NASA Systems Engineering

MODEL BASED SYSTEMS ENGINEERING

NASA MBSE Implementation

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NASA Systems Engineering
MODEL BASED SYSTEMS ENGINEERING
What is MBSE?

• INCOSE definition of MBSE
  – Model-based systems engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification and validation, beginning in the conceptual design phase and continuing throughout development and later life cycle phases (Systems Engineering Vision 2020, INCOSE-TP-2004-004-02).

• MBSE is not a new process being added to the existing SE processes.

MBSE is systems engineering through the use of models.
MBSE Infusion And Modernization Initiative

**FY16:** Learn & Align

**FY17:** Learn & Apply

**FY18 & FY19:** Develop Recognized Core Capability

**FY20:** Targeted Deployment

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**MBSE Vision**

**MBSE Roadmap**

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**MIAMI Leads**

- Planning: Strategy Group
- SE Workforce: Advisory Board
- Coalesce: Current Capability: Practitioner Working Groups
- New Capability: Development: MBSE Pathfinder

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**Digital Practitioner Community**

- Systems Modeling WG
- Systems Analysis and Data Visualization WG
- Infra-structure and Ecosystem WG
“A fully operational model-centric infrastructure that enables integration of physical models with domain discipline analytical models, simulations and cost models to support activities throughout lifecycle from concept through disposal”

- Shared system model is explicit, available, durable and authoritative
- System design kept current with 2-way information exchange with discipline models
- Agency-wide modeling standards facilitate multi-center collaboration
• Primarily utilizing MagicDraw 19.0 Service Pack 2 as the MBSE pathfinding tool throughout the Agency
• Marshall Space Flight Center (MSFC) is focusing on small wins by infusing MBSE through Tech Excellence (TE) projects
• Project scope is centered around lifecycle deliverables
• Process of Establishing common framework
MagicGrid 101

- The MagicGrid approach is based on the framework, which can be represented as a Zachman style matrix (link below), and is designed to guide the engineers through the modeling process and answer their questions, like “how to organize the model?”, “what is the modeling workflow?”, “what model artifacts should be produced in each step of that workflow?”, “how these artifacts are linked together?”, and so on.
- The approach includes the definition of the problem, solution, and implementation domains in the system model. They align with the processes defined by ISO/IEC/IEEE 15288 as follows: problem domain with the Stakeholder Needs Development process, solution domain with the Architecture Definition process, and implementation domain with the Design Definition process. Each domain is represented as a separate row of the MagicGrid framework.
- [https://www.zachman.com/about-the-zachman-framework](https://www.zachman.com/about-the-zachman-framework)
### MagicGrid 101 Cont.

<table>
<thead>
<tr>
<th>Layer of Abstraction</th>
<th>Specification</th>
<th>Concept</th>
<th>Problem</th>
<th>Requirement</th>
<th>Solution</th>
<th>Requirement</th>
<th>Experience</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stakeholder</td>
<td>Needs</td>
<td>Use</td>
<td>Cases</td>
<td>System</td>
<td>Context</td>
<td>Subsystems</td>
<td>Effectiveness</td>
</tr>
<tr>
<td></td>
<td>System</td>
<td>Requirements</td>
<td>Functional</td>
<td>Analysis</td>
<td>Logical</td>
<td>Communication</td>
<td>Component</td>
<td>Parameters</td>
</tr>
<tr>
<td></td>
<td>Component</td>
<td>Requirements</td>
<td>Component</td>
<td>Behavior</td>
<td>Component</td>
<td>Structure</td>
<td>Parameters</td>
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</tbody>
</table>
SysML 4 Pillars

1. Structure

2. Behavior

allocate

3. Requirements

Verify

4. Parametrics
NASA MBSE 4 Pillar SE Integration

GATE PRODUCTS: eg.NPR 7123.1B

NASA Evolution

Beginner: 4 Pillar basics
Intermediate: Integrating 4 Pillars (OOSEM)
Advanced: Model what’s needed for products!!
FY20+: Generate tailored NASA-standard profiles, artifacts and views
MSFC MBSE Architecture Approach
Stakeholder Expectations Definition Process

**From Project**

1. Initial Customer Expectations
2. Other Stakeholder Expectations
3. Customer Flow-down Requirements

**To Technical Requirements Definition and Requirements and Interface Management Processes**

- Validated Stakeholder Expectations
- Concept of Operations
- Enabling Product Support Strategies
- Measures of Effectiveness

1. Establish list of stakeholders
2. Elicit stakeholder expectations
3. Establish operations concept and support strategies
4. Define stakeholder expectations in acceptable statements
5. Analyze expectation statements for measures of effectiveness
6. Validate that defined expectation statements reflect bidirectional traceability
7. Obtain stakeholder commitments to the validated set of expectations
8. Baseline stakeholder expectations
9. Capture work products from stakeholder expectations activities

**FIGURE 4.1-1** Stakeholder Expectations Definition Process
MSFC MBSE Architecture Approach

### Stakeholder Needs

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Setting Temperature</td>
<td>It must be possible to set and maintain desired temperature in the cabin.</td>
</tr>
<tr>
<td>2</td>
<td>Heat and Cool Modes</td>
<td>Unit shall be able to heat and cool.</td>
</tr>
<tr>
<td>3</td>
<td>Noise Level</td>
<td>Climate control unit in max mode shall not be louder than engine.</td>
</tr>
<tr>
<td>4</td>
<td>Climate Control Mass</td>
<td>Mass of the unit shall not exceed 2 percent of the total car mass.</td>
</tr>
</tbody>
</table>
# SE Product Maturity

## TABLE 3.0-1: SE Product Maturity from NPR 7123.1

<table>
<thead>
<tr>
<th>Products</th>
<th>Formulation</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>KDP 0</td>
<td>KDP I</td>
</tr>
<tr>
<td></td>
<td>KDP 0</td>
<td>KDP I</td>
</tr>
<tr>
<td></td>
<td>KDP A</td>
<td>KDP B</td>
</tr>
<tr>
<td>Uncoupled/Loosely Coupled Programs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tightly Coupled Programs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projects and Single Project Programs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stakeholder identification and</td>
<td><strong>Baseline</strong></td>
<td>Update</td>
</tr>
<tr>
<td>Concept definition</td>
<td><strong>Baseline</strong></td>
<td>Update</td>
</tr>
<tr>
<td>Measure of effectiveness definition</td>
<td><strong>Approve</strong></td>
<td></td>
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<tr>
<td>Cost and schedule for technical</td>
<td>Initial</td>
<td>Update</td>
</tr>
<tr>
<td>SEMP</td>
<td>Preliminary</td>
<td><strong>Baseline</strong></td>
</tr>
<tr>
<td>Requirements</td>
<td>Preliminary</td>
<td><strong>Baseline</strong></td>
</tr>
<tr>
<td>Technical Performance Measures definition</td>
<td><strong>Approve</strong></td>
<td></td>
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<tr>
<td>Architecture definition</td>
<td><strong>Baseline</strong></td>
<td></td>
</tr>
<tr>
<td>Allocation of requirements to next lower level</td>
<td><strong>Baseline</strong></td>
<td></td>
</tr>
<tr>
<td>Required leading indicator trends</td>
<td><strong>Initial</strong></td>
<td>Update</td>
</tr>
<tr>
<td>Design solution definition</td>
<td>Preliminary</td>
<td><strong>Preliminary</strong></td>
</tr>
<tr>
<td>Interface definition(s)</td>
<td>Preliminary</td>
<td>Baseline</td>
</tr>
<tr>
<td>Implementation plans (Make/code, buy, reuse)</td>
<td>Preliminary</td>
<td>Baseline</td>
</tr>
<tr>
<td>Integration plans</td>
<td>Preliminary</td>
<td>Baseline</td>
</tr>
<tr>
<td>Verification and validation plans</td>
<td>Approach</td>
<td>Preliminary</td>
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<tr>
<td>Verification and validation results</td>
<td><strong>Initial</strong></td>
<td><strong>Preliminary</strong></td>
</tr>
<tr>
<td>Transportation criteria and instructions</td>
<td>Initial</td>
<td>Final</td>
</tr>
<tr>
<td>Operations plans</td>
<td>Baseline</td>
<td>Update</td>
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<tr>
<td>Operational procedures</td>
<td>Preliminary</td>
<td>Baseline</td>
</tr>
<tr>
<td>Certification (flight/usage)</td>
<td>Preliminary</td>
<td><strong>Final</strong></td>
</tr>
<tr>
<td>Decommissioning plans</td>
<td>Preliminary</td>
<td>Preliminary</td>
</tr>
<tr>
<td>Disposal plans</td>
<td>Preliminary</td>
<td>Preliminary</td>
</tr>
</tbody>
</table>
Requirement Challenges

- Tungsten carbide bushings
- Stainless steel
- Solid mahogany

- Sun shade
- Bell
- Cushions

- Design group’s initial design

- Corp. Product Architecture’s modified design

- Pre-release version

- General release version

- What the customer actually wanted
Requirement Extendibility
Requirement Development

VCC System Requirements Specification
Id = "SR-1"

- Automatic Temperature Control
  Id = "SR-1.1"
  Text = "The unit shall automatically switch from air conditioning to heating without manual intervention."

- Manual Temperature Control
  Id = "SR-1.2"
  Text = "The vehicle occupant (the driver or a passenger) shall be able to set the temperature he/she desires in the cabin."

- Temperature Display
  Id = "SR-1.3"
  Text = "The unit shall have a digital display for setting temperature."

- Sound Level
  Id = "SR-1.5"
  Text = "The unit shall not be louder than 50 dB while operating."

- Total Mass
  Id = "SR-1.6"
  Text = "The total mass of the unit shall not exceed 20 kg."

- Engine Use
  Id = "SR-1.7"
  Text = "For heating the air, the unit shall use mechanical power generated by the vehicle engine."
Requirement Derivation Process

Diagram:
- Block: Vehicle Occupant
- Block: Vehicle In Use
- Block: Feel Comfortable Temperature

Diagram Context:
- Package: Use Cases
- Use Case: Vehicle In Use
Activity Implementation

Diagram:
- **Start Climate Control**
- **Set Temperature**
- **Reach Required Temperature**
- **Maintain Temperature**
- **Turn off Climate Control**
- **Stop Climate Control**
- **Check System**
- **Display Temperature**
- **Turn on Climate Control**
Requirement Derivation Process
## Requirement Derivation Process

### Criteria

<table>
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<tr>
<th>Element Type:</th>
<th>Connector</th>
<th>Port A</th>
<th>Port A Features</th>
<th>Port B</th>
<th>Port B Features</th>
<th>Part B</th>
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<tbody>
<tr>
<td>1</td>
<td>Control System</td>
<td>inout p4 : I/O</td>
<td>in Control, out Status</td>
<td>in Control</td>
<td>out Control, in Status</td>
<td>UI System</td>
</tr>
<tr>
<td>2</td>
<td>Control System</td>
<td>inout p5 : I/O</td>
<td>in Control, out Status</td>
<td>in Control</td>
<td>out Control, in Status</td>
<td>Heating System</td>
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<td>3</td>
<td>Control System</td>
<td>inout p6 : I/O</td>
<td>in Control, out Status</td>
<td>in Control</td>
<td>out Control, in Status</td>
<td>Cooling System</td>
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<td>4</td>
<td>Climate Control Unit</td>
<td>inout p1 : Air</td>
<td>in Control, inout Air Flow</td>
<td>in Control</td>
<td>out Control, in Status</td>
<td>Heating System</td>
</tr>
<tr>
<td>5</td>
<td>Climate Control Unit</td>
<td>inout p1 : Air</td>
<td>in Control, inout Air Flow</td>
<td>in Control</td>
<td>out Control, in Status</td>
<td>Heating System</td>
</tr>
<tr>
<td>6</td>
<td>Climate Control Unit</td>
<td>inout p2 : I/O</td>
<td>in Control, out Status</td>
<td>in Control</td>
<td>out Control, in Status</td>
<td>UI System</td>
</tr>
<tr>
<td>7</td>
<td>Climate Control Unit</td>
<td>in p3 : Energy</td>
<td>in Electrical Power, in Mechanical Power</td>
<td>in Electrical Power</td>
<td>in Control, in Status</td>
<td>Control System</td>
</tr>
<tr>
<td>8</td>
<td>Climate Control Unit</td>
<td>in p3 : Energy</td>
<td>in Electrical Power, in Mechanical Power</td>
<td>in Electrical Power</td>
<td>in Control, in Status</td>
<td>Cooling System</td>
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<tr>
<td>9</td>
<td>Climate Control Unit</td>
<td>in p3 : Energy</td>
<td>in Electrical Power, in Mechanical Power</td>
<td>in Electrical Power</td>
<td>in Control, in Status</td>
<td>Heating System</td>
</tr>
<tr>
<td>10</td>
<td>Climate Control Unit</td>
<td>in p3 : Energy</td>
<td>in Electrical Power, in Mechanical Power</td>
<td>in Electrical Power</td>
<td>in Control, in Status</td>
<td>UI System</td>
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</table>
## Use Case Refinement

### Legend
- Refine
- Refine (Implied)

### Table

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<tr>
<th>Requirement</th>
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<th>4</th>
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<td>SR-1.2 Manual Temperature Control</td>
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<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
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<td>SR-1.3 Temperature Display</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>SR-1.5 Sound Level</td>
<td></td>
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<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>SR-1.6 Total Mass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR-1.7 Engine Use</td>
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<td></td>
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## Requirement to Design Trace

### Legend
- **Satisfy**

### VCCS Configuration [3 System Structure]

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<td>3</td>
<td>3</td>
<td>1</td>
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</table>

### 1 System Requirements
- SR-1.1 Automatic Temperature Control
- SR-1.2 Manual Temperature Control
- SR-1.3 Temperature Display
- SR-1.5 Sound Level
- SR-1.6 Total Mass
- SR-1.7 Engine Use
Stakeholder Need Trace
Mass Roll Up
# Mass Rollup Requirement Verification

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
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<tbody>
<tr>
<td>ECLSS_H2_Technology_Demonstration_System</td>
<td>ECLSS_H2_Technology_Demonstration_System@3839f730</td>
</tr>
<tr>
<td>mass : Real [1]</td>
<td>0.0000</td>
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<tr>
<td>/totalMass : Real</td>
<td>501.0000</td>
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<tr>
<td>Gas Manifold</td>
<td>Gas Manifold@411c1368</td>
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<tr>
<td>mass : Real [1]</td>
<td>0.0000</td>
</tr>
<tr>
<td>/totalMass : Real</td>
<td>250.0000</td>
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<tr>
<td>Manual Flow Valve</td>
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<tr>
<td>mass : Real [1]</td>
<td>0.0000</td>
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<tr>
<td>/totalMass : Real</td>
<td>250.0000</td>
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<tr>
<td>Flow Meter</td>
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<td>/totalMass : Real</td>
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<tr>
<td>/totalMass : Real</td>
<td>251.0000</td>
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<tr>
<td>A/D Conv, PCDU</td>
<td>A/D Conv, PCDU@7a84d3cf</td>
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<tr>
<td>/totalMass : Real</td>
<td>251.0000</td>
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<tr>
<td>Heater Zone 1</td>
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<tr>
<td>mass : Real [1]</td>
<td>251.0000</td>
</tr>
<tr>
<td>/totalMass : Real</td>
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<tr>
<td>Heater Zone 2</td>
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<td>mass : Real [1]</td>
<td>251.0000</td>
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<tr>
<td>/totalMass : Real</td>
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<tr>
<td>Sensor Elec.</td>
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<td>mass : Real [1]</td>
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<tr>
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<td>Sensor Elec.</td>
<td>Sensor Elec.@115c7c55</td>
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<td>/totalMass : Real</td>
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<td>Sensor Elec.</td>
<td>Sensor Elec.@b3c1d54</td>
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<tr>
<td>/totalMass : Real</td>
<td>251.0000</td>
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</table>
Views and Viewpoints

- ECLSS
- ECLSS H2 ConOps
- TOC
- Project Goal
- ECLSS_H2_Nominal Lifecycle ConOps
ECLSS Concept of Operations

Table of Contents

1. TOC
2. Project Goal
3. Scope

List of Figures

2.1. Project Goal

Chapter 1. ECLSS H2 ConOps

Chapter 2. Project Goal
NGO’s
MBMA Pathfinding

- Pathfinding approach with MagicDraw Plugin Cameo Safety and Reliability
NASA Future MBSE Work

- Pilot Patterns for deploying a Scalable Architecture
- Develop Profile (and patterns) for generating a complete set of tailorable 7123 products, artifacts and views
- Explore end verification and validation approaches.
- Research Configuration and Data Management approaches.
- Further investigation into PLM tools for complete Digital Thread
- Pilot Patterns for implementing S&MA Comprehensive Project Risk Management
- Exploring Teamwork Cloud Environment centered around Cameo Collaboration
CLM Takeaways Using MBSE

• Managing a Complex System
  – View multiple perspectives
  – Analyze change impacts
  – Evaluate system for consistency, accuracy, and completeness
  – Simulate the functionality of the system
  – Integrate with other disciplines

• Improved Communications
  – Graphical elements
  – Consistent definitions
  – Collaborative infrastructure
  – Authoritative data

• Enhanced Knowledge Transfer
  – Store models and model elements in a library
  – Reduced start-up time
  – Consistent information between projects and between project lifecycle phases
  – Iterative and multi-level modeling

➢ Reduced Time
➢ Reduced Cost
➢ Reduced Risk
➢ but…Requires up-front investment
Questions?

• Any Questions or go backs?

* Details can be found in backup charts
MBSE Trace to NPR 7123 17 SE Processes

- **System Design Processes**
  - Requirements Definition Processes
    - 1. Stakeholder Expectations Definition
    - 2. Technical Requirements Definition
  - Technical Solution Definition Processes
    - 3. Logical Decomposition
    - 4. Design Solution Definition

- **Technical Management Processes**
  - Technical Planning Process
  - Technical Control Processes
    - 9. Product Transition Process
  - Technical Assessment Process
    - 10. Technical Planning
    - 11. Requirements Management
    - 12. Interface Management
    - 14. Configuration Management
    - 15. Technical Data Management
  - Technical Decision Analysis Process
    - 16. Technical Assessment
    - 17. Decision Analysis

- **Product Realization Processes**
  - Evaluation Processes
    - 7. Product Verification
    - 8. Product Validation
  - Design Realization Processes
    - 5. Product Implementation
    - 6. Product Integration

- **Requirements Flow Down from Level above**
- **Realized Products to Level above**
- **Requirements Flow Down to Level below**
- **Realized Products from Level below**

System Design Processes applied to each WBS Model down and across system structure.

Product Realization Processes applied to each product up and across system structure.