INCOSE Model-Based Systems Engineering (MBSE) CubeSat Modeling Efforts

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International Council on Systems Engineering (INCOSE)
Space Systems Working Group (SSWG)

Agenda

- Project Objectives and Team
- INCOSE MBSE Initiative and Roadmap
- What is MBSE
- SSWG Challenge Project
- CubeSat Reference Model Development and Distribution
- CubeSat Reference Model Architecture
- Next Steps
- References

Project Objectives

Prove-out MBSE methodology on a CubeSat

Provide a CubeSat Reference Model
that CubeSat teams can use as a
starting point for their
mission specific CubeSat model

Team Composition

Aerospace Students and Professors

JPL and NASA Engineers

Engineers and Software Developers from NASA Centers, Aerospace Companies, and Modeling and Simulation Tool Providers

Telecons every Friday at 1pm east coast time

Meeting materials and links to meeting recordings in Google docs

Conference papers posted in INCOSE Space Systems Working Group Web Site

Email me to be included on the email reflector list:

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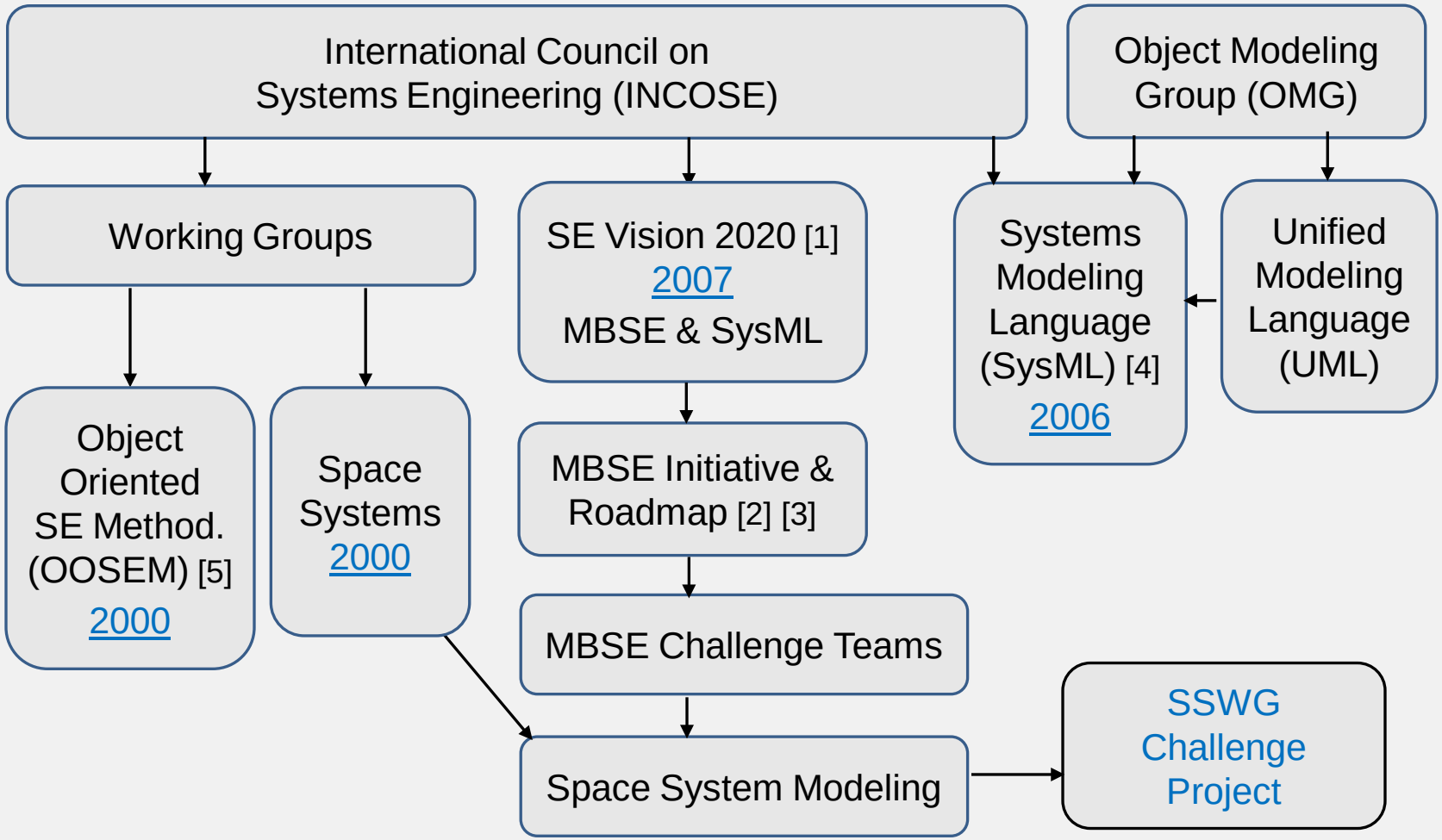
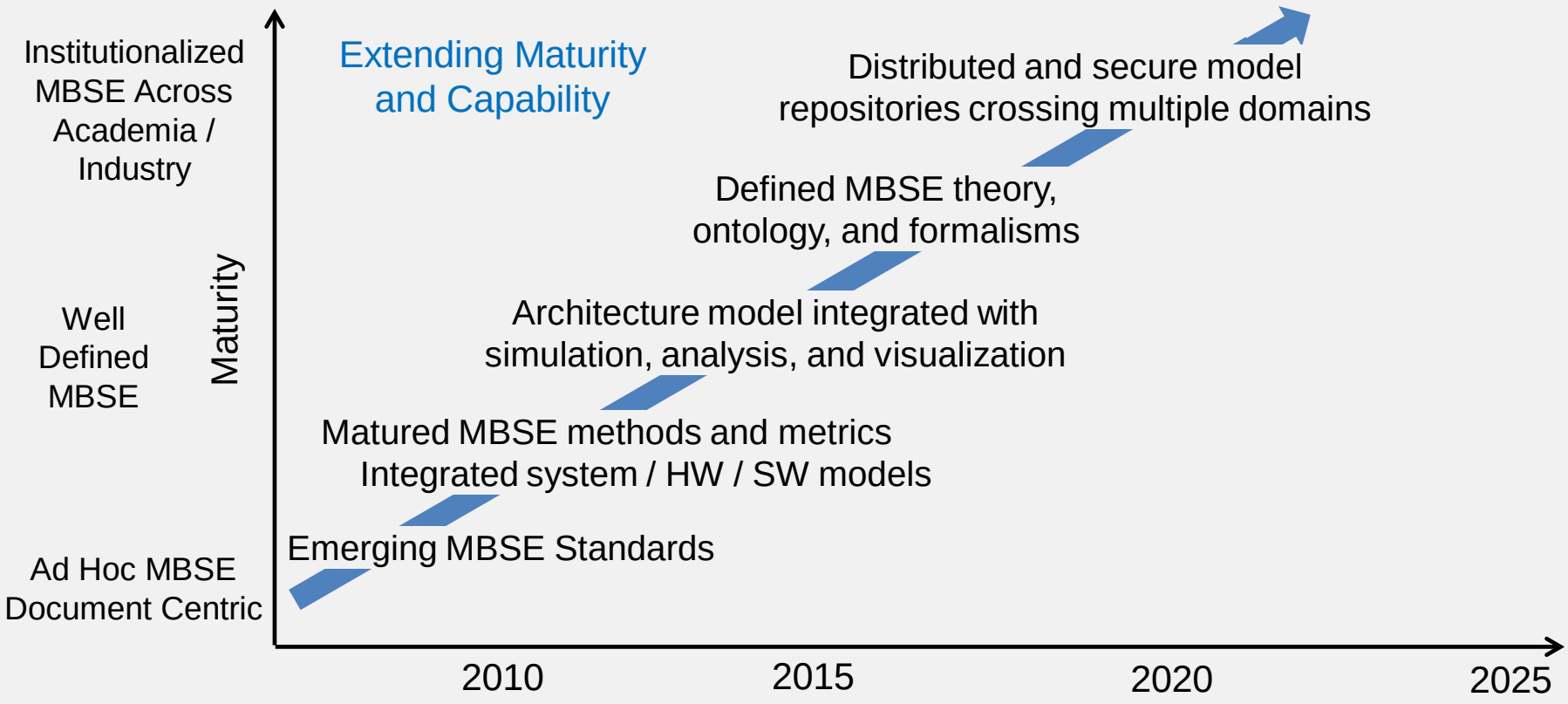
INCOSE MBSE Initiative - Genesis, Flow, Interaction



MBSE Roadmap



Adapted from [3]

MBSE

- INCOSE Systems Engineering Vision [1]
  - MBSE: Formalized application of modeling to support system requirements, design, analysis, verification, and validation activities
- Survey of Model Based Systems Engineering Methodologies [6], [7]
  - e.g. INCOSE OOSEM, IBM Telelogic Harmony SE, Vitech MBSE
  - MBSE: A collection of related processes, methods, and tools
- Object Management Group [4]
  - OMG SysML: A graphical modeling language for modeling complex systems including hardware, software, information, personnel, procedures, and facilities
  - SysML is just a language
  - SysML is not a methodology or a tool

MBSE

- INCOSE OOSEM [5] [8]
  - Objectives
    - Capture and analyze requirements and design information
    - Integrate MBSE methods with oo software and other engineering methods
    - Support system level reuse and design evolution
  - Activities
    - Analyze needs
    - Define logical architecture
    - Optimize, evaluate alternatives
    - Define system requirements
    - Synthesize allocated architectures
    - Validate and verify system

MBSE

INCOSE Object-Oriented Systems Engineering Methodology

System Modeling Tools

Interfaces with Other Models

SysML

Structure Diagrams

Block Definition
Internal Block

Behavior Diagrams

Use Case
Activity
Sequence
State Machine

Model Elements

Blocks
Actors
Flow
Constraint Blocks
Signals
Ports
...

Requirements Diagram

Parametric Diagram

Package Diagram

Diagrams are views of the underlying system model

Block Properties

Parts
References
Values
Constraints
Operations
...

A Block is the basic unit of structure

MBSE

Model Based Systems Engineering

Performing SE with models

System and subsystem level models

Integration of models and simulations

Authoritative, integrated repository of information from procurement through operations

SSWG Challenge Project

SSWG Challenge Project

INCOSE MBSE Challenge Project

Initiated in 2007

INCOSE SSWG

2007-2010

Phase 0

Modeled a SpaceSystem in SysML

Hypothetical FireSat

Space Mission Analysis and Design (SMAD)

MBSE CubeSat Project

Phase 1 [9]

CubeSat Framework

Preliminary RAX Model

Phase 2 [10]

RAX Behavior Modeling Power, Comm, State

Recent Efforts (Phase 3)

Enterprise Modeling for CubeSats [11]

RAX CubeSat Model Trade Studies [12]

Current Efforts (Phase 4)

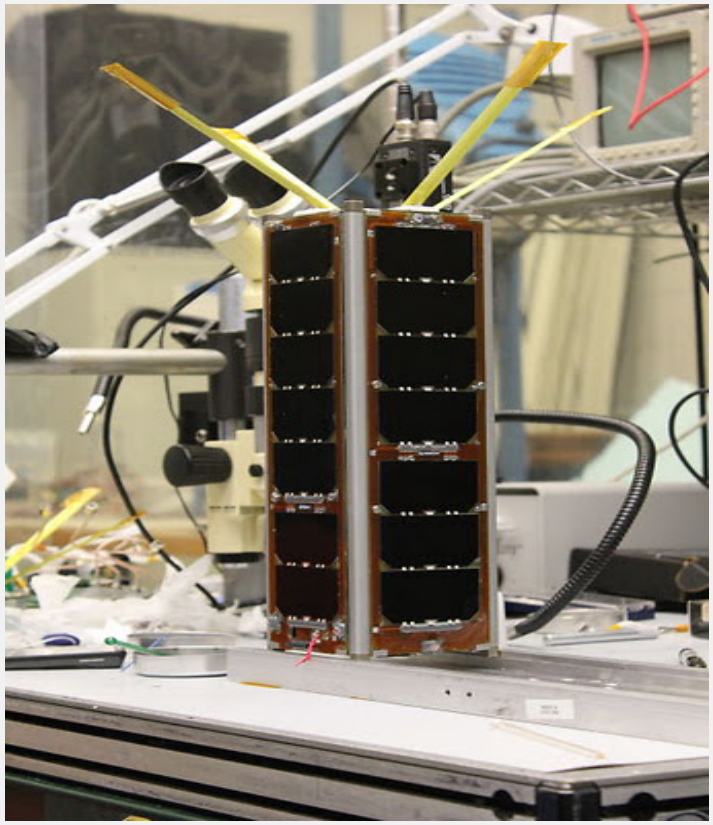
Develop a CubeSat MBSE Reference Model [13] [14]

MBSE CubeSat Project

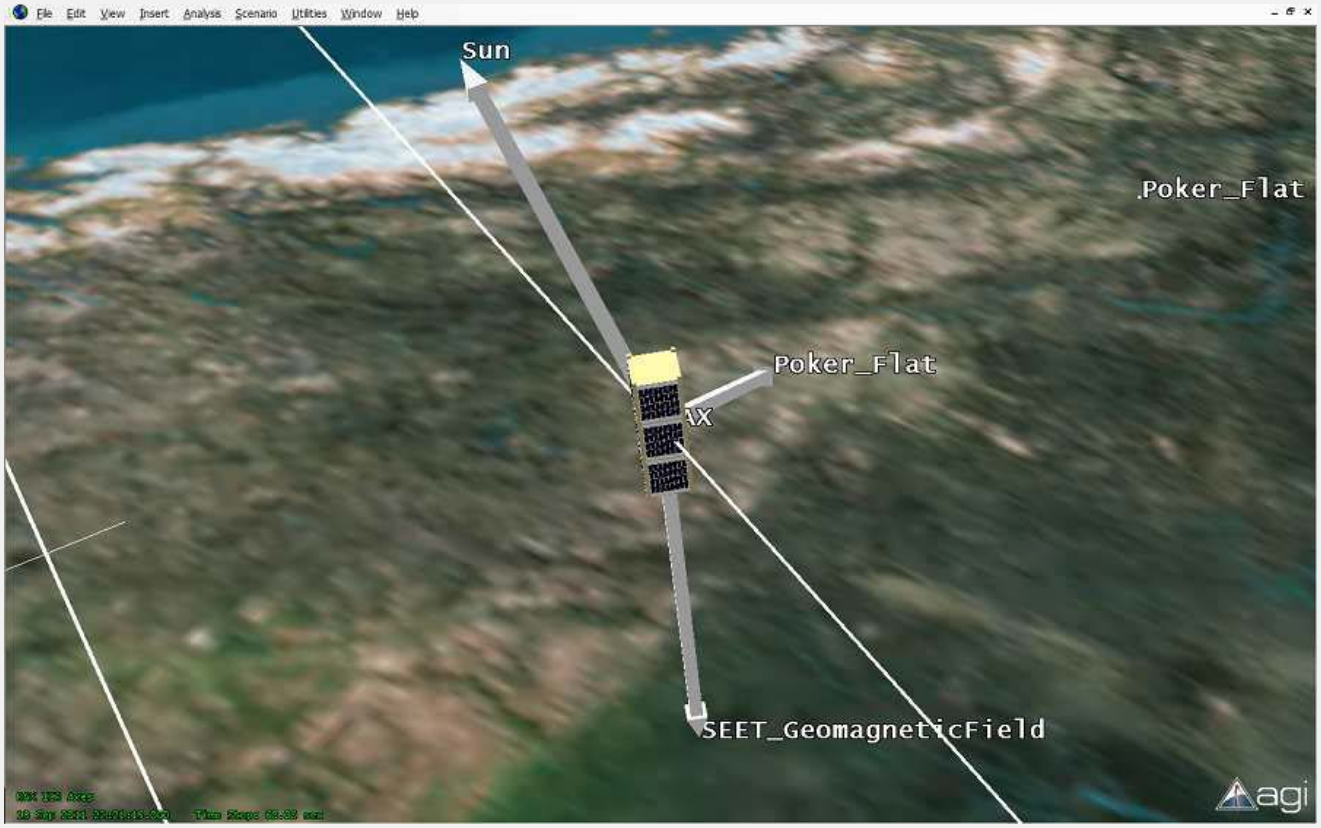
Initiated 2011

Radio Aurora Explorer (RAX) Mission

- Michigan Exploration Lab and SRI International mission
- Studies formation of magnetic field aligned plasma irregularities in the lower polar ionosphere
- Radar signal is transmitted by Incoherent Scatter Radar site in Poker Flat, Alaska and received by RAX's radar receiver
- Science data processed on-board, compressed, transmitted to the primary ground station and control center in Ann Arbor, Michigan



Radio Aurora Explorer (RAX) Mission



STK-generated schematic of RAX spacecraft with vectors pointing towards the experimental zone, Poker Flat, AK, the sun, and along the Earth's magnetic field.

Tools

- No Magic
  - Magic Draw: Graphical SysML modeling tool
  - Cameo Simulation Toolkit: Time-step execution of behavior models
- InterCAX
  - Pararamagic: Plug-in modudle for MagicDraw - wraps external models
  - Systems LIfecycle Management (SLIM): Version control and config mgt
- Analytical Graphics
  - Systems Tool Kit: Simulation and visualization of spacecraft behavior
- Phoenix Integration
  - Model Center: Graphical environment for creating simulation workflows by integrating of simulation models including STK scenarios.
  - MBSE Analyzer: Execution of parametric diagrams

Phase 2

Model Based Systems Engineering (MBSE) Applied to Radio Aurora Explorer (RAX) CubeSat Mission Operational Scenarios

2013 IEEE Aerospace Conference

Phase 2 - RAX Behavior Modeling - Power, Comm, State

System Model

No Magic - MagicDraw

SysML Models

Block Definition Diagram Internal Block Diagram

Activity Diagram State Machine Diagram Parametric Diagram

Phase 2 - RAX Behavior Modeling - Power, Comm, State

Orbit Dynamics

- Orbit and attitude
- Data collection and ground station access opportunities
- Solar power collection

Analytical Graphics Systems Tool Kit

- Mission modeling, analysis and visualization

Power

- Power gathering
- Subsystem power usage

Phoenix Integration ModelCenter

- Animation of SysML parametric diagrams.
- Interface with STK and MATLAB

Phase 2 - RAX Behavior Modeling - Power, Comm, State

Communication Download

- Signal to noise ratio
- Downlink data rate
- Available power

InterCAX
ParaMagic

- Execution of constraint behaviors in SysML parametric diagrams

- Trades of data downlink rate, available power, and signal to noise ratio
  - Data downlink rate and available power => Max feasible SNR
  - Data downlink rate and desired SNR => Min feasible power required
  - Available power and desired SNR => Max feasible data downlink rate

Phase 2 - RAX Behavior Modeling - Power, Comm, State

Mission System Activity
– Behavior and interactions

No Magic
Cameo Simulation Toolkit
– Animation of SysML state machines and activity models

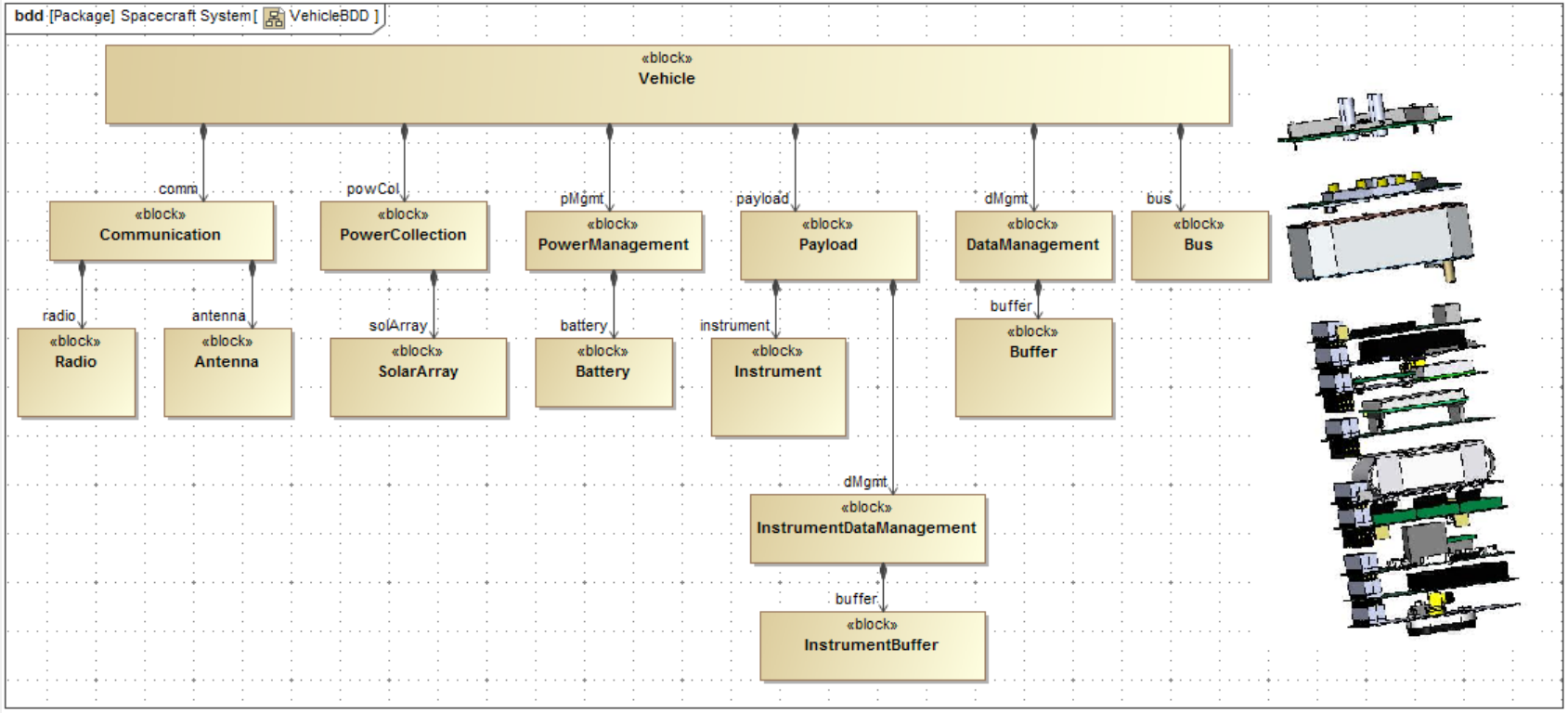
- Model commanding of subsystems for state changes and activities as directed by a command sequence
  - In-view of ground station uplink of command sequence
  - In-view of mission object – collect mission data
  - In-view of ground station – downlink mission data

Phase 3

Integrated Model-Based Systems Engineering (MBSE) Applied to the Simulation of a CubeSat Mission

2014 IEEE Aerospace Conference

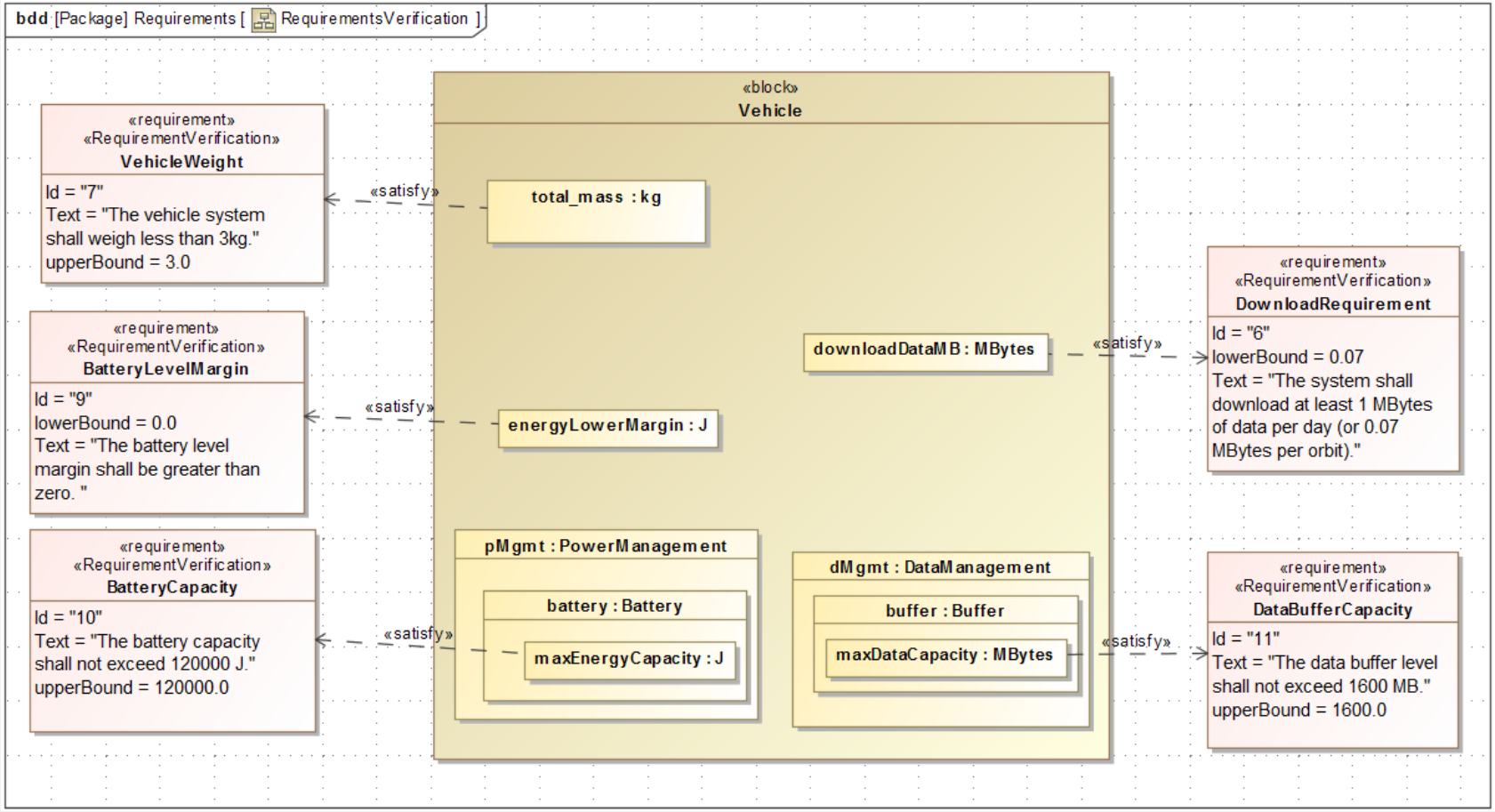
RAX CubeSat Model Trade Studies



Vehicle block definition diagram

Model: Power collection and management - Data collection and management

RAX CubeSat Model Trade Studies



Mapping of requirements to value properties of the Vehicle block

RAX CubeSat Model Trade Studies

State Diagrams

- Orbit
- Solar
- Experiment
- Download

Models behavior in response to internal and external events

Parametric Diagrams

- Get States
- Power Collection
- Update Energy
- Update Data
- Update Download

Mapped to analytical and simulation models that estimate RAX performance

Activity Diagrams

- Run Operation
  - Steps through time
- Update States
- Send Signals
  - Controls update of state values
- Update State Values

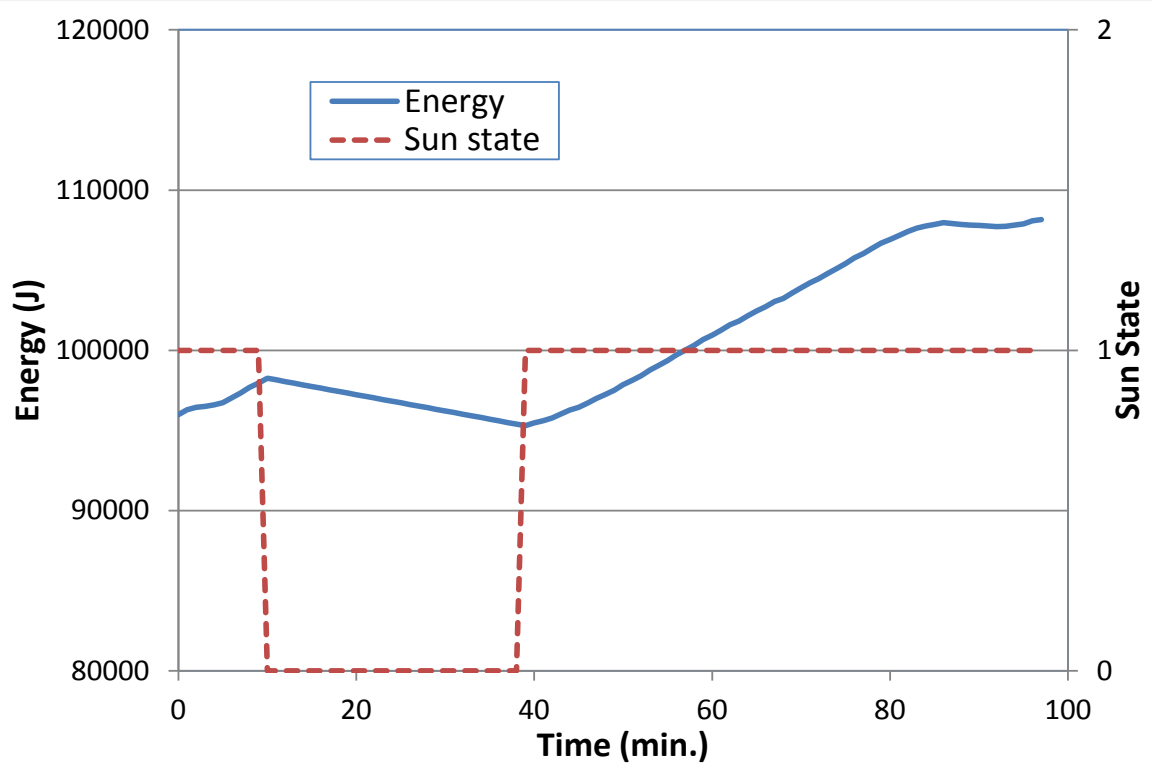
Defines actions in the activity along with the flow of input, output, and control

Use of SysML diagrams in RAX CubeSat mission simulation.

RAX CubeSat Model Trade Studies

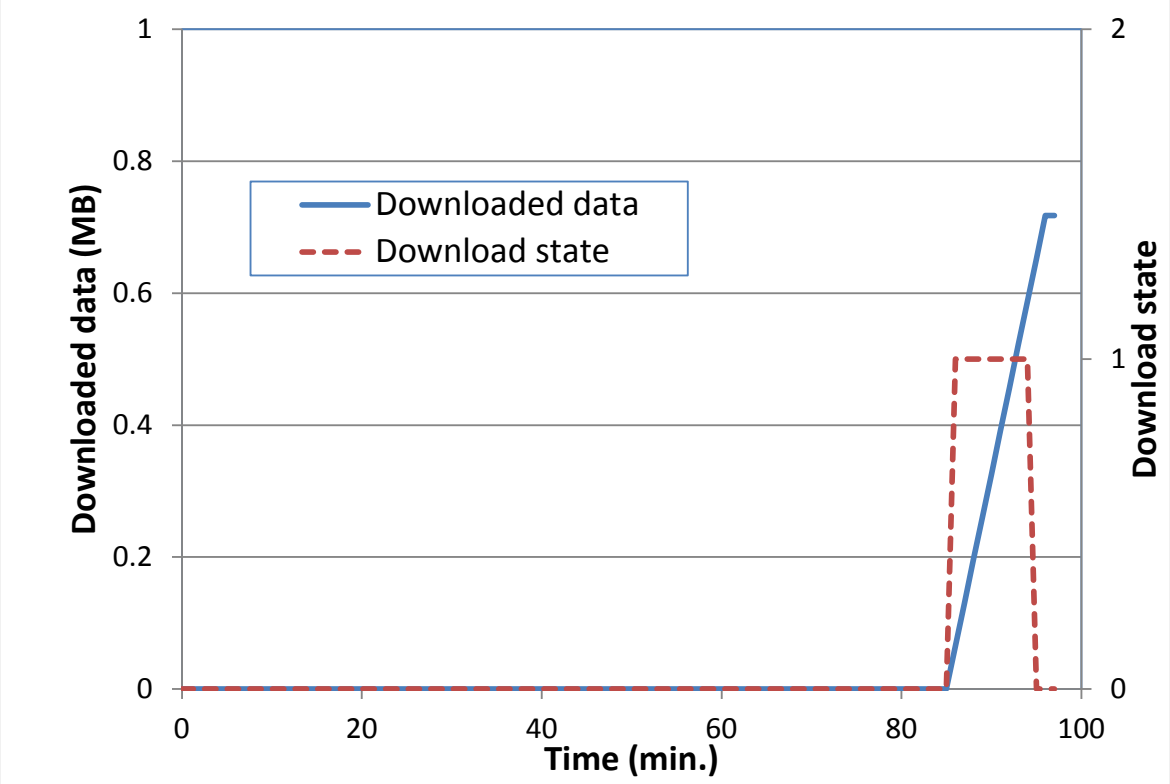
Trade Studies	Values Studied	Performance Metric
Solar Panel Area	• Nominal: 18.2 cm^2/side • ½ of nominal • ¼ of nominal	On-board energy
Max Battery Capacity	• Nominal: 115,000 J • Reduced: 100,000 J	On-board energy
Orbital Altitude	• Nominal: 811 km x 457 km • Low: 593 km x 250 km • High: 1311 km x 932 km	Quantity of data downloaded
Ground Station Network	• Ann Arbor & Menlo Park • Ann Arbor & Fairbanks • Fairbanks & Menlo Park	Quantity of data downloaded

RAX CubeSat Model Trade Studies



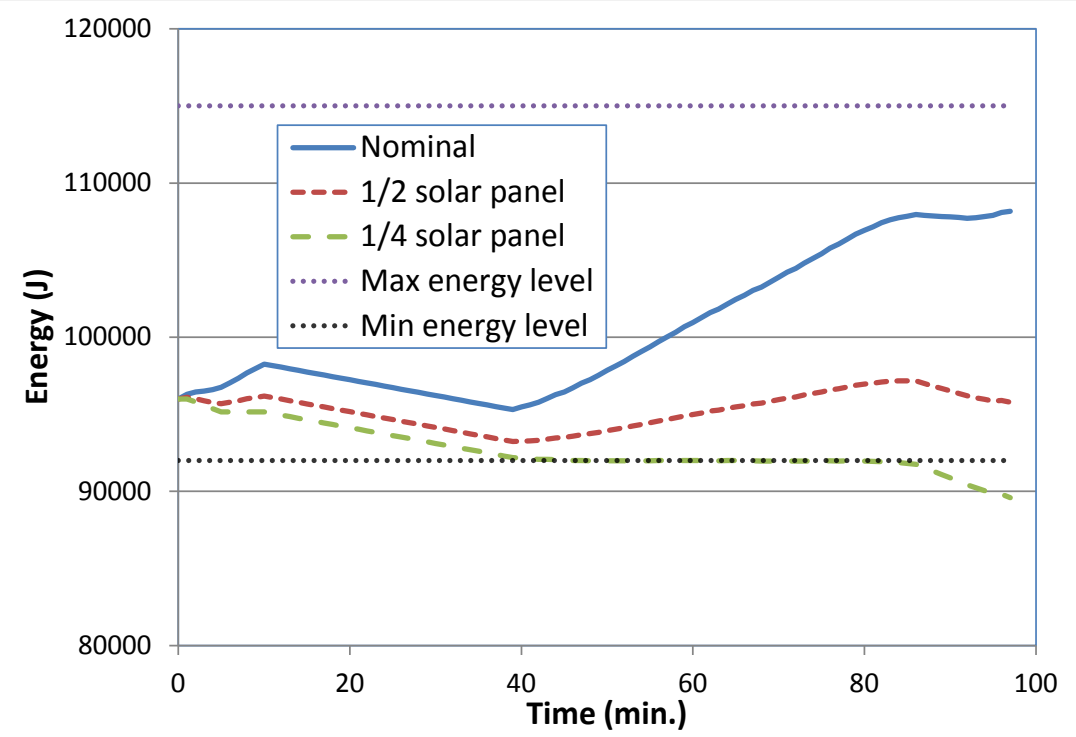
Time history of energy state of nominal RAX CubeSat design

RAX CubeSat Model Trade Studies



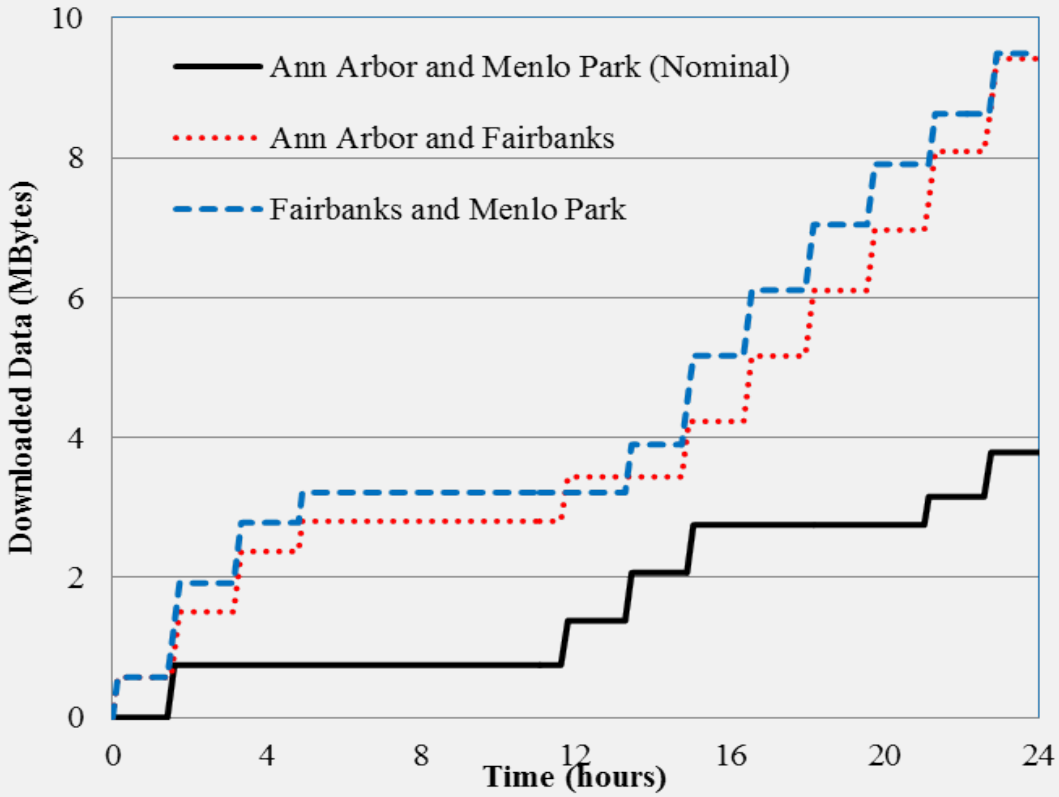
Time history of download state of nominal RAX CubeSat design.

RAX CubeSat Model Trade Studies



Impact of solar panel sizing on energy state

RAX CubeSat Model Trade Studies



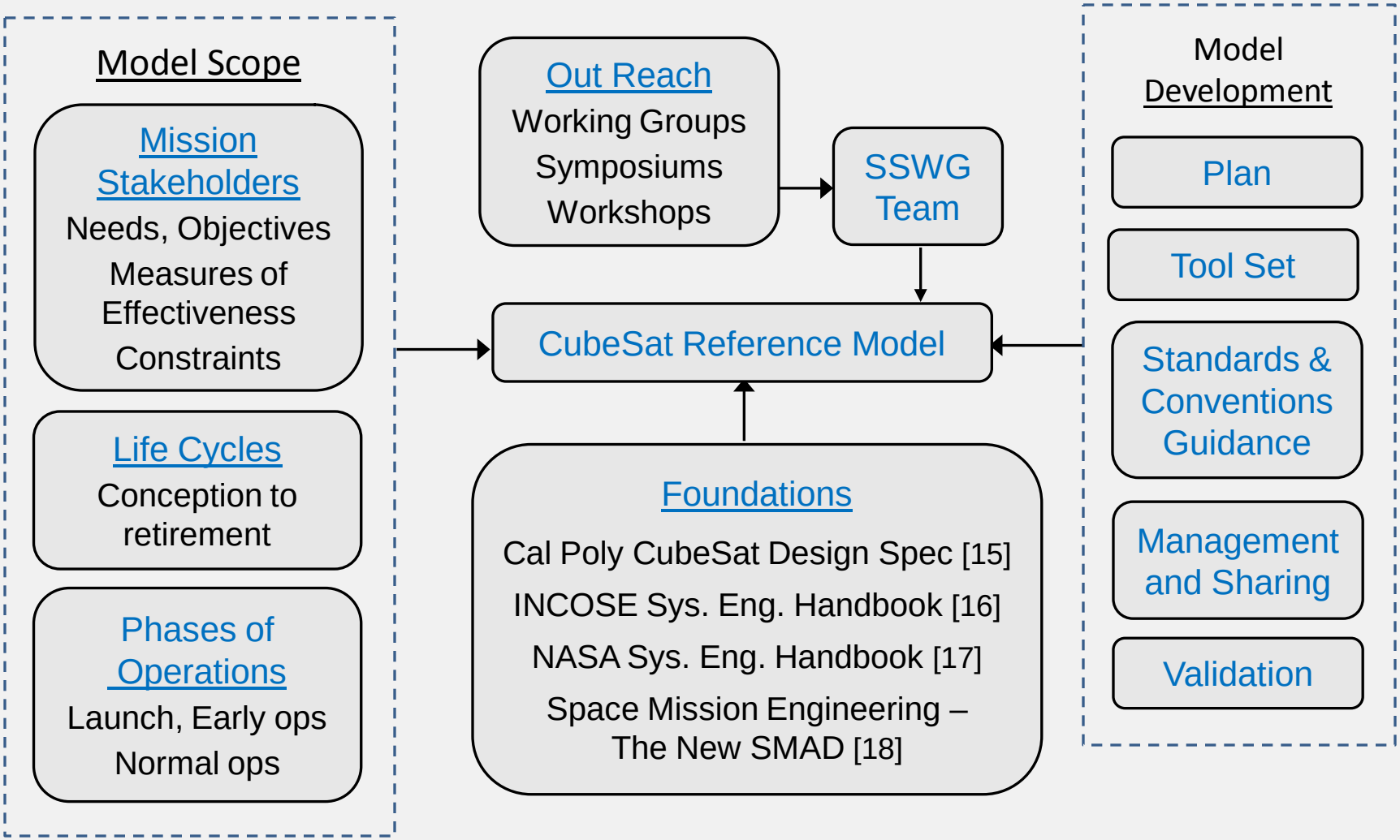
Selection of ground stations for data download

Phase 4

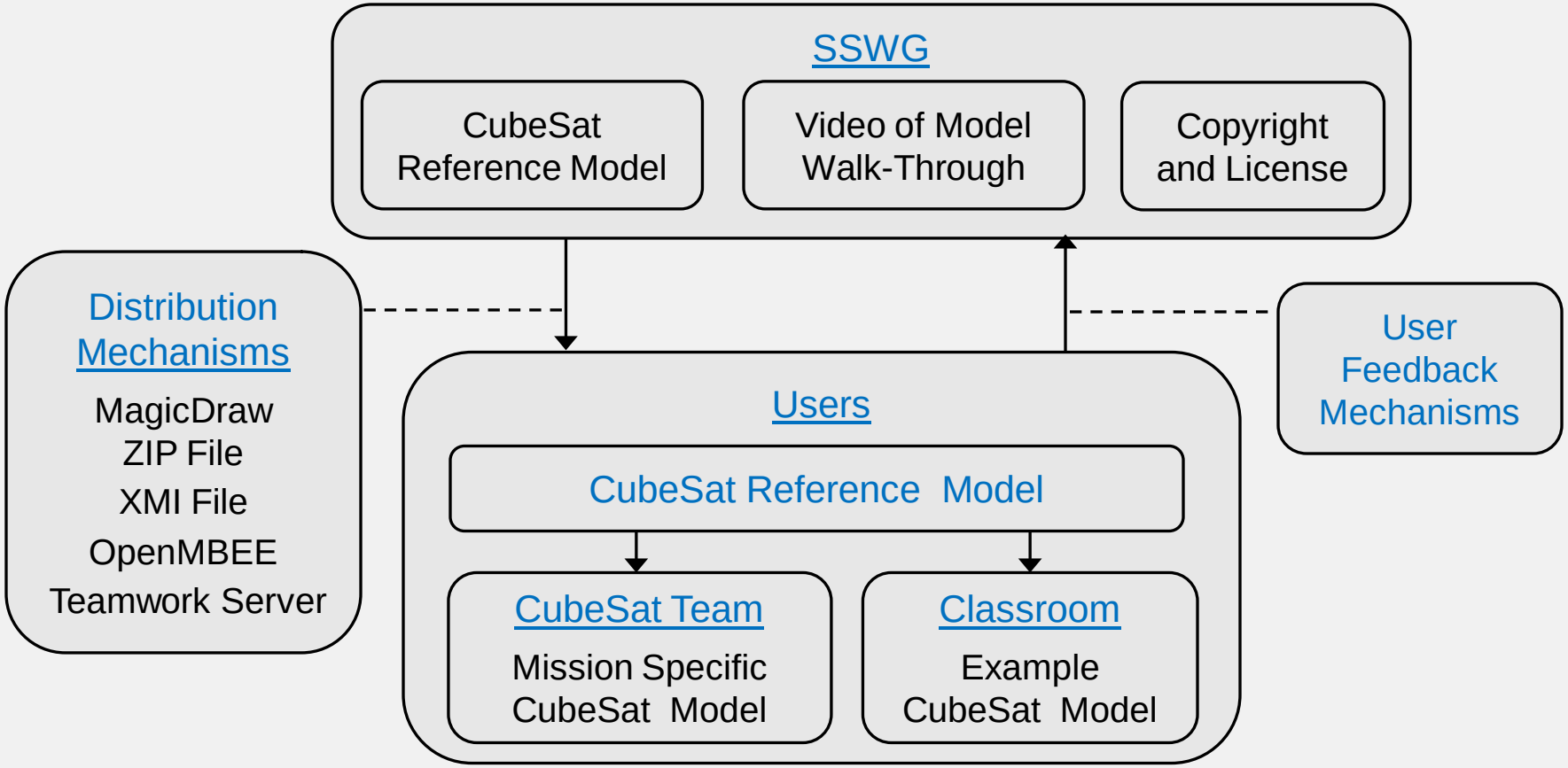
Develop and Distribute a CubeSat Reference Model

2015 IEEE Aerospace Conference
2015 Space Symposium

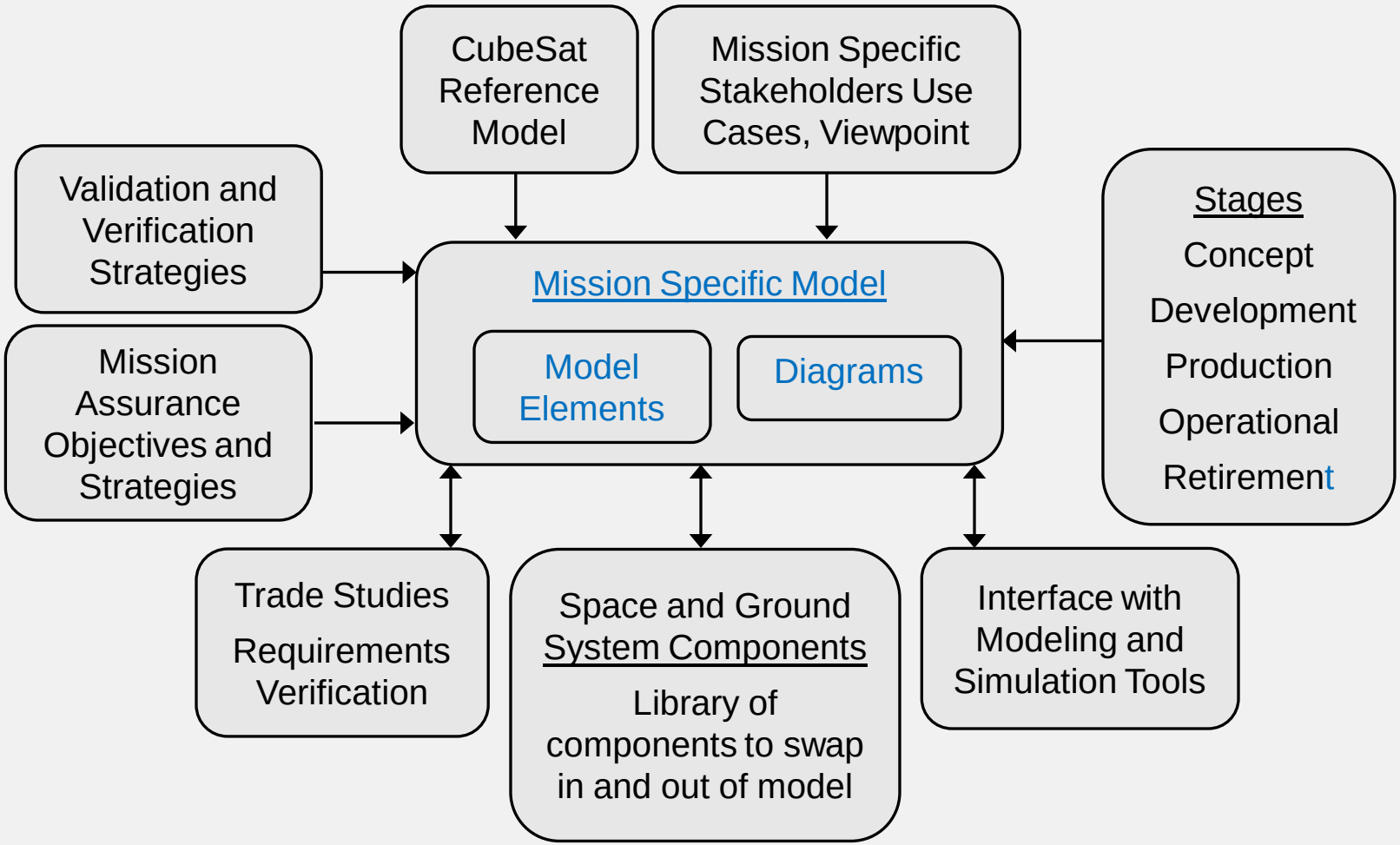
Development of the CubeSat Reference Model



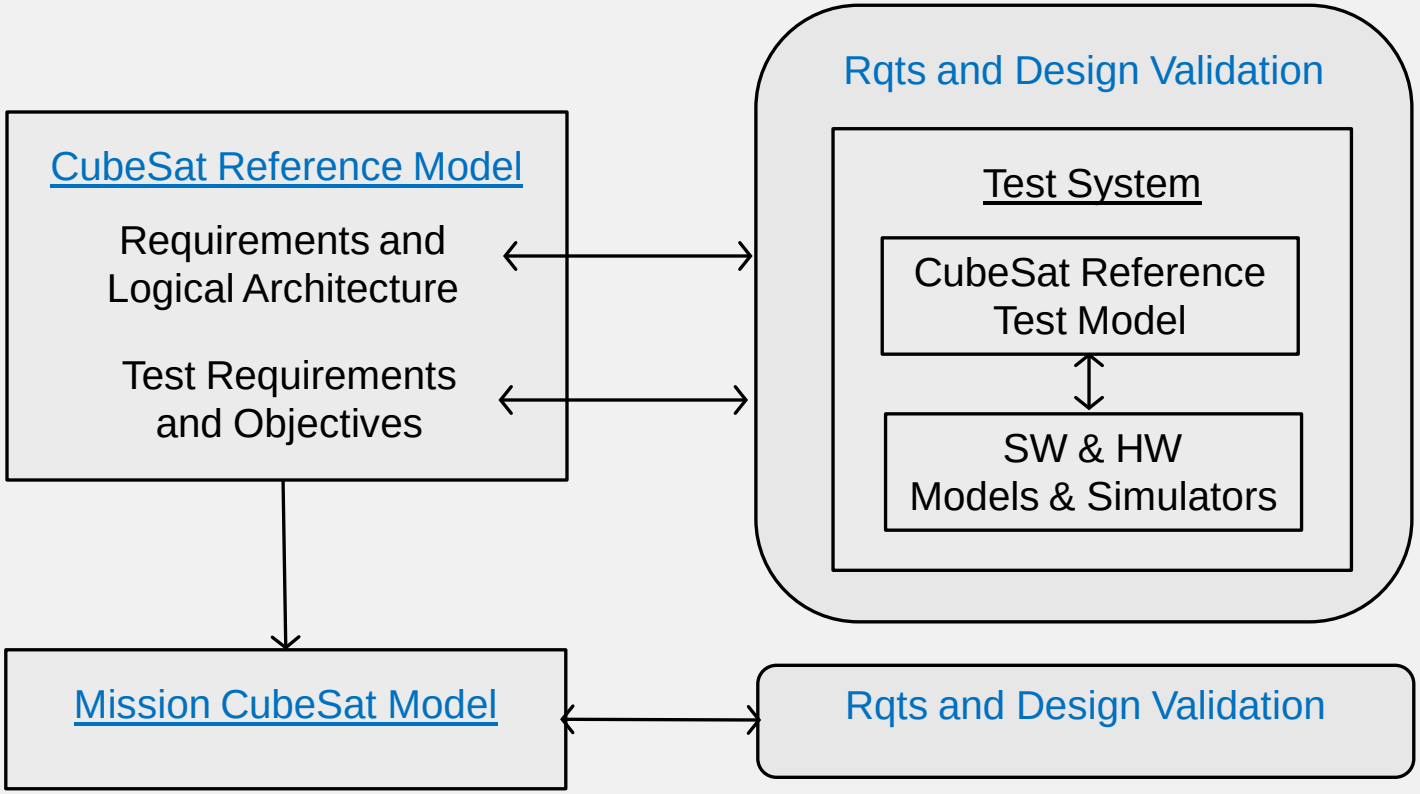
Distribution and Use of the CubeSat Reference Model



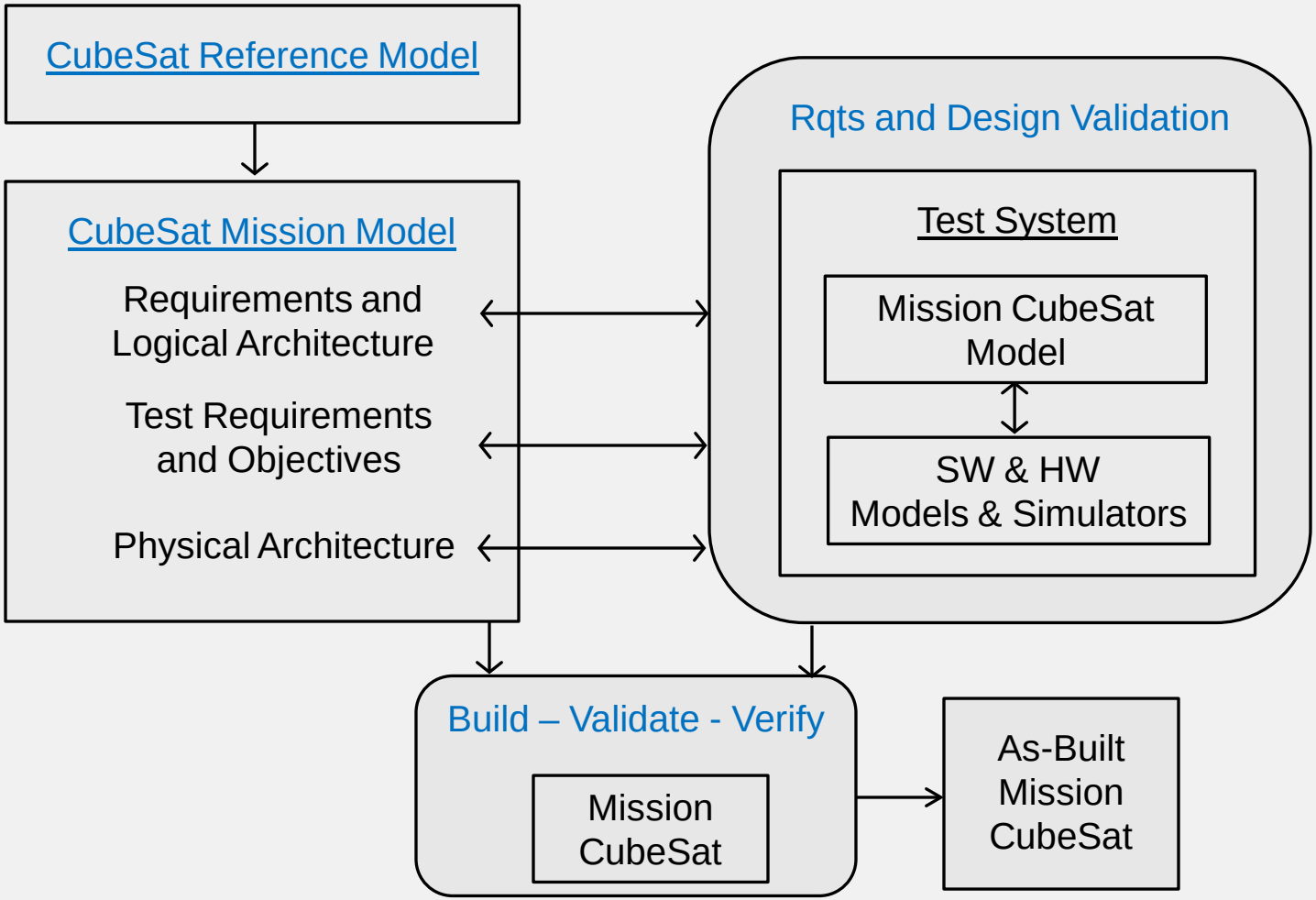
Development of a Mission Specific CubeSat Model



Validation and Verification



Validation and Verification



Measures of Effectiveness and Requirements

Concept Phase

Needs Analysis

MOE / MOP Definition and Validation

Model subsystems and components needed for Trade Studies

Production Phase

System Validation

Stakeholder Needs, MOEs, MOPs

Stakeholder

Needs, Objectives, Constraints

Mission Enterprise

MOEs - Requirements

Space System

MOPs - Rqts

Subsystems

Components

Ground System

MOPs - Rqts

Subsystems

Components

Concept and Development Phase

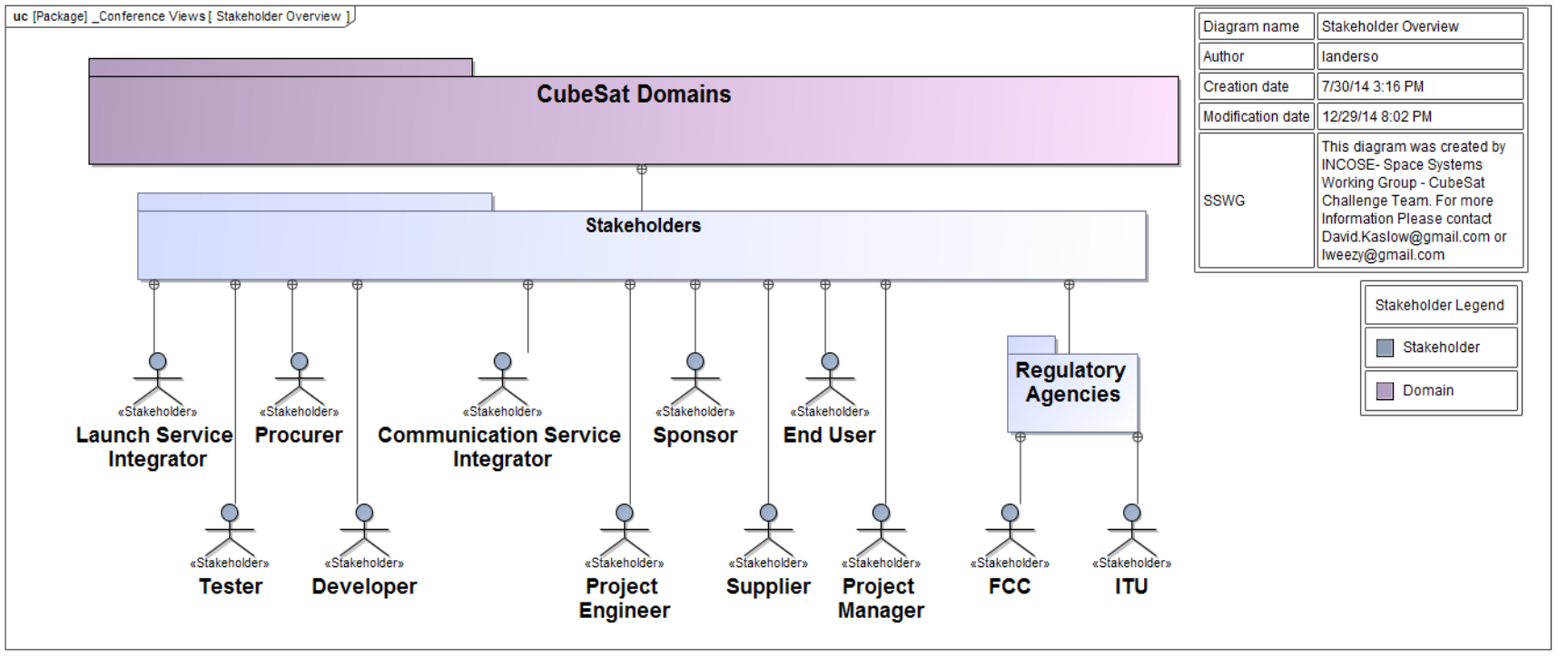
Requirements Analysis and Definition

Production Phase

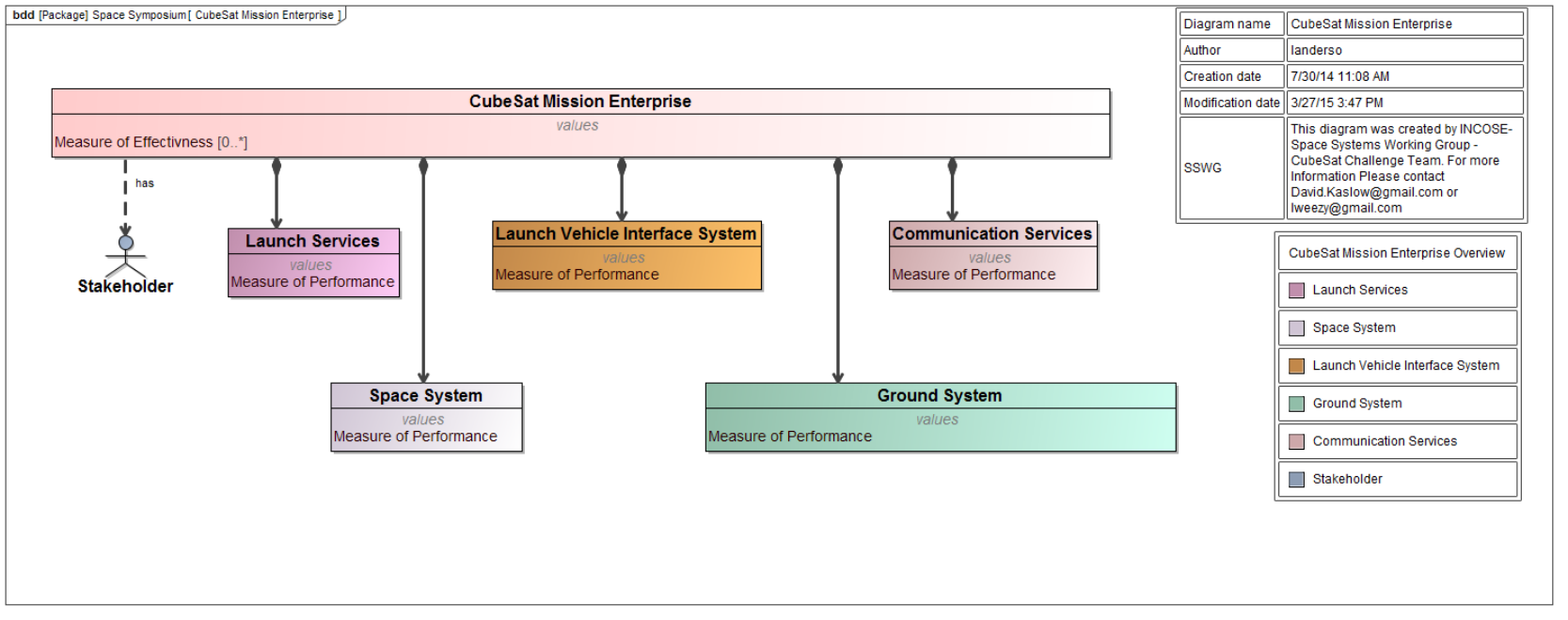
Requirements Verification

CubeSat System Reference Model Architecture

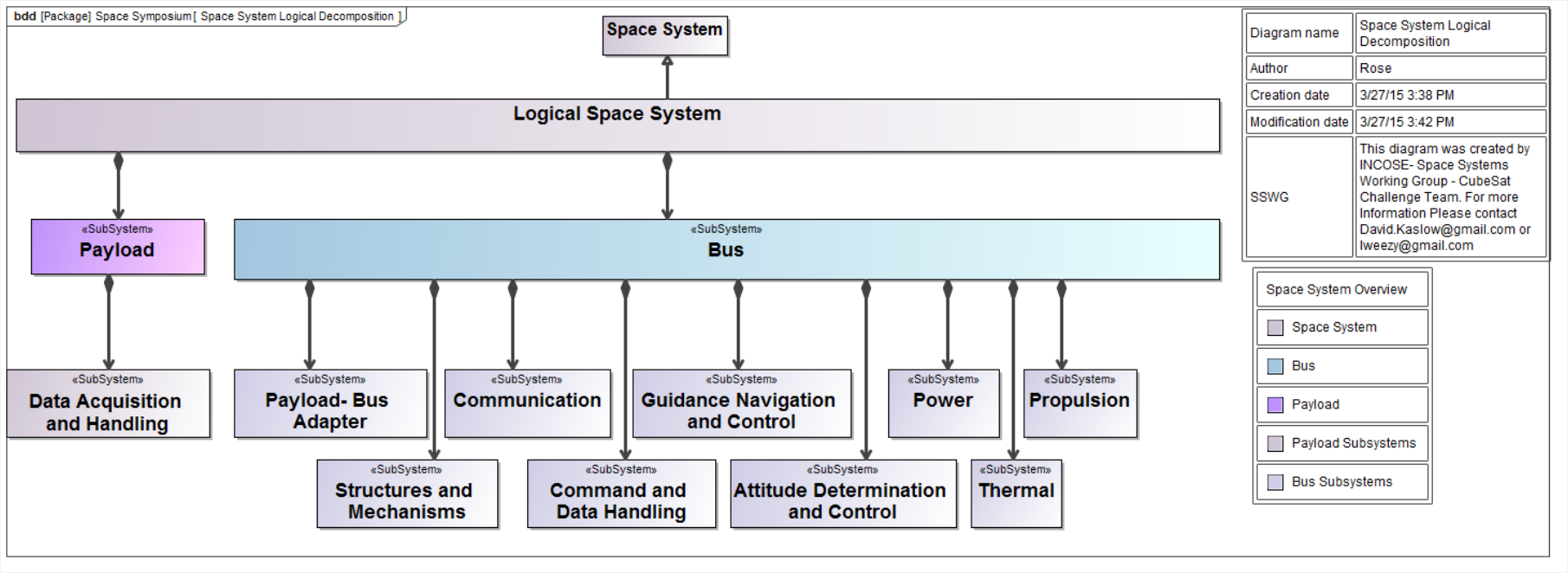
CubeSat Stakeholders



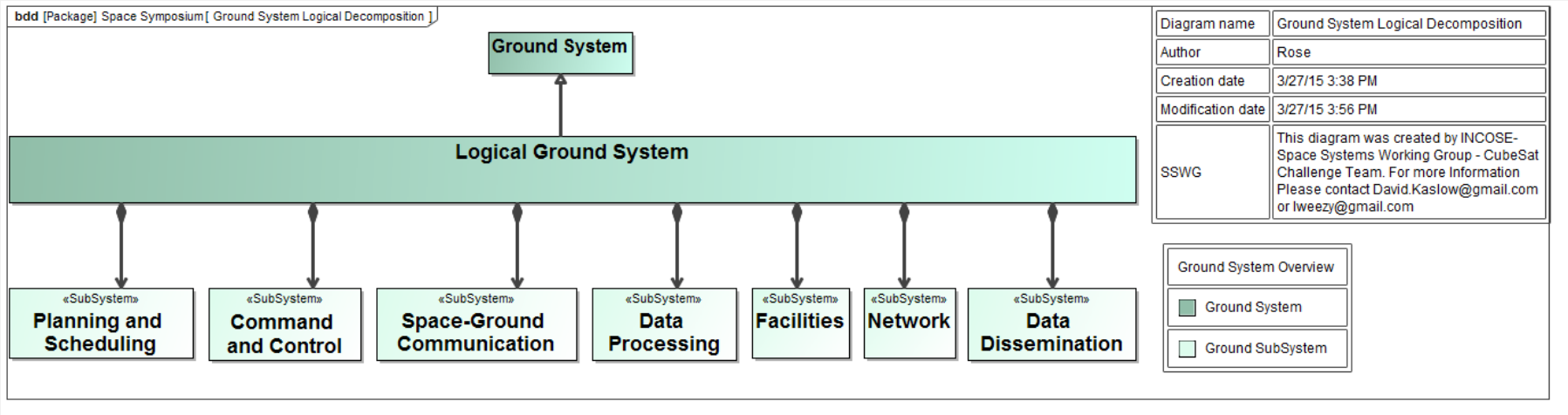
CubeSat Mission Enterprise



CubeSat Logical Space System



CubeSat Logical Ground System



Next Steps and References

Next Steps

- Develop model glossary / ontology
- Populate model with example:
  - Stakeholder needs, objectives, constraints
  - Mission and system requirements
  - MOEs and MOPs
- Demonstrate validation of MOEs and MOPs
- Provide the model to university aerospace program

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[10] S. Spangelo, L. Anderson, E. Fosse, L Cheng, R. Yntema, M. Bajaj, C. Delp, B. Cole, G. Soremekun, D. Kaslow, and J. Cutler, "Model Based Systems Engineering (MBSE) Applied to Radio Explorer (RAX) CubeSat Mission Operational Scenarios," *Proceedings of IEEE Aerospace Conference*, Big Sky, MT, March 2013.

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