MBSE in Development: SMAP Pilot Project

Presentation to Model-Centric Engineering Symposium & Workshop

January 24, 2012

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Note: The SMAP mission has not been formally approved by NASA. The decision to proceed with the mission will not occur until the completion of the National Environmental Policy Act (NEPA) process. Material in this document related to SMAP is for information purposes.

Agenda

- Objectives & Approach
- Flight System Behavior
- Electrical Systems Engineering
- Verification & Validation
- Conclusion & Discussion

Objectives of MBSE Pilot

- ***Customer-focused objective:*** **Provide value to a flight project using MBSE methodology and products**
- ***Institution-focused objective:*** **Advance and improve our systems engineering practices, leveraging MBSE where applicable**
  - Streamline our interfaces across JPL Divisions, to provide better cross-organization products
  - Streamline our interfaces across lifecycle phase boundaries
  - Update our SE practices to make them more competitive and able to handle systems of ever-increasing complexity

Approach/Scope of Work

- **Initial focus on 3 high-payoff cross-divisional challenges:**
  - Flight System Behavior Specification
  - Electrical System Modeling & Process Integration
  - System Verification and Validation

- **Flight system modeling as necessary to support these 2 areas**

- **1st Q FY12 is focused on conceiving and building the system model sufficient to support both main focus areas**

- **2nd Q FY12 is focused on developing additional detail in the model, identifying key modeling patterns, and addressing representational issues identified in prior work**

Flight System Behavior

Kenny Donahue, Alex Kadesch, Ethan Post, Mitch Ingham, John Day

Outline – Flight System Behavior

- Objective and Approach
- Current Status & Accomplishments
- Model Walkthrough (Snapshots from System Model)
- Auto-generated Functional Design Description (FDD) Product
- Observations & Lessons Learned

Flight System Behavior

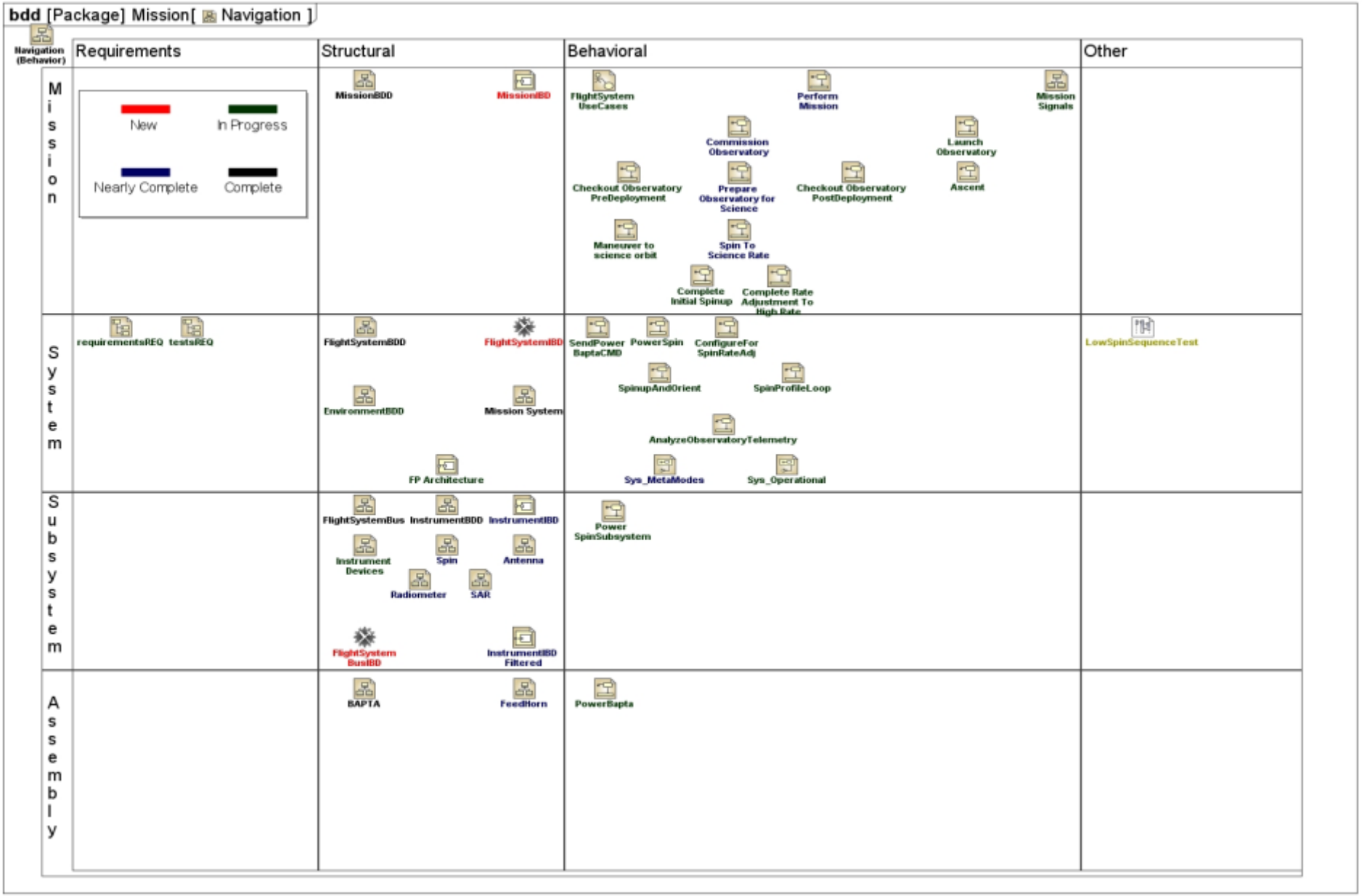
- **Objective: Better products and process, to enable more seamless organizational and lifecycle handoffs, leveraging MBSE-based system behavior specification**
  - Focus on improving L3 FS Behavior products, including the interface between FSE and Avionics/FSW
    - e.g.: FDDs, ICDs, Requirements
    - Engage with Division 34, in particular Section 349
  - Where possible, address lifecycle phase "handoffs", e.g.:
    - Requirements to design
    - Implementation to V&V
    - Delivery to operations

- **Approach: Focus on specifying system behaviors for critical activity - Antenna Spinning**
  - Use standardized representations where appropriate
    - e.g.: SysML Activity Models, Sequence Diagrams, State Charts
  - Address both nominal and off-nominal behavior
  - Tie back to Flight System elements in System Model
  - Tie into existing model-based SMAP FSW design artifacts, where appropriate
  - Investigate auto-generation of SE artifacts from System Model (e.g., FDDs, ICDs, activity plans, ops handbook, EVRs)

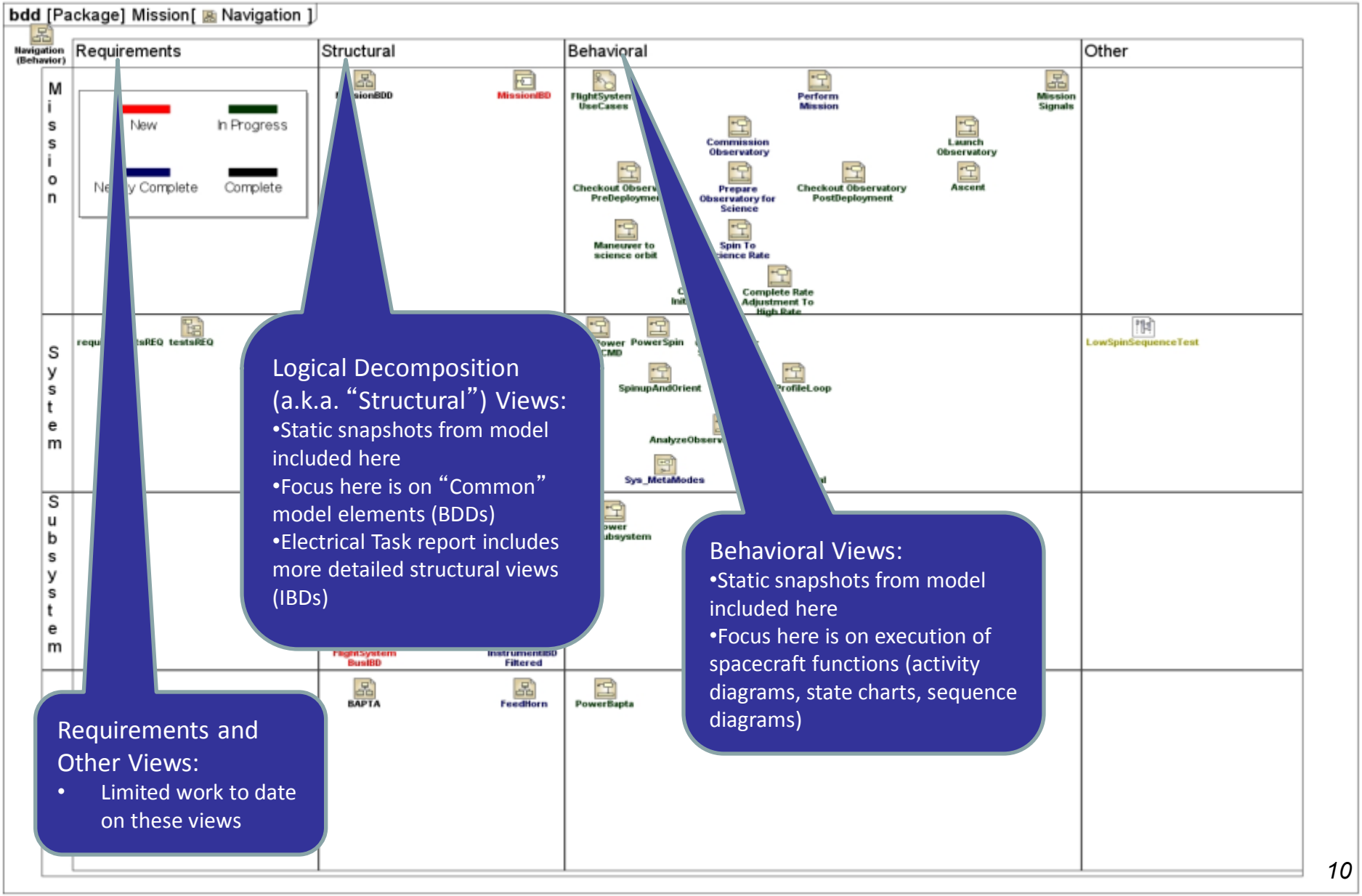
Current Status & Accomplishments

- **Developed initial SMAP System Model, elaborated with focus on Antenna Spinning Behavior, with functional behaviors allocated to appropriate FS elements.**
- **In collaboration with Elec Sys Modeling Team, worked out strategy for integration of Behavior and Electrical System Modeling tasks into common system model with appropriate inter-linkages.**
- **Made significant progress on Antenna Spinning Behavior description:**
  - Single consistent model developed from 4 FDDs and 5+ other documentation sources; worked out inconsistencies between these multiple sources.
  - End product will be less ambiguous and more complete than description in FDD.
- **Developed capability to auto-generate FDD documentation from System Model, and produced initial draft document.**
- **Started defining the off-nominal behavior representations.**

System Model Content



System Model Content



Logical Decomposition (a.k.a. "Structural") Views:
- Static snapshots from model included here
- Focus here is on "Common" model elements (BDDs)
- Electrical Task report includes more detailed structural views (IBDs)

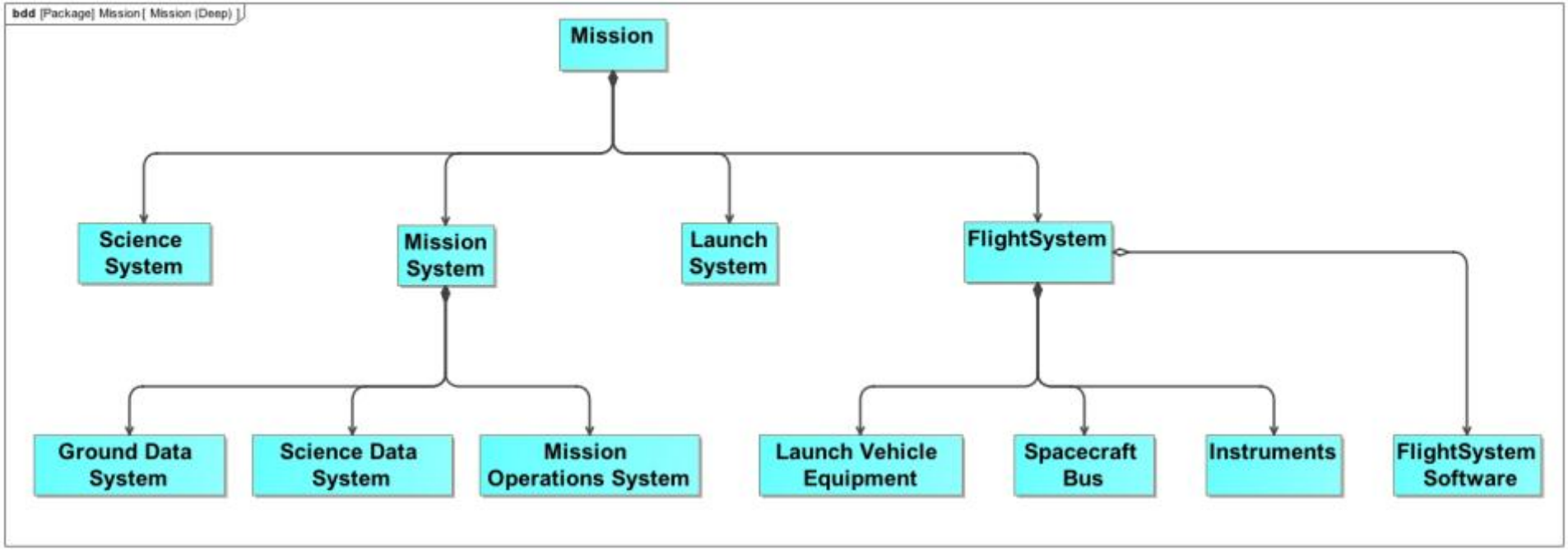
Behavioral Views:
- Static snapshots from model included here
- Focus here is on execution of spacecraft functions (activity diagrams, state charts, sequence diagrams)

Requirements and Other Views:
- Limited work to date on these views

System Model Walkthrough: Structural Views

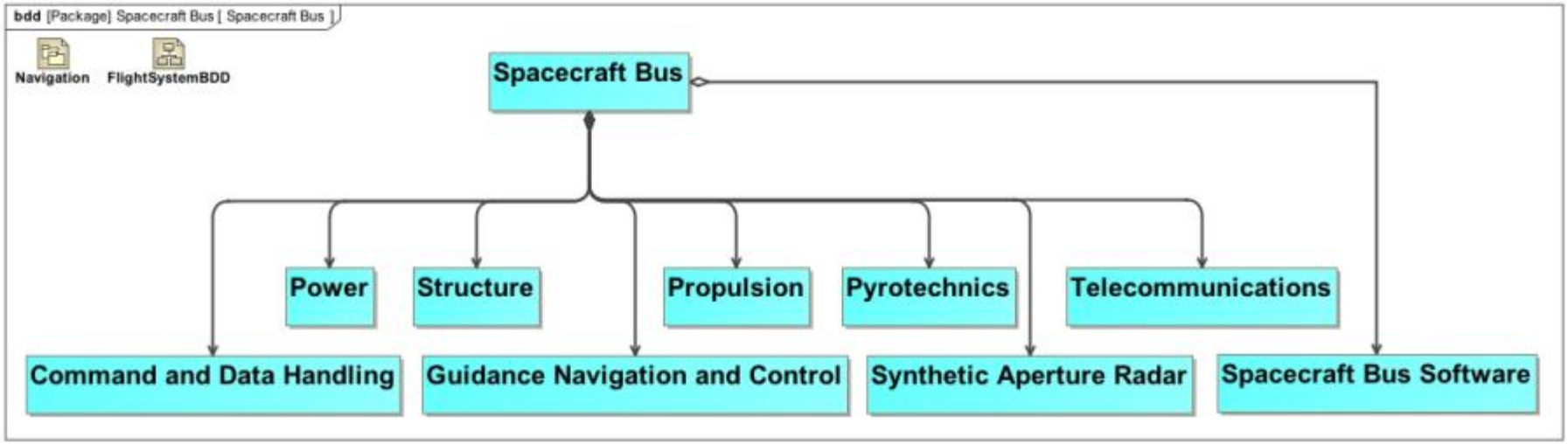
Mission Structure

- Top level of our structure decomposed down to the “system level”



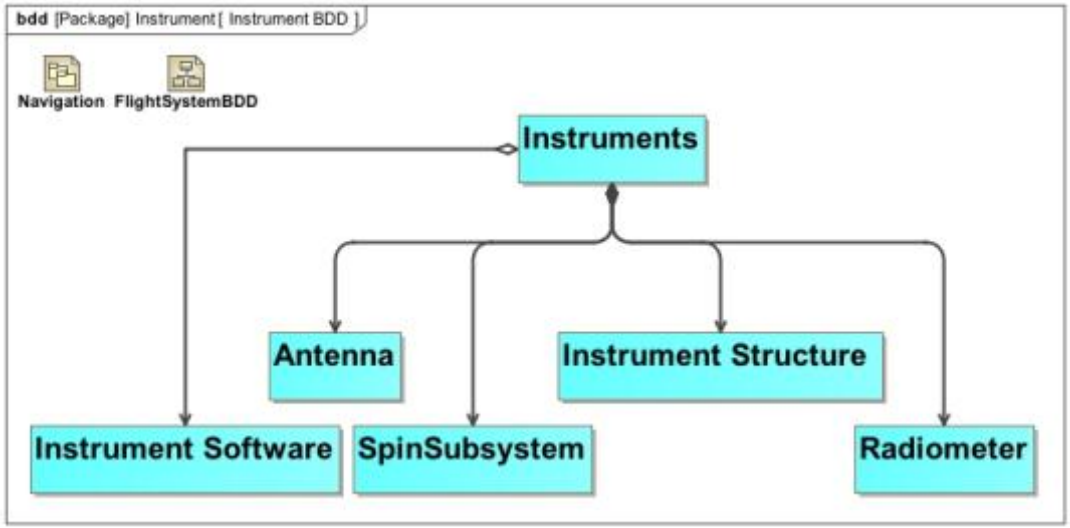
Spacecraft Bus Structure

- The Spacecraft Bus has a “black diamond” compositional relationship to the subsystems and a “white diamond” shared relationship to its software



Instrument Structure

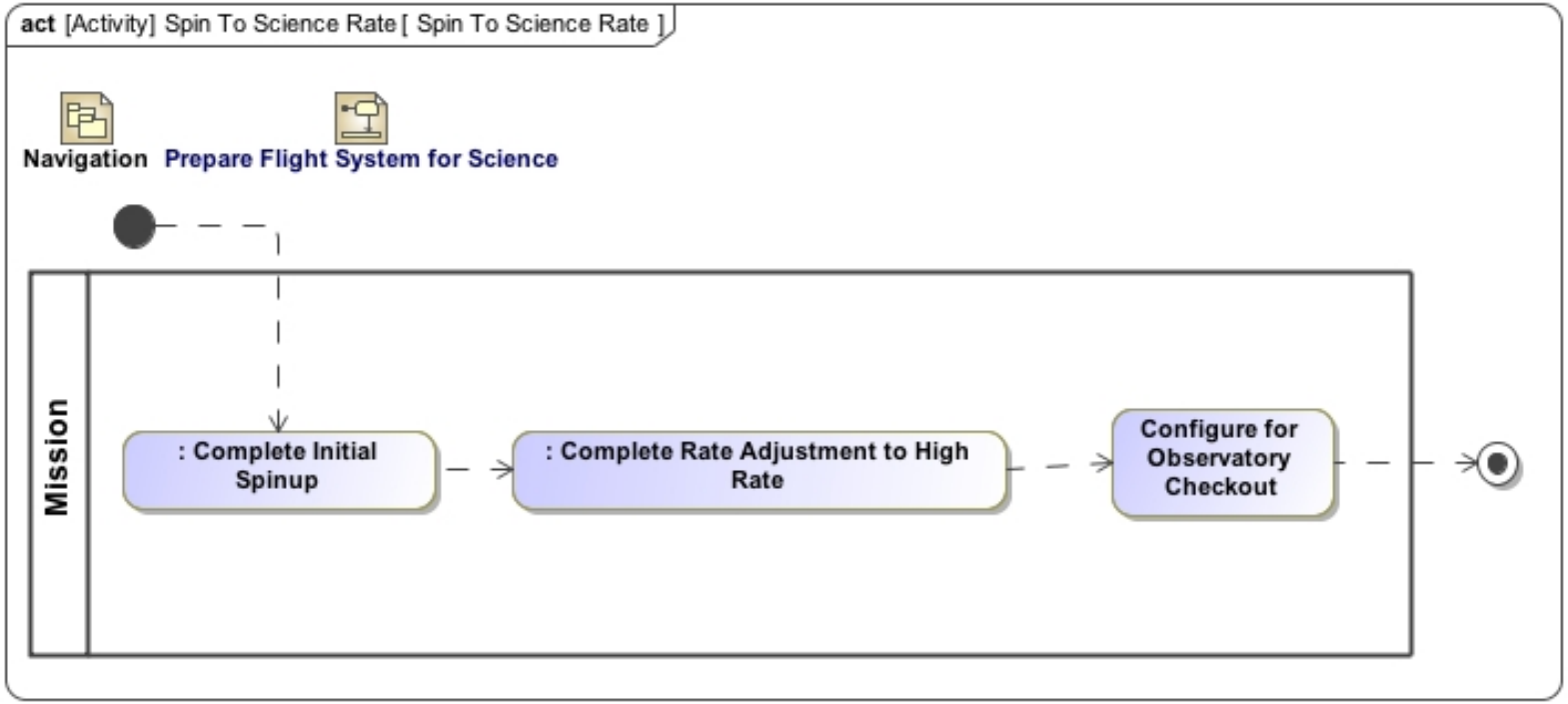
- Instruments have a shared relationship to software. This is the pattern we are using throughout the model
- All of the “black-diamond” children of Instrument physically live on the Instrument



System Model Walkthrough: Behavioral Views

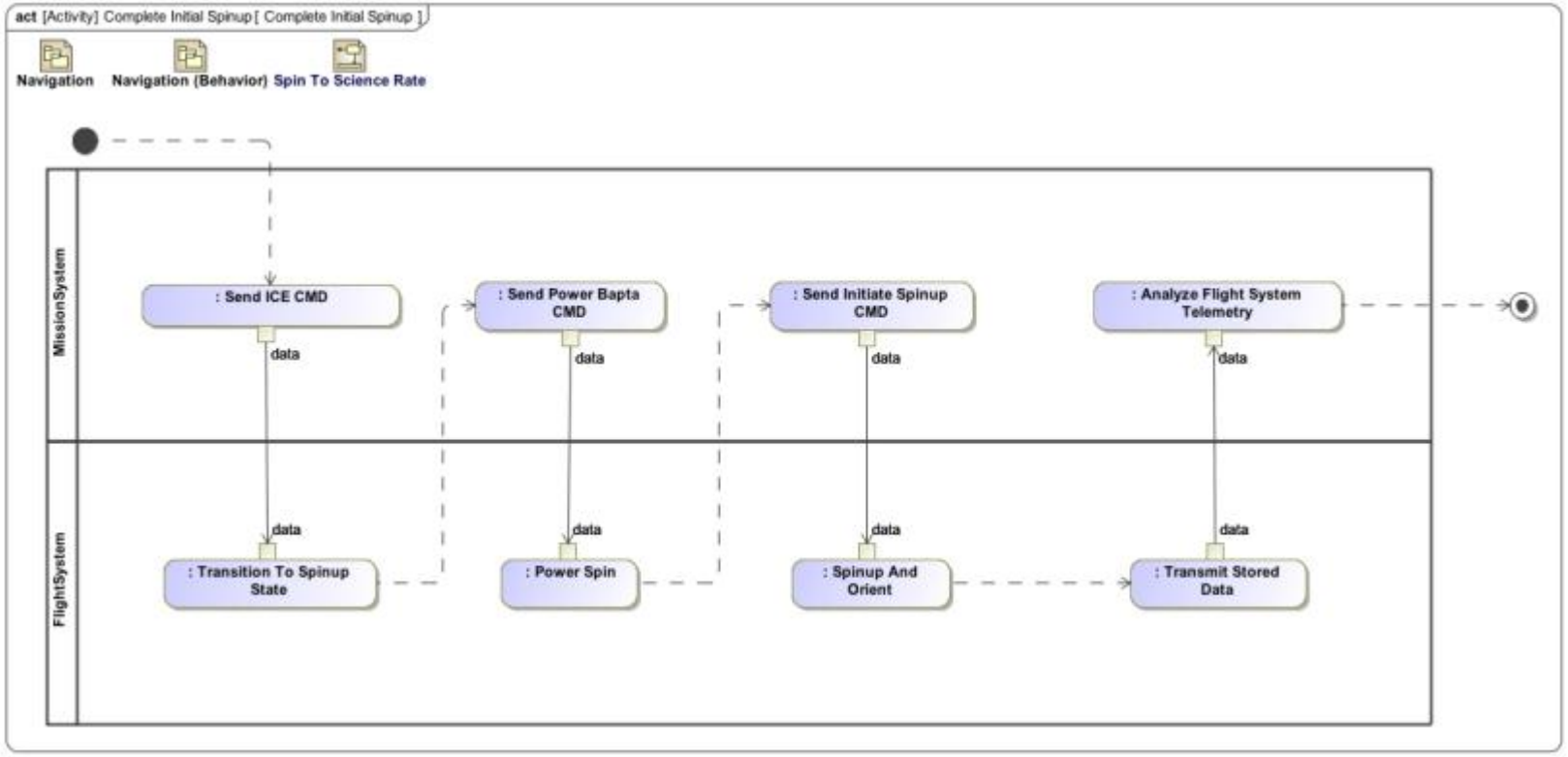
‘Spin To Science Rate’ Activity

- Complete Initial Spin-up and Complete Rate Adjustment to High Rate are decomposed further



‘Complete Initial Spin-up’ Activity

- Sequence of activities between the Flight System and the Mission System also representing the data sent between the two.



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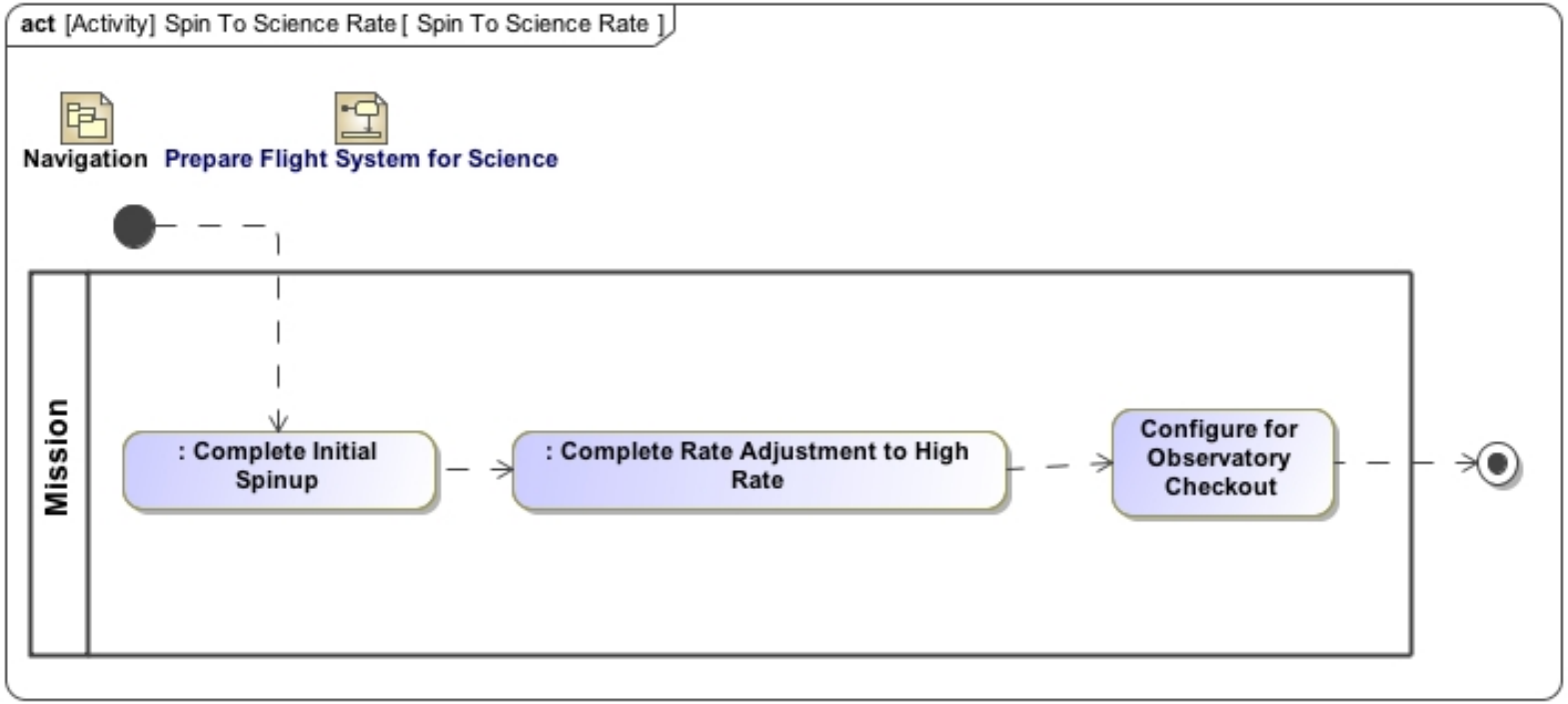
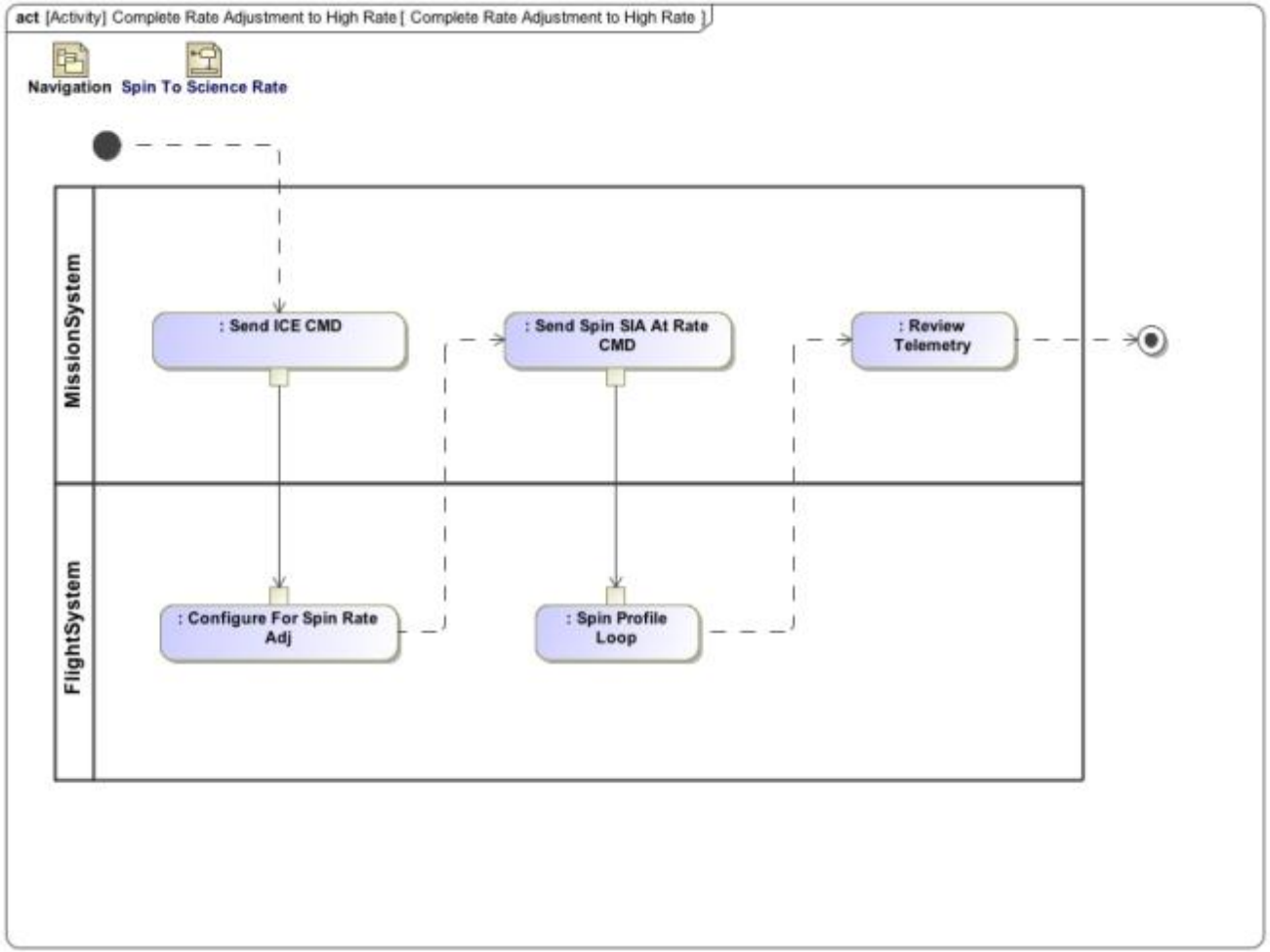
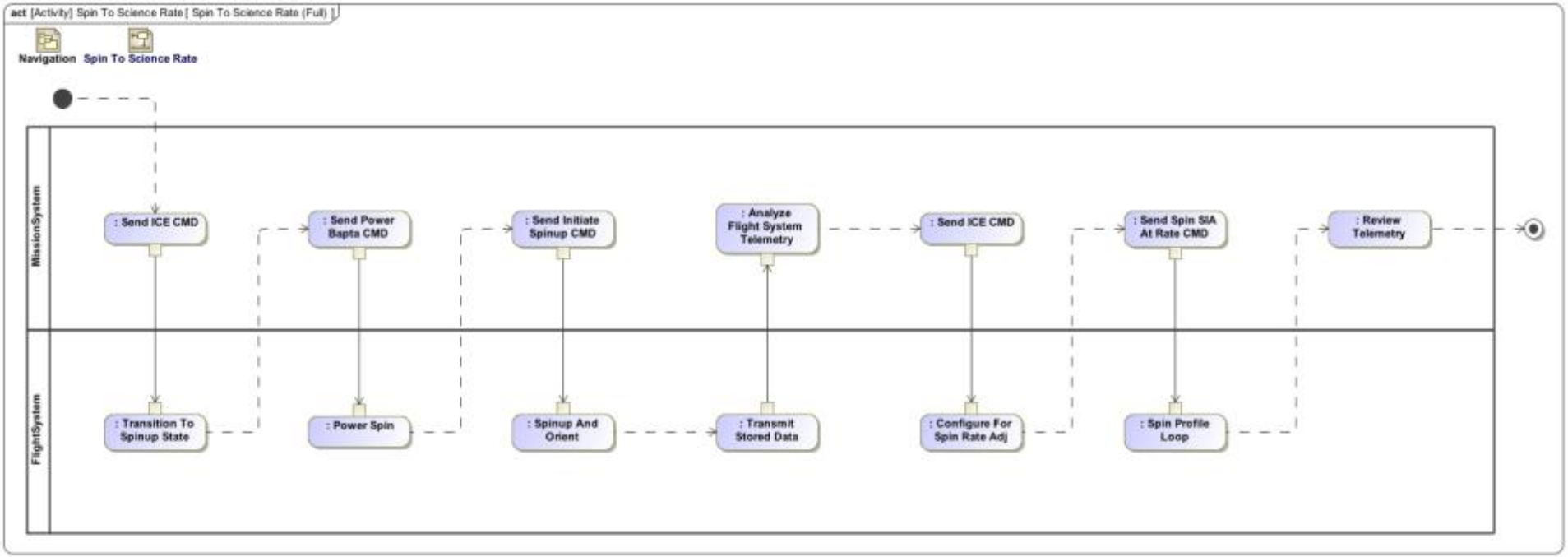


‘Complete Rate Adjustment to High Rate’ Activity



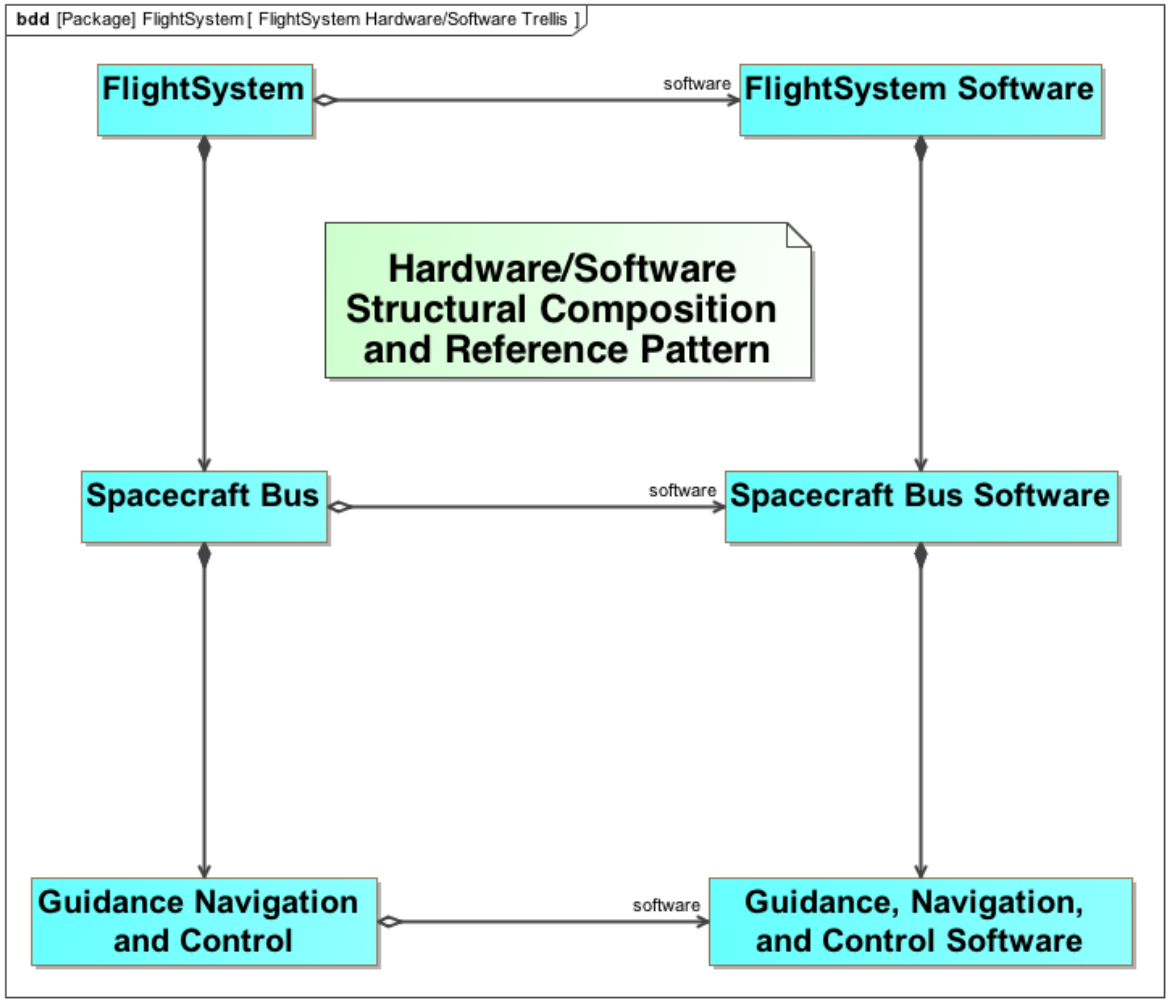
Spin to Science Rate: "Stitched View"

- Different view in which "Complete Initial Spin-up" and "Complete Rate Adjustment to High Rate" are merged into one diagram
- We are looking into automating this process

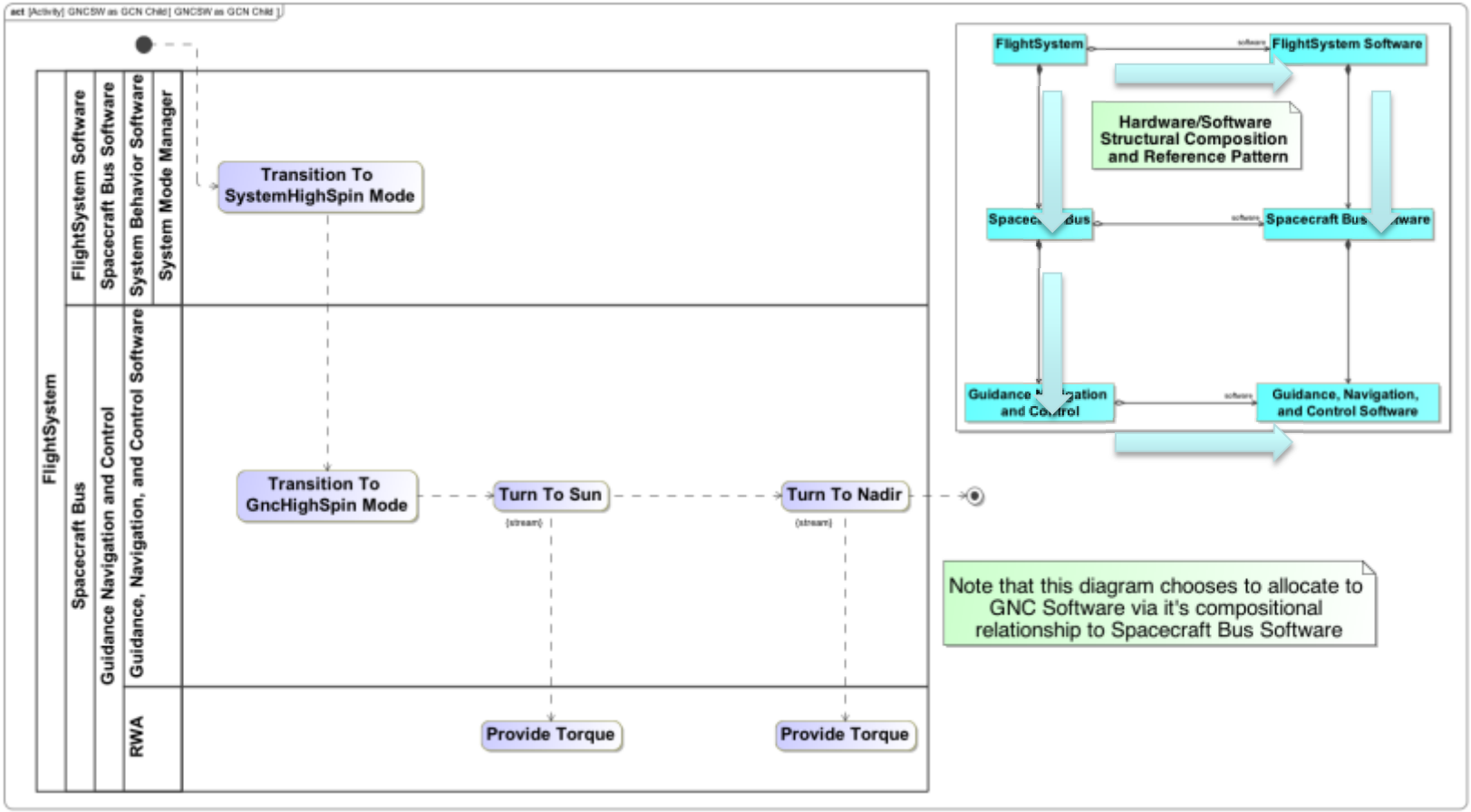


Behavioral Allocation to Software Elements

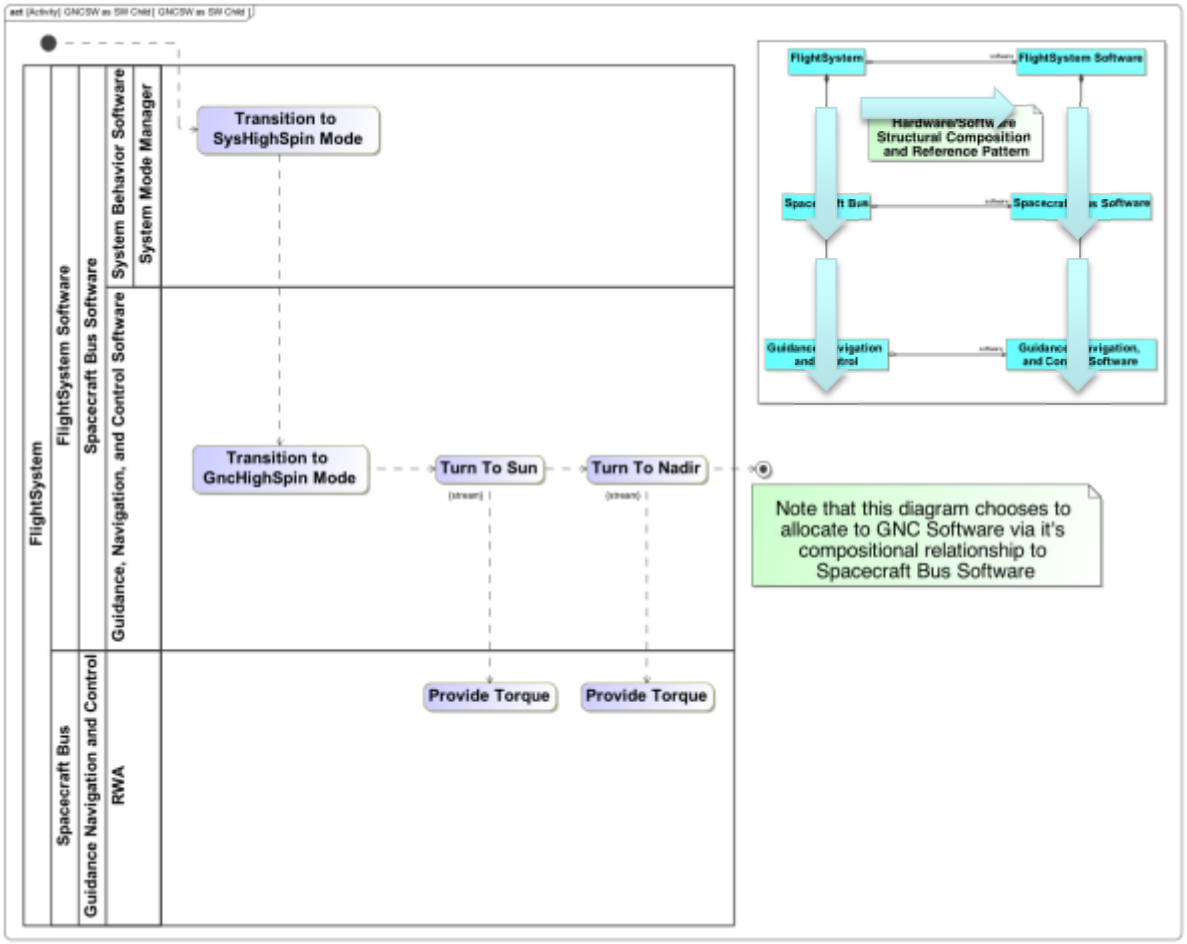
Relating Hardware and Software



Allocating Behaviors to Software: Option 1



Allocating Behaviors to Software: Option 2



Auto-Generated FDD Draft

Auto-generated Functional Design Description Document (Draft)

- **Developed DocGen "model" of FDD document**
  - Uses queries to get information from System Model and embed in FDD.
  - DocGen Plugin for MD allows for fast compilation to DocBook standard representation, which is easily translated to PDF or HTML.
  - DocGen allows us to generate the most up-to-date version of the document with a few button clicks.
  - Model can have multiple DocGen document models all which refer to the same source material, meaning that there is no need to maintain numerous disparate sources.

Observations & Lessons Learned

- Multiple ways of capturing design in a model; must work through different options to determine effective patterns
- System model provides single, unified source of information and reduces risk of inconsistency/divergence
- Source material contained a few inconsistencies; needed to make assumptions or go back to project to resolve
- Capturing off-nominal behavior not trivial; still working on effective patterns to apply
- Both teams working on common system model encourages early agreement on terminology and structural decomposition
- Can split responsibility among different teams and team members in different ways: e.g., by diagram type; common interest vs. individual interest

Electrical Systems Engineering

Alex Jimenez, Mark McKelvin, Jose Gomez-Mustafa, Scott Sneddon

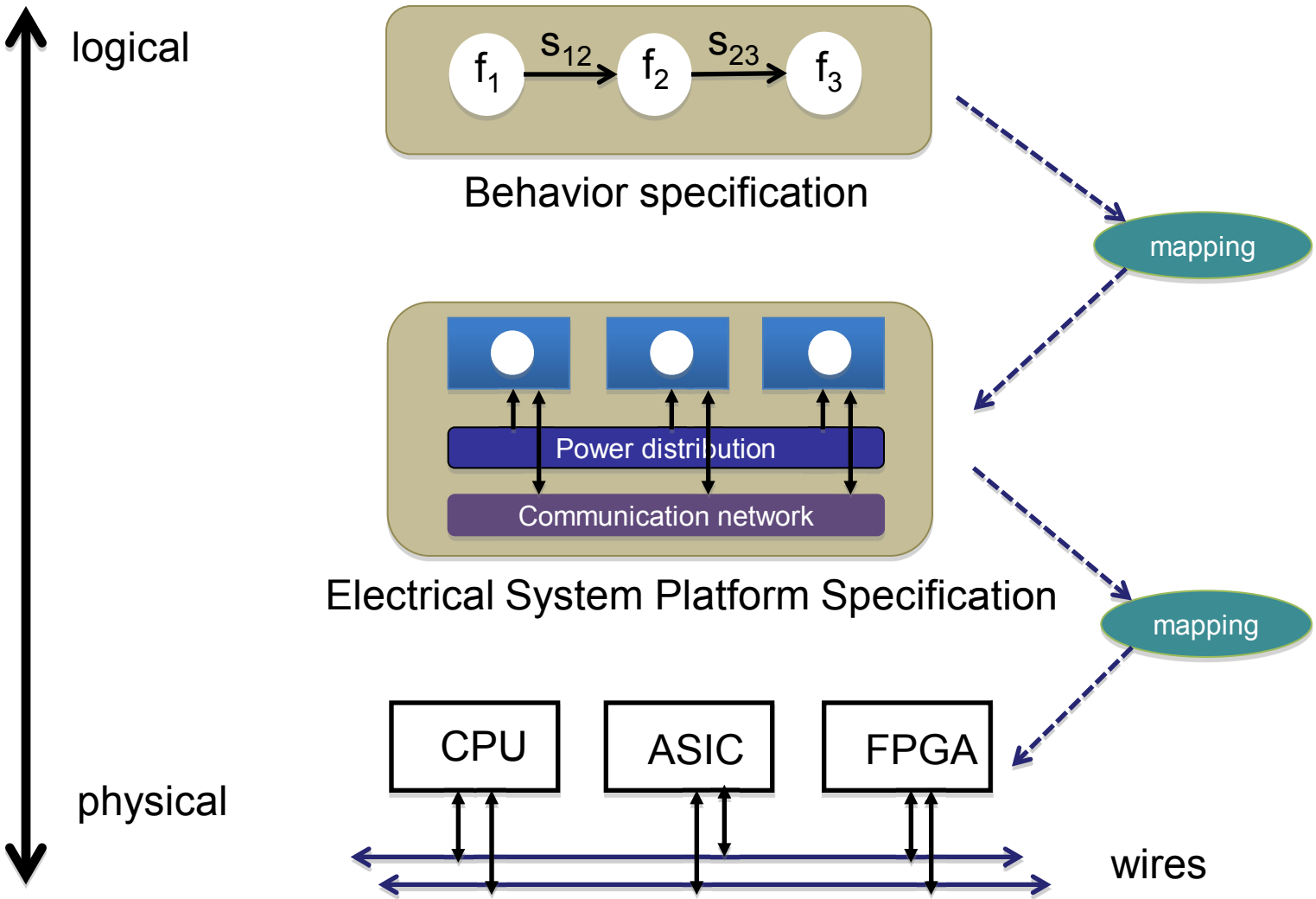
Outline – Electrical Systems Engineering

- **Objectives**
- **Conceptual System Architecture Design Flow**
- **SysML Electrical Model Development**
  - ❑ Electrical Flight Systems Engineering Ontology and Metamodel development.
  - ❑ Flight System Electrical Block Diagram views
- **Conclusion**
  - ❑ Accomplishments, Observations, and Future Plans

Objectives

- Define a set of concepts and their relations to describe electrical system interfaces and requirements: Electrical Flight System Engineering Ontology
- Develop a model based approach for the specification of electrical system interfaces
- Develop SMAP Flight System Electrical block diagrams within SysML

Conceptual System Architecture Design Flow

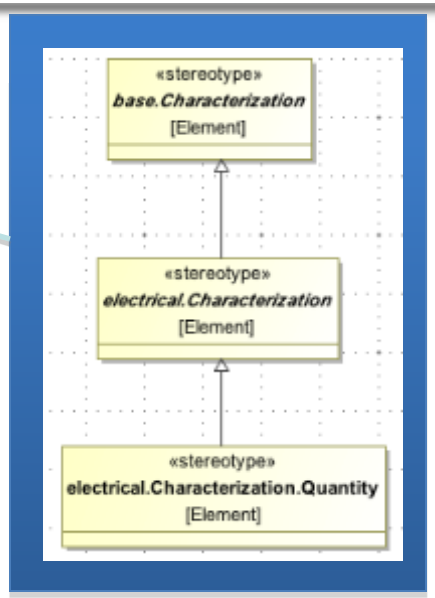


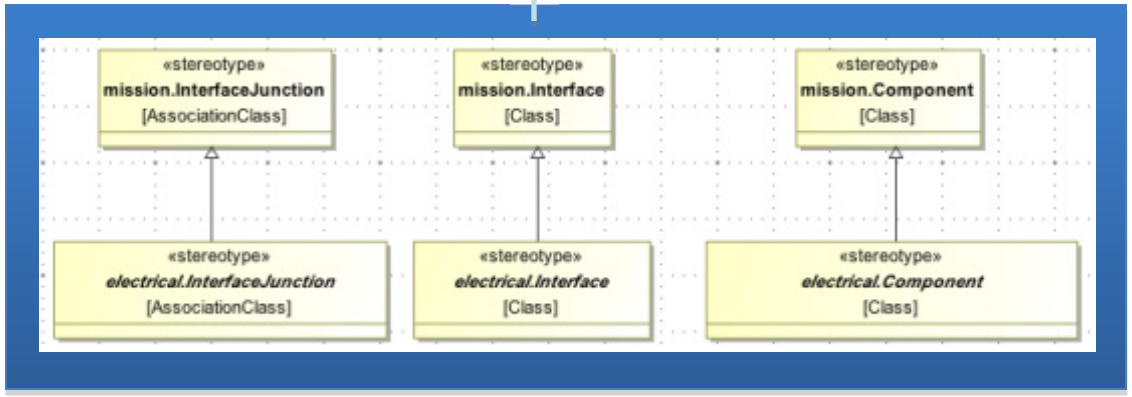
Electrical Flight Systems Engineering Ontology and Metamodel Development

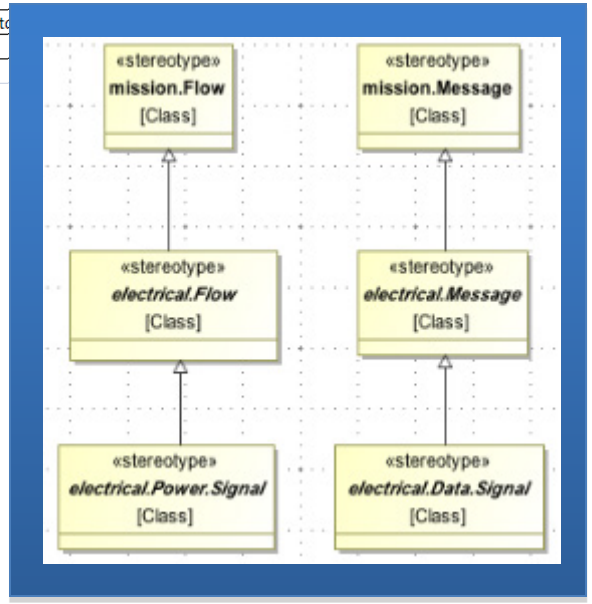
Electrical System Engineering Ontology Inputs 4/25/2011

Subsystem Number	Subsystem Name	Subsystem Accronym	Assembly	Properties	Values
2004	Power Subsystem	PWR	Power Switch Slice	Assembly Reference Designator	PSS-1
				Mass	0.5 kg
				Power Dissipation	2mW
				Bonding Requirement	2.5 mOhms
				Bonding Measurement	2.1 mOhms
				End Circuit Properties	
				Input Voltage	28V
				Output Voltage	5V
				Input Impedance	25 mOhms
				Output Impedance	
				Input Current	
				Operating Current	
				End Circuit Noise Category	POWER
				Noise Frequency	3 MHz
				E-C Connector(s)	2004PSS-1J2
				Signal names	CLOCK +, CLOCK -
				PInouts	1, 5
				Connector Properties	
				Connector Reference Designator	2004PSS-1J1, J2, J3 etc
				Connector Part Number	

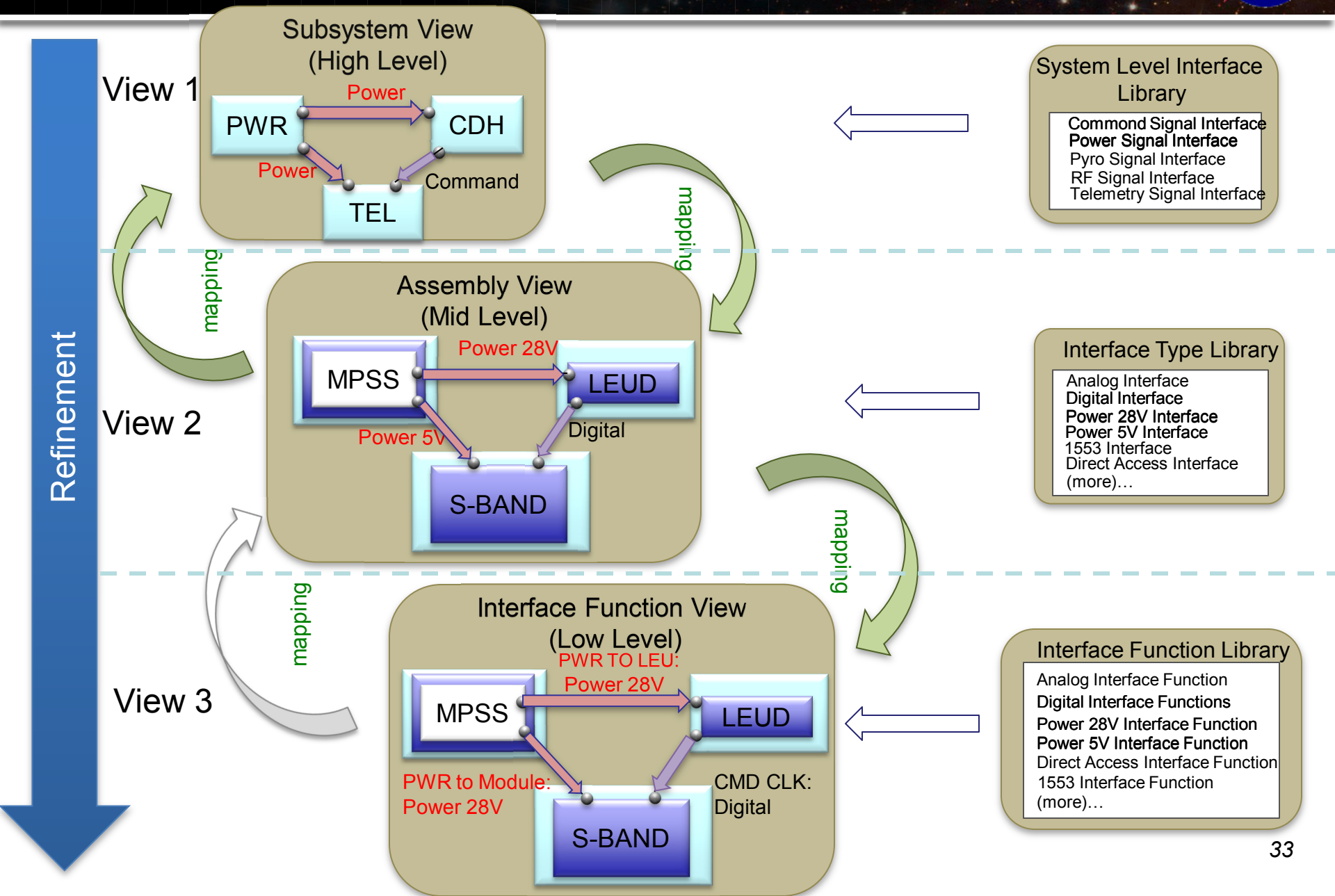
LEVEL 1 Block Diagram Electrical Interface FUNCTION TYPES	LEVEL 2 Block Diagram Electrical Interface FUNCTION TYPES
Power, Commands, Telemetry	Direct Access I/F
Power, Commands, Telemetry	Umbilical I/F
Commands, Telemetry	Analog I/F
Commands, Telemetry	Digital I/F
Commands, Telemetry	1553 I/F
Commands, Telemetry	RS422 I/F
Commands, Telemetry	Spacewire I/F
Commands, Telemetry	Serial I/F
Power	Power 28V I/F
Power	Power Low V I/F
Power	Power High V I/F
Pyro	Pyro I/F
RF	RF I/F
Power, Commands, Telemetry	Internal I/F
Commands, Telemetry	Discreet I/F







Flight System Electrical Block Diagrams Views



Conclusions

- **Accomplishments Summary:**
  1. Ontology is implemented as a meta model for the specification of electrical system interfaces
  2. Created a library of reusable model elements that are used to create model instances
  3. Created model instances of the SMAP Flight System Electrical Architecture at different levels of interface abstractions.

- **Observations :**
  1. Existing artifacts may be created and maintained using our model based approach to the specification of electrical system interfaces
  2. Consistent use of domain specific terminology should be defined and agreed upon by domain area experts
  3. Definition of multi-user collaboration processes are critical to the multi-disciplinary modeling task; going forward we can build upon IMCE collaboration guidelines

- **Next Steps for Q1:**
  1. Complete View 1, 2, 3 diagrams.
  2. Generate electrical interface function list.
  3. Model electrical system requirements.
  4. Modeling Electrical V&V: Document electrical integration procedure requirements.

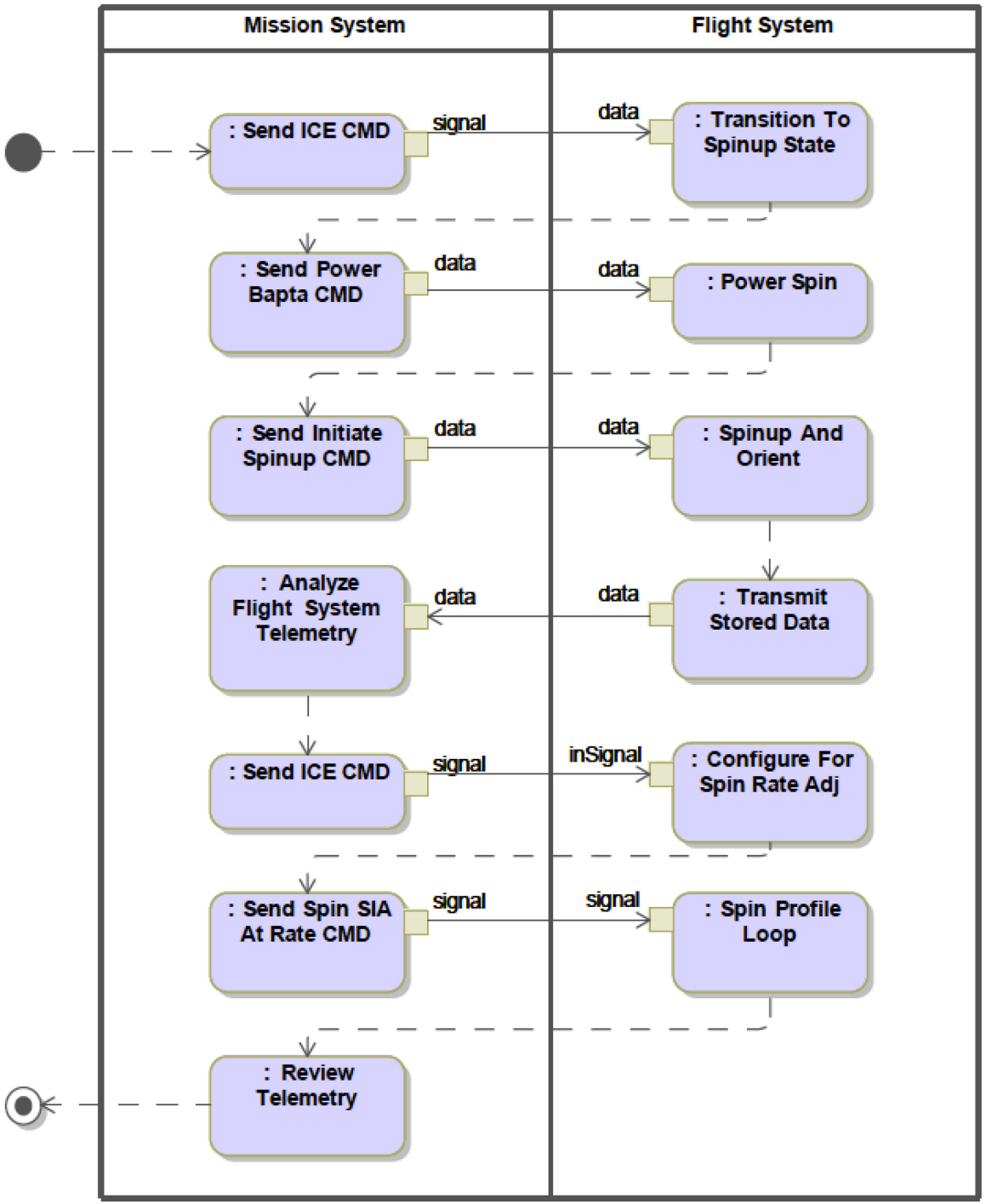
Verification and Validation

Omair Khan, Shaun Standley

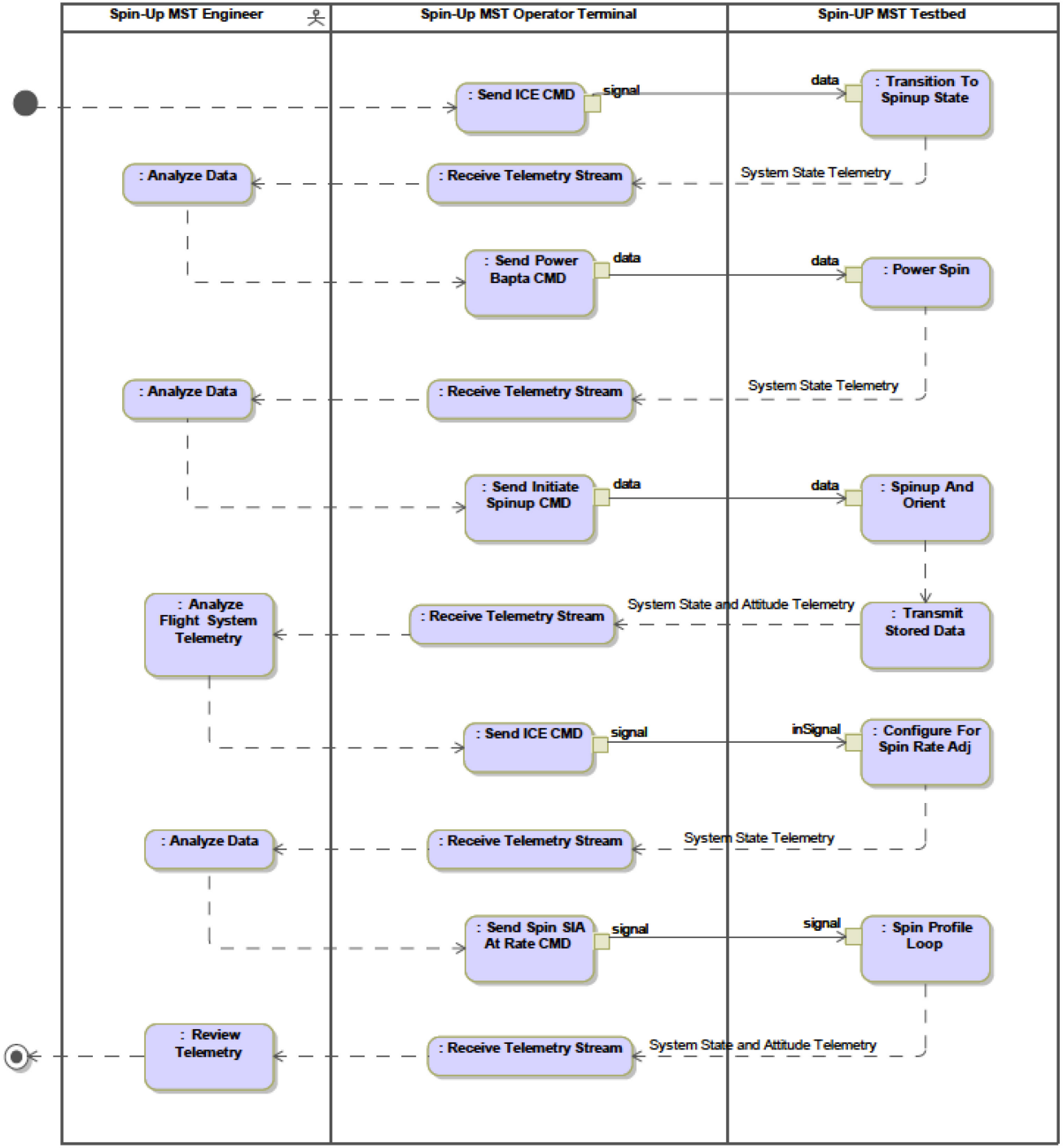
Model Based V&V Scope

- **The Model based V&V [MBV&V] aspect of the SMAP MBSE Pilot Program seeks to accomplish the following:**
  - Demonstrate and define best practices for how System V&V tests can be distilled from a mission model
  - Establish a MBV&V package of items (e.g. ground support equipment and test behavior catalog, diagram templates, etc.) that can be used in any model for V&V planning
  - Demonstrate how requirements and test-as-you-fly exceptions can be tracked in a model

- **The key goal in researching MBV&V in this project is to establish a consistent set of guidelines and modeling tools that will allow future projects to efficiently and coherently capture V&V related material**

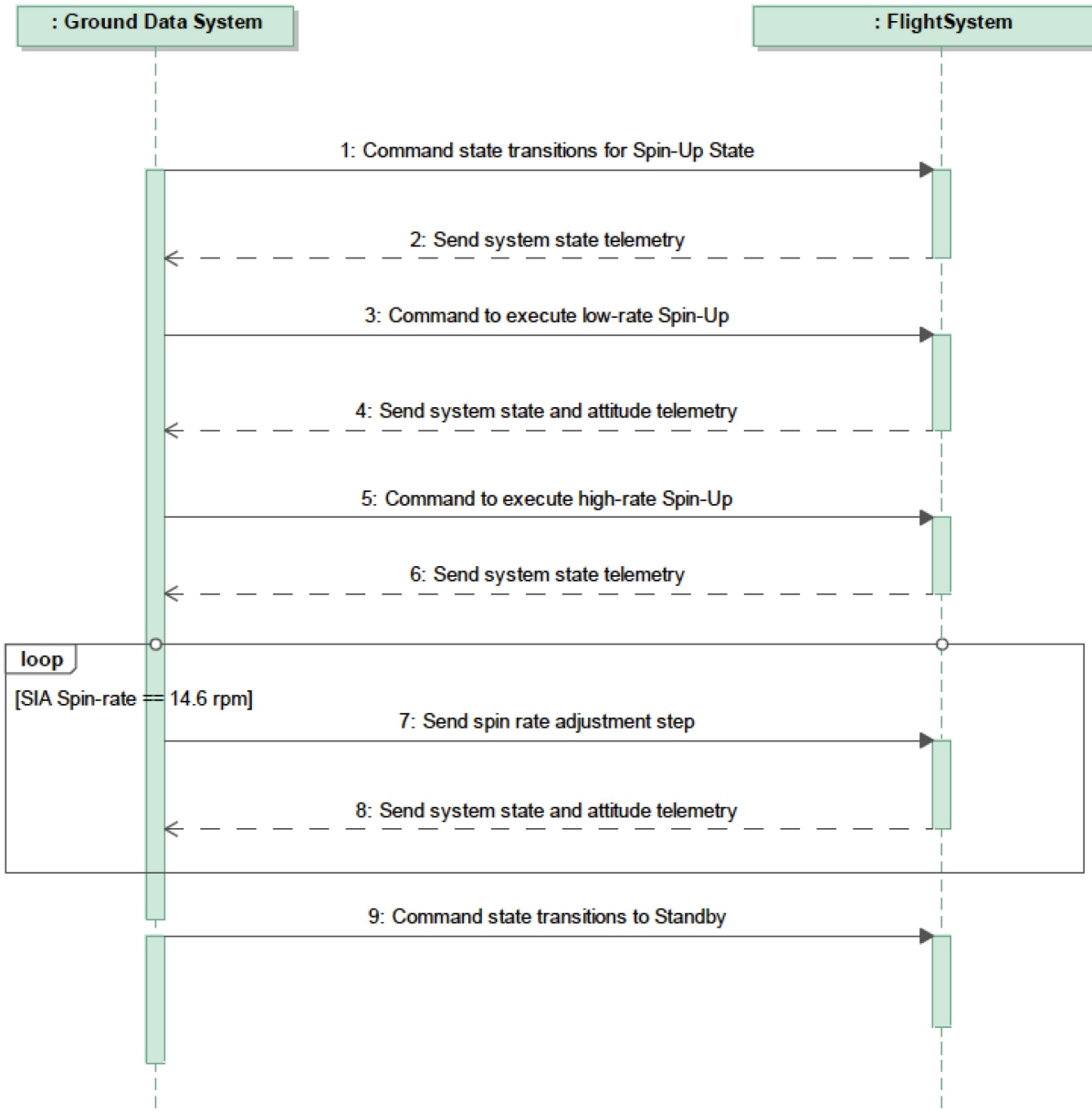


- ***By establishing a system model, the V&V quickly becomes apparent.***
- To the left is a level 2 behavior diagram of the nominal SMAP spin-up behavior (e.g. only flight components/systems are considered here)
- From this view, we can see all the scenario-relevant interactions and interfaces that will need to be verified by a V&V test.



- ***The nominal level 2 behavior diagram has been transformed to a test procedure diagram***

- Mission System activities have been replaced by the V&V engineer and the operator terminal, while the flight system has been replaced by a testbed.



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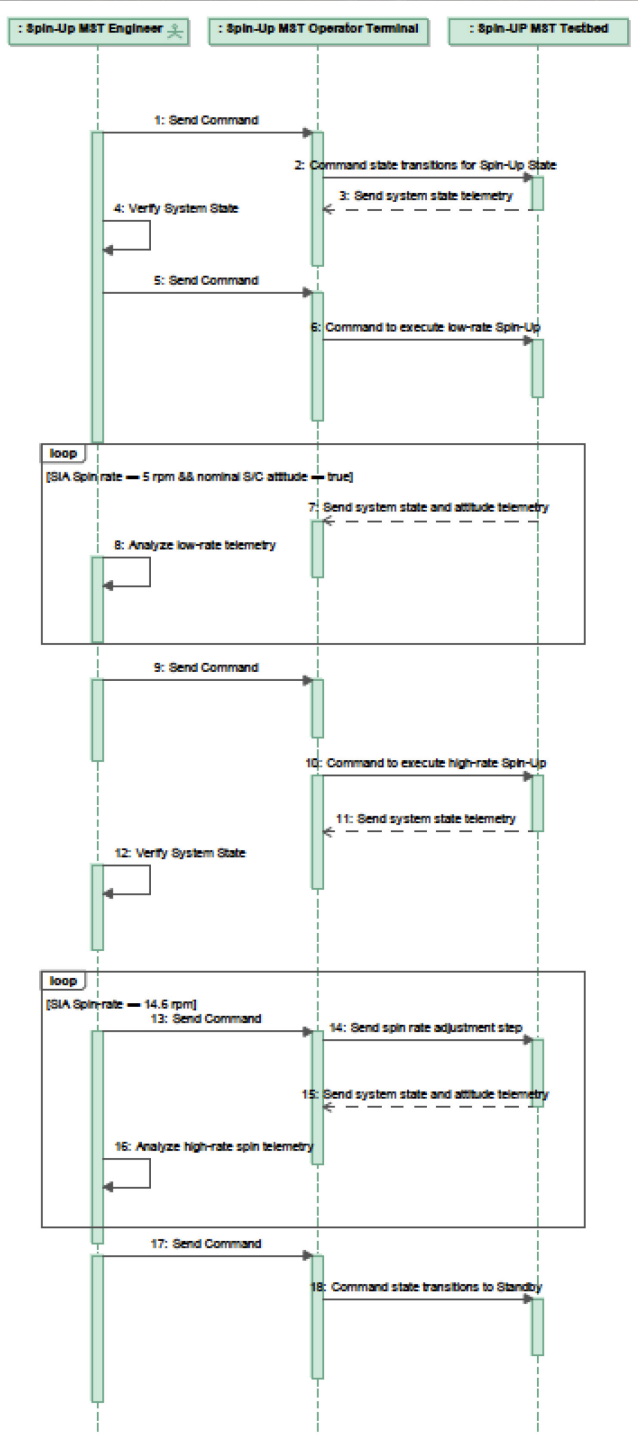

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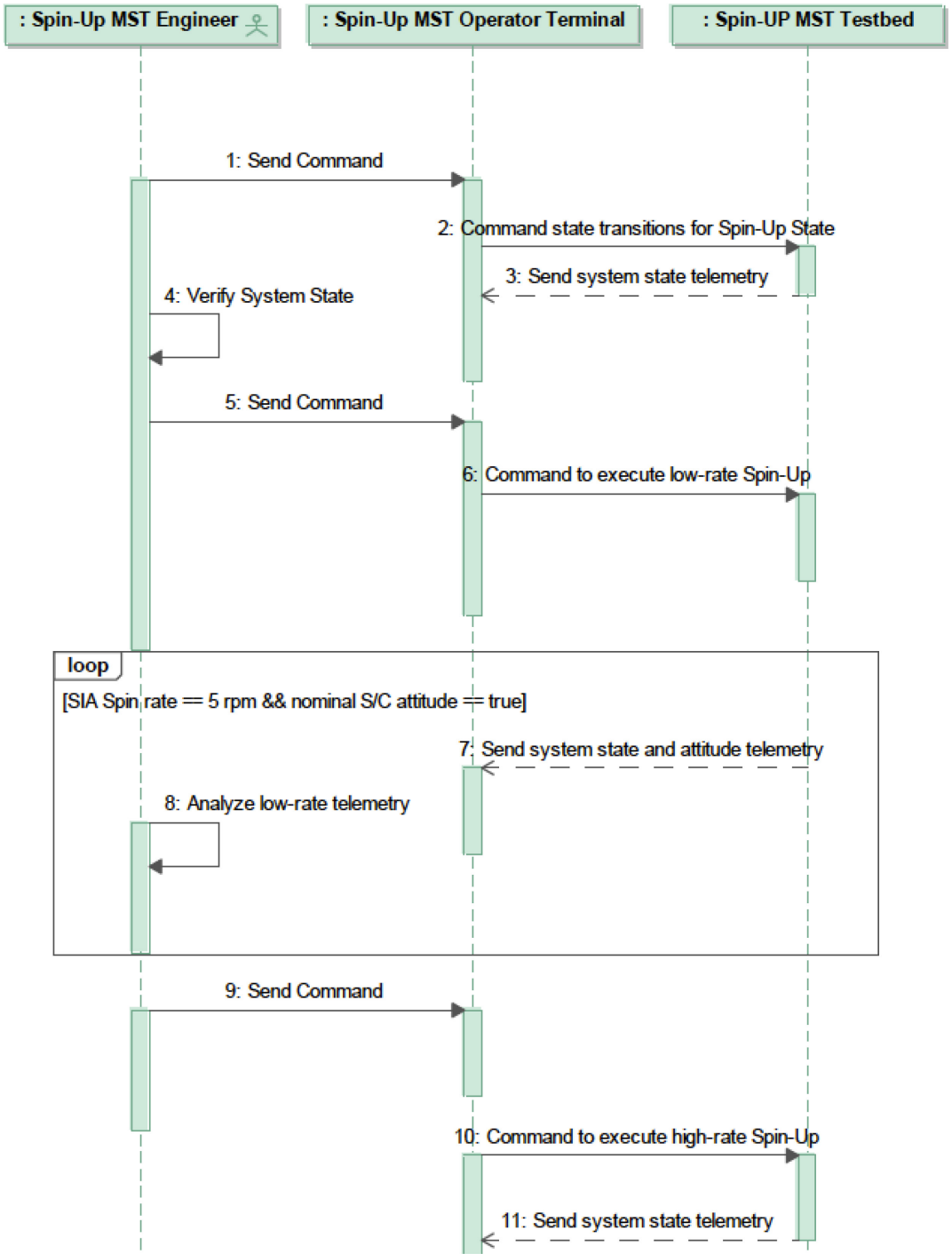


- Zoomed in view of test procedure diagram

Optical
- Optical Hardware
- Optical Measurement Tools
- Variable In-Line Fiber Optic Attenuator
- Optical Cable
- Optical GSE_Content

Software
- **Simulator**
- **Software GSE_Content**

General Equipment
- **Measuring Tape**
- **Laser-Based Measuring Device**
- **Rotary Stage**
- **Workstation Equipment**
- **Test Rack**
- **Test Bench**
- **General Equipment_Content**

Informational/Logical
- **PRBS-15**
- **Informational/Logical_Content**

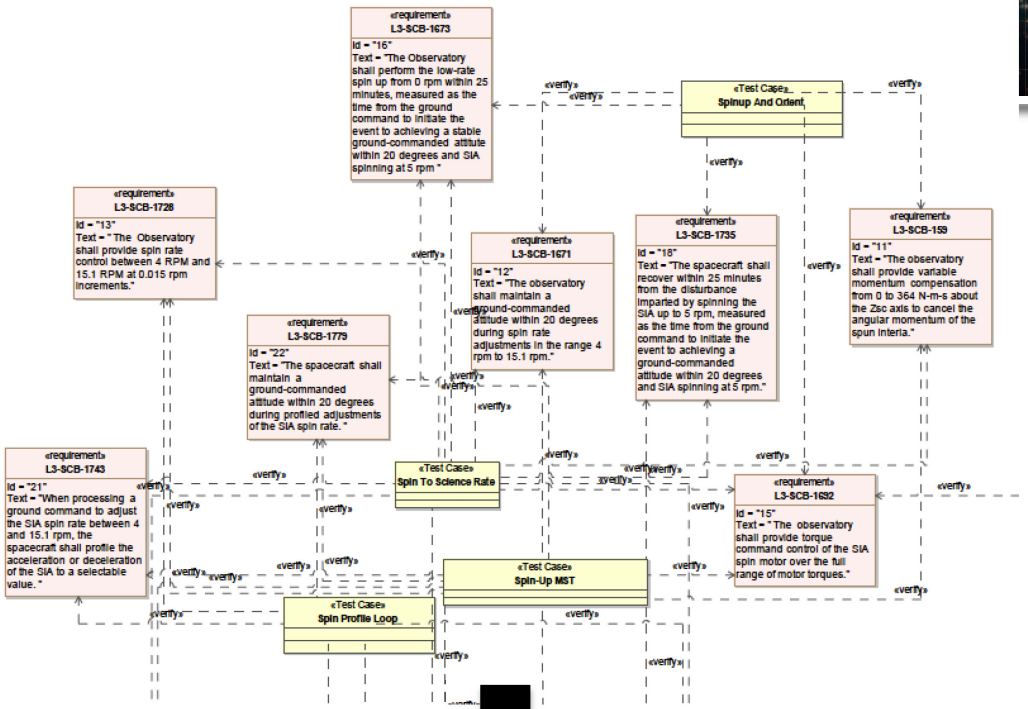
Facilities
- **Facility**
- **Facilities_Content**

Mechanical
- Ceiling Crane
- Passive FRAM Adapter Plate
- Adapter Plate
- ExPA Fit Check Plate FRAM Adapter
- Vibe Table Adapter Plate
- Dolly
- Low Profile Dolly
- Shipping Container
- Lifting Device
- Floor Crane
- Spreader Bar
- Forklift
- Mechanical Ground Support Equipment
- Scissor Lift
- TVac PFRAM Adapter Plate
- Industrial Scale
- MGSE Collection

Electrical
- Electrical Cables
- Digital Acquisition
- Breakout Box
- Load Box
- 1553 Simulator
- Digital I/O
- Connector Saver
- Function Generator
- Surge Protector
- Router
- Ethernet Switch
- Power Supply
- Electrical Measurment Tools
- Electrical GSE_Content

- Among the V&V modeling resources being developed is a ***ground support equipment catalog***. This catalog can be used by multiple system models to facilitate capturing V&V test configurations and context.
- ***The folders shown above show the various catalog items that have been captured so far.***

- Other V&V modeling support resources being developed include:
  - Catalog of common test behavior to facilitate creating test procedure diagrams
  - V&V diagram templates



	11 L3-SCB-159	12 L3-SCB-1671	16 L3-SCB-1673	17 L3-SCB-1675	15 L3-SCB-1692	14 L3-SCB-1694	13 L3-SCB-1728	19 L3-SCB-1682	18 L3-SCB-1735	21 L3-SCB-1743	22 L3-SCB-1779	TAYFE 1RBA cann...
Spin To Science Rate(spe...	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	
Configure For Spin Rate A...					↗							
Spin Profile Loop(signal :...				↗		↗	↗	↗		↗	↗	
Spinup And Orient(data :...	↗	↗	↗		↗				↗			
Transmit Stored Data(da...				↗								
Spin-Up MST	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗

- ***Requirement verification can be traced to elements in the model. By querying the model for requirement summaries, it is possible to handle requirements in a more complete and less cumbersome manner.***
- To the top-left, we see a messy diagram that is used to track requirements (shown in pink) to its verifying mission behaviors (shown in yellow). To the bottom-left, we see a neat summary of the former diagram.
- Aside from requirements, various exceptional conditions, such as test-as-you-fly exceptions for V&V tests, can also be tracked.
- Requirements (and their verification conditions) can be exported to Excel and DOORS.

Conclusion & Discussion

Conclusion

- The team has made great progress in a few weeks.
- Already starting to make real-world observations regarding how and where to apply MBSE, and what kinds of problems it can solve.
- Constructing a single model for multiple SE purposes is proving to be practicable, and in fact, powerful.

BACKUP

Plan for FY12

	Behavior Spec & Analysis (Nominal/off-nominal)	Fault Protection Artifact Integration/Generation	Behavior Verif & Validation	Behavior Interface (L3 Sys -> L4 Avionics)
Q1	**Antenna Spin-up** •System model • Partial system model • Block Diag for key comp'ts •System behavior • Activity diagrams • Sub-activity behavior •FDD v1.0 Consulting: 342	• Define and include FP representations	• Derive test cases from model content Contributing: 314	
Q2	• Tie to existing requirements • Improved doc generation • FDD v2.0	• Success tree (ST), fault tree (FT), FMECA generation Contributing: 513 Consulting: 342	• Derive test cases from FP content Contributing: 314	
Q3	• Behavior specification process description • FDD v3.0	• Refinements to FP artifacts Contributing: 513 Consulting: 342	• Relationships betw model & V&V items • Document V&V plan Contributing: 314	
Q4	• Apply specification process to Thermal FDD Consulting: 354 • FDD v4.0	• FP Behavior specification methodology	• Refine V&V plan • Sys behavior V&V methodology Contributing: 314	• Develop example L3-L4 behavior flowdown (model, req'ts) • Interface behavior flowdown methodology Contributing: 342