Battle of Hoth
Example for Mission Engineering

Matt Gagliardi
Matthew Hause
SYSTEM STRATEGY, INC.

POC: mhause@systemxi.com
Abstract

• As a means of exploring how to identify potential capability gaps within its air, land, and seas forces, the U.S. Department of Defense developed the Mission Engineering Guide to help define key terms and relationships between mission-related elements.

• This paper shows how UAF can be extended to leverage the concepts in the Mission Engineering Guide and use them to model missions and the resources used to execute them, while referencing a widely known Star Wars battle as an example.
What is Mission Engineering?

• Mission Engineering (ME) as the deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired warfighting mission effects.

• ME is a top-down approach that delivers engineering results to identify enhanced capabilities, technologies, system interdependencies, and architectures to guide development, prototypes, experiments, and SoS to achieve reference missions and close mission capability gaps.

• ME uses systems and SoS in an operational mission context to inform stakeholders about building the right things, not just building things right, by guiding capability maturation to address warfighter mission needs.

Mission Engineering Guide.
• **Mission:** The task, together with the purpose, that clearly indicates the action to be taken and the reason thereby. More simply, a mission is a duty assigned to an individual or unit.

• **Mission Thread (MT):** An end-to-end sequence of tasks, activities, and events to execute a mission.

• **Mission Engineering Thread (MET):** Mission threads that include technical details of the capabilities and systems required and utilized to execute the tasks and activities for a mission.
# The Unified Architecture Framework Grid

## Standard means of expression – model kinds/aspects

<table>
<thead>
<tr>
<th>Different Domains</th>
<th>Taxonomy</th>
<th>Structure &amp; Connectivity</th>
<th>Behavior</th>
<th>Information</th>
<th>Parameters</th>
<th>Constraints</th>
<th>Roadmap</th>
<th>Traceability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic</td>
<td>Business View, Identifying, Monetizing, Informing</td>
<td>Usage View, Understanding the SoS from Operational</td>
<td>Functional View, Disruption Identifying Cognitive</td>
<td>Implementation View, Cloud, Analytics and Edge Architecture, Interfaces, Behavior</td>
<td>Data in all forms</td>
<td>As-Is To-Be</td>
<td>Planning</td>
<td>Traceability across all levels</td>
</tr>
<tr>
<td>Operational</td>
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<td>Standards</td>
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• **Strategic Capability and Enterprise Concepts:**
  - Defines the “why” and “what” and “when” before the “how”.
  - For ME, these are used to define the mission goals, purpose, timescales, structure, architecture, quantitative metrics, and temporal and physical mission structures.

• **Operational Logical Architecture:**
  - Defines the enterprise architecture in a solution in-dependent form including behavior and structure.
  - These views define all aspects of the MT.

• **Security:**
  - Identifying risk, its mitigation, and integrating security into the architecture.
  - Mission risks and mitigation can be defined and quantified to increase mission success.

• **Standards:**
  - Definition of and compliance with standards in the architecture. Standards correspond to guidance, rules of engagement, doctrine, etc.
  - For specific elements of doctrine, the standard can be imported into the model, defined as types of requirements, and linked to model elements.
Mission Engineering and the UAF (2)

• **Resources/Systems:**
  • Systems, software, technologies, etc that will implement the solution by implementing the operational or logical elements.
  • These views and elements form the MET that implements the ME.
  • UAF also provides temporal concepts to show how the systems evolve over time as well as variations and trade off analysis between candidate solution architectures.

• **Personnel/ Human Factors:**
  • How people and systems interact, and their expected knowledge & skills.
  • These are the organizational structures, configurations, equipment, behavior, etc. pertaining to the MET.

• **Built-in Traceability:**
  • Between Multiple Views as well as Between Layers and Across Layers
  • These demonstrate that capability and mission goals have been met.
• We took a minimalist approach: only add what was absolutely necessary.

• Simple extensions to add some of the concepts to be implemented in UAF 1.3
  • Mission
  • Actual Mission Phase
  • Mission Thread
  • Mission Task
  • Mission Engineering Thread
  • Ref Doctrine
  • Extensions to the UAF diagrams.
The Battle of Hoth was a major battle fought in 3 ABY and was considered a major victory for the Galactic Empire and the single worst battlefield defeat suffered by the Rebel Alliance during the Galactic Civil War.

- The battle was an Imperial invasion led by Darth Vader, aimed at destroying the Rebel Alliance's Echo Base hidden on the remote ice world Hoth and capturing Luke Skywalker.

- The base's location was discovered when a Viper probe droid, deployed by Darth Vader's Death Squadron, landed on the planet - prompting the Rebels to begin an evacuation of Hoth.

https://starwars.fandom.com/wiki/Star_Wars:_Episode_V_The_Empire_Strikes_Back#The_Battle_of_Hoth
Why the Battle of Hoth?

- The example used in this paper is the Battle of Hoth from the second Star Wars movie, “The Empire Strikes Back”.

  - We are using this as an example because it is well known, contains a rich source of systems, strategies, missions, and behavior as well as illustrates joint operations.

  - As it is based on a movie, there are no issues of classified materials or problems relating to the release of information.

  - The actual model created to describe the complete mission would be a large undertaking requiring several diagrams.

  - For reasons of space and time, we have limited this to a set of example diagrams to express the main concepts covered.
Empire Planetary Invasion Missions

• The Empire Mission structure shown illustrates the complexity required to model missions.

• Empire doctrine proscribes that every military mission has two phases to it: Planning and Execution.

• A Planetary Invasion Mission is comprised of separate Scout, Landing, and Attack Missions, each with their own Planning and Execution Phases.

• These are all types of Invasion Missions.

• The Execution and Planning Phases both inherit Mission Tempo and Phase attributes.
Hoth Invasion Missions

- The Hoth Invasion is an instance of the Planetary Invasion Mission.
- This Actual Mission is made up of the Planning and Execution Phase as well as the Landing Mission, Attack Mission, and Scout mission.
- These Missions each have Planning and Execution Phases.
- The Execution phases all have Mission Threads and Mission Engineering Threads mapped to them.
- The Hoth AMEP Execution Phase has defined goals as well as Operational and Resource Architecture.
• The scenario & vignette elements are types of condition which means that they can define single conditions as well as sets of conditions.

• The scenario defines the conditions for the mission and the vignette for the mission phase.

• The actual scenarios and vignettes do the same for the actual mission and mission phase.

• As they are actuals, the define the precise conditions.
Hoth Execution Phase Actual Mission Goals

- Prior to planning the Mission Thread and Mission Engineering Thread, the Goals of the Mission are defined.

- These are to Destroy Rebel Defenses, Prevent Rebel Escape, and Capture Luke Skywalker.

- The constraint imposed by Capturing Luke Skywalker alive and unharmed is what causes the Mission to fail.

- The Empire normally executes their missions with extreme violence. This constraint, prevented this.
• The Planetary Attack capability hierarchy is shown on the left.

• This includes Ground Attack, Close Air Attack, etc.

• Linking the mission to the highest-level capability reduces the coupling of the two structures.

• These capabilities along with the associated metrics will form the basis for trade-off analysis of the candidate architectures and systems.
Strategic Actual Enterprise Phase Taxonomy Table

- Automatically generated table showing details of the Actual Missions and Phases.

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Type</th>
<th>Goal</th>
<th>Operational Architecture Of Enterprise Phase</th>
<th>Resource Architecture Of Enterprise Phase</th>
<th>Exhibits Capability</th>
<th>Slot</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Execute Hoth Invasion</td>
<td>Execution</td>
<td></td>
<td></td>
<td></td>
<td>③ Mission Tempo = Rapid and Forceful, ④ Mission Phase = Execution Phase</td>
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</tr>
<tr>
<td>2</td>
<td>Hoth AM</td>
<td>Attack</td>
<td></td>
<td></td>
<td></td>
<td>④ Invasion Planning Phase = Hoth AMPP, ⑤ Invasion Execution Phase = Hoth AMEP</td>
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</tr>
<tr>
<td>4</td>
<td>Hoth AMPP</td>
<td>Planning</td>
<td></td>
<td></td>
<td></td>
<td>④ Mission Phase = Planning Phase</td>
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<tr>
<td>5</td>
<td>Hoth Attack Mission</td>
<td>Attack</td>
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<tr>
<td>6</td>
<td>Hoth EP</td>
<td>Execution</td>
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<tr>
<td>7</td>
<td>Hoth Invasion</td>
<td>Planetary</td>
<td></td>
<td></td>
<td></td>
<td>⑤ LM = Hoth LM, ⑤ AM = Hoth AM, ⑤ SM = Hoth SM, ⑤ Invasion Planning Phase = Hoth PP, ⑤ Invasion Execution Phase = Hoth EP</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Hoth Landing Mission</td>
<td>Landing</td>
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<td></td>
<td>⑤ Invasion Execution Phase = Hoth LMEPP, ⑤ Invasion Planning Phase = Hoth LMP</td>
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</tr>
<tr>
<td>9</td>
<td>Hoth LM</td>
<td>Landing</td>
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<tr>
<td>10</td>
<td>Hoth LMEP</td>
<td>Execution</td>
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<td>⑤ Mission Phase = Execution Phase</td>
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<tr>
<td>11</td>
<td>Hoth LMPP</td>
<td>Planning</td>
<td></td>
<td></td>
<td></td>
<td>⑤ Mission Phase = Planning Phase</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Hoth PP</td>
<td>Planning</td>
<td></td>
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</tr>
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<td>13</td>
<td>Hoth Screen Mission</td>
<td>Scout</td>
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<td>14</td>
<td>Hoth SM</td>
<td>Scout</td>
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<tr>
<td>15</td>
<td>Hoth SMPP</td>
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<td>17</td>
<td>Plan Hoth Invasion Mid</td>
<td>Planning</td>
<td></td>
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</tr>
</tbody>
</table>
Weapon Resources Taxonomy

- Defines the interactions that will take place at both the Operational and Resource levels.

- Blaster weapons are directed energy weapons, so the transmitted elements are types of energy, a natural resource.
Logical Data Model

- Initial data model of the information interactions at the Operational level.
- These should be expanded to include attributes and other elements.
• Defines the Operational Architecture hierarchy of the context in which the Empire (Blue Force) and Rebel Forces (Red Forces) will engage.

• The Empire forces are those which will be deployed as part of their attack strategy. These are the abstract elements, from which Resources will be chosen to implement them.

• The Rebel Forces are less clear. They have been discovered by reconnaissance systems. Additional attributes such as provenance, confidence level, etc. should be added.

• The addition of Friendly, Enemy, and Neutral stereotypes are shown later.

• The Rebel Forces were able to escape as the Empire underestimated the strength of the ground forces cannon which destroyed one of their spaceships.
- IBD version of the Operational Architecture.
- An abstract/solution independent expression of the proposed battle.
- Interactions include Information Exchanges between troops and commanders, weapons fire, sustained damage, scan data, etc.
Operational Performers to Capabilities Mapping Matrix

- Automatically generated table.
- Traceability between the required Capabilities and the proposed Operational Performers. The Scout Forces and Air Transport Forces are not included in the Attack context.
- All required capabilities have been exhibited.
Planetary Invasion Processes – Mission Threads and Tasks Decomposition

- This is the functional hierarchy of the Execute Planetary Invasion Mission Thread.
- It is broken into Mission Threads of Scout Planet, Weaken Planetary Defenses, Attack Primary Objective and Deploy Attack Force.
- Each of these are further decomposed into Mission Tasks.
The Empire forces are those which will be deployed as part of their attack strategy. These are the abstract elements, from which Resources will be chosen to implement them.

Each has a set of Operational Activities that they can perform.

If MBSE is already established in an organization, these would be part of a library and reused.

For a new installation, these would form the basis of the library to be populated as further missions are defined.

These activities are referenced by the Mission Tasks.
Strategic Traceability

- Traceability table showing the Actual Missions, Mission Threads, Mission Tasks and operational activities that exhibit the required capabilities.

- The scope has been focused on the Planetary Attack capability and its owned capabilities.

- This helps to validate the Mission thread against the required capabilities.

- Metrics could be added to determine the required and provided measures for trade-off analysis.
Rebel Operational Processes

• Once again, these are the Rebel Force elements that have been discovered as well as their perceived functionality.
This is an abbreviated form of the Mission Thread. Details have been excluded to ensure that the diagram is legible.

Note the interactions between the rebel and Empire Forces.

The Ground Attack Forces Fire Weapons and the Rebel Forces Incur Damage and Emit a Visual Signature. The Signature is detected and analyzed by the Assess Damage and Scan for Rebel Defense Forces activities.

Counter attacks as well as other Rebel offensive activities should also be defined.
**Logical Data Model Usage**

- Summary table showing the Information Elements and their relationships.
- They do not all appear on activity diagrams, indicating that the behavioral model is not yet complete.

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Participates in Activity</th>
<th>Info Exchange</th>
<th>Exchange Source</th>
<th>Exchange Target</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Attack</td>
<td>Command Attack</td>
<td>&quot;OE21 Operational Exchange flow for Attack(1)&quot;</td>
<td>Empire Command</td>
<td>Empire Air Attack Forces</td>
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<td></td>
<td></td>
<td>Commence Attack</td>
<td>&quot;OE22 Operational Exchange flow for Attack(1)&quot;</td>
<td></td>
<td>Empire Space Forces</td>
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<td></td>
<td></td>
<td>Destroy Defense Forces</td>
<td>&quot;OE23 Operational Exchange flow for Attack(3)&quot;</td>
<td></td>
<td>Empire Ground Attack F</td>
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<td>2</td>
<td>Battle Damage Ass</td>
<td>Assess Damage</td>
<td>&quot;OE34 Operational Exchange flow for Battle Damage(1)&quot;</td>
<td>Empire Ground Attack F</td>
<td>Empire Command</td>
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<td>Scan for Rebel Defense Forces</td>
<td>&quot;OE35 Operational Exchange flow for Battle Damage(1)&quot;</td>
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<td>Empire Space Forces</td>
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<td>Supervise Attack</td>
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<td>Damage Report</td>
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<td>&quot;OE27 Operational Exchange flow for Damage(1)&quot;</td>
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<td>&quot;OE28 Operational Exchange flow for Damage(1)&quot;</td>
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<td>&quot;OE29 Operational Exchange flow for Damage(1)&quot;</td>
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<td>Rebel Escape Transport</td>
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<td>Rebel Air Defense Force</td>
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<td>Empire Ground Attack F</td>
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<td>4</td>
<td>Evacuate</td>
<td>Fire Weapons</td>
<td>&quot;OE24 Operational Exchange flow for Evacuate(1)&quot;</td>
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<td>Fire Weapons</td>
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<td>&quot;OE8 Operational Exchange flow for Fire(1)&quot;</td>
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<td>&quot;OE32 Operational Exchange flow for Fire(1)&quot;</td>
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<td>6</td>
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<td>&quot;OE7 Operational Exchange flow for Movement(1)&quot;</td>
<td>Rebel Command</td>
<td>Rebel Ground Defense F</td>
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<td>Objective Reached</td>
<td>Inform Command</td>
<td>&quot;OE12 Operational Exchange flow for Objective(1)&quot;</td>
<td>Empire Ground Attack F</td>
<td>Empire Command</td>
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<td>Command Destroy Objective</td>
<td>&quot;OE12 Operational Exchange flow for Objective(1)&quot;</td>
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<td>&quot;OE17 Operational Exchange flow for OPORD(1)&quot;</td>
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<td>Empire Space Forces</td>
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<td>&quot;OE18 Operational Exchange flow for OPORD(1)&quot;</td>
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<td>Empire Scout Forces</td>
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<td>&quot;OE19 Operational Exchange flow for OPORD(1)&quot;</td>
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<td>&quot;OE21 Operational Exchange flow for OPORD(1)&quot;</td>
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<td>Empire Ground Attack F</td>
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<td></td>
<td>&quot;OE22 Operational Exchange flow for OPORD(1)&quot;</td>
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<td></td>
<td>&quot;OE23 Operational Exchange flow for OPORD(1)&quot;</td>
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<td></td>
<td>&quot;OE24 Operational Exchange flow for OPORD(1)&quot;</td>
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<td>9</td>
<td>Scan Data</td>
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<td>&quot;OE39 Operational Exchange flow for Scan Data(1)&quot;</td>
<td>Rebel Shield</td>
<td>Rebel Command</td>
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<td>&quot;OE40 Operational Exchange flow for Scan Data(1)&quot;</td>
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<td>Scout Report</td>
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<td>&quot;OE33 Operational Exchange flow for Scout Report(1)&quot;</td>
<td>Empire Scout Forces</td>
<td>Empire Command</td>
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<td>11</td>
<td>Sector Scan</td>
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<td>&quot;OE37 Operational Exchange flow for Sector Scan(1)&quot;</td>
<td>Empire Scout Forces</td>
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<td>Status</td>
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<td>&quot;OE38 Operational Exchange flow for Sector Scan(1)&quot;</td>
<td>Rebel Ground Defense F</td>
<td>Empire Command</td>
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<td>13</td>
<td>Visual Signature</td>
<td>Emit Visual Signature</td>
<td>&quot;OE41 Operational Exchange flow for Visual Signature(1)&quot;</td>
<td>Rebel Ground Defense F</td>
<td>Empire Ground Attack F</td>
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<td>Scan for Rebel Defense Forces</td>
<td>&quot;OE42 Operational Exchange flow for Visual Signature(1)&quot;</td>
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<td></td>
<td></td>
<td>Assess Damage</td>
<td>&quot;OE43 Operational Exchange flow for Visual Signature(1)&quot;</td>
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</tr>
</tbody>
</table>
• Details the command hierarchy of the main organizations and posts.

• These posts and organizations are reused in subsequent diagrams/slides showing different configurations.

• Instead of showing composition a commands relationship is shown. This keeps its elements loosely coupled.

• These can then be inherited from and reused in other structures without overly constraining them.

• Competencies, equipment, and executed functions can also be shown.
• Similar structure to the previous slide for the AT-AT platoon reusing the previously defined structure.

• Posts are inherited as are organizations.

• Elements are inherited to take advantage of equipment and competencies, etc. and ensure uniformity to Empire structures.

• These will be combined with equipment to form capability configurations.
• Heavy Mechanized Platoon Structure combines the systems on the left with the organizations on the right.
• These can be deployed into battle and the functionality of the capability configurations as well as the organizations can be combined and documented.
• The Mission Engineering Thread detailing the various steps of Execute Hoth Planetary Invasion.

• The functions could either be part of the Mission Engineering Thread, or be functions performed by the resources, now that we have identified some of these.
• Diagrammatic mapping between the Operational and Resource behaviors of all types.

• These include the Mission Threads, Mission Tasks and Operational Activities as well as the Mission Engineering Threads and Functions.

• Weaken Planetary Defenses does NOT have an implementation, which is why the rebels were able to shoot the Spacecraft out of the sky.

• This mapping is essential to ensure a fully implemented battle plan.

• Other relationships could also be helpful within each domain. For example:
  • Offensive Actions and Defensive responses from both sides
  • Offensive and defensive systems
  • Etc.
- Traceability table generated to map the Operational behaviors to the resource behaviors.
- Structural tables can also be generated.
- This matrix could be used to spot holes in the defensive or offensive capabilities.
Finally, the Structure of the Resource Architecture using the previously defined Organizations and Capability Configurations is created.

The Intelligence Info element defines the source, confidence and provenance of the data surrounding actual rebel forces.

Given the multiplicity of the resources (8 Fighter Squadrons, 8 Light Mechanized Platoons, etc.) as well as all the posts and equipment in each one, this represents a massive scale.

This is shown on the following slide.
• This diagram illustrates the complexity of the structures defined so far.

• Showing the detailed interactions would quickly lead to quite complex diagrams.

• It would also be difficult to show interactions between lower-level elements as they are within deep structures.

• Strategies will need to be devised on the best way to model this.

• This may involve defining the lower levels together to form the mission engineering threads.
Actual Resources Structure

- Simple example showing the implementation of the Empire Persons, Organizations, and Posts.

- The Actual Persons represent identifiable people who fill specific posts.

- This could be used to ensure full staffing levels or simply to identify the main organizations and personnel.
• Automatically generated table showing the actual posts and the actual persons who fill them
Conclusions and Future Work (1)

• This model was built as a proof of concept for UAF support for Mission Engineering.
• The current UAF metamodel and future extensions (UAF 1.3/2.0) will address most Mission Engineering concepts.
• Standardization of MBSE concepts in a profile is beneficial
  • Reduces learning curve, miscommunication, confusion, etc.
• Examples of model-based standardizations
  • UML was created to standardize SW engineering
  • SysML to extend UML for systems engineering
  • UPDM/UAF to extend SysML/UML for DoDAF/MODAF/NAF
  • RAAML for safety and security in SysML model evaluation
• SysML provides many Mission Engineering concepts but needs extensions
• The approach taken in this presentation provides these extensions
• We will continue to build the model and examine the issues of resource architecture complexity, scale, and detail.

• We need to build behavioral models at both the detailed and high levels.
  • Reuse will be an essential part of this effort – libraries, patterns, GRAs, etc.

• Additional model elements to be added to the model
  • Effects and Outcomes
  • MOS, MOE, MOP, MOX, etc.
  • Other existing elements such as Drivers, Opportunities, Challenges, and Risks.

• Add state machines and sequence diagrams.

• We are socializing the model so that people can build on this to ensure that the UAF Mission Engineering extensions are fit for purpose.

• We will create an unofficial version of these profile extensions to bridge the gap until the next release.

• Finally, we encourage any and all comments to help us achieve our goals.
References

- DoD Joint Publication 3-0 (Joint Operations), Available online at https://irp.fas.org/doddir/dod/jp3_0.pdf, Accessed March 2023
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Questions?