33rd Annual INCOSE international symposium

hybrid event

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Lean Model-Based Systems Engineering on the NASA High-Density Vertiplex Subproject

Demetrios Katsaduros and Andrew Ging, NASA Ames Research Center

Agenda

- Speaker Introductions
- Purpose
- Subproject Background
- Benefits of MBSE to subproject
- Challenges
- How was MBSE implemented?
  - Behavior
  - Requirement
  - Structure
- Lessons Learned

Speaker Introductions

- Demetrios Katsaduros
  - Systems Engineer
  - 5.5 years at NASA
  - Purdue University
    - BS - Electrical Engineering
- Andrew Ging
  - SE Group Co-Lead
  - 17 years at NASA
  - Cal Poly Pomona
    - BS - Aerospace Engineering

Purpose

- Demonstrate impact of Model-Based Systems Engineering (MBSE) on full lifecycle design, build and fly aeronautics subproject.
  - SysML (Systems Modeling Language) paired with MagicDraw modeling tool provided digital elements for SE team to model a physical architecture.
- Outline MBSE challenges, solution and lessons learned.

What is HDV (High Density Vertiplex)?

- A subproject inside of NASA’s Advanced Air Mobility (AAM) project portfolio
- Focusing on the research, development and testing of concepts, requirements, software architectures, and technologies needed
- Product: air traffic management system for the terminal environment around passenger-carrying eVTOL vertiports
  – Verification & validation through small UAV flight tests as a proxy for Urban Air Mobility (UAM) vehicles

HDV Video


NASA
Mobile
Acoustics
Facility
N542AJ
Video courtesy of Joby Aviation

Characteristics of HDV Subproject

Development Lifecycle Model

- Spiral development: each design/build/fly iteration builds upon previous

Schedule

- Fast-paced: one design/build/fly iteration per year

Resources

- Lean: 1 ½ systems engineers for an approx. $5M per year project budget

Scope

- Flexible: Defined at a high-level upfront. Details defined and revised continuously in each iteration

MBSE must be efficient, fast, not-too-detailed, and adapt to frequent changes

Characteristics of HDV Subproject

Project Outcomes

- R&D and demonstrate a prototype UAM vertiport air traffic automation system

Project Technology Transfer Deliverables

- Reference architecture design for the Vertiport Automation System – MBSE model
- Vertiport Automation System ConOps

The MBSE model capturing the results of the research is a key end-product for technology transfer

Benefits of SysML and MBSE to HDV

SysML provides a model-centric means of carrying out the NASA SE common technical processes by providing tools for complete system modeling including

- Requirements capture
- System Design Capture
- Interface management

MBSE serves HDV by:

1. Documenting the subproject's logical/reference architecture for external distribution
2. Capturing the subproject's physical architecture in a single-source-of-truth for internal use

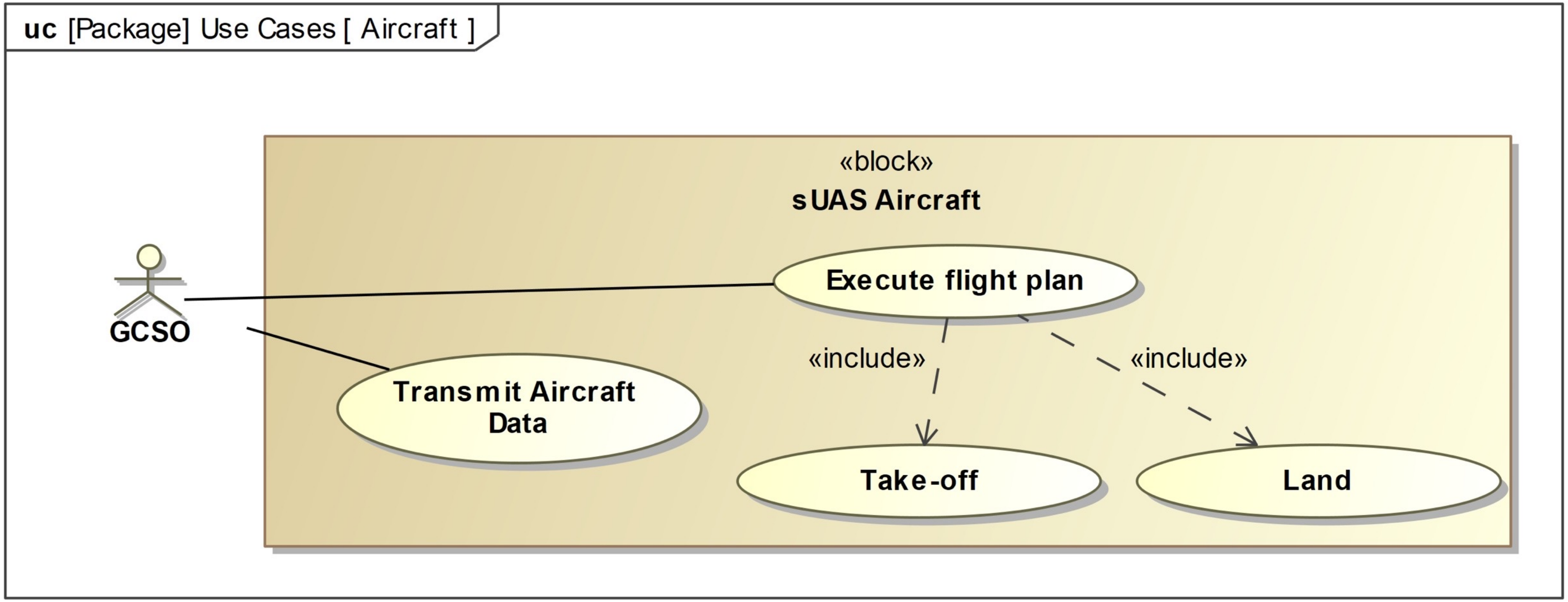
Challenges

1 ▶ 2 ▶ 3 ▶ 4 ▶ 5

1. MBSE Adoption prior to subproject formulation
2. Small & lean SE team learned MagicDraw from scratch
3. HDV is the 1st team in AAM to proceed with MagicDraw
4. Multi-Center and multiple time zone collaboration
5. Implementation of HDV SE and Integration with other projects

How was MBSE implemented?

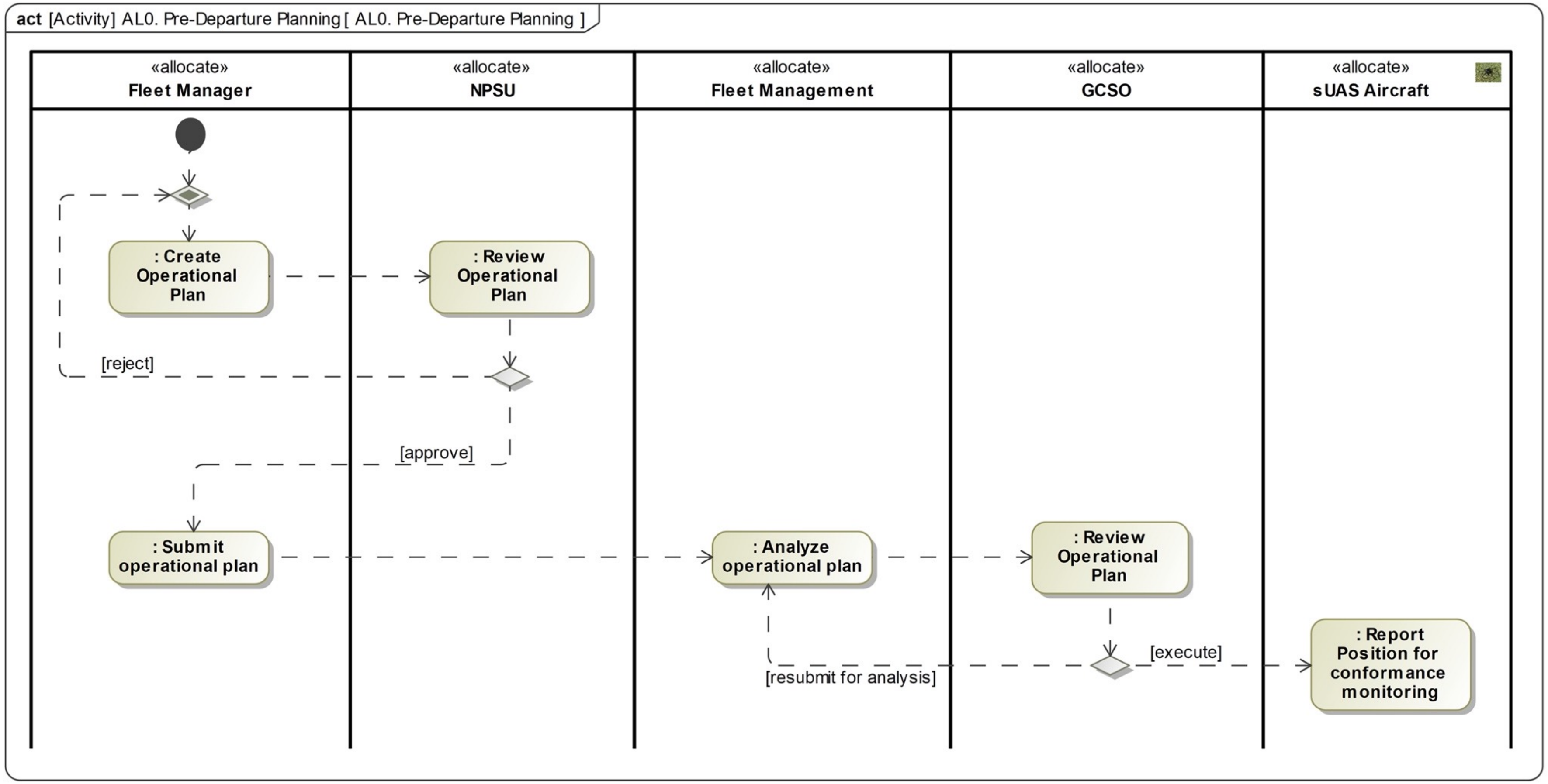
Behavior Diagram



Use Case Diagram

HDV uses use case diagrams to represent how external entities (i.e, actors) interact with a system.

Credits: NASA / Aeronautics Research Mission Directorate (ARMD) / Airspace Operations and Safety Program (AOSP) / Advanced Air Mobility (AAM) Project / High Density Vertiplex (HDV) Subproject



Activity Diagram

HDV uses activity diagrams to represent behavior by placing actions in order with their inputs/outputs.

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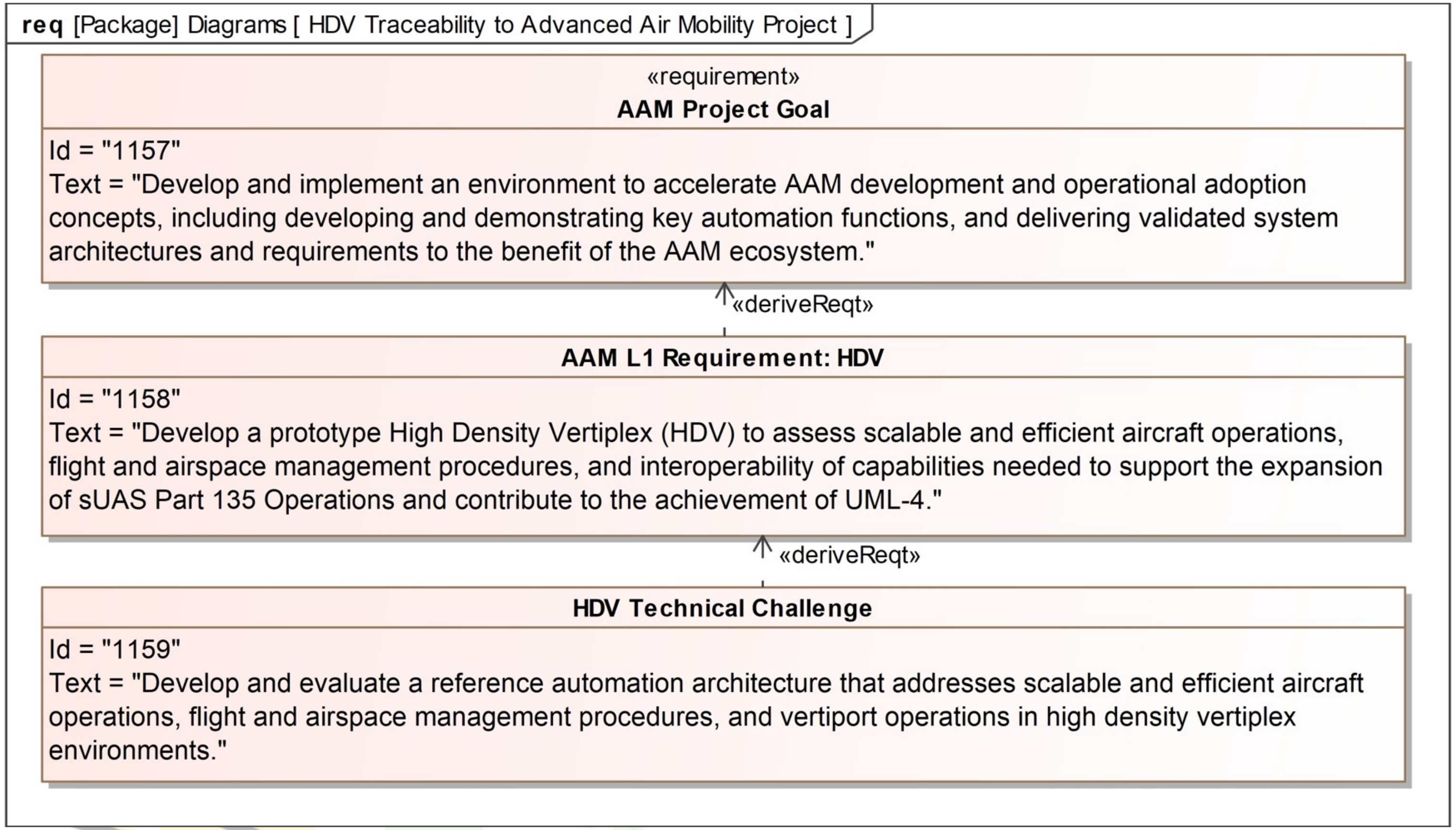
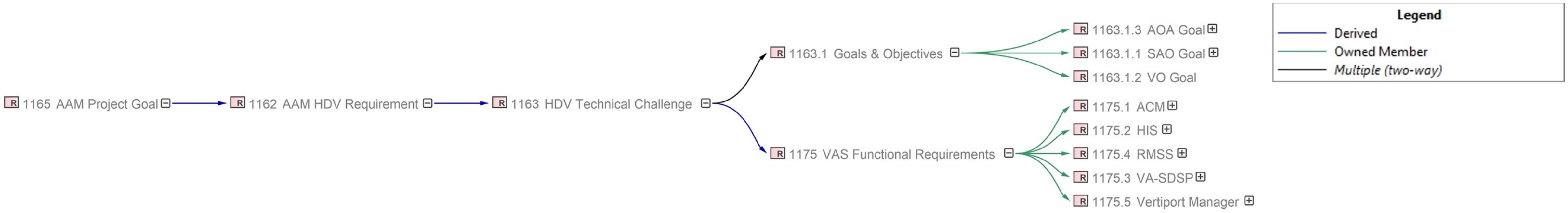
Requirement Diagram



Requirement Diagram

HDV uses requirements diagrams to show text-based requirements, their relationships with other requirements or elements and showcases traceability.

Credits: NASA / Aeronautics Research Mission Directorate (ARMD) / Airspace Operations and Safety Program (AOSP) / Advanced Air Mobility (AAM) Project / High Density Vertiplex (HDV) Subproject



Containment diagram

HDV uses the containment diagram to provide interactive requirement traceability.

Credits: NASA / Aeronautics Research Mission Directorate (ARMD) / Airspace Operations and Safety Program (AOSP) / Advanced Air Mobility (AAM) Project / High Density Vertiplex (HDV) Subproject

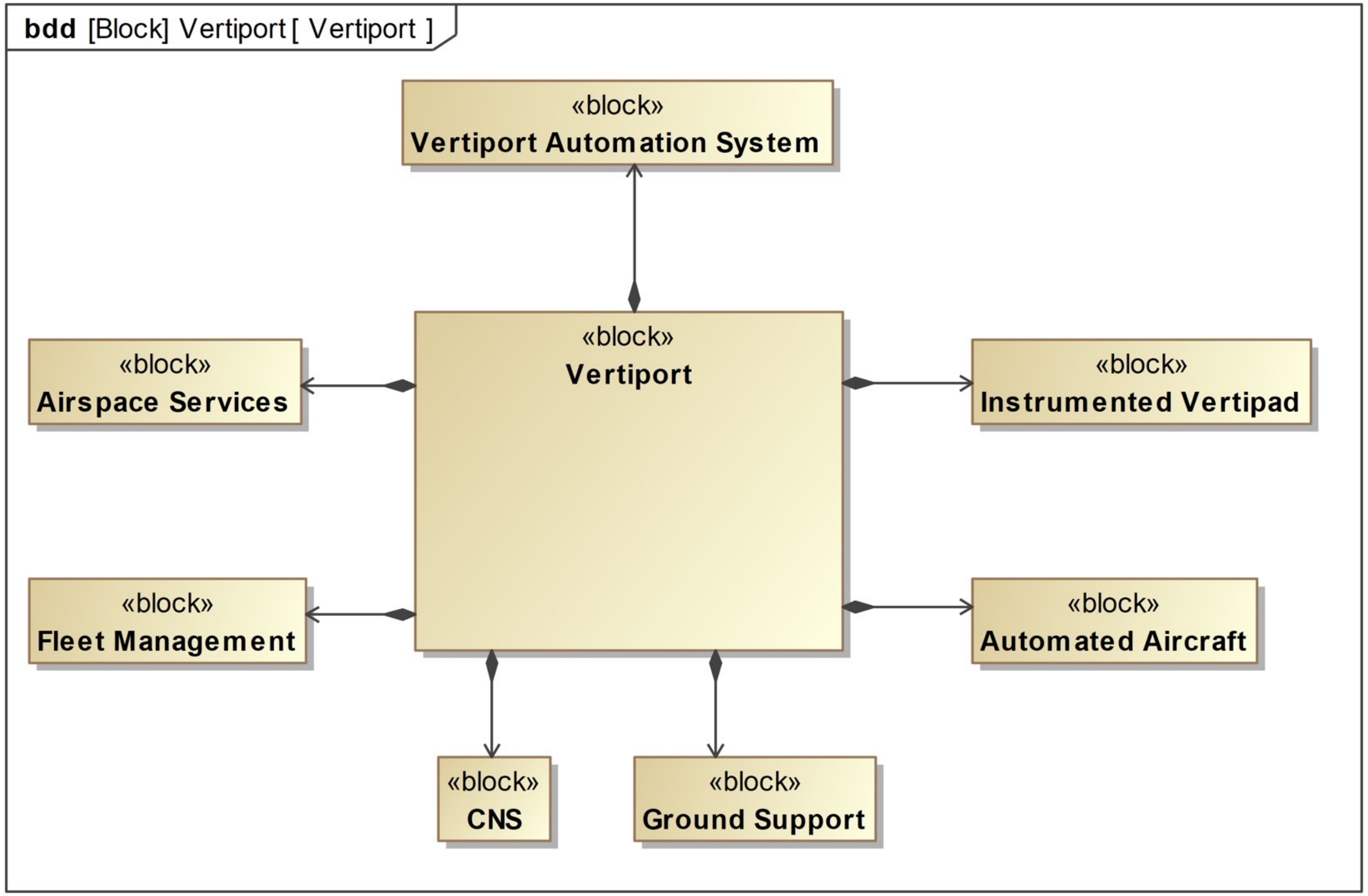
#	△ Name	Text	Satisfied By	Verify Method	Verified By
1	⊟ E 2 Aircraft	NASA aircraft shall operate autonomously and safely manage flight contingencies.	AAM Aircraft	Inspection	Test Procedure
2	E 2.1 AP Computer	NASA aircraft shall contain hardware to execute autonomous operations.	AP Computer	Inspection	AP Computer Hardware Screenshot
3	E 2.2 ADS-B Hardwar	NASA aircraft shall contain hardware to receive traffic broadcast from surrounding aircraft.	ADS-B In	Inspection	ADS-B Hardware Screenshot
4	E 2.3 GPS Hardware	NASA aircraft shall contain hardware to receive latitude and longitude coordinates.	GPS Antenna	Inspection	GPS Antenna Hardware Screenshot

Requirement Table

HDV uses requirement tables to create a requirements verification matrix with references to verification artifacts.

Credits: NASA / Aeronautics Research Mission Directorate (ARMD) / Airspace Operations and Safety Program (AOSP) / Advanced Air Mobility (AAM) Project / High Density Vertiplex (HDV) Subproject

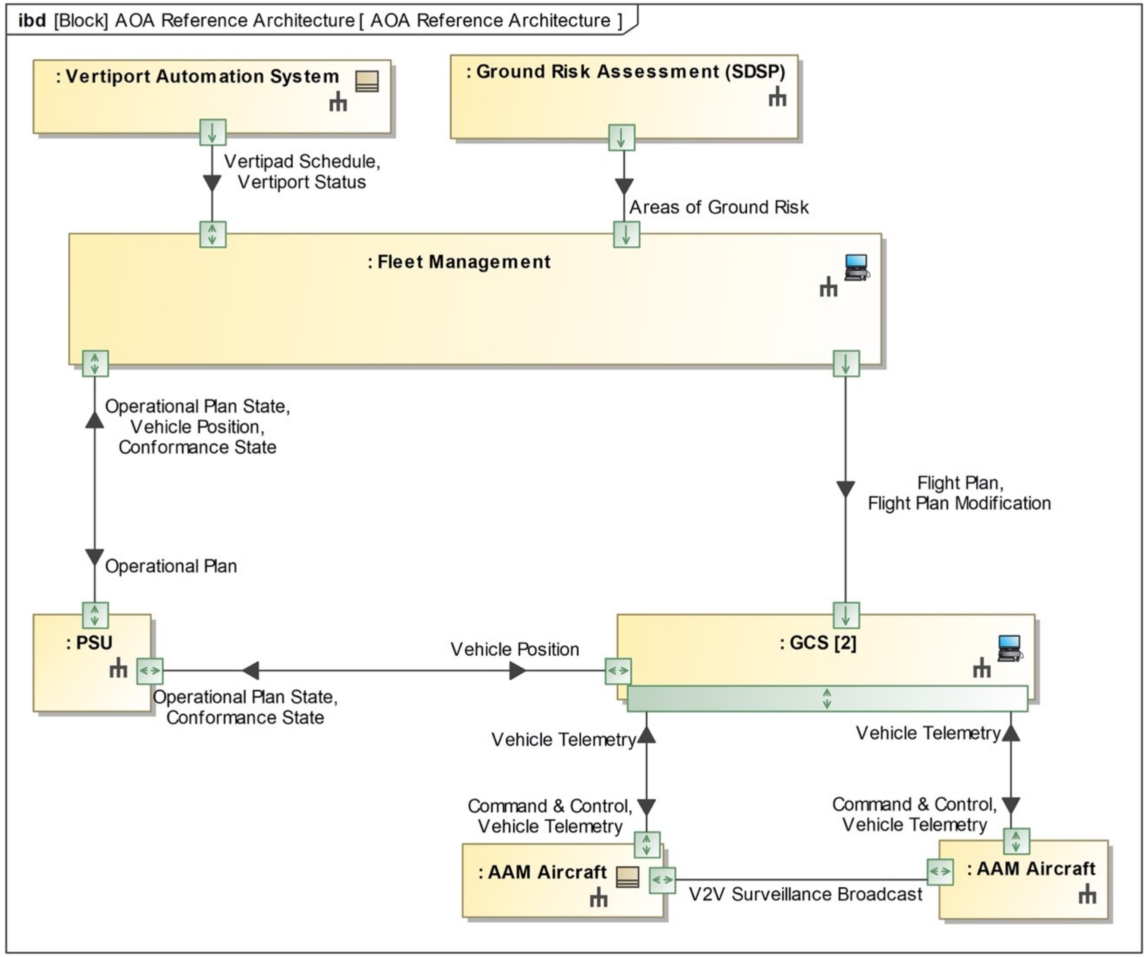
Structure Diagram



Block Definition Diagram

HDV uses block definition diagrams to represent system architecture via blocks, its composition and classification.

Credits: NASA / Aeronautics Research Mission Directorate (ARMD) / Airspace Operations and Safety Program (AOSP) / Advanced Air Mobility (AAM) Project / High Density Vertiplex (HDV) Subproject



Internal Block Diagram

HDV uses internal block diagrams to show the interfaces and connections between the parts of a block.

Credits: NASA / Aeronautics Research Mission Directorate (ARMD) / Airspace Operations and Safety Program (AOSP) / Advanced Air Mobility (AAM) Project / High Density Vertiplex (HDV) Subproject

SysML Diagrams Not Used

- Sequence diagram
  - Activity diagrams are enough for ops flow
  - Messages/data (high-level) captured in ibd
  - Below desired MBSE detail threshold
    - low-level details carried out by SW team
- State machine diagram
  - Below detail threshold (completed by SW team)

SysML Diagrams Not Used

- Parametric diagram
- Package diagram

Lessons Learned

Lessons Learned / Reinforced

- An MBSE Plan is crucial to focus limited bandwidth to do 1, then 2… n, processes well
  - Rather than do every aspect of SysML poorly
  - The plan will change as needs are discovered/understood, but it's still needed
- MBSE model fidelity increases with team review/feedback
  - They will not review model on their own time, need to setup meetings to walk thru model
  - Keep goodwill with team by providing value, e.g., diagram exports
  - Exported rqmts skeleton/draft to engineer leads who fleshed out with additional rqmts, then imported back into the model

Lessons Learned / Reinforced - 2

- Due to 1st-time using tool and complexity (both reference and physical architectures)
  - Expect mistakes, rework
  - Every additional stakeholder/model-recipient adds complexity and requires a % of bandwidth

Impact of MBSE on HDV

Traditional Method

- White paper documentation
- Static PowerPoints for system modeling

MBSE Method

- Dynamic models
- Traceability
- User Interacting Diagrams
- Report generation

Moving forward?

- System Modeling
- Verification and Validation
- Simulation
- Shareability

Thank you for listening!

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Thoughts?