Enabling Autonomous Flight and Operations in the National Airspace System

Summary of Urban Air Mobility (UAM) Discussions

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1. Introduction

With an impending pilot shortage, expected growth in aviation, and a need for scalability and efficiency to reduce cost, future civil aviation operations are envisioned to take advantage of continuing advances in machine intelligence, data analytics, high-bandwidth and secure data networks, and increasingly capable sensors. Together, these technologies will enable increasingly autonomous systems. Many stakeholders have expressed the value of defining a national strategy to support the introduction of autonomous systems. A national strategy that establishes clear goals for enabling operations, characterizes maturity levels and increasingly autonomous system options, identifies a path towards acceptance, and pulls resources together to conduct tests to assess maturity will have common benefit. Given this interest and deemed usefulness, NASA has been encouraged to take the initiative to facilitate these efforts.

On August 6th and 7th, 2019, NASA conducted the second of a series of workshops to bring together stakeholders and define a national strategy to enable increasingly autonomous operations. The workshops focused on identifying needs and use cases for increasingly autonomous civil aviation operations in the National Airspace System (NAS). The second workshop considered two use cases with the potential to be enabled by autonomous systems in the future: Urban air mobility (UAM) and small unmanned aircraft systems (sUAS). The following is a summary of workshop results for the UAM use case.

The goals of the workshop were to discuss and identify:

- The minimum viable products to make progress towards increasingly autonomous flight and operations in the NAS
- Where NASA collaboration with industry will be most productive
- Possible collaborative demonstrations
- Steps toward operationalization of increasingly autonomous systems.

To address the workshop objective of developing a national strategy for steps to achieve operational systems, a minimum viable product (MVP) strategy was adopted. An MVP is a product with just enough features to satisfy early customers and capable of providing feedback for future product development. The MVP strategy directly addresses near-term market needs and business cases and may be beneficial in addressing long-term multi-phase advancements of complex systems by overcoming unknowns via implementing and operationalizing realizable capabilities as early as possible.

These topics were discussed in two breakout groups. Each breakout group met for three breakout sessions. The notes, discussions, and priorities generated by the breakout group participants are summarized in this report. On the first day, five keynote presentations addressed several topics to provide context and discussion points during the breakouts, and an instruction briefing explained the MVP strategy prior to the breakout sessions. The results of all sessions for the two breakout groups were combined and presented to a plenary at the end of the second day. The workshop agenda can be found in Appendix 1: Workshop Agenda.

2. Minimum Viable Products (MVPs)

The first task covered by workshop attendees was to identify needs, minimum viable products, progression towards their autonomous operations, and needed aircraft, ground, and cloud-based capability levels. Some general thoughts were first considered to identify the minimum viable product. It was agreed that the product should be robust enough to survive a single crash, integration into airspace is essential for most use cases, and demonstrations should start in a simple environment that increases with complexity. As a step toward a long-term product, the MVP should be thought of as a 30% solution, and the human-autonomy interface should be a low but increasing piece of the solution. Several scenarios were considered for the MVP.

2.1. High-level need fulfilled by an MVP

The group discussed high level needs that should be fulfilled by the MVP. The needs fall into two categories, defined below. These categories describe the types of markets that potentially exist for UAM technologies. MVPs for each of these categories would likely have different requirements and constraints.

Category 1. Personal Mobility: A personal mobility MVP would allow reduced commute times and the expected associated costs. This category also includes special use cases such as emergency medical transport (i.e., air ambulance).

Category 2. Cargo Delivery: A cargo delivery MVP would address autonomously delivered cargo between locations. There was discussion on the benefits of starting with lower-risk rural areas, as was done for UTM, to gain public trust. Using UAM vehicles for firefighting and other emergency services was considered a special case, where the ability to transport firefighting resources using autonomous vehicles could help with public acceptance of UAM. This special case could be an area where an autonomous MVP could provide great public benefit.

2.2 General Characteristics of an MVP

The participants discussed how a successful MVP for UAM operations must be used for routine operations. These operations would have to be integrated with near-current day airspace infrastructure and likely operate in most (if not all) classes of airspace, including controlled airspace. It's also expected that multiple UAM operating companies will be sharing most sections of airspace. The MVP will become the basis for UAM operations that are likely to evolve rather than revolutionize airspace operations. For UAM operations, the ability to recover from an off-nominal situation will be paramount to be an MVP.

For these operations to be economically feasible, they need not be immediately profitable. However, they will need to build a demand in the market that is sustainable when they achieve operational levels where they can take advantage of economies of scale.

A quick turnaround time at the UAM ports may become a requirement to achieve high tempo operations. This has implications for batteries and chargeability. Similarly, UAM operations being available in "nearly" all weather conditions will help build demand when ground traffic is likely to get even more congested. For user acceptance, high availability will be essential. Additionally, UAM vehicles will need to have a small noise footprint to be acceptable to the public, and this is also a requirement for a minimum viable product.

2.3 Routes to MVP

Participants discussed if the route to achieving the minimum viable product requires starting with cargo operations prior to passenger carrying operations. Cargo operations are lower risk and therefore, could be easier to achieve and would be a useful testing ground for technologies used in higher-risk passenger operations.

UAM operations flying simple trajectories defined by fixed routes will also be a good starting point before evolving to complex operations. UAM operations are significantly different from UTM (UAS traffic management) operations since they operate using larger vehicles (larger than 55 pounds drones), are likely to operate above 400 ft above ground level, will sometimes carry passengers, and pose a higher safety risk. UAM companies aim for these operations to use eVTOL(electric vertical take-off and landing) vehicles or hybrid to start with until the characteristics of the battery are well known and defined.

Two operational modes were considered as starting points for MVPs: piloted simplified vehicle operations (SVO), and unpiloted remote supervisory operations (RSO). Passenger UAM operations will likely be piloted operations in the near term before they can evolve to more pilotless autonomous operations in future. Simplifying vehicle operations will reduce training needs for pilots and therefore lower operating costs which is essential for market viability. One potential progression to fully autonomous operation is illustrated in Figure 2.3-1.

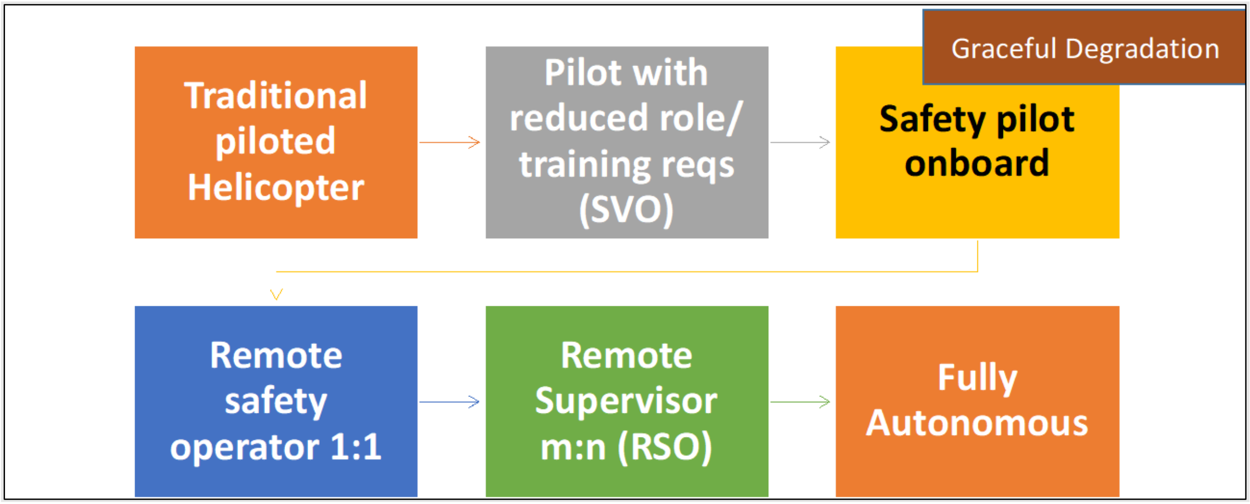

Figure 2.3-1: Progression from current helicopter operations to fully autonomous UAM

In this example, UAM could progress forward from existing piloted helicopter operation by introducing SVO where the pilot has increased automation to assist them, reducing their workload and training needs. Next, automation would expand to operations in nominal and most off-nominal conditions with a pilot on-board to provide human expertise during unexpected events. To enable the pilot to fulfill this role, the automation would need to gracefully degrade or fail to a state where it will be easy for the human pilot to take over. The next proposed step will remove the pilot from the vehicle and make them a remote safety operator. In this state, the human operator would be responsible for a single vehicle. The vehicle would operate largely autonomously, receiving safety guidance from the remote operator. The next step could go through RSO with a few supervisors for several vehicles. The final step would be a fully autonomous vehicle where the entire flight would be managed by an autonomous system.

There was also discussion about where the MVP will fit in terms of rules and regulations. The options include using current regulations or creating a future part 21. These options will need to be resolved by the FAA.

2.4. MVP Concept of Operations (ConOps)

There were two example ConOps defined for the minimum viable product. The first was defined for low-populated areas because of the reduced risks in a rural environment. There was, however, some concern for limited markets in those locations. It was expected that these would be low tempo operation, in the range of one to five operations per hour in the given low populated area, with high separation between consecutive operations. The UAM operations would be flown between origin and destination ports and will need to operate below traditional air traffic (see Figure 2.4-1). They will need to identify emergency landing spots in the area.

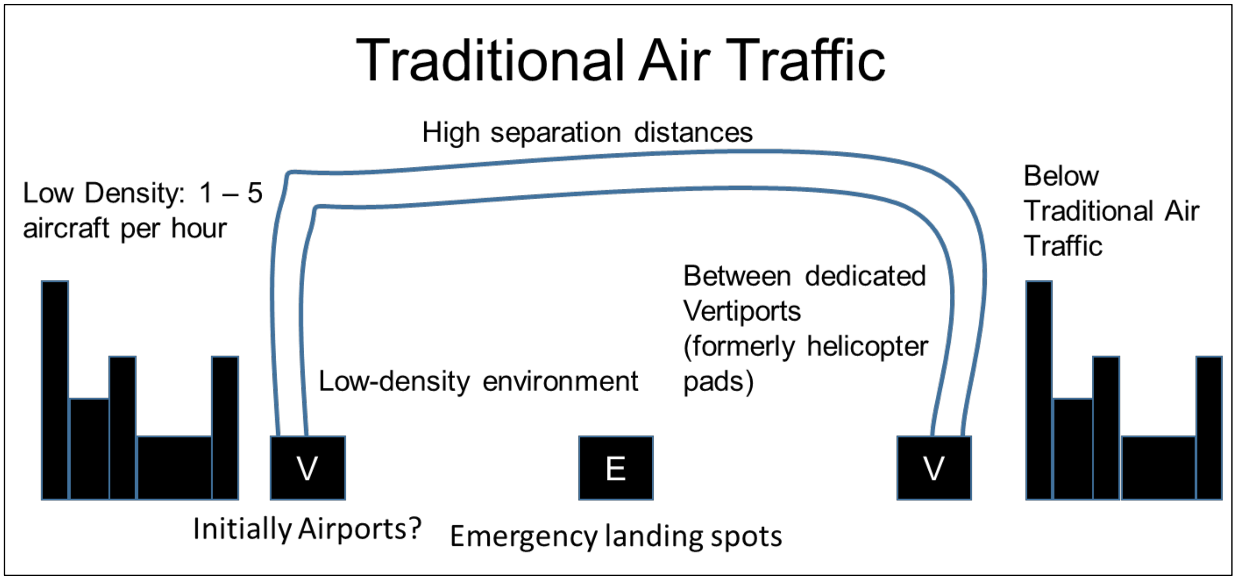

Figure 2.4-1: Conops 1 for MVP

A variant of this could be passenger operations over bodies of water. This solution could also work for island hopping in Hawaii in Figure 2.4-2 and for urban areas as shown for the San Francisco Bay Area in California in Figure 2.4-3. Over-water MVPs have the added benefit of less noise constraints.

Figure 2.4-2: UAM operations over the ocean for island hopping in Hawaii.

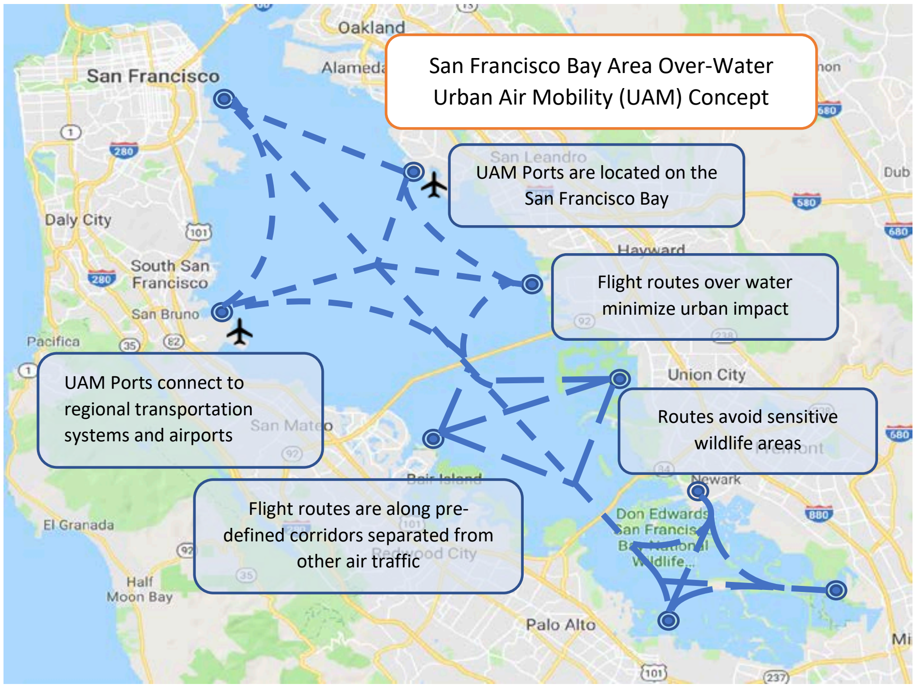

Figure 2.4-3: UAM operations over the water bodies in the Bay Area, CA.

The second MVP ConOps example is illustrated in Figure 2.4-4. Here operations would have matured and graduated to urban environments. Flight volumes are planned above the skyline but below the traditional air traffic (IFRs/VFRs). The tempo of the operations will be higher than ConOps 1, and thus, the separation between the flights will be less. Vehicles would still operate between designated origin and destination vertiports defined in the urban environment.

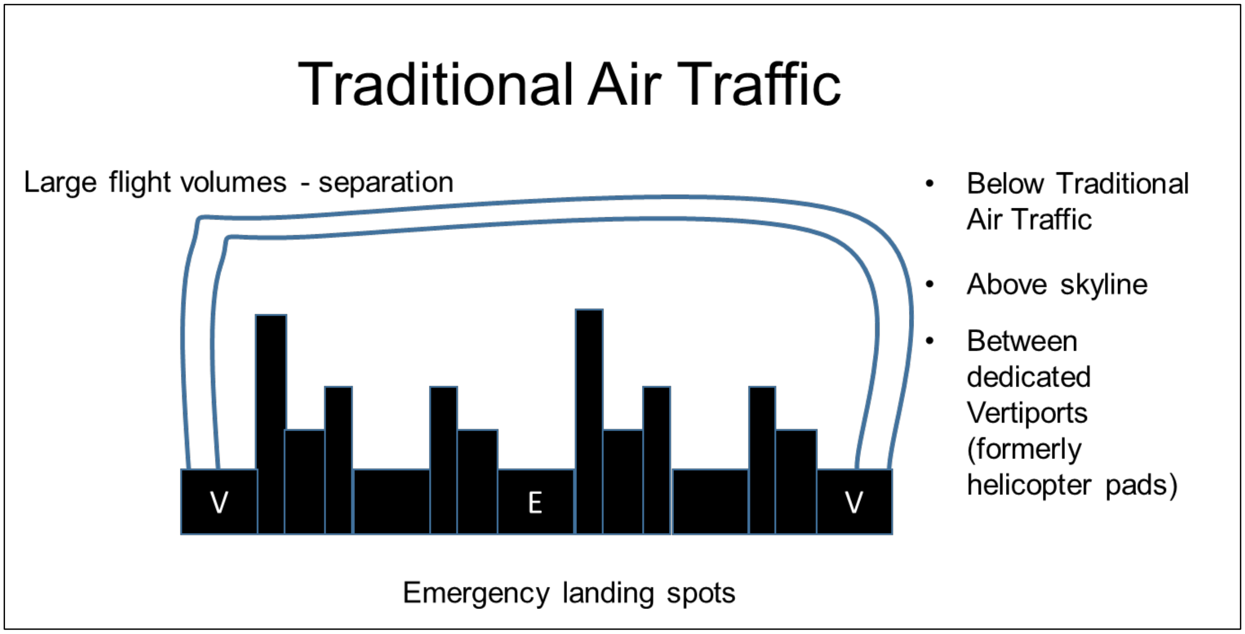

Figure 2.4-4: Conops 2 for MVP

2.5. General Discussions

There were several additional key discussions during the first session. The first such discussion was on architectures for managing UAM operations in Controlled Airspace. The architecture under discussion involved airspace structures akin to VFR (visual flight rules) corridors dedicated to UAM operations. These corridors would be separate from all other traffic and may use the UTM paradigm within the corridors. They may start with VFR operations initially until they can handle IFR (instrument flight rules) operations. Note that there will be a need for common equipage in this controlled airspace.

The other consideration was about the level of autonomy that will be acceptable and how far can we go without humans—especially pilots. The current rules in 91.3 specify that Humans are responsible for automation. Will this need to be modified as system become more autonomous? It was preferred that we move towards task-oriented automation because it is easier to certify the tasks and functions rather than identifying automation as a whole. There will be several societal issues if UAM operations become fully autonomous. There will always be a need for human communication about the mission and expectation that passengers on-board will “take over” if the need arises due to automation failure. A fully autonomous system can encompass the entire eco-system rather than just the vehicle, where human users are not seen as back-up for a degraded system. Another important discussion for full autonomy is who would be responsible for liabilities. Under current rules and regulations, the human operator has to take final responsibility and is liable for failures.

3. Research Gaps, Needs, and Strategy

The second task for workshop attendees was to identify major research gaps, identify where research is needed to get us from the current state-of-the-art to the desired future state, and discuss strategies for addressing the gaps.

Technology

- High-bandwidth, rieliable, and secure communications
- Assisted take-off and landing
- UTM infrastructure for UAM
- Technologies to support VFR operations, including accurate, detailed, and robust perception of the environment, especially in adverse or challenging conditions
- Certifyable low SWAP-C Technologies
- Collision avoidance – mature standards for UAM DAA (detect and avoid) and define interoperability with other airspace or vehicle collision avoidance
- Resilient CNS – especially navigation in a GPS-denied environment

Regulations

- Legal challenges – there are gaps in how to address legal challenges that may arise with UAM operations, particularly around liability for errors and failures
- Regulatory clarity – there is a need to address policy and data gaps to provide clarity to participants seeking regulatory approval for UAM vehicles and operations
- Roadmap from VFR to IFR operations – a need was identified for a roadmap for how UAM operations can progress from VFR operations to IFR operations

Standards

- Interoperability and interfaces (e.g., data exchange, DAA definitions)
- Operating environmental conditions – winds, weather
- A/C and flight standards collectively
- UAM certification
- Cybersecurity – a gap was identified for a lack of standardized cybersecurity approaches and requirements
- Handling non-cooperative traffic (malicious or benign)
- Identify minimum equipage requirements for operating in controlled airspace

a.Automation

- Resilient architecture design – the automation architecture needs to be designed to be resilient to a wide range of potential disruptions
- Contingency management – there is a gap in ensuring that automation can be designed to properly identify and react to contingencies during operations
- Autonomous landing – there is a gap in ensuring a safe, autonomous landing in most weather conditions
- Integrated vehicle health management – there is a need for autonomous vehicles to be able to monitor the health of on-board systems and the airframe.

a.Infrastructure

- Vertiports – there are gaps in understanding design considerations for vertiports
- Charging stations – charging stations need to be able to charge vehicles quickly to ensure economic viability of UAM
- Spectrum management – UAM operations will require significant data exchange so management of available radio spectrum is important

a.Other

- Trust in autonomy – there is a need to build trust in autonomous vehicles and system among the general public
- Data – there is a strong need for relevant, labeled data that can be used in model training, V&V, and to inform policy-making

Figure 3-1: Gaps and Needs

4. Collaboration Topics Where NASA Research Could Help

The workshop participants were asked to help identify areas where NASA could help to enable autonomous UAM. The conversation expanded to include opportunities for NASA and the FAA to work together to advance specific areas.

One need area of major concern was the definition of standards and guidelines for the community. NASA can help coordinate across standards bodies as well as provide procedures and tools to verify and validate autonomous systems leading to their certification. This can be enhanced by creating government/industry working groups that focus on specific aspects. NASA can also provide guidance on cybersecurity needs and methods. The participants had an interest in NASA focusing on resilient automation and developing and testing technologies and procedures for contingency management. NASA can continue to build on their work in human autonomy teaming (HAT) with a focus on simplified vehicle operations (SVO) for MVP operations and remote supervisory operations (RSO), including training needs. NASA can work with industry to develop pre-competitive technologies and tools. NASA can also provide access to operational data and organize opportunities for tests and demonstrations. There were several infrastructure areas where the participants thought NASA could contribute, including communications and spectrum management. Specifically, reducing voice-issued clearances and communicating additional operational data such as intent. There was also strong interest in NASA extending the UAS Traffic Management (UTM) system to manage UAM traffic.

The participants also enumerated several ways that collaboration between NASA (with other government organizations) and industry would be most productive. The full list of topics discussed is included below:

1. Public acceptance (noise, privacy, safety, trust)
2. Public policy (that supports public acceptance and includes working with DOT)
3. Technology providers (air framers, avionics, platform, apps, sensors, airspace management, communications (esp. re spectrum), geofence providers)
4. Security (physical port and transport, DHS)
5. Cyber security (e.g., DHS)
6. Intermodal operations (e.g., DOT)
7. Infrastructure (airport and vertiport standards, communications)
8. Standards and best practices (e.g., ASTM, SAE, RTCA, ICAO, etc.) – on certification, interfaces, contingency management, equipage, etc.
9. Certification (e.g., FAA)
10. Spectrum allocation (FCC)
11. Current operations (e.g., DHS)

5. Action Plan for Collective Demonstrations

The workshop participants were also asked to help identify an action plan for collective demonstrations through which UAM technologies would be matured and validated. The demonstrations would be designed to help NASA and other federal agencies enable UAM and would culminate in a near-MVP capability level.

The participants identified four scenarios that could be explored. Each scenario becomes increasingly complex with additional (or complementary) capabilities demonstrated. These scenarios are described in Section 5.1. Section 5.2 goes into detail on one of the scenarios (Scenario 2). Section 5.3 describes potential relevant sUAS scenarios that could be used to mature technologies for UAM in a lower-risk environment.

5.1: Scenarios for Collective Demonstrations

In the area of Urban Air Mobility, several scenarios were developed as potential collaborative demonstrations. Scenario one involves using an existing helipad, with a defined route, to demonstrate safety and efficiency of UAM operation. In this scenario, the UAM vehicle would stay below 1500 feet and would incorporate a simplified role for an onboard human operator. The demonstration would include a simple flight from point A to point B under control of a UTM-like UAM traffic solution. In addition to demonstration of capability, the collaboration would provide an opportunity to identify operational requirements and procedures as well as capabilities to be demonstrated through follow on collaborations.

The proposed second scenario moves from rural to urban settings, showing UTM and ATM interoperability, and operation within higher density routes. An example of significant societal benefit would be an emergency operation by EMS with medical personnel and a patient onboard. The scenario includes non-standard vehicle and airspace operations (including transfer from UTM to traditional ATM), as well as introduction of non-participating aircraft. Additional detail for this scenario can be found in Section 5.2.

Two additional collaborative demonstration scenarios include a team competition at an airport to determine the "last drone standing," and industry participation in NASA's planned UAM Grand Challenge. The details of these scenarios were not discussed at the workshop.

5.2: Additional Detail for Scenario 2

During the workshop, the participants found that they did not have time to explore the details of all the scenarios; instead, they chose to define one scenario (Scenario 2) in greater detail.

The purpose of Scenario 2 is to demonstrate increasing density and complexity of routes. Complexity can be demonstrated by transitioning from a rural or suburban environment to an urban environment and takeoff and landing from a non-vertiport site (e.g., a medical facility). This scenario also demonstrates UTM and ATM interoperability.

A specific, realistic example for this scenario could be emergency transport of EMS/medical personnel to a scene or patient. This scenario incorporates non-standard situations with vehicle and airspace management (including interaction with UTM and ATM). Introducing non-participating aircraft supports an added level of complexity and demonstration of additional capability. An additional challenge could involve integration with general aviation pathways and broad area networks without encroachment (emphasis regarding avoiding conflict and creating a safe and well defined UAM corridor).

Demonstrated, required capabilities for this scenario includes spectrum / C&C battle as required by FCC and FAA for safe operation in the NAS. Integration of humans with vehicle and airspace autonomy elements is also critical for safety and efficiency. Aspects of vertiport management (urban setting) and leveraging UAM airspace structure should be included. Finally, the demonstration of capability should remain as vehicle agnostic as possible.

Detailed steps for achieving the Scenario 2 demonstration include the following:

1. Get FAA buy-in, extending to their ecosystem of influence (and budgets)
2. Share data with standards organizations to help develop appropriate UAM-relevant standards
3. Develop a public engagement strategy (leverage public – private partnerships)
4. Develop an industry partnership strategy (e.g., vertiport owners, vehicle manufacturers)
5. Engage with current state and local organizations on lessons learned
6. Work with an existing autonomous system (e.g., DoD-NASA TTT Resilient Autonomy (RA) platform and others)
7. Take tactical steps to improve system operation (in UAM context)
8. Cover airspace to ground operations (e.g., with management tools)
9. Explore role allocation and responsibilities for flights from 500 – 1500 feet
10. Take an incremental approach to development and testing
11. Gather data on UAM (e.g., passenger experience, performance, DAA…) to inform and help define Well Clear and other operational and air worthiness standards
12. Develop strategic UAM – UTM traffic avoidance system

5.3: Potential for Earlier, Relevant sUAS Collaborative Demonstrations

One of the breakout groups focused on the applicability of early sUAS demonstrations to development and eventual demonstration of UAM capabilities. Demonstration of some UAM critical capabilities may be feasible sooner using sUAS. These sUAS scenarios are described in this section

One area of common interest is to demonstrate new sensing and analysis capabilities for micro-weather. The goal is to experiment with and demonstrate how sensing and predictive modeling supports safe operations, starting with sUAS. Testing should occur in various challenging environments such as a suburban test range and urban canyons. The tests should occur both with and without micro-weather information sharing.

A second area identified for collaboration is successive demonstrations RSO with a number of human operators (M) each supervising a number of vehicles (N). These are also called M:N operations (where N>>M). Operational tests can help to define N, the number of vehicles safely operated by each human. Demonstration of appropriate sharing of responsibility and handoff between human operators is critical. These M:N tests need to be conducted in a variety of environments with demonstration of onboard autonomous capabilities.

Communication, particularly diverse redundancy for communication links, was identified as a key capability to be demonstrated in relevant operating environments. Examples include 5G and airborne WiFi. These demonstrations could be conducted over Moffett Field to test negotiation and data sharing. It is also critical to test in environments prone to communication disruptions such as urban canyons and noisy radio environments. Demonstrations of procedures with loss link or other disruptions is critical.

Several examples were given of ongoing and potential demonstrations of safety technologies and requirements. Initial demonstration of safe operations could mix other aircraft with sUAS that have been granted limited COAs. Another critical capability to demonstrate is collective data sharing and digital fabrics for safe operations. NASA has already extended the Aviation Safety Reporting System to accommodate reports of unmanned aircraft incidents.

Some participants note that data collection needs to be conducted in the context of a safety case. There is an IPP portal for providing data for shared analysis. It was noted that the New York test site has been collecting data from Syracuse airspace, including Griffith Air Force Base over the last two years, but they have only analyzed 2% of that data. Analyzing this data could add useful insights for future UAM Operations

LVC-DE (Live Virtual Constructive-Distributed Environment) is currently difficult to use because of cybersecurity requirements and lack of NASA resources to help manage.

A few other areas ripe for collective demonstrations were mentioned in brief, including:

- A series of demonstrations on acceptable levels of noise
- Safe flight for people and valuable property (referenced the ASSURE program), including safe disintegration upon impact, land/ditch away from people and valuable property, effectiveness of parachutes
- Demonstrations of certifiable autonomy including autonomously handling a graded series of failures that currently requires a human pilot or operator, certification of run-time monitors and watchdogs, and non-adaptive AI and pre-trained machine learning

Acknowledgements

This report was put together with help from Christine Clark, Bryan Barmore, Jessica Nowinski, Chris Teubert, and Savita Verma. The authors would also like to thank Parimal “PK” Kopardekar and Mark Ballin for their hosting the workshop; the session moderators Irene Gregory, William Chan, Chris Teubert, Bryan Barmore, Wes Ryan, and Jessica Nowinski; and the scribes Savvy Verma and Ryan Hendricks. Finally, we would like to thank everyone who participated in this workshop.

Appendix 1: Workshop Agenda

TUESDAY, AUGUST 6, 2019 (DAY 1)		
TIME	**ITEM**	**PRESENTER**
7:30am – 8:30am	Registration	
8:30am – 8:40am	Welcome	Eugene Tu Center Director, NASA Ames Research Center
8:40am – 8:50am	Welcome	Jaiwon Shin Associate Administrator, ARMD, NASA
8:50am – 9:35am	Guaranteed Scaled, High-Tempo, and Safe Autonomous Operations	Alfredo Giuliano Intelligent Systems Manager, Aurora Flight Sciences
9:35am – 10:15am	Lessons Learned from Autonomous Small UAS	Sanjiv Singh CEO, Near Earth Autonomy
10:15am – 10:30am	*Break*	*All*
10:30am – 11:30am	Perspective on Autonomy for Commercial and Military Usage	Michael McNair Innovation Manager Francis Govers Autonomy Lead, Bell
11:30am – 12:00pm	Certification Considerations for Autonomous Flight and Operations	Michael Romanowski Director, Policy & Innovation, FAA
12:00pm – 1:30pm	*Lunch*	*All*
12:00pm – 1:30pm Bldg. 152, Rm. 116	**SPECIAL BREAKOUT SESSION:** In-Time System-Wide Safety (SWS) Assurance Concept of Operations Development	Register in advance
1:30pm – 2:30pm	Moving Forward Safely	Gur Kimchi Vice President, Prime Air at Amazon
2:30pm – 2:45pm	Breakout session instructions	Parimal Kopardekar Director, NARI, NASA
2:45pm – 3:00pm	*Break*	*All*
3:00pm – 5:00pm	**BREAKOUT SESSION 1:** Each group will identify an MVP for UAM simplified vehicle operations and remotely piloted operations	
5:00pm – 7:00pm	*No Host Reception: Space Bar*	*All*

WEDNESDAY, AUGUST 7, 2019 (DAY 2)		
TIME	**ITEM**	**PRESENTER**
8:00am – 8:30am	**KEYNOTE**	Anil Nanduri Vice President, Intel
8:30am – 9:30am	**PANEL: INVESTING IN AUTONOMY** MODERATOR: Damineh Mycroft Boeing/HorizonX We need to understand investor sentiment related to autonomy. For example, what feasibility products are needed for continue investments.	Srini Ananth Intel Capital Kirsten Bartok AirFinance/High Lift Capital Peter Shannon Radius Capital Steve Taub In-Q-Tel
9:30am – 10:15am	**PANEL: NASA PROGRAM AND PROJECT CONTENT—SEEKING COLLABORATORS** MODERATOR: John Cavolowsky Director, Transformative Aeronautics Concepts Program, NASA	Vanessa Aubuchon Autonomous Systems, Transformative Tools & Technologies (TTT) William Chan Air Traffic Management – eXploration (ATM-X) Misty Davies System-Wide Safety (SWS) Ken Goodrich Advanced Air Mobility (AAM)
10:15 –10:30am	*Break*	*All*
10:30am – 12:00pm	**BREAKOUT SESSION 2:** Each group will identify research gaps requiring attention in order to implement increasingly autonomous operations in progressively complex airspace and areas.	
12:00 – 1:00pm	*Lunch*	*All*
1:00pm – 3:00pm	**BREAKOUT SESSION 3:** Each group will identify a strategy that will lead to collective demonstrations and operational implementation of increasingly autonomous systems in the NAS.	
3:00 – 3:15pm	*Break*	*All*
3:15pm – 4:00pm	**BREAKOUT SESSIONS REPORT:** sUAS	Vanessa Aubuchon NASA
4:00pm – 4:45pm	**BREAKOUT SESSIONS REPORT:** Mid-size Urban Air Mobility	Christopher Teubert NASA
4:45pm – 5:00pm	Wrap-up and Next Steps	Parimal Kopardekar

Full agenda, including presentations, can be found here:
https://nari.arc.nasa.gov/aero-autonomy/w2