Developing and Distributing a CubeSat Model-Based Systems Engineering (MBSE) Reference Model – Interim Status

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

NDIA Systems Engineering Conf.

October 24-27, 2016

Agenda

Project Objectives, Team, Phases

Current Phase – Develop CubeSat Reference Model

CubeSat System Reference Model

CubeSat Reference Information

Object Management Group

Approach to Validation

Next Steps

References

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 Object Management Group (OMG) international specification standard

Project Team

Aerospace students, professors, engineers, s/w developers

From government, industry, academia, tool providers

Email to be included on the email reflector list:

david.kaslow@gmail.com

Telecons every Friday at 1pm east coast time

Meeting materials and links to meeting recordings in Google docs

Conference papers posted in INCOSE SSWG Web Site

http://www.incose.org/ChaptersGroups/WorkingGroups/government/space-systems

Model-Based Systems Engineering (MBSE)

Model Based Systems Engineering (MBSE) [1]

Formalized application of modeling to support requirements, design, analysis, validation, and verification

Systems Modeling Language (SysML) [2]

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

- Systems Engineering Methodology
- System Modeling Tools
- Interfaces with Other Models

Project Phases

INCOSE MBSE Challenge Project

Initiated 2007

INCOSE SSWG

2007-2010

Phase 0

Modeled a Space System in SysML

Hypothetical FireSat - SMAD

Phase 1

CubeSat Framework

Prelim. RAX Model [3]

Phase 2

RAX Behavior Modeling Power, Comm, State [4]

Recent Efforts

Phase 3

RAX CubeSat Model

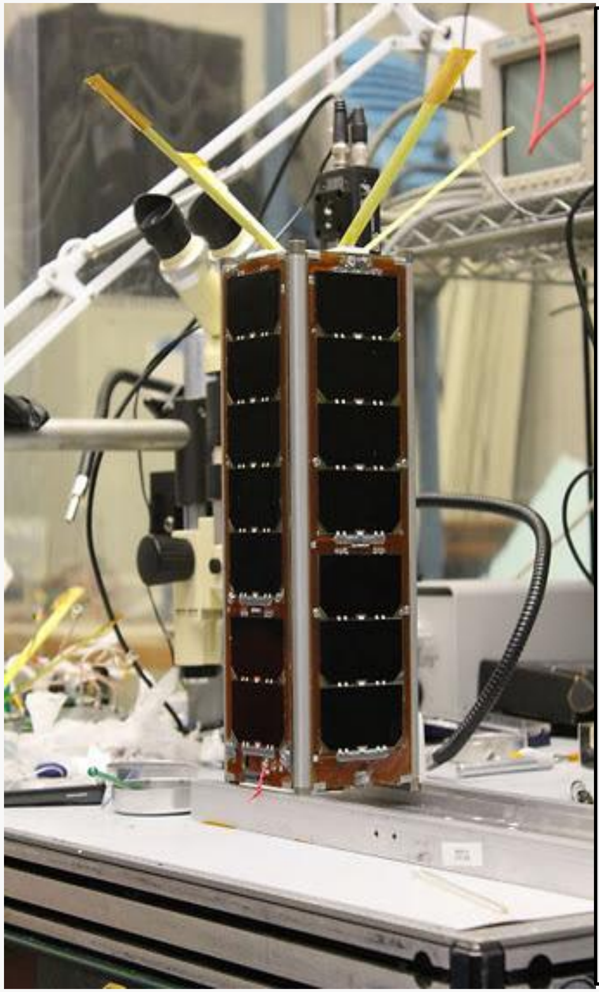
Trade Studies [5]

Current Efforts

Phase 4

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

Concept Phase Trade Studies



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

Concept Phase Trade Studies

Trade Studies	Trade Space	Performance Metric
Solar panel area	• Nominal:18.2 cm^2/slide • 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

Current Phase – Develop CubeSat Reference Model

Systems Engineering Methodology

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 will provide the logical architecture.

Examples of Logical Architecture

SSWG Team – CubeSat System SysML Model Development

Stakeholders

Univ. CubeSat Team
INCOSE
OMG
Cal Poly – CubeSat Spec
NOAA – Remote Sensing
NASA – Orbital Debris
FCC – Comm Spectrum
...

Logical Architectural Elements

Ground Segment
Ground Subsystems

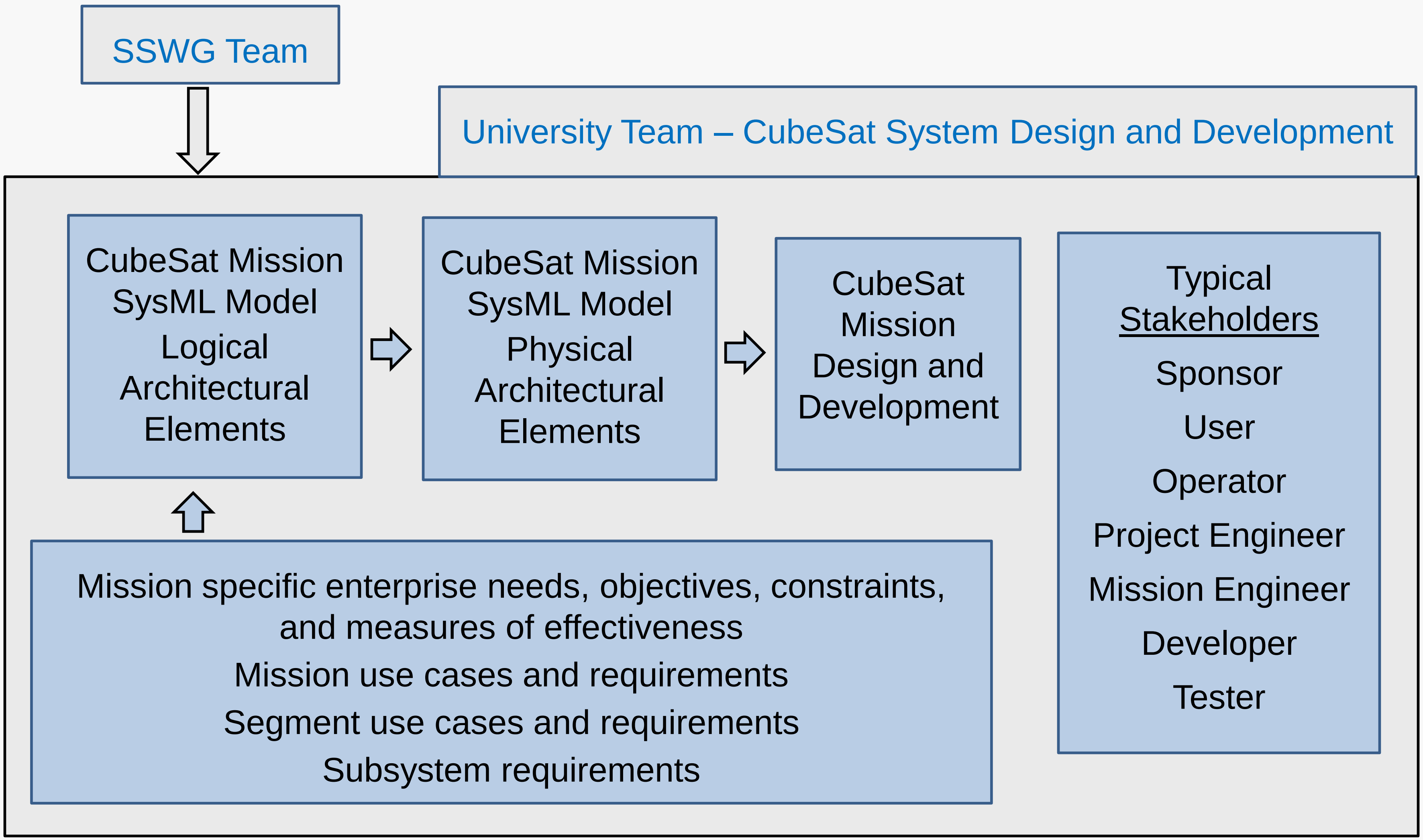
Technical Measures
Requirements
Use Cases
Data Flow
...

Space Segment
CubeSat
CubeSat Subsystems

Ground Station Services

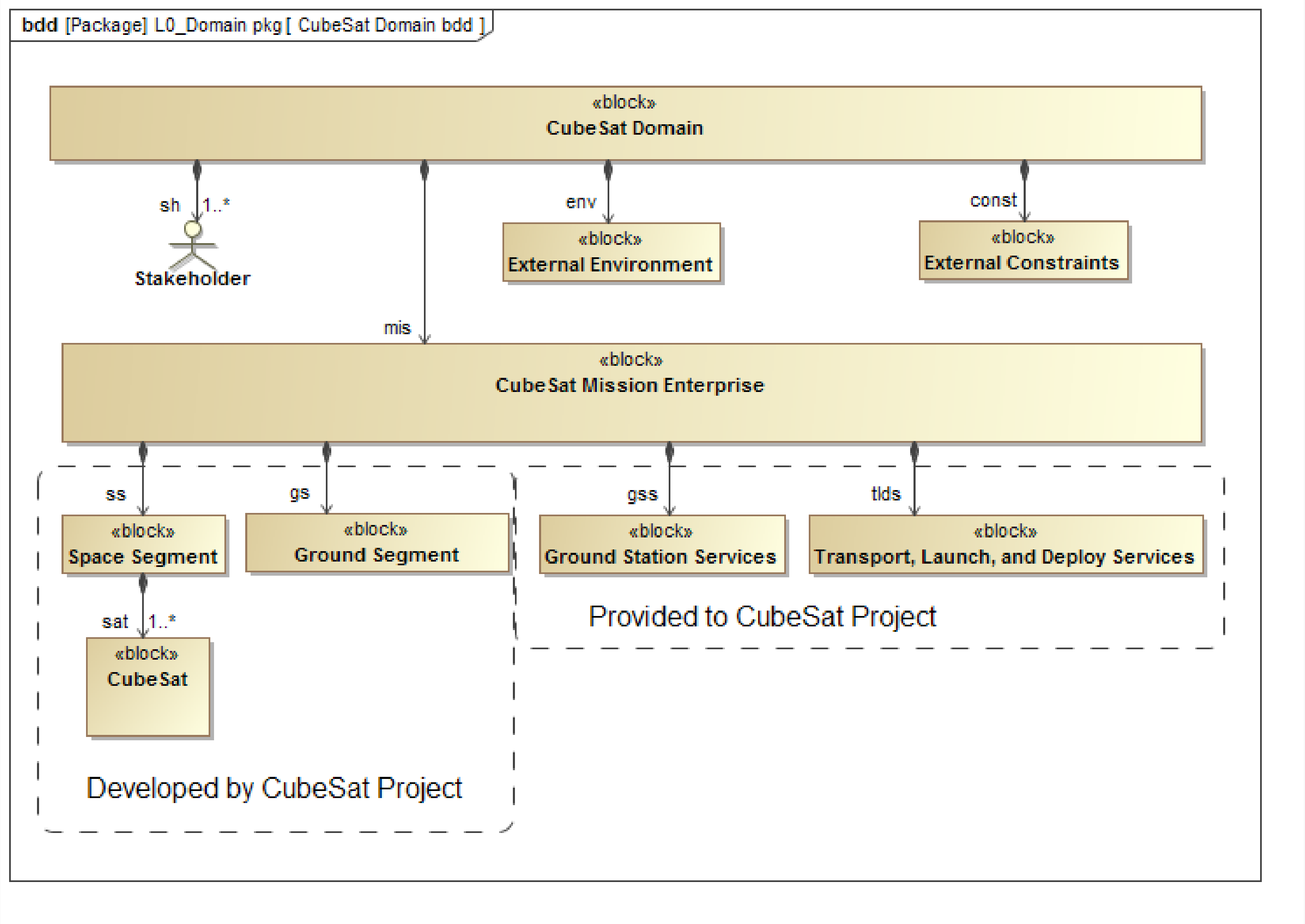
Transport, Launch, and Deploy Services

Application of SSWG Team Logical Architecture

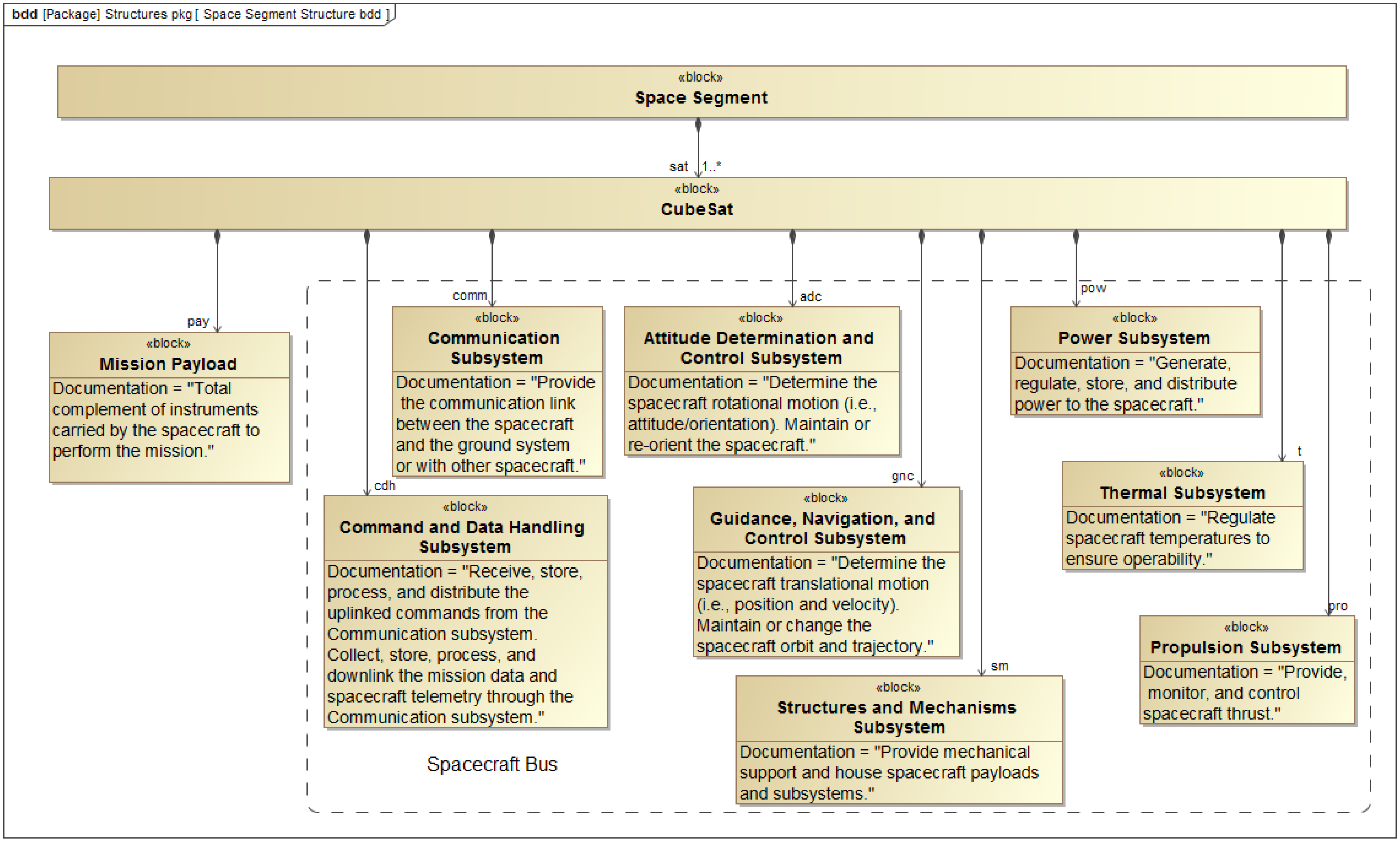


CubeSat System Reference Model

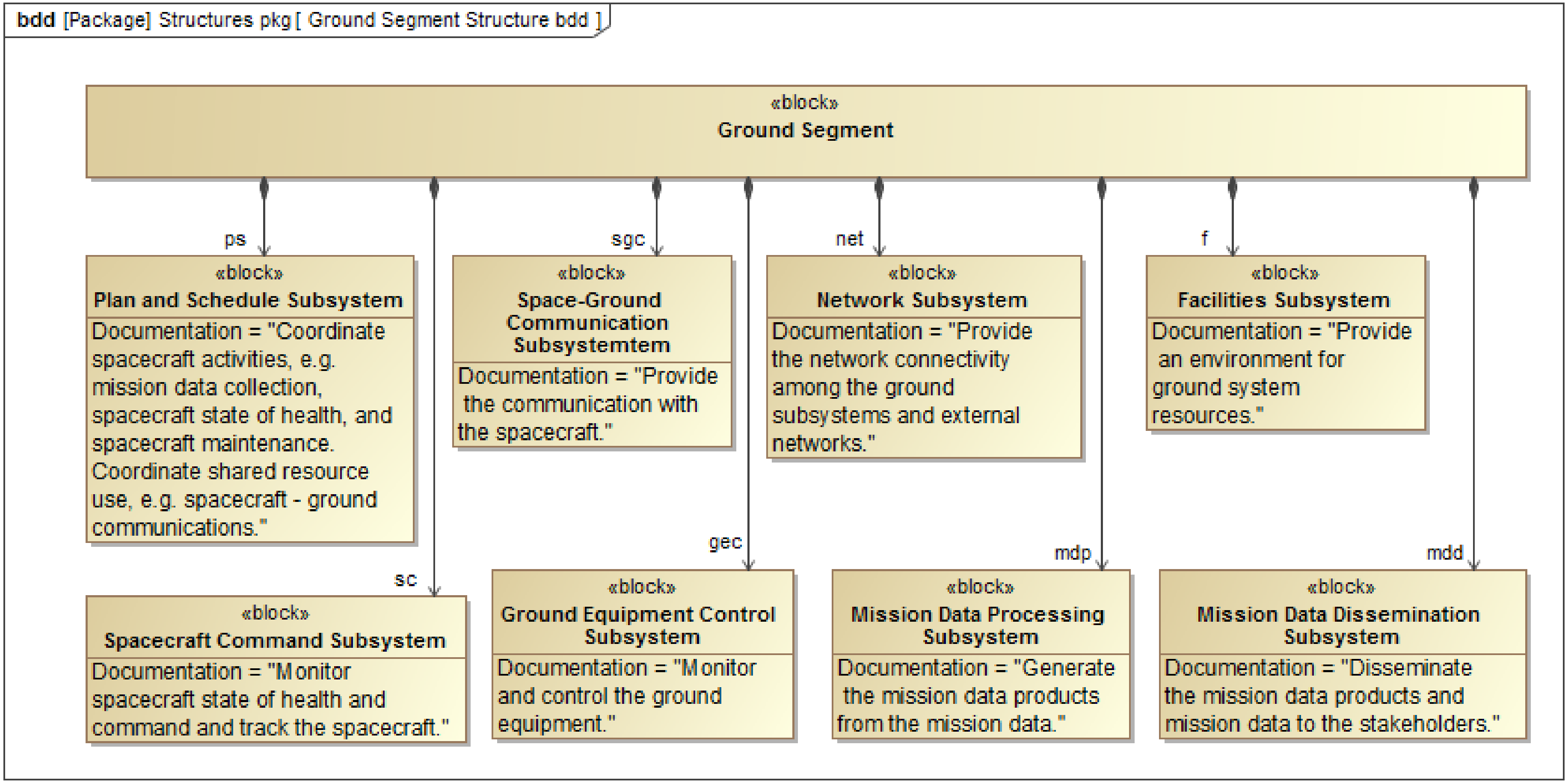
CubeSat Domain and Mission Enterprise



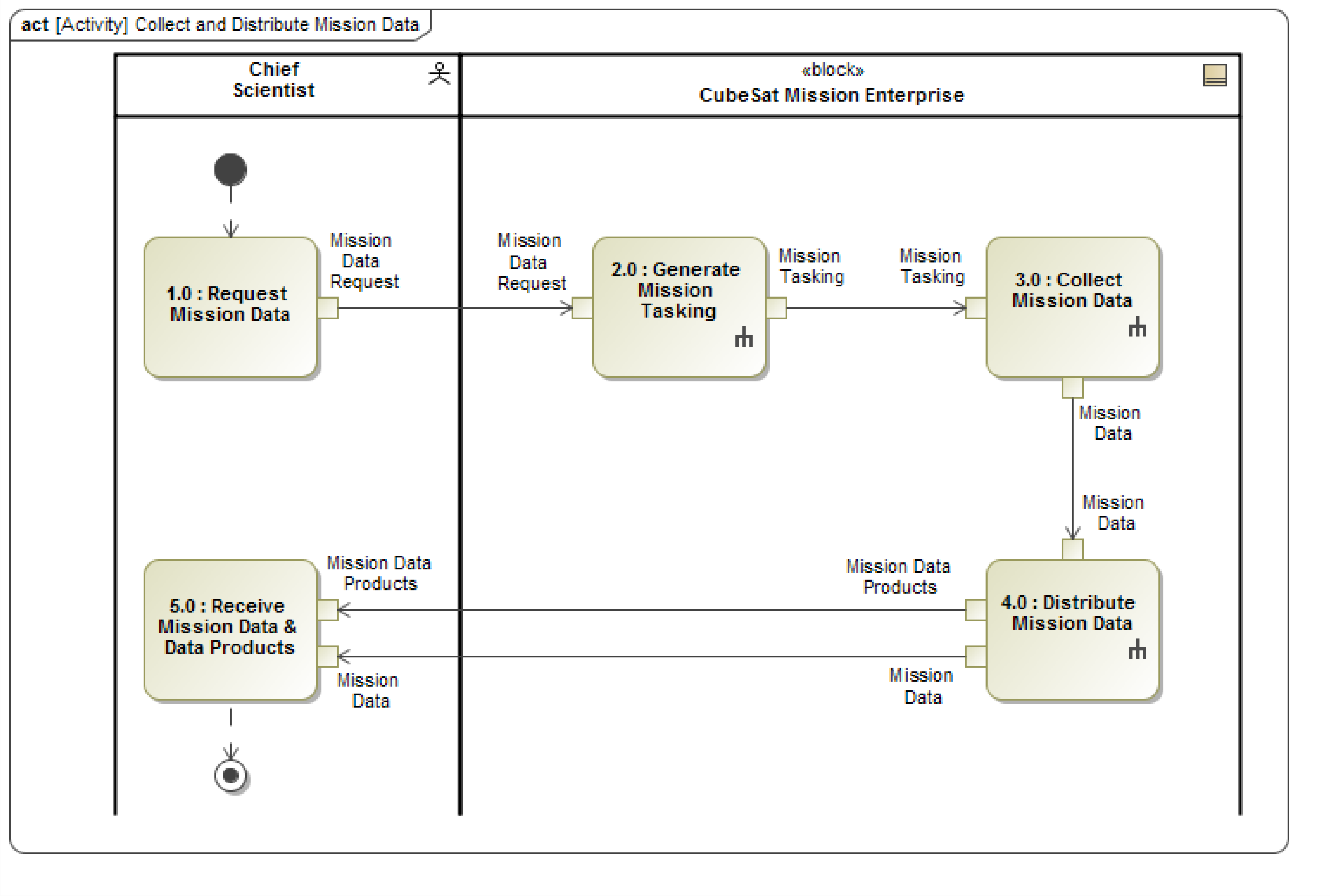
CubeSat Logical Architecture



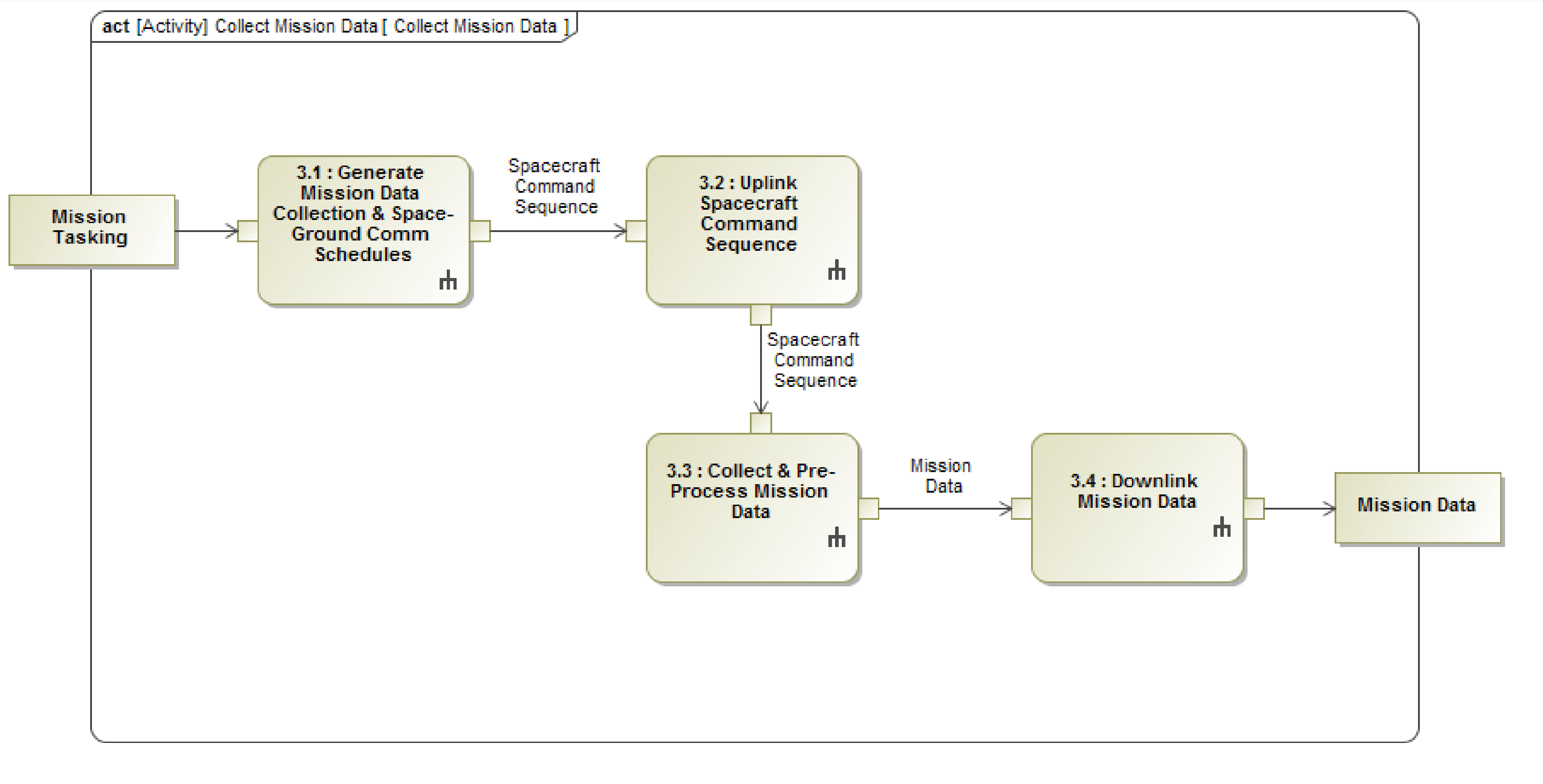
CubeSat Ground Segment Logical Architecture



Example Use Case
Collect and Distribute Mission Data

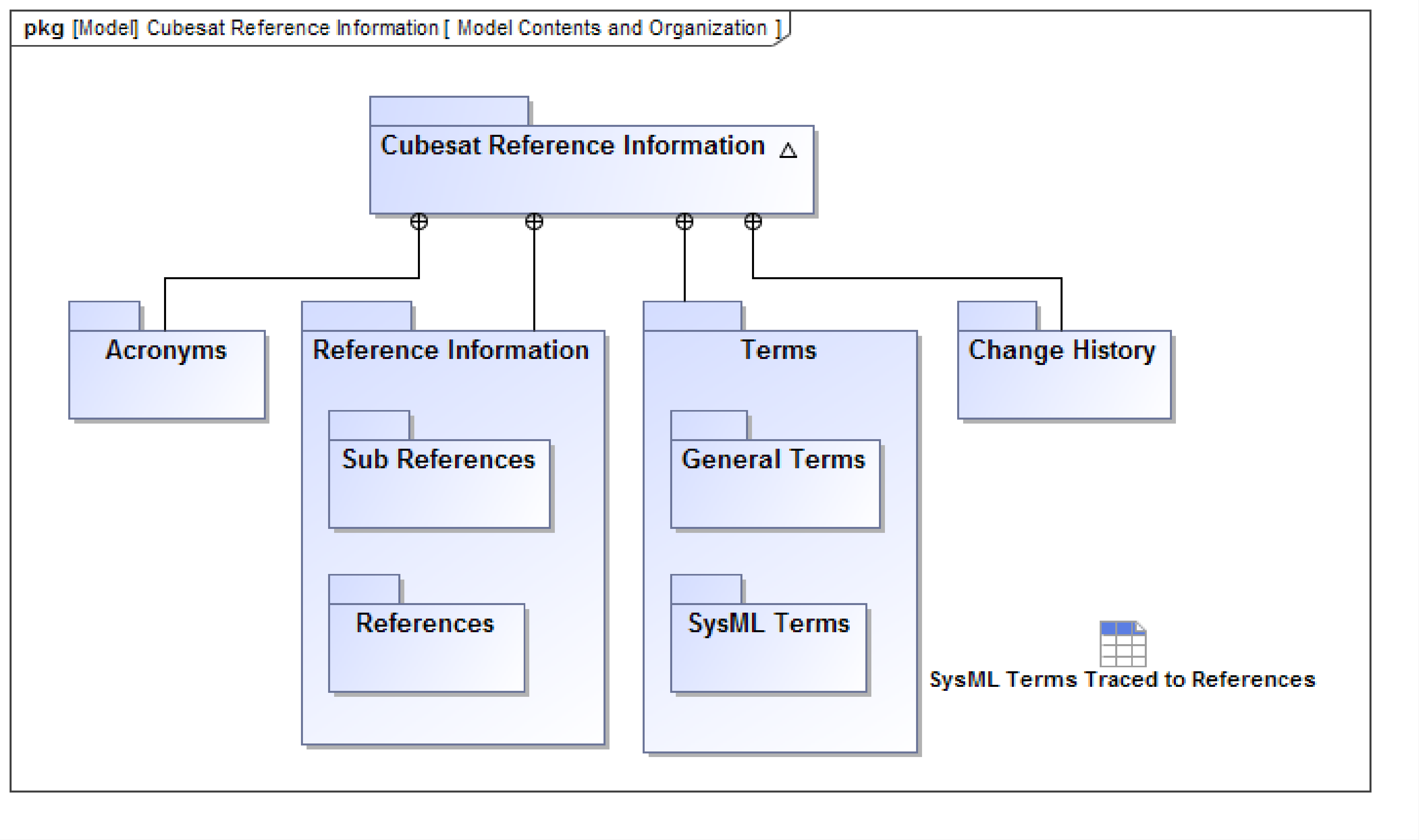


Collect Mission Data



CubeSat Reference Information

CubeSat Reference Information



General Terms (partial)

#	Term	Description
1	Concept of Operations	Describes how the system will fulfill the stakeholder needs and objectives. What the system will do and the rational.
2	Key Performance Parameter	TMs that are so critical that failure to meet threshold performance will result in reevaluation of a technical solution and with the possibility of project termination.
3	Measures of Effectiveness	Operational measures of success that are closely related to the achievement of mission objectives being evaluated, in the intended operational environment under a specified set of conditions. MOEs trace to mission objectives which trace to mission needs. System validation and verification, based on the MOPs and TPMs, provide confidence that the MOEs will be achieved.
4	Measures of Performance	Characterize the physical or functional attributes relating to the system operation; i.e., they provide insight into the performance of the specific system. MOPs trace to system requirements which in turn trace to mission requirements and to mission needs and mission objectives. MOPs can also trace to MOEs.
5	Mission Needs	A concise description of the needs or services that the system must provide. It should be solution-independent and only describe the problem the system is supposed to solve. The mission need drives everything else.
6	Mission Objectives	The broad set of goals that must be achieved in order to successfully satisfy the stated mission need, such as the purpose to be achieved, product to be produced, or a service to be performed
7	Mission Requirements	Derived from the Mission Objectives and Mission Constraints and documented in a simple, concise, verifiable, and understandable format. They should be stated in terms of operational and mission outcomes rather than implementation and solution concepts.
8	Stakeholder	Any entity (individual or organization) that has an interest in the system. Typical stakeholders include users, operators, organization decision makers, parties to the agreement, regulatory bodies, developing agencies, support organizations, and society at large They can also include interoperating and enabling systems.
9	Technical Measures	Technical Measures provide the stakeholders insight into the definition and development of technical solution. MOEs, KPPs, MOPs, and TPMs are TMs.
10	Technical Performance Mea	Measure attributes of a system element within the system to determine how well the system or system element is satisfying specified requirements TPMs trace to subsystem requirements. TPMs can also trace to MOPs. Verification activities provide data to the technical measurement process that is used to assess how well the technical measure is either projected to meet, or is meeting, its stated value.

Terms Traced to References (partial)

#	Name	Specifying Element
1	Activity Diagram	9.2 THE ACTIVITY DIAGRAM : SubReference A.7 ACTIVITY DIAGRAM : SubReference
2	Behavior Diagram	
3	Block	7.3 MODELING THE STRUCTURE AND CHARACTERISTICS OF BLOCKS USING PROPERTIES : Subl 7.4 MODELING FLOWS : SubReference
4	Block Definition Diagram	7.1.1 BLOCK DEFINITION DIAGRAM : SubReference A.4 BLOCK DEFINITION DIAGRAM : SubReference
5	Internal Block Diagram	7.1.2 INTERNAL BLOCK DIAGRAM : SubReference A.5 INTERNAL BLOCK DIAGRAM : SubReference
6	Package Diagram	6.2 THE PACKAGE DIAGRAM : SubReference A.3 PACKAGE DIAGRAM : SubReference
7	Parametric Diagram	8.1.1 DEFINING CONSTRAINTS USING THE BLOCK DEFINITION DIAGRAM : SubReference 8.1.2 THE PARAMETRIC DIAGRAM : SubReference A.6 PARAMETRIC DIAGRAM : SubReference
8	Requirement Diagram	13.1 OVERVIEW (Modeling Requirements) : SubReference A.11 REQUIREMENT DIAGRAM : SubReference
9	Sequence Diagram	A.8 SEQUENCE DIAGRAM : SubReference 10.2 THE SEQUENCE DIAGRAM : SubReference
10	State Machine Diagram	11.2 STATE MACHINE DIAGRAM : SubReference A.9 STATE MACHINE DIAGRAM : SubReference
11	Structure Diagram	7 MODELING STRUCTURE WITH BLOCKS : SubReference
12	Use Case Diagram	12.2 USE CASE DIAGRAM : SubReference A.10 USE CASE DIAGRAM : SubReference

Sub References (partial)

#	Name	Parent Ref : Reference	Description : String	Sub Ref Type : Sub Ref Type
1	6.2 THE PACKAGE DIAGRAM	A Practical Guide to SysML, 3rd ed. : Re		Section
2	7.1.1 BLOCK DEFINITION DIAGRAM	A Practical Guide to SysML, 3rd ed. : Re		Section
3	7.1.2 INTERNAL BLOCK DIAGRAM	A Practical Guide to SysML, 3rd ed. : Re		Section
4	7.3 MODELING THE STRUCTURE AND CHARACTERISTICS OF BI	A Practical Guide to SysML, 3rd ed. : Re		Section
5	7.4 MODELING FLOWS	A Practical Guide to SysML, 3rd ed. : Re		Section
6	7 MODELING STRUCTURE WITH BLOCKS	A Practical Guide to SysML, 3rd ed. : Re		Section
7	8.1.1 DEFINING CONSTRAINTS USING THE BLOCK DEFINITION	A Practical Guide to SysML, 3rd ed. : Re		Section
8	8.1.2 THE PARAMETRIC DIAGRAM	A Practical Guide to SysML, 3rd ed. : Re		Section
9	9.2 THE ACTIVITY DIAGRAM	A Practical Guide to SysML, 3rd ed. : Re		Section

Object Management Group (OMG)

OMG

An International, Open Membership, Not-for-Profit
Technology Standards Consortium (27 Years)

- Provides only specifications and does not provide implementations
  - Available for free

- OMG
  - Develops a Request for Proposal which specifies the requirements for a CubeSat Reference Model
  - Issues the RFP
  - Evaluates submitted CubeSat Reference Models and
  - Adopts one.
  - Before a specification can be accepted as a standard by OMG, the members of the winning submitter team must guarantee that they will develop a conforming product within 1 year.

OMG

Unified Modeling Language: *UML® remains the world's only* standardized modeling language

Systems Modeling Language: SysML™ supports the specification, analysis, design, and verification and validation of a broad range of complex systems.

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.

Architecture Frameworks: Unified Profile for DoDAF and *MoDAF(UPDM*); evolving into the "Architecture Framework" (AF)

Common Object Request Broker Architecture: CORBA® remains the only language - and platform-neutral interoperability standard

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.

Approach to Validation

Approach to Validation

- Define scope of CRM based on:
  - CRM needs and objectives
  - INCOSE – OMG Memorandum of Understanding
  - INCOSE Technical Product Plan
  - OMG RFP process
- Populate model with a representative mission to demonstrate completeness
  - Stakeholder needs, objectives, technical measures
  - Requirements and use cases – mission, segment, subsystem
- Evaluation by several university CubeSat teams
  - Ease of navigation, population, and use.
  - Meeting their needs and applicability to their mission-specific CubeSats

Next Steps

Next Steps

- Continue Development of Model
- Provide Model to University Teams and Refine Model
- OMG Process for Adopting a CubeSat Reference Model

References

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[1] 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

[2] Object Management Group (OMG), OMG Website. [Online]. Available: http://www.omgsysml.org/

[3] Object Management Group (OMG), OMG Wiki. [Online]. Available: http://www.omgwiki.org/MBSE/doku.php?id=mbse:incoseoosem

[4] 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.

[5] 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.

[6] L. Anderson, B. Cole, R. Yntema, M. Bajaj, S. Spangelo, D. Kaslow, C. Lowe, E. Sudano, M. Boghosian, R. Reil, S. Asundi, and S. Friedenthal, "Enterprise Modeling for CubeSats," *Proceedings of IEEE Aerospace Conference*, Big Sky, MT, March 2014.

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[8] 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.

[9] 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.

[10] 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

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