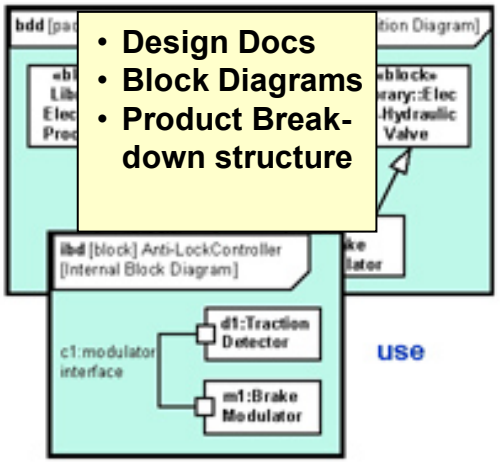


(2007)

"SysML is the new industry-standard language designed specifically to support modern systems engineering."

Mapping Text-based & Analysis tools onto a system model

Structure



- Design Docs
- Block Diagrams
- Product Break-down structure

definition

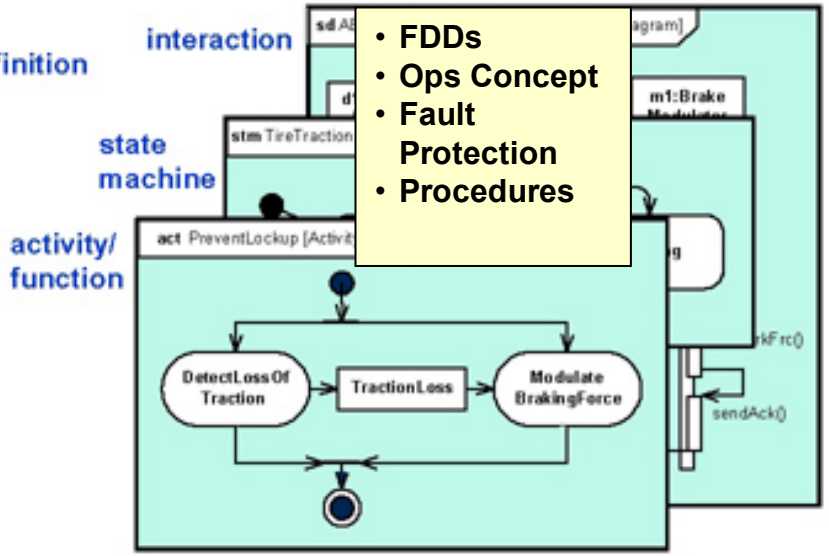
use

Behavior

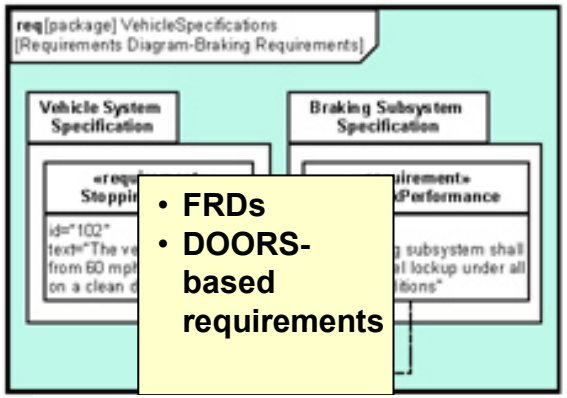
interaction

state machine

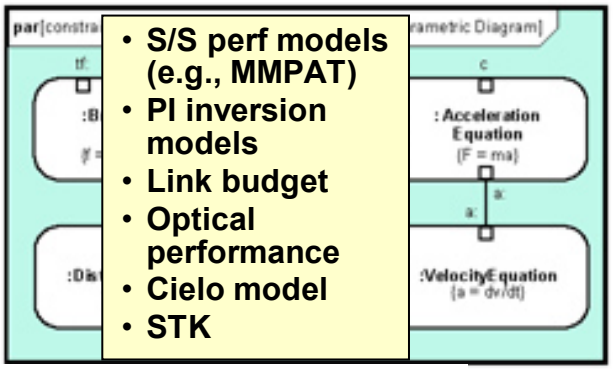
activity/ function



- FDDs
- Ops Concept
- Fault Protection
- Procedures



- FRDs
- DOORS-based requirements

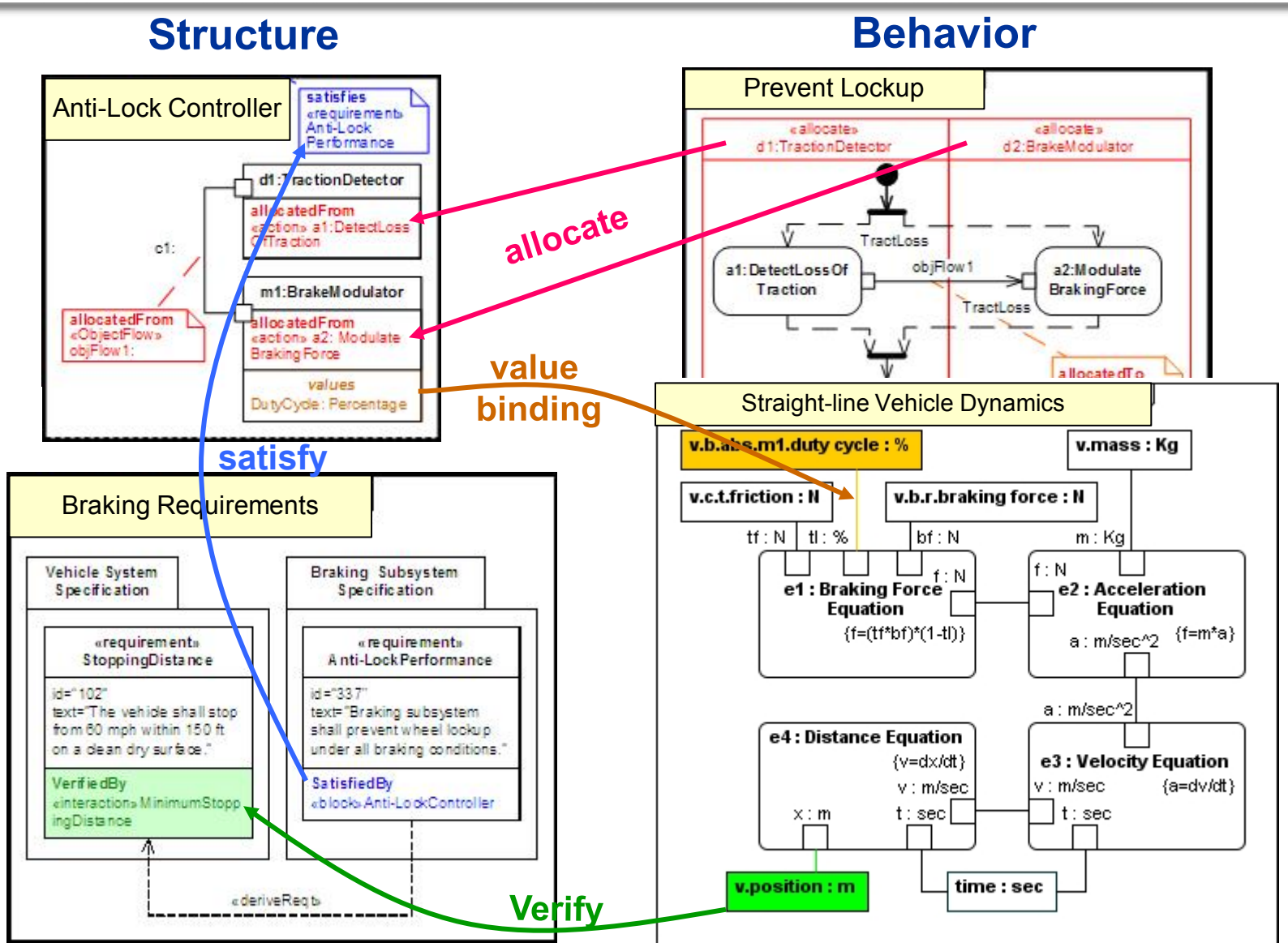


- S/S perf models (e.g., MMPAT)
- PI inversion models
- Link budget
- Optical performance
- Cielo model
- STK

Requirements

Parametrics (a.k.a Analysis)

Interconnections within a System Model



2. Objectives

- Our objectives are to answer the following questions:
  1. **How can we use *static models* in SysML to help us generate V&V products, organize V&V work and improve process?**
  2. **What are the possibilities of *executable models* and can they be used effectively for early requirements validation?**

Motivation

- As ATLO time is staying constant and spacecraft complexity is ever increasing; comprehensive V&V on the flight hardware is not possible so we are always looking for ways models can be incorporated in the workflow.
- Just having a system expressed as a formal model makes the V&V issues easier to identify and resolve
- V&V products captured in SysML make them more accessible and reusable
- Simulations generated directly from system models allow for a more thorough understanding of nominal and off-nominal spacecraft behavior; some design validation can take place at L2 and L3 before any hardware exists

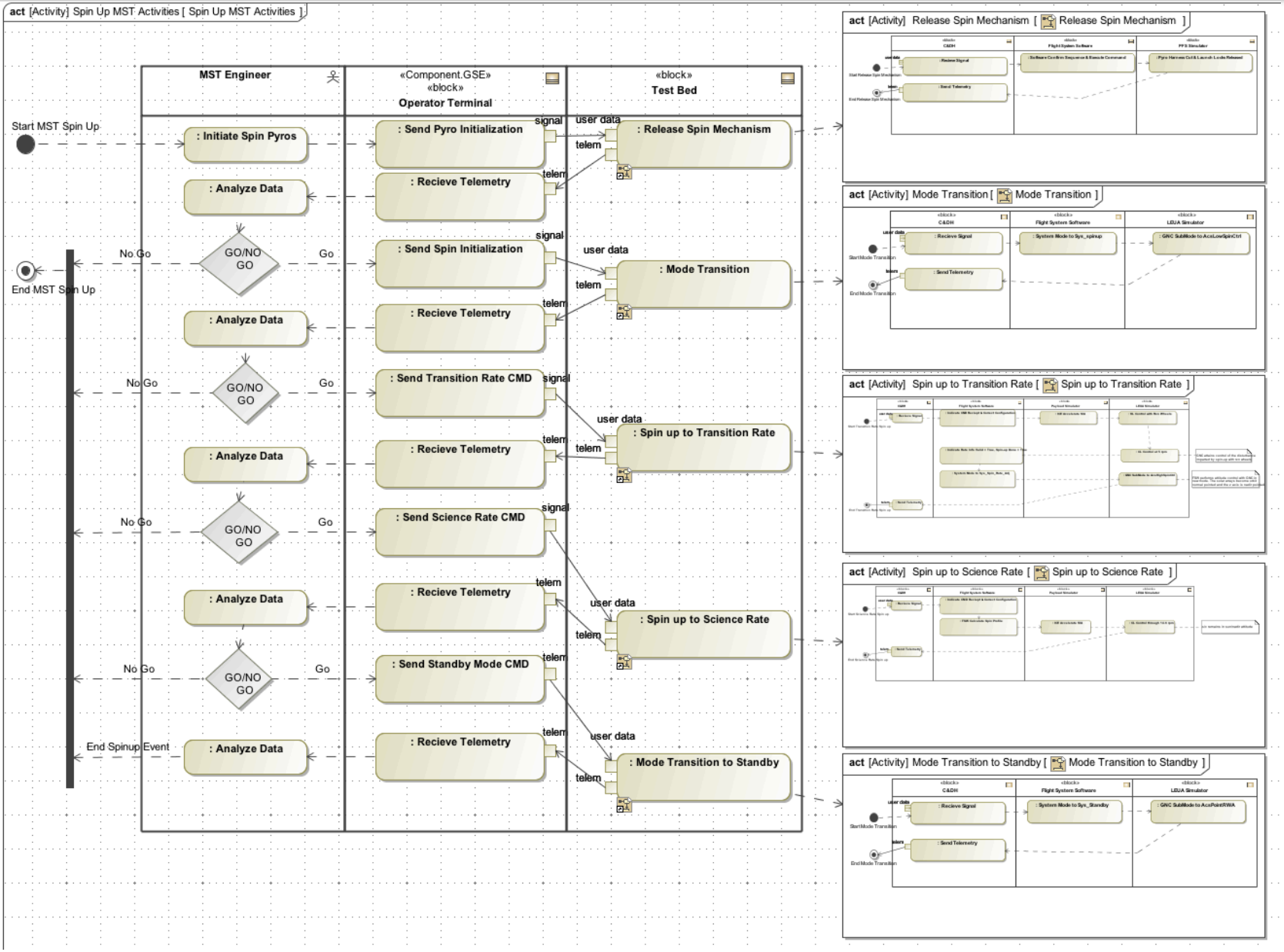
3. Early Progress

1. Generate V&V products such as test plans and procedures as static models, using the SMAP spin-up event as a reference case.

2. Generate a V&V pattern and test equipment/SSE catalog.

3. Create a simulation of the SMAP uplink process directly from static models, and use it to validate the structure of commands in the R1 command database

3. Products: Spin-up Mission Scenario Test Plan

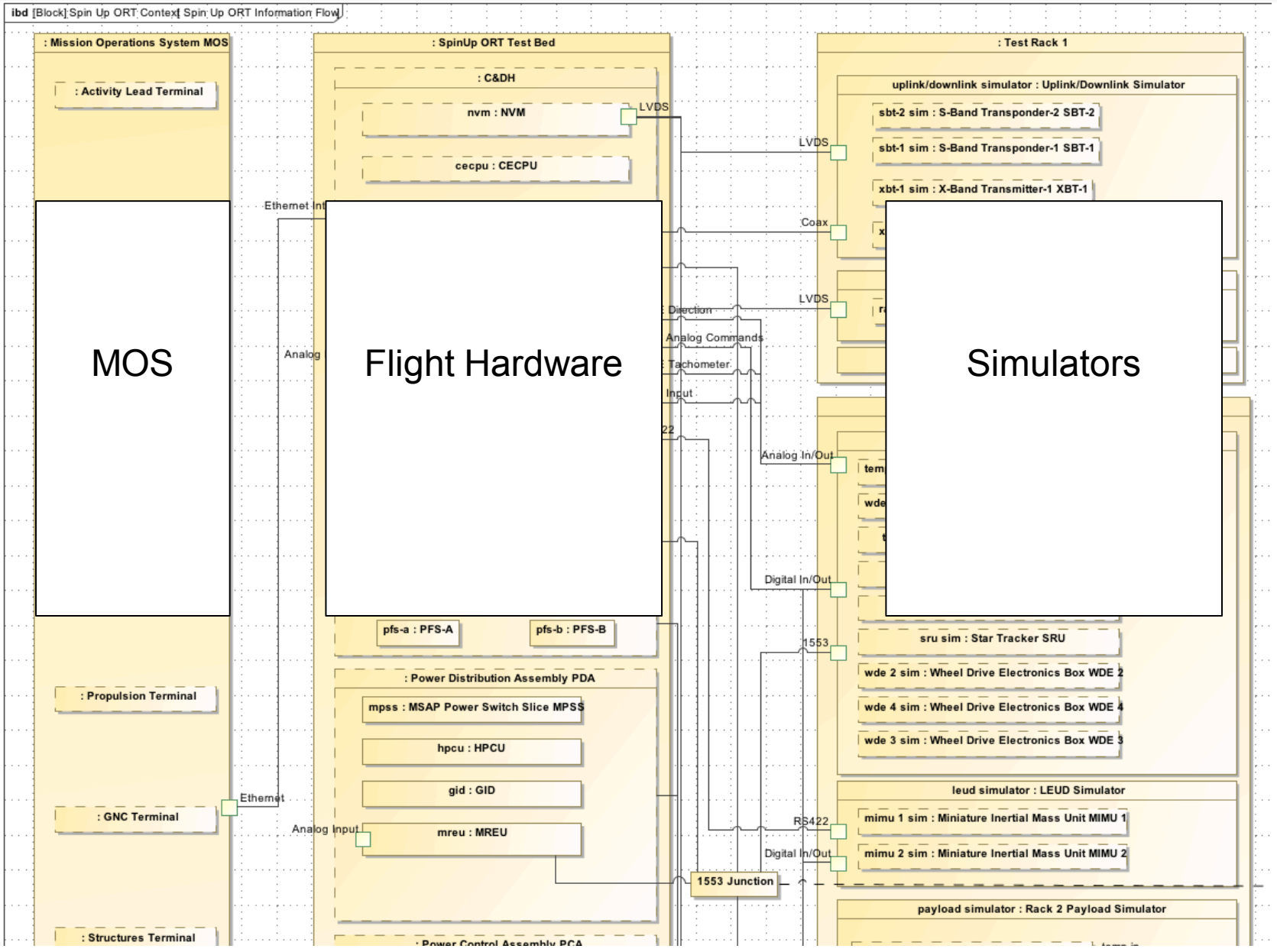


Products: Requirement Verification Matrix

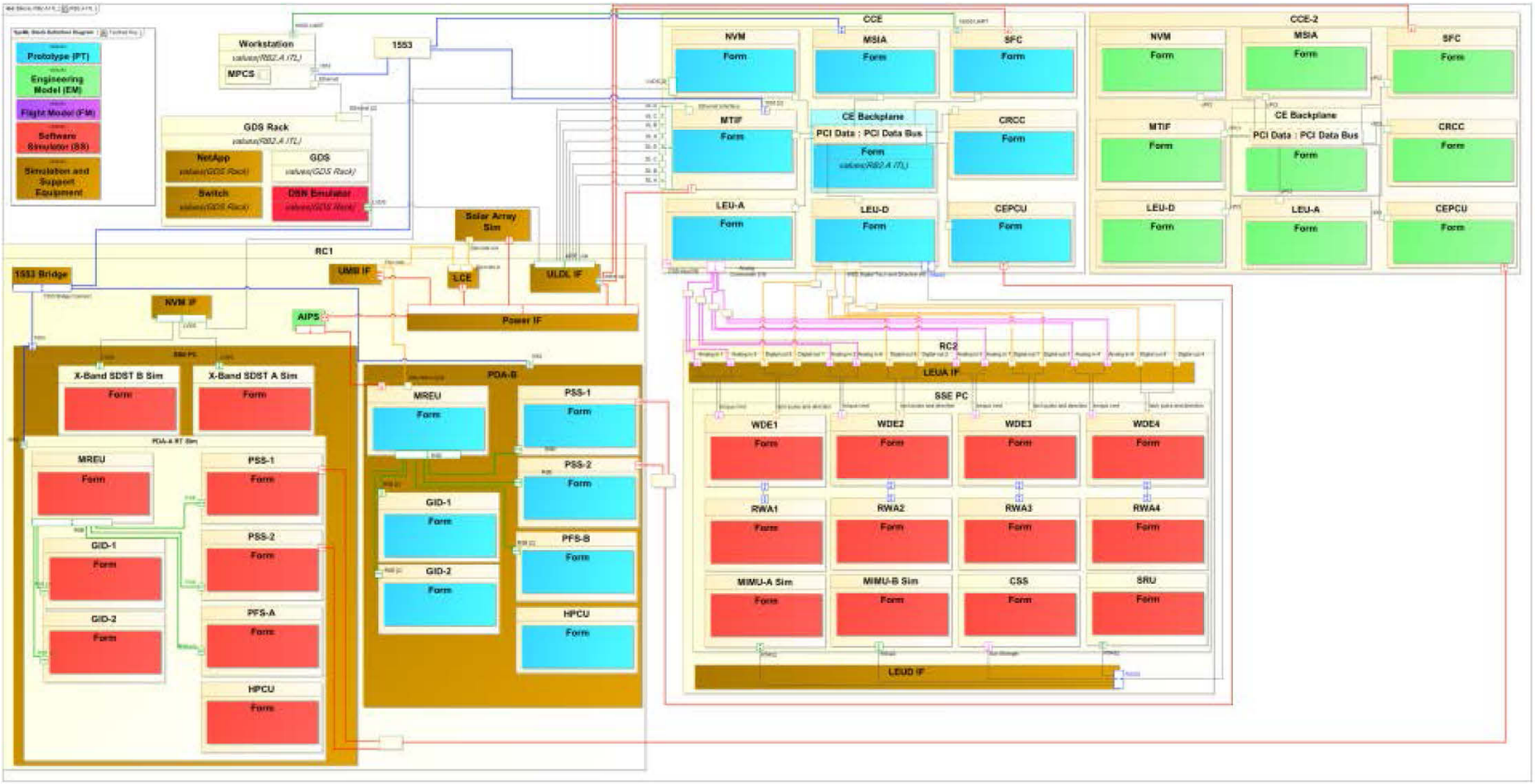
Using the tool's capability to store and connect information we can query the model to show relationships, for example between requirements and their corresponding verification activities, producing an improved NASA gate product more efficiently.

	1 L3-SCB-159 [...	2 L3-SCB-1671...	3 L3-SCB-1673...	4 L3-SCB-1675...	5 L3-SCB-1692...	6 L3-SCB-1694...	7 L3-SCB-1728...	8 L3-SCB-1682...	9 L3-SCB-1684...	10 L3-SCB-173...	11 L3-SCB-174...	12 L3-SCB-177...
Spin Up MST Context	1		1	1			1	1	1	1	1	1
Spin Up MST Context	1		1	1			1	1	1	1	1	1
Spin Up MST Test Plan	↗		↗	↗			↗	↗	↗	↗	↗	↗
Spin Up ORT Context	1	1	1	1	1	1	1	1	1	1	1	1
Spin Up ORT Context	1	1	1	1	1	1	1	1	1	1	1	1
Spin Up ORT Test Plan	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗

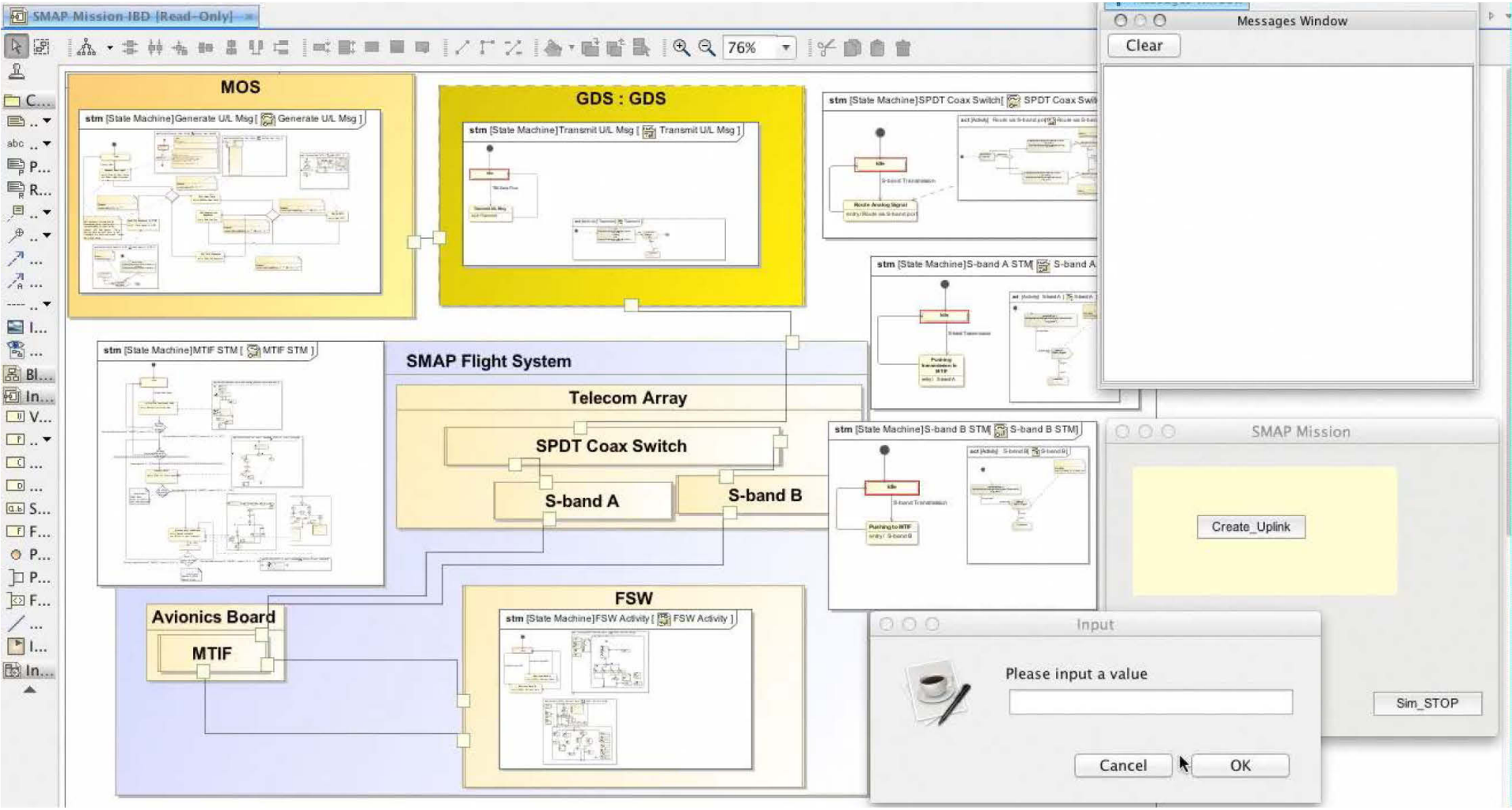
Products: SMAP Spin-Up Ops Readiness Test ibd



Products: Reference Bus Integrated Test Lab ibd



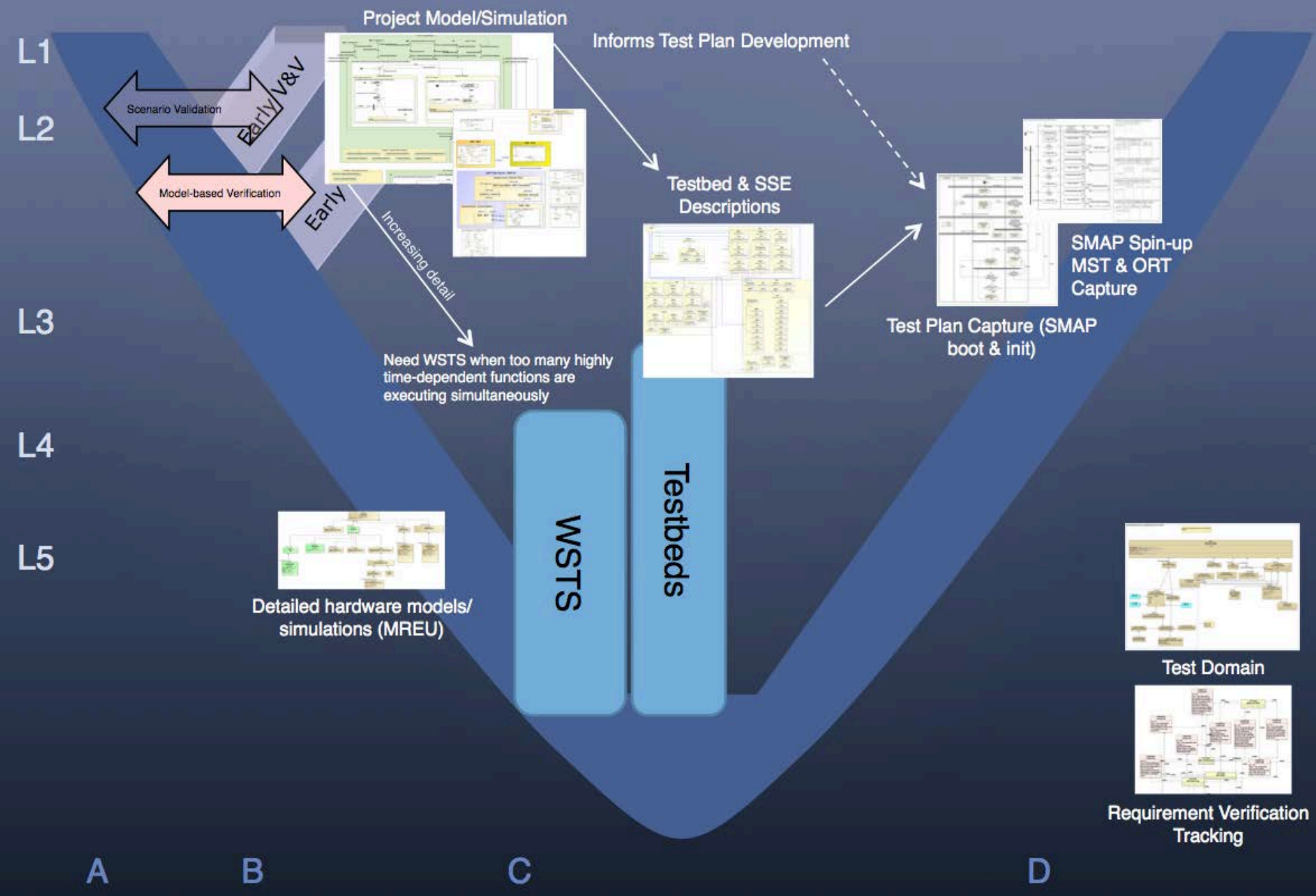
Products: SMAP Uplink Simulation



5. Value Proposition

- **Simulations derived directly from models enable us to detect defects in the design, validate ops concepts and validate scenarios early in the project lifecycle, reducing the cost of remediation later on**
  - Validate the model itself
  - Validate the design
- **V&V products developed as views developed from an integrated model**
  - take advantage of precursor models developed by designers by using existing design material
  - provide more inheritance from plans, to testbed procedures, through integration procedures, to operational procedures than our existing products can
  - are more intuitive to modify and execute than text based procedures
  - The procedure can become the script for configuring and running the unit under test
- **All of the above save time and money during the development cycle, making JPL more competitive**

6. Product Development Strategy



7. Next Steps – FY13

Our Overriding Objective for 2013:

How do system models and the products developed so far work with our existing models like WSTS & hardware testbeds?

- Design and produce a SysML procedure-driven WSTS Simulation
- Design and produce a SysML procedure-driven test, with the testbed driven directly by the procedure
- Continue with SysML Model V&V products and methodology
  - Further develop SysML Model V&V Methodology by creating test plans and test procedures for SMAP and
  - Testbed diagrams for Reference Bus using MBV&V patterns
- Produce SMAP Thermal Control Subsystem model and add to the project system model we are developing
- Investigate SysML model validation using the 7009 standard. Investigation of formal methods for MBV&V – static and dynamic

8. What we propose for SLO collaboration

- **Produce system design and specification using an integrated modeling approach**
  - Functional and behavior descriptions
  - Requirements
  - Operations Concepts
  - Scenarios
- **Plan integration & test and V&V in parallel with the system design, using the same toolset**
  - V&V Plans and procedures
  - I&T Plans and procedures
  - Testbed plans
  - Test-as-you-Fly exceptions

9. JPL help with such projects

1. Possible Magicdraw licenses
2. Possible assistance with Cubesat hardware
3. Advice and help

BACKUP CHARTS – Other Achievements

- **Publications**
  - Khan, Sievers, Standley, *Model-Based Verification and Validation of Spacecraft Avionics*, Infotech@Aerospace 2012 Conference, Santa Ana, CA, May 2012
  - Ingham, Day, Donahue, Kadesh, Kennedy, Khan, Post, Standley, *A Model-Based Approach to Engineering Behavior of Complex Aerospace Systems*, Infotech@Aerospace 2012 Conference, Santa Ana, CA, May 2012
  - Khan, Dubos, Tirona, Standley, *Model-Based Verification and Validation of the SMAP Uplink Processes*, IEEE Aerospace Conference Big Sky, Montana, Mar 2- Mar 9 2013 (submitted)

- **Trained 4 engineers in executable models:** Omair Khan, Greg Dubos, Joe Tirona, Corrina Gibson