Applying Model-Based Systems Engineering (MBSE) to Develop an Executable Model for the RAX CubeSat Mission

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MBSE Project Overview and Roadmap

INCOSE MBSE Challenge Project

*Initiated in 2007*

INCOSE SSWG

*2007-2010*

Modeled a Space System in SysML

Hypothetical FireSat - SMAD

MBSE CubeSat Project

*2011 to Present*

CubeSat Framework

Preliminary RAX Model

**Recent Efforts**

CubeSat Framework

Availability

Enterprise Modeling for CubeSats

All lifecycle phases

Incorporate cost models

RAX CubeSat Model

Trade Studies

**RAX CubeSat Model**

Availability to Academic Community

INCOSE - International Council on Systems Engineering
INCOSE MBSE Challenge Project

INCOSE MBSE Roadmap Out to 2020 Time Frame
Maturation / incorporation of MBSE
Academic and industry.

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

Systems Modeling Language (SysML) Diagrams
- Requirements
- Structures
  - Block Definition
  - Internal Block
- Interactions
  - Data, Control, Messages
- Behaviors
  - Activity
  - Sequence
  - State
  - Use Case
- Parametrics

INCOSE / Object Management Group (OMG) project – UML based

SysML is a modeling language not an engineering methodology
### INCOSE MBSE Challenge Project - Roadmap

<table>
<thead>
<tr>
<th>MBSE Capability</th>
<th>Reduced cycle times</th>
<th>System of systems interoperability</th>
<th>Design optimization across broad trade space Cross domain effects based analysis</th>
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<tr>
<td>Institutionalized MBSE across Academia/Industry</td>
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<td>Well Defined MBSE</td>
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<td>Ad Hoc MBSE Document Centric</td>
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#### 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

Refer to activities in the following areas:

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

CONCLUSIONS

Much was learned but hypothetical nature prevented an actual demonstration of verification of model.

INCOSE MBSE Challenge Project
Initiated in 2007

INCOSE SSWG – 2007-2010
Modeled a Space System in SysML
Hypothetical FireSat - SMAD
MIT, Georgia Tech, JPL, NASA, Others

Demonstrated an Interface – 2011
Between SysML model and STK / AGI Components
**Project Goals**

- Demonstrate the practical application of MBSE and SysML
- CubeSat modeling framework
- Interface CubeSat SysML with COTS modeling, analysis, visualization tools
- Apply framework to realistic mission

**Capture subsystem functions in the form of behaviors and allowing for time-dependent execution of these behaviors**
MBSE CubeSat Project – 2011 to Present

**RAX Mission**
- Michigan Exploration Lab and SRI International
- 3U CubeSat
- Study ionosphere plasma irregularities that disturb space – ground communication and navigation
- Radar signal transmitted from a site in Poker Flat and received by RAX
- Data processed, compressed, transmitted to ground station / control center

**Conclusions**
- Successfully demonstrated application of MBSE and SysML to create CubeSat framework
- Lacking in ability to execute realistic behavioral scenarios

RAX is an Operating On-Orbit Mission
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Systems Engineering

Recent Efforts

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RAX CubeSat Model
Availability to
Academic Community
RAX CubeSat Model – Recent Effort

Develop a Executable RAX Model / Execute Trade Studies
Analytical Graphics, Phoenix Integration, S. Spangelo (Consultant)

**Scope of Effort**

- Code developed from scratch based on CubeSat framework published documentation
- Focus on capturing characteristics of RAX design and operations
- Not a detailed representation of actual design and operations
- A practical demonstration of MBSE and SysML
- Intended as a demonstration of interfacing with COTS capabilities
  - That is, some STK capabilities were not activated, e.g. solar power calculations
**Model Elements**

Model the science data collection / management and power collection / management aspects of the RAX mission

**System Model**
- S/C Vehicle
- Orbit
- Attitude Scheme
- Operations
- Ground Network
- External Environment
- Experimental Zone

**Spacecraft Subsystems**
- Mission Payload
- Communication
- Power Collection
- Power Management
- Data Management
- Bus

**Requirements**
- Data Collection
- Data Storage
- Data Download
- Battery Capacity
- Battery Margin
Model Diagrams

State Diagrams
- Orbit
- Solar
- Experiment
- Download

Activity Diagrams
- Run Operation
  - Steps through timeline
- Update States
- Send Signals
  - Controls update of state values
- Update State Values

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

Parametric Diagrams
- Defines equations that constrain properties of blocks

State Diagrams
- Models behavior in respond to internal and external events.
RAX CubeSat Model – Recent Effort

No Magic
MagicDraw
Cameo
Simulation Toolkit

Behavior Diagrams
Cameo
Simulation Toolkit
time-steps through a scenario

Capture dynamics
of operations

Phoenix Integration
ModelCenter
AnalysisServer
MBSE Analyzer

Parametric Diagrams
ModelCenter
models are imported into
MagicDraw
SysML model

Capture analytical
relationships

Analytical Graphics
Systems Tool Kit

Analytical Models
STK and MATLAB
analysis models are wrapped and integrated with
ModelCenter

Capture solar state,
access to exper. zone,
access to grd stations

CubeSat WS Aug. 2013
Logan, Utah
RAX CubeSat Model – Recent Effort

Structural Diagrams

Mission Level

Captured from MagicDraw

Vehicle Level
RAX CubeSat Model – Recent Effort

**Trade Space**
- Solar panel area
- Battery capacity
- Orbit Altitude
- Ground Station
- Network

**Requirements**
- Data Collection
- Data Storage
- Data Download
- Battery Capacity
- Battery Margin

**Next Step**
Free distribution to academic CubeSat community
Provides a start at modeling their CubeSats
Evaluate benefit of expanding model

**Conclusions**
Successfully demonstrated using MBSE / SysML to:
- Develop a model
- Interface with COTS tools
- Carry out trade studies

First known integration of a space system SysML model with:
- Diverse analytical models
- Simulation engines
- Special-purpose high-fidelity space system model
## Resources

### INCOSE MBSE Workshops
- 2011 - Demo of SysML model - STK interface
- 2012 - Working Through System Models
- 2013 - Using MBSE for Operational Analysis

### IEEE Aerospace Conferences
- 2012 - Applying Model Based Systems Engineering (MBSE) to a Standard CubeSat
- 2014 - Enterprise Modeling for CubeSats (submitted)
- 2014 - Integrated Model-Based Systems Engineering (MBSE) Applied to the Simulation of the RAX CubeSat Mission (submitted)

### Open to all to actively participate or just monitor

#### SSWG Bi-Weekly Telecons
Louise Anderson
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#### Google Group and Docs
CubeSat MBSE
Dave Kaslow
dkaslow@agi.com

#### AGI blog and video