MBSE on NASA’s Proposed Europa Mission

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Agenda

• Introduction
• Europa?
• MBSE on the Europa Project?
• How’s that going?
• Recommendations
INTRODUCTION
Introduction

• Me: Europa Project for ~2 years
• MBSE for 7
• Roles:
  – Practitioner
  – Systems Engineer on FS requirements team
    • Do requirements engineering, *happen* to use MBSE as tool of choice
    • SW developer for query, automation, tool, visualization, and any other as-need infrastructure
  – Model System Engineer for PSE
    • One interface between SEs with more traditional skill sets and system model
    • My particular role is software management
EUROPA?
“Europa, with its probable vast subsurface ocean sandwiched between a potentially active silicate interior and a highly dynamic surface ice shell, offers one of the most promising extraterrestrial habitable environments, and a plausible model for habitable environments beyond our solar system”

“Visions and Voyages”, 2011 Planetary Decadal Survey

- How do we solve Europa’s mysteries? By potentially sending a spacecraft and instruments to collect data for our investigation!
- Europa Project:
  - Early phase
  - Dual focus on system/design architecture and closing big trades and requirements derivation, analysis, and flow-down.
MBSE... ON EUROPA

(not literally)
MBSE on the Europa Project

• Europa is fully MBSE mission concept
  – We use MBSE to do our SE
  – MBSE is not the product

• Specifically, for our phase:
  – MELs, PELs, resource allocation and analysis, system decomposition, etc
  – All systems engineering activities
    • Requirements (derivation, justification, traceability, analysis, maturity, history, verification, document generation, metrics, etc.)
    • This talk will focus on the SE aspects
What can you do with MBSE?

• Single Source of Truth
  – Multiple interfaces (tailored), no confusion
  – Living, interlinked, customized views of data

• Automated generation of traditional and non-traditional documents
  – Gate products
  – Release documents
  – Analysis products, spreadsheets, visualizations, etc.

• Semantically rich (and rigorous) patterns for expressing SE knowledge
  – Reduces interpretation confusion
  – Forces clarity, completeness, correctness
  – Machine analyzable and queryable
What does the Europa Project do with that?

Custom visualizations

Gate Products for Release (read-only)

System Model

Spacecraft and Project Requirements Documents

Burndown, work to go, quality, and other metrics

Automation and query plugins and libraries

Model validation: completeness & correctness reports; metrics

Modeling client

Web Portal (read-write)

GDS Integration and Test Flow

Other engineering analysis tools

Constraint Allocation

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Information System Fault Management

Radio Mission Assurance

Partnerships

Science Data Set Distribution

Configuration

Electrical Navigation

Accessibility

Delta-V

Flyby Campaign Approach

Motion

Time Management

Mechanical

Business

eimote Imaging

Payload

Plasma Instrument for Magnetic Sounding (PIMS)

g and Altimetry

Radar for Europa Assessment and Sounding: Ocean to Near Surface (REASON)

Europa Imaging System (EIS)

Risk Management

Operations Strategy

Launch Vehicle Trajectory

Project Organization

Mass Spectrometry

Fields & Particles Sampling

Verification & Validation

Interior Characterization of Europa using Magnetometry (ICEMAG)

Electrical Power

Propulsion

Risk

Biological Cleanliness

Infrared Spectroscopy

Mapping-Imaging Spectrometer for Europa (MISE)

Short Wavelength Infrared Spectrometer

Environmental Approach

Observation Strategy

Trajectory Approach

Topographic Imager

Control Coordination

Dynamics

Launch Services

Volumetric Considerations

Project Phases

Technical Margins

Thermal Imager

Software Architecture

Project Implementation

Operability

Flyby Robustness

Space Asset Protection

Monitoring and Estimation

Flight System Pointing

Mission Operations System

Environment Compatibility

Safety

Mechanisms

Electronics Parts

Trajectory Design

Langmuir Probes

Reconnaissance Camera

Fault Tolerance

Mass Spectrometer for Planetary Exploration

Observing Opportunities

Magnetometer

External Communications

Support Equipment

Mass

Organization Conflict of Interest

Project/Institutional Interaction

Project Schedule and Schedule Reserves

Education and Public Outreach

GDS Integration and Test Flow

Integration and Test System

Jupiter Trajectory

Orbital Debris

Flights System Pointing

Flyby Robustness

Space Asset Protection

Control Coordination

Redundancy

Payload

Fault Management

Project Requirement (Proxy Concept)

Launch

Contamination

Space Asset Protection

Configuration

Information System

Schedule

Flyby Robustness

Space Asset Protection

Control Coordination

Redundancy

Payload

Fault Management

Project Requirement (Proxy Concept)

Launch

Contamination

Space Asset Protection

Configuration

Information System

Schedule

Automation and query plugins and libraries

Resources and Margins (read-write)

PEL

MEL
What have we done with MBSE?

- Requirements → documents
- Requirements → traceability
What have we done with MBSE?

• Requirements context, rationale, justification, narrative

• “Functional” decomposition
What have we done with MBSE?

- **Traceability**

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**Concept Hierarchy**
Sankey Data Generated on Mon Oct 05, 2015 at 11:06 AM by mjackson
Concept Maturities: **Identified Draft Prelim Baseline Final**

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**Requirements Allocation**
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**Requirements Trace**
Sankey Data Generated on Mon Jan 25, 2016 at 12:28 PM by mjackson
Constraint Maturities: **Identified Draft Prelim Baseline Final**
What have we done with MBSE?

• Maturity Evolution
What have we done with MBSE?

- Metrics! Validation! History!

Was this supposed to have one of those?

Set of elements to check

<table>
<thead>
<tr>
<th>Rule 1</th>
<th>pass e1 e4</th>
<th>fail e2</th>
<th>skip e3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule 2</td>
<td>pass</td>
<td>fail e2 e1</td>
<td>skip e3 e4</td>
</tr>
</tbody>
</table>

Also: store records in model; generate metrics
What else (if only there was more time…)

- Requirements → documents
- Requirements → traceability
- Requirements context, rationale, justification, narrative
- “Functional” decomposition
- Maturity Evolution
- Metrics! Validation! History!
- MEL, PEL, resources, margin
- Point design
- Instrument fact sheets
- System block diagrams
Intangibles

- MBSE is not a product
- Intangible benefits:
  - Information consistency: reduced overhead, increased confidence
  - No “where’s the latest” confusion
  - Propagation of changes
  - Drives out assumptions (and forces clarity)
  - Changes tracked and versioned
  - Ease of communicating and maintaining current project baseline
  - Cross-training/experience for earlier-career engineers
• MBSE is not trivial
  – Efforts require systems engineering, management, planning, discipline

• “Modeling” is not a data entry job
  – MBSE is simply a way of doing systems engineering.
  – People who become skilled at modeling are still primarily systems engineers (with a different tool of choice)

• There are growing pains and upfront engineering costs

• Do we think it’s worth it? Yes!
LET’S TALK LOGISTICS
Unique Europa challenges:

• **Scope**: trying to capture information from across the project, content from >40 people who need to interact with the environment in some way. 10-15 people working in the modeling tool.

• **Tooling**: Needed to build infrastructure (automation, web interfaces, query and analysis, etc.)
  – Challenge: it is being developed as MBSE approach is applied.

• **Architecture Framework**: project chose to use an approach to architecting and requirements development that is new to many on project.
Focus areas

• Staffing for operation, training, and development of new tools

• Knowledge representation
  – Need precise semantics in order to model

• Information organization and storage

• Process
People

Large one-time investment in modeling patterns, ontologies, frameworks

Systems Engineering
Ontologies, Architecture
Frameworks, Patterns

Whether your SEs work in model directly or you have a team of superusers...

Modeling team is not data entry
Is actual SE job
Teams, Tools, Process

• **Staffing of teams**
  – Mix of career levels
  – Mix of skills (traditional SE vs software)

• **Selection/development of tools**
  – Leverage OTS when possible
  – …but we have significant and ongoing development of supporting infrastructure
    • Good: all projects can re-use
    • Bad: can be frustrating, incur all of one-time expense

• **Process**
  – Have had to do a lot of process engineering
    • Good: clarity, formality, automation
    • Bad: “well this will be easy!” => unpleasant surprises
RECOMMENDATIONS
Recommendations

• Apply SE and actively manage MBSE
  – You should have modeling **requirements**
  – Success criteria for modeling effort
  – Specific products (documents, analyses, etc.)
  – **Do not model for the sake of modeling**

• Before you model...
  – Agree on information model (knowledge representation)
  – Use cases, scenarios (drive out unknown unknowns in knowledge representation)
  – What can you do with “vanilla” tools? What additional features do you want/need?
Recommendations

• Choosing your team
  – Do you want your SEs to be modelers?
    • Do you want to train them?
    • Do they want to learn?
    • SE ↔ modeler:
      – Good: cross-training, exposure, target skills
      – Bad: bottlenecks, lag
  – SE/Software combination is very effective
    • Do you need something beyond your MBSE tool? Then you will need developers
    • Personal bias: SEs who code 😊
      – I’ve seen what people do with excel…
    • Get everyone talking algorithms
Final Recommendations

• MBSE is not a product

• MBSE efforts need to be scoped and managed as real projects
  – Because they are

• Decide what success looks like before you start

• Enjoy!
Acknowledgements

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• PSE and FSE
• JPL Integrated Model Centric Engineering (IMCE)
• JPL Computer-Aided Engineering (CAE)
What is the System Model?

“Model” is a very broad term

**System Model**: Model of the system to support systems engineering
What is MSET?

- Responsible for capturing architecture and baseline design systematically
- Responsible for integrity of the system model content and analysis results
- Responsible for developing requirements on modeling environment
What problems does MBSE try to address?

- Gaps and issues in project design because of implicit assumptions
- Inconsistency between information sources (project documents, etc.):  
  - Disconnected tools with their own data store: inconsistent or incorrect analysis results
- Communicating and maintaining current project baseline
- Common changes need to be made separately to all information sources  
  - Bigger issue when you have multiple variants  
  - Bigger issue when you have a large # of information sources
- Tracking changes to the project baseline over time
- What to do with our early career hires & interns?
Value Proposition

• Better Products delivered More Efficiently:
  – Model repository can act as a single source of truth
  – By providing a structured and interconnected representation, consistency can be maintained
  – Capturing information in a structured way can reduce implicit assumptions
  – Validation of model structure can identify gaps and inconsistencies
  – Common changes can be made in one place and propagated to various products via automated transformations
  – The impact of changes can be identified by tracing relationships
  – System level analyses can utilize the model to produce consistent results
Conclusion – From Brian Cooke (PSE)

• The Europa Project concept has embraced MBSE as core to our formulation effort
• Product development and release efficiency improvement realized (and getting better)
• Some SE process improvement realized with much more to come
• Shift from document-based to model-based is slow but progressing; MBSE is ready to support flagship class mission formulation
What MBSE is NOT!

• SysML & MagicDraw – These are just tools that allow us to implement MBSE
• A particular toolset or methodology
• The solution to all our problems
The same piece of underlying information will show up in multiple views.

- Which is the one to edit?
- Which one is the source of truth?
- Who can edit what?
- What happens if someone else edits it?
Heterogeneity of Stakeholders

Many stakeholders with different backgrounds, perspectives, use cases, and work styles

Systems

Project Management

Spacecraft Subsystems
- Avionics
- GNC
- Power

MOS/GDS

MDNav

System Model
Case Study: “Automatic Document Generation”

- Often, gate products need to be delivered in a particular format and signed by the appropriate parties.
- For MBSE to be successful, the information in the repository needs to be easily translated into this.

This is often thought of as “push button.”
LESSONS LEARNED
Keep it Super Simple

• Patterns (aka Data Structures):
  – Identify an approach for what needs to be captured, and try to maintain that scope.
  – Keep it flexible but remember diminishing returns. Refactoring can always be done later.
  – Flight the urge to make “rapid” changes when unexpected corner cases arise -> need to keep whole team on the same page.

• Communicating with the Project:
  – Keep terminology consistent, avoid jargon.
  – Make sure value is clearly communicated, be upfront about gaps.
Conclusions

• The MBSE effort combining people, processes, & software tools is it’s own system.

• The value of employing an MBSE effort depends strongly on the particular implementation.

• Consistency matters but need to be flexible.

• MBSE is not a magical solution: the effort needs to be considered in staffing, resources, and schedule.