Space Systems Working Group Team

- International Group of Engineers
- Commercial and Government
- Students/Academic Team
  - MIT
  - Georgia Tech
Objective

• Can models (with documentation) improve communication, characterization, and specification of the system over documents alone?

• Can such a model achieve enough commonality to be reusable
FireSat Mission

• FireSat Example (From Space Mission Analysis and Design (SMAD), Third Edition, by Wiley J. Larson and James R. Wertz (editors).)

  – Realistic and sharable
  – A mission to detect identify and monitor forest fires from orbit
  – Widely regarded as definitive text on space systems for concept/feasibility studies
  – Examples are sufficiently detailed to create models
Approach

• Treat book as documented design set
  – Information “siloed” by discipline
  – Various expert authors – conflicting perspectives
  – NOT a critique of the books content, format
    • Special thanks to Wertz and Larson!

• Compare Model to Documents

• Capture reusability
  – Same intent as book
  – Provides compelling demonstration of MBSE
  – Provide as a resource for anyone doing Space Systems engineering
Wymorian MBSE

- Wymore Documents – explicitly tied to system models
  1. Problem Situation
  2. Operational Need
  3. System Requirements
  4. System Requirements Validation
  5. Concept Exploration
  6. System Functional Analysis
  7. System Physical Synthesis
- Commutative property does not apply
  - Systems engineers make these documents DOES NOT imply that making these documents means you are doing Systems Engineering.
# Types of Document-based Information in FireSAT

<table>
<thead>
<tr>
<th>System Documents</th>
<th>FireSAT Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept of Operations</td>
<td>Mission Objective, system requirements</td>
</tr>
<tr>
<td>Requirements (SRDs, FRDs etc)</td>
<td>system requirements</td>
</tr>
<tr>
<td>Interfaces (ICDs etc)</td>
<td>Data flow diagram, system requirements</td>
</tr>
<tr>
<td>Functional Designs</td>
<td>Power functional decomposition</td>
</tr>
<tr>
<td>Analysis-specific engineering reports (trades, reliability etc)</td>
<td>Solar Array selection</td>
</tr>
<tr>
<td>End-to-end Information systems spec</td>
<td>Data flow diagram</td>
</tr>
</tbody>
</table>
Most of this information is usually spread across documents as assumptions. This includes the FireSAT example. Properties of the concept are sprinkled across the example as they are relevant to the example. The modeling methodology provided a way for collecting this stuff in a more reality oriented presentation.
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Mission Requirements and Measures Of Effectiveness

Supporting measures come from systems that make up the enterprise.

Measure of Performance on Flight System

(30 min, 50 users) Requirement Translates to Effectiveness measure.
Parametrics Issues

- Would like to be able to see instance values on these
- Stronger connection between requirements and model properties
Affects

• Responsiveness <-> Coverage
• Coverage <-> Orbit Design
• Orbit Design <-> Power Design
Mission Orbit/Trajectory Design

![Diagram of orbit parameters and equations](image)

- **DistanceFromCenterOrbit_Foci**: Real
- **RightAscensionOfAscendingNode**: Real
- **VelocityVector**: Real
- **Inclination**: Real
- **TrueAnomaly**: Real
- **Eccentricity**: Real
- **SemimajorAxis**: Real
- **MagnitudePositionVector**: Real
- **ArgumentOfPerigee**: Real
- **FlightPathAngle**: Real

**Constraint**: GeomOfEllipse

\[ r = \frac{a^2}{1 - e^2} \frac{1}{1 + e \cos(\alpha)} \]
Parametrics and Activities

- Want to show how a function or goal (delta-v) causes a change in the orbit
- Can't show this
  - Putting activity on IBD creates separate usage (meaning is unclear)
  - No way to bridge properties onto activity diagram at all
- It is often desirable to show constraints on functions
- Constraints and activity blocks live in harmony on BDDs why not IBDs and Activity diagrams?
- At the end of the day you have a tree of parts and the leaves are all functions, properties and constraint properties
  - SysML should be consistent in combining these depictions
Functional descriptions and requirements
Activities Issues

• Not clear why activities allocated or composed into a blocks are different then operations.
  – Inconsistent
  – leads to lots of extra linking and mapping or just disconnects in model
• Would prefer actions to be like parts
  – Use same on activity or IBD
Specific Configuration
Activities or state models would be useful to show change say from different modes of spacecraft.
Model Reuse Benefits

• Understanding model reuse at an early stage
  – Becomes a proven set of common modeling tools
  – Extends value of effort
  – Simplifies overall modeling effort
  – Library is testable
Space Systems Model Library

• A collection of reusable artifacts expressed in SysML and various numerical implementations (e.g. Matlab scripts)
  – Thermal, Mechanical, Power etc
  – Functions, Parts etc
• Resource for facilitating MBSE in Space Systems
• Envision a “tool kit” and “building blocks”
Lack of Robust Model Interchange

• Library is stuck in tool of implementation
• Tools for testing are limited
• Need rules (pre-processing) to ensure built as intended
• No way to tell what fidelity will be provided
• No way to know when it is appropriate to use library elements
• Is ontology the Solution?
Parametrics Equation expression

• Desired to show “mathematical symbols”
• Have list of appropriate solvers within constraint
• TABLES
  – Toggling between diagrams and tables of values and equations is HIGHLY desirable
• Sets of alternatives are pain-staking to represent
Timing, Timelines and Time

- Desire to express states, functions, events etc on a timeline
- No way in SysML to account for time as a first-class element of the model
- Would be very useful to have time related info at least on activities (duration, etc – like a PERT chart)
- Suggestion: Parametrics are part of structure and behavior, make time the 4th pillar
Useability

• Many Systems Engineers don’t have a lot of software/language background
• SysML tools are built on Software tools
  • Many assumptions
  • Software versioning tools
  • Lots of manual stuff
  • Poor support for making Systems Engineering work products – Documents
  • Where are my tables?
What next

- Look at profiling time based examples
- Explore some more state analysis examples
- Rich future for SysML execution
References

8. Terrile, R. “Automated Design of Spacecraft Telecommunications using Evolutionary Computational Techniques”.
11. Sandy’s book
Back Up Slides
What is State Analysis?

- A model-based systems engineering methodology
  - Based on familiar principles from control theory
  - Complementary to the functional decomposition approach
  - Intended to help address the complexity challenge
- It provides a methodical and rigorous approach for:

  - state-based behavioral modeling
    - Capturing mission objectives in detailed scenarios motivated by operator intent
    - Modeling behavior in terms of system state vars & the relationships between them
  - goal-directed operations engineering
  - state-based software design
    - Describing the methods by which objectives will be achieved