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

www.incose.org www.omg.org

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

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
- Mission data collect
- Payloads
- …

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.omgsysml.org/

[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

[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.

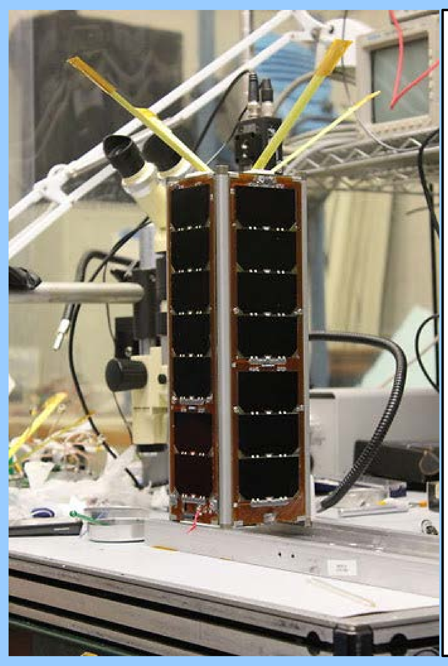
[8] D. Kaslow, B. Ayres, M.J Chonoles, S. Gasster, L. Hart, C. Massa, R. Yntema, B. Shiotani, "Developing and Distributing a CubeSat Model-Based System Engineering (MBSE) Reference Model – Interim Status #2", *Proceedings of IEEE Aerospace Conference*, Big Sky, MT, March 2016

[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 Systems Engineering (MBSE) Reference Model – Status", ", *Proceedings of the 32st Space Symposium*, Colorado Springs, CO, April 2016.

SSWG Challenge Project

- 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 – 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	• 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

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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

SSWG Team – CubeSat System SysML Model Development

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

Model Release
Validation Verification Accreditation
Approval Mechanism
Maintenance

OMG
Repository
Configuration Manage
Intellectual Property Protection
Distribution

Mission Team – CubeSat System Development

Typical Stakeholders
Sponsor
User
Operator
Project Manager
Mission Engineer
Developer
Tester
...

Two Teams – Two Groups of Stakeholders

SSWG CubeSat Reference Model Development

Actors
Stakeholders
Guidance and Regulations
Domain
Enterprise
...

Ground Segment
Ground Subsystems
...

Technical Measures
Requirements
Use Cases
Data Flow
Validation
Verification
...

Space Segment
CubeSat
CubeSat Subsystems
...

Ground Station Services
Transport, Launch, and Deploy Services
...

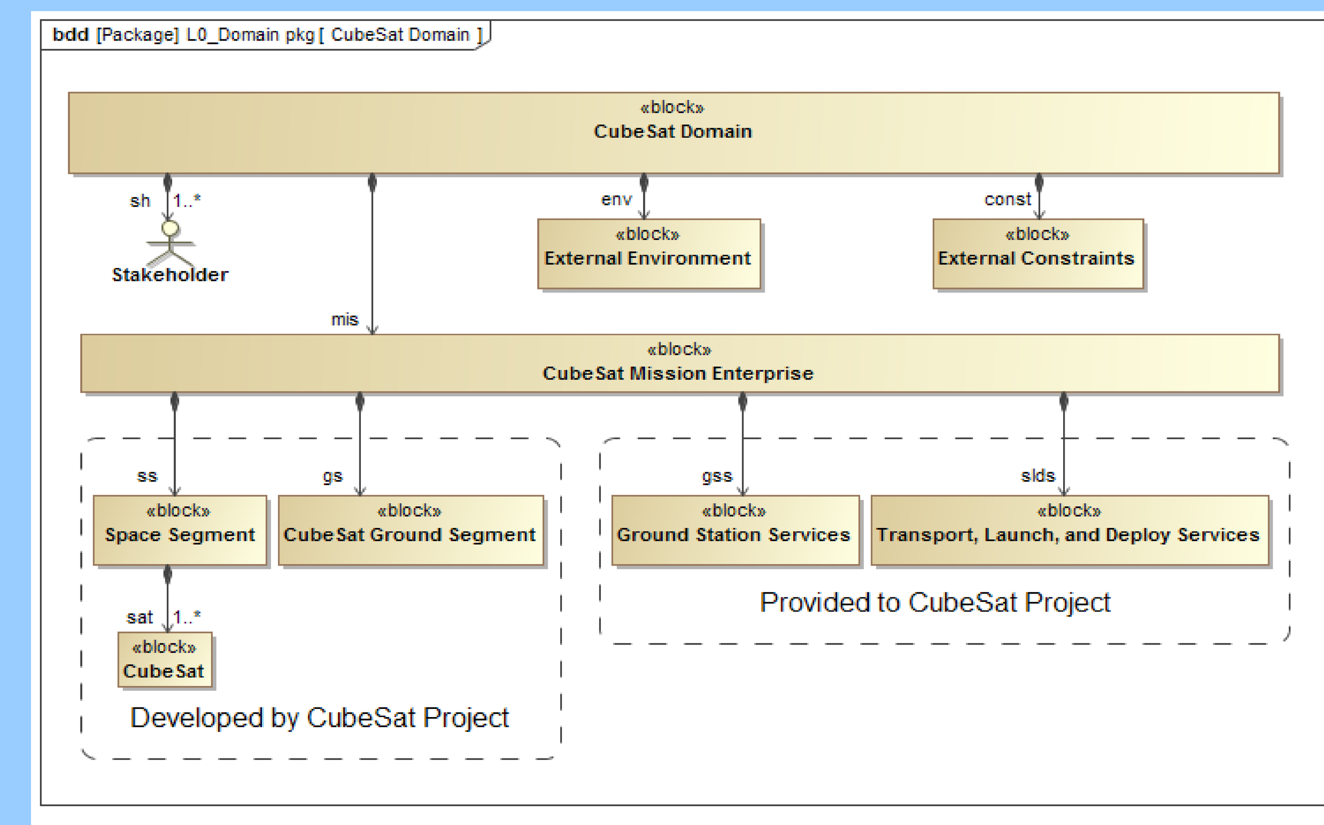
Mission Team – CubeSat System Design and Development

CubeSat SysML Model Logical Architectural Elements ⇨ CubeSat Mission Logical Architectural Elements ⇨ CubeSat Mission Physical Architectural Elements ⇨ CubeSat Mission Design and Development

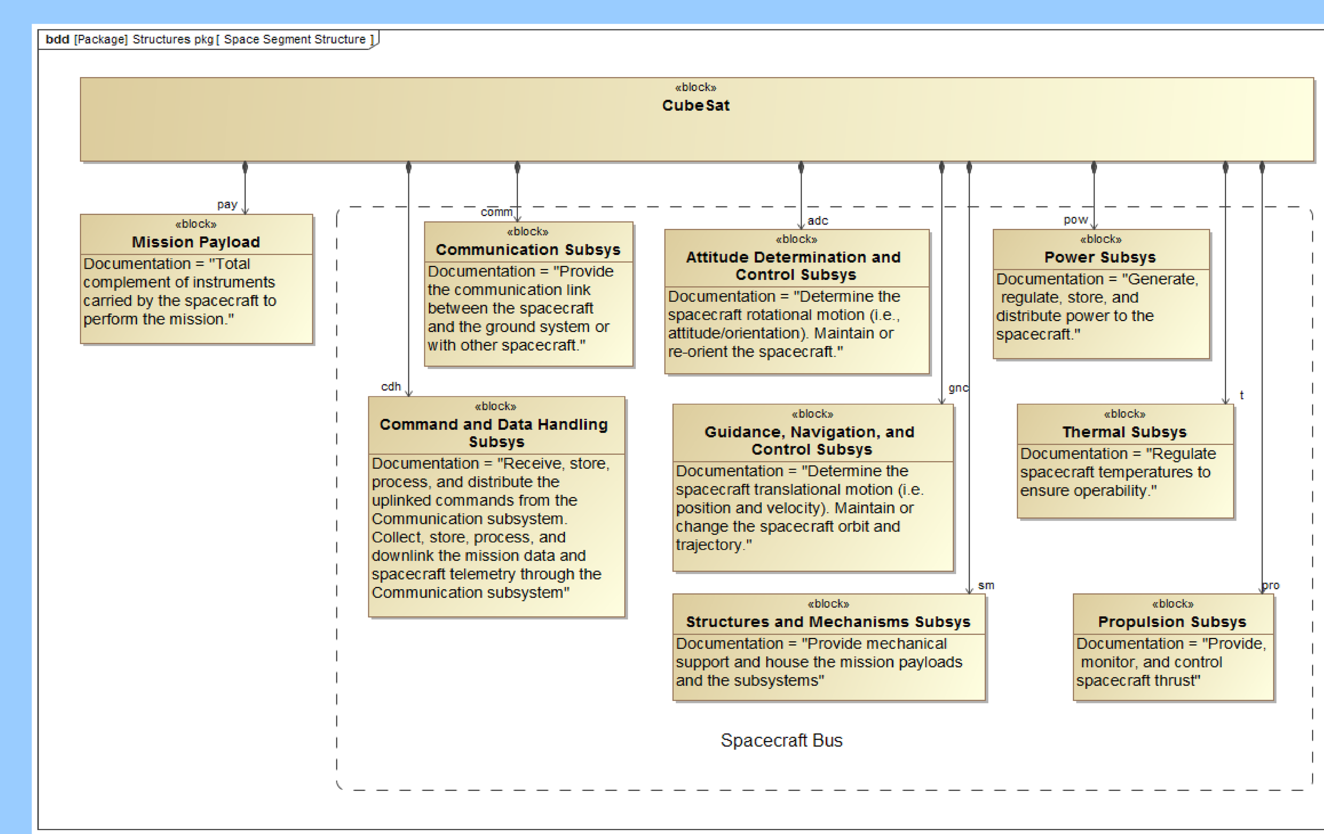
Mission specific enterprise needs, objectives, constraints, and measures of effectiveness
Mission use cases and requirements
Segment use cases and requirements
Subsystem requirements

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

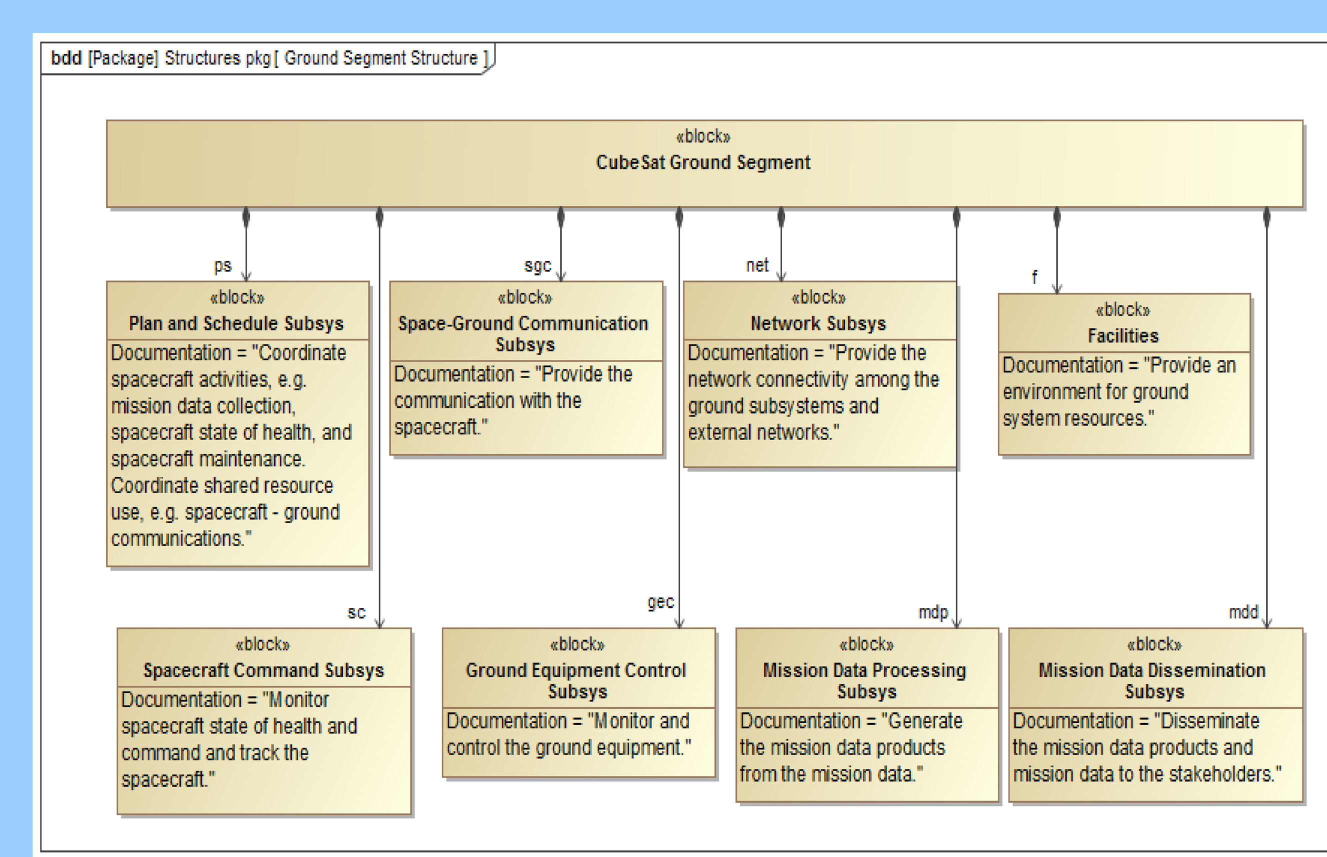
CubeSat Reference Model Views – Phase 4 [9]



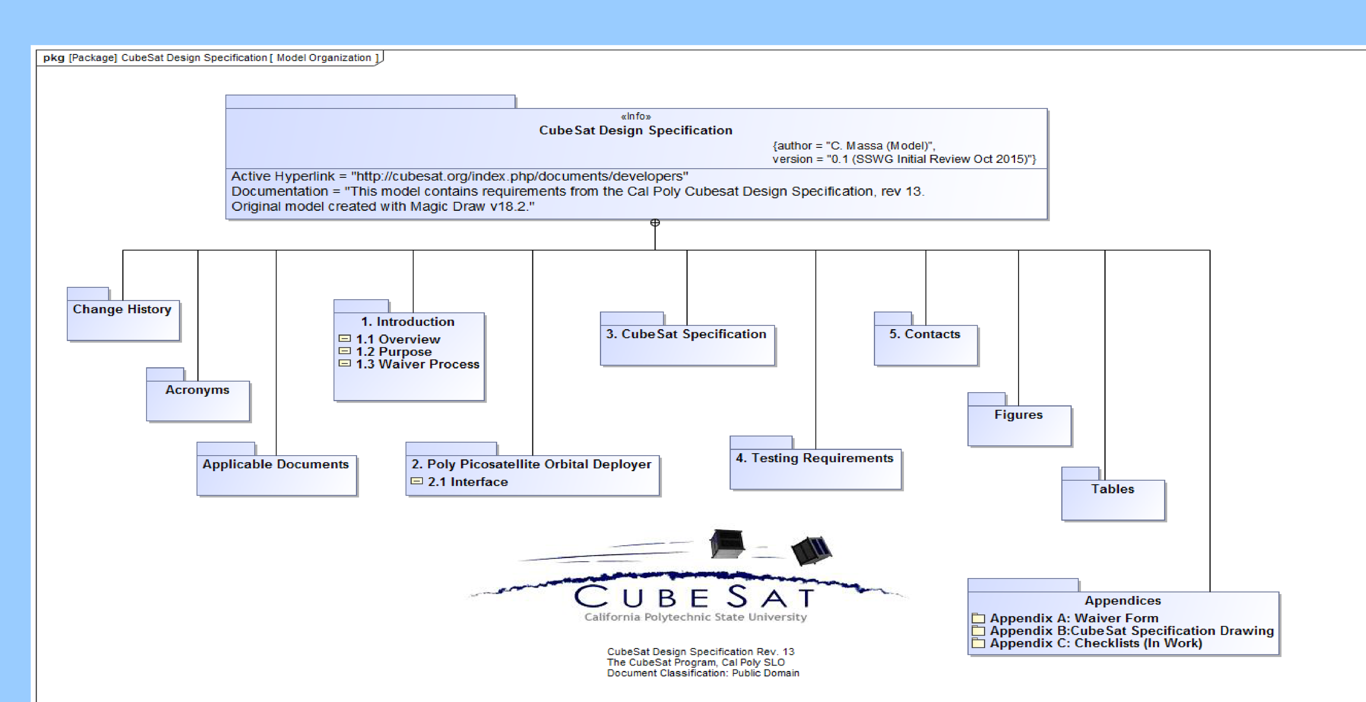
CubeSat Domain and Mission Enterprise



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.

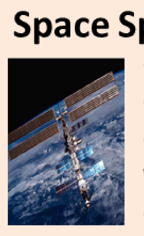
Model Based Systems Engineering (MBSE) – with INCOSE: Provides processes & methods used in industry with specific emphasis on methodology and develops useful *metrics* that can be used on MBSE-related programs & projects; more specifically, *tool metrics* & *process metrics*.

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



- XTCE (XML Telemetry and Command Exchange)
- GEMS (Ground Equipment Monitoring Service)
- SOLM (Spacecraft Operations Language Metamodel)

Work-In-Process

- XTCE 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

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