

# CubeSat Model-Based Systems Engineering (MBSE) Reference Model – Model Distribution and Application – Interim Status #2

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

Chair: David Kaslow

Object Management Group (OMG) Space Domain Task Force



## Project Objectives

Demonstrate MBSE methodology as applied to a CubeSat mission.  
Provide a CubeSat Reference Model that CubeSat teams can use as a starting point for their mission-specific CubeSat model  
Obtain International Specification Standard & Create Testbed



## Team Composition

Aerospace Students and Professors  
Engineers and Software Developers from NASA Centers, Aerospace Companies, Modeling and Simulation Tool Providers  
Email to be included on the email reflector list:  
[david.kaslow@gmail.com](mailto:david.kaslow@gmail.com)  
Standards to be worked through OMG Space Domain Task Force

## Team Meeting

Telecons every Friday at 1 pm ET  
Meeting materials and links to recordings in Google docs  
Conference papers posted in INCOSE SSWG Web Site  
<http://www.incose.org/ChaptersGroups/WorkingGroups/government/space-systems>  
Anticipated Standards Task Planned for Dec 2016 – Jun 2018

## From Document-Centric to Model-Centric

### Document Based Design

Create, Update, Review, Config Control, ...

System Specs:  
Rqts, Ops Con, Interfaces, ...

Subsys. Specs  
...

### Ad Hoc Modeling

In support of:

Rqts analysis  
Payloads

Mission data collect  
...

## Traditional Systems Engineering

Systems Engineering Methodology

System Modeling Tools

Interfaces with Other Models

Systems Modeling Language (SysML) [1]

A graphical modeling language for modeling complex systems including hardware, software, information, personnel, procedures, and facilities

**MBSE – Formalized application of modeling to support requirements, design, analysis, validation, and verification [2]**

### The Model

#### SysML Model Elements

Blocks, Actors, Flow, Signals, Ports, ...

#### Block Properties

Parts, Values, Operations, ...

System design resides in the model not in documents

Model updates are automatically populated into the system views

Diagrams are views of the underlying system model

Structures

Requirements

Behaviors

Parametrics

Traditional documents can be generated from the model as needed

**Authoritative, integrated repository of information that evolves from procurement through retirement**

[1] Object Management Group (OMG), OMG Website. [Online]. Available: <http://www.omg.org/sysml/>

[2] Systems Engineering Vision 2020, INCOSE –TP\_2004-004-02, ver. 2/03, September 2007. [Online]. Available: [http://oldsite.incose.org/ProductsPubs/pdf/SEVision2020\\_20071003\\_v2\\_03.pdf](http://oldsite.incose.org/ProductsPubs/pdf/SEVision2020_20071003_v2_03.pdf)

[3] S. Spangelo, D. Kaslow, C. Delp, B. Cole, L. Anderson, E. Fosse, B. Gilbert, L. Hartman, T. Kahn, and J. Cutler, "Applying Model Based Systems Engineering (MBSE) to a Standard CubeSat," in *Proceedings of IEEE Aerospace Conference*, Big Sky, MT, March 2012.

[4] 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.

[5] D. Kaslow, G. Soremekun, H. Kim, S. Spangelo, "Integrated Model-Based Systems Engineering (MBSE) Applied to the Simulation of a CubeSat Mission", *Proceedings of IEEE Aerospace Conference*, Big Sky, MT, March 2014.

[6] D. Kaslow, L. Anderson, S. Asundi, B. Ayres, C. Iwata, B. Shiotani, R. Thompson, "Developing a CubeSat Model-Based System Engineering (MBSE) Reference Model – Interim Status", *Proceedings of IEEE Aerospace Conference*, Big Sky, MT, March 2015.

[7] D. Kaslow, L. Anderson, S. Asundi, B. Ayres, C. Iwata, B. Shiotani, R. Thompson, "Developing and Distributing a CubeSat Model-Based System Engineering (MBSE) Reference Model", *Proceedings of the 31st Space Symposium*, Colorado Springs, CO, April 2015.

[8] D. Kaslow, B. Ayres, M.J. Chonoles, S. Gasster, L. Hart, C. Massa, R. Yntema, B. Shiotani, "Developing and Distributing a CubeSat Model-Based System Engineering (MBSE) Reference Model – Interim Status #2", *Proceedings of IEEE Aerospace Conference*, Big Sky, MT, March 2016

[9] D. Kaslow, B. Ayres, M.J. Chonoles, S. Gasster, L. Hart, A. Levi, C. Massa, R. Yntema, B. Shiotani, "Developing and Distributing a CubeSat Model-Based System Engineering (MBSE) Reference Model – Status", *Proceedings of the 32nd Space Symposium*, Colorado Springs, CO, April 2016.

## SSWG Challenge Project

INCOSE MBSE Challenge Project  
[Initiated 2007](#)

### Phase 1

CubeSat Framework  
Prelim. RAX Model [3]

### Recent Efforts

#### Phase 3

RAX CubeSat Model Trade Studies [5]

INCOSE SSWG  
[2007-2010](#)

### Phase 0

Modeled a Space System in SysML  
Hypothetical FireSat - SMAD

### Phase 2

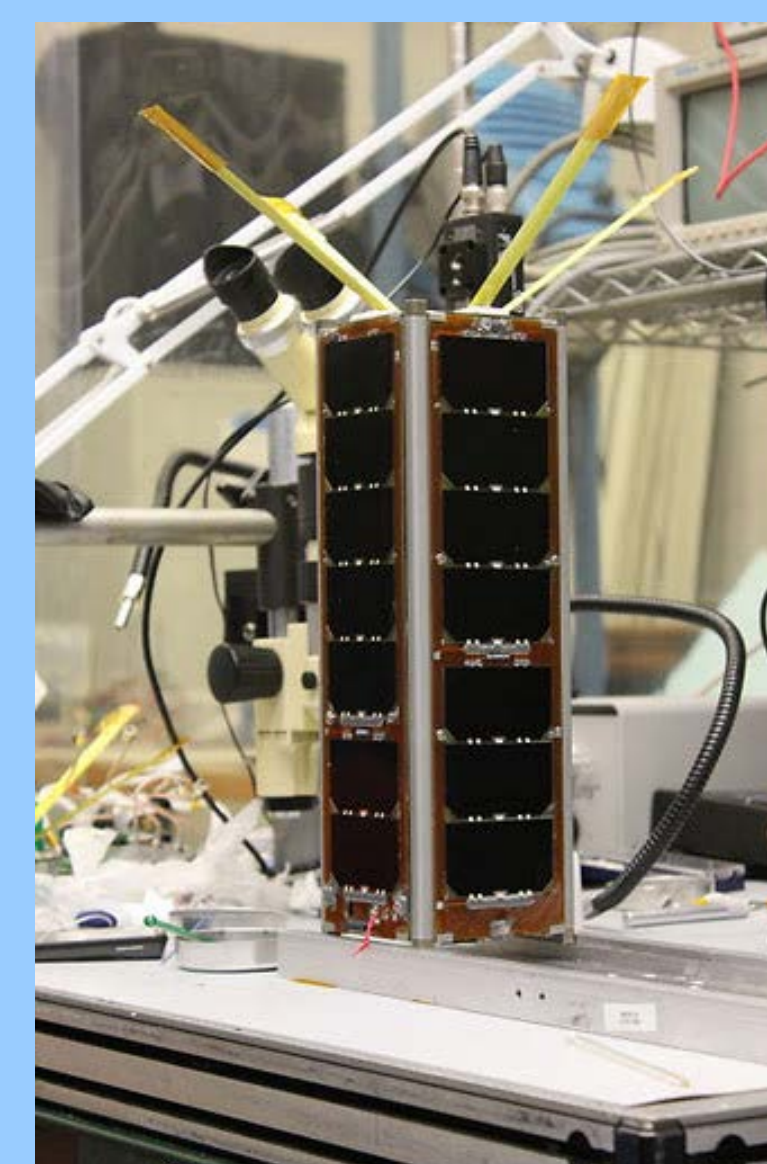
RAX Behavior Modeling Power, Comm, State [4]

### Current Efforts

#### Phase 4

Develop a CubeSat MBSE Ref. Model [6] [7] [8] [9]

## Concept Phase Trade Studies – Phase 3 [5]



### Radio Aurora Explorer (RAX) CubeSat 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

### 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

Trade Studies	Trade Space	Performance Metric
Solar Panel Area	<ul style="list-style-type: none"> <li>• Nominal: 18.2 cm<sup>2</sup>/slide</li> <li>• ½ of nominal</li> <li>• ¼ of nominal</li> </ul>	On-board energy
Max Battery Capacity	<ul style="list-style-type: none"> <li>• Nominal: 115,000 J</li> <li>• Reduced: 100,000 J</li> </ul>	On-board energy
Orbital Altitude	<ul style="list-style-type: none"> <li>• Nominal: 811 km x 457 km</li> <li>• Low: 593 km x 250 km</li> <li>• High: 1311 km x 932 km</li> </ul>	Quantity of data downloaded
Ground Station Network	<ul style="list-style-type: none"> <li>• Ann Arbor &amp; Menlo Park</li> <li>• Ann Arbor &amp; Fairbanks</li> <li>• Fairbanks &amp; Menlo Park</li> </ul>	Quantity of data downloaded

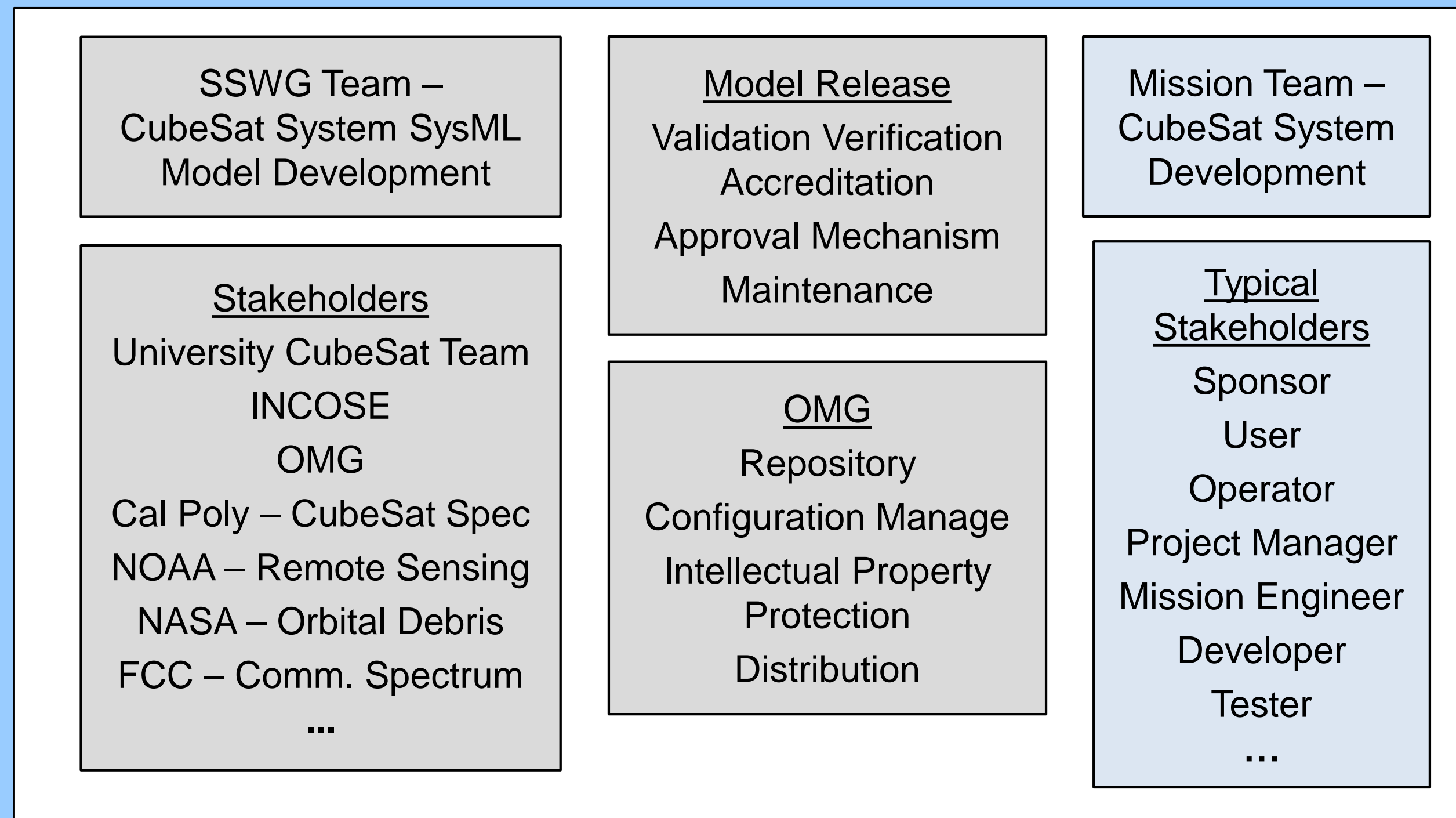
## CubeSat Reference Model Logical Design to Mission Specific CubeSat Model

Logical architecture decomposes the system into components that interact to satisfy system requirements  
The components are abstractions of physical components that perform system functionality but without imposing implementation constraints

Physical architecture defines physical components that interact to satisfy the system requirements  
The physical components of the system include hardware, software, persistent data, and operational procedures

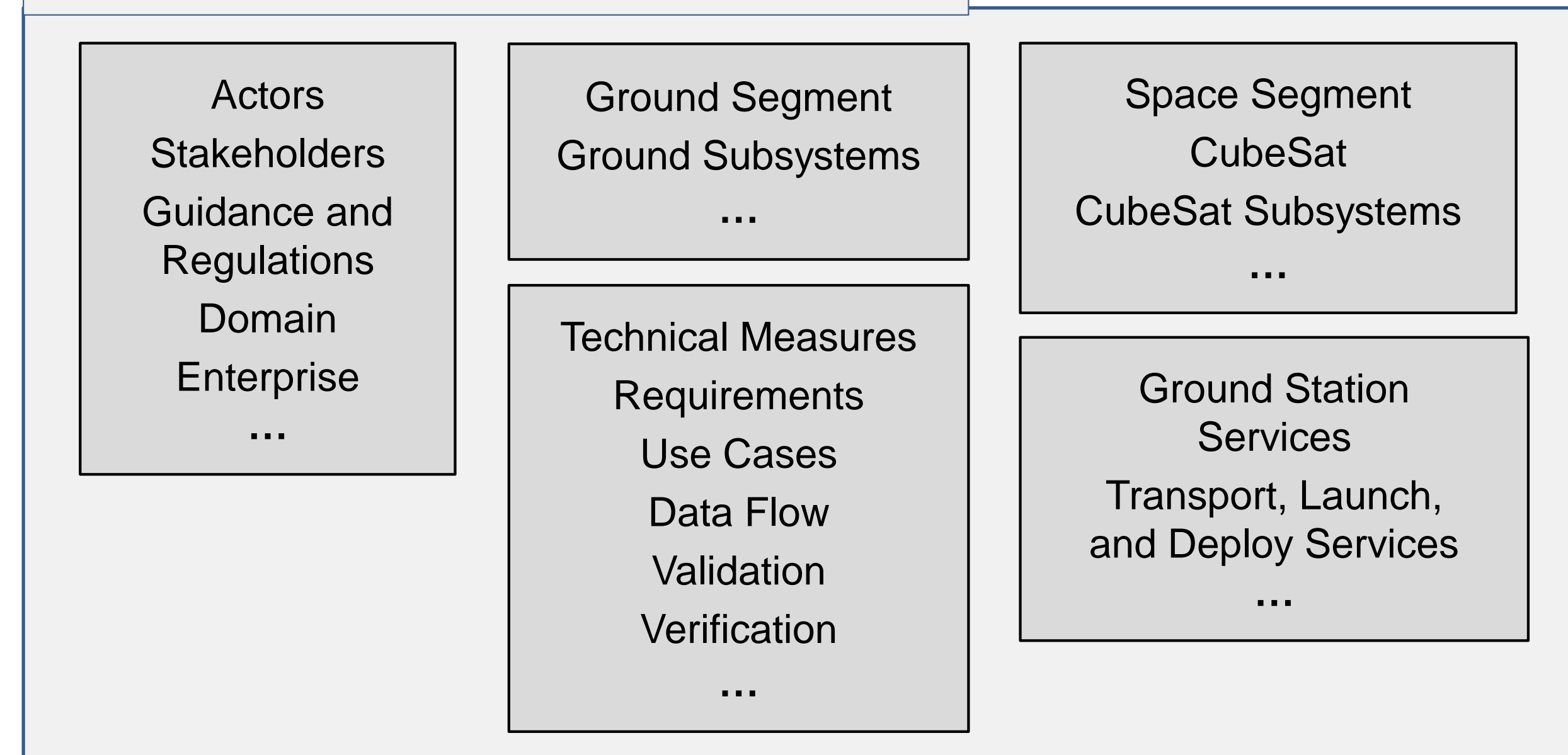
The CubeSat Reference Model provides the logical architecture

### Logical and Physical Architectures

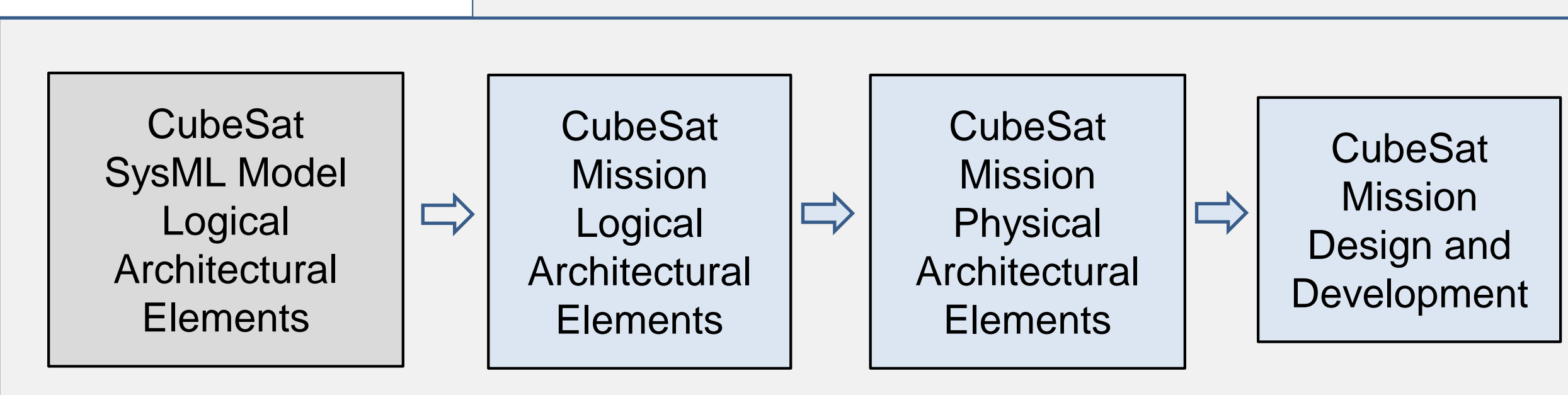


### Two Teams – Two Groups of Stakeholders

#### SSWG CubeSat Reference Model Development



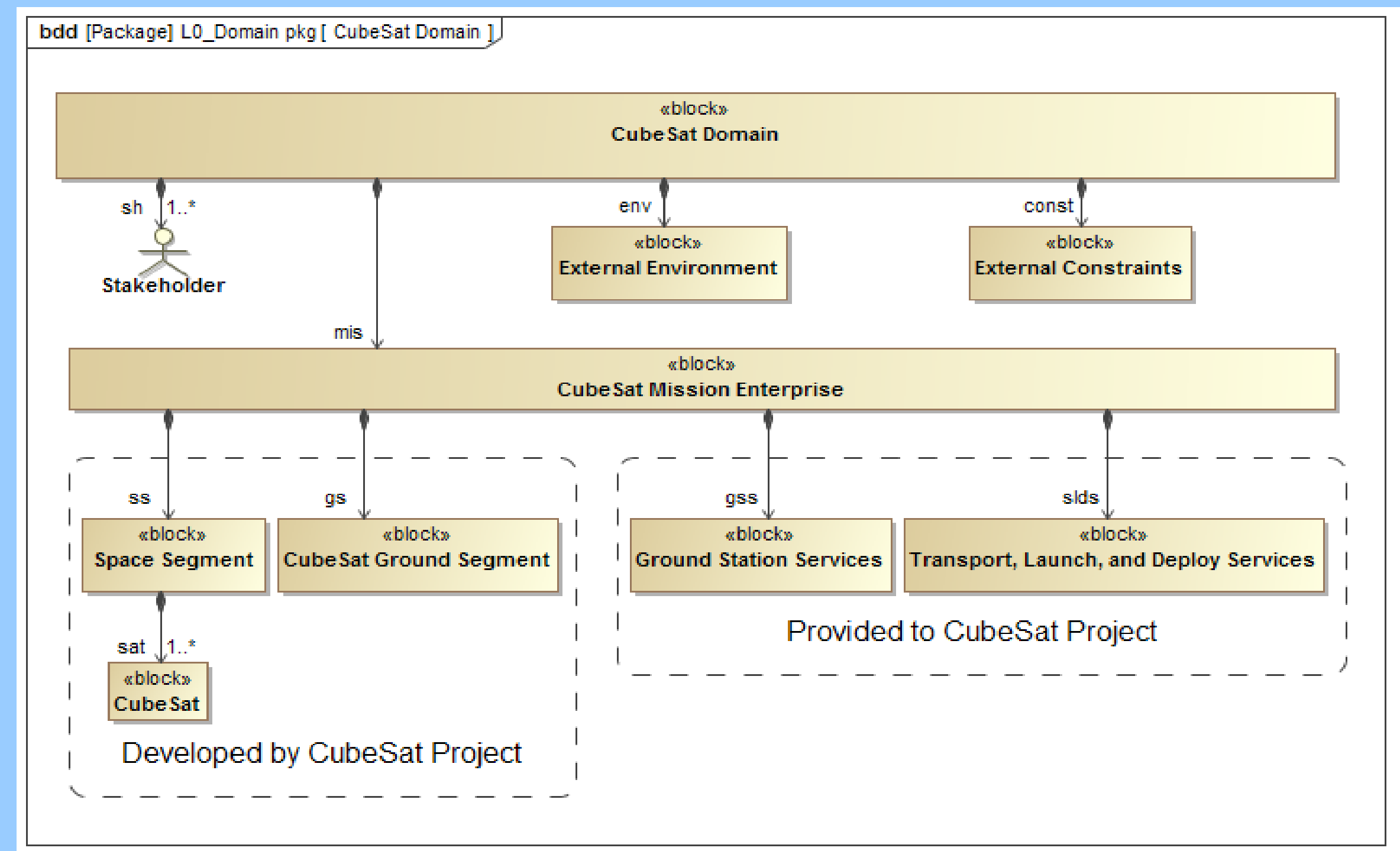
#### Mission Team – CubeSat System Design and Development



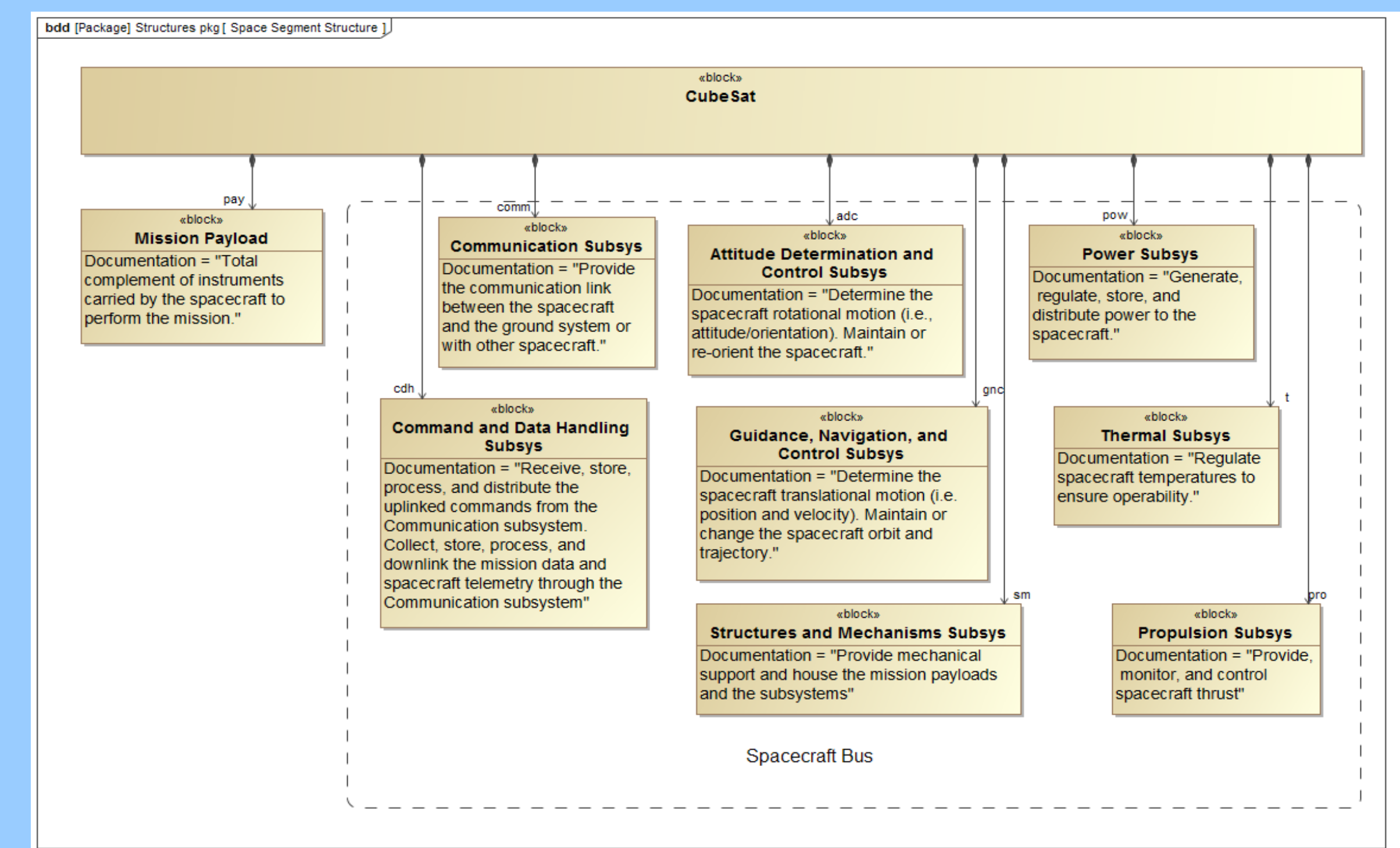
Mission specific enterprise needs, objectives, constraints, and measures of effectiveness  
Mission use cases and requirements  
Segment use cases and requirements  
Subsystem requirements

### CubeSat Reference Model Provides the Foundation for the CubeSat Mission Specific Model

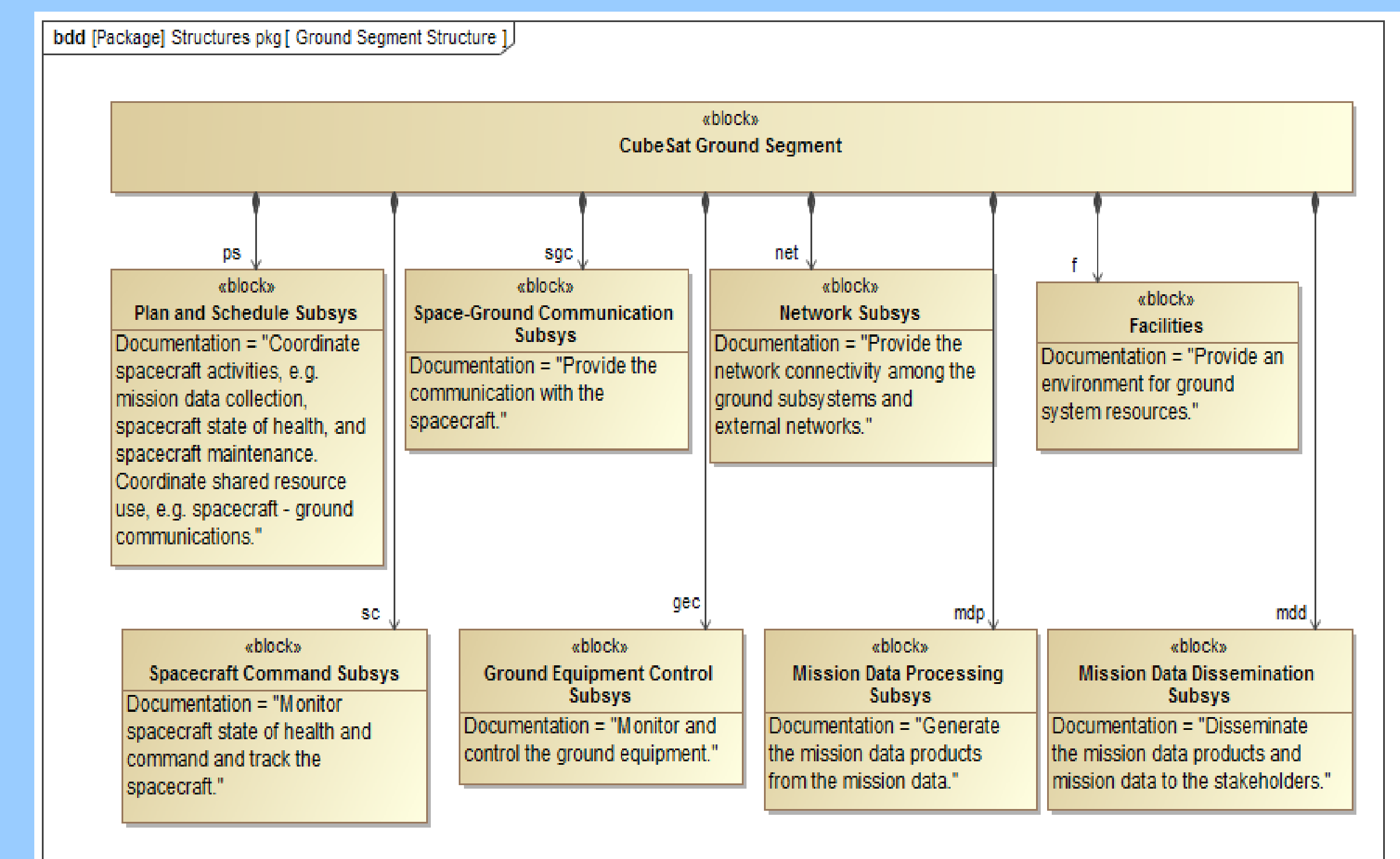
## CubeSat Reference Model Views – Phase 4 [9]



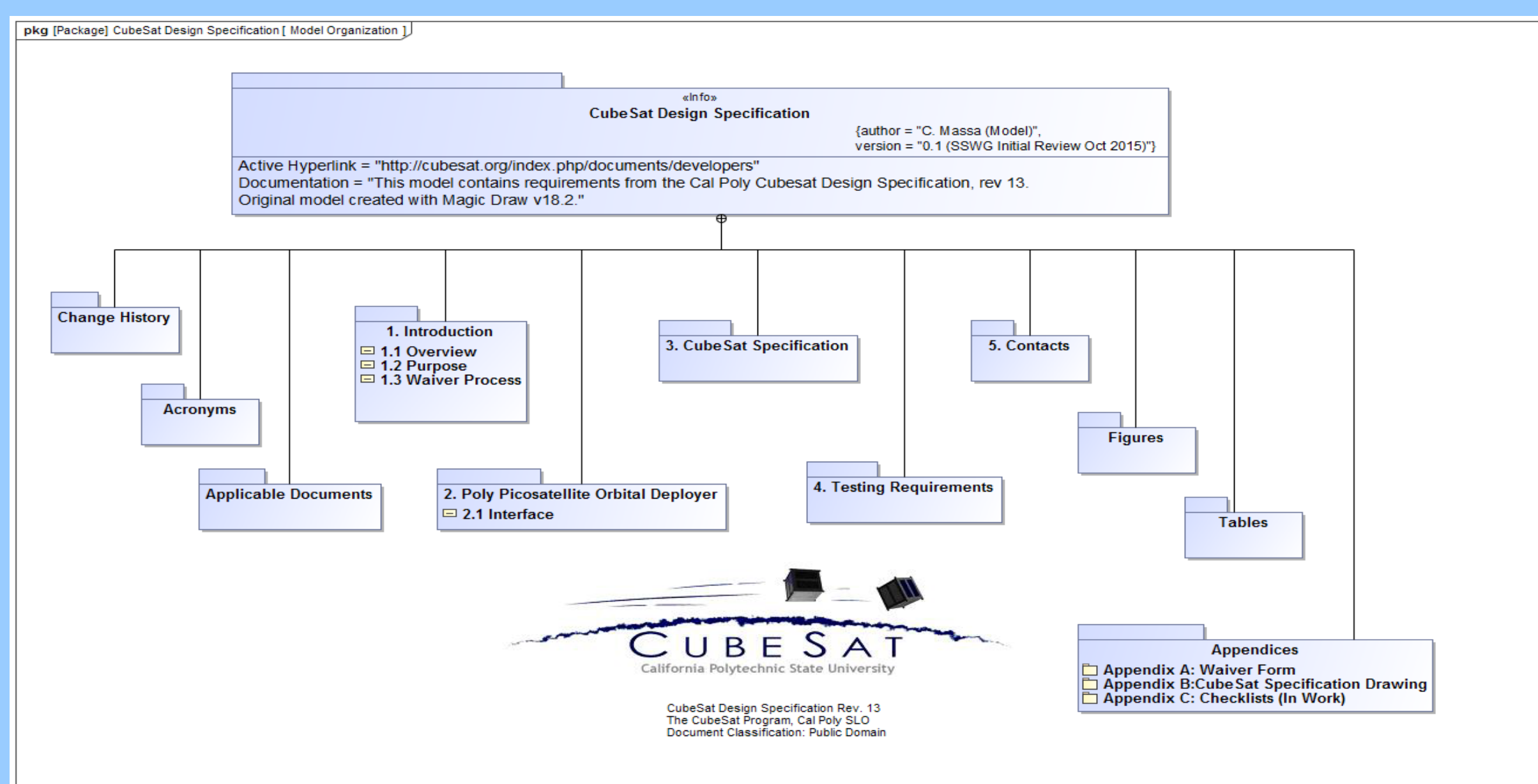
### CubeSat Domain and Mission Enterprise



### CubeSat Logical Architecture



### CubeSat Ground System Logical Architecture



### Cal Poly Design Spec SysML Model Organization

### Best-Known Successes

- Architecture Frameworks:** Unified Profile for DoDAF and MoDAF (UPDM); evolving into the "Architecture Framework" (AF)
- Business Process Modeling Notation:** BPMN™ provides businesses with the capability of understanding their internal business procedures
- Common Object Request Broker Architecture:** CORBA® remains the only language - and platform-neutral interoperability standard
- Data Distribution Service:** DDS™, Real-time, data-centric, publish-subscribe OMG specification for data distribution
- Meta-Object Facility:** MOF™, the repository standard and the basis for non-proprietary tool usage. A central way to query, view and transform languages.
- Model Based Systems Engineering (MBSE) – with INCOSE:** Provides processes & methods used in industry with specific emphasis on methodology and develops useful *metrics* that can be used on MBSE-related programs & projects; more specifically, *tool metrics* & *process metrics*.
- Systems Modeling Language:** SysML™ supports the specification, analysis, design, and verification and validation of a broad range of complex systems.
- Unified Modeling Language:** UML® remains the world's only standardized modeling language
- XML Metadata Interchange:** XMI®, the XML-UML standard purpose is to enable easy interchange of metadata between UML-based modeling tools & MOF-based metadata repositories.
- Space Specifications**
  - XTCX (XML Telemetry and Command Exchange)
  - GEMS (Ground Equipment Monitoring Service)
  - SOLM (Spacecraft Operations Language Metamodel)
- Work-In-Process**
  - XTCX 1.2 Revision Task Force deadline 23 May 2016
- Software-Based Communications**
  - Software-Defined Radio, Cognitive Radio (modeling SW-based communications)
  - JTRS SCA Standard Modeling
  - CORBA run-time infrastructure
  - Works with other organizations (Winn Forum, IEEE, JPEO)

### Next Steps

- Continue Development of Model
- Engage University CubeSat Team and Update Model
- Provide Model to University Team and Refine Model
- OMG Process for Adopting a CubeSat Reference Model
- Develop a Request for Proposal (RFP) which specifies the requirements for a CubeSat Reference Model
- OMG issue RFP
- OMG evaluates submitted CubeSat Reference Models and adopts one