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# National Campaign (NC)-1 Strategic Conflict Management Simulation (X4) Community Based Rules

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# Executive Summary

Projected demand for transportation services in the urban environment has led to the development of several Concepts of Operation for Urban Air Mobility, or UAM. UAM is a concept for the transportation of people and goods in the metropolitan environment using small, efficient aircraft over short distances as part of an expanding multimodal transportation network. UAM will leverage emerging technologies including electric Vertical Takeoff and Landing (eVTOL) aircraft, increasing levels of automation and a new operational paradigm in dense airspace where a set of agreed-upon rules govern the procedures and interactions defining a cooperative environment in which operators are entrusted with a range of functions typically conducted by Air Traffic Control (ATC). These rules, proposed in the FAA NextGen Office's UAM Concept of Operations [1], were originally termed Community Based Rules or Community Business Rules (CBRs), and will in the future termed Cooperative Operating Practices (COPs); this document uses the original term, CBR.

CBRs are a set of rules, developed by the UAM community and (where necessary) approved by the FAA that govern the interactions between UAM entities and limit the need for ATC services including, but not limited to, separation control by ATC, addressing a fundamental challenge to scaling UAM operations. UAM community development of CBRs is anticipated to accelerate the adoption of new practices while retaining the regulatory authority of the FAA within required domains (e.g., NAS safety, security and equal access). However, there currently exists no agreed industry forum or defined procedures for CBR development. Investigation of best practices for the development of UAM CBRs was identified by NASA and the FAA NextGen Office as a research need.

In collaboration with seven industry partners, NASA participated in a series of simulations that investigated elements of the envisioned UAM operations, with a primary focus on Strategic Conflict Management (SCM). The development and conduct of cooperative UAM simulations with seven industry partners provided a unique opportunity to investigate CBR development practices. Development of CBRs for the UAM SCM simulations was conducted in parallel with simulation capability development and was closely related to requirements definition for the simulations. As such, the CBR development effort presented herein had two objectives: explore CBR development practices in collaboration with the industry partners and develop an initial set of UAM CBRs to support simulation requirements definition and development.

Consensus was achieved among NASA and the industry partners on 24 CBRs that were developed to support the cooperative simulation operations across five topic areas: General (related to test requirements), Operational Intent, Conformance Monitoring, Demand Capacity Balancing, and Airspace Constraint Management. Additional topic areas and CBRs were discussed but were deemed outside the scope of the simulation; these are included in the appendices.

A collaborative, iterative process was employed for developing the CBRs engaging both NASA and Industry; because CBR development is envisioned to be community-driven, opportunities were sought that provided industry partners leadership roles in developing CBRs. The following key observations and recommendations may aid the UAM industry in future CBR development efforts:

- The lack of a defined process proved challenging initially. Stakeholder engagement in the early stages of CBR development was intermittent and may have been due to the lack of a clear definition of roles and responsibilities of those involved in the effort.
- Industry leadership of CBR topic areas proved successful. Discussions in these topic areas were engaging, with alternate viewpoints freely discussed and detailed CBRs resulting. This points to the importance of identifying the best-suited leadership in technical areas for CBR development.
- Discussions within a CBR topic area were typically dominated by only a few participants. Whereas all industry partners contributed to CBR development, within each topic area, technical leadership was evident even when not formally established. This observation may indicate that smaller, focused groups may be more effective in initial CBR development than an open forum or large standards development effort (although both maybe required prior to FAA review and approval for some CBRs).
- Identifying suitable forums for initial UAM CBR development and identifying the most effective industry participants and leadership will be crucial for successful CBR development. Although the operational need for UAM CBRs may not be immediate, establishing the forums and leadership to define the processes for CBR development is a prudent early step to UAM realization.

# Table of Contents

# 1. Introduction

## a. Purpose

This memorandum documents the methods and outcomes of a joint effort between NASA and seven Urban Air Mobility (UAM) industry partners to develop Community Based Rules (CBRs) for the conduct of a series of experiments investigating strategic conflict management for UAM operations. To focus this document on the CBRs (their development, results and lessons learned), background on UAM in general and the Strategic Conflict Management (SCM) Simulation (X4) will be brief. Those unfamiliar with UAM and X4 are encouraged to read the documents cited in those sections for more detail.

This memorandum is organized as follows: Sub Sections 1.b and 1.c provide brief overviews of the UAM airspace environment and the SCM study, respectively, to illustrate the need for a common set of UAM operating practices. The general purpose of these practices, called Community Based Rules (CBRs), will then be discussed in Section 2, along with a proposed categorization of CBRs. Section 3 details the specific objectives of CBRs for the SCM study and describes the processes NASA and its industry partners used to develop them. A brief overview of the CBRs resulting from this process, along with two examples, are presented and discussed in Section 4. The memorandum closes with observations and lessons learned (Section 5) from the CBR development effort and discussion of potential paths forward (Section 6). The appendices include the catalog of all CBRs developed and discussed during this effort.

## b. Background

### *i. Urban Air Mobility (UAM) Overview*

UAM is an envisioned air transport concept to move high volumes of passengers and cargo in the urban environment. UAM will utilize new vehicle types (e.g., electric Vertical Takeoff and Landing, eVTOL), that address the noise, safety, and security requirements of high-density air traffic operations at low altitudes in the urban environment. UAM operations are envisioned to be coordinated through a federated system of operators and services, relying on a common understanding of the operating environment, aircraft states and intent, as well as rules governing the interactions between operators, aircraft, and services. The FAA NextGen Office and the NASA AAM Project have proposed Concepts of Operation [1,2] to meet the intermediate and long-term needs of UAM, respectively. The NASA Air Traffic Management – eXploration (ATM-X) UAM Subproject supports the National Campaign (NC) by conducting simulation activities with NC-1 airspace partners where they demonstrate their capabilities for UAM airspace management in preparation for the NC flight tests.

### *ii. Strategic Conflict Management Simulation (X4) Overview*

The fourth in a series of studies investigating UAM concepts and requirements, X4 is focused on the Strategic Conflict Management (SCM) element of the UAM operations. SCM is the first layer of Conflict Management (CM) [3], aimed at reducing the need for tactical conflict management (i.e., separation provision and collision avoidance), and includes airspace organization/management, traffic synchronization and demand/capacity balancing (DCB). Airspace organization and management in X4 is consistent with the concept outlined in [1], utilizing 'corridors' in Class B airspace that contain UAM tracks and providing a well-defined network of routes where UAM operations are to occur. The design of corridors in the X4 study met two high-level criteria: 1) establish routes connecting UAM vertiports identified in previous work [4], and 2) minimize interaction with existing air traffic. The latter criterion was accomplished by analyzing air traffic data in the Dallas/Fort-Worth area in relation to proposed locations for corridors connecting vertiports [5]. The X4 simulation activities aimed to collaborate with the industry in developing and testing a set of initial UAM airspace capabilities, so that the results and findings can help inform future ConOps and standards development. Investigation of CBR development practices in the X4 simulation supports the goal of informing future Concepts of Operation and potentially UAM standards development. [6]

# 2. CBR Overview

This section provides a very brief overview of the purpose and categorization of CBRs. The reader is encouraged to review [7] for a more in-depth description of CBRs, considerations for their development, and how government regulators (e.g., Federal Aviation Administration) and industry might interact to develop, review and administer UAM CBRs.

### a. Purpose

Community Based Rules (CBRs) are business rules agreed upon by relevant stakeholders and coordinated, qualified and/or approved by regulatory authorities as appropriate. They reflect agreement across UAM industry stakeholders regarding specific elements and interactions, including the manner in which they will be conducted and governed.[7]

### b. Categorization

Before development of CBRs that capture agreement on how UAM operations are to occur, there must be agreement on how such CBRs will be developed, reviewed, approved, updated, and retired. Thus, two broad categories of CBRs were proposed: Administrative and Operational, as well as a further decomposition of related CBRs into groups hereafter referred to as *CBR Topic Areas*.

#### *i. Administrative CBRs*

Administrative CBRs address how CBRs will be developed, reviewed, approved, modified, and retired when they are replaced or no longer needed. Additionally, administrative CBRs may define minimum expected content for operational CBRs. Because administrative CBRs will detail review, approval, and administration, they will need to be developed prior to operational CBRs.

#### *ii. Operational CBRs*

As stated in [7], "Operational CBRs are those that reflect agreements on the direct conduct of operations, rather than focusing on the management of the CBRs themselves. At their heart, they concentrate on actions, exchanges, and rules to ensure overall service expectations and needs are met."

#### *iii. CBR Topic Areas*

CBRs will cover a broad range of elements and interactions across UAM domains. Grouping CBRs into related topic areas may be useful to help UAM industry allocate development of CBRs more effectively. Additionally, it may not be efficient to review CBRs individually, but rather to do so as a set of closely related CBRs that address a specific capability (e.g., Demand Capacity Balancing). This aggregated view allows one to evaluate the interactions and consequences of the related CBRs.

## 3. X4 CBR Development

Early discussions between NASA and NC Airspace industry partners demonstrated a lack of understanding on CBRs as proposed in the FAA and NASA UAM ConOps documents. Although there was general agreement that CBRs would be necessary to ensure effective coordination between operators, it was less clear what the scope of CBRs would be, how they would be developed, what content they would contain, and by what processes and by whom they would be reviewed and approved. With the objective of preparing for NC flight activities, SCM X4 provided a unique opportunity for NASA to explore CBR development with the UAM industry partners.

### a. Objectives

The primary objective of the SCM X4 CBR development effort was to explore the CBR development process with the NC airspace partners toward a better understanding of future CBR development for UAM operations in the NAS. The secondary objective was to develop CBRs that would define operating practices in the X4 simulation and guide requirements development for the same; the authors acknowledge that the CBRs presented herein are in the limited context of the X4 simulation and that much work remains to build consensus within the broader UAM community toward CBRs for administrative and operational implementation.

### b. Scope

Development of X4 CBRs was limited to those needed to model and simulate strategic conflict management in a federated service architecture, specifically, those technical and procedural elements required of the UAM airspace service providers detailed in the SCM X4 scenarios [6]. NASA and NC Airspace partners identified, but did not engage in detailed discussion on, several out-of-scope topics that may require CBR development; these are included in Appendix A.3 for reference.

### c. Approach

A significant challenge to developing UAM CBRs is the lack of an agreed upon industry-led forum and thus a defined CBR development process. Whereas many processes that would be required for CBR development are beyond the scope of this effort (e.g., regulatory review and approval requirements), X4 provided an opportunity to explore CBR development while building consensus among NASA and industry partners on how to accomplish the objectives of the SCM X4 Simulation. Due to software development and simulation schedules, it was not practical to complete CBRs prior to simulation planning and development. Thus, a parallel approach to simulation planning and development with CBR development was employed. SCM X4 scenarios and objectives broadly defined the CBR topic areas and the discussion of each CBR topic area was phased to support the simulation software development schedule. A collaborative approach was used to iteratively refine CBRs through increasingly detailed discussions at biweekly meetings between NASA and NC Airspace Partners. Table 1 provides the steps involved in that iterative process.

**TABLE 1: X4 CBR DEVELOPMENT PROCESS**

| |
|---|
| 1. Conceptualize proposed X4 capabilities for meeting Scenario/Sprint objectives |
| 2. Discuss capability implementation options – function, roles, responsibilities |
| 3. Evaluate implementation details in assessing alternatives – e.g., development requirements |
| 4. Form consensus on approach for X4 implementation |
| 5. Draft CBR to capture developing consensus |
| 6. Propose Generalized CBR that captures consensus without prescribing solution |
| 7. Revise/Refine CBR, rationale language through informal comment adjudication until consensus is achieved (*or lack of strong objection and agreement on X4 implementation*) |

Steps 1-4 focus primarily on the X4 simulation objectives to meet specific scenario and/or 'Sprint[1]' objectives (e.g., 'What are the Operational Intent requirements to meet X4 strategic conflict management needs?'). The goal of the discussions in steps 1-4 were to come to general agreement within the X4 team (NASA and industry partners) as to what capability should be implemented in X4 (within resource and schedule constraints) that effectively meets the objectives of the simulation scenario. For example, in response to the question posed above, a general agreement reached after Step 4 might be "Operational Intent should be shared with the PSU[2] network, should contain estimated times (departure, arrival and key points between), and should only be accepted if it meets airspace requirements (e.g., corridor bounds, speed restrictions, etc.), and complies with capacity restrictions." Through Step 4, the discussions did not directly consider how capabilities may be captured in one or more CBRs.

The capabilities identified at the conclusion of Step 4 represent a notional agreement between NASA and industry partners. Steps 5-7 formalize and generalize that agreement in one or more CBRs using a simple template to encourage expression of different viewpoints and stimulate discussions toward a more formal agreement on CBRs for the topic area. Of note, Step 5 was included to remove X4-specific implementation details from the CBR description. The objective here was to develop CBRs for X4 that might also form the basis for further CBR development for UAM operations in the NAS thus separating the agreement from the X4 implementation details. Key elements of the X4 CBR template were: 1) the generalized CBR description, 2) the rationale for the CBR in the general UAM context, and 3) the X4 implementation details (used to inform X4 software development requirements). Figure 1 shows a sample CBR presented in collaborative discussions.

[1] 'Sprint' in the context of the SCM X4 effort refers to a defined set of simulation and test capabilities. X4 activities are organized as sprints to focus and phase development efforts into smaller efforts, aiding software development, communication with partners, and simulation capability testing.

[2] A PSU is an entity that provides services to the UAM Operator to help them meet UAM operational requirements that enable safe, efficient, and secure use of the airspace. Multiple PSUs employed by different operators will be part of a 'PSU network' and subject to interoperability requirements.[1]

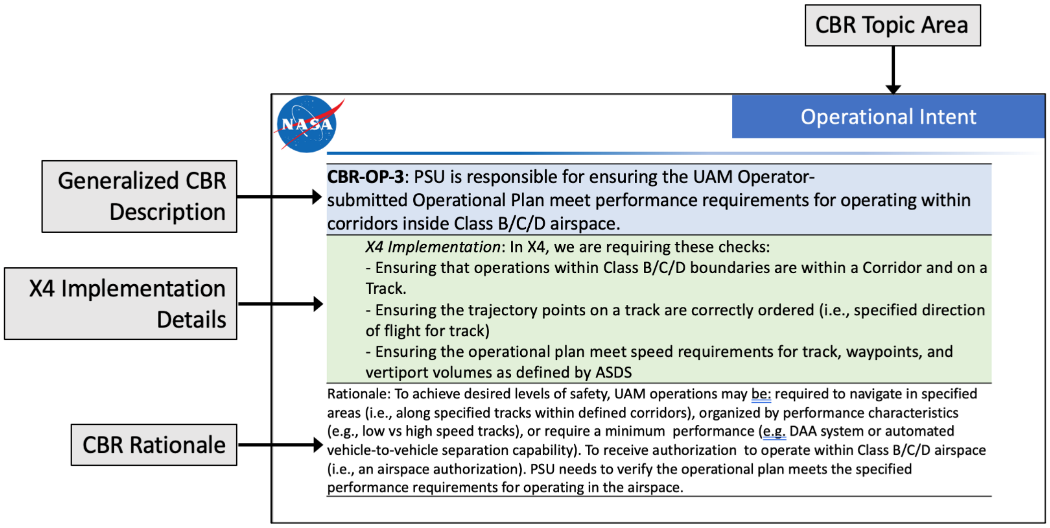


FIGURE 1: CBR TEMPLATE AND SAMPLE CBR[2]

CBR development was driven by the software development and testing schedule. For each software sprint, one or more CBR topic areas were discussed. A total of seven CBR topic areas were identified: General (related to sprint test requirements), Operational Intent, Conformance Monitoring, Demand Capacity Balancing (DCB), Airspace Constraint Management (ACM), Go-Arounds, and Emergency Management. Schedule and resources did not allow for software implementation of the 'Go-Arounds' or 'Emergency Management' topic areas, and consensus was not achieved on CBRs for these topic areas. The candidate CBRs included in Appendix A for these topic areas are the result of work through 'Step 5' of the process summarized in Table 1. To track CBR status and allow more time to build consensus when necessary while progressing to following topic areas in line with the software development schedules, CBRs in all stages of development were maintained in a catalog for all X4 participants. This catalog (Appendix A) was maintained in a spreadsheet and used to track CBR status in three worksheets/tabs: finalized (CBRs with consensus achieved), candidate (draft CBRs currently under development), and 'parking lot' (those deemed out of scope for X4, but possibly of future interest). The CBR catalog was also used to collect comments on individual CBRs as well as new candidate CBRs. Newly proposed CBRs and comments were reviewed and adjudicated at following biweekly discussions with all X4 participants until consensus was achieved.

NC Airspace Partners were encouraged to take a lead role in developing CBRs for topic areas where they had either expressed an interest in doing so or were a recognized leader/contributor in the field outside their participation in NC. Two partners answered the call: Metron led DCB CBR development (and offered a DCB service to other participants that was compliant with the finalized DCB CBRs) and Unmanned Experts led development of ACM CBRs leaning on their expertise in the areas of public-safety/emergency-response operations.

As agreement on X4 capabilities came into focus and consensus was developed for CBRs in a topic area, software development activities accelerated. One or more simulation participants developed software implementations intended to meet the CBRs for a topic area. For the collaborative simulations to be a success in the federated environment, CBR implementations needed to be correct. Concurrent with CBR refinement, NASA developed (sprint) test procedures to ensure implementations of the finalized CBRs were correct in preparation for participation in following X4 sprint tests and collaborative simulations.

## d. CBR Testing

As proposed in [7], CBRs may consist of both a human-readable format similar to the description and (possibly) the rationale presented above in Figure 1, as well as a digital expression of that CBR for testing and operational implementation. The form and specific function of the latter are not well understood at this time and will largely be dictated by regulatory review/approval processes. Although development of digital expressions of CBRs was not an objective of this effort, by nature of the X4 system requirements tracing to CBRs (and due to the phasing of CBR development with the software sprint testing schedule), airspace partner and NASA implementations of the CBRs were tested and (manually or automatically) verified as a requirement for participation in the X4 collaborative simulations. All seven partners and NASA passed all sprint tests, verifying correct implementation of the CBRs. The reader is referred to [6] for a description of X4 Sprint testing. A sample test procedure is included in Appendix C.

# 4. Example X4 CBRs

The X4 CBR development effort resulted in agreement on 24 CBRs across five topic areas. An additional seven CBRs remained in candidate (draft) form and 15 were deemed out of scope for X4. Two examples of finalized X4 CBRs are provided in this section: the complete set of 24 CBRs that were finalized according to the process previously outlined are presented in Appendix A. The 22 additional draft and out-of-scope CBRs are included for reference in the CBR catalog (Appendix B). Because X4 CBR development was driven by topic areas related to simulation scenarios, with one exception (onboarding requirements), Administrative CBRs were not addressed. The two following subsections provide the agreed-upon descriptions, rationale, and X4 Implementation details for two CBRs for which consensus was achieved. CBRs are presented by 'Topic Area' and identified by a unique CBR identifier (e.g., the first CBR in the 'Conformance Monitoring' topic area would be identified as CBR-CM-1). Attempts were made to generalize the CBR descriptions to enhance their utility beyond this effort, but it is noted that they were developed in the context of supporting the SCM X4 simulation and did not include input from those outside the X4 participant group. While it is hoped these CBRs may form the basis for continued work toward CBRs for UAM operations in the NAS, it is acknowledged that these are incomplete and require input from a broad group of additional UAM stakeholders to achieve that goal. In the following examples (and Appendix A), 'Author Commentary' (where included) is not part of the CBR and is provided by the authors for additional context of the development and/or implementation of the CBR.

## *a. Example Administrative CBR*

**Topic Area**: General (Onboarding Requirements)
**Topic Area Lead**: NASA UAM-SP
<u>Identifier</u>: CBR-GEN-1

<u>Description</u>: The PSU should meet onboarding requirements to participate in the PSU Network

<u>Rationale</u>: Security and Authentication are required for the PSU Network, due to the safety-critical nature of the operational plan, and due to the system's connectivity to FAA systems (which will include its own onboarding process).

<u>X4 Implementation Details</u>: For X4, we are requiring PSUs to successfully complete the following tests:
-For Scenario 1 Collaborative Sim: Connectivity, Operational Intent, Nominal Flight, Authorization, and Strategic Conflict Management
-For Scenario 2 Collaborative Sim: All Scenario 1 Requirements + Constraints and Operation Modification
-For Scenario 3: All Scenario 2 Requirements + Go-Around Operational Modification

Author Commentary: This CBR provides a good example of the role generalization plays in the formation of many of the X4 CBRs. The description makes no mention of specific onboarding requirements for PSUs, simply that those requirements will need to be met. The rationale provides the reason (safety/security) for this requirement, but again provides no details on that onboarding process. Finally, the X4 implementation details specify which tests need to be completed to meet the intent of this CBR for X4. The detailed test procedures are documented elsewhere and made available to test participants in advance of onboarding/testing. A sample test procedure is included in Appendix B. Although CBR generalization affords architectural flexibility, it is noted that this places much of the detailed work required to realize a functionality elsewhere; As UAM matures, it is expected CBRs may become substantially more detailed to reflect the increased knowledge and consensus of operators and stakeholders.

*b. Example Operational CBR*

**Topic Area**: Conformance Monitoring (CM)

**Topic Area Lead**: NASA UAM-SP

Identifier: CBR-CM-2

Description: PSU should set the state of the operation plan from 'Activated' to "Non-Conforming" based on horizontal, vertical, and time deviations from the Operation Intent.

Rationale: Maintaining safety in UAM depends on an accurate picture of the intent for all operations. To this end, deviations from operational intent must be recognized in a timely manner and communicated to the PSU network.

X4 Implementation Details: For X4, we are requiring 1500 ft lateral and 250 ft vertical within 60 seconds of the ETA. The X4 performance values are applied to discrete operational intent points (vertiport, corridor entry point, corridor exit point), the suggested requirements ensure there is at least one point within the time bounds that is within the horizontal and vertical limits.

Author Commentary: Lengthy discussions on the definition and role of conformance monitoring for UAM preceded the development of CBRs for the same. Initial disagreements about the need for continuous, along-path conformance monitoring (similar to Required Navigational Performance conformance monitoring), instead of at the discrete points likely to be used for operational planning and demand capacity balancing, delayed building consensus on this CBR. Consensus was only achieved when the CBR description was generalized to basic principles and the rationale free of implementation-specific details. The finalized CBR left open the possibility for implementations that were true to a trajectory-based system but did not over-specify the simple conformance monitoring needs of initial strategic conflict management capability being investigated in X4.

# 5. Observations and Lessons Learned

The objectives of the X4 CBR development effort were twofold: 1) explore and learn about the CBR development process toward recommendations for future development of CBRs for UAM operations in the NAS, and 2) support X4 software requirements development through targeted CBR development. Without a priori criteria to evaluate the utility of CBR development to support software requirements development, an a posteriori criterion of simulation success may suffice. On this metric, the effort should be rated a qualified success. While each of the eight NC X4 participants passed all eight Sprint Tests verifying CBR implementation, five of eight participants fully completed the Scenario 1 collaborative simulation and four of eight fully completed the Scenario 2 collaborative simulation. The remainder of the participants partially completed the collaborative sims, fulfilling a subset of the requirements. This indicates that although CBR development in support of software requirements development was successful at the individual capability level and possibly the topic area level, the integration of these capabilities to complete the collaborative simulations was not as straight-forward. This may indicate the need for additional CBRs, or possibly additional qualification/sprint testing between participants.

Perhaps more valuable than a qualitative assessment of CBR utility toward software requirements development are the observations and lessons learned from the process of CBR development itself. As previously discussed, there is no established process for developing CBRs, as well as no established approval mechanisms, the lack of which complicates the definition of an effective process for their development. The following is a summary of the key observations and lessons learned regarding the process used to develop CBRs for the SCM X4 Simulation:

- The lack of a defined process may have led to difficulties in engaging industry partners in the early stages of CBR development for X4. Early UAM development was driven by the NASA simulation team. Initial CBR topic areas (Operational Intent and especially Conformance Monitoring) took considerable time to achieve consensus. This may have been due to delving into a new process without sufficient direction or it may have (at times) been due to a deference to NASA as the X4 simulation host and evaluator of participant performance (i.e., “NASA sees it this way, so

let's just get on with it"). However, when it came time to implement the notional agreements on X4 capability, underlying disagreements became apparent and multiple CBR iterations were sometimes necessary to achieve consensus. It is hoped the steps outlined in Section 3 provide a template for development of operational CBRs, but it is acknowledged that review and approval requirements of regulatory authorities will ultimately drive the development process.
- Industry leadership of CBR topic areas proved successful. CBR development for the DCB and ACM topic areas were characterized by engaging, detailed discussions with participants freely offering alternate viewpoints on X4 capabilities and longer-term UAM needs. Although the CBRs still sometimes required multiple iterations, the results captured the depth of the problem addressed by the topic area, possibly more so than the CBRs develop in the NASA-led topic areas.
- Discussions on a topic area were typically dominated by only a few participants. Whether NASA or Industry led, discussions that framed the capability needs within a topic area were usually dominated by 1-3 participants. This is to be expected given the varied backgrounds of the participants and highlights the importance of identifying those best suited to develop CBRs in a given domain or topic area, and possibly limiting initial CBR development to a small group of key players before considering the input of those less likely to be substantially involved in drafting CBRs for a topic area.
- Identifying a suitable forum or forums for UAM CBR development and identifying the most effective industry participants and leadership will be crucial for effective CBR development. One of the motivators for UAM is the perception that the FAA is challenged to rapidly integrate new technologies and concepts into the National Airspace System. UAM, guided by CBRs, represent one potential solution to this problem- allow the nascent user community to develop the rules by which they will operate safely without significantly impacting existing NAS users. In theory this sounds like the perfect solution. The reality is that significant work must be done simply to identify how CBRs will be developed prior to attempting to form consensus within the UAM community on critical operational aspects. Productive initial steps on this journey might be: 1) identifying a suitable forum for those initial discussions to occur, even if operational CBRs may not be needed for some time, and 2) identifying early, high-priority CBR topics to exercise evolving methods and forum(s).

# 6. Next Steps

Whereas the effort documented herein may provide a template for some aspects of CBR development, it is critical that UAM industry lead this effort, as industry will be providing CBRs to the regulator(s) for review when the appropriate time comes. As noted in the preceding section, the UAM community must identify an appropriate forum or forums for the development of UAM CBRs. Early activities of such a forum might include:

- Identification of forum leadership
- Identification of sponsor or regulator participant in forum
- Identification of key industry participants, as well as participants from outside the UAM community as needed
- Development of initial Administrative CBRs to
  - Define the expected format and content of CBRs (both administrative and operational)
  - Collaborate with regulatory authorities to identify or assist in development of review and approval processes
- Identification and Prioritization of CBRs needed for initial UAM operations

Although it may be premature for the UAM industry to devote significant resources and effort toward the develop of operational CBRs, preparing for that eventuality by taking the aforementioned steps may be prudent.

The collaboration between regulators and UAM Industry, as well as the consensus that will be required within the UAM Industry will drive the form and purpose of the forum for developing CBRs. The Collaborative Decision Making (CDM) initiative may provide a template for developing CBRs as the challenge is similar: coordinating operational policies and procedures for competing entities with some common interests (e.g., efficient NAS utilization) and under the authority of a regulator that must authorize and/or approve the proposed policies and procedures. Likewise, the SWIM Industry–FAA Team (SWIFT) initiative provides an open forum for collaboration on shared information services via SWIM, leading to enhanced interoperability amongst NAS users and the FAA. Commercial Space access also required substantial coordination between competing industry entities and may additionally provide insight into effective forum(s) for CBR development. It is recommended that the UAM industry initiate reviews of the CDM and SWIFT initiatives, Commercial Space regulatory development, and other such activities toward identifying the needs of a CBR development forum.

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7. NASA/CR-2022-0015818, LSTechnologies, Introduction to Community Based Rules., October 2022.

# 8. Appendix A: Finalized X4 CBRs

This appendix presents the complete set of finalized CBRs resulting from the development process presented in Section 3. A single Administrative CBR and 23 Operational CBRs resulted from this effort and are presented below.

## a. *Administrative CBRs*

Administrative CBRs were not the focus of this effort, but while specifying requirements for participation in X4 collaborative simulations, it was recognized that verification of expected capabilities in a federated simulation architecture would be beneficial. Simulation participants, each developing software to achieve a shared objective (e.g., share operational intent with other PSUs), must rely on each other to properly implement the agreement. This CBR was aimed at levying a requirement on all participants to pass tests verifying proper implementation of the yet-to-be-developed CBRs for X4.

**Topic Area**: General (Onboarding Requirements)
**Topic Area Lead**: NASA UAM-SP
Identifier: CBR-GEN-1

Description: The PSU should meet onboarding requirements to participate in the PSU Network

Rationale: Security and Authentication are required for the PSU Network, due to the safety-critical nature of the operational plan, and due to the system's connectivity to FAA systems (which will include its own onboarding process).

X4 Implementation Details: For X4, we are requiring PSUs to successfully complete the following tests:
-For Scenario 1 Collaborative Sim: Connectivity, Operational Intent, Nominal Flight, Authorization, and Strategic Conflict Management
-For Scenario 2 Collaborative Sim: All Scenario 1 Requirements + Constraints and Operation Modification
-For Scenario 3: All Scenario 2 Requirements + Go-Around Operational Modification

Author Commentary: This CBR provides a good example of the role generalization plays in the formation of many of the X4 CBRs. The description makes no mention of specific onboarding requirements for PSUs, simply that those requirements will need to be met. The rationale provides the reason (safety/security) for this requirement, but again provides no details on that onboarding process. Finally, the X4 implementation details specifies which tests need to be completed to meet the intent of this CBR for X4. The detailed test procedures are documented elsewhere and made available to test participants in advance of onboarding/testing. A sample test procedure is included in Appendix B.

## b. *Operational CBRs*

Consensus was reached on 23 Operational CBRs across 4 topic areas: Operational Intent, Conformance Monitoring, Demand Capacity Balancing (DCB) and Airspace Constraint Management (ACM). CBRs presented below are grouped within their respective topic area, and in the order the topic areas were discussed in the biweekly meetings.
**Topic Area**: Operational Intent (OP)
**Topic Area Lead**: NASA UAM-SP
Identifier: CBR-OP-1

Description: Strategic Operational Intent should include a common, minimum set of information

Rationale: Operation Plan needs to include strategic operational intent for the purposes of Demand Capacity Balancing. This information needs to be standardized and should be capable of conveying four-dimensional information about the planned flight path.

X4 Implementation Details: For X4, we are requiring:
-Origin with Estimated Time of Departure (ETD)
-Defined waypoints from ASDS with Estimated Times of Arrival (ETAs) that will be used by the operation

-Destination with ETA

Author Commentary: CBR-OP-1 represents a shift from previous X-series studies in that it specifies in the rationale that the Operational Intent should be “capable of conveying four-dimensional information about the planned flight path.” This is a departure from the volume-based reservations of prior studies and UAS Traffic Management (UTM). Revisions to this CBR from its original draft focused on X4 Implementation Details and specifically which information would meet the intent of the CBR description for X4 activities. Ultimately, the minimum information required was driven by the needs of DCB and Conformance Monitoring.

Identifier: CBR-OP-2

Description: Strategic operational Intent should be shared with all participants in the PSU network

Rationale: In order to execute strategic conflict management cooperatively, Strategic Operational Intent needs to be made available to all participants in the PSU Network.

X4 Implementation Details: For X4, will limit information sharing to only participants on the PSU network

Author Commentary: Discussions for this CBR related to the extent of sharing required by this CBR. Comments noted that some sensitive information (e.g., public safety operations) may not be suitable for sharing, that not all information is necessary to be shared, and that making Strategic Operational Intent available to other PSUs rather than sharing may be sufficient.

Identifier: CBR-OP-3

Description: PSU is responsible for ensuring the UAM Operator-submitted Operational Plan meet performance requirements for operating within corridors inside Class B/C/D airspace.

Rationale: To achieve desired levels of safety, UAM operations may be: required to navigate in specified areas (i.e., along specified tracks within defined corridors), organized by performance characteristics (e.g., low vs high speed tracks), or require a minimum performance (e.g. DAA system or automated vehicle-to-vehicle separation capability). To receive authorization to operate within Class B/C/D airspace (i.e., an airspace authorization). PSU needs to verify the operational plan meets the specified performance requirements for operating in the airspace.

X4 Implementation Details: In X4, we are requiring these checks:

- Ensuring that operations within Class B/C/D boundaries are within a Corridor and on a Track.
- Ensuring the trajectory points on a track are correctly ordered (i.e., specified direction of flight for track)
- Ensuring the operational plan meet speed requirements for track, waypoints, and vertiport volumes as defined by ASDS

Author Commentary: The need for this CBR was identified by the NASA software development team noting lack of traceability of an airspace authorization system requirement to any identified CBR.

Identifier: CBR-OP-4

Description: Performance requirements to operate within UAM corridors (or other airspace designated for UAM operations) shall be imposed only when necessary for safety or when their absence would have a significant adverse impact on UAM operational efficiency.

Rationale: Following the principle of ‘flexibility where possible, structure where necessary,’ performance requirements for operating within airspace designated for UAM should only be imposed where necessary to ensure safety or maintain desired level of operation efficiency of the UAM system. Additional CBRs may identify necessary performance requirements on UAM operations and a rationale demonstrating their necessity.

X4 Implementation Details: In X4, ASDS will prescribe performance requirements (detailed in CBR-OP-3) for UAM operators to ensure Operational Intent is contained within the prescribed corridors in B/C/D airspace, and along prescribed tracks within these corridors. Additionally, speed restrictions may be prescribed for some tracks and waypoints to ensure simulation objectives are met (i.e., exercising DCB functionality).

Author Commentary: CBR-OP-4 reflected a preference among some participants to only impose restrictions on UAM operations when necessary and defaulting to a position of flexibility and accommodation. Also of note, the comments for this CBR were forward-looking recognizing dynamic restrictions envisioned in the NASA and FAA ConOps documents would likely require more detailed CBR development.

Identifier: CBR-OP-5

Description: PSU is responsible for ensuring the UAM Operator-submitted Operational Plan does not violate any airspace constraints (e.g., TFR).

Rationale: Airspace Constraints define areas where UAM (and potentially all aircraft) are not allowed to operate for a prescribed period of time. The reasons for creating Airspace Constraints are varied, but the PSU must ensure that submitted Operational Plans do not violate any airspace constraints.

X4 Implementation Details: In X4, the PSU is required to check an Operator-submitted Operational Plan for compliance with Airspace Constraints at the time of Operational Plan submission and to only accept plans without violations.

Author Commentary:CBR-OP-5 illustrates a key tenet of the UAM concept, which is to minimize burden on existing NAS users and ATC by stating that the PSU is responsible for ensuring that proposed UAM operations are only approved if they abide by all airspace constraints (including those imposed by UAM-external entities).

Identifier: CBR-OP-6

Description: The PSU is responsible for deleting any operational intents that are no longer intended to be flown, and for ensuring that only one operational intent is associated with an operation at any one time.

Rationale: Logical data integrity is required to ensure quality and correctness of operational intent data in support of many UAM functions and attributes (e.g., DCB, shared intent, conflict management, to prevent gaming, etc.). Thus, the PSU must ensure there is only one operational Intent for an operation at any time, and that Operational Intents are deleted once they are no longer necessary to support an intended operation.

X4 Implementation Details: Author Commentary: The need for CBR-OP-6 was identified by an airspace partner after CBR development for the Operational Intent topic area had nominally been completed. Multiple participants (including NASA) had implemented logic to PSU operations management to address operation deletion but had not expressed the need for a CBR to formalize the requirement. This illustrates that there may be requirements not readily identified and captured in CBRs, but that may be crucial for the safety of the system. Methods for ensuring such requirements are captured should be considered.

**Topic Area**: Conformance Monitoring (CM)
**Topic Area Lead**: NASA UAM-SP
Identifier: CBR-CM-1

Description: UAM Operator should provide position updates at a minimum pre-determined frequency to its monitoring PSU for the duration of the flight.

Rationale: In order for the PSU to conduct Conformance Monitoring, it will need surveillance on the flights. Cooperative surveillance provided via the operator (aka telemetry) will be a required input to that function. Strategically, the PSU should monitor departure times (and maybe other information).

X4 Implementation Details: In X4, we are requiring >= 0.2 Hz

Author Commentary: Commenters noted the original implementation requirements (0.2 Hz) did not allow for future UAM needs, including tactical conflict management and high-precision operations. Revisions to the CBR refined the rationale and adjusted the X4 implementation to establish a minimum update rate and indicate higher update rates may be needed and/or implemented.

Identifier: CBR-CM-2

Description: PSU should set the state of the operation plan from 'Activated' to "Non-Conforming" based on horizontal, vertical, and time deviations from the Operation Intent.

Rationale: Maintaining safety in UAM depends on an accurate picture of the intent for all operations. To this end, deviations from operational intent must be recognized in a timely manner and communicated to the PSU network.

X4 Implementation Details: For X4, we are requiring 1500 ft lateral and 250 ft vertical within 60 seconds of the ETA.

The X4 performance values are applied to discrete operational intent points (vertiport, corridor entry point, corridor exit point), the suggested requirements ensure there is at least one point within the time bounds that is within the horizontal and vertical limits.

Author Commentary: Lengthy discussions on the definition and role of conformance monitoring for UAM preceded the development of CBRs for the same. Initial disagreements about the need for continuous, along-path conformance monitoring (similar to RNP conformance monitoring) instead of at the discrete points likely to be used for operational planning and demand capacity balancing delayed building consensus on this CBR. Consensus was only achieved when the CBR description was generalized to basic principles and the rationale free of implementation-specific details. The finalized CBR left open the possibility for implementations that were true to a trajectory-based system but did not over-specify the simple conformance monitoring needs of initial strategic conflict management capability being investigated in X4.

Identifier: CBR-CM-3

Description: PSU should set the state of the operation plan from 'Activated' to "Non-Conforming" when no position report is provided to the PSU network for a predetermined amount of time.

Rationale: Maintaining safety in UAM depends on an accurate picture of the where the aircraft is. To this end, surveillance drops must be recognized in a timely manner and communicated to the PSU network.

X4 Implementation Details: For X4, we are requiring the PSU to set the state to "Non-conforming" if no position report has been received for 10 seconds.

Author Commentary: It should be noted the selection of 10s for this criterion was based on observed ADS-B surveillance dropouts in prior flight demonstration activities rather than from analysis of UAM surveillance needs. Further analysis would be required to determine a suitable value for UAM operations in the NAS.

Identifier: CBR-CM-4

Description: PSU shall set the state of the operation plan from 'Non-Conforming' to "Activated" when the conditions for "Non-Conforming" are not met (ref. CBR-CM-2 and CBR-CM-3)

Rationale: Because nominal operations are expected to be in conformance with their operational intent, the default state of an operation is "Conforming," and should be set as such except when any condition for the "Non-Conforming" state is met (as defined in other CBRs and supporting implementation requirements).

X4 Implementation Details: For X4, we are requiring the PSU to set the state to "Activated" if none of the criteria for setting the state to "Non-Conforming" are met. The 'contingent' state is not considered in X4, but may be in future efforts (i.e., the exclusion of 'contingent' state is not meant to imply that it is not needed or useful).

Author Commentary: CBR-CM-4 addresses the return of a non-conforming UAM operation to the conforming state. The ASTM F38 body, of which a number of the industry partners participate include an additional state (contingent) that was not modeled in SCM X4. This CBR removes any confusion about the implementation of conformance state in X4.

**Topic Area**: Demand Capacity Balancing (DCB)
**Topic Area Lead**: Metron
Identifier: CBR-DCB-1

Description: Capacity information about shared resources should be discoverable by PSUs.

Rationale: Resource owner would be responsible for defining the capacity information and making it available to PSU; as there could be different resource owners for different resources, there needs to be a way for PSU to discover how the information can be obtained.

X4 Implementation Details: In X4, the capacity information will be defined by NASA and provided to all X4 partners.

Author Commentary: This CBR stays true to the intent to be implementation agnostic; it is applicable to both federated and centralized DCB, only requiring that capacity restrictions be available to PSUs. Consideration of PSU notification of capacity changes was noted in the CBR catalog comments, but the static model of resource capacity in X4 [6] precluded the need to do so.

Identifier: CBR-DCB-2

Description: PSU should obtain capacity information from an authoritative source for each shared resource utilized by a proposed operation at the time of posting.

Rationale: There should be a single source of truth regarding capacity for each resource. The capacity information will be used by all PSUs to detect demand-capacity imbalance. The authoritative source is responsible for notifying the PSU network of any changes to capacity.

X4 Implementation Details: X4 assumes the capacity information is provided by a single authoritative source. For example, the X4 Capacity Information Service (CIS) provides capacity information about vertiports, and defines the associated capacity values (e.g., 2 operations over 12 minutes). These capacity information and values are to be used by all PSUs during the "Strategic Conflict Management" Sprint 5. The CIS in X4 will not provide notification of capacity changes because the capacity in X4 is static.

Author Commentary: Of note, this CBR only requires that resources must have a single source of capacity information; one capacity information source may cover multiple resources, but each resource may only have a single authoritative source for consistent capacity identification by DCB.

Identifier: CBR-DCB-3

Description: PSUs is responsible for obtaining information pertaining to shared UAM resource use by other operations in the airspace in support of demand capacity balancing.

Rationale: Estimating demand on shared resources requires identification of operations using those resources as well as ETAs for those operations at the shared resources. Relevant operations include those managed by other PSUs on the PSU network (where applicable).

X4 Implementation Details: (NASA) In X4, relevant operations are defined as operations that are using the same shared resources, and PSUs shall obtain the latest information about those operations via DSS. PSUs should do this via subscriptions using DSS for the intended area(s) of operation and not via operational volume.

Author Commentary: Feedback from industry partners was instrumental in revising the draft CBR to be more implementation agnostic and allow for PSU obtaining information about relevant operations without the assumption of the X4 implementation (DSS) and likewise without excluding the possibility of a DSS implementation.

Identifier: CBR-DCB-4

Description: PSU shall use estimated demand for shared resource consistent with how capacity is defined by the authoritative source of capacity information for each resource.

Rationale: Consistent application of shared resource capacity constraints requires common definitions of demand and capacity be applied by all PSUs and DCB services. The resource owner defines capacity and thus the metric through which demand is derived for each resource (provided as part of the provision of capacity information by the authoritative source, see CBR-DCB-2).

X4 Implementation Details: In X4, the demand estimates will be based on the definition of demand provided by the X4 Capacity Information Service (e.g., 2 operations over 12 minutes) for each shared resource.

Author Commentary: Refinement of candidate CBR was necessary to remove ambiguity regarding demand estimation (i.e., demand is to be estimated according to the capacity definition per the authoritative capacity source).

Identifier: CBR-DCB-5

Description: PSU submitted operational plans should include information needed for DCB.

Rationale: This CBR helps identify if there are information that need to be provided in additional to those specified in CBR-OP-1, for the purpose of demand-capacity balancing. Note: If there are additional information identified, either CBR-OP-1 could be updated or we can track this as a separate, DCB CBR.

X4 Implementation Details: For X4, information included in the operational plans to support DCB include vertiport departure and arrival ETAs.

Author Commentary: The X4 implementation of this CBR is redundant with CBR-OP-1; both implementations require the information needed for DCB. However, the general form of the CBR-DCB-5 description allows for resource constraints that may require additional info and may not be required of all UAM operations (i.e., those that do not plan to use that resource). For this reason, the CBR was retained in the finalized list even though it was not needed for X4.

Identifier: CBR-DCB-6

Description: PSUs are responsible for ensuring submitted operation plans meet all applicable DCB resource constraints.

Rationale: The PSU is the assumed entity for ensuring shared resources meet DCB constraints. The operation plans should only be submitted by PSU to the PSU network when there is no violation of these constraints. This does not imply that the PSU is required to perform DCB itself (services may be employed), just that it is responsible for ensuring DCB constraints are met. In X4, we are assuming PSU will perform the DCB itself or utilize a service made available to its PSU.

X4 Implementation Details: For X4, the applicable DCB constraints will be applied as flow capacity constraints at vertiports only and in the form of N operations per M minutes. X4 capacity at each vertiport will be provided by the Capacity Information Service (CIS) and will be uniform for all vertiports at 2 operations per 12 minutes based on 10 operations per hour (arrivals + departures).

Author Commentary: CBR-DCB-6 provides another example of an implementation-agnostic CBR description. Unique to this CBR though, is that the SCM X4 simulation included more than one implementation to meet the intent of CBR-DCB-6. First, as NASA initially proposed, DCB is a function of the PSU, so not only is the PSU responsible for ensuring operations are compliant with DCB restrictions, the PSU also performs the computations to determine if that is the case. Alternatively, a DCB service implementation was also available to PSUs that performed the DCB computations. Participants were left to decide which implementation approach made the most sense for their PSU. CBR-DCB-5 captures the true requirement that, independent of where DCB computations occur (whether internal to a PSU or as part of a DCB service), the PSU is responsible for ensuring that submitted operation plans meet the DCB requirements.

Identifier: CBR-DCB-7

Description: PSU shall apply same rules in considering uncertainty when detecting capacity-demand imbalance.

Rationale: Demand has to be estimated according to the definition of operational demand that the capacity source constrains, including how uncertainty is defined. Doing otherwise would result in comparing apples (capacity) and oranges (demand).

X4 Implementation Details: Uncertainty about operations not accounted, using submitted ETAs without buffers to estimate / predict demand

Author Commentary: CBR-DCB-7 is intended to be consistent with CBR-DCB-4 and simply expands on the capacity-source driven demand estimation to require that any treatment of uncertainty in demand estimates for the purposes of DCB must be that treatment defined by the capacity source. No operational uncertainty was modeled or considered in X4. A thorough treatment of the definition of capacity and method of demand estimation in CBR-DCB-4 may render this CBR redundant.

Identifier: CBR-DCB-8

Description: PSUs submitted operational plans should adhere to nominal scheduling rules when a predicted demand-capacity imbalance exists on a shared resource.

Rationale: To promote efficiency and fairness, PSUs should have a common method of identifying which operation(s) would be modified when there is a predicted demand-capacity imbalance.

X4 Implementation Details: The nominal rule applied is First-Requested, First-Served. DCB in X4 shall only be applied to operations prior to departure.

Author Commentary: CBR-DCB-8 illustrates the cross-topic nature that is inevitable with some CBRs. DCB itself is not explicitly considered with scheduling logic, but application of delay or schedule adjustments resulting from predicted capacity shortfalls require agreed-upon scheduling rules and prioritizations to ensure fairness (and possibly to prevent gaming between PSUs). For simplicity, the X4 implementation employs a first-requested, first-served prioritization. Other prioritization schemes should be considered for UAM (e.g., optimization, market-based, etc.).

Identifier: CBR-DCB-9

Description: PSUs submitted operational plans should adhere to a set of allowable resolution strategies for a specific operation when a demand-capacity imbalance is detected.

Rationale: PSUs should use the same or complementary set of strategies to resolve demand-capacity imbalance to ensure the resolutions promote fairness and equity.

X4 Implementation Details: All demand-capacity resolution strategies are allowed, subject to the constraints of the airspace.

Author Commentary: CBR-DCB-9 is the result of an acknowledgement that when resource competition occurs, competing interests may result in counterproductive actions from a system perspective. Given the requirements of equity and fairness in allocation of NAS resources, it may be necessary to enumerate allowable DCB resolution strategies. However, no such limitations were imposed in X4 simulations.

Identifier: CBR-DCB-10

Description: PSUs should record and submit data elements to authorities for purposes of audit under the terms defined by the authority.

Rationale: For the purposes of auditing for efficiency and fairness, data may be specified by relevant authorities, that must be recorded by PSUs and submitted when requested.

X4 Implementation Details: PSULogset should be submitted by the PSU to NASA.

Author Commentary: CBR-DCB-10, like CBR-DCB-9, acknowledges the potential for counterproductive actions in a resource-limited environment and recognizes the utility (and possible requirement from regulators) to have audit capability of DCB actions.

**Topic Area**: Airspace Constraint Management (ACM)
**Topic Area Lead**: Unmanned Experts
Identifier: CBR-ACM-1

Description: The airspace regulatory authority (FAA), through an appropriate interface (e.g., FIMS/FIDXP) shall have sole authority for approval of EXTRINSIC UAM airspace constraints. At the discretion of the regulator, and through appropriate approval mechanisms, other UAM entities may be permitted to declare and submit UVRs/ACMs under conditions and procedures defined in LOAs or policies.

Rationale: EXTRINSIC UAM ACM factors are those that impact the safety, capacity, or flow of the UAM system outside of the natural ability of the system to compensate for minor disruptions, which are Considered INTRINSIC UAM ACM factors (see CBR-ACM-1B). Examples of EXTRINSIC factors include vertiport closures, wide-area airspace closures impacting vertiport access, wide-scale network outages (e.g., GPS, power, CNS), and traditional FIMS ACMs such as TFRs etc.

While the airspace regulator retains sole authority over airspace where UAM operations occur (including approval/creation of constraints impacting that airspace), UAM may benefit from the regulator permitting other entities to create airspace constraints in some EXTERNAL instances. The conditions under which the regulator permits other entities to create airspace constraints would need to be detailed in Letters of Agreement (LOAs) or other (policy) documents

X4 Implementation Details: For X4, only those PSUs with the scope utm.constraint_management have authorization to create and share Airspace Constraints; only the NASA PSU will have this authority/scope.

> Author Commentary: CBR-ACM-1 and CBR-ACM-2 are the result of lengthy discussions on who has the authority to create airspace constraints with the UAM environment and under what conditions. These two CBRs were initially drafted as a single CBR that missed an important distinction between airspace constraints that were the result of external-to-UAM factors (e.g., a Temporary Flight Restriction imposed by the regulator) and those that were the result of factors within the UAM environment (e.g., UAM vertiport configuration change). The missing distinction is that some of the latter type had the potential to impact legacy NAS operations and should thus include external entities in creation of ACMs to address these factors. Thus, the concept of extrinsic and intrinsic UAM airspace constraints was proposed. Those factors that could be managed within normal UAM compensation mechanisms (i.e., they do not impact any operations outside the UAM environment) are intrinsic UAM airspace constraints. Those with the potential for impacting operations outside the UAM environment are deemed extrinsic UAM airspace constraints, even if the factor requiring their creation are purely internal to the UAM environment (e.g., closure of a UAM vertiport leading to diversions of UAM outside the UAM environment). CBR-ACM-1 considers the authority and mechanisms for creating extrinsic UAM airspace constraints; CBR-ACM-2 does the same for intrinsic UAM airspace constraints. The language of CBR-ACM-1 description was revised several times to reflect what is understood to be correct terms indicating the sole authority of the regulator to create/approve airspace constraints, while capturing the need/benefit of allowing other entities to declare/request their creation under pre-determined conditions (e.g., according to terms of an LOA).

Identifier: CBR-ACM-2

Description: Appropriate authorization is required for PSUs and other UAM network entities, to create or share INTRINSIC UAM ACMs across the UAM network.

Rationale: Rationale: INTRINSIC UAM ACM factors are those that impact the safety, capacity, or flow of the UAM system within the natural ability of the UAM system to compensate for such minor disruptions, Examples of INTRINSIC factors include vertiport restrictions, local-area airspace closures not unduly impacting vertiport access, local network outages (e.g., loss of relay station or PSU). These disruptions should be catered for by the various elements of the UAM network to include ASDS, AA, DSS and DCB.

X4 Implementation Details: For X4, only those PSUs with the scope utm.constraint_management have authorization to create and share Airspace Constraints; only the NASA PSU will have this authority/scope.

Author Commentary: see CBR-DCB-ACM-1

Identifier: CBR-ACM-3

Description: Upon notification of an airspace constraint, (for any impacted operation) PSU shall obtain, in a timely manner, and in accordance with prioritization ensuring safe airspace avoidance for all impacted operations, a revised Operation Plan that circumvents all ACM, EXTRINSIC and INTRINSIC, (and shall share the revised Operational Plan with the PSU network per CBR-OP-2).

Rationale: A new airspace constraint may impact already accepted, and in some cases airborne, operations. To prevent violations with airspace constraints that may present a safety hazard to the UAM operation and others, the operation plan must be revised to circumvent the new airspace constraint (as well as any others). Timely in this context means 'with sufficient time to ensure the airspace constraint can be avoided' or (if already in violation) 'as soon as practical to expeditiously exit the airspace constraint volume'.

X4 Implementation Details: For X4, a revised Operational Plan must be obtained no later than TBD minutes prior to predicted violation of airspace constraint. No prioritization between operations being managed by different PSUs is required. Further, NASA is not prescribing a solution regarding how a revised Operation Plan is obtained, as it falls under the Operator-PSU interface. Likewise, each partner may determine if/how prioritization within its set of managed operations is employed.

Author Commentary: CBR-ACM-3, in the event that an airspace constraint impacts an operation (e.g., an active operation is predicted to enter an airspace constraint volume), places the responsibility of obtaining a revised operational plan on the PSU. Discussions on this CBR were brief once appropriate language was agreed upon for CBR-ACM-1 and CBR-ACM-2. Ultimately, this requirement was not implemented in X4 due to challenges with synchronization in the simulation environment, and thus the (tentative) time criterion of 3 minutes was not finalized.

# 9. Appendix B.1: CBR Catalog- Finalized CBRs

| ID | Name/Org | Focus Area | Description (Required) | Rationale (Required) | X4 Implementation(s) (Required) | Notes & Comments (Optional) |
|---|---|---|---|---|---|---|
| Candidate CBR Number | Originating organization | (1) Operational Intent<br><br>(2) Conformance Monitoring<br><br>(3) Strategic Conflict Management<br><br>(0) Other | Description or definition of candidate CBR. | Rationale for need of candidate CBR. Include cost and benefits considerations where possible. Include impacts to effectively implementing the CBR. | X4 Implementation notes: Details on how this CBR will be met in X4? | Comments welcome. (Comments are retained after consideration and CBR refinement to provide context for current CBR language.) PLEASE USE RED FONT FOR ANY NEW COMMENTS REGARDING FINALIZED-CONSENSUS CBRs |
| CBR-GEN-1 | NASA | 0 | The PSU should meet onboarding requirements to participate in the PSU Network | Security and Authentication are required for the PSU Network, due to the safety-critical nature of the operational plan, and due to the system's connectivity to FAA systems (which will include its own onboarding process). | For X4, we are requiring PSUs to successfully complete the following tests:<br>-For Scenario 1 Collaborative Sim: Connectivity, Operational Intent, Nominal Flight, Authorization, and Strategic Conflict Management<br>-For Scenario 2 Collaborative Sim: All Scenario 1 Requirements + Constraints and Operation Modification<br>-For Scenario 3: All Scenario 2 Requirements + Go-Around Operational Modification | |
| CBR-OP-1 | NASA | 1 | Strategic Operational Intent should include a common, minimum set of information | Operation Plan needs to include strategic operational intent for the purposes of Demand Capacity Balancing. This information needs to be standardized, and should be capable of conveying four-dimensional information about the planned flight path. | For X4, we are requiring:<br>-Origin with Estimated Time of Departure (ETD)<br>-Defined waypoints from ASDS with Estimated Times of Arrival (ETAs) that will be used by the operation<br>-Destination with ETA | Partner 1: Do we need vehicle information as part of the minimum set of information to support DCB?<br><br>Partner 2: It would be worth clarifying if an operation plan can only include specified waypoints (from ASDS), or if other points can be included as well. Particularly in class G or E, where there are no defined waypoints in ASDS, it may be beneficial for operators to still be required to define intent. One option could be include waypoints at a minimum frequency, even if not in ASDS.<br><br>"Partner 3: One component that may also need to be incorporated into the operational intent is performance information.<br>It is clear that a PSUs anticipated performance of achieving the 4D trajectory is necessary in conducting conformance monitoring, however this performance may also weigh on the inter-PSU DCB calculations.<br>In other words, will the DCB calculations rely on discrete 4D definitions (e.g., I plan to arrive at waypoint X at 12:00 PM)? Or, will it need to incorporate performance (e.g., I plan to arrive at waypoint X at 12:00 PM +/- 5 min). |

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| | | | | | | In this week's airspace partner meeting, we made good progress on the DCB interoperability flows. I think future DCB discussions should focus on how, exactly, to conduct the demand/capacity calculation. This will inform whether or not performance is required in the operational intent exchange"<br><br>NASA: EXPECT PSU/UAM Operator to meet the performance requirements defined in ASDS. Also, 'speed' is required as part of the Strategic Operational Intent information.<br>NASA: For UAM operations in Class B/C/D, the above minimum set of information is required, additional points can be included. For UAM operations in Class E/G, Operational Plans need to include, at a minimum, the arrival and departure vertiports. (For X4, navigational points can be provided for Class E / G operations, however, SCM / DCB conflicts at these navigational points are expected.) |
| CBR-OP-2 | NASA | 1 | Strategic operational Intent should be shared with all participants in the PSU network | In order to execute Strategic Conflict Management cooperatively, Strategic Operational Intent needs to be made available to all participants in the PSU Network. | For X4, will limit information sharing to only participants on the PSU network | Partner 1: Considerations about sharing sensitive information related to public safety operations will need to be accommodated here.<br><br>Partner 2: This depends on the form that strategic conflict management takes. For example, if there is a centralized DCB service, PSUs do not technically need to know other PSU intent for strategic conflict management. However, there may be other reasons that it is needed, such as situational awareness and for tactical deconfliction. Generally we agree that strategic operational intent should be shared with everyone.<br><br>Partner 3: Suggest you align the description with the rationale/discussion: op intents should be "made available" (as opposed to "shared") with all participants in the PSU network. |

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| | | | | | | NASA: Expect minimum information to be shared, not expecting sensitive information to be required but could discuss further in the future.<br>NASA: Expect strategic operational intent to be shared with other PSUs determined by the DSS, and also likely with other "ATM Operators crossing Corridor", which could include public safety and other entities. For X4, will limit information sharing to only participants on the PSU network |
| CBR-OP-3 | NASA | 1 | PSU is responsible for ensuring the UAM Operator-submitted Operational Plan meet performance requirements for operating within corridors inside Class B/C/D airspace. | To achieve desired levels of safety, UAM operations may be: required to navigate in specified areas (i.e., along specified tracks within defined corridors), organized by performance characteristics (e.g., low vs high speed tracks), or require a minimum performance (e.g. DAA system or automated vehicle-to-vehicle separation capability). To receive authorization to operate within Class B/C/D airspace (i.e., an airspace authorization). PSU needs to verify the operational plan meets the specified performance requirements for operating in the airspace. | In X4, we are requiring these checks:<br>- Ensuring that operations within Class B/C/D boundaries are within a Corridor and on a Track.<br>- Ensuring the trajectory points on a track are correctly ordered (i.e., specified direction of flight for track)<br>- Ensuring the operational plan meet speed requirements for track, waypoints, and vertiport volumes as defined by ASDS | NASA: Added this CBR for PSU checks to support airspace authorization |
| CBR-OP-4 | NASA | 1 | Performance requirements to operate within UAM corridors (or other airspace designated for UAM operations) shall be imposed only when necessary for safety or when their absence would have a significant adverse impact on UAM operational efficiency. | Following the principle of 'flexibility where possible, structure where necessary,' performance requirements for operating within airspace designated for UAM should only be imposed where necessary to ensure safety or maintain desired level of operation efficiency of the UAM system. Additional CBRs may identify necessary performance requirements on UAM operations and a rationale demonstrating their necessity. | In X4, ASDS will prescribe performance requirements (detailed in CBR-OP-3) for UAM operators to ensure Operational Intent is contained within the prescribed corridors in B/C/D airspace, and along prescribed tracks within these corridors. Additionally, speed restrictions may be prescribed for some tracks and waypoints to ensure simulation objectives are met (i.e., exercising DCB functionality). | Partner 2: Agreed. Beyond X4, how will PSUs be notified about changes in the performance requirements for a corridor? Is it a dynamic process just like for the constraints, or is it static? The role of ASDS or other entity in the notification processes will also need to be explored.<br>NASA: The dynamic use of corridor structure is beyond the scope of X4, as are the considerations that might drive such changes (e.g., wide range of vehicle performance capabilities, tactical conflict management mechanisms and related corridor exit probability, etc.). New CBRs may be needed to address management of changes to performance requirements and/or corridor/track structure. <no changes for now to CBRs> |

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| CBR-OP-5 | NASA | 1 | PSU is responsible for ensuring the UAM Operator-submitted Operational Plan does not violate any airspace constraints (e.g., TFR). | Airspace Constraints define areas where UAM (and potentially all aircraft) are not allowed to operate for a prescribed period of time. The reasons for creating Airspace Constraints are varied, but the PSU must ensure that submitted Operational Plans do not violate any airspace constraints. | In X4, the PSU is required to check an Operator-submitted Operational Plan for compliance with Airspace Constraints at the time of Operational Plan submission and to only accept plans without violations. | |
| CBR-OP-6 | Metron | 2 | The PSU is responsible for deleting any operational intents that are no longer intended to be flown, and for ensuring that only one operational intent is associated with an operation at any one time. | Logical data integrity is required to ensure quality and correctness of operational intent data in support of many UAM functions and attributes (e.g., DCB, shared intent, conflict management, to prevent gaming, etc.). Thus, the PSU must ensure there is only one operational Intent for an operation at any time, and that Operational Intents are deleted once they are no longer necessary to support an intended operation. | | Partner 2: From the current CBRs it's not clear that there is a requirement to delete any stale/errant/old operational plans, so this CBR was added to catch this case. Open for discussion as to whether it is necessary. |
| CBR-CM-1 | NASA | 2 | UAM Operator should provide position updates at a minimum pre-determined frequency to its monitoring PSU for the duration of the flight. | In order for the PSU to conduct Conformance Monitoring, it will need surveillance on the flights. Cooperative surveillance provided via the operator (aka telemetry) will be a required input to that function. Strategically, the PSU should monitor departure times (and maybe other information). | In X4, we are requiring >= 0.2 Hz | Partner 1: Can/should the update rate change depending on the class of airspace and/or other factors such as the number of aircraft in the adjacent airspace or met conditions?<br><br>Partner 3: This is an ok starting point for X4, but I imagine the frequency will have to be high in order to assure some of the tight performance tolerances that will be required in the UAM environment.<br>Suggest characterizing as >= 1Hz in case a PSU/Operator partnership wishes to have a higher frequency.<br><br>NASA: Updated CBR with ">=" to support the case when PSU / UAM Operator wishes to provide at higher frequency. More research to be done to consider other factors. |
| CBR-CM-2 | NASA | 2 | PSU should set the state of the operation plan from 'Activated' to "Non-Conforming" based on horizontal, vertical, and time deviations from the Operation Intent. | Maintaining safety in UAM depends on an accurate picture of the intent for all operations. To this end, deviations from operational intent must be recognized in a timely manner and communicated to the PSU network. | For X4, we are requiring 1500 ft lateral and 250 ft vertical within 60 seconds of the ETA.<br><br>The X4 performance values are applied to discrete operational intent points (vertiport, corridor entry point, corridor exit point), the suggested requirements ensure there is at least one point within the time | Partner 3: "The PSU should not share intent that is further than these limits." - I am not tracking with this. It will have to be explained more. "Multiple actors in the system will be involved in ensuring that the flight path is adherent to the operational intent" - I would say multiple actors CAN be involved in monitoring. However, if you want to enable this then you must include performance measures in the operational intent exchange model (see my comments above on this). The X4 performance values you identified pertain to the "path." I believe they should be applied to the operational |

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| | | | | | bounds that is within the horizontal and vertical limits. | intent points (vertiport, corridor entry point, corridor exit point, etc.). What you're suggesting is a continuous check. However, flight planning and DCB will be based on discrete points, altitudes, and time with associate tolerances. This indicates a disconnect between the operational intent definition/derivation and the conformance monitoring thereof.<br><br>NASA: Updated rationale. "Maintaining safety in UAM depends on an accurate picture of the intent for all operations. To this end, deviations from operational intent must be recognized in a timely manner and communicated to the PSU network. |
| CBR-CM-3 | NASA | 2 | PSU should set the state of the operation plan from 'Activated' to "Non-Conforming" when no position report is provided to the PSU network for a predetermined amount of time. | Maintaining safety in UAM depends on an accurate picture of the where the aircraft is. To this end, surveillance drops must be recognized in a timely manner and communicated to the PSU network. | For X4, we are requiring the PSU to set the state to “Non-conforming” if no position report has been received for 10 seconds. | |
| CBR-CM-4 | NASA | 2 | PSU shall set the state of the operation plan from 'Non-Conforming' to "Activated" when the conditions for "Non-Conforming" are not met (ref. CBR-CM-2 and CBR-CM-3) | Because nominal operations are expected to be in conformance with their operational intent, the default state of an operation is "Conforming," and should be set as such except when any condition for the "Non-Conforming" state is met (as defined in other CBRs and supporting implementation requirements). | For X4, we are requiring the PSU to set the state to "Activated" if none of the criteria for setting the state to "Non-Conforming" are met. The 'contingent' state is not considered in X4, but may be in future efforts (i.e., the exclusion of 'contingent' state is not meant to imply that it is not needed or useful). | Partner 4: Will there be a Contingent state if the operation stays in NonConforming state for some time? Based on the ASTM standards, an operation can go in Contingent state if its unable to return to Conforming within a set period of time.<br>NASA: see comments column in red. |
| CBR-DCB-1 | NASA | 3 | Capacity information about shared resources should be discoverable by PSUs. | Resource owner would be responsible for defining the capacity information and making it available to PSU; as there could be different resource owners for different resources, there needs to be a way for PSU to discover how the information can be obtained. | In X4, the capacity information will be defined by NASA and provided to all X4 partners. | Partner 4: If the capacity information for any resource changes for any reason, is the CIS service responsible for informing the PSUs of the recently updated availability of a resource that possibly could have been requested by a PSU, but because of the capacity constraint was not plan planned as a part of the operation?<br>NASA: see changes to DCB-2 rationale and X4 implementation |

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| CBR-DCB-2 | NASA | 3 | PSU should obtain capacity information from an authoritative source for each shared resource utilized by a proposed operation at the time of posting. | There should be a single source of truth regarding capacity for each resource. The capacity information will be used by all PSUs to detect demand-capacity imbalance. The authoritative source is responsible for notifying the PSU network of any changes to capacity. | X4 assumes the capacity information is provided by a single authoritative source. For example, the X4 Capacity Information Service (CIS) provides capacity information about vertiports, and defines the associated capacity values (e.g., 2 operations over 12 minutes). These capacity information and values are to be used by all PSUs during the "Strategic Conflict Management" Sprint 5. The CIS in X4 will not provide notification of capacity changes because the capacity in X4 is static. | |
| CBR-DCB-3 | NASA | 3 | PSUs is responsible for obtaining information pertaining to shared UAM resource use by other operations in the airspace in support of demand capacity balancing. | Estimating demand on shared resources requires identification of operations using those resources as well as ETAs for those operations at the shared resources. Relevant operations include those managed by other PSUs on the PSU network (where applicable). | (NASA) In X4, relevant operations are defined as operations that are using the same shared resources, and PSUs shall obtain the latest information about those operations via DSS. PSUs should do this via subscriptions using DSS for the intended area(s) of operation and not via operational volume. | Partner 3: Technically, the PSU doesn't identify relevant operations - the DSS does. Perhaps reword to something like, "The PSU shall obtain information from relevant operations pertaining to their use..."<br>NASA: The wording was intentionally vague so as to remain implementation agnostic... if the PSU needs to employ the DSS to retrieve information from other PSUs on the network, that is fine... if there is only one PSU managing operations and the PSU is able to identify relevant operations internally, that is OK as well. The CBR has been reworded to keep that intent, but to not imply the PSU is required to have that ability internally.<br><br>Partner 4: How is intended areas of operation going to be different than operational volume? Perhaps a workflow diagram for these communications with DSS and CIS Service with PSU might help understand more about each entity role when requesting for shared resources.<br>NASA: Intended areas of operation will cover all operations managed by a PSU, which could be done via subscription area(s) (e.g., covering the entire UAM area) or operational volumes. Point taken on diagram to better communicate information flow... we'll work on that. |
| CBR-DCB-4 | NASA | 3 | PSU shall use estimated demand for shared resource consistent with how capacity is defined by the authoritative source of capacity information for each resource. | Consistent application of shared resource capacity constraints requires common definitions of demand and capacity be applied by all PSUs and DCB services. The resource owner defines capacity and thus the metric through which demand is derived for each resource (provided as part of the provision of capacity information by the | In X4, the demand estimates will be based on the definition of demand provided by the X4 Capacity Information Service (e.g., 2 operations over 12 minutes) for each shared resource. | Partner 3: I don't quite follow the phrase, "...with how demand is defined by the authoritative source..." The authoritative source defines capacity (I think we're all agreed there). That capacity definition, which will likely differ from source to source, therein defines the metric through which demand is derived. Conceptually, I think we're on the same page. I bumped on this because |

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| | | | | authoritative source, see CBR-DCB-2). | | saying the AS will define demand may lead people to believe that there's a separate metric/field/etc. that the AS will share that is distinct from its capacity (I do not believe this latter part to be true). NASA: agreed... reworded to reflect capacity is defined by resource owner and specifies a metric that is used to estimate demand. |
| CBR-DCB-5 | Metron | 3 | PSU submitted operational plans should include information needed for DCB. | This CBR helps identify if there are information that need to be provided in additional to those specified in CBR-OP-1, for the purpose of demand-capacity balancing. Note: If there are additional information identified, either CBR-OP-1 could be updated or we can track this as a separate, DCB CBR. | For X4, information included in the operational plans to support DCB include vertiport departure and arrival ETAs. | |
| CBR-DCB-6 | Metron | 3 | PSUs are responsible for ensuring submitted operation plans meet all applicable DCB resource constraints. | The PSU is the assumed entity for ensuring shared resources meet DCB constraints. The operation plans should only be submitted by PSU to the PSU network when there is no violation of these constraints. This does not imply that the PSU is required to perform DCB itself (services may be employed), just that it is responsible for ensuring DCB constraints are met. In X4, we are assuming PSU will perform the DCB itself or utilize a service made available to its PSU. | For X4, the applicable DCB constraints will be applied as flow capacity constraints at vertiports only and in the form of N operations per M minutes. X4 capacity at each vertiport will be provided by the Capacity Information Service (CIS) and will be uniform for all vertiports at 2 operations per 12 minutes based on 10 operations per hour (arrivals + departures). | |
| CBR-DCB-7 | NASA | 3 | PSU shall apply same rules in considering uncertainty when detecting capacity-demand imbalance. | Demand has to be estimated according to the definition of operational demand that the capacity source constrains, including how uncertainty is defined. Doing otherwise would result in comparing apples (capacity) and oranges (demand). | Uncertainty about operations not accounted, using submitted ETAs without buffers to estimate / predict demand | |
| CBR-DCB-8 | Metron | 3 | PSUs submitted operational plans should adhere to nominal scheduling rules when a predicted demand-capacity imbalance exists on a shared resource. | To promote efficiency and fairness, PSUs should have a common method of identifying which operation(s) would be modified when there is a predicted demand-capacity imbalance. | The nominal rule applied is First-Requested, First-Served. DCB in X4 shall only be applied to operations prior to departure. | |
| CBR-DCB-9 | Metron | 3 | PSUs submitted operational plans should adhere to a set of allowable resolution strategies for a specific operation when a demand-capacity imbalance is detected. | PSUs should use the same or complementary set of strategies to resolve demand-capacity imbalance to ensure the resolutions promote fairness and equity. | All demand-capacity resolution strategies are allowed, subject to the constraints of the airspace. | |

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| CBR-DCB-10 | Metron | 3 | PSUs should record and submit data elements to authorities for purposes of audit under the terms defined by the authority. | For the purposes of auditing for efficiency and fairness, data may be specified by relevant authorities, that must be recorded by PSUs and submitted when requested. | PSULogset should be submitted by the PSU to NASA. | |
| CBR-ACM-1 | UMEX | 4 | The airspace regulatory authority (FAA), through an appropriate interface (e.g., FIMS/FIDXP) shall have sole authority for approval of EXTRINSIC UAM airspace constraints. At the discretion of the regulator, and through appropriate approval mechanisms, other UAM entities may be permitted to declare and submit UVRs/ACMs under conditions and procedures defined in LOAs or policies. | Rationale: EXTRINSIC UAM ACM factors are those that impact the safety, capacity, or flow of the UAM system outside of the natural ability of the system to compensate for minor disruptions, which are Considered INTRINSIC UAM ACM factors (see CBR-ACM-2). Examples of EXTRINSIC factors include vertiport closures, wide-area airspace closures impacting vertiport access, wide-scale network outages (e.g., GPS, power, CNS), and traditional FIMS ACMs such as TFRs etc. While the airspace regulator retains sole authority over airspace where UAM operations occur (including approval/creation of constraints impacting that airspace), UAM may benefit from the regulator permitting other entities to create airspace constraints in some EXTERNAL instances. The conditions under which the regulator permits other entities to create airspace constraints would need to be detailed in Letters of Agreement (LOAs) or other (policy) documents | For X4, only those PSUs with the scope utm.constraint_management have authorization to create and share Airspace Constraints; only the NASA PSU will have this authority/scope. | |
| CBR-ACM-2 | UMEX | 4 | Appropriate authorization is required for PSUs and other UAM network entities, to create or share INTRINSIC UAM ACMs across the UAM network. | Rationale: INTRINSIC UAM ACM factors are those that impact the safety, capacity, or flow of the UAM system within the natural ability of the UAM system to compensate for such minor disruptions, Examples of INTRINSIC factors include vertiport restrictions, local-area airspace closures not unduly impacting vertiport access, local network outages (e.g., loss of relay station or PSU). These disruptions should be catered for by the various elements of the UAM network to include ASDS, AA, DSS and DCB. | For X4, only those PSUs with the scope utm.constraint_management have authorization to create and share Airspace Constraints; only the NASA PSU will have this authority/scope. | |

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| CBR-ACM-3 | UMEX | 4 | Upon notification of an airspace constraint, (for any impacted operation) PSU shall obtain, in a timely manner, and in accordance with prioritization ensuring safe airspace avoidance for all impacted operations, a revised Operation Plan that circumvents all ACM, EXTRINSIC and INTRINSIC, (and shall share the revised Operational Plan with the PSU network per CBR-OP-2). | A new airspace constraint may impact already accepted, and in some cases airborne, operations. To prevent violations with airspace constraints that may present a safety hazard to the UAM operation and others, the operation plan must be revised to circumvent the new airspace constraint (as well as any others). Timely in this context means 'with sufficient time to ensure the airspace constraint can be avoided' or (if already in violation) 'as soon as practical to expeditiously exit the airspace constraint volume'. | For X4, a revised Operational Plan must be obtained no later than TBD minutes prior to predicted violation of airspace constraint. No prioritization between operations being managed by different PSUs is required. Further, NASA is not prescribing a solution regarding how a revised Operation Plan is obtained, as it falls under the Operator-PSU interface. Likewise, each partner may determine if/how prioritization within its set of managed operations is employed. |

# 10. Appendix B.2: CBR Catalog- Candidate CBRs

| ID | Name/Org | Focus Area | Description (Required) | Rationale & Discussion (Required) | X4 Implementation(s) (Required) | Notes & Comments (Optional) |
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| Candidate CBR Number | Name of commenter and/or organization | (1) Operational Intent<br><br>(2) Conformance Monitoring<br><br>(3) Strategic Conflict Management<br><br>(4) Airspace Constraint Management<br><br>(5) Go-Arounds, Contingencies, Emergencies<br><br>(0) Other | Description or definition of candidate CBR. | Rationale for need of candidate CBR. Include cost and benefits considerations where possible. Include impacts to effectively implementing the CBR. | X4 Implementation notes: Details on how this CBR will be met in X4? | Comments welcome. |
| CBR-GA-1 | NASA | 5 | CBR-GA-1 (PSU and coordination with local participants): PSU is responsible for conducting and coordinating traffic management procedures with participating vertiports and defining process to notify local participants. These procedures should consider holding patterns, sequencing, and demand restrictions. | The timing of approaches/landings can be thrown off, i.e., need to reinsert go-around aircraft into arrival sequence, or sequence/delay other UAM aircraft that may be impacted.<br>•Might require further coordination with vertiports and other PSUs with operations in the vicinity.<br>Notification to PSU Network could be accomplished two ways:<br>•Via operational plan update, might be optional, as timing permits (depends if the PIC / operator is able to communicate it via PSU)<br>•Via PSU conformance monitoring: would this be considered a 'nonconforming' event? | not implemented in X4 | Partner 2: Could this CBR be extended to any resource owners? There may be other resources for which coordination is required. Different CBRs may be appropriate depending on whether the coordination is strategic (pre-departure) or tactical. Pre-departure coordination should include intent updates and compliance with DCB and should be the responsibility of the PSU. However, tactical coordination |

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| | | | | | | will be dependent on the capabilities of the aircraft, and some operators may not be able to coordinate appropriately through a PSU, in which case the coordination is the responsibility of the operator/pilot. |
| CBR-GA-2 | NASA | 5 | CBR-GA-2 (rules + procedures within corridors): PSU shall comply with right-of-way ("ROW") rules tailored for operations within UAM corridors and with procedures that allow for alerts and maneuvering that remain within the corridor's boundaries. | Certain events may result in UAM vehicles within the corridor needing to deviate from their planned / established trajectory to avoid other UAM. Design of the airspace would need to support these maneuvers. What features of corridors are needed to allow RoW and prioritization within corridors? Passing lanes, holding, etc.? | not implemented in X4 | |
| CBR-EM-1 | NASA | 5 | The UAM Operator/PIC shall comply with ANSP-established procedures for emergency operations, whether inside or outside a UAM corridor. | During any emergency, the pilot should contact ATC immediately for assistance.<br>As stated in FAA Order 7110.65Z, an emergency is defined as either a distress or an urgency condition , intended for the PIC or airframe. In the event of an emergency, the aircraft in distress requires prioritization over others.<br>Basic information as required by FAA Order 7110.65, should be exchanged by ATC to pilot and PSU Network. | not implemented in X4 | |

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| CBR-EM-2 | NASA | 5 | PSU should notify ANSP, as soon as practical, when an UAM aircraft declares an emergency. | When an emergency occurs, ANSP (ATC/FAA) would require notification following established procedures described in EM-1 as soon as practical. This follow-on notification from PSU may occur as soon as the PSU network becomes aware of the emergency. CBR-EM-1 requires that existing procedures for emergencies be followed and includes the requirement for the PIC/UAM Operator to notify ATC. The notification under existing procedures is considered urgent and should occur as soon as it is safe to do so (aviate, navigate, communicate). While notification of an emergency to ATC is urgent, providing additional/contextual information to the ANSP is not urgent and may be provided by the PSU through digital means. Thus, notification of the emergency and TBD additional information should be provided as soon as the PSU becomes aware of the emergency. | not implemented in X4 | |
| CBR-EM-3 | NASA | 5 | PSU shall notify ANSP when an UAM aircraft exits the corridor and enters into controlled airspace. | When an UAM aircraft exits the corridor and enters into the controlled airspace without an ATC clearance (e.g., UAM aircraft is non-conforming and exits corridor into Class B airspace without a prior clearance), ANSP/ATC would require notification. Although not all such events would result in an impact to ATC, such detection and notification via the PSU would enable advisories and | not implemented in X4 | Partner 2: An operation should be able to exit a corridor without being declared an emergency - so long as it complies with the requirements of the airspace into which it is exiting (e.g., receiving clearance to enter). ATC must, |

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| | | | | alerting to be activated to notify those in the ATC control environment of the circumstance. | | however, be informed regardless of the reason for exiting. The PSU conformance monitoring function should identify when an operation is contingent, and this information should be communicated to the PSU network and ATC. NASA: Agreed... 'emergency' removed from the language of revised CBR. |
| CBR-EM-4 | NASA | 5 | Upon notification of an emergency from an UAM aircraft, PIC or UAM operator, the PSU shall share the emergency status of the operation and all pertinent information about the operation with the PSU network. | Regulations require that aircraft under distress/emergency are given top priority and right-of-way. Thus, it is necessary for all PSUs to have knowledge of a declared emergency so that supporting services (e.g., DCB) can comply with the required prioritization. | not implemented in X4 | |
| CBR-CM-5 | Metron | 2 | The PSU is responsible for deleting any operational intents that are no longer intended to be flown, and for ensuring that only one operational intent is associated with an operation at any one time. | Logical data integrity is required to ensure quality and correctness of operational intent data in support of many UAM functions and attributes (e.g., DCB, shared intent, conflict management, to prevent gaming, etc.). Thus, the PSU must ensure there is only one operational Intent for an operation at any time, and that Operational Intents are deleted once they are no longer necessary to support an intended operation. | | Partner 2: From the current CBRs it's not clear that there is a requirement to delete any stale/errant/old operational plans, so this CBR was added to catch this case. Open for discussion as to whether it is necessary. |

# 11. Appendix B.3: CBR Catalog- Parking Lot CBRs

| ID | Name/Org | Focus Area | Description (Required) | Rationale & Discussion (Required) | X4 Implementation(s) (Required) | Notes & Comments (Optional) |
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| Candidate CBR Number | Name of commenter and/or organization | (1) Operational Intent<br><br>(2) Conformance Monitoring<br><br>(3) Strategic Conflict Management<br><br>(0) Other | Description or definition of candidate CBR. | Rationale for need of candidate CBR. Include cost and benefits considerations where possible. Include impacts to effectively implementing the CBR. | X4 Implementation notes: Details on how this CBR will be met in X4? | Comments welcome. |
| CBR-PL-1 | NASA | 0 | PSU should publish telemetry information for Non-conforming targets. | When a target is non-conforming, regardless of reason or which system is identifying the non-conforming condition, the telemetry information on that target should be made available for other actors in the system so that they can most effectively manage the potential contingency scenario. | not implemented | Partner 1: The definition of non-conforming and/or the system will need to accommodate exigent circumstances |
| CBR-PL-2 | UMEX | 0 | Emergent user communities should take the lead in developing CBRs that are relevant to their operations and be supported by the aviation community | Emergent user communities know their requirements and issues better than anyone else. | not implemented | e.g., public safety, agriculture, freight, or passenger transport, etc. Competing interests will then need to be reconciled. |
| CBR-PL-3 | UMEX | 0 | Disaster response CBRs must have appropriate authorization and authorities to implement the response(s) | Significant disaster response will need to mobilize large portions of the UAM/AAM system, which will require appropriate authority and preparedness well in advance of when they are needed | not implemented | e.g., UML-4 areawide disaster response |
| CBR-PL-4 | UMEX | 0 | Public safety has input into the airspace management process | Examples include warning orders, TFRs, be on the lookout (BOLO), or system hold | not implemented | Incident response and other public safety-related circumstances will require this |

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| CBR-PL-5 | UMEX | 2 | X verifies and enforces CBRs and other UAM/AAM constructs | Who, when, how? | not implemented | |
| CBR-PL-6 | UMEX | 3+ | Priority rules are established when public safety is involved | Strategic and pre-tactical | not implemented | |
| CBR-PL-7 | UMEX | 3+ | Priority rules are established when public safety is not involved | Strategic and pre-tactical | not implemented | |
| CBR-PL-8 | Metron | 3 | PSUs should strategically mitigate air risk. | Delegation of separation provision from ATC to UAM systems/pilots will require that collision risk is mitigated to a level that allows tactical conflict management mechanism(s) to operate within their design parameters (where applicable) to provide safe separation from hazards. Depending on the requirements of the airspace, mitigation of air risk could be through the use of strategic deconfliction based on a separation criteria or through DCB by complying with a capacity constraint on an airspace resource. | not implemented | |
| CBR-PL-9 | Metron | 3 | To promote efficient and fair operations PSUs should [make a best effort to] operate according to allocated resources and intent [TBD% of the time]. | Collaborative planning could be subject to gaming by operators. There should be a set of agreed upon rules PSUs must adhere to and enforce that aim to maintain efficiency, fairness, and equity for utilizing shared resources. | No rules and agreement specified. | |
| CBR-PL-10 | Metron | 3 | PSUs submitted operation plans should adhere to control actions when required by authorized services. | Centralized control actions, such as applied in traditional ATM, may be required for AAM operations under some circumstances. | This CBR will not be exercised in X4. | |

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| CBR-PL-11 | NASA | 3 | UAM Operators may submit operational plans "early" | Allow better resource management for Vertiport Operators to know about operations in advance (especially applicable with scheduled operations in early UML) | UAM Operators can submit the operational plans as early as they want. | Additional CBRs would need to be developed to preclude PSUs or operators from "gaming the system". For example, compliance monitoring and reporting would be part of the process to reinforce the CBRs. |
| CBR-PL-12 | NASA | 3 | PSU must verify demand-capacity compliance of all operational plans by the agreed decision timeline. | Allow common compliance requirements to be implemented to support different operational needs (both on-demand and scheduled operations) to account for changes | PSU must verify demand-capacity compliance of operational plans prior to departure. | |
| CBR-PL-13 | NASA | 1 | PSUs shall submit Operational Intent within prescribed times for type of operation. | To preclude gaming and ensure fair access to and efficient use of shared UAM resources, rules may be required for when operational intent should be submitted. Additionally, it is acknowledged that fair and efficient use of resources needs to consider the type of operation (e.g., scheduled, on-demand, first-responders, etc.) that may necessitate different rules for different types of operations. | Since X4 is looking at on-demand operations, we are limiting Operational Intent submissions to be no earlier than 30 minutes prior to proposed departure time. | Might replace CBR-PL-11 & CBR-PL-12 |
| CBR-PL-14 | NASA | 4 | PSU Shall set the state of an operation to *TBD* if violation of an airspace constraint is imminent (i.e., not providing sufficient time to obtain a revised Operational Plan circumventing the constraint) or if operation is currently in violation of an airspace constraint. | Failure to provide a revised Operational Plan circumventing an airspace constraint in a timely manner leads to imminent violation and (potentially) the need to take more urgent action. Lacking a timely revision to Operational Intent for an impacted operation, the PSU shall detect the imminent violation and initiate appropriate action (defined by additional, TBD CBR) by setting the state of the operation to 'TBD'. | Not implemented in X4. | Partner 2: Agreed. |

| | | | | | | |
|---|---|---|---|---|---|---|
| CBR-PL-15 (Shelved) | NASA | 3 | PSU? shall monitor shared resource demand for demand/capacity imbalances and notify the resource owner and/or PSU network <or> obtain a revised OI for impacted operations (whether airborne or pre-departure) that is compliant with resource capacity restrictions. | Because both demand and capacity are dynamic in UAM, imbalances may arise that impact an operation prior to departure after an operation has been accepted, or even after departure. The extent to which approved/active operations may require revision to operational plans to mitigate demand-capacity imbalances will depend on a variety of (often complex) factors: proximity of the operation to the shared resource, ability of the aircraft to absorb delay (energy reserves), available buffers/holding near or at the impacted resource (e.g., vector patterns, overflow landing pads or proximate vertiports), etc. Effective allocation of roles for PSU, Fleet Operator, DCB Services and Vertiport Managers regarding mitigation of demand-capacity imbalances that impact *approved/active* operations, has yet to be determined. | Not implemented in X4. | Partner 2: DCB is a strategic tool that preconditions the flow so that it can be managed tactically. In the timescale of UAM operations, it may be sufficient to handle airborne replanning tactically, without the need to comply with DCB constraints. This should be verified through a safety analysis. For X4, activated (airborne) operations should not be required to comply with DCB constraints. However, intent changes for airborne operations should impact demand for resources, that could affect DCB for operations that are pre-departure. These operations could be required to replan using the DCB process. This process will need to be carefully analyzed with respect to the prioritization scheme used for DCB. X4 prioritization based on the request time will most likely not be sufficient to properly handle operations that need to be replanned unless additional data linking the new request (replan) to an old request (accepted) is available to DCB.<br>NASA: Agreed... CBR has been shelved pending necessary discussions that are beyond the scope of X4. |

# 12. Appendix C: Sample Sprint Test Procedure- Sprint 3: Nominal Flight Test Procedure

## 1. Test Description

This procedure tests the simulation of assigned route:

1. Connectivity between the Participant PSU and FIMS-AZ
2. Connectivity between the Participant PSU and the Discovery and Synchronization Service (DSS)
3. Connectivity between the Participant PSU and the Data Collection Environment via UDC PSU
4. Collection of telemetry data during simulation of nominal flight in the Data Collection Environment via the UDC PSU

| Key | Sprint Name | Test(s) Description |
|---|---|---|
| X4-Sprint-3 | Sc1 Nominal Flight Sprint | Each participant will be assigned a route from origin to destination vertiports.<br>For each operation, a PSU will successfully PUT an operation plan to the DSS and receive a list of PSUs to notify. Successfully POST the operation plan to PSUs identified by the DSS. Update the Operation state to Activated, and have the vehicle takeoff, fly the assigned route, then land. While in the Activated state, respond to requests for vehicle telemetry data. After landing, delete the operation from the DSS and inform the applicable PSUs.<br>A second operation will be submitted with the expectation of becoming NonConforming. The participant can choose the best way to become non-conforming based on the architecture of their system. |

All tests are included in this procedure as there is commonality in the setup, and dependencies between the subsystems. If the procedure is only intended to exercise a subset of the tests identified above, the other steps should be identified with a Pass/Fail status of 'N/A' and the reasoning indicated in the 'Test Coordinator Notes' section.

## 2. References

### 2.1. Subscription Area

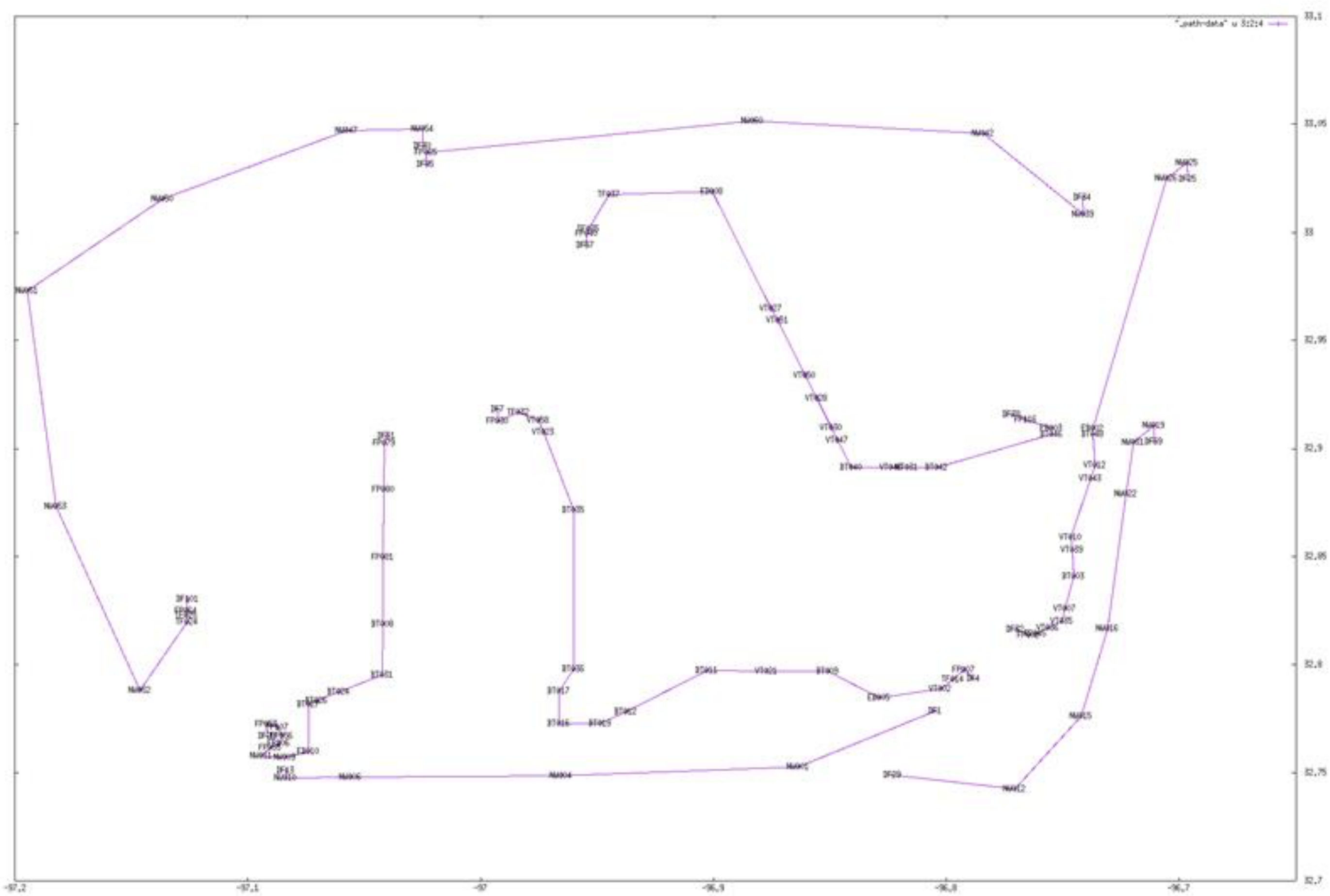
The subscription area uses an outline_circle, centered at DFW, with the following volume definition:

- Longitude = -97.040850
- Latitude = 32.894116
- Radius = 40233 m (approx. 25 miles)

### 2.2. Participant Assigned Route

Route information is defined in data retrieved from ASDS.

| Participant | Origin Vertiport | Destination Vertiport | Route |
|---|---|---|---|
| **SkyGrid** | DF101 | DF30 | DF101..FP064.TRS19.TF024..NW052..NW053..NW051..NW050..NW047..NW054..DF30 |
| **Avision** | DF13 | DF1 | DF13..NW010..NW006..NW004..NW001..DF1 |
| **Collins** | DF29 | DF59 | DF29..NW012..NW015..NW016..NW022..NW031..NW019..DF59 |
| **Metron** | DF32 | DF25 | DF32..FP002.TRS30.VT035.TRK01.EB002..NW026..NW025..DF25 |
| **OneSky** | DF34 | DF95 | DF34..NW039..NW042..NW060..FP065..DF95 |
| **NASA** | DF51 | DF28 | DF51..FP079.DFW02.BT031.TRK61.EB010..NW009..NW011..FP055..FP106..FP056..FP107..FP053..DF28 |
| **ANRA** | DF7 | DF4 | DF7..FP030.TRS34.VT058.TRK51.BT016.TRK21.EB005..VT002.TRS01.FP007..DF4 |
| **Unmanned Experts** | DF78 | DF57 | DF78..FP116..EB003.TRK02.BT046.TRK30.ED008..TF037.TRS25.FP040..DF57 |




## 2.3. Application Interfaces

| Description | Open API Version | Reference Link(s) |
|---|---|---|
| FIMS-Authz API | 3.0.0 | https://github.com/nasa/uam-apis/tree/x4/openapi/fims-authz FIMS-AUTHZ API |
| ASDS API | 3.0.0 | https://github.com/nasa/uam-apis/tree/x4/openapi/asds ASDS API |
| PSU to DSS API | 3.0.3 | https://github.com/nasa/uam-apis/tree/x4/openapi/psu PSU-to-DSS API |
| PSU to PSU API | 3.0.3 | https://github.com/nasa/uam-apis/tree/x4/openapi/psu PSU-to-PSU API |

# 3. Pre-Test

## 3.1. NASA Test Coordinator Checks

Be familiar with How-To Conduct Tests

1. Check a subscription has already been set up for data collection (see How-To Setup For Data Pipeline UDC)
2. Check FIMS-AZ is up and running.
3. Check participant PSU's Client Identifier is registered/setup within FIMS-AZ.
4. Check Discovery and Synchronization Service (DSS) is up and running.
5. Check UAM Data Collector (**UDC**) PSU is up and running.

## 4. Test Steps

| # | For Participants | For Test Coordinators | Pass / Fail | Test Coordinator Notes |
|---|---|---|---|---|
| 1 | Wait for Test Coordinator to set up and announce Data Collection (**UDC**) PSU subscription before start of testing. | Check UAM Data Collector (**UDC**) PSU had already submitted a subscription to the DSS using the extents identified in the Subscription Area section.<br><br>Ref. How-To Setup For Data Pipeline UDC<br><br>Note that this step can be performed at the beginning of the test day, and does not need to be repeated for each test run, just in a given test day.<br><br>Dashboard shows the subscription was received by DSS and a subscription id was provided.<br><br>The Subscription 'id' is: (Optional) Post Test: Data Collection PSU logs show the following endpoint(s) are exercised and a successful HTTP Response (i.e. 2xx) is received:<br><br>1. PUT Subscription (Data PSU-to-DSS) | | |
| 2 | Participant PSU request an access token from FIMS-AZ for **DSS** with **audience = '<url removed>'** | Dashboard or log shows the Participant PSU was issued a FIMS-AZ token to Participant PSU for audience.<br><br>(Optional) Post Test: FIMS-AZ log shows the following endpoint(s) are | | |

| # | For Participants | For Test Coordinators | Pass / Fail | Test Coordinator Notes |
|---|---|---|---|---|
| | | exercised and a successful HTTP Response (i.e. 2xx) is received:<br><br>1. POST token (Participant PSU-to-FIMS) | | |
| 3 | Participant PSU uses token received from FIMS-AZ for DSS to submit operational intent, with volumes that encompass the waypoints identified in assigned route in References section of this procedure, to DSS for simulating a ***Conforming*** flight. | Querying DSS will show an Operation with:<br><br>1. Operation 'state' of Accepted<br><br>The ***Conforming*** Operation 'operational_intent_id' is: | | |
| 4 | Participant PSU request an access token from FIMS-AZ for Data Collector (**UDC)** PSU with **audience = '<url removed>'** | Dashboard or log shows the Participant PSU was issued a FIMS-AZ token to Participant PSU for audience.<br><br>(Optional) Post Test: FIMS-AZ log shows the following endpoint(s) are exercised and a successful HTTP Response (i.e. 2xx) is received:<br><br>1. POST token (Participant PSU-to-FIMS) | | |
| 5 | Participant PSU uses token received from FIMS-AZ for UDC to submit operational intent to UDC PSU for assigned route in References section of this procedure.<br><br>UDC PSU base URL will be in subscriptions from DSS response in Step 3 like <url removed> | Dashboard shows an Operation with:<br><br>1. Operation 'state' of Accepted<br>2. Operation identifier should be same as Step 3<br><br>Post Test: UDC shows the following endpoint(s) are exercised and a successful HTTP Response (i.e. 2xx) is received:<br><br>1. POST Operational Intent Details(Participant PSU-to-UDC PSU) | | |

<table>
<tr><th>#</th><th>For Participants</th><th>For Test Coordinators</th><th>Pass / Fail</th><th>Test Coordinator Notes</th></tr>
<tr><td>6</td><td>Participant PSU change the operation state to 'Activated'. Simulated vehicle to begin flying the route. Participant PSU's simulated flight will remain in Conforming status.</td><td>Dashboard shows an Operation with:<br><br>1. Operation 'state' of Activated,<br>2. 'version' is incremented from value in Step 3<br>3. Telemetry data of simulated operation during Activated state<br><br>Post Test Checks:<br><br>1. POST Operation Intent Details(Participant PSU-to-UDC PSU)<br>2. GET Telemetry (UDC PSU-to-Participant PSU)</td><td></td><td></td></tr>
<tr><td>7</td><td>When the simulated vehicle lands at its destination Vertiport, Participant PSU ends the operation.</td><td>Dashboard shows an Operation with:<br><br>1. Operation 'state' of Ended,<br><br>Post Test Checks:<br><br>1. Query DSS using Operation identifier and should get back 'not found' response.<br>2. POST Operational Intent Detailswith Operational Intent JSON omitted (Participant PSU-to-UDC PSU)</td><td></td><td></td></tr>
<tr><td>8</td><td>Participant PSU uses token received from FIMS-AZ for DSS to submit operational intent, with volumes that encompass the waypoints identified in assigned route in References section of this procedure, to DSS for simulating a NonConforming flight.<br><br>NOTE: Operational Intent should be same as Step 3, that is, only simulated flight goes NonConforming.</td><td>Query DSS will show an Operation with:<br><br>1. Operation 'state' of Accepted<br><br>The NonConforming Operation 'operational_intent_id' is:</td><td></td><td></td></tr>
</table>

| # | For Participants | For Test Coordinators | Pass / Fail | Test Coordinator Notes |
|---|---|---|---|---|
| 9 | Participant PSU uses token received from FIMS-AZ for UDC to submit operational intent to UDC PSU for assigned route in References section of this procedure.<br><br>UDC PSU base URL will be in subscriptions from DSS response in Step 8 like <url removed> | Dashboard shows an Operation with:<br><br>1. Operation 'state' of Accepted<br>2. Operation identifier should be same as Step 8<br><br>Post Test: UDC shows the following endpoint(s) are exercised and a successful HTTP Response (i.e., 2xx) is received:<br><br>1. POST Operational Intent Details (Participant PSU-to-UDC PSU) | | |
| 10 | Participant PSU changes the operation state to 'Activated'. Participant PSU's simulated vehicle to begin flying the route. | Dashboard shows an Operation with:<br><br>1. Operation 'state' of Activated<br>2. 'version' is incremented from value in Step 8<br>3. Telemetry data of simulated operation during Activated state<br><br>Post Test Checks:<br><br>1. POST Operation Intent Details (Participant PSU-to-UDC PSU)<br>2. GET Telemetry (Data PSU-to-Participant PSU) | | |
| 11 | While Participant PSU simulates flight flying route, its vehicle becomes **NonConforming** and reports all flight state changes **to other PSUs subscribed** (see Subscriptions within DSS response in Step 8).<br><br>NOTE: The participant PSU can choose the best way to become non-conforming based on the architecture of their system. | Dashboard shows an Operation with:<br><br>1. Operation 'state' changing to NonConforming<br>2. 'version' is incremented from value in Step 10<br>3. Telemetry data shows flight along its route (if possible, note reason for non-conforming status change)<br>4. Operation 'state' changes back to Activated | | |

| # | For Participants | For Test Coordinators | Pass / Fail | Test Coordinator Notes |
|---|---|---|---|---|
| | | 5. 'version' is incremented again<br><br>Post Test Checks:<br><br>1. POST Operation Intent Details (Participant PSU-to-UDC PSU) with all status changes<br>2. GET Telemetry (UDC PSU-to-Participant PSU) | | |
| 12 | When Participant PSU's simulated vehicle lands at its destination Vertiport, Participant PSU ends the operation by announcing to DSS and **to other PSUs subscribed** (see Subscriptions within DSS response in Step 8). | Dashboard shows an Operation with:<br><br>1. Operation 'state' of Ended<br><br>Post Test Checks:<br><br>1. Query DSS using Operation identifier and should get back 'not found' response.<br>2. POST Operation Intent Details with Operational Intent JSON omitted (Participant PSU-to-Data PSU) | | |
| 13 | None. | **Close/Delete subscription setup for** UDC PSU.<br><br>Note that this step can be performed at the end of the test day, and does not need to be repeated for each test run in a given test day.<br><br>Query DSS using Subscription Identifier and should get back 'not found' response. | | |

## 5. Post Test Analysis

| # | For Test Coordinator | Result |
|---|---|---|
| 1 | Verify that all endpoints identified in the procedure 'Post Test' verification statements are exercised as expected from: | |

| # | For Test Coordinator | Result |
|---|---|---|
| | 1. Data Collection PSU logs<br>2. FIMS Logs<br><br>In the event that a message was not exchanged as expected, include the corresponding step number in the Result description. | |
| 2 | Verify that there are no failed data exchanges (i.e., HTTP response of 4xx) with the data pipeline | |
| 3 | Verify that telemetry data was collected by Data Collection PSU via data pipeline. | |