Preliminary Evaluation of National Campaign Scenarios for Urban Air Mobility

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Abstract: Urban Air Mobility and Advanced Air Mobility concepts offer a novel method for transportation of passengers and cargo. Whereas the concept may reduce congestion of roads and highways, it also introduces new complexity to the National Airspace in terms of management of such operations. NASA, in partnership with FAA and industry, approaches these complexities with research and development activities such as flight tests and simulations, in order to better understand the impacts and necessary mechanisms by which these operations could be integrated. One example of such research and development activity that NASA is conducting is the Advanced Air Mobility National Campaign effort. Flight-test scenarios were proposed as part of the National Campaign and tested in simulation for evaluation with industry partners prior to the Flight test. This simulation, exercised as an engineering evaluation, provided a data collection opportunity to better understand what iterations and modifications would be needed to successfully demonstrate the flight-test scenarios in order to mature the concept of Urban Air Mobility and Advanced Air Mobility.

Keywords: UAM, Urban Air Mobility, Advanced Air Mobility

I. Introduction

NASA's vision for Advanced Air Mobility (AAM) is to help emerging aviation markets develop a safe air transportation system that would allow moving people and cargo between places previously not served or underserved by aviation in addition to metropolitan urban areas [1,2]. Advanced Air Mobility (AAM) encompasses a range of innovative aviation technologies (small drones, electric aircraft, automated air traffic management, etc.) that are transforming aviation's role in everyday life, including the movement of goods and people. Urban Air Mobility (UAM) represents one of these AAM concepts with highly automated aircraft providing commercial services to the public over densely populated cities to improve mobility. The improvement of UAM envisages a future in which advanced technologies and new operational procedures enable practical and cost-effective air travel as an integral mode of transportation in metropolitan areas. This includes flying to local, regional, intra-regional, and urban locations using revolutionary new electric Vertical TakeOff and Landing (eVTOL) aircraft that are only just now becoming possible.

NASA and the FAA have been collaborating to describe the innovative UAM operations through a Concept of Operations (Conops) document [3,4]. The document also describes the challenges of these operations, which range from integration of UAM operations in the National Airspace System (NAS), safety, noise impacts, public acceptance, and integration with other new entrants such as small drones.

Integration of UAM operations in the NAS has been the focus of the research conducted at NASA Ames Research Center under the Air Traffic Management – eXploration (ATM-X) UAM sub-project. Previous research on UAM operations focused on understanding the capabilities and limitations of helicopter operations in the current day environment that could be applicable to UAM [5]. The research found that current day requirements for helicopter operations, similar to UAM operations, for obtaining verbal clearances to Class Bravo airspace was the biggest limiting factor to scalability of these operations. Digitizing communication would not be a feasible solution for such clearances for UAM operations as it would simply substitute the verbal communications and would not reduce the workload for the air traffic controllers. To make the UAM operations scalable, the use of traffic management similar to the small Unmanned Aircraft Systems (sUAS) was proposed as a solution to reduce the burden on air traffic control. The UAS Traffic Management (UTM) paradigm [6,7], describes a service-oriented architecture with a focus on third party services. Another study [8] investigated if the performance of the UTM architecture and implementation from UTM's Technical Capability Level 4 (TCL-4) [9,10,11] were extensible for UAM operations, and if the data exchange between multiple operators as planned under UTM were adequate for UAM operations in shared airspace. The study found that additional research would be necessary to provide guidance on the number and size of volumes to be used per operation.

The study reported in this paper defines and iterates on a UAM specification as an evolution of the UTM specification. A

UAM specification would enable both nominal and off-nominal operations based on the concept of operations developed by NASA and the FAA. Scenarios were identified by the National Campaign (NC) sub-project at NASA to demonstrate nominal and off-nominal use-cases in order to determine the information exchanges between Air Navigation Service Provider (ANSP) and Provider of Services for UAM (PSU), as well as exchanges between multiple PSUs. As an iteration of UTM, NASA utilized the ASTM standard [12], a specification developed for small Unmanned Aircraft Systems as a baseline. The main objectives of this engineering evaluation were to utilize the specification for the NC use-cases with industry partners in order to explore information and data exchange requirements, identify key questions regarding access of controlled airspace from the ANSP perspective, and to explore digital airspace integration procedures.

In the next section, Section II, concepts of operations and the relevant architecture that exist for UAM operations will be described. In Section III, a description of the approach that includes a high-level overview of the airspace definitions, assumptions, test plans, and NC Scenarios/Use Cases will be provided. Section IV will describe the results from analyzing the post-simulation data and capture some of the lessons learned. Section V will include a summary and proposed next steps.

II. BACKGROUND

The approach to airspace management for UAM operations simulated in this study is an extension of the concept for UTM to enable UAM operations, with special consideration given to ensuring the extensions are interoperable with the existing Air Traffic Management (ATM) system. Details of the UTM operational concept are included in the Federal Aviation Administration's (FAA's) UTM Concept of Operations (ConOps) document [12]. An integral aspect of this airspace management approach is the idea that third parties will provide airspace management services to aircraft operation. The UTM architecture described in [6,7] refers to the service providers for UAS as UAS Service Suppliers (USS). The FAA Nextgen UAM Conops v1.0 [3] defines an architecture that describes many key entities.

For the purposes of these tests, a subset of software components was selected to be demonstrated. Fig. 1 shows the software architecture utilized in these tests. One of those entities is the PSU (analogous to USS in UTM). It supports UAM operators with meeting UAM operational requirements that enable safe, efficient, and secure use of the airspace and shares operational intent for the flights in the vicinity. The Flight Information Management System Authorization (FIMS AZ) authorizes and authenticates PSUs to ensure access is provisioned only to those permitted to use the system. The Discovery Synchronization Service (DSS) enables a PSU to identify other PSUs with active operations or subscriptions in the area of interest. A Data Collection PSU was a component developed by NASA leveraging the PSU Application Programming Interfaces (API) to collect data during the simulation. (This PSU simply collects data but does not submit operations.) NASA also developed a system called Data Pipeline that collected simulation data both real time and post simulation. The tests described in this paper were designed to highlight key challenges related to extending the UTM concept to UAM when utilized for nominal and off-nominal scenarios. Understanding these challenges will further the development of detailed concepts and procedures for UAM operations in the NAS.

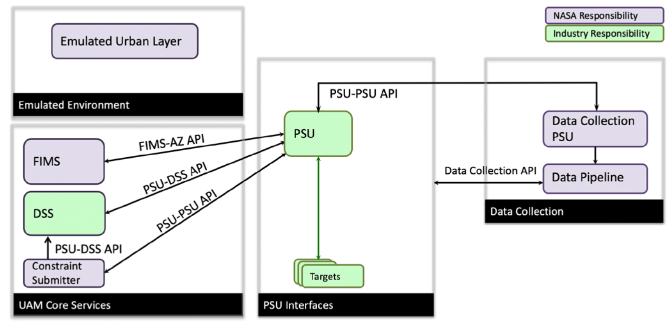

Fig. 1. Architecture used for evaluation of scenarios

III. APPROACH

A. Scenarios

Three scenarios defined by NASA's AAM National Campaign Project were selected as use-cases for evaluation in this experiment.

The focus of Scenario 1 was to traverse and conform to a defined operation plan under nominal conditions. In Scenario 1, the PSUs performed pre-departure flight planning for UAM aircraft using the provided routes and interfaced with the UAM Core Services, as seen in Fig. 1, to submit and announce the operation. This was followed by simulation of vehicle(s) that conformed to that operation plan. Fig. 2 shows a notional depiction of a UAM flight traversing in Class Golf from origin A to destination B.

Fig. 2. Notional depiction of Scenario 1

Scenario 2 was an extension of Scenario 1's nominal flight operations with an objective to perform a re-route due to a temporary flight restriction (TFR), also referred to as an airspace constraint, on the route of the planned operation. While the operations were in-flight, the UAM Core Services, using the defined APIs, announced an airspace constraint along the nominal flight path. The PSU involved with the operation had to re-plan the operation so that it would not enter the volumetric restriction. Fig. 3 shows an operation planned from Class Delta to another Class Delta via Class Golf. The airspace constraint is announced in Class Golf and requires the operations to modify their plans in-flight in order to reroute around the airspace constraint.

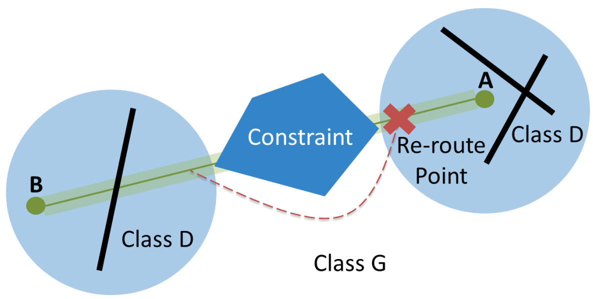

Fig. 3. Notional depiction of Scenario 2

Scenario 3 also extends Scenario 1's nominal flight operations but explores off-nominal situations. In this scenario, the landing vertipad becomes unavailable, requiring the operation to re-plan while airborne and perform a go-around maneuver (3A), or divert to an alternate landing vertipad (3B). Fig. 4 and Fig. 5 provide a notional depiction of the Scenario 3A and 3B, respectively.

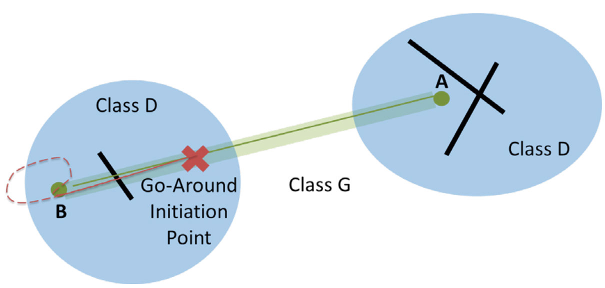

Fig. 4. Notional depiction of Scenario 3A (Go-Around)

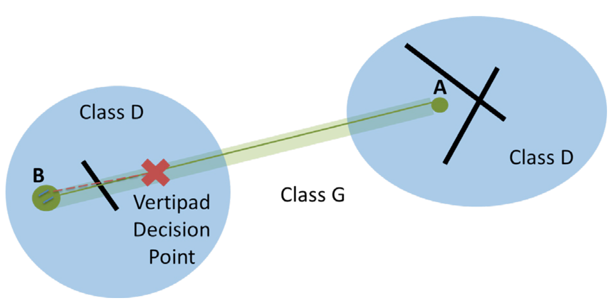

Fig. 5. Notional depiction of Scenario 3B (Landing on alternate vertipad)

Further description for the selected scenarios are available in the ARMD Advanced Air Mobility National Campaign – Announcement of Collaborative Partnership Opportunities 2 [14].

B. *Assumptions*

Several operational assumptions were made for the simulation tests. It was assumed that these operations were pre-authorized to operate on the routes inside controlled airspace (Class Delta) for Scenario 2 and Scenario 3 via some current-day tool like letter of agreement. The UAM routes were designed such that they were de-conflicted from traditional traffic and no interaction with traditional traffic or small UAS was assumed for these tests. Thus, there was no other traffic (traditional or small UAS) other than UAM traffic planned for these tests. For all the scenarios, only one industry partner at a time performed the tests and did not have to share the planned routes or vertiports with any other partner/operator. The weather conditions were assumed to be visual meteorological conditions where the vehicles could fly Visual Flight Rules (VFR) with no wind. For all three scenarios, it was assumed that communications with air traffic control were either not required (e.g. Class Golf/ Class Echo in VFR) or that the communication had already occurred; such as the re-route for Scenario 2 was already approved for the operation. Similarly, it was assumed that a go-around pattern is pre-approved, pre-published, and available for use by the industry partners. Additionally, landing on a different vertipad at the vertiport would be managed by the operators and not require any ATC communications. Other detailed assumptions can be found in the technical memorandum [15].

C. *Emulated Environment*

To test the NC use-cases, a generic airspace was created by utilizing two Class Delta airports in the Dallas area and transposing them to Edwards Airforce Base in Southern California. This was done to account for terrain since the the live flight test was planned at Edwards. The Dallas airports were selected due to their usage in previous tests. Industry partners received a set of adaptation files used to define a common airspace for each scenario. All scenarios provided the applicable airspace definitions, available landing / takeoff vertipads, and the nominal routes between the vertipads with defined altitudes for operations where relevant.

Scenario 1 included Class Golf airspace that emulated the Edwards airspace, and no cruise altitude restrictions were provided for this airspace. For Scenario 2 the adaptation included Class Delta airspace and included a portion of the Class Delta airspace referred to as 'UAM Airspace' in which UAM operations were allowed to occur under an assumed predefined agreement with ATC. The 'UAM Airspace' was identified by de-conflicting it from the historical VFR flights in the Class Deltas utilized for this scenario. Scenario 2 also provided the location of the airspace constraint and the re-route planned for this scenario to enable the industry partner to modify the affected active operations. Scenario 3's airspace included the go-around pattern and the location of the alternate landing pad. Fig 6. shows the emulated airspace with the two Class Deltas, the nominal and the off-nominal route.

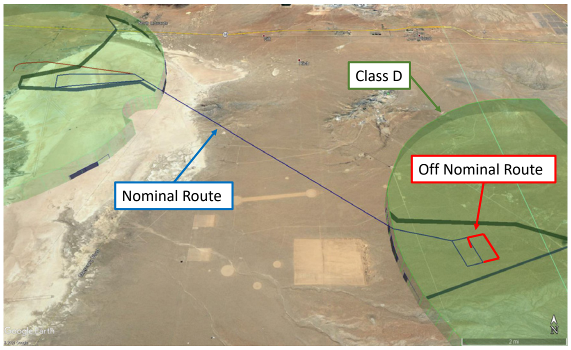

Fig. 6. Emulated Airspace for testing NC scenarios

D. Requirements

All industry partners were required to interface with the test event's defined airspace systems as described in the Background section and adhere to the airspace as defined in the Emulated Environment section.

For each scenario test, the industry partner was required to plan at least 5 concurrent operations on the route identified in the test procedure. To support this, the operations were to start within 3 minutes of each other. The volumes of each operation were to have no intersections in space and time with the volumes of other operations. During an off-nominal event (such as the airspace constraint in Scenario 2), the industry partner was required to re-plan their operation while airborne.

Industry partners were required to simulate vehicles traveling at speeds representative of a UAM operation (i.e. 70 to 150 knots). The vehicle was always to remain within an active 4D volume from its operation plan.

E. Test Plans

The evaluation of the use-cases utilized a sequence of tests including validation and connectivity tests, followed by functional tests, and finally the scenario test.

The validation test procedures were performed against the industry partner's PSU to exercise the applicable API, without connecting to other subsystems. Connectivity tests were performed at the beginning of each test session and only covered the systems needed for that day's testing.

The functional tests provided a preliminary assessment of capabilities to ensure coverage of expected functionality for the respective scenario test. These tests included capabilities that may be encountered (such as Non-Conformance) but may not be specifically required in the relevant scenario. This provided additional confidence that the scenario test would be successful and collected data would be reflective of the use-case's requirements.

The scenario tests were the main data collection events in which the industry partners participated. The scenario tests exercised system capabilities required for one of the three given scenarios. During the scenario tests, a PSU was expected to support five or more concurrent operations within the emulated environment.

F. Data Collection and Metrics

Data were collected throughout the testing with each of the eleven industry partners. For each of the functional and scenario tests, the Data Collection PSU collected data exchanged using the industry standard PSU API. The PSUs submitted additional data models using the Data Collection API to provide context to the PSU API exchanges. Definitions of these interfaces and the models exchanged were shared and version controlled on Github repository [12, 13]. All collected data were stored in the same database to aid in post-test analysis.

System requirements and scenario definitions were collectively used to identify operational and system performance metrics. The metrics were planned to assess the success of a given test procedure based on test or scenario requirements, and to assess the capabilities required for three selected scenarios. There were 38 metrics planned and computed but results for a subset is included here for brevity.

IV. Results

Eleven industry partners participated in the simulations that evaluated the three scenarios. Out of the eleven industry partners, nine were able to perform testing with the UAM Core Services. Of those nine industry partners, as shown in Table I, seven were able to complete Scenario 1, four of those seven were able to complete Scenario 2, and only two were able to complete all cases in Scenario 3. The rest of the results section describes metrics for the different scenarios.

TABLE I. Industry Partner Participation

Scenario	Number of Industry Partners Completed	Total Number of Test Runs	Total Number of Operations Flown
1	7	13	70
2	4	8	39
3	2	4	14

A. Scenario 1: Conformance to Nominal Operations

Scenario 1 required the operator to submit an operation plan and conform to that plan. Operational volumes were used in UTM and continued to be used for UAM operations in this simulation to support pre-departure strategic de-confliction. Volumes consist of a 2D polygon parallel to the Earth's surface with minimum and maximum altitudes. In addition, the volumes were temporally bound with a start and end time.

In addition to sharing operation intent for operation planning, the volumes were used to share the criteria to determine operation conformance. While in flight, the PSU is expected to monitor the vehicle position and confirm that the vehicle is within the planned volumes both spatially and temporally. Vehicle position was not shared with other PSUs while conforming to the operational plan. When the vehicle was not conforming, "NonConforming," to the operational plan, the PSU would alert other PSUs and enable the querying of that vehicle's positions. The scenario tests did not require vehicles to enter a "NonConforming" state, but industry partners were required to provide vehicle position data at all times and monitor conformance for data collection purposes.

The exact design of UAM volumes and the definition of 'de-conflicted' for those volumes is not standardized or enforced (e.g. by a validation check) in the DSS API. The DSS only identifies potential conflicts for an operation based on its general area. It was an 'expectation' by the DSS that a PSU would perform its own detailed de-confliction checks, and only needed to prove to the DSS that it was aware of the other operations in the airspace.

Based on these uses for operational volumes, the industry partners were permitted to design their volumes and manage de-confliction of their own operations for this test. The industry partners were requested, however, to support at least five operations on the route concurrently, and to have no overlapping operational volumes between the concurrent operations. These requests would support both constraining the size of the volumes, and de-conflicting operations.

Fig. 7 shows examples of the operational volumes used by the operations of three different PSUs during Scenario 1. Table II shows the approximate values of the spatial and temporal boundaries used for an operational volume at approximately the same location for each operation shown in Fig. 7. Despite the differences in sizes between Operation A's (blue) and B's (green) volumes, the corresponding PSUs supported five concurrent operations with no volume intersections with other operations. This was primarily a result of the volume durations. The volume sizes for Operation C (purple) may have supported multiple operations with no volume intersections; however, the duration of each volume caused intersections with other operations.

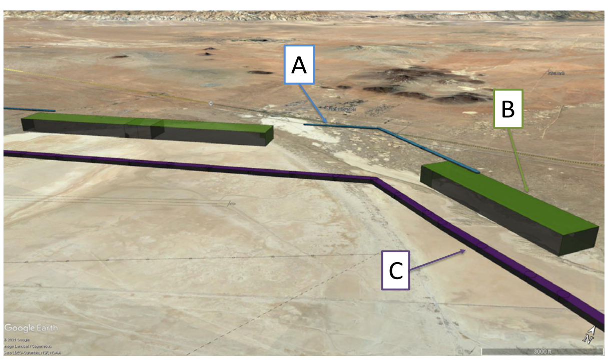

Fig. 7. Operations from Three Different Operators

TABLE II. APPROXIMATE VOLUME SIZE OF A COMPARABLE OPERATIONAL VOLUMES FOR THE THREE OPERATORS

Operation (Color)	Horizontal Size (ft^2)	Vertical Size (ft)	Duration (s)
A (Blue)	471,000	48	82
B (Green)	12,448,000	656	82
C (Purple)	850,000	206	7,200

Such differences make it clear that the range of sizes and durations is very wide. As vehicles are required to conform to the operation plan, larger operational volumes provide easier conformance. Larger operational volumes spatially or temporally, however, may increase the difficulty of planning operations with no volume intersections with other PSUs. Given the varying operational volume sizes, Fig. 8 shows the industry partner distribution for the percentage of operations with volumes that intersected the volumes of other active operations at any time for Scenario 1.

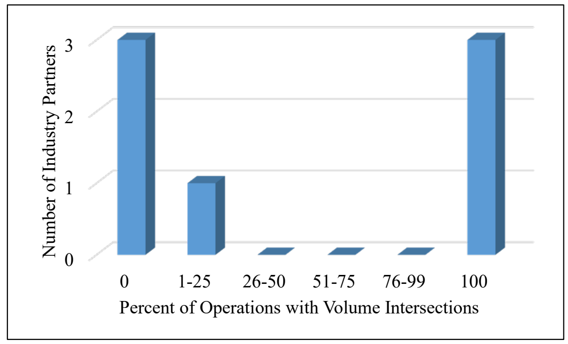

Fig. 8. Industry Partner Distribution of Percentage of Operations with Volume Intersections

The results in Fig. 8 were calculated using the versions of operation plans that were active at the same time and compared each volume in those plans to find volumes with a common geographic area at a common time. As shown in Fig. 8, some industry partners had 100% of their operations intersecting. This was due to their business logic for how to manage operations using the defined APIs. Those PSUs had alternate means to de-conflict their own operations internally, and therefore did not enforce non-intersecting volumes for their own operations. In the example of Operation C from Fig. 7, the PSU could have maintained de-confliction of its own operations using the vehicle information (such as position). This is allowed by the DSS, as 'de-conflicted' is not fully defined and, especially for self-de-confliction, can be interpreted multiple ways. Although de-confliction of a PSU's own operations may be supported this way, the volumes used in this case would not have allowed equitable use of the airspace by other PSUs.

Thus, Scenario 1 allowed us to uncover the need for a standardized method for sizing operational volumes. Standardizing the method to size the operational volumes will help ensure that volumes are not unnecessarily large and providing easier conformance at the expense of reducing the availability of the airspace to other PSUs. We also found that UAM operations using the API will require additional definition on intersecting operations and how conformance and separation for those operations is met.

B. Scenario 2: Response to Airspace Constraint

Scenario 2 tested the ability of the operators to re-plan their operations due to an airspace constraint. There were no requirements for exactly when the re-plan needed to occur, just that the operation could not enter the constraint area and must remain conforming to its active operation plan. Fig. 9 shows the industry partner distribution for percent of operations that intersected with the airspace constraint and performed a re-plan.

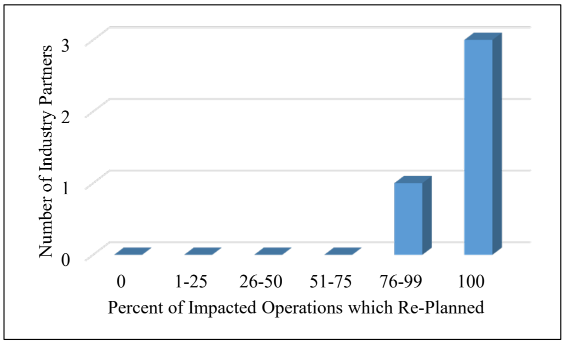

Fig. 9. Industry Partner Distribution of Percent of Impacted Operations Re-Planned to Avoid the Constraint

In general, operations successfully re-planned to avoid the constraint as seen in Fig. 9. This included both in-flight and pre-departure cases. Operations which re-planned were requested to use a pre-defined re-route. This would allow comparison of the re-plans performed by the different PSUs. Most partners successfully used the pre-defined re-route as seen in Fig. 10. One industry partner exercised the pre-planned route as well as the industry partner's own algorithms to calculate a route around the constraint. In both cases, the operations managed to avoid the constraint volume.

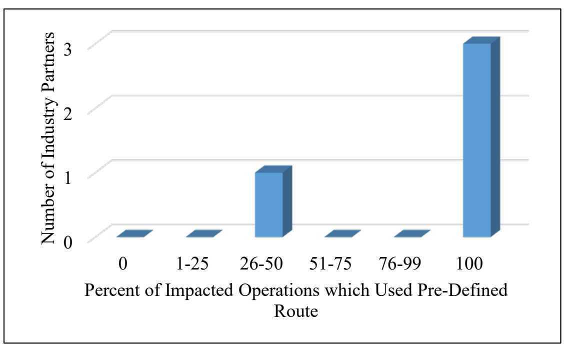

Fig. 10. Industry Partner Distribution of Percent of Impacted Operations Re-Planned Using the Pre-Defined Route

During a functional test leading to the scenario test, an industry partner was unable to re-plan their operations when submitting the updates to the DSS less than 1 second apart. When the DSS receives an operation plan, it checks that the plan is using the most recent operation details for other operations active in the airspace. These operation re-plans appeared to be rejected due to this check and the rate the re-plans were submitted. There were several different approaches implemented by the industry partners to work around these rejections. In order to ensure that operation re-plans are accepted, additional requirements may be needed regarding when to submit the re-plans due to an airspace constraint.

As a result of these rejected operation re-plans, the corresponding vehicles became "NonConforming," as they flew the modified route instead of the route accepted by the DSS. Although this may have been an artifact of the design of the industry partner's system, it further emphasizes the need to clearly define the requirements and prevent these rejections by the DSS. If these operations continued to fly the original route, the operations would have flown through the airspace constraint and violated the requirements of this scenario.

Scenario 2 tested the ability of the operations to respond to an airspace constraint while they were on the ground and airborne. Some of those operations matched the re-route provided to them whereas others flew a dynamically generated re-route created by their respective PSUs. Requirements for operation re-plans due to an airspace constraint and/or the implementation of DSS should be further investigated for UAM operations to limit the potential for operation plan rejections.

C. Scenario 3: Off-Nominal Landing

Scenario 3 investigated several off-nominal situations that included flying a go-around pattern and landing at an alternate location, which was either an alternate landing vertipad or an airport surface. In order to force one of these responses (go around or landing at alternate locations), a constraint was placed on the original landing location as soon as the first operation in the sequence landed. This allowed for approximately 3 min for the second operation to re-plan to land at the adjacent landing vertipad and approximately 6 min for the third operation to re-plan to perform a go-around and land at its original location after the constraint expired. Two additional operations flew the same route as well to observe any downstream impact of the re-plans. In the separate test run, an operation announced a contingent state while in flight, and re-planned to land on an airport surface.

Although only two of the industry partners were able to perform the Scenario 3 data collection, the data suggest that the approximate three and six minute time windows provided enough advanced notice to re-plan the operations and not cause a conflict with other operations. In Scenario 3, the operations which performed the go-around were able to re-sequence into the flow of traffic without intersecting the volumes of other operations. In Fig.11, Operation A (green) is completing its go-around maneuver before Operation B (blue) arrives along the nominal route. The ability to re-plan quickly, as aided by having the waypoints associated with the go-around pre-defined, potentially helped minimize the impact of the re-plan on other operations. In the operational world, the go-around points would be pre-published and available for operators to use when required.

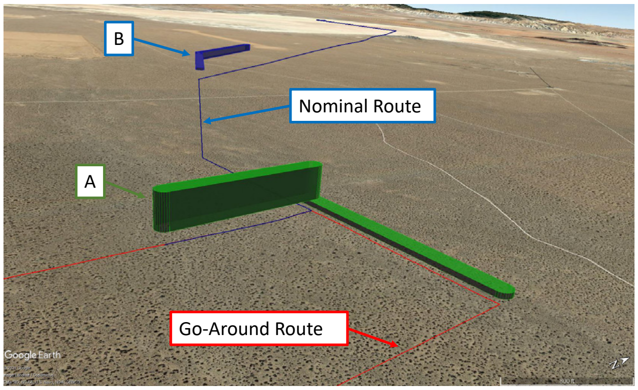

Fig. 11. Go-Around Operation Re-Sequencing into Traffic

Larger operational volumes (similar to Operation B as identified in the Scenario 1 results section) could potentially restrict operations near vertiports. For the alternate vertipad scenario, the destination vertiport included two usable vertipads separated by approximately 230 feet (KGKY-a and KGKY-b) as seen in Fig. 12. The operation was expected to re-plan to use the alternate vertipad. The larger volumes of those operations encompassed both vertipads. Although this allowed the operation to use either vertipad in the event that one became unavailable, it would prevent other operations from using the other vertipad due to an intersection of operational volumes. This outcome illustrates another motivation for standardization of the method to size operational volumes.

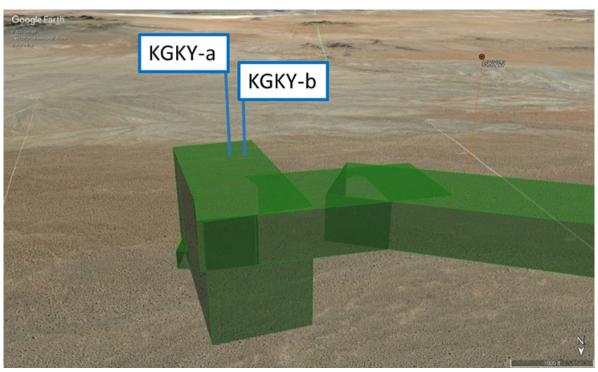

Fig. 12. Operation Volumes Near Vertipad

In addition to the scenarios described above, the ability to announce a contingent state and perform a contingency landing on an airport surface was also tested. The two partners that performed Scenario 3 were able to announce the contingency and perform the expected re-plan. Due to the number of operations and the route used, no other operations were impacted by the contingent operations. As described in the assumptions, there also was no traditional air traffic or interface with ATC performed in this simulation. The procedures and data exchanges required for a contingency or emergency landing could be further tested in a future human-in-the-loop study to explore ATC or potential traditional air traffic impacts.

V. Summary

The simulation reported in this paper tested three NC scenarios and enabled participating industry partners to demonstrate their capabilities and software components in a simulated environment. This simulated environment was purposefully similar to that of future flight test activities planned under the National Campaign sub-project. Out of the eleven original industry partners, nine were able to perform testing with UAM Core Services developed by NASA. Of those nine industry partners, seven were able to complete Scenario 1, four of those seven were able to complete Scenario 2, and two of those four were able to complete Scenario 3. Requirements for running the three NC scenarios were provided to the industry partners and testing spanned several months. Only a single industry partner tested using the UAM Core Services at any given time. All seven industry partners were able to run at least the five concurrent operations as required by the simulations.

The testing provided insights into how the operations were able to conform to the requirements of the airspace. It was observed that the requirement for intersecting operational volumes and size of operational volumes that were suggested for UTM would need to be re-defined for UAM operations. It was also observed that there is no standardization for operational volumes design and that some industry partners created large volumes whereas others used small volumes. The size of the volume affects the conformance to the volumes, as was also found in previous studies [4]. It is suggested that usage of 4D trajectories and standardization of the method to size volumes for the operations should be explored for future tests related to UAM operations. Another insight related to rejection of an operation re-plan by the DSS while in flight. This could lead to operations becoming 'NonConforming.' This is especially true if the re-plan was to avoid an airspace constraint. The tests also explored off-nominal situations that would require re-planning of operations leading to a go-around or landing at alternate locations. These events would have an impact on the rest of the downstream operations especially during high density and require further investigation. If at any given time the operations exit their designated airspace and enter controlled airspace, there will necessarily be implications for contacting ATC, especially if the operations are in a positively controlled environment. Insights gained from the testing and analysis have been valuable and will aid in building rigorous requirements for future simulations planned for NC in pursuit of preparing the industry partners for future flight tests with NASA.

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