Enabling Autonomous Flight and Operations in the National Airspace System

Summary of Mid-Sized Cargo 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 a common benefit. Given this interest and deemed usefulness, NASA has been encouraged to take the initiative to facilitate these efforts.

On April 23 and 24, 2019, NASA conducted the first 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 first workshop considered two use cases with the potential to be enabled by autonomous systems in the future: reduced crew operations for domestic and international large-transport-category aircraft, and autonomous medium-sized cargo/freighter operations. The following is a summary of workshop results for the medium-sized cargo/freighter operations 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 the 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 were made that addressed several topics. Before the first breakout session, an instruction briefing that explained the MVP strategy was presented to participants. 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 the minimum viable products for autonomous mid-sized cargo. It was agreed that the product should be robust enough to survive a single crash, integrate into airspace (for most use cases), and that demonstrations should begin in a simple environment that limits complexity. As a step toward a long-term product, the MVP should be 30% solution, and the human-autonomy interface should be a slow, but increasing piece of the solution. Several scenarios were considered for the MVP.

One potential evolution of human-autonomy teaming modes is illustrated in Figure 2-1. Here you can see the evolution from traditional piloted mid-sized cargo freighter, through piloted with simplified vehicle operations (SVO), through unpiloted with a remote safety operator, to fully autonomous operations. There was some disagreement on this progression, as some of the participants believed that steps 2 & 3 should be skipped, progressing directly from traditional piloted vehicles to autonomous with a remote safety operator (RSO).

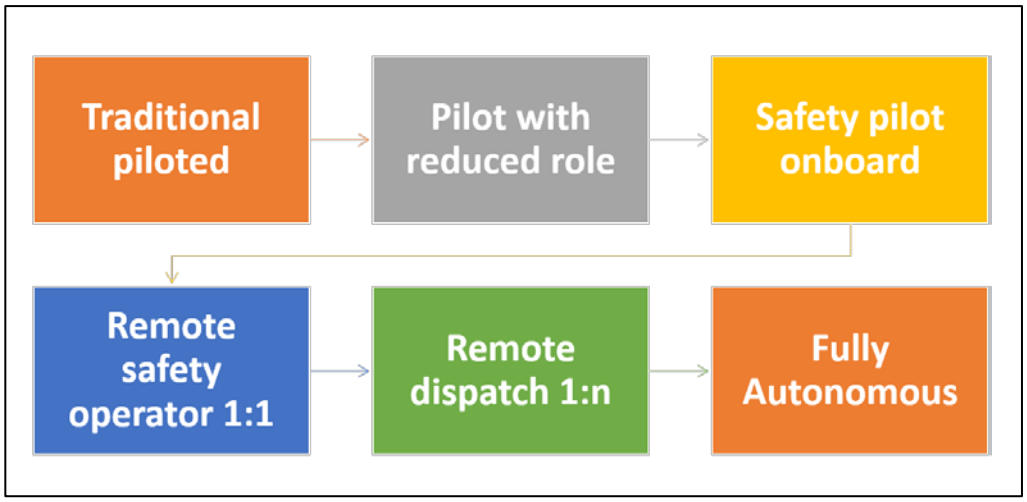

Fig 2-1. The human-autonomy interface should be a slow, but increasing piece of the solution.

There was general agreement that autonomy could assist immediately with long flights that are difficult for high-volume flights, and routes that are dangerous or with difficult conditions.

Mission needs were also considered. Autonomous cargo and freighters could save time and costs in scenarios such as inaccessible locations, firefighting and medical emergencies (where there is already public acceptance), scheduled deliveries, agriculture, remote markets, and other scenarios where human pilots are not practical.

Participants identified and explored four MVP scenarios: firefighting, offshore cargo, infrastructure inspection, and general cargo delivery.

2.1. Scenario 1: Firefighting

Autonomous operations can significantly benefit firefighting efforts by reducing pilot risk and improving performance in perception-obscured environments. Risk tolerance is high in these situations, which could lead to quicker adoption of this technology. From a humanitarian perspective, this is a good target for an MVP. However, the flight environment is challenging with low perception, challenging dynamics, and night operations. Many of the participants believe this scenario would be best served by unmanned vehicles with remote safety operators.

	TCL 1	TCL 2	TCL 3	TCL 4 (MVP)
Aircraft	• Known destination and route told • Single vehicle • Single trip • Pilot-supervised autonomous flight • Manual drop data acquisition system	• Known destination and vehicle plans	• Known destination and dynamic re-planning • Auto flight planning • Missed approach re-planning	• Picks drop (sensor based) • Closed loop drop control • Flight planning, drop planning, autoflight, drop contingency management
Ground	• Mission defined		• Human drop planning	• Retardant reload • Fire drop location and dispatch aircraft
Cloud	• Fire locations known			• Multi-vehicle coordination • Surveillance with firefighters • Interaction with other aircraft

Table 2.1-1. Possible progression of autonomous flight demonstrations in firefighting scenario.

2.2. Scenario 2: Offshore Cargo

In this scenario, flight over water minimizes risk. This is also a good business-case model because these customers typically have money and are open to finding faster delivery methods. Customers could be offshore oil platforms, wind farms, or coastal communities with limited land routes. Wind gusts make this a challenging flight environment. However, for this use case, separation from other airspace traffic may be feasible, reducing complexity. Fully autonomous vehicles, or autonomy assistance for pilots in these challenging situations may be feasible.

	TCL 1	TCL 2	TCL 3	TCL 4
Aircraft	• Existing airframe (certified) • Optionally piloted • DO-365 DAA	• Unmanned	• Dynamic re-routing, planning	• Self-separation • Machine communication
Ground	• Mission planning	• Voice comms • Command by approval	• Command by exception	• Dispatch
Cloud	• SWIM/AOC • Data feeds			• UTM (Full) • ATM-X

Table 2.2-1. Possible progression of flight demonstrations in offshore delivery scenario.

2.3. Scenario 3: Infrastructure Inspection

These scenarios could include inspection of takeoff and landing airstrips, railways, pipelines, etc. This is a scenario of great interest to industry and government due to the high cost of infrastructure inspections. Medium-size vehicles are ideal for long-distance inspections. For these scenarios, routes could be preset, contingency planning could be considered, and a remote supervisor could oversee operations.

2.4. Scenario 4: General Cargo

Autonomation for general cargo flights is of great interest to industry. For cargo being flown between airports, there would be an opportunity to integrate with existing air traffic in both controlled and uncontrolled airspace and potentially over land and water. Near-term, a safety pilot could be onboard or operating remotely (likely 1:1). Long-term, there will likely be one remote supervisor monitoring multiple aircraft. In near-term remote cases, communication with air traffic control could go through the safety pilot/operator/supervisory who would then send the instructions to the aircraft. More meaningful demonstrations would include direct communication with the aircraft, but many of the participants believed this would require the FAA to implement more-complete text-based communications.

3. Research Gaps, Needs, and Strategy

There is much to be accomplished to enable autonomous flight and operations, but the most important needs identified are listed below.

3.1. Communications

Use of voice: How do we introduce autonomy in a voice-dominated ecosystem? The MVP will initially use some type of voice control that will require human transcription or natural language processing that can handle regional terms, regional speech patterns and accents, and poor connections. For longer term capability, a fully text-based and robust message set is needed along with communication standards.

Air-to-ground link: Near term, the service provider wants to communicate directly with the operator and not the vehicle. The vehicle should not act as a relay of communication between the service provider and the operator (i.e., decision maker). In the near term the operator may be performing piloting or command and control functions for the vehicle (perhaps in one operator to many vehicle paradigms) and so can perform direct communication with service providers. The service provider should be able to communicate with the decision maker instructions such as “change of trajectory” and responses such as “unable”. The communication links and protocols should support trajectory negotiation between the vehicle (operator/decision maker) and the service provider on the ground.

Vehicle-to-vehicle links: In addition, communication dropout needs to be addressed, and to improve safety, there must be vehicle-to-vehicle communication, including communication between autonomous and human-piloted vehicles. Vehicle-to-vehicle communication will be increasingly needed to support functions that gradually transfer to the vehicles, such as separation assurance and merging into traffic streams.

Cloud-based communication: The cloud may increasingly serve as a mechanism for communicating and sharing a wide range of information, such as automated PIREPS, weather information, wind measurements, maps of ambient noise or noise of overflights, up to date obstacle data, maps of emergency landing sites, and maps of hazardous materials.

Communication technologies: For unmanned aircraft system (UAS) traffic management systems, commercial communication and navigation technologies such as LTE and 5G are being explored, but state-of-research and synchronization between commercial and aviation groups is poor and needs improvement. CPDLC (controller pilot data link communications) and its message set were not designed to replace voice and may only serve as near-term solution; but ultimately new infrastructure and robust message sets that support autonomous functions and increasingly replace voice will be needed.

Communication security: we do not have secure scalable communication solutions.

3.2. Detect and Avoid

Low-altitude, robust, non-cooperative detect and avoid systems will be needed. An autonomous detect and avoid (DAA)/sense and avoid (SAA) is needed to maintain the safety of the vehicle with respect to other vehicles and hazards where there might not be enough time for a human to respond and for improved scalability of operations since providing human-based safety services will be limited by workload. DAA/SAA systems will likely be required onboard the vehicle to maintain safety in cases of communication loss.

3.3. Health Monitoring and Contingencies

Both long-term, full-authority contingency management and short-term autonomous mitigation for common contingencies are required. For this, diagnostic and prognostic technologies will be needed, as well as data assurance and sensor fault detection methods.

3.4. Landing

Short-term autonomous systems will require an all-weather instrument landing system (ILS) with precision landing capability that will rely on perception technologies and/or airport infrastructure. For longer term, an inexpensive autonomous landing infrastructure solution is needed.

3.5. Surface Operations

Technology for safe surface operations of autonomous aircraft is necessary. Longer term, technologies for autonomously preparing aircraft and pre-flight safety inspection will help reduce costs and improve turnaround time. These technologies could also be applied to piloted vehicles.

3.6. Navigation

In flight, and a robust, all-weather, low-cost navigation system for GPS-denied locations will be needed.

3.7. Certification

The data required for rigorous certification of autonomous systems must be established. Additionally, the certification role must be clearly assigned. There must also be a safety assurance process for data (i.e., cloud, radar) and services provided (i.e., weather information), and verification and validation of autonomous decisions.

3.8. Human Autonomy Teaming

For successful autonomy teaming, clear lines of authority must be established as well as the ability to handoff authority for human intervention in a contingency situation. Support technologies, best practices, and standards for simplified vehicle and M:N remote supervisory operations will be needed.

3.9. Airspace Integration

A key tradeoff in the integration of autonomous vehicles into the airspace is how much the autonomous vehicle's operation adheres to the current airspace structure versus how much the airspace structure changes to accommodate the autonomous operation. In the near-term, it is likely that vehicle operation will need to adhere to many of the current airspace structures that are difficult to change. However, a long-term solution needs to revisit the airspace structure, in terms of rules, regulations, procedures, etc. and make the necessary changes to provide the scalability needed for high-tempo autonomous operations (as well as other high-temp new entrant operations such as urban air mobility and UAS).

3.10. Data

With data from multiple sources, the computer must be able to make distinctions in order to make decisions. There must also be a way to detect bad data. What data services will require certification or validation, and how will this be accomplished?

There is a strong need for large quantities of quality, relevant, labeled data sets to train machine-learning algorithms, build models, and certify technologies.

3.11. Other Challenges and General Thoughts

Cloud-based computing for autonomous systems can provide performance advantages and efficiency through shared resources, but the challenge to their adoption is the assurance of secure, reliable communication links. Information services and shared services such as weather should be considered, especially those currently available from commercial and public sources.

The challenges and considerations by one of the two tracks is summarized in Figure 3-1.

VEHICLE	OPERATIONAL
• Secure, reliable communication links • Sense and avoid (taxi and flight) • Vehicle contingency management • Vehicle diagnostics and prognostics • Assurance methods • Resilient GNC •	• Air traffic control (ATC)/NAS integration • Regional airline associations and training (ground service operations, dispatch, ground crew) • Communications protocols – digital and voice • Operational contingency management • Scalability • Acceptance • Economics business case • Controlled/uncontrolled airspace compatibility ▪ ATC interaction ▪ Traffic rule conformance • Minimum equipage

Fig. 3-1. Autonomy Challenges.

4. Collaboration Topics Where NASA Research Could Help

Workshop participants were asked to help identify areas that 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. The following areas were identified:

4.1. Airspace Integration

Participants identified airspace integration as one of the top areas where NASA could help. This included airspace infrastructure technology as well as standards and best practices for integrating into the National Airspace System (NAS).

Specifically, many of the participants were interested in communication technologies. They were interested in NASA developing ATC clearance requirements for airport-to-airport operations and communicating clearance changes. They also suggested that NASA could identify the complete set of information that an autonomous system needs to be compliant with ATC. Participants also explicitly identified NASA could help tailor procedures and communication paradigms to autonomous operations.

They were interested in modeling the impact of autonomous vehicles and operations in the NAS and evaluating the effects of non-cooperative aircraft. They were also interested in technologies and standards for predictable, communicated, and fail-safe system-wide contingency management.

4.2 Ground Infrastructure

In the near-term, NASA could evaluate if the current infrastructure is capable of supporting autonomous operations and identify technological gaps. Long-term, NASA could create concepts of operations and enabling technologies for completely autonomous ground operations.

4.3. Certification and Testing

Another major area where the participants felt NASA and the FAA could contribute is in the identification of standards and best practices for the testing and certification of autonomous systems and vehicles.

4.4. Data

Participants also identified that NASA and the government could produce and distribute relevant, labeled datasets for creation of models and certification of technologies. This is an area that frequently comes up in discussions with academia and industry. Example datasets could include sensor data from multiple aircraft, surveillance data needed for detect and avoid systems, and data from military unmanned aircraft operations.

4.5. Safety and Robust/Resilient Technologies

Finally, the participants felt that NASA could help with technologies for maintaining safety. Notably this included exploring non-GPS navigation sources, redundancy, and how to monitor integrity along with technology to enable weather-tolerant autonomous operations

NASA could also contribute to defining safety and performance thresholds for autonomy and define “safe” for various MVPs. This could also include the definition of safety metrics, assisting in the quantification of safety to inform autonomous decision making.

Participants also identified technologies and practices for designing for resiliency.

5. Action Plan for Collective Demonstrations

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

The participants also identified a number of attributes that a potential demonstration could include:

- Capability to modify autonomous instrument flight rules (IFR) flight plan to adapt to dynamic changes in flight plan requirements (strategic and tactical)
- Early flight scenarios that emulate an ATC environment
- Early flight demos that include cargo class operations at civil airports and early remote supervisory operations
- Demonstrations to identify emergency landing site(s) and then execute the reroute
- Sequencing and then test vehicle deconfliction
- Demonstration and investigation of vehicle-to-vehicle communication methods and their uses
- Concept for supporting shared situational awareness between aircraft and ground
- Use of a fleet manager to manage communications between aircraft and ground
- Demonstration to determine workable number of aircraft a human can manage at a given time.
- Examination of communications issues from digital and voice mode incongruences, such as:
    - Running machine learning algorithms in shadow of actual operations to acquire training data for natural language processing
    - Standardizing language/commands for conducting entire flight
    - Examining how a human (be the natural language processor) can do the job as intermediary between digital comm from aircraft and voice comm with ATC
    - Leveraging work from major data product providers, e.g., Google
    - Testing and developing neural network system for communication
    - Standardizing and augment CPDLC
- Demonstration of intent communication capabilities so that surrounding operators can respond to the off-nominal event
- Data/information requirements, e.g., for an aircraft to execute its mission
- Minimum operation performance standards for safety requirements
- Use of existing system that could serve an analogy to target system and reconcile that system's capabilities against the needs of the concept.
- Reconciliation of differences between information we have on our maps and what we need to facilitate safe navigation

The participants discussed how some technologies could be demonstrated in current mid-sized cargo (possibly in shadow mode), where higher-risk technologies could first be demonstrated in sUAS surrogate environments. These technologies could later be combined as illustrated in Figure 5-1.

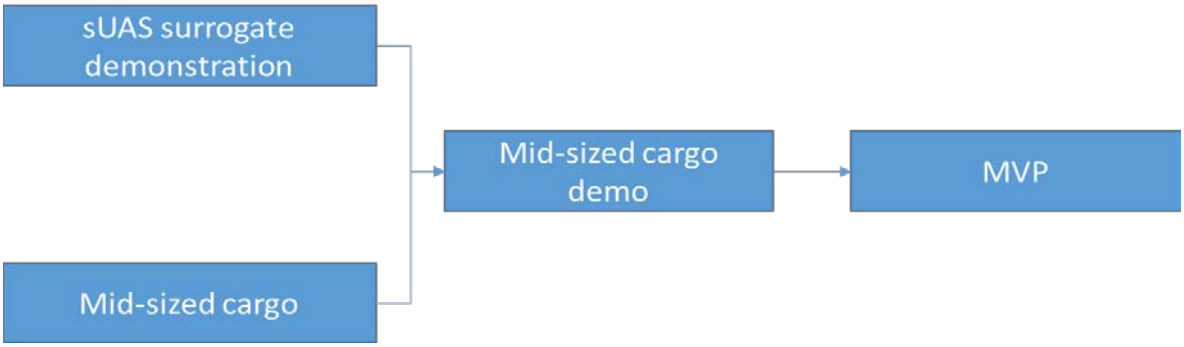

Figure 5-1. Potential Demonstration Routes

Acknowledgements

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Appendix 1: Workshop Agenda

ENABLING AUTONOMOUS FLIGHT AND OPERATIONS IN THE NATIONAL AIRSPACE SYSTEM WORKSHOP 1 TUESDAY, APRIL 23, 2019 (DAY 1)		
TIME	**ITEM**	**PRESENTER**
7:30am – 8:30am	Registration	
8:30am – 8:45am	Welcome, Logistics, and Workshop Goals	Dr. Parimal Kopardekar Acting Director, NARI, NASA
8:45am – 9:00am	**OVERVIEW:** NASA Aeronautics' Vision	Dr. Jaiwon Shin Associate Administrator, ARMD, NASA
9:00am – 9:30am	**KEYNOTE:** Lessons Learned from Autonomous Cars	Dr. Sebastian Thrun CEO, Kitty Hawk Corporation
9:30am – 10:00am	**KEYNOTE:** Lessons Learned from Autonomous Small UAS	Dr. Sanjiv Singh CEO, Near Earth Autonomy
10:00am – 10:30am	*Break*	*All*
10:30am – 10:45am	**KEYNOTE:** Reduced Crew Operations	Raj Singh Managing Director, JetBlue Technology Ventures
10:45am – 11:15am	**KEYNOTE:** Certification Considerations for Autonomous Flight & Ops	Dr. Michael Romanowski Director, Policy & Innovation, Aircraft Certification Service, FAA
11:15am – 12:15pm	**KEYNOTE:** Perspective on Autonomous Mid-size Cargo /Freighters & Reduced Crew Transport-Category Aircraft	Joseph Keegan Director, Autonomous Systems and Disruptive Mobility, The Boeing Company
12:15pm –12:30pm	Breakout session instructions	Dr. Parimal Kopardekar
12:30am – 1:30pm	*Lunch*	*All*
1:30pm – 4:30pm	**BREAKOUT SESSION 1:** Identify needs, MVPs, & progression towards autonomous operation, including ground systems & cloud-based capability levels.	Vanessa Aubuchon, NASA Ferne Friedman-Berg, FAA Sandy Lozito, NASA Jill Marlowe, NASA
4:30pm – 5:00pm	Wrap-up	Dr. Parimal Kopardekar

ENABLING AUTONOMOUS FLIGHT AND OPERATIONS IN THE NATIONAL AIRSPACE SYSTEM WORKSHOP 1 WEDNESDAY, APRIL 24, 2019 (DAY 2)		
TIME	**ITEM**	**PRESENTER**
8:00am – 8:30am	**KEYNOTE:** FAA & Innovation	Carl Burleson Acting Deputy Administrator, FAA
8:30am – 9:45am	**PANEL:** Autonomy Considerations, Operational Needs, and Research Gaps Moderator: Dr. John Cavolowsky, Director, Transformative Aeronautics Concepts Program, NASA	Prof. Ella Atkins, University of Michigan Andy Lacher, MITRE – ASTM Prof. Amy Pritchett, Penn State University Wes Ryan, FAA Capt. Bill Secord, FedEx – Air Line Pilots Assoc.
9:45am – 10:00am	*Break*	*All*
10:00am –11:30am	**BREAKOUT SESSION 2:** Identify research gaps, needs, & strategy to implement increasingly autonomous ops in complex airspace and areas.	Irene Gregory, NASA Husni Idris, NASA Wes Ryan, FAA Confesor Santiago, NASA
11:30am – 12:30pm	*Lunch*	*All*
12:30pm – 2:00pm	**BREAKOUT SESSION 3:** Identify action plan for collective demonstrations & operational implementation of increasingly autonomous systems in the NAS	Karen Tung Cate, NASA Natasha Neogi, NASA Mark Skoog, NASA Chris Teubert, NASA
2:00pm – 2:15pm	*Break*	*All*
2:15pm – 3:30pm	**BREAKOUT SESSIONS 1-3 REPORT:** Autonomous Medium-size Cargo/Freighters	Chris Teubert, NASA
3:30pm – 4:45pm	**BREAKOUT SESSIONS 1-3 REPORT:** RCO for Domestic & International Aircraft	Vanessa Aubuchon, NASA
4:45pm – 5:00pm	Wrap-up and Next Steps	Dr. Parimal Kopardekar