MBSE Execution of Scalable Autonomous Operations for a High Density Vertiplex

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The High Density Vertiplex (HDV) subproject of NASA's Advanced Air Mobility (AAM) project adopted Model-Based Systems Engineering (MBSE) and NASA SE processes were executed via MBSE using MagicDraw. Since the adoption of MBSE and utilization of MagicDraw, the systems engineering team has made tremendous strides in each pillar of MBSE including, requirements, behavior, and structure. Scalable Autonomous Operations (SAO) was a stage in the development of the High Density Vertiplex focusing on the autonomous terminal operations of a vertiport with sUAS aircraft. MBSE served the systems engineering team to document and verify the physical architecture and capture a logical architecture of SAO for distribution to the AAM community. This paper will detail methodologies that were created to successfully execute NASA SE processes via MBSE in the SAO stage as well as highlight challenges and lessons learned.

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.

High Density Vertiplex[2], 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.

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. HDV focused on the development and testing

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[1] Systems Engineer, Systems Engineering Team.

[2] 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.

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 focused 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[3].

The HDV subproject addresses 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 leveraged 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 density operations into and out of a vertiport environment.

C. HDV Systems Engineering

HDV utilized a design/development/test approach to build-up 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 focused its development on the technology gaps associated with these use cases (e.g., auto-land capability and vertiport automation).

III. Motivations for Utilizing MBSE and Preexisting Lessons Learned

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 SE team utilized MBSE in all stages of this full-cycle aeronautics project because it offers dynamic techniques to accomplish the common technical processes.

IV. MBSE Scheme

SysML built into MagicDraw offered many tools to accomplish NASA SE common technical processes which have eliminated document-centric techniques. HDV has used these capabilities to capture system requirements, validate/verify requirements, create traceability mechanisms, model the structure of systems/subsystems, and display decision making and interfaces of systems. Diagrams are built from elements which HDV uses to model its system, connections and interfaces between technology and humans. Diagrams and tables also enable HDV to display information effectively and give the engineering team a dynamic and on-demand capability of making changes.

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[3] 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.

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 the logical architecture as referred to by the NASA SE Handbook but extends to include requirements, structure and functions.

B. Requirements

C. Structure

D. Behavior

V. Challenges, Lessons Learned, and Solutions

A. Challenges

B. Lesson(s) Learned

C. Solutions

Appendix

Acknowledgments

References