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

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The High Density Vertiplex (HDV) subproject of NASA's Advanced Air Mobility (AAM) project adopted Model-Based Systems Engineering (MBSE) in July of 2020, prior to subproject formulation. A small and lean team of HDV Systems Engineers (SE) are utilizing MagicDraw to execute NASA SE processes via MBSE. The SEs learned how to use MagicDraw from scratch and HDV is the first project for which the SEs have utilized MagicDraw. This paper will demonstrate project technical execution via MBSE, utilizing the digital elements built into the SysML (Systems Modeling Language). SysML provides a model-centric means of carrying out the NASA SE common technical processes by providing tools for complete system modeling, including requirements and interface management and design capture. The authors also leverage and extend SysML to perform other SE tasks, such as Verification and Validation (V&V) tracking. MBSE has two main purposes for HDV: 1) documenting the subproject's logical architecture for distribution outside of the subproject, 2) capturing the subproject's physical architecture in a single-source-of-truth for use by the subproject's members. This paper details the challenges, lessons learned, and solutions that were encountered in implementing MBSE in the first iteration on a multi-iteration, full-lifecycle design, build, fly project.

I. Nomenclature

II. Introduction

A. Introduction to the Advanced Air Mobility (AAM) Project

As part of its work with the aviation community to identify and address the challenges ahead for advanced air mobility concepts, NASA initiated the Advanced Air Mobility Project within the Integrated Aviation Systems Program (IASP) of the Aeronautics Research Mission Directorate (ARMD). AAM is a broad mission that spans the ARMD portfolio and is managed through the AAM Mission Integration Office (AMIO). The critical commitment of AAM is as follows: Based on validated operational concepts, simulations, analyses, and results from National Campaign demonstrations, the AAM Mission will deliver aircraft, airspace, and infrastructure system and architecture requirements to enable sustainable and scalable medium density advanced air mobility operations. There are three areas of focus within the overall NASA AAM Mission portfolio: vehicle development and operations, airspace design and operations, and community integration.

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High Density Vertiplex[3], along with the other two AAM sub-projects: National Campaign (NC) and Automated Flight and Contingency Management (AFCM), and other NASA research projects in ARMD are working together to advance the three areas of focus identified in the AAM Mission portfolio. The Critical Commitment flows down to the AAM Project Office which aims to develop and implement an environment to accelerate AAM development and operational adoption concepts, including developing and demonstrating key automation functions, and delivering validated system architectures and requirements to the benefit of the AAM ecosystem.

B. Introduction to the High-Density Vertiplex (HDV) Subproject

HDV is responsible for the development and maturation of automation technologies and architectures that serve AAM community needs for infrastructure to support AAM operations. To this end HDV will focus on the development and testing of concepts, requirements, software architectures, and technologies needed for the terminal environment around vertiports, specifically focusing on automation to increase safety, efficiency, and scalability of flight operations in these environments. While HDV technologies, requirements, and architectures will be relevant to broad AAM operations, the HDV project will focus on uses cases that are specific for urban operations, which are closely aligned with Urban Air Mobility (UAM) operations.

Key barriers for UAM operations in the vertiport domain include: a lack of standardization around required technologies and performance to support high tempo and throughput UAM business cases around vertiports, mature concepts, procedures, and technologies supporting automated approach and landing, automated merging and spacing, and automated contingency decision making for eVTOL operations in vertiport environments. A barrier also exists in the development of evaluation and testing practices necessary for demonstrating that automated mitigations warrant "safety credit" from the regulator as a means of compliance to existing or future regulations. This is particularly true for the use of automation to support Beyond Visual Line of Sight (BVLOS) operations for UAS. Furthermore, a key barrier exists between required data information exchanges between the aircraft, airspace service provider, and the vertiport systems to support increasingly dense operations. Addressing these barriers are critical to ensuring that the industry is ready to support UAM Maturity Level 4 (UML-4) operations[4].

The HDV subproject will address these challenges by designing concepts, procedures, and technologies focused on UAM operations and leveraging subscale testing using small UAS as a proxy for full-scale UAM vehicles to assess suitability and verify requirements for UAM and vertiport automation architectures. HDV will leverage research technologies from the ARMD portfolio to develop a testing environment which captures the interactions and data exchanges between aircraft automation, automation in airspace services, and automation on the vertiport to evaluate the proof of concept of medium to high density operations into and out of a vertiport environment.

C. HDV Systems Engineering

The HDV subproject will use an iterative "crawl, walk, run" spiral design/development/test approach to build-up complexity in the operational environment, and integrate and mature the aircraft-airspace-vertiport automation technology needed to support three main use cases: (1) automated landing, (2) automated merging and spacing, and (3) automated contingency decision making. HDV will focus development on the technology gaps associated with the use cases (e.g., auto-land capability and vertiport automation). HDV testing will increase the operational complexity

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[3] A *Vertiport* is defined as an identifiable ground or elevated area, including any buildings, or facilities thereon, used for the vertical takeoff and landing of an aircraft. A *High Density Vertiport* is qualitatively defined as a vertiport that supports an increasing number of aircraft movements at or near vertiport capacity. High density refers to the average aircraft movements at a vertiport needed to support UAM Maturity Level 4 operations. A *Vertiplex* is defined as multiple vertiports in a local region with interdependent arrival and departure operations.

[4] UML-4 consists of medium density and medium complexity operations with collaborative and responsible automated systems. At UML-4, medium density is characterized as hundreds of simultaneous operations over a single metropolitan area or region. Medium complexity includes low-visibility operations, aircraft operating near one another in high-density routes, and operations to/from high-throughput aerodromes. There are also automated systems that do not require human oversight or mitigation of potential failures for some functions. These collaborative and responsible automated systems enable humans to have roles that differ from those performed by humans in the traditional aviation system and it is anticipated that UAM aircraft at UML-4 will utilize a network of third-party providers of services to UAM (PSUs) to manage scheduling of routes and provide automated, tactical deconfliction, in addition to other services.

with each schedule package culminating in the Integrated Automation Systems (IAS) assessment of full-scale[5] electric vertical take-off and landing (eVTOL) aircraft flying into multiple nearby vertiports with interdependent arrival and departure operations, defined as a vertiplex.

III. Motivations for Utilizing MBSE and Preexisting Lessons Learned

The HDV SE team utilized MBSE in the first stage of a full-cycle aeronautics project because it offers dynamic techniques to accomplish the common technical processes. NASA has three sets of common technical processes as outlined in NPR 7123.1, NASA Systems Engineering Processes and Requirements: system design, technical management, and product realization.

The parent AAM project chose to pilot the utilization of MBSE and is using it to capture the project's reference architecture.

IV. MBSE Scheme

Using SysML built into MagicDraw offers an array of tools to accomplish NASA SE common technical processes and HDVs use of these tools have eliminated "old school" document-centric techniques, to take advantage of MBSE. HDV has used the capabilities of MagicDraw to capture system requirements, model systems/subsystems, validate/verify system requirements, create traceability mechanisms, and display decision making and interfacing to systems. The SysML language produces products for HDV's use to accomplish its SE tasks in forms of diagrams, tables, and elements. Elements are the building blocks to the diagrams for which HDV uses them to model its system and introduce connections and interfaces between technology and humans. Diagrams and tables enable HDV to display information effectively and give the engineering team a dynamic and "on-the-spot" way of implementing changes.

A. Reference vs. Physical Architecture

Since the prototype technology developed by HDV for V&V will not be transferred outside of NASA for direct use by industry or the FAA, the key deliverables external to NASA are the lessons learned and documentation of the specification (in the form of requirements) and "reference architecture." The reference architecture is essentially what is called the logical architecture by the NASA SE Handbook but extends to the requirements and functions as well.

B. Requirements

C. System/Subsystem(s) Architecture Modeling

D. Traceability

E. Decision Making / Interface

MagicDraw enables the SE team to produce activity diagrams where decision making and interfacing are put on display inside of these diagrams.

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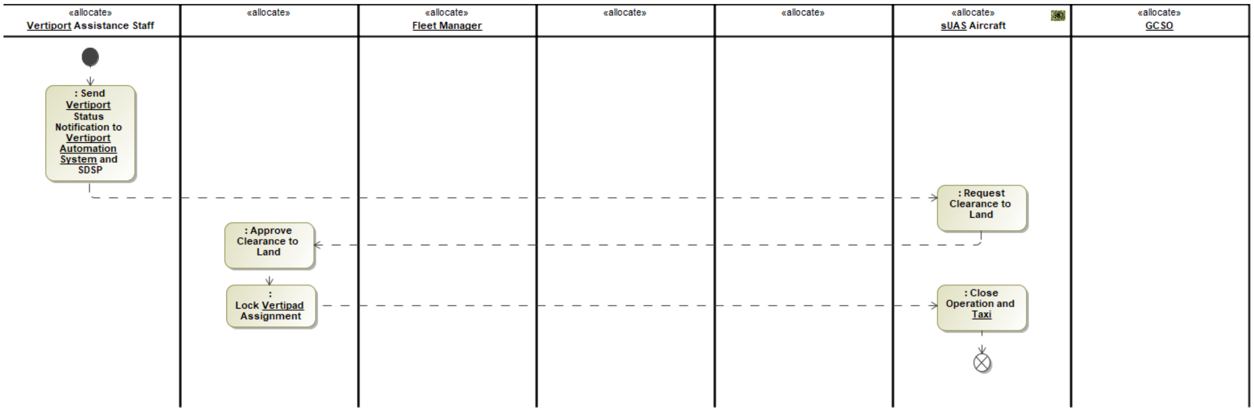
[5] Full-scale eVTOL aircraft refers to an electric aircraft that is capable of vertical takeoff and landing and carrying weight equivalent to at least one passenger.



V. Challenges, Lessons Learned, and Solutions

There were challenges encountered and wrong paths taken from which we needed to pivot. There are also new lessons learned and solutions to challenges that could apply elsewhere.

A. Challenges

B. Lesson(s) Learned

C. Solutions

Appendix

Acknowledgments

References