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hybrid event

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# Validation of Digital System Models: A Framework and SysML Profile for Model-Based Systems Engineering

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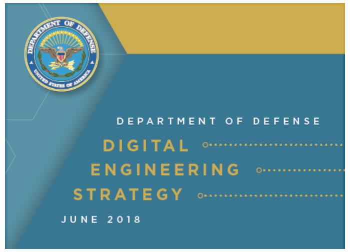
# Overview

- Introduction and Motivation
- Related Work – DE, MBSE, and Validation
- Methodology – Framework, Process, and SysML Profile
- Application of the Validation Profile
- Conclusions and Future Work

# Introduction and Motivation

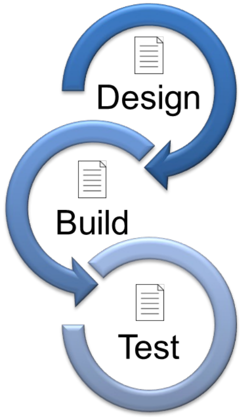
# Introduction

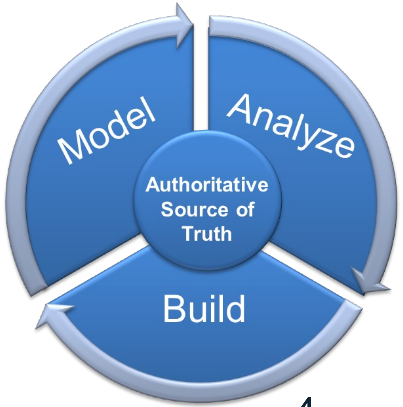
## Digital Systems are the future of DoD Acquisition




- Defense programs will be “born-digital”
- Digital models will replace documents and static artifacts
- The Authoritative Source of Truth (ASoT) will be leveraged from cradle to grave
- Development will be via a Model-Analyze-Build methodology
- Digital twins developed and tested prior to the build of a physical system


- **Digital Transformation (DT) will drive Digital Engineering (DE), Model-Based Systems Engineering (MBSE), and Digital Materiel Management (DMM) in the development of DoD weapons systems via an ASoT and digital twin**

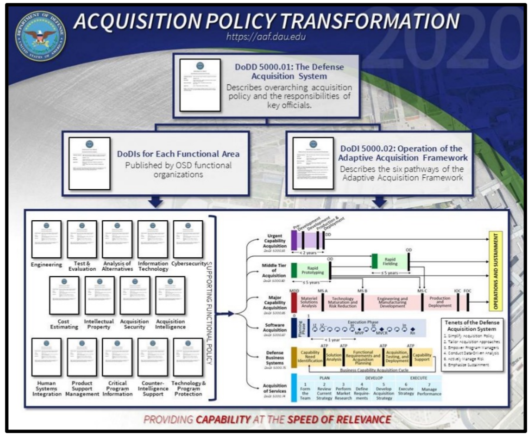


# Motivation

## Potential impact to all DoD acquisition programs

- Applies to Systems-in-Sustainment (SiS) and Systems-in-Development (SiD)
- Facilitate the Adaptive Acquisition Framework (AAF)
- Digital lifecycle models will allow for agility and rapid prototyping





- Certified ASoT is the foundation of DT/DE
- Certification via Validation, Verification, and Accreditation (VV&A)

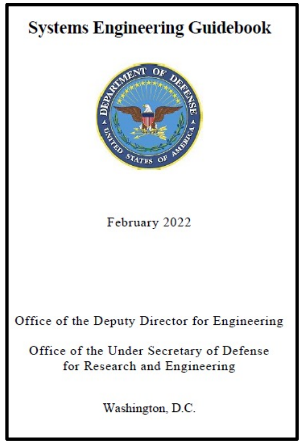
**How can a fully-digital design be trusted? The answer may lie in VV&A.**

# Related Work – DE, MBSE, and Validation

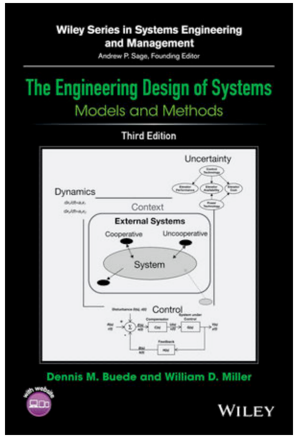
# System Validation

**Validation in DoD Acquisition is synonymous with <u>Validation of Systems</u>**

- **DoD SE Guidebook and Defense Acquisition University**
  - Validation provides objective evidence that the system **capability complies with stakeholder performance requirements**, achieving its use in its **intended operational environment**.
  - **"Was the right system built?"** is typically answered during Operational Test and Evaluation




- **The Engineering Design of Systems – Buede and Miller**
  - A system's validity addresses whether we have **built the right system**. By extension **model validity** concerns whether we have **built the right model**.



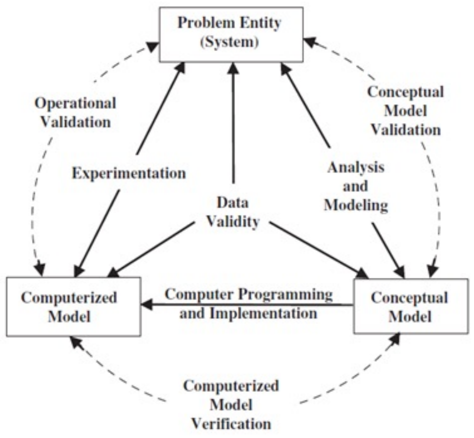
# Model Validation

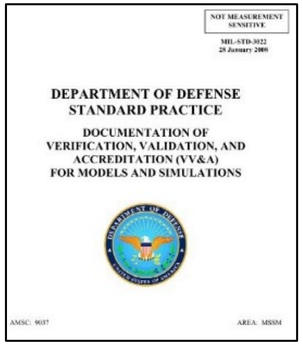
**<u>Validation of Modeling and Simulation</u> (M&S)**

- **Definition 1.** Validation is the process of determining the **degree to which** a model and its associated data are an **accurate representation of the real world** from the perspective of the **intended uses** of the model (Bair and Tolk, Cook and Skinner, DoD M&S Glossary).

- **Definition 2:** Model validation is substantiating that within its domain of applicability the model behaves with **satisfactory accuracy** consistent with the study **objectives** (Balci).

- **Definition 3:** The process of determining the degree to which a **model, simulation, or federation of models and simulations, and their associated data** are accurate representations of the real world from the perspective of the intended use(s) (MIL-STD-3022).





NOT MEASUREMENT SENSITIVE

MIL-STD-3022
28 January 2008

DEPARTMENT OF DEFENSE
STANDARD PRACTICE

DOCUMENTATION OF
VERIFICATION, VALIDATION, AND
ACCREDITATION (VV&A)
FOR MODELS AND SIMULATIONS

AMSC: 9037 AREA: MSSM

**Three core elements of M&S model validation: the model, the real world, a bounding principle**

# MBSE Model Validation

## Validation of MBSE System Models

- Inherently different than both systems and M&S validation
- Reality (real-world instantiation or data) not guaranteed for comparison / referent
- Occurs continuously throughout life cycle, not just during OT&E
- Existing system and M&S validation guidance could be applied, but not a seamless transition

## Why is MBSE validation required?

- For a given scenario (use case) model credibility must be established
- MBSE model is pedigreed data in the ASoT – must be validated prior to acceptance
- Guidance underdeveloped in comparison to M&S

## What is needed for MBSE validation?

- Model use cases, model requirements, model validation test cases, and validation relationships
- Requires guidance, methodology, and best practices

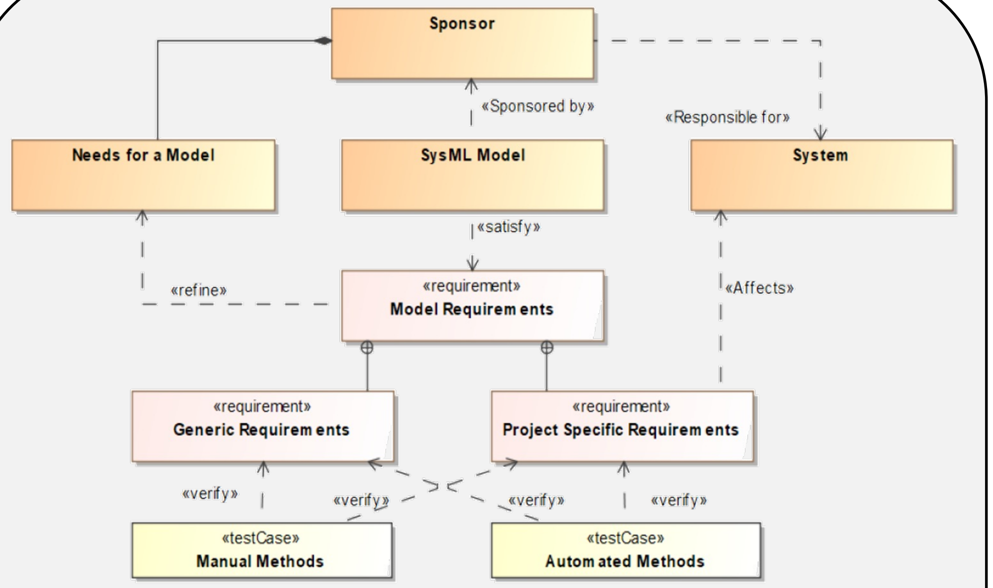


**MBSE will not succeed without correct and complete systems engineering models (Hecht and Chen)**

# Methodology – Framework, Process, and SysML Profile

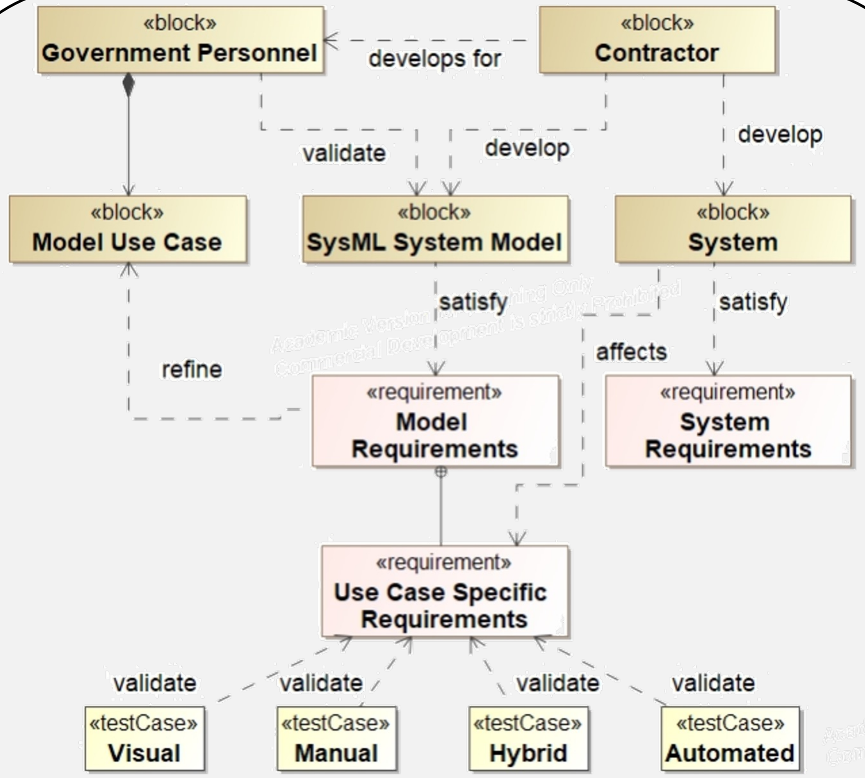
# Methodology – Metamodel

## Metamodel for Verification and Validation



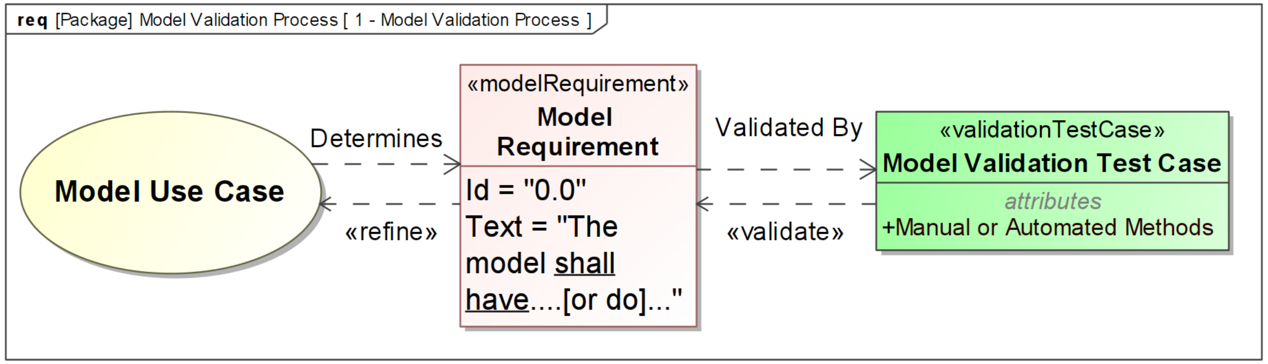

Hecht and Chen,
The Aerospace Corporation

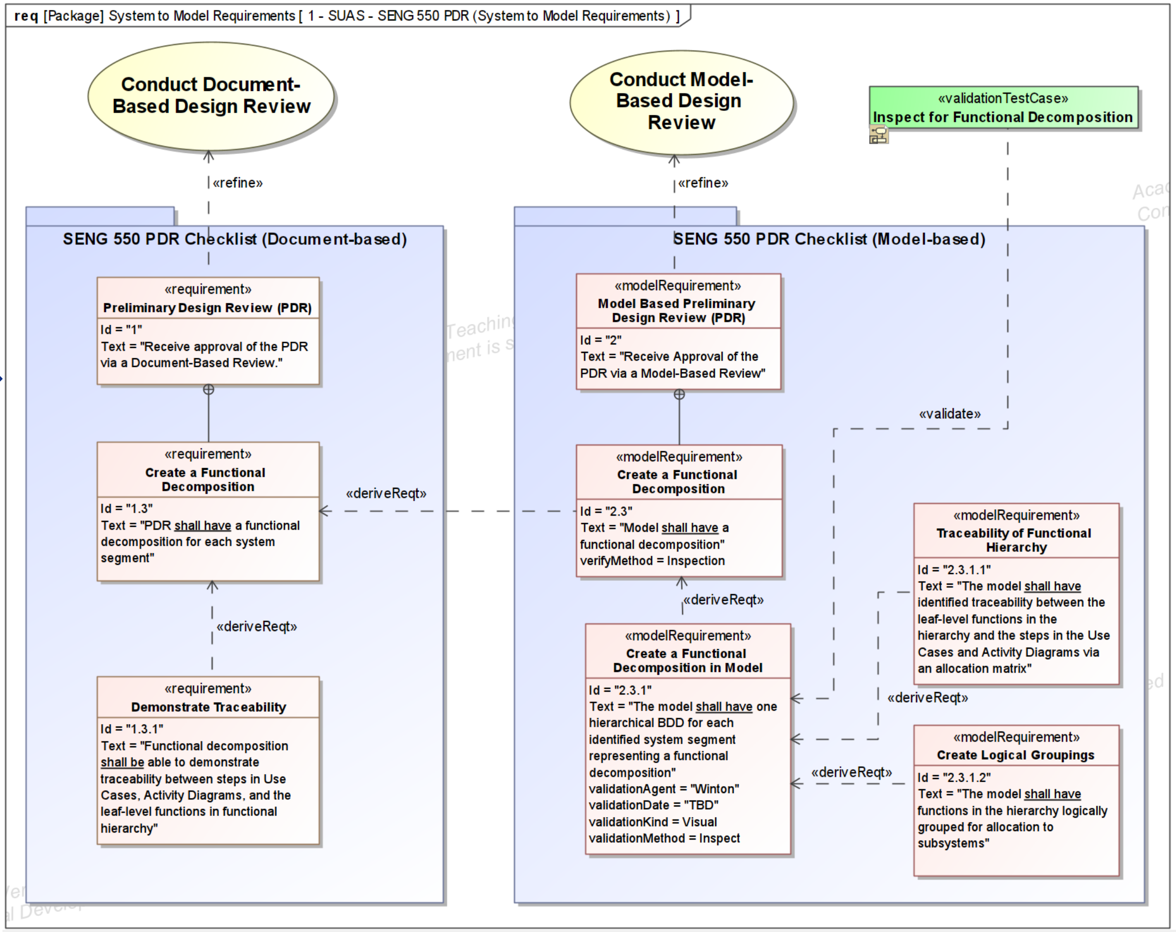
## Metamodel for Validation of Government Digital System Models



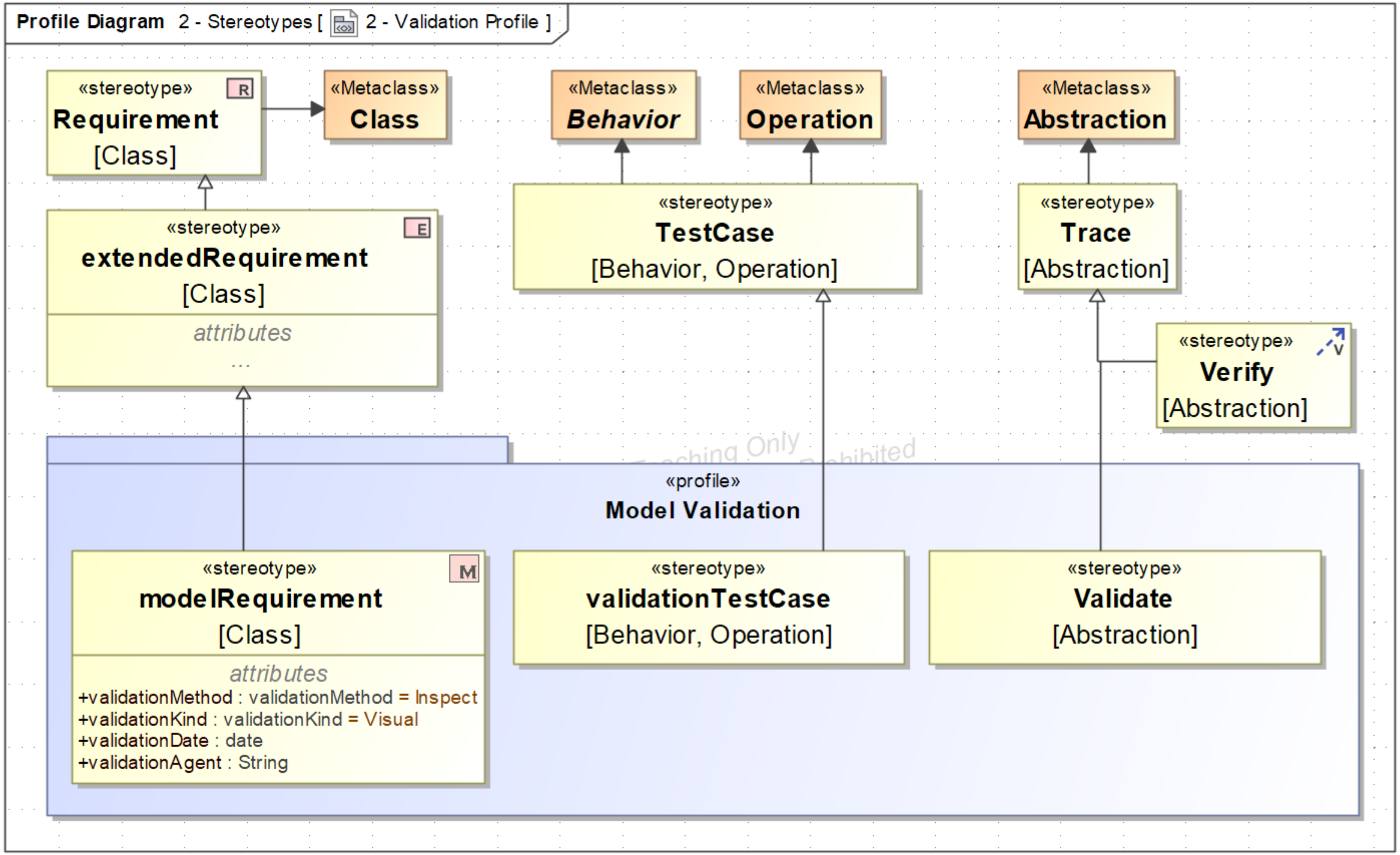

Winton,
Air Force Institute of Technology

# Methodology – Framework

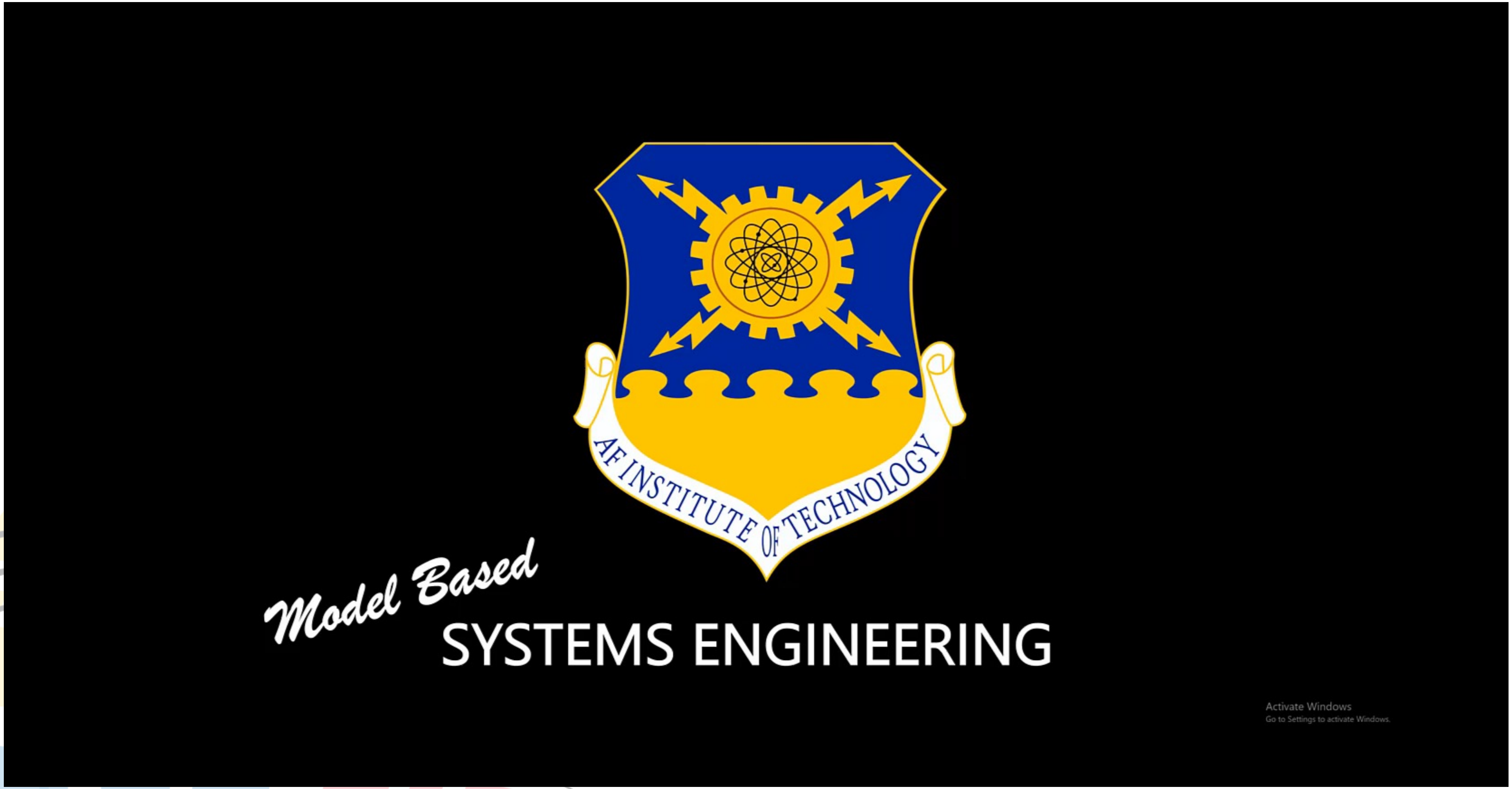


# Methodology – SysML Validation Profile

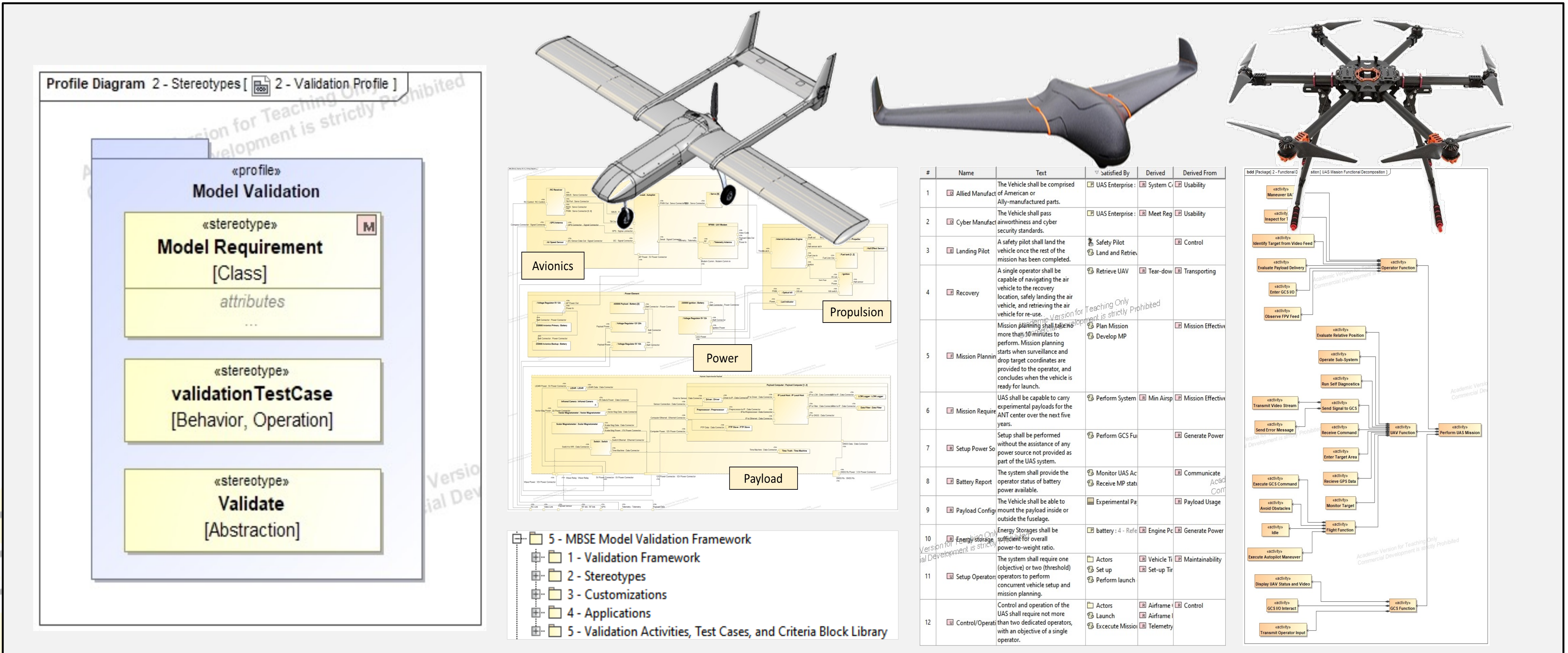


# Methodology – Framework Execution



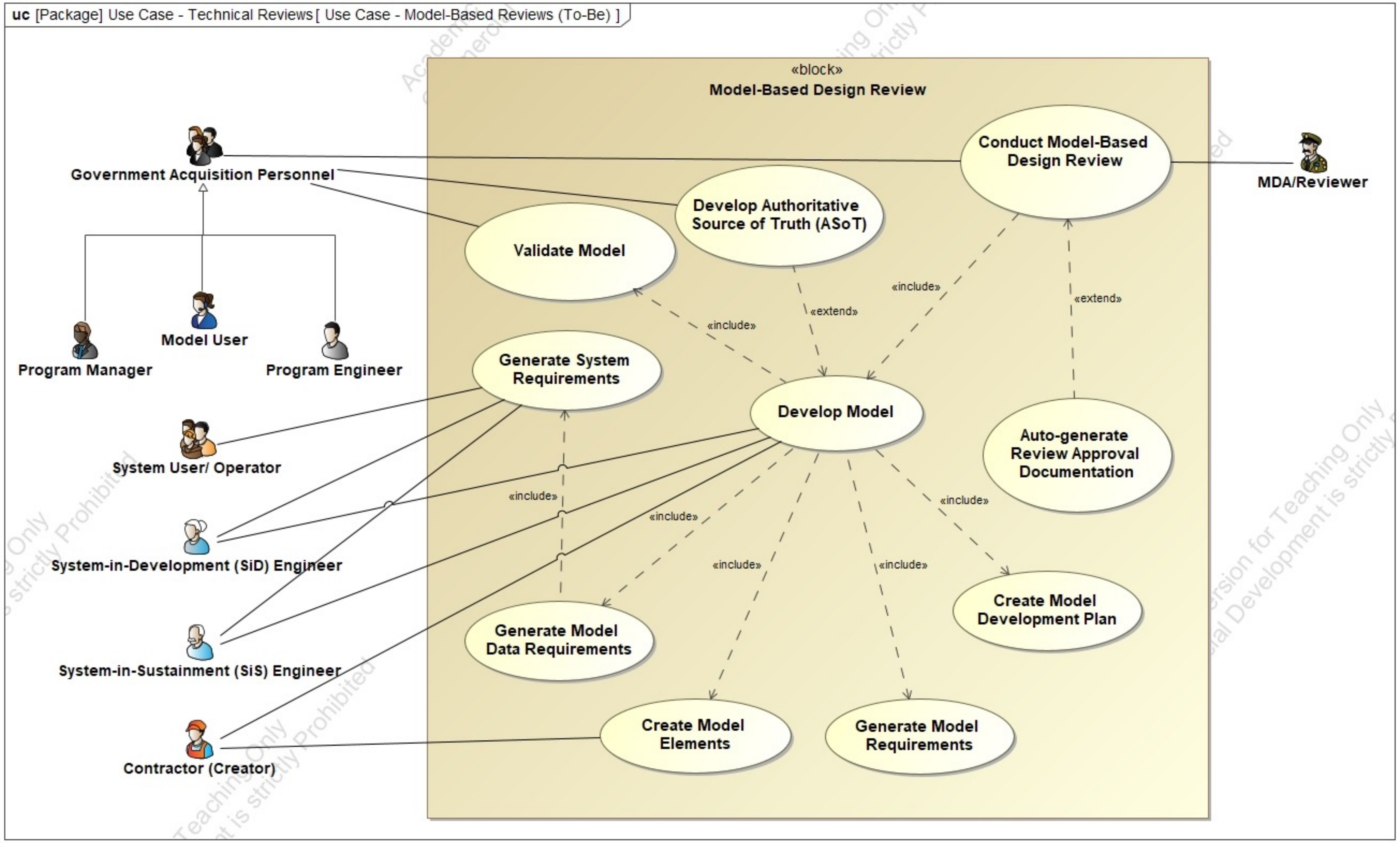
# Application of the Validation Profile

# Application – AFIT SUAS Reference Architecture

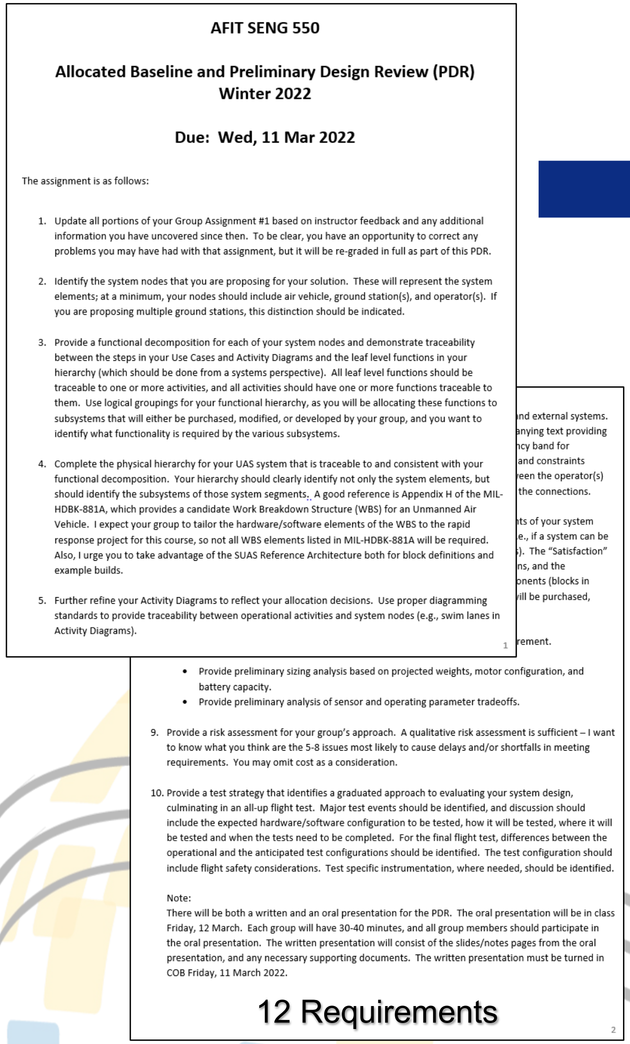



AFIT SUAS Reference Architecture

# Application – Use Cases



# Application – Document-to-Model Translation


AFIT SENG 550

Allocated Baseline and Preliminary Design Review (PDR)
Winter 2022

Due: Wed, 11 Mar 2022

The assignment is as follows:

1. Update all portions of your Group Assignment #1 based on instructor feedback and any additional information you have uncovered since then. To be clear, you have an opportunity to correct any problems you may have had with that assignment, but it will be re-graded in full as part of this PDR.
2. Identify the system nodes that you are proposing for your solution. These will represent the system elements; at a minimum, your nodes should include air vehicle, ground station(s), and operator(s). If you are proposing multiple ground stations, this distinction should be indicated.
3. Provide a functional decomposition for each of your system nodes and demonstrate traceability between the steps in your Use Cases and Activity Diagrams and the leaf level functions in your hierarchy (which should be done from a systems perspective). All leaf level functions should be traceable to one or more activities, and all activities should have one or more functions traceable to them. Use logical groupings for functional hierarchy, as you will be allocating these functions to subsystems that will either be purchased, modified, or developed by your group, and you want to identify what functionality is required by the following subsystems.
4. Complete the physical hierarchy for your UAS system that is traceable to and consistent with your functional decomposition. Your hierarchy should clearly identify not only the system elements, but should identify the subsystems of those system segments. A good reference is Appendix H of the MIL-HDBK-881A, which provides a candidate Work Breakdown Structure (WBS) for an Unmanned Air Vehicle. I expect your group to tailor the hardware/software elements of the WBS to the rapid response project for this course, so not all WBS elements listed in MIL-HDBK-881A will be required. Also, I urge you to take advantage of the SUAS Reference Architecture both for block definitions and example builds.
5. Further refine your Activity Diagrams to reflect your allocation decisions. Use proper diagramming standards to provide traceability between operational activities and system nodes (e.g., swim lanes in Activity Diagrams).

1

...nd external systems. ...anying text providing ...cy band for ...and constraints ...een the operator(s) ...the connections.

...ts of your system ...e., if a system can be ...). The "Satisfaction" ...ns, and the ...onents (blocks in ...ill be purchased, ...rement.

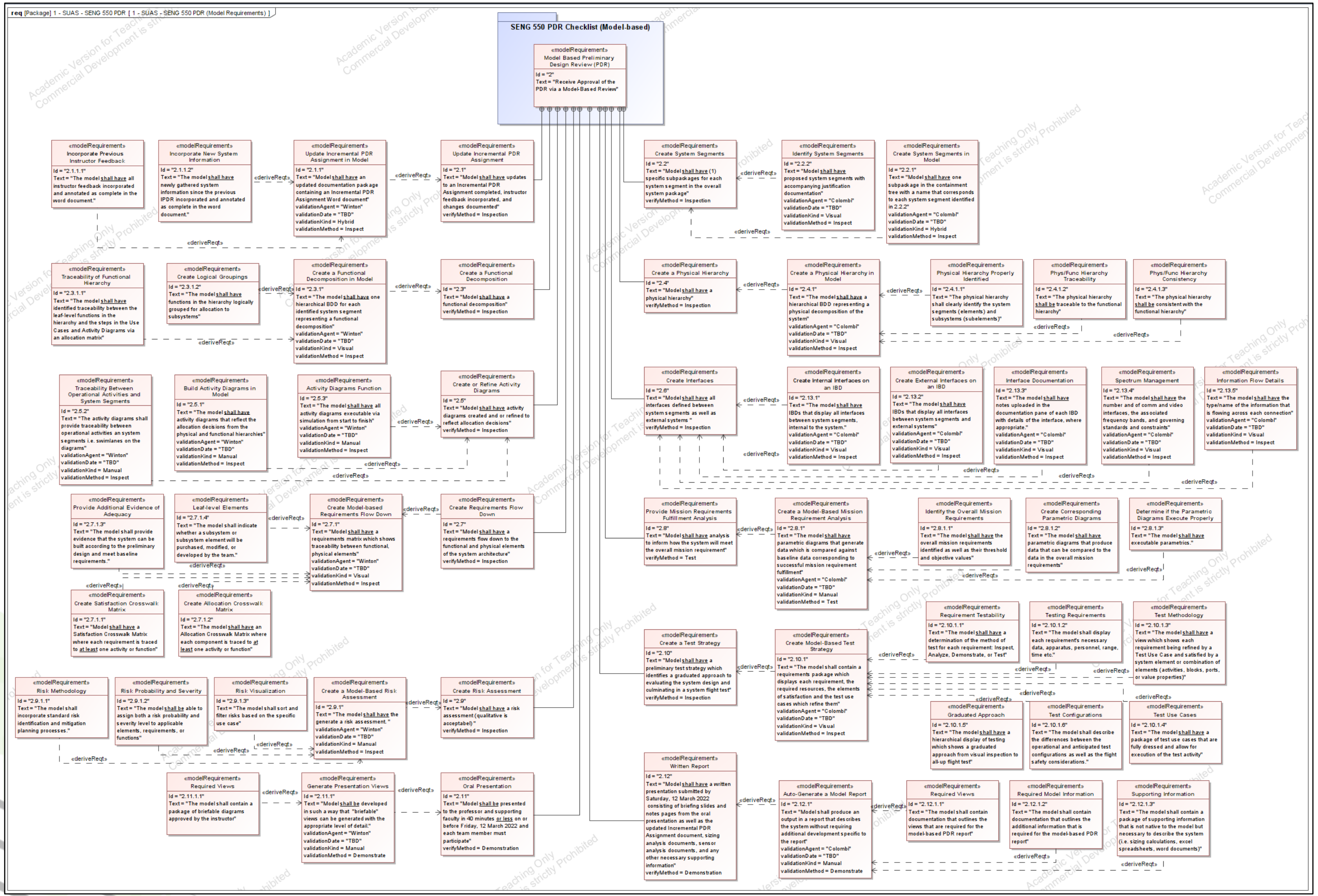
- Provide preliminary sizing analysis based on projected weights, motor configuration, and battery capacity.
- Provide preliminary analysis of sensor and operating parameter tradeoffs.

9. Provide a risk assessment for your group's approach. A qualitative risk assessment is sufficient – I want to know what you think are the 5-8 issues most likely to cause delays and/or shortfalls in meeting requirements. You may omit cost as a consideration.
10. Provide a test strategy that identifies a graduated approach to evaluating your system design, culminating in an all-up flight test. Major test events should be identified, and discussion should include the expected hardware/software configuration to be tested, how it will be tested, where it will be tested and when the tests need to be completed. For the final flight test, differences between the operational and the anticipated test configurations should be identified. The test configuration should include flight safety considerations. Test specific instrumentation, where needed, should be identified.

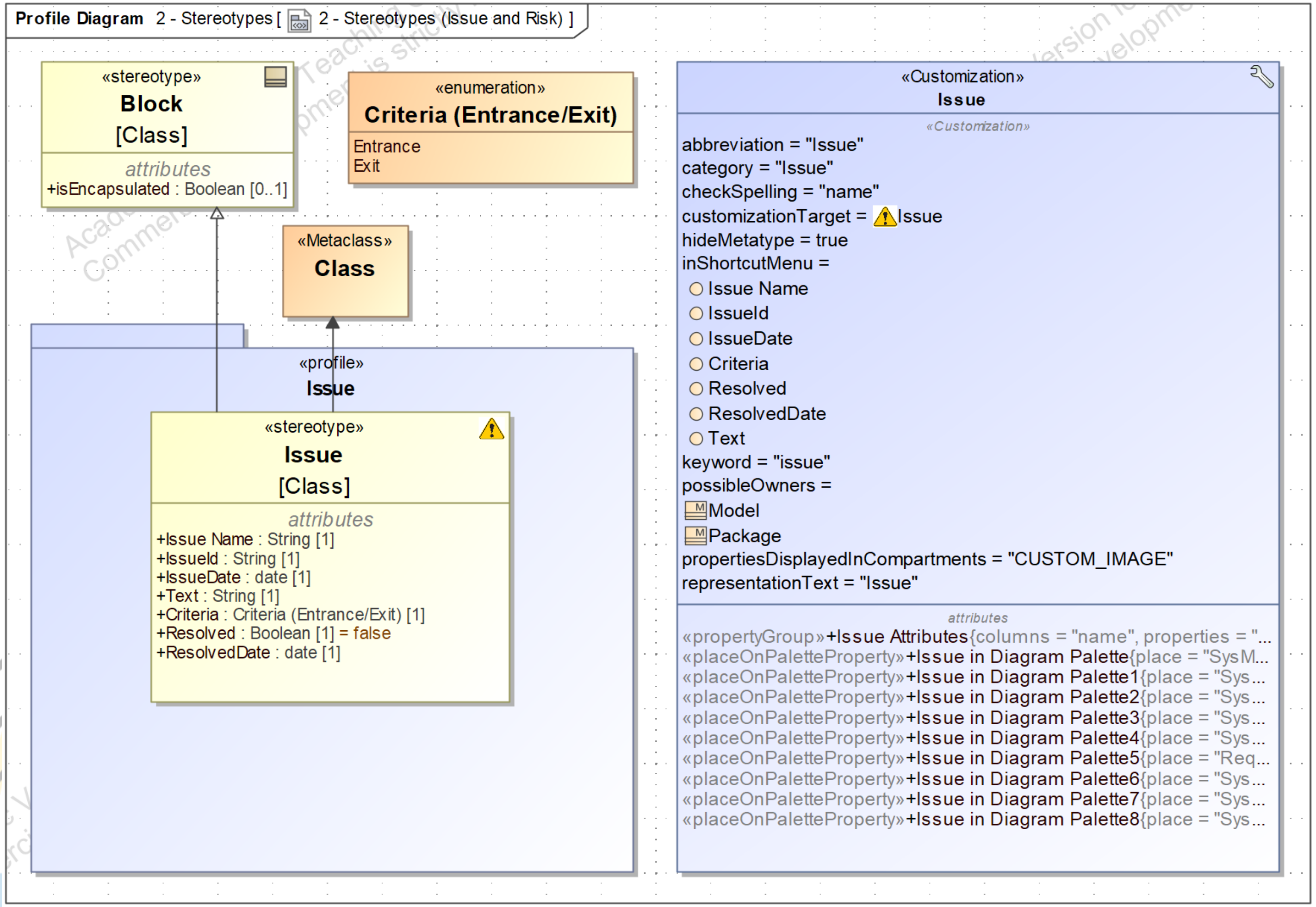
Note:
There will be both a written and an oral presentation for the PDR. The oral presentation will be in class Friday, 12 March. Each group will have 30-40 minutes, and all group members should participate in the oral presentation. The written presentation will consist of the slides/notes pages from the oral presentation, and any necessary supporting documents. The written presentation must be turned in COB Friday, 11 March 2022.

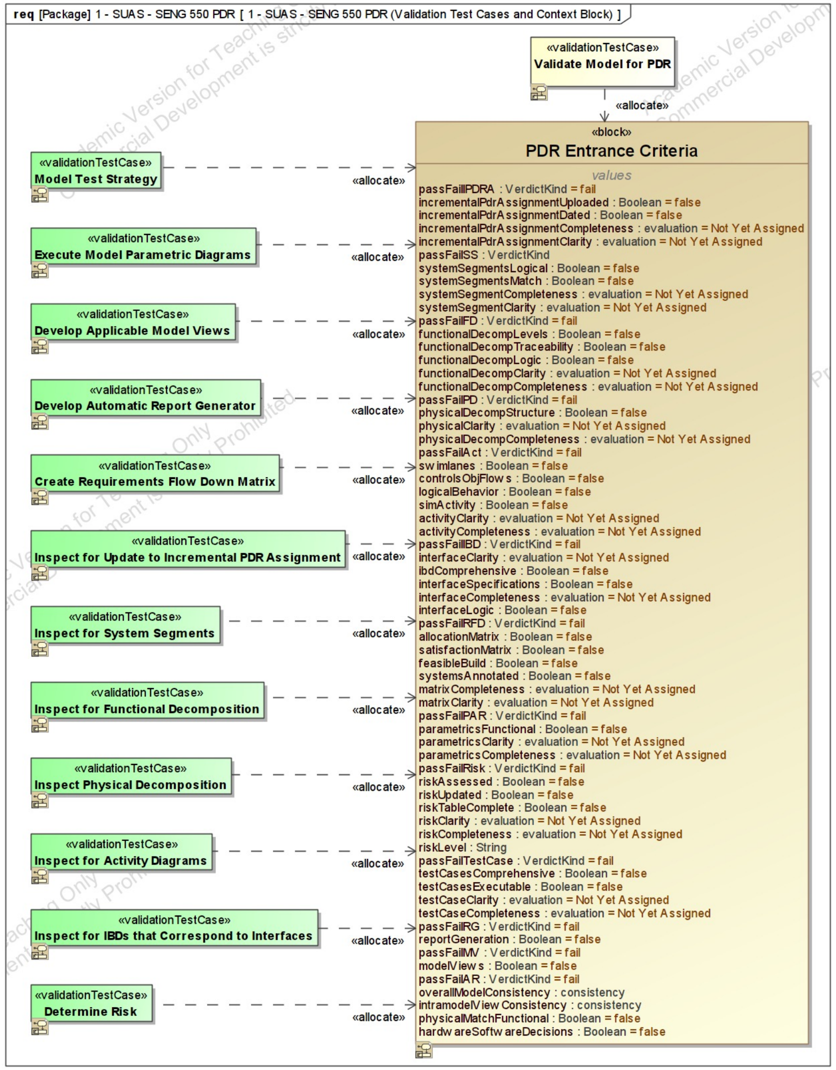
2

12 Requirements



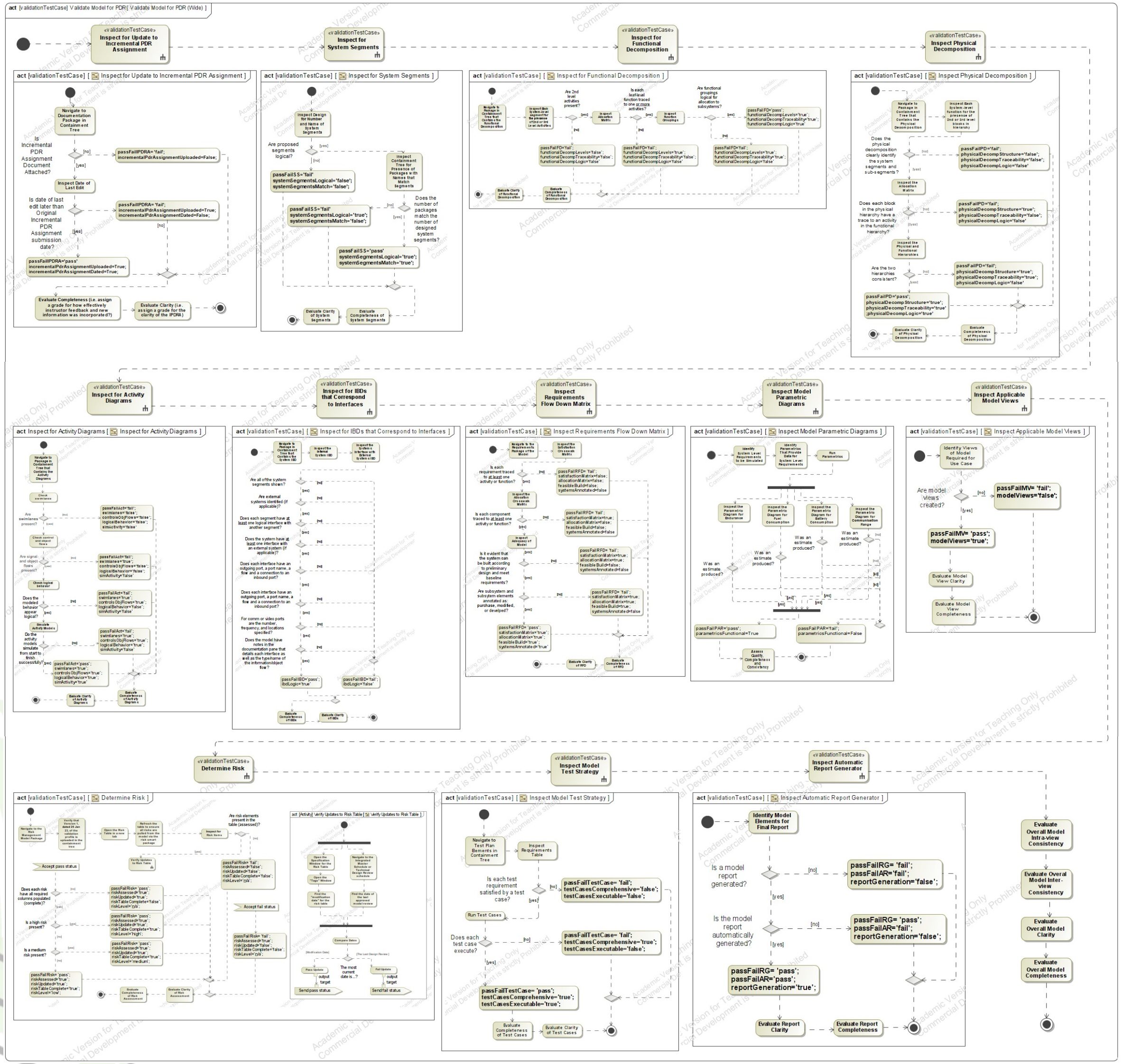
# Application – Custom Elements and Validation Context Block



# Application – Activity Diagram for Validation Test Cases

12 Validation Test Cases: One for each of the 12 SENG 550 PDR Assignment Items



# Application – Instantiated Context Block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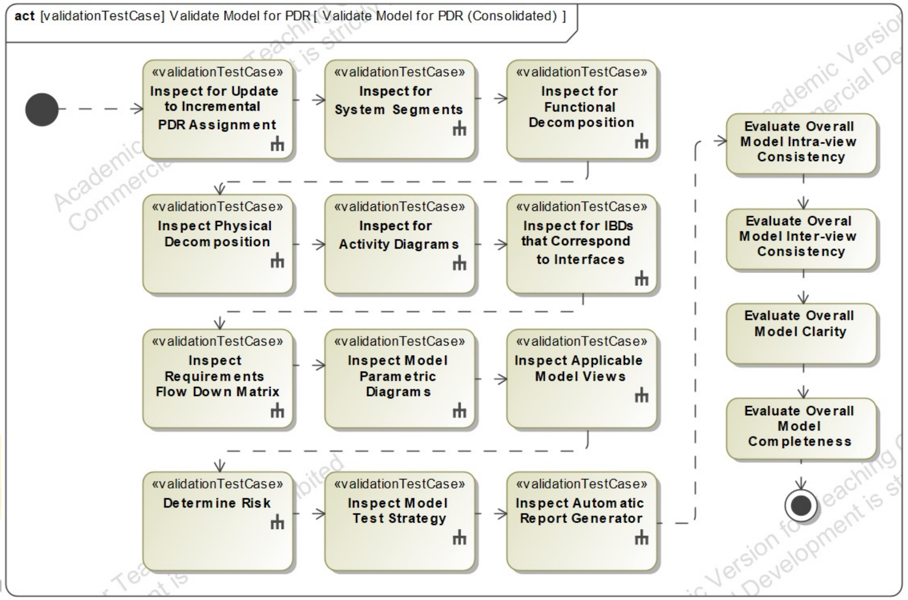


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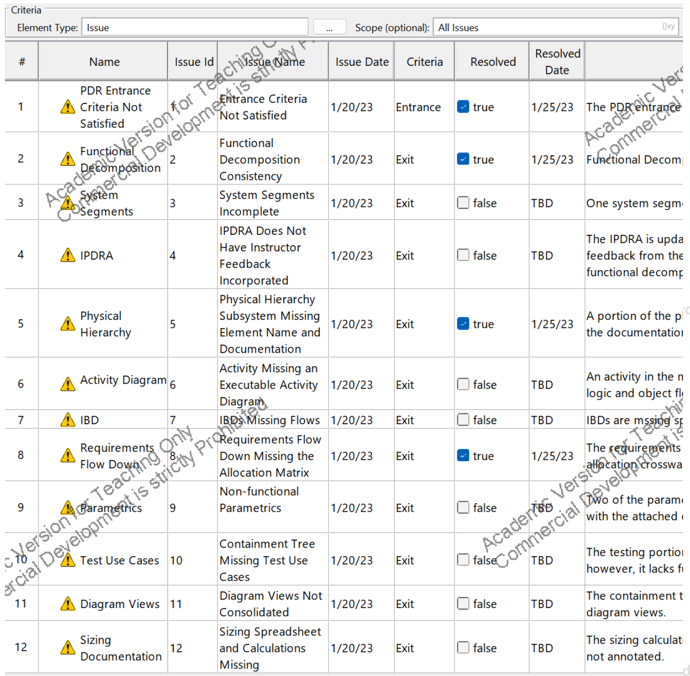
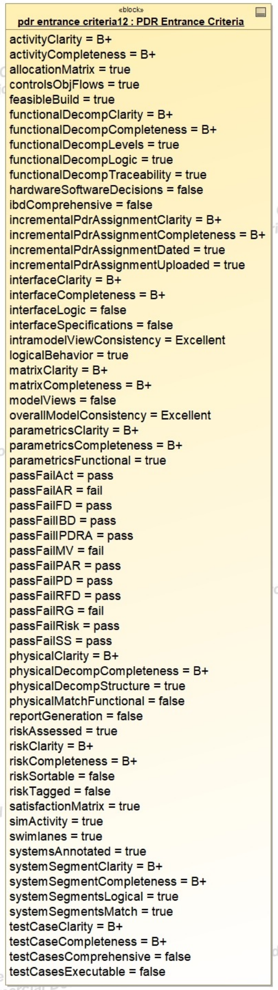


Criteria

Element Type: Issue    Scope (optional): All Issues

| # | Name | Issue Id | Issue Name | Issue Date | Criteria | Resolved | Resolved Date | |
|---|---|---|---|---|---|---|---|---|
| 1 | PDR Entrance Criteria Not Satisfied | 1 | Entrance Criteria Not Satisfied | 1/20/23 | Entrance | true | 1/25/23 | The PDR entrance |
| 2 | Functional Decomposition | 2 | Functional Decomposition Consistency | 1/20/23 | Exit | true | 1/25/23 | Functional Decom |
| 3 | System Segments | 3 | System Segments Incomplete | 1/20/23 | Exit | false | TBD | One system segm |
| 4 | IPDRA | 4 | IPDRA Does Not Have Instructor Feedback Incorporated | 1/20/23 | Exit | false | TBD | The IPDRA is upda feedback from the functional decomp |
| 5 | Physical Hierarchy | 5 | Physical Hierarchy Subsystem Missing Element Name and Documentation | 1/20/23 | Exit | true | 1/25/23 | A portion of the p the documentatior |
| 6 | Activity Diagram | 6 | Activity Missing an Executable Activity Diagram | 1/20/23 | Exit | false | TBD | An activity in the n logic and object fl |
| 7 | IBD | 7 | IBDs Missing Flows | 1/20/23 | Exit | false | TBD | IBDs are missing sp |
| 8 | Requirements Flow Down | 8 | Requirements Flow Down Missing the Allocation Matrix | 1/20/23 | Exit | true | 1/25/23 | The requirements allocation crosswa |
| 9 | Parametrics | 9 | Non-functional Parametrics | 1/20/23 | Exit | false | TBD | Two of the param with the attached |
| 10 | Test Use Cases | 10 | Containment Tree Missing Test Use Cases | 1/20/23 | Exit | false | TBD | The testing portio however, it lacks f |
| 11 | Diagram Views | 11 | Diagram Views Not Consolidated | 1/20/23 | Exit | false | TBD | The containment t diagram views. |
| 12 | Sizing Documentation | 12 | Sizing Spreadsheet and Calculations Missing | 1/20/23 | Exit | false | TBD | The sizing calculat not annotated. |



# Application – Validation Results

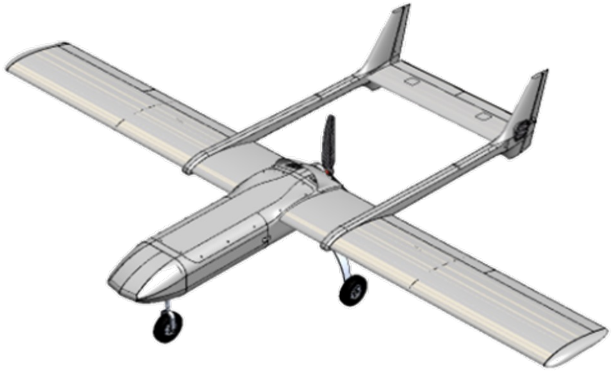
- **Successes:**
  - Use case to perform academic model-based PDR
  - 12 translated Model Requirements (and derivations) satisfied through Validation Test Cases
  - Activity Diagrams executed and populated Criteria scoresheet with "measures of closeness"
  - Issues and entrance/exit criteria captured in the custom issue table

- **Failures:**
  - None

- **Validation Determination: FULLY VALID**
  - Model **VALID** for executing a model-based PDR

«block»
**pdr entrance criteria12 : PDR Entrance Criteria**

activityClarity = B+
activityCompleteness = B+
allocationMatrix = true
controlsObjFlows = true
feasibleBuild = true
functionalDecompClarity = B+
functionalDecompCompleteness = B+
functionalDecompLevels = true
functionalDecompLogic = true
functionalDecompTraceability = true
hardwareSoftwareDecisions = false
ibdComprehensive = false
incrementalPdrAssignmentClarity = B+
incrementalPdrAssignmentCompleteness = B+
incrementalPdrAssignmentDated = true
incrementalPdrAssignmentUploaded = true
interfaceClarity = B+
interfaceCompleteness = B+
interfaceLogic = false
interfaceSpecifications = false
intramodelViewConsistency = Excellent
logicalBehavior = true
matrixClarity = B+
matrixCompleteness = B+
modelViews = false
overallModelConsistency = Excellent
parametricsClarity = B+
parametricsCompleteness = B+
parametricsFunctional = true
passFailAct = pass
passFailAR = fail
passFailFD = pass
passFailIBD = pass
passFailPDRA = pass
passFailMV = fail
passFailPAR = pass
passFailPD = pass
passFailRFD = pass
passFailRG = fail
passFailRisk = pass
passFailSS = pass
physicalClarity = B+
physicalDecompCompleteness = B+
physicalDecompStructure = true
physicalMatchFunctional = false
reportGeneration = false
riskAssessed = true
riskClarity = B+
riskCompleteness = B+
riskSortable = false
riskTagged = false
satisfactionMatrix = true
simActivity = true
swimlanes = true
systemsAnnotated = true
systemSegmentClarity = B+
systemSegmentCompleteness = B+
systemSegmentsLogical = true
systemSegmentsMatch = true
testCaseClarity = B+
testCaseCompleteness = B+
testCasesComprehensive = false
testCasesExecutable = false



Type: Issue … Scope (optional): All Issues … Filter:

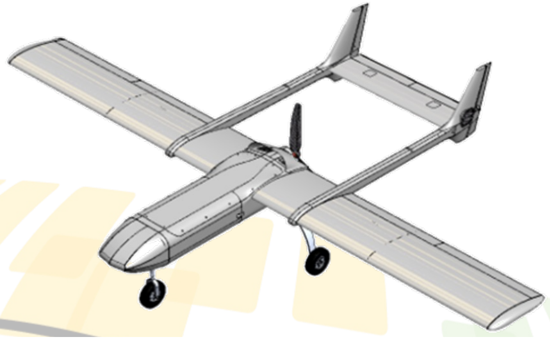
| Name | Issue Id | Issue Name | Issue Date | Criteria | Resolved | Resolved Date | Text |
|---|---|---|---|---|---|---|---|
| PDR Entrance Criteria Not Satisfied | 1 | Entrance Criteria Not Satisfied | 1/20/23 | Entrance | true | 1/25/23 | The PDR entrance criteria were not adequately met to transition into the PDR. |
| Functional Decomposition | 2 | Functional Decomposition Consistency | 1/20/23 | Exit | true | 1/25/23 | Functional Decomposition is not consistent with the physical decomposition. |
| System Segments | 3 | System Segments Incomplete | 1/20/23 | Exit | false | TBD | One system segment has an incomplete description in the documentation. |
| IPDRA | 4 | IPDRA Does Not Have Instructor Feedback Incorporated | 1/20/23 | Exit | false | TBD | The IPDRA is updated with knowlege since the last review however, key feedback from the instructor was not included: system segment clarity, functional decomp consistency with the physical decomp. |
| Physical Hierarchy | 5 | Physical Hierarchy Subsystem Missing Element Name and Documentation | 1/20/23 | Exit | true | 1/25/23 | A portion of the physical hierarchy is missing a logical element name as well as the documentation explaining the susbsystem. |
| Activity Diagram | 6 | Activity Missing an Executable Activity Diagram | 1/20/23 | Exit | false | TBD | An activity in the model is missing an executable activity diagram to show the logic and object flow between a critical subsystem. |
| IBD | 7 | IBDs Missing Flows | 1/20/23 | Exit | false | TBD | IBDs are mssing specific information descriptions for the information flows. |
| Requirements Flow Down | 8 | Requirements Flow Down Missing the Allocation Matrix | 1/20/23 | Exit | true | 1/25/23 | The requirements flow down package of the containment tree is missing an allocation crosswalk matrix. |
| Parametrics | 9 | Non-functional Parametrics | 1/20/23 | Exit | false | TBD | Two of the parametric diagrams do not produce a data output in accordance with the attached documentation. |
| Test Use Cases | 10 | Containment Tree Missing Test Use Cases | 1/20/23 | Exit | false | TBD | The testing portion of the model contains a draft test plan and test activities, however, it lacks fully dressed test use cases. |
| Diagram Views | 11 | Diagram Views Not Consolidated | 1/20/23 | Exit | false | TBD | The containment tree does not have a consolidated package for presentable diagram views. |
| Sizing Documentation | 12 | Sizing Spreadsheet and Calculations Missing | 1/20/23 | Exit | false | TBD | The sizing calculations supporting information is not attached and a reason is not annotated. |



**The Osprey model can be validated but in its current form, would not pass a PDR**

# Additional Use Case Demonstrations

- **Use Case 1:** Osprey Mark IV - Academic PDR with Criteria and Issue Element
- **Use Case 2:** Osprey Mark IV - DoD PDR with Automated Risk Analysis
- **Use Case 3:** Skywalker X-8 - Simulated Operations Scenario with Born-Digital Model Requirements
- **Use Case 4:** Tarot 960 Hexframe Pixhawk 2 Autopilot - Simulated Sustainment Scenario



- A full analysis is contained in the AFIT School of Engineering and Management thesis titled "Validation of Digital System Models" which can be found at https://scholar.afit.edu/ or https://discover.dtic.mil/

# Conclusions and Future Work

# Results – Observations

## 1. SiD versus SiS interact in a continuous cycle

- SiD can integrate models into ASoT at inception
- SiS require additional translation and development to convert document-based to model-based
- Both rely on models and ASoT

## 2. Perspective differences:

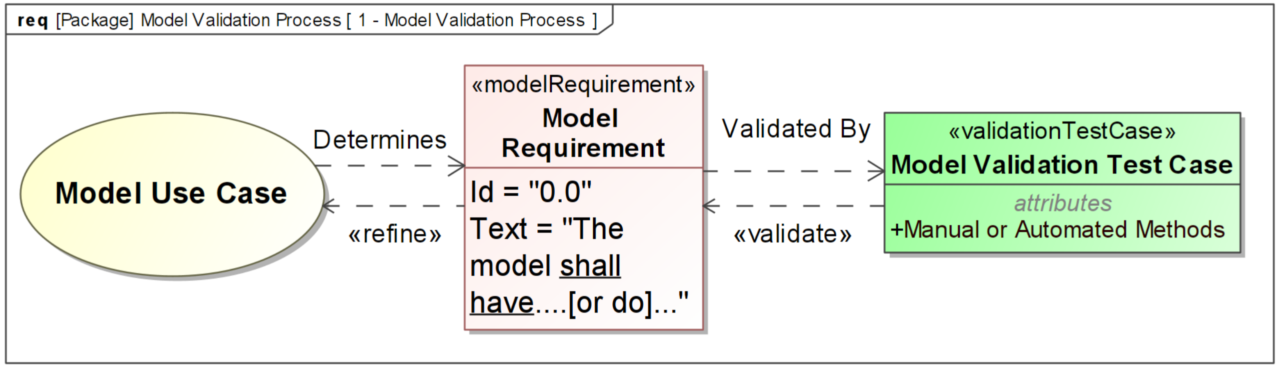
- Model developers versus model users
- Students versus instructors, developers versus reviewers
- All roles use model requirements in a different way
  - Rubric versus evaluation, design choices versus evaluation criteria

## 3. Criteria for validation must be established early

- Contractors will want and need
- Early application increases effectiveness

# Conclusions

1. **MBSE Model Validation Framework with SysML Profile and Customizations**
2. **Newly Proposed MBSE Model Validation Definition**
   - **Definition 4:** MBSE model validation is the structured process of demonstrating that a model is a suitable representation of a real system-in-sustainment or a conceptual system-in-development that satisfies model requirements derived from the intended use case(s).
3. **Use cases bridge academic and real-world implementation of validation profile**
   - Proof-of-concept on academic RA with academic and simulated real-world use cases
4. **A validated need for validation of MBSE digital system models**



# Future Work

1. **Increase capability of automated methods**
   - Size of future models will likely make manual and inspection methods difficult or impossible
   - Efficiency gains through opaque actions (Jython, Javascript), Alf, adaption of verification suite to validation suite
2. **Demonstrate on a real system, like the F-16 fuel subsystem structure**
   - Validation of a model prior to OT&E can generate substantial cost and schedule savings for a program
3. **Prototype on SiS modification, ACAT III, or rapid acquisition program**
   - Integration of model-based, digital validation practices from the inception of a born-digital program
   - Cradle-to-grave validation is key
4. **Pursue application areas in AFOTEC and MAJCOM T&E**
   - Cost savings to programs
   - Manpower savings to T&E efforts
   - Scheduling savings for MRTFB

# Questions

# References


**Sources:**

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**Images:**

1. F-16: https://media.defense.gov/2021/Sep/29/2002864183/-1/-1/0/200317-F-AI558-9202.JPG
2. B-52: https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104465/b-52h-stratofortress/
3. JDAM: https://media.defense.gov/2021/Oct/03/2002866609/-1/-1/0/180222-F-MQ799-9078.JPG
4. T-7: https://www.boeing.com/defense/t-7a/index.page
5. NGAD: https://www.defensenews.com/air/2022/06/01/the-air-forces-next-gen-fighter-has-moved-into-a-critical-new-phase/
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