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 though operations

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

SysML is a modeling language not an engineering methodology

INCOSE / Object Management Group (OMG) project – UML based
INCOSE MBSE Challenge Project - Roadmap

MBSE Capability

Maturity

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

Extending Maturity and Capability

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

Institutionalized MBSE across Academia/Industry

Well Defined MBSE

Ad Hoc MBSE Document Centric

2010

INCOSE SSWG – 2007-2010

INCOSE MBSE Challenge Project
Initiated in 2007

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

Conclusions
Much was learned but hypothetical nature prevented an actual demonstration of verification of model
MBSE CubeSat Project – 2011 to Present

**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**

**CubeSat Framework / Preliminary RAX Model**
SSWG, Univ of Michigan, JPL, AGI, InterCAX, Others

**MBSE and SysML Enable**
- Connecting system level model to analytical tools
- Executing dynamic simulation of end-to-end mission
- Identifying failure to satisfy requirements, sub-optical designs
- Accommodating re-evaluation when design changes occur
- Operational mission planning / execution and responding to component degradation
## MBSE CubeSat Project – 2011 to Present

### RAX Mission

- Michigan Exploration Lab and SRI International
- 3U CubeSat
- Study ionosphere plasma irregularities that disturb space – grid comm 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

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**RAX is an Operating On-Orbit Mission**
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RAX CubeSat Model – Recent Effort

Scope of Effort

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

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
RAX CubeSat Model – Recent Effort

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

Models behavior in respond to internal and external events.

**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

Defines equations that constrain properties of blocks

**Model Diagrams**
Defines actions in the activity along with flow of input/output and control
RAX CubeSat Model – Recent Effort

Model Interaction

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

MATLAB
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

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AGI blog and video