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

MBSE Vision
MBSE Roadmap

Digital Practitioner Community
Systems Modeling WG
Systems Analysis and Data Visualization WG
Infra-structure and Ecosystem WG

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

FY16:
FY17:
FY18 & FY19:
FY20:

Learn & Align
Learn & Apply
Develop Recognized Core Capability
Targeted Deployment
“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
MSFC MBSE Advocacy

• 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
• http://www.15288.com/about_standards.php
### MagicGrid 101 Cont.

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

1. Structure
2. Behavior
3. Requirements
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

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:
  - **1. Setting Temperature**: It must be possible to set and maintain desired temperature in the cabin.
  - **2. Heat and Cool Modes**: Unit shall be able to heat and cool.
  - **3. Noise Level**: Climate control unit in max mode shall not be louder than engine.
  - **4. Climate Control Mass**: Mass of the unit shall not exceed 2 percent of the total car mass.
# 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>
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<tr>
<td></td>
<td>KDP 0</td>
<td>KDP 1</td>
</tr>
<tr>
<td></td>
<td>KDP II</td>
<td>KDP III</td>
</tr>
<tr>
<td></td>
<td>Periodic KDPs</td>
<td></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>
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<td></td>
</tr>
<tr>
<td></td>
<td>Pre-Phase A</td>
<td>Phase A</td>
</tr>
<tr>
<td></td>
<td>Phase B</td>
<td>Phase C</td>
</tr>
<tr>
<td></td>
<td>Phase D</td>
<td>Phase E</td>
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<tr>
<td></td>
<td>Phase F</td>
<td></td>
</tr>
<tr>
<td>MCR</td>
<td>SRR</td>
<td>MDR/SDR</td>
</tr>
<tr>
<td>PDR</td>
<td>CDR</td>
<td>SIR</td>
</tr>
<tr>
<td>ORR</td>
<td>FRR</td>
<td>DR</td>
</tr>
<tr>
<td>DRR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Stakeholder identification and development
- **Baseline**
- Update
- Update
- Update
- Update

### Concept definition
- **Baseline**
- Update
- Update
- Update
- Update
- Update

### Measure of effectiveness definition
- **Approve**

### Cost and schedule for technical and operational performance
- Initial
- Update
- Update
- Update
- Update
- Update
- Update
- Update
- Update
- Update
- Update

### SEMP
- Preliminary
- **Baseline**
- **Baseline**
- Update
- Update
- Update

### Requirements
- Preliminary
- **Baseline**
- Update
- Update
- Update

### Technical Performance Measures definition
- **Approve**

### Architecture definition
- **Baseline**

### Allocation of requirements to next lower level
- **Baseline**

### Required leading indicator trends
- **Initial**
- Update
- Update
- Update

### Design solution definition
- Preliminary
- **Preliminary**
- **Baseline**
- Update
- Update

### Interface definition(s)
- Preliminary
- Baseline
- Update
- Update

### Implementation plans (Make/ code, buy, reuse)
- Preliminary
- Baseline
- Update

### Integration plans
- Preliminary
- Baseline
- Update
- **Update**

### Verification and validation plans
- Approach
- Preliminary
- Baseline
- Update

### Verification and validation results
- **Initial**
- **Preliminary**
- **Baseline**

### Transportation criteria and instructions
- Initial
- Final
- Update

### Operations plans
- Baseline
- Update
- **Update**

### Operational procedures
- Preliminary
- Baseline
- **Update**
- Update

### Certification (flight/uso)
- Preliminary
- **Final**

### Decommissioning plans
- Preliminary
- Preliminary
- **Baseline**
- Update
- **Update**

### Disposal plans
- Preliminary
- Preliminary
- Preliminary
- **Baseline**
- Update
- **Update**

---

Requirement Challenges

Tungsten carbide bushes
- Stainless steel
- Solid mahogany

What Product Marketing specified

Sun shade
- Bell
- Cushions

What the salesman promised

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

```
req [Package] 1 System Requirements [ System Requirements ]

- **<requirement>**
  VCC System Requirements Specification
  Id = "SR-1"

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

- **<functionalRequirement>**
  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."

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

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

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

- **<physicalRequirement>**
  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
Activity Implementation
Requirement Derivation Process
Requirement Derivation Process
## Requirement Derivation Process

<table>
<thead>
<tr>
<th>#</th>
<th>Part A</th>
<th>Port A Features</th>
<th>Port B</th>
<th>Port B Features</th>
<th>Part B</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Control System</td>
<td>inout p4 : I/O, out Status</td>
<td>in Control, out Control</td>
<td>out Control, in Control</td>
<td>UI System</td>
</tr>
<tr>
<td>2</td>
<td>Control System</td>
<td>inout p5 : I/O, out Status</td>
<td>in Control, out Control</td>
<td>out Control, in Control</td>
<td>Heating System</td>
</tr>
<tr>
<td>3</td>
<td>Control System</td>
<td>inout p6 : I/O, out Status</td>
<td>in Control, out Control</td>
<td>out Control, in Control</td>
<td>Cooling System</td>
</tr>
<tr>
<td>4</td>
<td>Climate Control Unit</td>
<td>inout p1 : Air, in Air Flow</td>
<td>in Air Flow, in Control</td>
<td>in Air Flow, in Control</td>
<td>Heating System</td>
</tr>
<tr>
<td>5</td>
<td>Climate Control Unit</td>
<td>inout p1 : Air, in Air Flow</td>
<td>in Air Flow, in Control</td>
<td>in Air Flow, in Control</td>
<td>Heating System</td>
</tr>
<tr>
<td>6</td>
<td>Climate Control Unit</td>
<td>inout p2 : I/O, out Status</td>
<td>in Control, out Control</td>
<td>in Air Flow, in Control</td>
<td>UI System</td>
</tr>
</tbody>
</table>
# Use Case Refinement

## Legend
- Refine
- Refine (Implied)

## Diagram
- 1 System Requirements
  - SR-1 VCC System Requirements Specification
    - 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
## Requirement to Design Trace

![Diagram of Requirement to Design Trace]

### Legend
- Satisfy

### VCCS Configuration [3 System Structure]

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
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<tbody>
<tr>
<td>Control System Design</td>
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<tr>
<td>Cooling System Design</td>
<td>2</td>
</tr>
<tr>
<td>Heating System Design</td>
<td>2</td>
</tr>
<tr>
<td>Sensors System Design</td>
<td>2</td>
</tr>
<tr>
<td>Total Mass</td>
<td>1</td>
</tr>
<tr>
<td>UI System Design</td>
<td>1</td>
</tr>
<tr>
<td>soundLevel : dBA</td>
<td>1</td>
</tr>
<tr>
<td>totalMass : mass[kilogram]</td>
<td>1</td>
</tr>
<tr>
<td>in p1 : iHeat</td>
<td>2</td>
</tr>
<tr>
<td>in p2 : iElectricity</td>
<td>3</td>
</tr>
<tr>
<td>in p3 : iMechanical Power</td>
<td>3</td>
</tr>
<tr>
<td>mass : mass[kilogram]</td>
<td>1</td>
</tr>
<tr>
<td>out p4 : ~iHeat</td>
<td>2</td>
</tr>
<tr>
<td>out p6 : iMoisture</td>
<td>2</td>
</tr>
</tbody>
</table>
Stakeholder Need Trace

Legend
- Refine

2 Functional Analysis
- Cool
- Display Data
- Heat
- Prepare System
- Reach Required Temperature
- Transfer Data

4 Measurements of Effectiveness
- MoEs Holder
- /Sound Level : dBA
- /Total Mass : mass[kilogram]
Mass Roll Up

Diagram showing the model-based systems engineering for mass roll up, including the verification of VCCS Configuration and Total Mass with constraints and requirements.
Mass Rollup Requirement Verification

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
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<tr>
<td>ECLSS_H2_Technology_Demonstration_System</td>
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<tr>
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<tr>
<td>/totalMass</td>
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<td>Gas Manifold</td>
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<td>Manual Flow Valve</td>
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<td>Flow Meter</td>
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<tr>
<td>Pressure Relief Valve</td>
<td>Pressure Relief Valve@43f893e1</td>
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<td>A/D Conv, PCDU</td>
<td>A/D Conv, PCDU@7a84d3cf</td>
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<td>Heater Zone 1</td>
<td>Heater Zone 1@4af8ca6a</td>
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<td>Heater Zone 2</td>
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<td>Sensor Elec.</td>
<td>Sensor Elec.@6ccf0733</td>
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<td>Sensor Elec.</td>
<td>Sensor Elec.@418c082c</td>
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<tr>
<td>Sensor Elec.</td>
<td>Sensor Elec.@115c7c55</td>
</tr>
<tr>
<td>Sensor Elec.</td>
<td>Sensor Elec.@b3c1d54</td>
</tr>
</tbody>
</table>
Traceability
Views and Viewpoints
ECLSS Concept of Operations

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- 1. TOC
- 2. Project Goal
- 3. Scope

List of Figures
- 2.1. Project Goal

Chapter 1. ECLSS H2 ConOps
Chapter 2. Project Goal
MBMA Integration

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

Requirements Flow Down from Level above

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
10. Technical Planning

Technical Control Processes
11. Requirements Management
12. Interface Management
13. Technical Risk Management
14. Configuration Management
15. Technical Data Management

Technical Assessment Process
16. Technical Assessment

Technical Decision Analysis Process
17. Decision Analysis

Realized Products to Level above

Product Realization Processes

Product Transition Process
9. Product Transition

Evaluation Processes
7. Product Verification
8. Product Validation

Design Realization Processes
5. Product Implementation
6. Product Integration

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