Model-Based Systems Engineering Approach to Managing Mass Margin

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Systems Engineering Concerns

Multiple Sources of Truth

• Consistency and correctness
  – Multiple mass equipment lists (MELs)
    • Different versions of MEL spreadsheets owned by the systems and subsystems engineers
  – Implicit block diagram and MEL relationship
    • Manual creation of the diagrams and MELs
    • Visual consistency and correctness verification of the diagrams and MEL

• Iterating the architecture and design
  – Manual updating MEL and block diagrams *consistently* and *correctly*
Model-Based Systems Engineering Framework

Model as the Single-Source-of-Truth

Consistency
- Enforced by having a single-source-of-truth, the models

Correctness
- Enforced through verification checks and reviews from various viewpoint of the Model
Model-Based Systems Engineering Approach to Managing Mass Margin

EHM MODEL-BASED SYSTEMS ENGINEERING FRAMEWORK
EHM Model-Based Systems Engineering Framework

Viewpoint-Based Framework Concept

Models
System, Programmatic, etc.

Viewpoint-1
Viewpoint-2
Viewpoint-3
Viewpoint-n

View-1
View-2
View-3
View-n
EHM Model-Based Systems Engineering Framework

EHM Viewpoint-Based Framework

SysML Models
System, Programmatic, etc.

Block Diagram Viewpoints
Mass Equipment List Viewpoints
Mass Margin Viewpoints
Power Equipment List Viewpoints

Block Diagram
MEL Table
Mass Margin Analysis & Report
PEL Table

Data Margin Viewpoints
Data Margin Analysis & Report

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EHM Model-Based Systems Engineering Framework

EHM Viewpoint-Based Framework

SysML Models
System, Programmatic, etc.

Block Diagram Viewpoints → Mass Equipment List Viewpoints → Mass Margin Viewpoints

Block Diagram → MEL Table → Mass Margin Table
Model-Based Systems Engineering Approach to Managing Mass Margin

MODELS FOR MELS AND MASS MARGIN ANALYSIS
Models for MELs and Mass Margins

System Structural Model

SysML Models
System, Programmatic, etc.

«Hardware Product»

Product-1

mass characterization

«Mass Characterization»

Mass Characterization

values

- Mass Contingency: Real = 0.25
- Mass Current Best Estimate: kg = 2.5
- Mass Maximum Expected Value: kg = 3.125

P2-A → P2-B

P4-1 → P4-2

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Models for MELs and Mass Margins

Work Breakdown Structure Model
Models for MELs and Mass Margins

Work Package Supplies Model

SysML Models
System, Programmatic, etc.

Flight System

«supplies»

are Product»

«supplies»

«supplies»

«supplies»

«supplies»
Model-Based Systems Engineering Approach to Managing Mass Margin

EHM PROJECT VIEWS AND VIEWPOINTS
Block Diagram Views

SysML IBDs as Block Diagram
Block Diagram Views

EHM Carrier Block Diagram

Block Diagram Views

EHM Carrier Prop Schematics

EHM Project Views and Viewpoints

Mass Equipment List (MEL) Views

SysML Models
System, Programmatic, etc.

Block Diagram Viewpoints
Mass Equipment List Viewpoints
Mass Margin Viewpoints

Block Diagram
MEL Table
Mass Margin Table
## Mass Equipment List (MEL) Views

### Deployment

<table>
<thead>
<tr>
<th>Products</th>
<th>CBE (kg)</th>
<th>Cont.</th>
<th>MEV (kg)</th>
<th>Num Of Units</th>
<th>Total Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight System</td>
<td>106.4</td>
<td>0.28</td>
<td>136.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Product-1</td>
<td>2.5</td>
<td>0.25</td>
<td>3.1</td>
<td>2</td>
<td>6.25</td>
</tr>
<tr>
<td>Product-2</td>
<td>47.5</td>
<td>0.28</td>
<td>60.7</td>
<td>2</td>
<td>95</td>
</tr>
<tr>
<td>Product-3</td>
<td>1.2</td>
<td>0.30</td>
<td>1.6</td>
<td>1</td>
<td>1.56</td>
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<tr>
<td>Product-4</td>
<td>10.4</td>
<td>0.25</td>
<td>13.0</td>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>Product-5</td>
<td>25.5</td>
<td>0.30</td>
<td>33.2</td>
<td>1</td>
<td>33.15</td>
</tr>
<tr>
<td>Product-6</td>
<td>3.2</td>
<td>0.30</td>
<td>4.2</td>
<td>2</td>
<td>8.32</td>
</tr>
</tbody>
</table>

- **Spacecraft System**
- **Payload System**
- **C&DH**
- **Power**

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## Mass Equipment List (MEL) Views

### Bill of Materials

<table>
<thead>
<tr>
<th>WorkPackages</th>
<th>Products</th>
<th>Mass per Unit</th>
<th>Total Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CBE (kg)</td>
<td>Cont.</td>
<td>MEV (kg)</td>
</tr>
<tr>
<td>Project</td>
<td>106.4</td>
<td>0.28</td>
<td>136.0</td>
</tr>
<tr>
<td>Payload System</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Product-1</td>
<td>2.5</td>
<td>0.25</td>
<td>3.1</td>
</tr>
<tr>
<td>Product-3</td>
<td>1.2</td>
<td>0.30</td>
<td>1.6</td>
</tr>
<tr>
<td>Spacecraft System</td>
<td>99.0</td>
<td>0.28</td>
<td>126.6</td>
</tr>
<tr>
<td>C&amp;DH</td>
<td>41.6</td>
<td>0.25</td>
<td>52.0</td>
</tr>
<tr>
<td>Product-4</td>
<td>10.4</td>
<td>0.25</td>
<td>13.0</td>
</tr>
<tr>
<td>Power</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Product-5</td>
<td>25.5</td>
<td>0.30</td>
<td>33.2</td>
</tr>
<tr>
<td>Product-6</td>
<td>3.2</td>
<td>0.30</td>
<td>4.2</td>
</tr>
</tbody>
</table>
EHM Project Views and Viewpoints

Mass Margin View

SysML Models
System, Programmatic, etc.

Block Diagram Viewpoints
Mass Equipment List Viewpoints
Mass Margin Viewpoints
Mass Margin Table

Block Diagram
MEL Table
Mass Margin View

Mass Margin Table

From MEL: Bill-of-Materials View

Based on the ΔV and the propulsion system type

From the Launch Vehicle description

Based on the Mass Margin equation

CONCLUSION

Model-Based Systems Engineering Approach to Managing Mass Margin
Conclusion

Consistency
• Enforced by having a single-source-of-truth, the models

Correctness
• Enforced through verification checks and reviews from various viewpoints of the Models

Used in the EHM project to help design three different mission concepts in just three months with a high degree of confidence in the consistency, correctness and even completeness.