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)

Telecon every Friday at 1pm EST
Meeting materials and links to meeting recording in Google docs
Email me to be included on the email reflector list
MBSE Initiative - MBSE Roadmap

MBSE Capability

- Reduced cycle times
- System of systems interoperability
- Design optimization across broad trade space
- Cross domain effects based analysis

Extending Maturity and Capability

- Distributed & secure model repositories crossing multiple domains
- Defined MBSE theory, ontology, and formalisms
- Architecture model integrated with Simulation, Analysis, and Visualization
- Matured MBSE methods and metrics, Integrated System/HW/SW models
- Emerging MBSE standards

Institutionalized MBSE across Academia/Industry

Well Defined MBSE

Ad Hoc MBSE Document Centric

Maturity

2010 2020 2025

Refer to activities in the following areas:

- Planning & Support
- Research
- Standards Development
- Processes, Practices, & Methods
- Tools & Technology Enhancements
- Outreach, Training & Education


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MBSE and SysML

Model Based Systems Engineering (MBSE)
Performing SE with models
System and subsystem level models
Integration of models and simulations
Authoritative, integrated repository of information from procurement through operations

INCOSE – OMG Project:
Systems Modeling Language (SysML)
Requirements
Parametrics
Structure
Behavior
Block Definition
Activity
Internal Block
Sequence
State
Use Cases

SysML is not a methodology or a tool
SysML

**Structure Diagrams**
- Block Definition
- Internal Block

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

**Block Properties**
- Parts
- References
- Values
- Constraints
- Operations
- Receptions

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

A Block is the basic unit of structure

Diagrams are views of the underlying system model

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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

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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
Phase 3 – RAX Mission Simulation

**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.
## Phase 3 – RAX Mission Simulation

<table>
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<tr>
<th>Trade Studies</th>
<th>Values Studied</th>
<th>Performance Metric</th>
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<tbody>
<tr>
<td>Solar Panel Area</td>
<td>• Nominal: 18.2 cm²/side</td>
<td>On-board energy</td>
</tr>
<tr>
<td></td>
<td>• ½ of nominal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• ¼ of nominal</td>
<td></td>
</tr>
<tr>
<td>Max Battery Capacity</td>
<td>• Nominal: 115,000 J</td>
<td>On-board energy</td>
</tr>
<tr>
<td></td>
<td>• Reduced: 100,000 J</td>
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<tr>
<td>Orbital Altitude</td>
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<tr>
<td></td>
<td>• Low: 593 km x 250 km</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• High: 1311 km x 932 km</td>
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<tr>
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<td>• Ann Arbor &amp; Menlo Park</td>
<td>Quantity of data downloaded</td>
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<tr>
<td></td>
<td>• Ann Arbor &amp; Fairbanks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Fairbanks &amp; Menlo Park</td>
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</tr>
</tbody>
</table>
MBSE CubeSat Project

Phase 4

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

Lifecycles
Conception through retirement

Phases of Operations
Launch
Early ops
Normal ops
Degraded Sustainment

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

Mission Stakeholders
Needs, Objectives, Measures of Effectiveness, Constraints

Foundations
NASA System Engineering Handbook
CubeSat Mission Design Based on Sys Eng Approach, S. Asundi
INCOSE Systems Engineering Handbook
A Practical Guide to SysML. Friedenthal et al

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CubeSat Reference Model – Implementation

**SysML Diagrams**
- Package Diagrams,
- Block Def Diagrams,
- Internal Block Diagram,
- Requirements,
- Parametrics,
- Behaviors

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

**CubeSat Reference Model**

**Interface with COTS Modeling and Simulation Tools**

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

**Mission Specific CubeSat**

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CubeSat Domain
Stakeholders

Diagram name: Stakeholder Overview
Author: Nandco
Creation date: 7/30/14 3:16 PM
Modification date: 7/30/14 3:42 PM

SSWG: This diagram was created by INCOSE - Space Systems Working Group - CubeSat Challenge Team. For more information, please contact david.kaliszewski@gmail.com or lisa.app@gmail.com

Legend:
- Stakeholder
- Domain

Diagram showing the CubeSat Domain and various stakeholders including Launch Service Integrator, Procurer, Communication Service Integrator, Sponsor, End User, Project Manager, Supplier, Project Engineer, Tester, Developer, Regulatory Agencies (FCC, ITU).
Mission Needs, Objectives, MOEs, Constraints
Operational Domain
External Environment and External Constraints
Mission Enterprise
Logical Space System
Logical Ground System
Next Steps

- Physical Model
- Library of Components
- Development Domain
- Sustainment Domain
- Retirement Domain
Appendix A
INCOSE Systems Engineering Vision 2020

- Model-based systems engineering (MBSE)
  - Formalized application of modeling to support system requirements, design, analysis, verification and validation activities
  - Begins in the conceptual design phase and continues throughout development and later life cycle phases
  - Part of a long-term trend toward model-centric approaches adopted by other engineering disciplines, including mechanical, electrical and software
  - Expected to:
    - Replace the document-centric approach
    - Be fully integrated into the definition of systems engineering processes

- Systems Modeling Language (SysML)
  - A general purpose graphical modeling language for specifying, designing, analyzing and verifying complex systems
  - Adopted by the Object Management Group (OMG) 2006 and is being implemented in MBSE support tools

From http://www.incose.org/ProductsPubs/products/sevision2020.aspx
SysML

SysML Diagrams

- Package Diagram
  - Block Definition Diagram
  - Internal Block Diagram

- Structure Diagram

- Requirement Diagram
  - Activity Diagram
  - State Diagram
  - Sequence Diagram

- Parametric Diagram

- Behavior Diagram
  - Use Case Diagram
SysML

- Package Diagrams are containers for model elements. Package diagrams are used to describe model organization (6.2, A3)

- Requirement diagrams depict requirements and their relationship with other requirements, design elements, and test cases (13.1, A11)
  - SysML requirement elements have compartments for name, ID, text and traceability.
  - The traceability compartments include owner derived, derived from, satisfied by, and verified by

- Blocks are the modular units of structure in SysML (7.3, 7.4)
  - They define a system component or an item that flows through the system as well as external entities, conceptual entities, or other logical abstractions

- Parametric diagrams define systems of equations that constrain the value properties of the blocks (8.1.1, 8.1.2, A6)

References are to section in A Practical Guide to SysML: The Systems Modeling Language,
• Structure diagrams describe how the system is put together the architecture of the system
• Block definition diagrams define the characteristics of blocks in terms of structure and behavior features, the relationships between the blocks, and the parametric constraints (7.1.1, A4)
• Internal block diagrams describe the internal structure of blocks in terms of how their parts are interconnected (7.1.2, A5)
• Behaviors diagrams describe how a block deals with inputs and outputs and changes to its internal state (7.3.4)
  – Behavior diagrams describe what the system must do to meet requirements
SysML

- Activity diagram models behavior in terms of the flow of inputs, outputs, and control (9.2, A7)
- Sequence diagram represents the interaction between structural elements of a block, as a sequence of message exchanges (11.2, A9)
- State machine diagram describe state dependent behavior of a block through out its life cycle (A8)
- Use case diagram models the relationships between the system under consideration or subject, its actors, and use cases (A10)