Developing a CubeSat Model Based System Engineering (MBSE) Reference Model

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

Prove-out MBSE methodology on a CubeSat

Provide a CubeSat Reference Model and a CubeSat Project 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 Commercial Modeling and Simulation Tool Providers

Telecons every Friday at 1pm east coast time
Meeting materials and links to meeting recordings in Google docs
Email me to be included on the email reflector list
INCOSE MBSE Initiative - Genesis, Flow, Interaction

International Council on Systems Engineering (INCOSE)

INCOSE Working Groups

Space Systems Working Group 2000

INCOSE SE Vision 2020 [1]

2007 MBSE & SysML

MBSE Initiative & Roadmap [2], [3]

MBSE Challenge Teams

Space System Modeling

Object Modeling Group (OMG)

Systems Modeling Language (SysML) [4]

2006

Unified Modeling Language (UML)

SSWG Challenge Project
Emerging MBSE Standards

- Defined MBSE theory, ontology, and formalisms
- Architecture model integrated with simulation, analysis, and visualization
- Matured MBSE methods and metrics
- Integrated system / HW / SW models

Adapted from [3]

Institutionalized MBSE Across Academia / Industry

Well Defined MBSE

Ad Hoc MBSE Document Centric

Extending Maturity and Capability

Distributed and secure model repositories crossing multiple domains

2010 2015 2020 2025

Adapted from [3]
**MBSE and SysML**

**INCOSE Systems Engineering Vision 2020** [1]
MBSE: Formalized application of modeling to support system requirements, design, analysis, verification, and validation activities

**Survey of Model Based Systems Engineering Methodologies** [5], [6]
e.g. INCOSE OOSEM, IBM Telelogic Harmony SE, Vitech MBSE
MBSE: A collection of related processes, methods, and tools

**Object Oriented Systems Engineering Method**
**OOSEM**
Top down, scenario driven process that uses SysML

**Object Management Group** [4]
SysML: A graphical modeling language for modeling complex systems including hardware, software, information, personnel, procedures, and facilities
SysML is a language, it is not a methodology, it is not a tool.

Diagrams are views of the underlying system model.

A block is the basic unit of structure.

- Structure Diagrams
  - Block Definition
  - Internal Block

- Behavior Diagrams
  - Use Case
  - Activity
  - Sequence
  - State Machine

- Parametric Diagram

- Model Elements
  - Blocks
  - Actors
  - Flow Specifications
  - Constraint Blocks
  - Interfaces
  - Signals
  - Ports
  - ...

- Requirements Diagram

- Package Diagram

- Block Properties
  - Parts
  - References
  - Values
  - Constraints
  - Operations
  - Receptions
SSWG Challenge Project

INCOSE MBSE Challenge Project
Initiated in 2007

INCOSE SSWG 2007-2010
Phase 0
Modeled a Space System in SysML
Hypothetical FireSat - SMAD

MBSE CubeSat Project 2011 to Present
Phase 1
CubeSat Framework
Preliminary RAX Model
Phase 2
RAX Behavior Modeling
Power, Comm, State

Recent Efforts (Phase 3)
Enterprise Modeling for CubeSats
All lifecycle phases
RAX CubeSat Model Trade Studies
Tools

- **No Magic - MagicDraw**
  - Graphical SysML modeling tool

- **No Magic - Cameo Simulation Toolkit**
  - Enables the time-step execution of behavior models within Magic Draw

- **InterCAX - Paramagic**
  - Plug-in module for MagicDraw
  - Enables the execution of parametric models and system trades
  - Wraps external models such as MATLAB/Simulink, Mathematica, or Excel
Tools

- **Analytical Graphics - Systems Tool Kit**
  - Simulation and visualization of spacecraft behavior

- **Phoenix Integration - ModelCenter**
  - Graphical environment for creating simulation workflows by integrating various types of simulation models, including Excel spreadsheets, STK scenarios, and MATLAB scripts.
  - Once a simulation workflow is created, PHX ModelCenter executes the workflow, automatically transferring data between the simulators

- **Phoenix Integration - MBSE Analyzer**
  - Enables the execution of parametric diagrams via ModelCenter
MBSE CubeSat Project

Phase 3

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

**State Diagrams**
- Orbit
- Solar
- Experiment
- Download

Models behavior in response to internal and external events

**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

**Parametric Diagrams**
- Get States
- Power Collection
- Update Energy
- Update Data
- Update Download

Mapped to analytical and simulation models that estimate RAX performance

Time step through a scenario and model:
- Energy collection and usage
- Data collection, storage, and downlink
MBSE CubeSat Project

Phase 4

Developing a CubeSat Model Based System Engineering (MBSE) Reference Model
CubeSat Reference and Project Models

**CubeSat System Reference Model**
SysML elements for specifying requirements, design, development, and operations

**CubeSat Project Model**
Processes and methods for design, development, and operations
Includes SysML activity and sequence diagrams

**Cal Poly CubeSat Design Specification [7]**
Mechanical, Electrical, Communication Licenses, Imaging Licenses, Debris Mitigation, Verification Reporting and Signoff
CubeSat Reference Model - Scope

Lifecycles
Conception through retirement

Phases of Operations
Launch
Early ops
Normal ops
Degraded

CubeSat Reference Model
A model that can be used as a starting point for a mission specific CubeSat model

Mission Stakeholders
Needs
Objectives
Measures of Effectiveness
Constraints

Foundations
INCOSE Systems Engineering Handbook [8]
NASA System Engineering Handbook [9]
Applied Space Systems Engineering [10]
CubeSat Mission Design Based on Systems Engineering Approach [12]
CubeSat Reference Model – Goal

**SysML Diagrams**
- Packages
- Requirements
- Parametrics
- Behaviors
- Structures

**No Magic’s Magic Draw**
Graphical SysML Modeling Tool

**CubeSat Reference Model**

**Mission Specific CubeSat**

**Space and Ground – System Components**
Library of components to swap in and out of model

**Interface with COTS Modeling and Simulation Tools**
CubeSat System Reference Model
CubeSat Stakeholders

[Diagram showing CubeSat Domain with various stakeholders including Launch Service Integrator, Procuer, Communication Service Integrator, Sponsor, End User, Tester, Developer, Project Engineer, Supplier, Project Manager, Regulatory Agencies (FCC, ITU).]
CubeSat Mission Needs, Objectives, Requirements
CubeSat Operational Domain

CubeSat Operational Domain

CubeSat Mission Enterprise — External Environment — External Constraints

INCOSE SSWG MBSE CubeSat Project
CubeSat External Environment and External Constraints

Diagram name: CubeSat Operational Domain - External
Author: Iandersso
Creation date: 7/30/14 11:09 AM
Modification date: 7/30/14 1:59 PM

This diagram was created by INCOSE: Space Systems Working Group - CubeSat Challenge Team. For more information please contact David.Kaslow@gmail.com or twemo@gmail.com

Diagram elements:
- CubeSat Operational Domain
- External Environment
  - Natural Environment
  - Induced Environment
    - Space Environment
    - Earth Environment
    - Launch Environment
    - Cyber Environment
    - Shipping
- External Constraints
  - Technical Constraints
  - Licenses
  - Regulations
- Orbit
CubeSat Mission Enterprise
CubeSat Logical Space System

Diagram name: Logical Space System
Author: sanderso
Creation date: 7/31/14 2:22 PM
Modification date: 9/23/14 6:59 PM

This diagram was created by INCOSE: Space Systems Working Group - CubeSat Challenge Team. For more information please contact Oskar Kostow@gmail.com or weero@gmail.com

Space System Overview
- Space System
- Bus
- Payload
- Payload Subsystems
- Bus Subsystems
Next Steps and References
Next Steps

- Determine the level of model definition at each of the lifecycle stages
- Create models for the concept and development stages
- Validate the models by applying them to a hypothetical CirrusSat mission
- Provide the models to a university aerospace engineering program


References


