



MBSE on NASA's Proposed Europa Mission

Maddalena Jackson

Flight System Requirements Team

Model System Engineering Team

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



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EUROPA?

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?

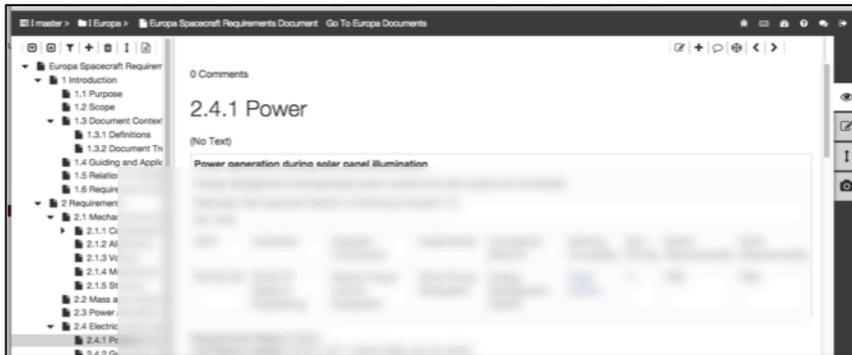


- Single Source of Truth
 - Multiple interfaces (tailored), no confusion
 - Living, interlinked, customized views of data
- Automated generation of traditional and non-traditional documents
 - Gate products
 - Release documents
 - Analysis products, spreadsheets, visualizations, etc.
- Semantically rich (and rigorous) patterns for expressing SE knowledge
 - Reduces interpretation confusion
 - Forces clarity, completeness, correctness
 - Machine analyzable and queryable

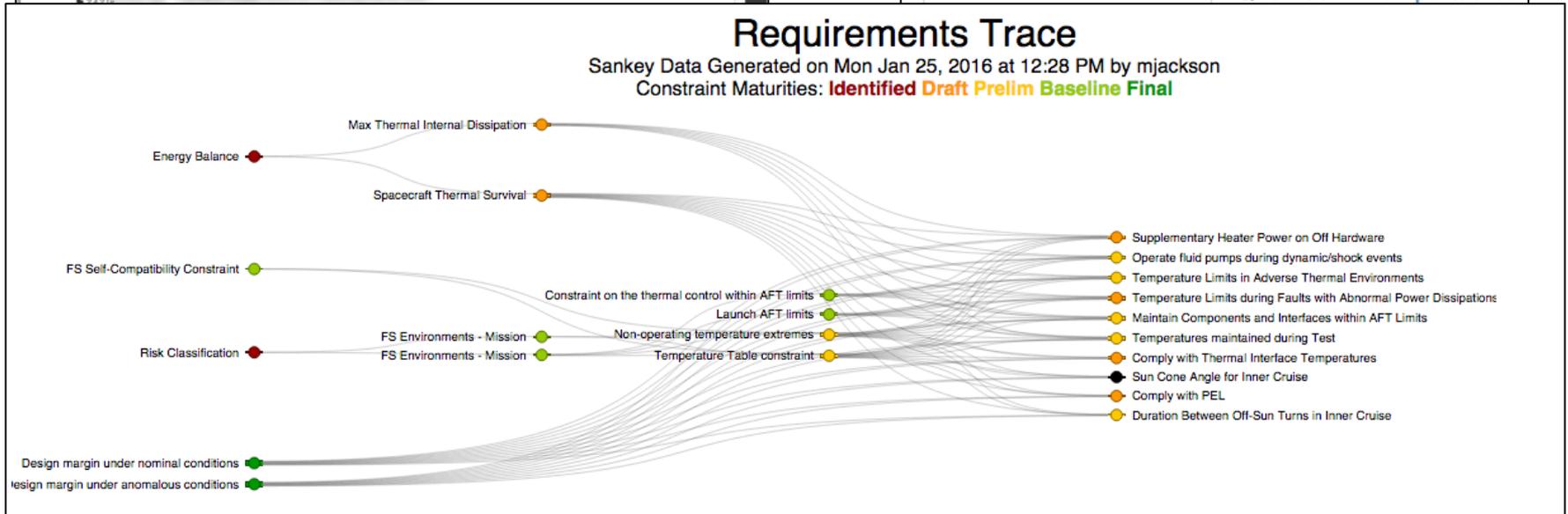
What have we done with MBSE?



- Requirements → documents
- Requirements → traceability



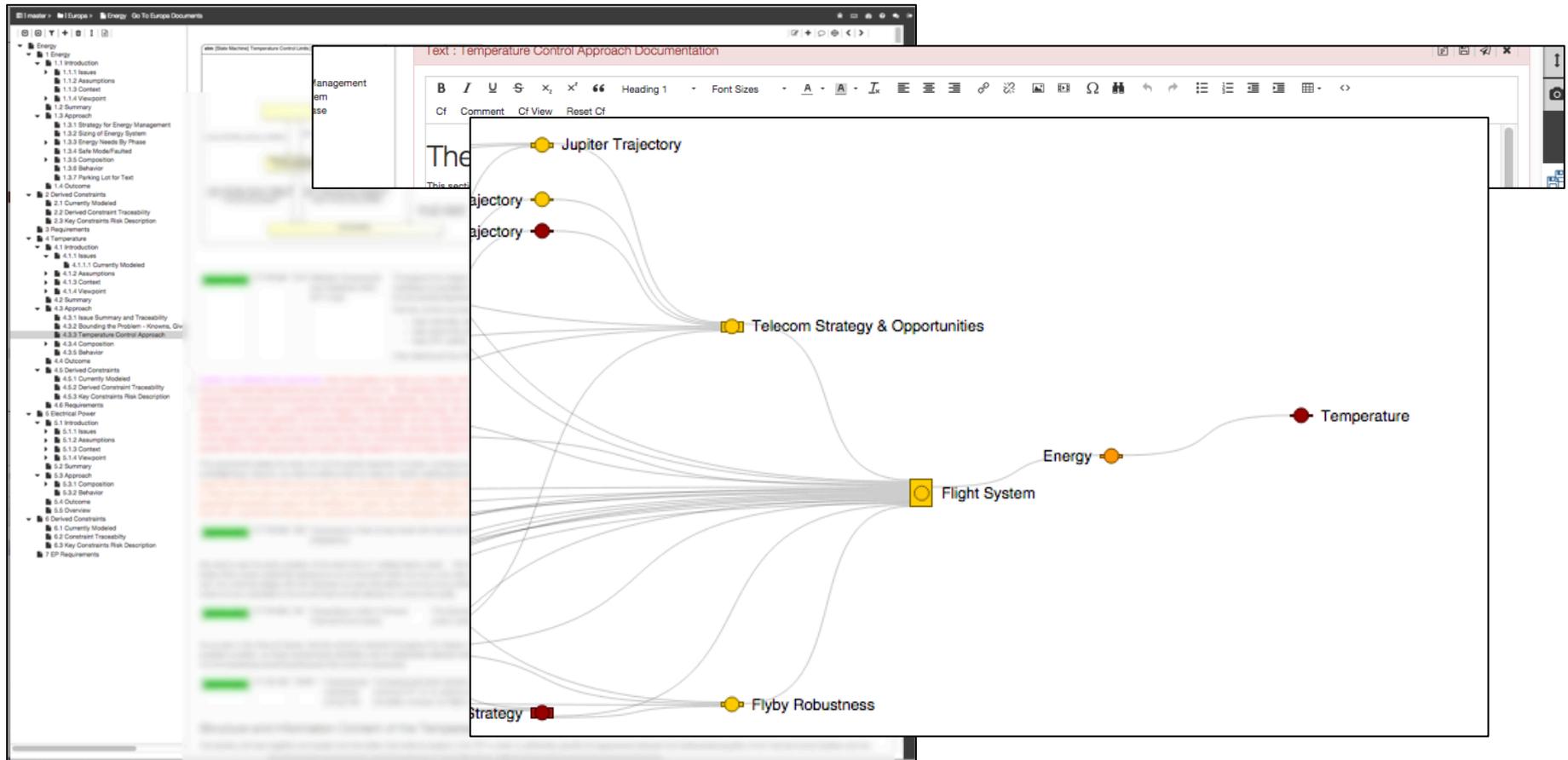
Parent Requirement(s)	Child Requirement(s)
RQ103.735 - Energy Balance	RQ101.691 - Supplementary Heater Power on Off Hardware RQ104.302 - Operate fluid pumps during dynamic/shock events RQ101.041 - Temperature Limits in Adverse Thermal Environments RQ101.041 - Operate fluid pumps during dynamic/shock events RQ102.584 - Temperature Limits during Faults with Abnormal Power Dissipations



What have we done with MBSE?



- Requirements context, rationale, justification, narrative
- “Functional” decomposition



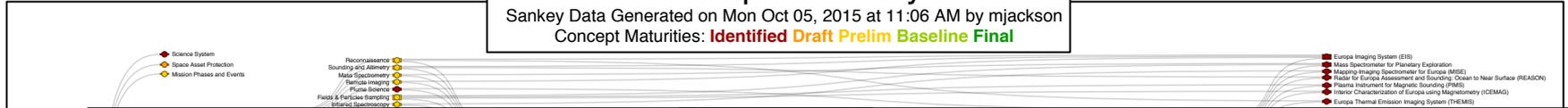
What have we done with MBSE?



- Traceability

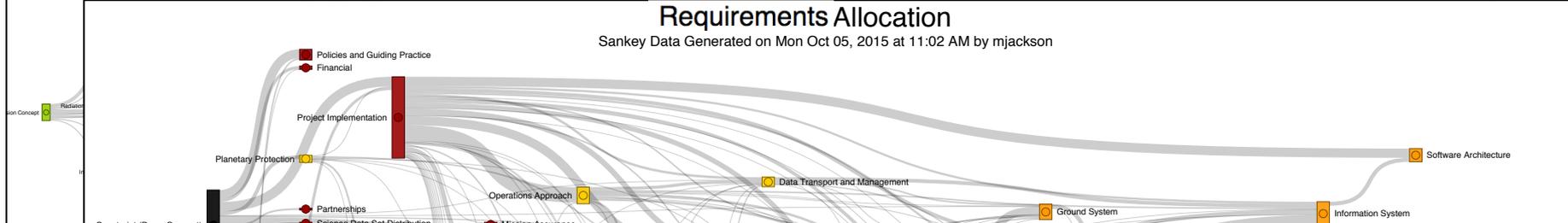
Concept Hierarchy

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



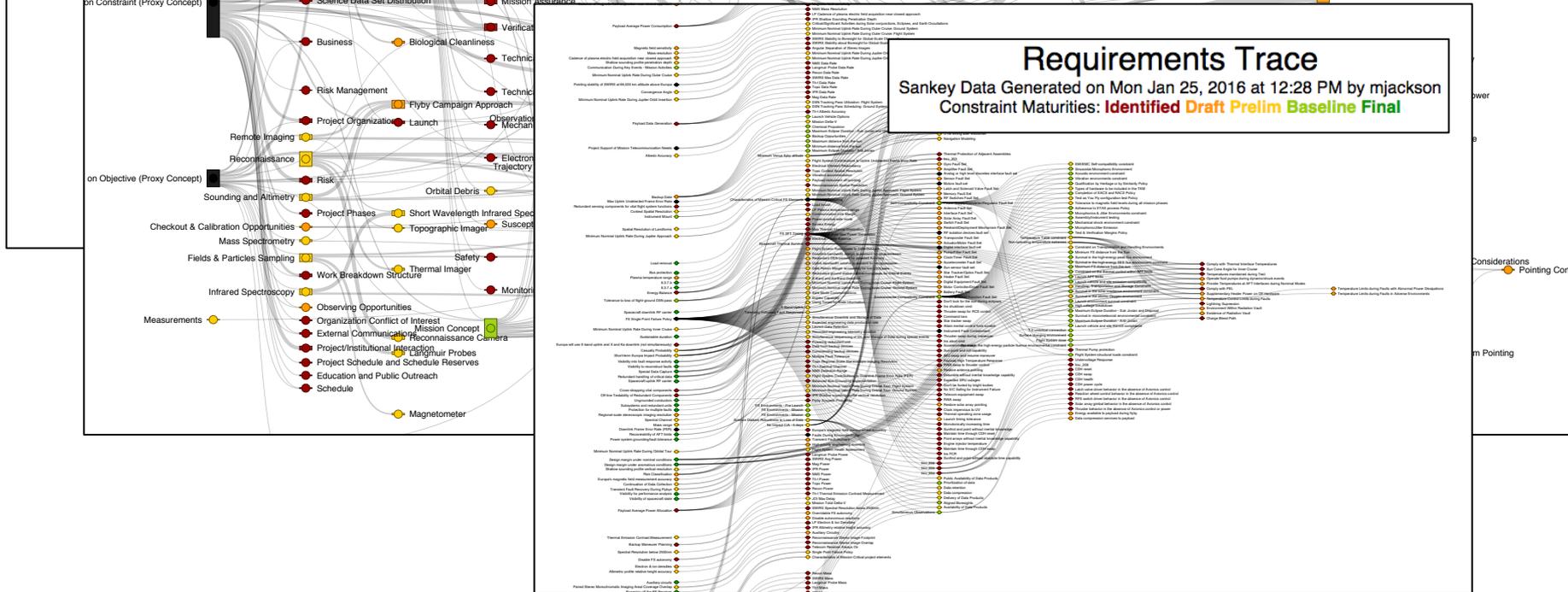
Requirements Allocation

Sankey Data Generated on Mon Oct 05, 2015 at 11:02 AM by mjackson



Requirements Trace

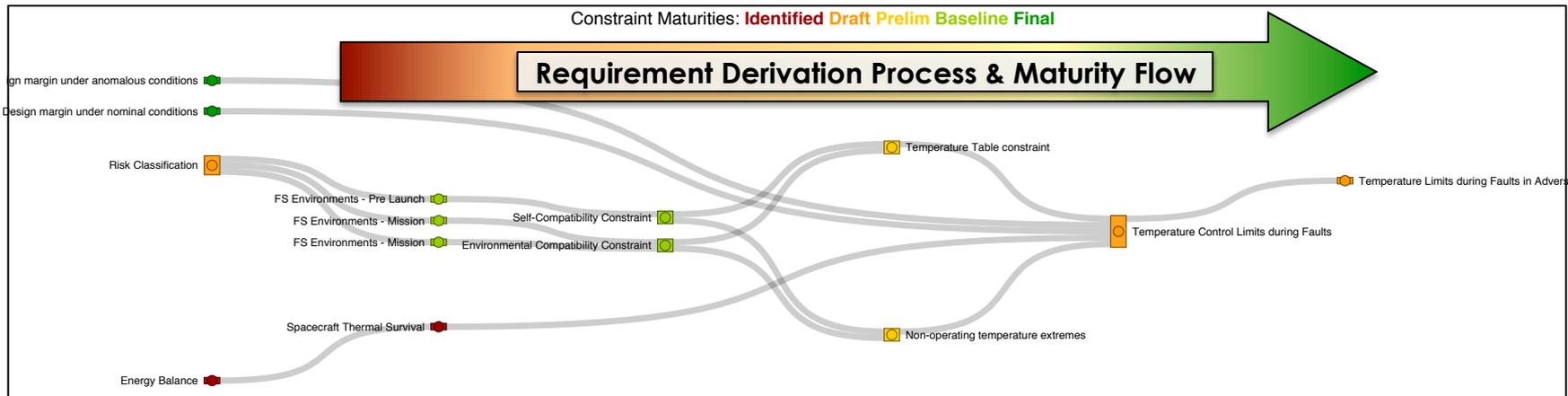
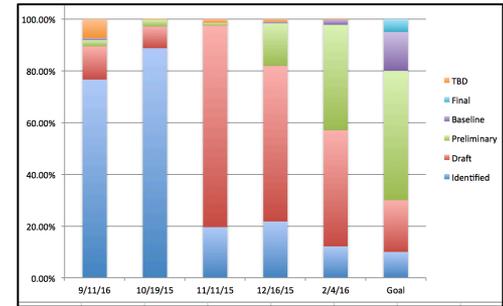
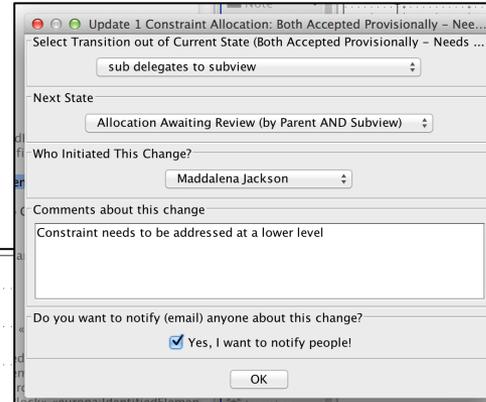
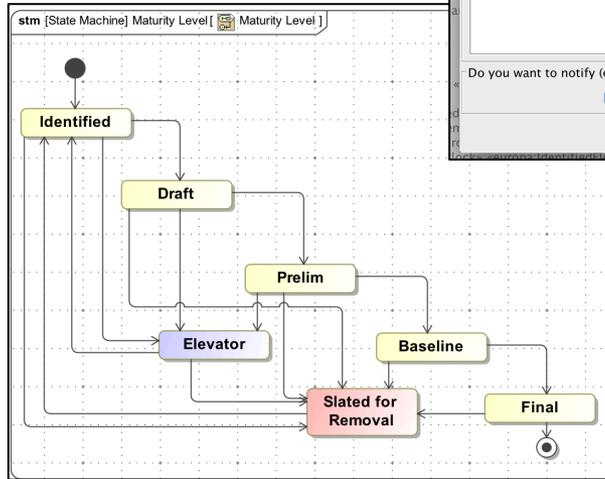
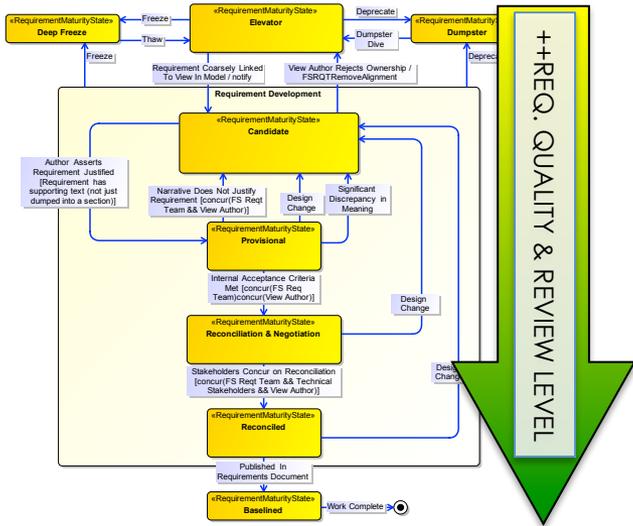
Sankey Data Generated on Mon Jan 25, 2016 at 12:28 PM by mjackson
Constraint Maturities: **Identified** **Draft** **Prelim** **Baseline** **Final**



What have we done with MBSE?



- Maturity Evolution

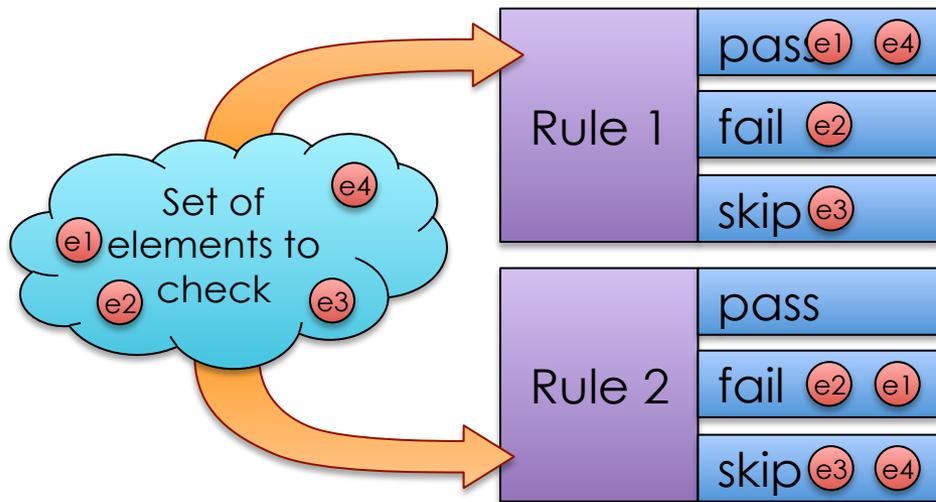
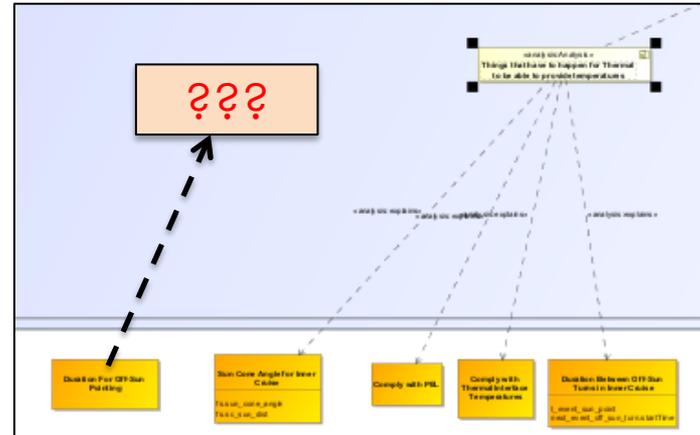


What have we done with MBSE?



- Metrics! Validation! History!

Was this supposed to have one of those?



Results for Rule: allConstraintsTraceToParent

Alert: TRACE: at least one trace to a parent
 Description: all linked constraints must constrain a conceptual element with <<europa:constrains>>
 Applies To: mission:Requirement
 Total Elements Evaluated: 7

VIOLATORS: 5 | PASSED: 2 | SKIPPED: 0 | SKIPPED (N/A): 0 |

Afid	Name of Validated Element	Validation Result	Model ID
RQ101.916	Uplink Re-transmit Attempts	FAILED	_17_0_2_3_f36036c_1380586409090_1713_30703
RQ101.913	Processing at Maximum Uplink Rates	FAILED	_17_0_2_3_f36036c_1380586629373_871672_31028
RQ100.696	Instrument Sequences	FAILED	_17_0_2_3_f36036c_1380654798802_58135_30666
RQ100.673	Information Structure	FAILED	_17_0_2_3_f36036c_1380570837251_801942_28653
RQ101.910	Processing Uplink Data Stream	FAILED	_17_0_2_3_f36036c_1380586561865_227644_30963
RQ101.911	Uplink Frame Error Rate	PASS	_17_0_2_3_f36036c_1380586734624_886838_31074
RQ101.907	Uplink Accountability Report	PASS	_17_0_2_3_f36036c_1380586511996_571134_30900

Results for Rule: hasMaturityChar

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

Reality check



- 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:



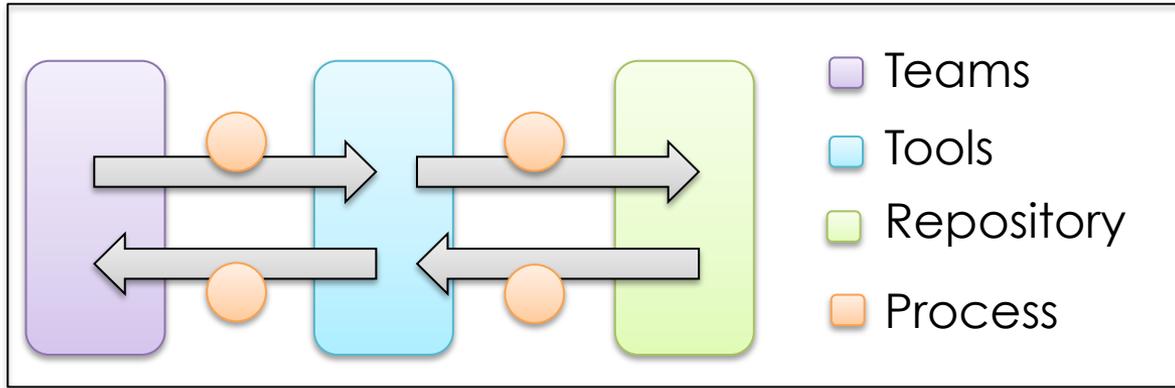
- **Scope:** trying to capture information from across the project, content from >40 people who need to interact with the environment in some way. 10-15 people working in the modeling tool.
- **Tooling:** Needed to build infrastructure (automation, web interfaces, query and analysis, etc.)
 - Challenge: 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

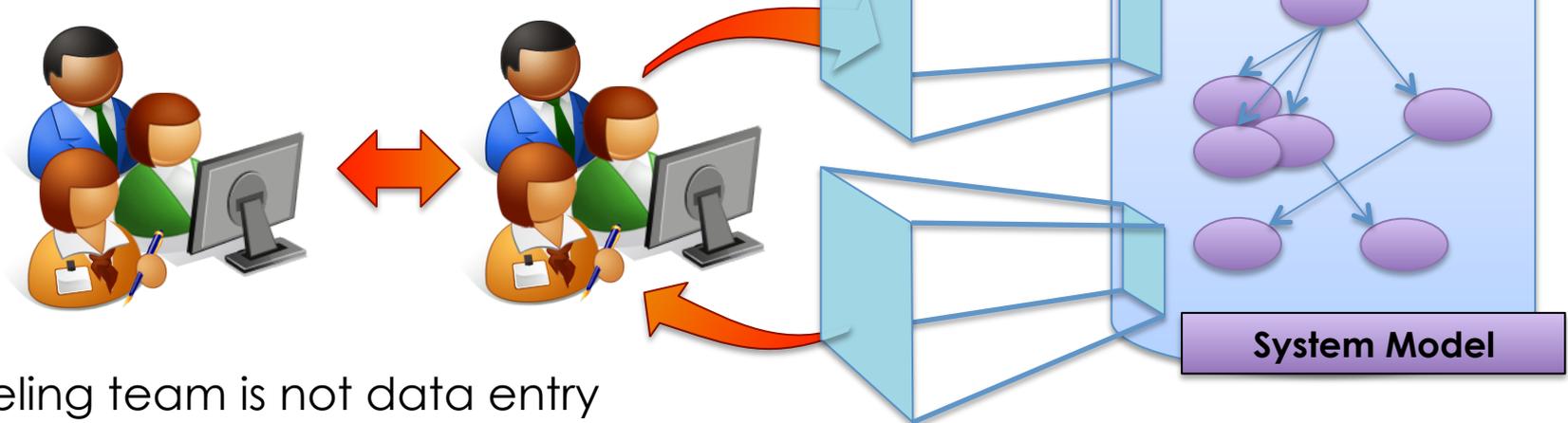
People



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

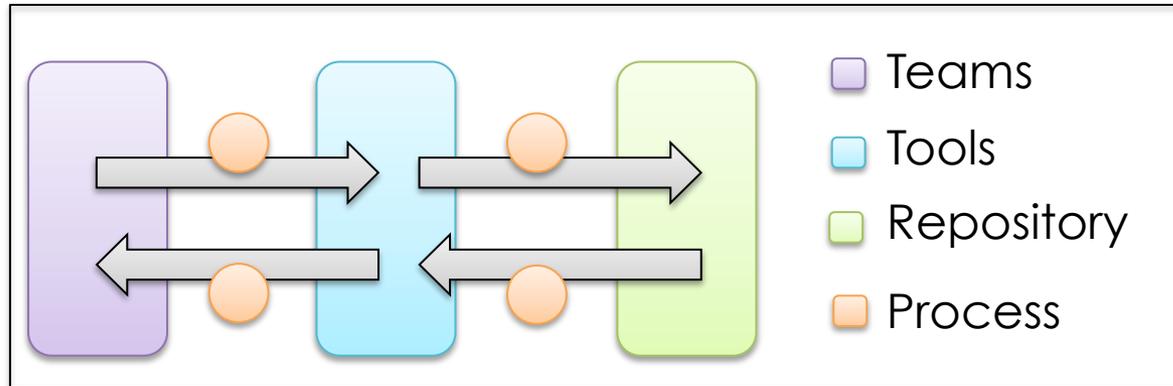
Systems Engineering
Ontologies, Architecture
Frameworks, Patterns

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

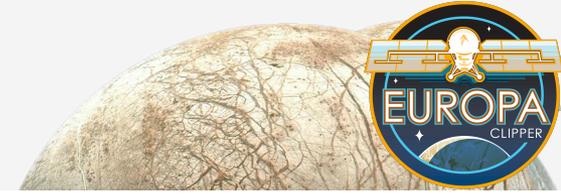


Modeling team is not data entry
Is **actual SE job**

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 \leftrightarrow 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



- Alek Kerzhner, Todd Bayer, Brian Cooke, Marcus Wilkerson – slide ~~cannibalism~~ inspiration
- MSET and FSRQT for hard work and support in making MBSE viable
- PSE and FSE
- JPL Integrated Model Centric Engineering (IMCE)
- JPL Computer-Aided Engineering (CAE)



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BACKUP

What is the System Model?



“Model” is a very broad term

$$\frac{dS_i(t)}{dt} = r_{VI} \cdot V_i(t) + r_{NI} \cdot N_i(t) - S_i(t) \cdot (\lambda_{VI}(t) + \lambda_{NI}(t)) - \pi_i(t) \cdot S_i(t) + a \cdot S_{V_i}(t)$$

$$\frac{dV_i(t)}{dt} = S_i(t) \cdot \lambda_{VI}(t) - c_{NI} \cdot \lambda_{NI}(t) \cdot V_i(t) - r_{VI} \cdot V_i(t) + r_{NI} \cdot B_i(t) \cdot V_i(t) + a \cdot V_{V_i}(t)$$

$$\frac{dN_i(t)}{dt} = S_i(t) \cdot \lambda_{NI}(t) - c_{VI} \cdot \lambda_{VI}(t) \cdot N_i(t) - \pi_i(t) \cdot N_i(t) + a \cdot N_{V_i}(t)$$

$$\frac{dB_i(t)}{dt} = c_{NI} \cdot \lambda_{NI}(t) \cdot V_i(t) + c_{VI} \cdot \lambda_{VI}(t) \cdot N_i(t) + a \cdot B_{V_i}(t)$$

$$\frac{dS_{V_i}(t)}{dt} = r_{VI} \cdot V_{V_i}(t) + r_{NI} \cdot N_{V_i}(t) - S_i(t) - a \cdot S_{V_i}(t)$$

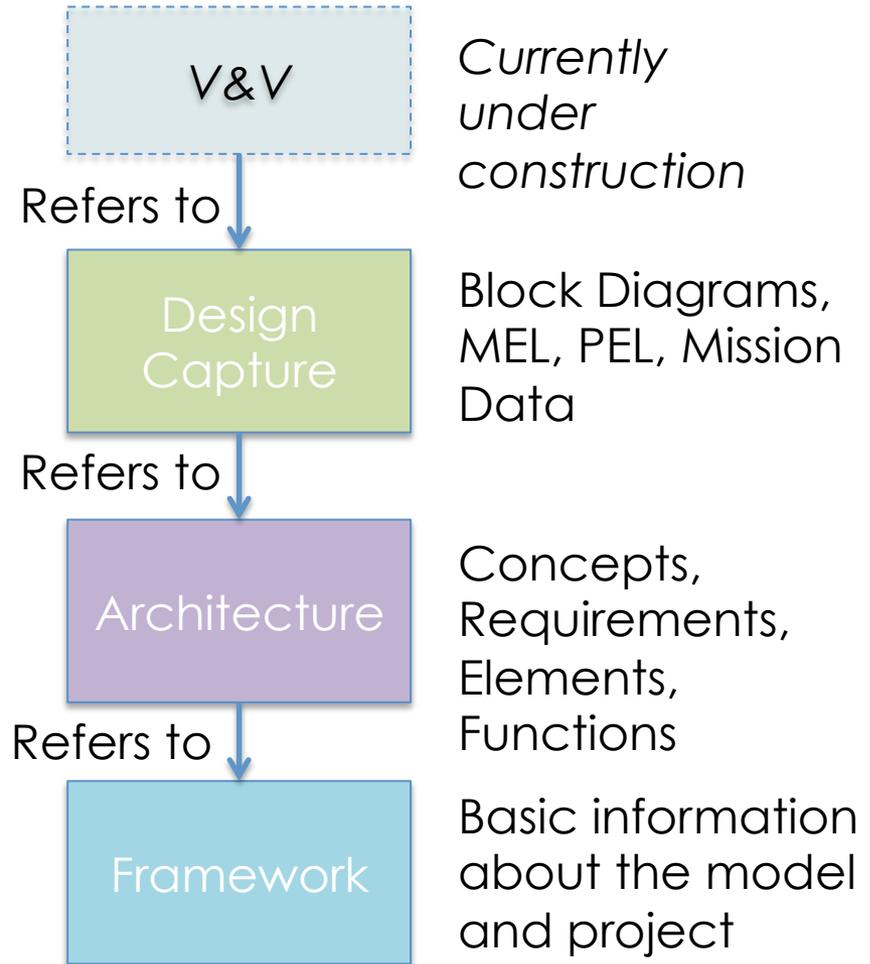
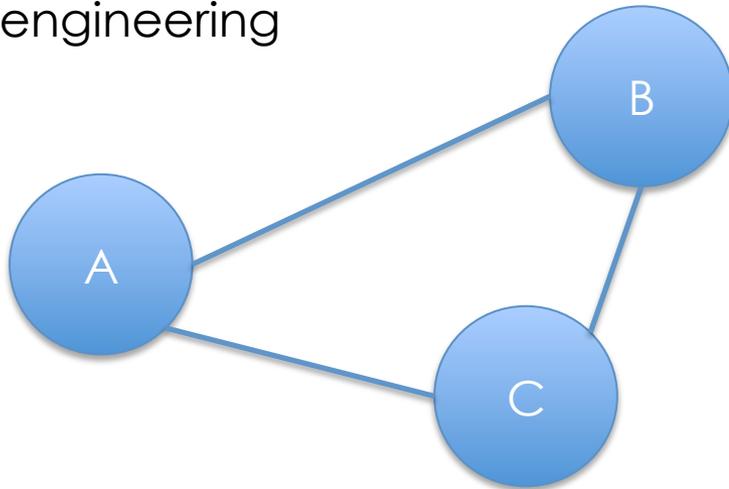
$$\frac{dV_{V_i}(t)}{dt} = S_{V_i}(t) \cdot (1 - \gamma) \cdot \lambda_{VI}(t) - V_{V_i}(t) \cdot (r_{VI} + \lambda_{VI}(t)) - B_{V_i}(t) + \pi_i(t) \cdot V_i(t) - a \cdot V_{V_i}(t)$$

$$\frac{dN_{V_i}(t)}{dt} = S_{V_i}(t) \cdot \lambda_{NI}(t) - c_{VI} \cdot \lambda_{VI}(t) \cdot (1 - \gamma) \cdot N_{V_i}(t) - r_{NI} \cdot N_{V_i}(t) - B_{V_i}(t) + \pi_i(t) \cdot N_i(t) - a \cdot N_{V_i}(t)$$

$$\frac{dB_{V_i}(t)}{dt} = c_{NI} \cdot \lambda_{NI}(t) \cdot V_{V_i}(t) + c_{VI} \cdot \lambda_{VI}(t) \cdot (1 - \gamma) \cdot N_{V_i}(t) - B_{V_i}(t) \cdot (r_{NI} + r_{VI}) + \pi_i(t) \cdot B_i(t) - a \cdot B_{V_i}(t)$$

Not only this

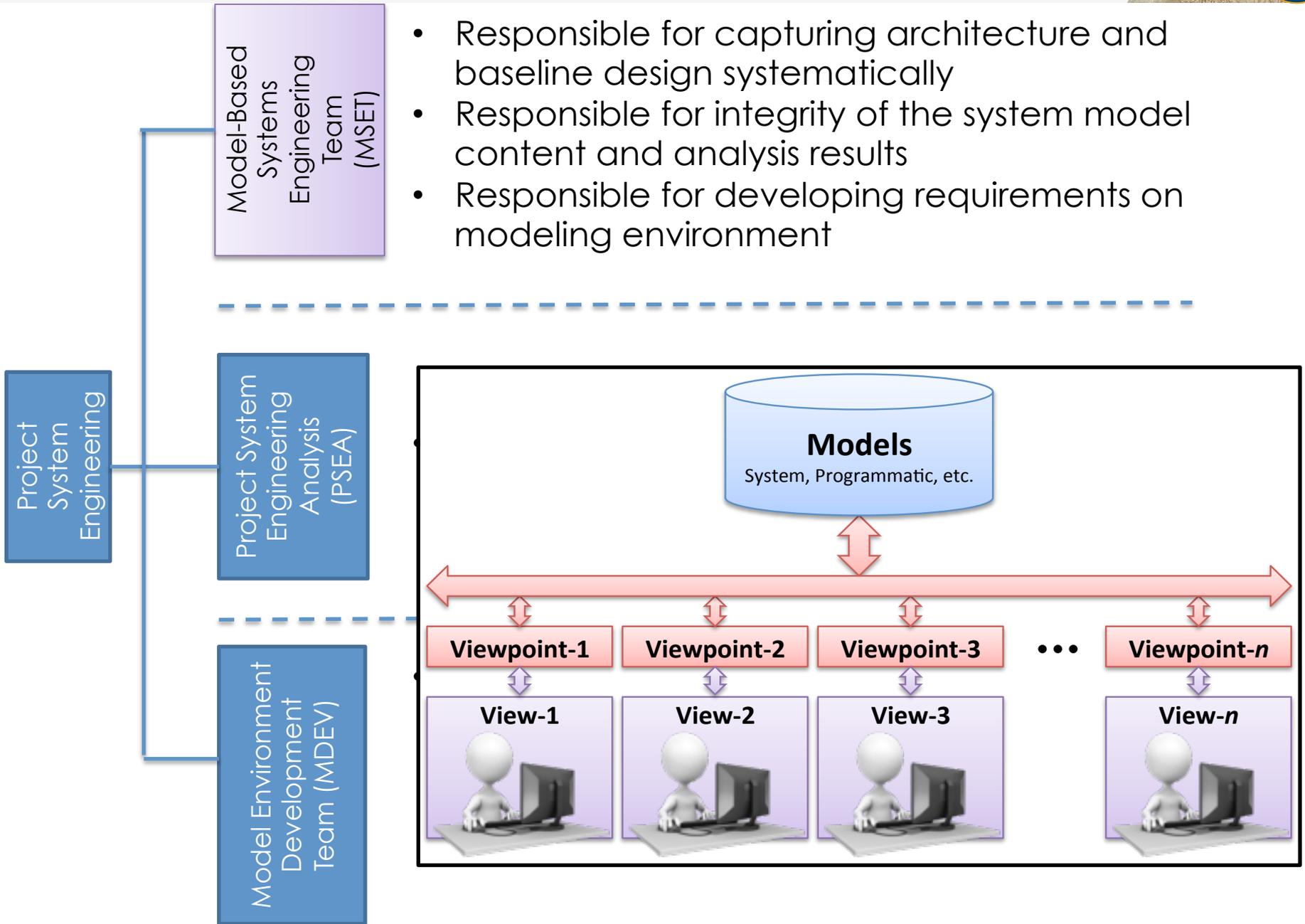
System Model: Model of the system to support systems engineering





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)



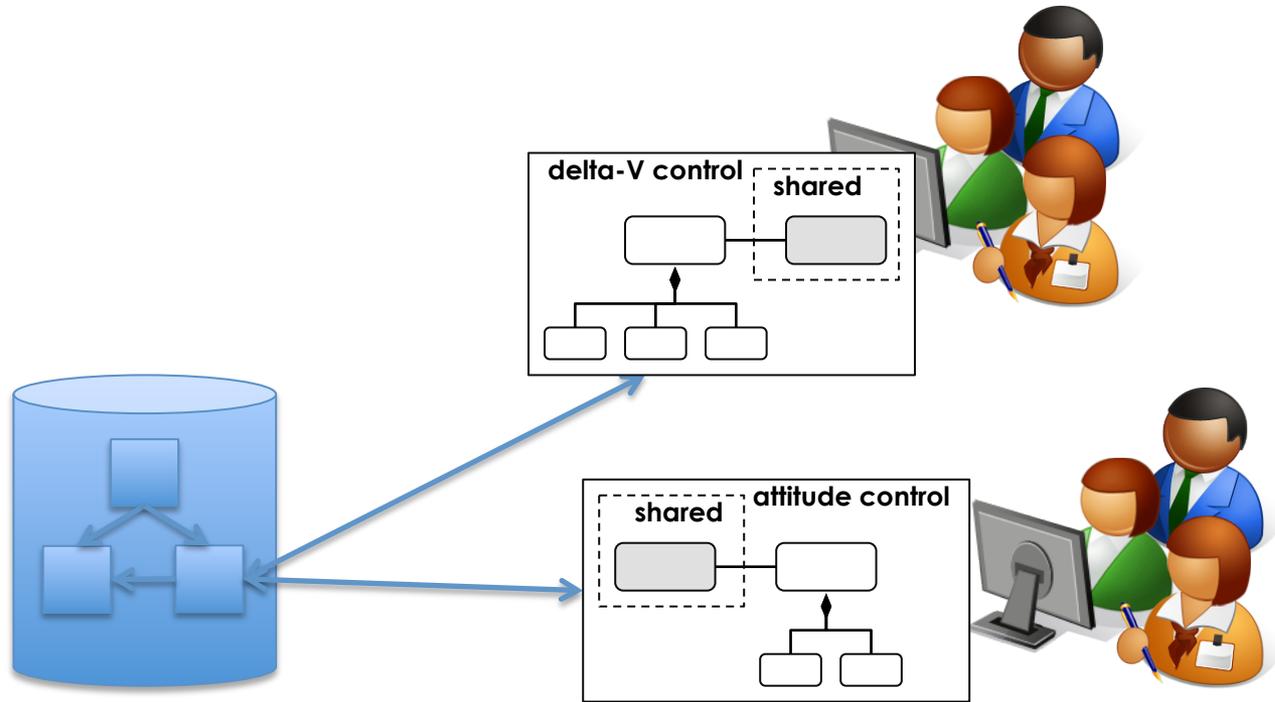
- The Europa Project concept has embraced MBSE as core to our formulation effort
- Product development and release efficiency improvement realized (and getting better)
- Some SE process improvement realized with much more to come
- Shift from traditional SE to MBSE is ready to support flagship class 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

Single source of truth



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

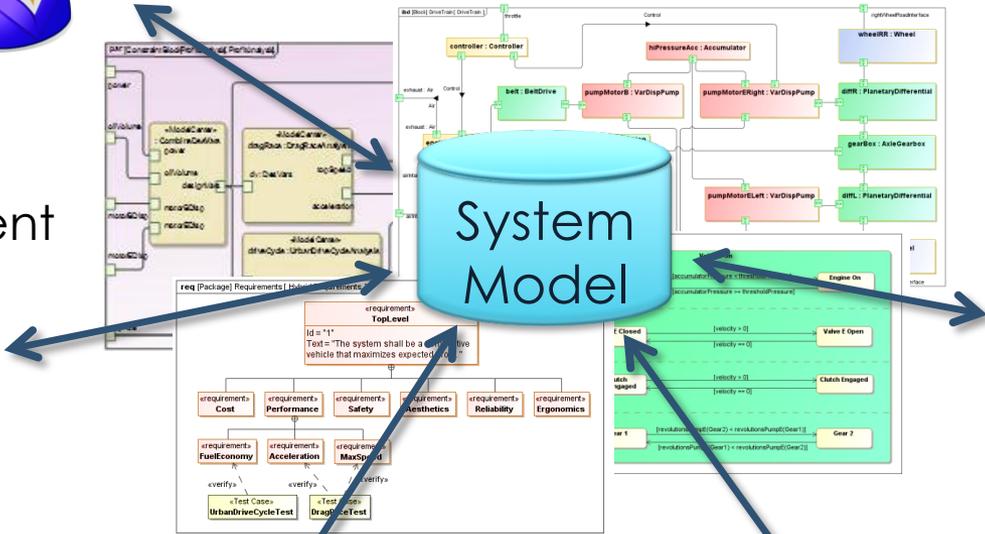


Many stakeholders with different backgrounds, perspectives, use cases, and work styles

Systems



Project Management



Spacecraft Subsystems

- Avionics
- GNC
- Power



MOS/GDS

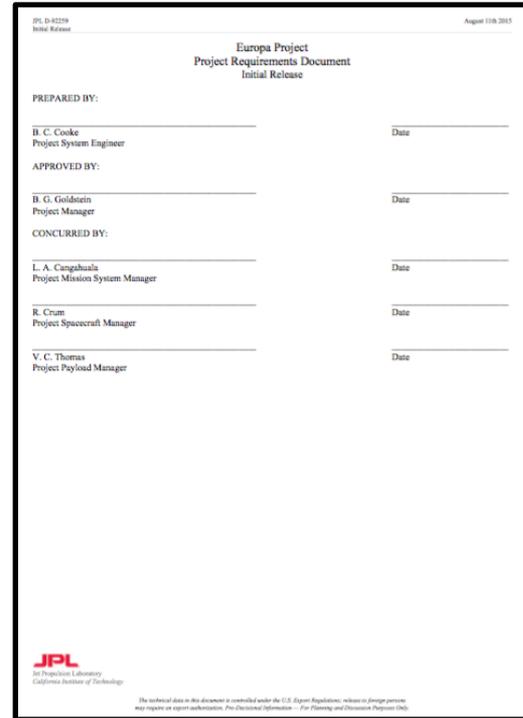


MDNav

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 its 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.