m:N WORKING GROUP

ANNUAL STATUS REPORT

ANNUAL SUMMARY

September 30, 2022 – September 30, 2023

EXECUTIVE SUMMARY

This document serves as an annual report of m:N Unmanned Aircraft Systems (UAS) subgroup activities, addressed challenges, and roadmaps for the future. The subgroups consist of small Unmanned Aircraft Systems (sUAS), Large UAS, High Altitude Platform Systems (HAPS), and Urban Air Mobility (UAM). Also included in this report are participant lists for each subgroup (Appendix B) and future roadmap and outreach plans.

The subgroups meet in a virtual format multiple times throughout the year. Twice a year, participants from all the subgroups come together as part of the m:N working group to brief each other in person on progress, challenges, and path forward ideas for successful incorporation of UAS into the airspace.

Recent m:N in person meetings include:

- November 29-30, 2022 at the NASA Ames Research Center in Mountain View, CA
- May 9 & 11, 2023 at AUVSI's Xponential conference in Denver, CO
- The next in person working group meeting is planned for November 28-30, 2023 at NASA Langley in Hampton, Virginia

The m:N UAS working group is run by Jay Shively (Adaptive Aerospace) and Andy Thurling (Thurling Aero Consulting) and is comprised of members from government, industry, and academia in an effort to identify and reduce barriers to m:N operations. This effort also includes identifying requirements, use cases, and metrics to support organizations and groups including the Federal Aviation Administration (FAA) and Radio Technical Commission for Aeronautics (RTCA's) SC-228 Detect and Avoid committee. Each subgroup is run by a government/industry team which includes:

sUAS Subgroup
Garrett Sadler (NASA)
Scott Scheff (HF Designworks)

Large UAS Subgroup
Husni Idris (NASA)
Brandon Suarez (Reliable Robotics)

HAPS Subgroup
Andy Thurling (Thurling Aero Consulting)
Jeff Homola (NASA)

UAM Subgroup
Jay Shively (Adaptive Aerospace)
Mike Politowicz (NASA)

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Challenge Statement

How do we properly integrate UAS into the airspace knowing that we have such a variety of platforms, use cases, and potential operator types?

What does integration look like in the near-term, mid-term, and far-term?

What might some of the challenges be to success?

To meet the above statements, subgroups discuss lessons learned from today's autonomous and semi-autonomous operations, current research, and work to plan out a roadmap for incorporating UAS into the civilian airspace. As part of this work, definitions and terminology for operator types and scenarios were developed, as they relate to their associated subgroup. The subgroups also discuss near term, mid-term, and long term use cases, identify what technologies would be needed, and what the timelines look like for sUAS, large UAS, UAM, and HAPS.

This next section of the report will summarize each subgroup's activities for the past year.

sUAS Working Group

The primary goals of the sUAS working group are to help identify, discuss, and resolve sUAS barriers under the m:N paradigm. This includes technical, operational, regulatory/policy, and public acceptability. The sUAS working group aims to help further define sUAS use cases in support of the FAA and Operational Services and Environmental Definition (OSED) documentation. The sUAS use cases focus on survey/inspection and package delivery scenarios, Detect and Avoid (DAA) alerting and guidance, and interactions with other sUAS as well as general public perception of sUAS.

Recent Meeting Dates:
August 31, 2023
May 09, 2023
March 30, 2023
January 19, 2023
September 29, 2022

Upcoming Meeting Date:
November 28-30, 2023

A further summary of sUAS work is included in the following pages.

sUAS Meeting Structure

The sUAS working group meets quarterly and is led by:

- Garret Sadler, Co-Lead (NASA)
- Scott Scheff, Co-Lead (HF Designworks)
- Meghan Saephan, Member-at-Large (NASA)
- Phillip Walker, Member-at-Large (SIFT)

sUAS working group meetings are 90 minutes long and typically organized around introductions, announcements, and a guest speaker for the first half hour. The remaining hour is devoted to discussing and solving some of the larger sUAS challenges in terms of airspace integration, technology readiness, operator training, and public acceptance.

Guest speakers are members of the sUAS group that share areas of research they are currently focused on as it relates to sUAS. When pertinent, the sUAS working group opens the discussion up to other subgroups (such as when Autumn Alderdice, Aviation Safety Inspector with the FAA gave a talk on the "FAA Evaluation and Approval Process for Many to 1 in Commercial UAS Applications").

sUAS discussions over this past year have included definitions [sUAS, Pilot In Command (PIC), *m*, *N*, etc.], use cases (near term and far term), and most recently discussions around safety, automation, and complexity in a UAS environment.

Note that beginning with the January 19th meeting, the Swarms working group combined with the sUAS working group and Swarm co-leads Meghan Saephan and Phillip Walker became members-at-large of the sUAS working group.

A further breakdown of sUAS discussion points can be found below.

Definitions

As with all the subgroups, initially, there generally was not a well-accepted definition of many of the key terms surrounding the platform types, operations, and operators. The sUAS subgroup met over the past year to come to a mutual agreement on the following definitions:

sUAS - Sub-class of UAS that are <55lbs; fly <400 ft AGL; fall under Part 101 (recreation)/part 107 (commercial); have varying degrees of automation; and can be used for small payload delivery, aerial recon, agriculture, infrastructure inspection, emergency services, military/DoD

Swarm - Sub-class of a multi-agent system where members must interact with each other to cooperatively accomplish high-level goals (versus purely dividing labor among members)

m – a remote operator with control authority (able to make a change in behavior of) over a drone. There will be an assumption of a single accountable person, this person could be responsible for more than one vehicle. Note that the sUAS subgroup is considering avoiding the use of the term remote pilot or pilot. Pilot is not defined in the regulations. PIC and Remote Pilot In Command (RPIC) are defined; but there are stipulations surrounding "pilot".

N – the number of simultaneous aircraft in "flight" that are controlled or supervised by a single remote operator. Some of these aircraft might be in pre-flight, but those are potentially managed by someone else.

Remote Operator – a person, or persons who provide commands to the autonomous systems. Will have ability to communicate with air traffic management network (dependent on requirements/regulations). Has the ability and authority to change the behavior of the autonomous system based off their own decision criteria.

UAS Service Supplier (USS) – USS nominally provides strategic deconfliction. Could additionally provide information about weather, UAS Volume Restrictions (UVRs), etc. but there is not a standardization on these aspects

Air Traffic Controller (ATC) – sUAS can currently operate with USS and without the need for ATC coordination. However under some circumstances, such as an aircraft going rogue, ATC would potentially need to be notified, especially if the aircraft enters the UTM environment.

Roadmap Challenges

The sUAS working group has been developing a list of roadmap challenges with mitigations and timeline plans for 1 year, 5 years, and 10 years out. **A list of sUAS barriers and mitigation plans can be found in Appendix C**.

Use Cases

The sUAS subgroup has developed two use cases which they used to help identify roles, technologies, constraints, and requirements. Use case #1 is for current day operations involving inspection/power line surveying with sUAS. Use case #2 is longer term (10 years out) and involves swarms of sUAS for package delivery.

Use Case 1: Inspection/Power Line Surveying with sUAS

For use case #1 the assumption is that there are multiple sUAS covering a large area, necessitating m:N operations.

Use case #1 is further broken down as follows:

Operators/Key Roles

- Remote operators
- Operations center supervising managing the remote operators
- Someone to monitor feeds from sUAS to make sure nothing is missed, or to make sure a power line isn't getting obscured
- Manager to coordinate with outside entities

Hardware platforms, limitations, and capabilities

- Beyond Visual Line of Sight (BVLOS) challenges including lost link and the cost effectiveness of a Detect And Avoid (DAA) solution
- Weather and the challenges of operating in cloudy environments, light rain, wind, etc.
- Security
- Auto responses to allow for higher 1:N ratios

Technology Constraints/Barriers

- Light Detection and Ranging (LiDAR) limitations and capabilities for DAA
- Size, Weight, and Power (SWaP) tradeoffs with sensor payloads and safety/redundant systems
- Flight duration/endurance
- Communications infrastructure/robustness. Logistics of managing multiple sUAS that are in various parts of their mission and will need to come in and out for refueling/recharging, maintenance, etc.
- Ground Control Station (GCS) capabilities and logistics of managing multiple sUAS. Need a User Interface (UI) that enables operators to run these envisioned missions.

Environment

- Considering BVLOS, rural, urban, weather, flight restrictions, and infrastructure (comms, power, internet, etc.)

Training needs

- What experience will the remote operator be coming to the table with, what will their background be?
- Credentials
- Crew resource management
- Training on DAA, BVLOS, scenarios, how to interact with manned pilots
- Understanding sensor data
- Understanding how to use the displays
- Emergency response plans and contingency management
- Crew coordination training including how to offload control from one operator to another
- Operations role training

Public Acceptance

- Public acceptance of powerline surveying in non-populated areas vs. in a city
- Public announcements that sUAS exercises are going on
- Have universal signage when sUAS activity is occurring so it enters the public consciousness
- Show that systems work
- Inform public who is in control; who orchestrates each event – today the public doesn't have much knowledge of manned operations but maybe at first, we want this for sUAS operations as they start to come on line.

Additional Research Needed

- Sociological research on public acceptance
- Well clear (including altitude) between manned/unmanned platforms
- What is the optimum number of assets one (or a few) people can handle
- How much of the tasking is given to the platform vs. the operator
- User interfaces
- Human-system work allocation
- Emergency procedures

What data might be needed for a safety case

- Flight safety records
- Mean Time Between Failure (MTBF)

- BVLOS 91-113b [Part 91 of the Code of Federal Regulations, Title 14, which deals with general flight rules, to handle beyond-visual-line-of-sight (BVLOS) operations]
- DAA sensors
- Lost Link/Loss of Control
- Training records, proof of a credible training program
- Proof of right personnel (remote operators, maintainers, etc.)

Use Case 2: sUAS Swarms

For use case #2, Swarms of sUAS will be used for package delivery. Under this use case, multiple sUAS will be entering and leaving a distribution hub.

Operators/Key Roles

- Remote operators
- Manager of operations
- Airspace coordination – UTM, USS, etc.
- Package delivery/logistics companies

Hardware platforms, limitations, and capabilities

- DAA for all elements: crewed, uncrewed, weather, terrain
- SWaP of aircraft and payload
- Supply chain availability
- Security and trust – particularly cybersecurity of swarm operations
- Last mile considerations
- Battery capability
- Workload management
- 5G build out/infrastructure
- Software and firmware updates, testing, scheduling, consistency, and homogeneity
    - Getting FAA approval for software updates – process of approval as well as update cadence
- Landing locations, especially ad hoc

Technology Constraints/Barriers

- Technology to enable advanced management via UTM
- Need to characterize how vehicles of different sizes and payloads will interact with each other
- Fuel, battery, energy constraints
- Security and trust, particularly cybersecurity of swarm operations
- Last mile considerations
- Understanding and controlling for emergent behavior of swarm
- Designing testing for understanding emergent behavior
- Communication hardware and software updates – handling bandwidth, radio frequency management
- Sensors (i.e., DAA), SWaP concerns
- Bandwidth challenges – DAA, Remote ID
- Deconfliction among swarm members – landing spots, charging pads, etc. (need to identify and then figure out how many can safely land in a specific area).

Environment

- Urban, cities

- Micro-climates of urban canyons
- Modeling and technology for safe navigation of the urban environment: obstacles, micro-weather, very local forecasting
- Farm/Agriculture
- Forest
- GPS denied environments
- Repeated patterns in swarms: groups of drones may regularly operate in an area of way that changes the environment (e.g., for wildlife or people in the area)

Training needs

- Workload and SA management techniques
- Fatigue monitoring and management of operators
- Training for how to identify unexpected or off-nominal behaviors (e.g., emergent behaviors of swarms)
- Reference analogues of emergent behavior from current-day operations
- How to prevent unwanted emergent behaviors or mitigate them before they become a problem behavior
- Training on potentially different interfaces given type and capability of swarm
- How is training regulated? How do we know the training is sufficient? How do we know the user is adequately trained?
- Put training standards/certifications in place. System and operator both determined to be safe. Consistent evaluations

Public Acceptance

- Pollution and noise
- Lots of small aircraft in the sky
- Security and trust, particularly cybersecurity of swarm operations. Attack can be on hundreds of coordinating vehicles.
- Knowing that operators are adequately trained and that safeguards are in place

Additional Research Needed

- Sociological research on public acceptance
- Well clear (including altitude) between manned/unmanned platforms
- User interfaces
- Human-system work allocation
- Emergency procedures
- State of the art in terms of technology capabilities – how far can LiDAR go, range for comms, etc.
- Simulations to prove out concepts, how to you make them credible and easy to train on
- Pushing updates – how, when. How to you keep consistent across platforms
- Establishing trust between different entities that are part of the overall system.
- Identifying and being able to accommodate for ad hoc landing locations
- When/how does the human interject themselves (nominal vs. off-nominal)

What data might be needed for a safety case

- Flight safety records
- Mean Time Between Failure (MTBF)

- BVLOS 91-113b [Part 91 of the Code of Federal Regulations, Title 14, which deals with general flight rules, to handle beyond-visual-line-of-sight (BVLOS) operations]
- DAA sensors
- Lost Link/Loss of Control
- Training records, proof of a credible training program
- Proof of right personnel (remote operators, maintainers, etc.)
- Safety handbooks, protocols, contingency scenarios, emergency response plants, SMS data, etc.
- Mission approval – location approval (including proper routes and contingencies for when things go wrong/different than planned), personnel, hardware platforms, permits.
- At what points might we see breaks in the system when we scale to swarm activity where you have a concentrated number of homogenous vehicles working together?

Safety, Automation, and Complexity in the UAS Environment – Moving Forward

The sUAS working group has identified a list of key takeaways, including the need for regulatory mechanisms that can accommodate small system updates without requiring certification. The subgroup feels that the specific m:N ratio is not as important as the capability and reliability of the system. There is also a need to define who is included in the “m” category.

The mature state of sUAS operations will be characterized by highly autonomous fleets which manage their own safe outcomes and seamless integration into airspace with others, responsive to dynamic demands and constraints. The role of the human will shift towards strategic, higher-level tasking rather than direct vehicle control. Additionally, the sUAS subgroup recognizes that delivery companies desire a high level of autonomy where vehicles can self-correct with low human intervention. Trust in autonomy is restricted by external, non-autonomous factors, and humans are still needed for critical decision-making and troubleshooting.

The suggested timeline for the package delivery use case from today is 0-3 years for near-term, 3-8 years for mid-term, and 8+ years for far-term. The service area would progress from low-density, rural areas in the near-term, to low-density suburban or small cities in the mid-term, and finally to major cities in the far-term.

Remaining questions revolve around aligning regulatory timelines with technological advancements, enabling high degrees of autonomy through research, defining the “*m*” in m:N, and addressing security requirements for large-scale sUAS operations in the civilian airspace.

Additionally, in the future the role of *m* could change as *N* increases. There could be more of a human on the loop rather than human in the loop; with the human taking on more of a supervisory role. There will also be a need to understand the potential for multiple, overlapping incidents. If the probability of these incidents increases, that will affect the ratio. Over time as technologies improve automation is expected to increase. As has been found in other industries and from lessons learned with Loon HAPS, higher level of automation/autonomy can degrade operator vigilance. The operator will need to decide on standard tasks that promote engagement, optimize workload, and maintain situational awareness (SA). As a path forward the sUAS working group will need to look at meaningful human control; designing throughout the lifecycle to optimize use of human capabilities.

Large UAS Working Group

The primary goals of the Large UAS working group is to help identify, discuss, and resolve Large UAS barriers under the m:N paradigm. This includes technical, operational, regulatory/policy, and public acceptability. The Large UAS working group aims to help further define Large UAS use cases in support of the FAA and OSED documentation. The Large UAS use cases focus on encounter scenarios, traffic display, DAA alerting and guidance, and ATC interactions.

Recent Meeting Dates:
September 7, 2023
February 9, 2023
November 29-30, 2022

Upcoming Meeting Date:
September 28, 2023
November 2, 2023
November 16, 2023
November 28-30, 2023

A summary of Large UAS work is included in the following pages.

Large UAS

The Large UAS working group is led by:

- Husni Idris, Co-Lead (NASA)
- Brandon Suarez, Co-Lead (Reliable Robotics)

The Large UAS working group has been tackling the following challenges:

1. Pilot shortage and the desire for transition to remotely supervised control of multiple aircraft

2. Both long range and regional operations with moderate-to-high density and complexity

3. Can the Pilot in Command (PIC) with automation assistance resolve conflicts and avoid congestion strategically before the controller is involved?

4. High workload for the PIC when supervising multiple vehicles with different performances, phases of flight, Command and Control (C2) latencies, environments (controlled or uncontrolled airspace), etc.

The large UAS working group continues refining their use cases, assessing feasibility and impacts of potential concept elements including development of metrics and models, as well as data analyses for validation. The subgroup also provides insights into other groups and programs including working with members of NASA's PAAV project (Pathfinding for Airspace with Autonomous Vehicles).

The large UAS working group also explores current m:N research including remote pilot complexity metrics and assessments, as well as remote pilot trajectory management. The working group also discusses generating Visual Flight Rules (VFR) heat maps, VFR traffic patterns and identifying encounter scenarios, intent and trajectory models, and understanding VFR data quality and limitations.

Leveraging research and discussions, there are currently two use cases the Large UAS group has developed and works with; one for near-term and one for mid-term (intermediate).

Near-Term Large UAS Near-Term Use Case: Point-to-Point Cargo Operations

In the near-term use case, assumptions include point-to-point cargo operations under Instrument Flight Rules (IFR) with minimal ATC interaction, normal Very High Frequency (VHF) voice communication through the aircraft, no changes to ATC infrastructure, and remote pilots trained for m:N operations.

The environment consists of IFR enroute operations with naturally low densities (altitude doesn't affect density, as all airspace above the Minimum Enroute Altitude for the route is controlled) which allows one aircraft to be in "high tempo" phase (e.g., surface, take-off, departure, approach, landing). Additionally, the assumption is that one remote pilot can handle two aircraft enroute under nominal conditions. Under the m:N ratio, two remote pilots would be responsible for approximately three aircraft during all nominal phases of flight. That being said, remote operators can share tasks for the same vehicle and, at times, one remote pilot may focus on one or two aircraft.

The role of PICs involves voice communication with ATC (this would be the primary bottleneck for determining "*N*"), flight plan updates for weather and other operational reasons, and contingency/emergency management with the option to switch back to 1:1 if needed. The technologies would include an airborne DAA system with manual pilot response and satellite communication (SATCOM) datalinks for Command and Non-Payload Communications (CNPC) or terrestrial networks with similar latency, with a maximum utilization of Datacom.

Functions involve assistance from Dispatcher/Supervisor to manage workload and scheduling, shared avionics between remote pilots, Crew Resource Management (CRM) training updates, the ability to introduce new or swap existing crew members during flight, and the consideration of automation as a team member. With regard to automation, operations would be conducted using full autopilot (no hand-flying) with flight plan and flight path validation and automated checklists.

The goal is to maintain the timeline by keeping additional work to only Operational Approval. Operational approval is estimated to take approximately 3 years.

Near-Term Large UAS Use Case: Key Takeaways

The first major key takeaway from the large UAS subgroup's near-term use case for m:N operations is the need for flexibility in determining future ratios. The FAA would rather know ahead of time if the ultimate goal is a higher ratio, such as 5:50 or higher. Secondly, the group identified important human factors considerations for display and GCS modifications to enable m:N operations. This includes addressing how to best monitor critical flight information, perform handoffs between remote pilots, and treat automated systems as teammates. Lastly, the primary bottleneck in determining the appropriate "*N*" for the near-term use case is the amount of voice communication required. The group noted that the "*N*" value could be higher if operations are conducted in particularly low-density areas or if technologies are developed to reduce the voice communication workload.

Large UAS Mid-Term (Intermediate) Use Case

In the intermediate use case for large UAS, the goals are to increase the m:N ratio and relax operational tempo constraints, which can be achieved with the assumption that new certified hardware would come in at a lower cost per unit in the future. Other assumptions include point-to-point IFR cargo operations, enabling VHF voice communication through the aircraft, changes to ATC infrastructure for ground-ground voice communication, and the addition of a new remote crew member (e.g., a dispatcher trained in m:N operations).

The environment consists of low densities in enroute airspace and medium to high densities in published departure and arrival procedures. The proposed m:N ratio involves two remote pilots responsible for approximately six aircraft during departure, enroute, and arrival.

The PIC's role includes flight plan updates for weather and other operational reasons, as well as contingency/emergency management with a potential switch back to 1:1 if needed. Technologies such as airborne DAA with Auto-RA (Resolution Authority), SATCOM datalinks for CNPC or terrestrial networks with similar latency, ground-ground voice communications, and a maximized utilization of Datacom.

Functions include a fleet control interface, dynamic assignment of aircraft to remote pilot, and seamless handoffs within a control center. Automation involves full autopilot (no hand-flying), flight plan and path validation, automated Airborne Collision Avoidance System (ACAS) X for Large UAS (ACAS Xu) Resolution Advisories (RA) execution, and automated checklists with resolutions.

The timeline for implementing these operations is estimated to be 5+ years after initial operations; which would be approximately 9-10 years from now.

ATC Interactions in a UAM landscape

At the most recent meeting (September 7, 2023), the Large UAS group discussed the role of ATC and its interactions within a UAM environment. Identified issues surrounding ATC interactions include those related to clearance/call delivery, clearance/call receipt, clearance/call response, clearance/call execution, and behavior differences from crewed or 1:1 UAS flights. Pertaining to these issues, the following assumptions were made:

- UAS flight has one or more human "at the controls" who is/are simultaneously "at the controls" of one or more other UAS flights
- UAS operates within the NAS without the use of corridors and/or segregated airspace
- Problems of 1:1 are solved and those UAS are already flying
- Automation is available to assist with tasks
- "PIC" and legal responsibility will be discussed at a later meeting

Discussions have included the need for situation awareness tools/impactful user interface design (to support voice comms and data link), automation (automated clearance readbacks, maneuver response, checks for command input errors), procedures and best practices (including prioritizing responding to clearances/maneuvers over calls/advisories, mitigation to prevent step-ons when making calls due to DAA warning-level alerts, ATC pre-coordination to facilitate a common operating picture of expected UAS behavior in different situations), and role and responsibilities.

Leveraging PAAV work, a notional command center solution was also suggested and can be found in the figure 1.

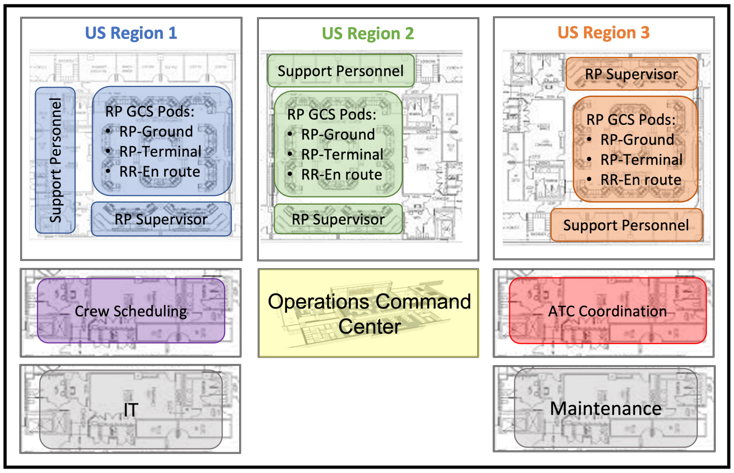


Figure 1. Notional Ops Center as envisioned by PAAV Tabletop 4 Participants

Image courtesy of: C. Wolter, K. Davikoff, and C. Rorie, "Pathfinding for airspace with autonomous vehicles (PAAV) tabletop 4 report," NASA/TM-2023-0006884, NASA Ames Research Center, Moffett Field, CA, March 2023.

For next steps the Large UAS working group will continue refining their use cases as well as assess feasibility and impacts of potential concept elements including development of metrics and models, as well as data analyses for validation.

UAM Working Group

The Urban Air Mobility (UAM) working group looks at how UAM enables highly automated, cooperative, passenger or cargo-carrying air transportation services in and around urban areas. This working group leverages the FAA UAM CONOPS (Concept of Operations), v. 2.0 dated April 26, 2023

Recent Meeting Dates:
September 15, 2023
July 14, 2023
November 29-30, 2022

Upcoming Meeting Date:
November 28-30, 2023

A summary of UAM work is included in the following pages.

UAM

The UAM working group meets at multiple points in the year. Meetings typically include member presentation topics and then deep dive into challenges, use cases, and definitions surrounding UAM. The UAM working group is led by:

- Mike Politowicz, Co-Lead (NASA)
- Jay Shively, Co-Lead (Adaptive Aerospace)
- Scott Scheff, Member-at-Large (HF Designworks)

Recent UAM outputs have included defining longer-term (10+ years out) operations. As part of this use case development the UAM working group investigated the following challenges:

1. How do you transition to remote operators when you start with onboard pilots?
2. What challenges are associated with carrying passengers?
3. What are some of the barriers for autonomous flight (e.g., regulations)?
4. What are some UAM-specific requirements (e.g., corridors)?

Key considerations for the above challenges include:

- Authority vs. responsibility vs. accountability
- Situation awareness necessary for operator to execute functions
- Vehicle distribution (e.g., multiple geographical regions)
- Handoff criteria (e.g., off-nominal)
- Passenger communications
- Passenger safety regulations
- Transport vs. air tours (i.e., sightseeing)
- Operator medical requirements

The Longer Term use case includes:

Operators/Key players/Related challenges

- PIC – ultimately this role will get subsumed by the Fleet Manager role because automaton will replace the functionality of the PIC
- Fleet Manager – Determines routes and operations by pulling in various data sources including weather. Ensures that capacity matches demand. Serves as a safety planner and dispatcher supervising the fleet (perhaps at some point automation could be good enough that you don't need this). Could handle emergencies such as on board heart attack vs. fire, etc. to determine which aircraft gets priority along a certain route and landing area/vertiport. Makes corner case/edge case decisions that the system might not know or have experienced.
- Maintainer – personnel who maintain the systems. Could be aircraft related but could also be related to peripheral systems (i.e., weather server stops working so someone comes in to get it back on line).
- Decompose human vs. automation tasks (i.e., handling of medical emergencies on board)

Hardware Platforms, Limitation, and Capabilities

- SWaP – limited in how many passengers you are carrying as well as how many batteries the aircraft can carry
- Duration/endurance of aircraft
- Sensor payloads – might be different between cargo and passengers. Redundancy in terms of how many sensors (and this might be different depending on type and use case)
- Mishaps – "Crush Zones" when building a passenger aircraft, imposes design constraints

Technology Constraints/Barriers

- Autonomous flight
- What solutions are needed to make m:N UAM operations a reality – could include the need to reword/tweak sections of the existing Part 91 regulations
- Need to develop new technologies to meet operational and communications needs
- Comms (voice and data) and what happens when comms are denied
- DAA sensors
- Radar Field Of View (FOV) and range
- Operations of sensors in degraded environments
- Security/cyber security and susceptibility
- ADS-B, lighting, emitters – equipment that gets you seen and allows communication of intention
- SWAP, charging stations (locations and amount of them), infrastructure to support all this
- Bandwidth limitations

Environment

- Intra vs. Intercity operations
- Dense vs. Sparse airspace
- Transportation of people vs. cargo
- Origins to destinations directly
- Highest volume possible but keep it safe
- No visibility conditions at times
- Comms challenges at times
- Worse case – High traffic, lack of all comms, fast/slow movers together in the airspace, small/light vs. passenger carrying aircraft, piloted vs. autonomous
- Perhaps autonomous AC can operate closer to each other due to sensor suites
- Collaboration with folks on the ground (location, ETA, etc.)
- Collaboration with first responders
- What kinds and how many platforms are in the vicinity
- Unpredictable route
- Improper route due to malfunction
- System needs to account for what each failure type looks like (i.e., what happens if the aircraft suddenly goes straight down)

Training Needs

- Need to develop new procedures to meet operational and communications needs

- How to prioritize when there is a medical emergency
- Going from low to high workload when issues are encountered

Public Acceptance

- Demonstrate a system that is safer than human piloted
- sUAS could likely pave the way to public acceptance
- Good safety track record
- Show value of system

Additional Research Needed?

- Early vs. Intermediate vs. Mature operations
- Human AI teaming
- AI algorithms, ensuring its clean AI data, robust, and reliable
- Validation of AI that it meets the intent, tradeoffs in mission paths and landing spots in emergency scenarios
- Select, train, and certify those in supervisory roles (note this isn't a traditional role today)

What data might be needed for a safety case?

- Simulation data
- Real world – start by looking at sUAS first
- AI data – Large Language Models (LLM)
- Transportation data on cargo and passenger- where do people and packages go and come from

Additional topics being tackled also include:

- Coming to an agreed upon definition for UAM vs. AAM (Advanced Air Mobility), where UAM is seen as a subset of AAM) types of UAM aircraft, Types of UAM missions, types of UAM operating environments.
- Solving barriers to autonomous flight – solutions are needed to make m:N UAM operations a reality, including the need to reword/tweak sections of the existing Part 91 regulations.
- While there are similarities in visions for mature at scale operations among UAM members, there are also differences which are motivated by different use cases
    - Early vs. Intermediate vs. Mature operations
    - Intra vs. Intercity operations
    - Dense vs. Sparse airspace
    - Transportation of people vs. cargo
- There is still a need to define/understand the role of the pilot and other crew. Perhaps this includes redefining the "Pilot in Command".
    - The PIC is the person aboard the UAM aircraft who is ultimately responsible for the operation and safety during flight. While this CONOPS assumes a pilot onboard the aircraft; operations described do not preclude a remote pilot or automated operations. (FAA UAM CONOPS v2.0)

- Whereas increasing the level of automation onboard an aircraft historically has increased pilot training requirements due to the need for the pilot to be the "backstop" in case of automation failure, the SVO concept is based on the premise that the aircraft operator (i.e., human "pilot") need never be responsible for the functions that the automation handles
    - There is a need to clearly define who is responsible and what they are responsible for.
    - The automation could be responsible for things but at the end of the day there is also accountability and that should fall to the person in the seat. But does this mean the low skilled person? Or is there a manager role above them that holds the accountability?
    - An operator can take into consideration the needs of the passengers where automation might not be able to. Human might be able to come up with better alternatives (i.e., different landing locations).
- There will be a fleet manager role and that person is responsible for managing automated systems. May be assigned to an area, an entire fleet, or a group of platforms. Could be accountable for the PIC/Remote Operator. Fleet manager would/could implement UVRs. Fleet manager could get alerts such as an aircraft on the pad that can't take off and then they would be responsible for identifying maintenance to fix the issue/move the aircraft. Consider how this role relates to current dispatcher role, could have overlapping roles in some cases. Is there a need for a dispatch role if there is a fleet manager - probably and it depends on the scale of the m:N operations and the missions being conducted. Fleet manager could also communicate with passengers.
- There is a need to develop new procedures and technologies to meet operational and communications needs (digital comms, digital flight rules)
- Define/Understand the role of the other crew/ecosystem [to also include UAS Service Supplier (USS) and ATC]
    - PSU (Provider of Services for UAM) - An entity that supports UAM operators with meeting UAM operational requirements that enable safe, efficient, and secure use of the airspace. A PSU is the primary service and data provider for UAM stakeholders and the interface between the UAM ecosystem and the FAA. The PSU can be a separate entity from the UAM operator, or an operator can act as its own PSU. (FAA UAM CONOPS v2.0)
    - The PSU could work within cooperative operative environment perhaps without ATC; essentially another layer.
    - PSU could be more of an organization; several chains of people who handle a service, not just a single person/role.
    - ATC maintains safe movement of aircraft operating within the NAS. For high-density UAM operations this may be accomplished through ATM modernization. ATC will ensure the separation of non-participating aircraft from the cooperative operation and/or cooperative areas (CAs). (FAA UAM CONOPS v2.0)
    - Cooperative Areas - non-ATC maintained ATCE (ATC Environment) High Density - ATC could handle non cooperatives Potential use case - CA corridor that services many airports. Low density at entry point but once inside its high density (exit point as well). ATC responsible up to entry point, then PSU could take over.
    - UAM Operator - The person or entity responsible for the overall management and execution of one or more UAM operations. The operator plans operations, shares

flight information, and ensures infrastructure, equipment, and services are in place to support safe execution of flight. (FAA UAM CONOPS v2.0)
    - This could potentially be a Part 121/135 operator equivalent. This person (or entity) would sign operations agreement with FAA.
        - The company that is conducting the operations would effectively be the UAM operator.
    - UAS Service Supplier (USS) - Entities that support UAS operations under the UTM system. Potential scenarios may exist where USSs and PSUs need to share information to ensure cooperative separation during UAM landing and takeoff phases of flight within UTM environments (i.e., under 400 feet). (FAA UAM CONOPS v2.0)
        - PSU and USS similar notions/functions for different uses/use cases/customers
- Define boxes, corridors, and safety boundaries
    - Understanding our CONOPS with regard to corridors, USS, and ATC interactions
- How is automation enabling UAM operations?
    - i.e., V&V, roles and responsibilities, certification, etc.
- After automation has been fully implemented then what is left?
- What alternatives might be different from m:N that could drive the quantity of aircraft that are monitored, or is it the complexity of the operation? Hypothetically, if the ratio doesn't necessarily matter, what <u>does</u> matter?
    - How might the m change as the N increases?
    - What might guidelines look like for situations where specific ratios of m:N should be maintained?
    - What are the limits on N given a specific m in various scenarios?
    - What assumptions do we need to make about the operators' expected role when *N* is large compared to *m*?
    - Perhaps this boils down to what interventions are required/expected from the human. What is the warning, caution, advisory system like? Even fully automated systems still have people managing them - debugging, maintenance, upgrading, etc. How does criticality of cargo affect appetite for errors, or does it?

Safety, Automation, and Complexity in the UAM Environment – Moving Forward

The UAM subgroup has identified several key takeaways, including the need for clearer definitions and classifications in UAM, addressing barriers to autonomous flight, and redefining the role of pilots and crew. The group emphasized the importance of developing new procedures and technologies to meet operational and communications needs, such as digital communications and digital flight rules.

The group also discussed areas that need further research and development, such as:

- Reliable DAA systems
- Establishing medical requirements for PICs
- Determining workload capabilities for operators

- Defining the functions and SA required for human operators
- Addressing contingencies and hand-off procedures
- Achieving playbook-style operations
- Managing large operational areas
- Presenting relevant geographic information to flight crews
- Determining the role of ATC for UAM operations
- Effectively implement traffic sequencing in corridors to minimize ATC involvement
- Ensuring effective communication between operators and ATC

HAPS Working Group

The High Altitude Platform System (HAPS) working group looks at operations, aircraft types, DAA solutions for up/down transit, and cooperative traffic management for platforms operating at high altitudes (typically above 60,000 feet).

Recent Meeting Dates:
August 25, 2023
April 13, 2023
January 20, 2023
November 29-30, 2022
October 12, 2022

Upcoming Meeting Date:
November 28-30, 2023

HAPS

The HAPS working group is led by:

- Andy Thurling, Co-Lead (Thurling Aero Consulting)
- Jeff Homola, Co-Lead (NASA)

The High Altitude Platform System (HAPS) working group has been tackling the following challenges:

1. Airspace Integration
2. Pilot In Command (PIC) role and responsibility
3. PIC situation awareness
4. Operational safety determination

These challenges are further broken down below:

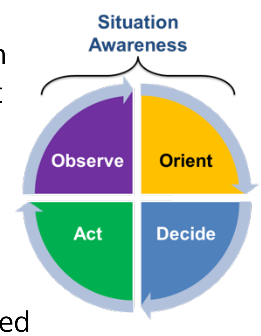
Airspace Integration

- What interactions associated with airspace operations or Air Traffic Management (including ATC) are constraints on m:N operations?
    - Looking at sUAS as an example there is a Collaborative Operating Environment (COE), and many similarities with HAPS: federated environment, shared intent, and third-party services

PIC Role and Responsibility

- How do you see PIC and operational control authority, responsibility, and accountability changing with m:N operations?
    - HAPS (and sUAS) have:
        - Fleet manager with one of the "m" designated as RPIC
        - "m" – the number of humans, one of whom is accountable and has PIC responsibility, designated by the Operator as the required team necessary to execute the CONOP
        - Note that the team size is dynamic (could be 1, 4, 8, etc.) and this dynamic number is defined in the operational concept. The operational certificate would allow for this. There might be qualifications and training for the crew members that would be defined in this certificate.

PIC Situation Awareness



- How does the human(s) responsible for flight safety maintain situation awareness to fulfill their role to both a) maintain control of the aircraft and b) manage the flight path?
    - Each use case would have their own implementation, based on mission and CONOP, but could use a common process for defining the functions and required information that would be needed.
    - The OODA (Observe, Orient, Decide, Act) loop could be leveraged

Operational Safety Determination

- How shall a conceptual framework for determining operational safety be established?
    - Referencing JARUS and ASTM activities
    - A common process could be leveraged
        - How should automation that enables m:N operations be qualified? Where does it reside: on aircraft, off aircraft, or both? Is it part of the Type Certification/airworthiness process?
        - How should criteria for determining the trustworthiness of automation for operational safety be established?
        - What measures/metrics are key to establishing whether the resulting behavior of automation is acceptable?
        - How shall appropriate means of compliance be defined?
    - HAPS has a fairly unique aspect to the "Organizational Response" due to the long sortie durations which are (mostly) boring; until something goes wrong and then they are not.

The HAPS group discusses the above challenges within the context of their use case and an inherently human-over-the-loop task which they see as an on-station task with the humans managing by exception. When an event/exception occurs more complex or beyond the capacity/capability of the "m" humans on duty at the time of the event/exception, it's the organization that is responsible for making all the needed humans available in order to handle the problem. When the organization degrades, workload increases and/or there are temporary reductions in safety margins which might be acceptable as long as this does not decrease safety below an agreed upon level and no single person is over tasked (more than 100%).

Ideally, during high stress periods decision making would be elevated up the organization, or at least would be executed in previously approved contingency management.

HAPS Use Case – High Altitude with Inclement Weather and Energy Management Concerns (note there is a near-term and far-term element to this use case)

The HAPS working group has used the above challenges to help derive a use case involving inclement weather where there are energy management concerns. In this use case high winds affect a subset of HAPS in a fleet. These HAPS do not have enough energy reserves to keep their position without drifting overnight. A possible solution might be to constrain the minimum altitude. This would require the team to evaluate if the power budget permits the HAPS to remain above the safe altitude at night, otherwise, the HAPS will need to be relocated. Under this use case, the HAPS team may also consider reducing the energy consumption by powering down some systems (e.g., communication payload) to preserve enough energy so as to maintain all vehicles above the safe altitude at night.

Moving forward the HAPS group anticipates having other industry stakeholders attend working group meetings and to continue gaining perspectives from those in adjacent industries.

Working with this use case, several key takeaways can be derived. First, there is an inherently international nature of HAPS operations with the need to adhere to ICAO rules in governing these operations. The HAPS working group has down-selected from their initial set of nine scenarios to a few use cases. Within each use case are key elements for m:N operations.

HAPS Far Term Use Case

In the HAPS far-term use case, the following assumptions were made:

- Operations are limited to on-station only, excluding transit to and from stratosphere (1:1 while in Air Traffic Controlled Environment).

- Collaborative Operating Environment (COE) is enabled by ICAO Standards and Recommended Practices (SARPs).

- Heterogenous operations are conducted in COE involving various types of HAPS such as fixed-wing aircraft, balloons, and airships. The density of operations is considered high for HAPS, with multiple operators participating in the COE.

- Roles, and the concept of the human *over* the loop, are depicted in 2 where the PIC role is over the loop at a strategic objective level:

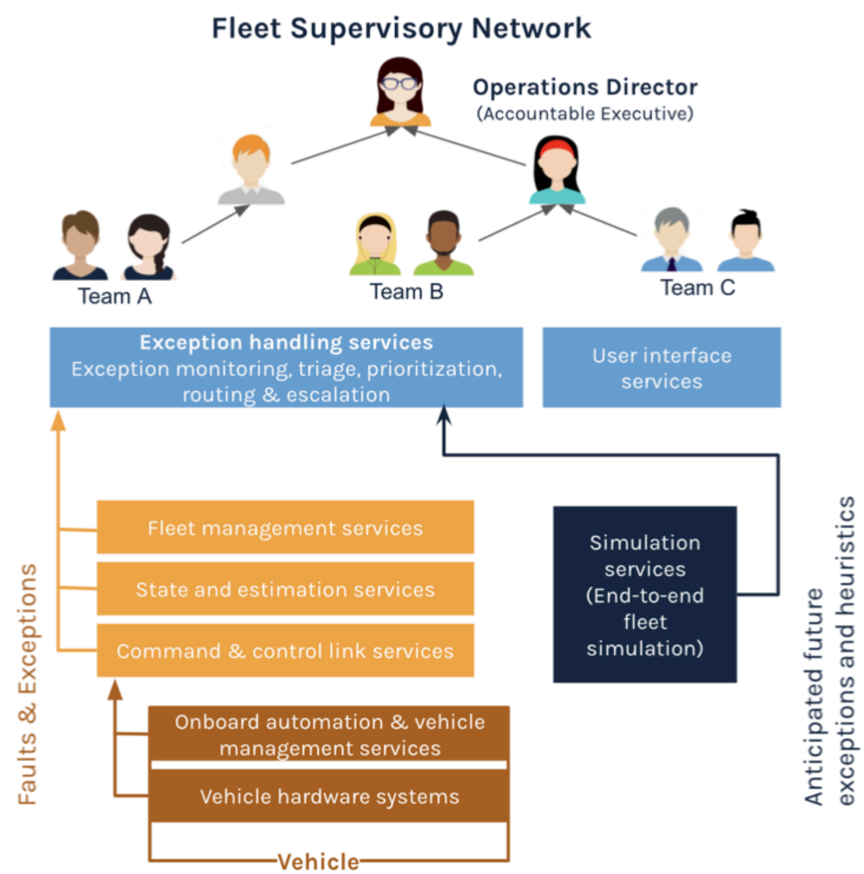


Figure 2. Fleet Supervisory Network, used with permission

Contingencies would be handled by Fleet and Systems Supervisory Network and supported by a virtual team of specialists.

HAPS Mid-Term Use Case

In the HAPS mid-term use case, the following assumptions were made:

- Some form of COE can be established, enabling dynamic deconfliction between operators
- Operations within the COE are heterogeneous, but do not include super or hypersonic vehicles
- The infrastructure supports multiple operators within the COE, such as having ETM support systems (similar to the Discovery and Synchronization Serve and the UTN Service Suppliers in UTM) in place

The environment for these operations is limited to the national context and low-density airspace, meaning there are no ICAO SARPs established (at the time) for governing the operations.

The m:N ratio in this mid-term use case is still dependent on the platform being used, but it is determined more on the economic breakeven point drawing on the safety demonstrated in near-term operations. In the mid-term, the focus is on expanding the operational “envelope” of m:N, i.e. the “N” in that ratio.

Regarding roles, the PIC operates in an On the Loop capacity, supervising strategic execution of operations.

HAPS Near-Term Use Case

In the HAPS near-term use case, the following assumptions were made:

- Some form of COE can be established
- Operations are limited to the national context, meaning there are no ICAO SARPs involved
- Non-certified systems operate on safety cases

The operations within the COE are homogenous, with each COE having a single operator. The airspace density in this use case is low. The m:N ratio is dependent on the platform being used; however, proving the safety of the operations has a greater influence on the determination of the m:N ratio.

The role of the PIC in this near-term use case is in an On the Loop capacity, supervising the execution of mission plans at a tactical level.

In terms of contingencies, the operations can draw insights from Airbus/Loon operations in Australia. Additionally, the current FCL regulations outlined in Annex 1 (part 61 commercial instrument) are applicable.

Overarching HAPS Assumptions

The HAPS breakout group has also identified the following assumptions:

- Operations are limited to on-station only, excluding transit to and from stratosphere
- HAPS encompasses different types of aircraft, including fixed wing aircraft, airships, and balloons

- The issue of voice communications has been resolved under HAPS use cases
- A DAA solution is accepted for up and down transit, involving the PIC on the loop
- Cooperative Traffic Management in the Stratosphere (CTMS) or other “ETM” like capability is accepted as a DAA solution for on-station operations
- A common worldwide definition of “Higher Airspace” is established
- The level of automation on aircraft remains consistent across the timeline, always following the mission plan
- m =< N (m is equal to or greater than N).
    - This ratio may change during a flight.
- A PIC is always in command and has authority of each aircraft.
- A pilot may serve as PIC for more than one aircraft simultaneously (and could be assisted by others).
- The PIC for a given aircraft may change during flight -- i.e., the PIC may hand-off the PIC role to another pilot during the flight.
- The PIC will be trained and certified for the tasks required to control the aircraft.
- Communication performance with the regulating agent (ATC, CTMS, USS) will be comparable to aircraft operating without a pilot on-board but occurs through other than radio communications.

HAPS Definitions

Similar to other subgroups, the HAPS working group has defined a few key terms and concepts as they pertain to the HAPS environment:

High Altitude Platform Systems (HAPS) - Attended autonomous fleet systems consisting of one or more uncrewed vehicles and the systems that manage them.

Fleet Operations Director - A first-person supervisory role which determines the appropriate procedures and protocols, especially in response to off-nominal situations or incidents.

Fleet and Systems Supervisory Network - A network of individuals, teams, and associated systems responsible for supervising the fleet and systems. Responsible parties are not necessarily collocated and operate as a virtual team.

Lighter than Air/Heavier than Air - HAPS vehicles can be hybrid and may not fall easily into one aircraft category or the other. There are two broad categories:

Heavier than Air - These vehicles require propulsion and True Airspeed to remain airborne.

Lighter than Air - These vehicles leverage buoyancy to maintain altitude and may have some True Airspeed Capability, which may be turned on/off dynamically.

m:N – Single or team of remote pilots and team (m) managing multiple aircraft (N)

m – The number of remote pilots and team managing N aircraft

Flight operations officer/flight dispatcher – A person designated by the operator to engage in the control and supervision of flight operations, whether licensed or not, suitably qualified in accordance with Annex 1, who supports, briefs and/or assists the PIC in the safe conduct of flight. (Ref: ICAO Annex 6, page 15)

Supervisory control – Refers to a high level of overall monitoring and management of individual aircraft. The pilot is on or over the loop.

Pilot in Command (PIC) – The plot designated by the Operator, or in the case of general aviation, the owner, as being in command and charged with the safe conduct of a flight. (RefL ICAO Annex 6, page 18).

Remote Pilot In Command (RPIC) – ref. ICAO

Control Station (CS)/Remote Pilot Station (RPS) – Remote station from which an RPAS is controlled or managed. Note we are looking more towards managing with the human over the loop. May switch control station to ground station down the road (SC-228 leans towards control station vernacular).

Moving Forward and Subgroup Considerations

- Subgroups still have value but maybe we need to change the types of subgroups to revolve around the big challenge areas (as seen by the HAPS group):
  - Challenge area #1 Airspace integration
    - Cooperative Operating Environment (COE) subgroup
      - Using Operator defined/ANSP approved Collaborative Operating Practices (COPs)
    - Air Traffic Control Environment (ATCE) subgroup
  - Challenge area #2 PIC Role and Responsibility
    - COE subgroup
    - ATCE subgroup
  - Challenge area #3 PIC Situation Awareness
    - Define the <u>process</u> for defining what information is needed and then breakout groups can solve the challenge in terms of their own environment
  - Operational Safety Determination
    - Define the <u>process</u> for doing the analysis and then breakout groups can solve the challenge in terms of their own environment
- Look at other perspectives
  - Could be manned aviation where ATC controllers have consistently been doing "m:N" operations
  - Other industries such as maritime and automotive
  - Look at Loon and their lessons learned
  - Regulators

Next Steps

Next steps include a face-to-face m:N working group meeting November 2023 to be held at NASA Langley, Hampton VA. The outcome of our m:N work continues to directly support the SC-228 group as they develop safety performance requirements (SPRs), operational services and environment definitions (OSED), interoperability requirements (INTEROP), minimum aviation system performance standards (MASPS), and minimum operational performance standards (MOPS).

For additional information or to join the m:N working group or its subgroups please reach out to the individuals listed below.

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m:N WORKING GROUP

A central goal of this working group is to bring together a broad collective of interested stakeholders from government, industry, and academia to identify and reduce barriers to m:N operations, an operational configuration that envisions a ratio of multiple operators (*m*) controlling multiple vehicles (*N*) between them. Barriers addressed by this working group are considered across a variety of multi-vehicle control contexts (e.g., Urban/Advanced Air Mobility, drone delivery, infrastructure inspection, disaster response and recovery, and high-altitude platform systems operations) and form the bases for future research to confront operational, technical, and regulatory gaps.

Learn more

https://nari.arc.nasa.gov/ttt-ram/multi-vehicle

Appendix A: Acronyms

AC	Aircraft
ACAS	Airborne Collision Avoidance System
ACAS Xu	Airborne Collision Avoidance System X for Large UAS
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
AI	Artificial Intelligence
ANSP	Air Navigation Service Provider
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
ATCE	Air Traffic Control Environment
AUVSI	Association for Uncrewed Vehicle System International
BVLOS	Beyond Visual Line of Sight
CNPC	Command and Non-Payload Communications
COE	Cooperative Operating Environment
COMMS	Communications
CONOPS	Concept of Operations
COPs	Collaborative Operating Practices
CRM	Crew Resource Management
CS	Control Station
CTMS	Cooperative Traffic Management in the Stratosphere
DAA	Detect And Avoid
DoD	Department of Defense
ESS	ETM Service Supplier
ETA	Estimated Time of Arrival
ETM	Class E Traffic Management
FAA	Federal Aviation Administration
FOV	Field Of View
GCS	Ground Control Station
HAPS	High Altitude Platform System
ICAO	International Civil Aviation Organization
ID	Identification
IFR	Instrument Flight Rules
INTEROP	Interoperability Requirements
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
LiDAR	Light Detection and Ranging
LLM	Large Language Model

MASPS	Minimum Aviation System Performance Standards
MOPS	Minimum Operational Performance Standards
MTBF	Mean Time Between Failure
NASA	National Aeronautics and Space Administration
OODA	Observe, Orient, Decide, Act
OSED	Operational Services and Environmental Definition
PAAV	Pathfinding for Airspace with autonomous Vehicles
PIC	Pilot In Command
PSU	Provider of Services for UAM
RA	Resolution Advisories
RP	Remote Pilot
RPIC	Remote Pilot In Command
RPS	Remote Pilot Station
RTCA	Radio Technical Commission for Aeronautics
SA	Situation Awareness
SARPs	Standards And Recommended Practices
SATCOM	Satellite Communication
SC	Special Committee
SMS	Short Message Service
sUAS	Small Unmanned Aircraft System
SWaP	Size, Weight, and Power
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UI	User Interface
USS	UAS Service Supplier
UTM	UAS Traffic Management
UVR	UAS Volume Restriction
VHF	Very High Frequency

Appendix B: Participant Lists

sUAS

Garrett Sadler: NASA (Government Lead)
Scott Scheff: HF Designworks (Industry Lead)
Meghan Saephan: NASA (Member at large)
Phillip Walker: SIFT (Member at large)
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Chuck Johnson: GIUAS
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Ryan Oksenhorn: Zipline
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Terence Tyson : NASA
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Vanessa Ventura: Joby Aviation
Verne Battiste: NASA
Wade Johnson: NASA
Casey Smith: NASA
Conrad Rorie: NASA
Cindy Pham: NASA
Vivian Tran: NASA
Keith Mottas: Atlantic Drone Pros
Chris Schupp: HF Designworks
Matthew Peel: Arizona State University
Harrison Wolf: Zipline
Michael Liquori: Airio
Ashton Albright: 4D Avionic Systems
Rob Knochenhauer: Censys Technologies
Autumn Alderdice: FAA
Tim Beglau: FAA
Crystal Kirkley: NASA
Bill Freeman: Primal Space
Barry Jenkins: Primal Space
Moshe Cohen: Ciconia
Will Stavanja: DroneUp
Douglas Coats: Ciconia
Eran Bar-On: Ciconia
Mehrnaz Sabet: Cornell University
Kent Etherton: AFRL
Blake Piper: Leidos
Dylan Cravens: Leidos
Janine Mator: Leidos
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Tim Skutt: Anzen Unmanned
Ben Carroll: Nuro
Jordan Conner: AFRL
Bill Kaliardos: FAA
Tim Bagnall: Mosaic
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Jon Murakami: FAA
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Michael Clamann: Cruise
Jared Stanley: Adinkra
Julianna Martorella: Zipline
Lou Glaab: NASA

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Large UAS

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Jillian Keeler: NASA
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Kevin Gildea: FAA
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Bryan Morrisey: Aerovironment
Michael Westenhaver: Reliable Robotics
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Nancy Cooke: Arizona State University
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Appendix C. sUAS Roadmap

Barrier	Mitigation	1 yr plan	5 yr plan	10 yr plan	Contingent on other barriers/misc
Keeping staff trained on technical systems when overseeing a system that is operating autonomously and situations where taking over is infrequent.	Methods for how to train users for operations; to include contingency scenarios; should this include checkrides, regular certification periodically? Training in sims leading up to actual operations? Every 24mo as an instructor pilot to test for skills/proficiency for manned aircraft - should this be similar for sUAS? Operation methods, testing, etc is regulated by FAA; will BVLOS need to have Operating standards regulated by FAA? FAA Part 135, Part 121? Scenario based training; utilize similar currency and annual trianing for RPICs? For systems, test for capabilities and set of criteria; also for company procedures IAW FAA regulatory policies.	Begin formulating/updating FAA regulations to account for current/future ops (large & small UAS)	Begin formulating training methods for operators to include: contingencies, regular certification/re-cert, simulations; continue drafting changes to FAA regulations	Finalize FAA regulations; finalize training methods/requirements	
Identifying and knowing what information the operator needs in nominal and off-nominal conditions	Depends on what system is alerting; prioritization of information to operator and when they need to act (mitigations can come from the use cases); any data bases for lessons learned for UAS incidents potentially from NTSB for mishaps (see if we can gain access from lessons learned); understanding levels of autonomy, categorizing various levels of automation from different UASs (will impact the level of RPIC workload if there is less or more automation); how do we ID required info operator needs on a nominal day (A/C specific details may drive what needs to be presented to	Begin characterization of levels of automation and RPIC workload; ID interface requirements (info presented to operator); Develop more use cases to incorporate into white paper; that use case covers 7 different types of events that could occur enroute; develop categorization of	Continue 1yr plan efforts	Formalize required levels of automation; interface requirements	

	operator); mitigations can be driven by category of automation bins and can drive info presented to operator; this is part of validation for Part 121 & Part 135 (FAA develops variety of scenarios that would be off-nominal to test the system and ensure system operates as advertised - these regs are held to a higher standard (operator & system certified separately)	varying levels of automation for different UASs;			
Ensuring calibrated trust between operator and system	System needs to have strong reliability record; training & certification on system may improve trust from operator to system (provide operator correct mental model of how aircraft functions); explicitly define tasks between automated system and operator (ensure there is no ambiguity in what operator's roles and responsibilities are); create an understanding of what system is actually capable of; reporting system of what the aircraft is doing and why - transparency of how system is operating (explainability). Don't be siloed, work with other researchers, domains, industries? Increasing levels of partnership/lessons learned/evaluations/observations between FAA and industry.	Need a means for ensuring/developing calibrated trust (metrics). Trust is needed between all stakeholders: manufacturers, operators, regulators. Have a shared definition of what trust means. Need a shared set of assumptions as well. Carve out and agree what tasks are better for the human and what are better for the system to perform (correct mental model for operator?).	Need a methodology to test trust along with verified calibrations of trust. Understanding pedigree - where the information came from to establish recommendations and earn trust. Events will be used to dictate how trust is/has been working. With a large variety of use cases (more events, more operators, repeating in same location with multiple operators as well as also in more locations).	Events will be used to dictate how trust is/has been working. With a larger variety of use cases (more events, more operators, more locations).	Ensuring calibrated trust between system/operator and regulatory bodies Transparency of the system is important for trust calibration (Chen et al., 2018, Miller, 2021 FAA sees the reverse: they see implicit trust in the system that may exceed its capability. Over-trust: belief that the system is infallible. Even after performing rigorous testing, operators can still see new things: "That's never happened before."
Ensuring calibrated trust between system/operator	Rigorous testing + time. Transparency, reliability, repeatability. Increasing levels of partnership/lessons	Coordinating so that the operator and regulatory bodies work together, which	Developing a testing/modeling methodology in partnership with	Widespread use and implementation of the developed and approved processes.	Ensuring calibrated trust between operator and system

and regulatory bodies	learned/evaluations/observations between FAA and industry.	includes the behind the scenes work (what goes into everything, "behind the curtain to see the wizard")	industry. Would allow industry to be more dynamic and have more efficient validation and approval processes.		
Scaling from lower number of vehicles under control to higher numbers (e.g., 1,000+ assets)	Current is 1:5 and trying to get to 1:10 (what is the HF of comms as sUASs proceed from Class G to more controlled airspaces; how many can the RPIC observe at a time and manage various contingencies in controlled airspace); need to completely understand the HF challenges presented to just 1 operator before moving to "m"; communications are a HUGE challenge; especially when DAA scenariors occur; how to manage the large amount of info coming to the RPIC; 1:N vs m:N have fundamentally different requirements (do they have similar challenges w/ similar solutions?); voice vs text can impact operations if they are not managed in a way that supports the operator. Understanding of infrastructure needs.	Identify necessary technologies and infrastructures to make this happen. Define roles and responsibilities for the various personnel who will be necessary to make this happen. Understand the mission(s). Establish notional ideas of how things can be grouped on the interface (i.e., how and when do you group entities).	Establish infrastructure. Assess workload demands and how to keep workload at "reasonable" levels. Identify ways to assess workload in real time and mitigate periods of high workload. Identify how to implement interfaces, such as groupings, features, etc. which may change in a dynamic environment.	Limited use. Testing for specific use cases.	Operational barriers. Higher numbers of assets may require a paradigm change from that of just supervising a few sUAS. Identifying and knowing what information the operator needs in nominal and off-nominal conditions.
Certifying autonomous systems					Contingencies such as how much human invovlement
Level of automation needed for m:N control Identifying how much workload a	At low scale (e.g. less than 5 aircraft per PIC) the tasks of humans are similar to the ones of a manned aircraft. We have a PIC role clearly defined, and their tasks are of tactical nature on the UAS				Contingent on Technical barriers. To manage such a scale, the level of automation might need to be such that we don't rely on having a human PIC as a fall back for the

single operator can handle	themselves. E.g. PICs perform tasks such as deconfliction, and generally can intervene on short reaction times. At very high scale (hundreds of UAS for each operator), the scale is such that the traditional CONOPS that which relies on a PIC, isn't going to work. The PIC role, tasks and responsibility will need to be redefined. At such a scale, it might not be possible or desirable for humans to intervene to perform tactical tasks such as last minute deconfliction on an individual aircraft basis.				automated deconfliction systems. Humans perform tasks with longer time frames, and manage the automation that manages the machines. This means that humans also might not need to stay attentive the way a PIC needs to remain alert to monitor the system. For m:N to be successful at a large scale (lots of sUAS being supervised by one or a few), we may need to accept that for these instances, there is no PIC. Humans are still involved, but their role is so different from that of a PIC, that its really a different role and likely a different name.
Identifying how much workload a single operator can handle	What kind of "m" are we looking for? What are their roles/responsibilities? Is there a max of N that should be applied? Currently 1:30 is active around the world safely.				How do you staff for spikes in workload? What about when there isn't enough workload to keep operator vigilant
Ensuring operations are safe enough and do not degrade the safety of the NAS.	Part 121 & Part 135 (very specific rules/regs on what is required, what areas pilots need training and regular certification); evals of aircraft system and pilot training are the foundation of safety certification for systems; manuals, policies, procedures from individual airlines include maintenance, training, etc is reviewed by FAA (design assesment/validation); do sUASs need to meet this level of scrutiny (YES); Part 135 for air carrier for sUAS (package delivery) - NOT Part 107;	Identify feasibility of test ranges/times that facilitate deconfliction for test operations w/o exposing public or commercial aviation to dangerous situations (stakeholders describe a key need of the industry for dedicated airspaces for testing of various UAS operations Some test sites have	One direction to take will be to identify 4D volumes/trajectories for test		How do you show operations are safe enough? What is the definition of safe enough (what is it for manned aviation)? Need for testing where things can happen, see failures and breakdowns without things being unsafe, similar to the way military have restricted airspace/ranges? Test ranges to allow for deconfliction w/ other manned aircraft Need for robust testing where things can happen, e.g., see failures and breakdowns without things being unsafe,

		existing capabilities for test, but there is a need to document requirements for testing. Waiver process is available, but need a distinct description of type of airspace needed in order to get approval for use. Bring in international data to utilize to help inform scalability and safety of use in NAS; however data needs to be from a similarly complex airspace to NAS that will inform how this could work in highly congested airspaces.			similar to the way military have restricted airspace/ranges. Provide areas where multiple operators can test and build a safety case. There are some UAS test ranges with operating COAs, but they still need to assume that there could be VFR traffic. Before they fly, they need to ensure that VFR traffic won't pass through the airspace. Today: you can't experiment on things that are out of the norm. Question for consideration: how do we bring in the data and test results from international testing?
Speed at which policies are created and requirements are made	FAA still waiting on policy decisions (there are recommendations from SMEs to management, standing by on approvals- this is a multiyear process); FAA wants to develop guidance etc, yet the technology for sUAS is changing, however operators/designs don't have a set of approved requirments to design to; industry SMEs/engineers/designers/operators need to have a good understanding of aircraft capes and what needs/should be onboard the aircraft; certification of aircraft is different from operator; certification for aircraft that is already approved will need and STC - (supplementary type certificate) if there are sig. improvements/mods (can take	Need for current/future policies to keep up with emgerging technologies and capabilities.			A lot of complexity faced today involves trying to be backwards compatible with legacy. Is there a path in which requirements/policies can be changed away from legacy assumptions? FAA is aware that they "do not evolve" at the speed of the industry. Regulators have to walk a fine line between regs and new tech. How does it get evaluated? Identify what is this new tech, what are applicable regs, how to evaluate.

	months to years to get approval depending on a/c complexity); for sUAS will there be a DAR?;				
Acceptance by general public of sUAS flying over residences, schools, businesses, etc.	Education on safety of sUAS, implementation of air corridors and which areas are restricted to sUAS (and why), education on what sUAS can and cannot do (i.e., they aren't filming you in your backyard). Enforcement of regulations.	Implementation of policies and procedures for when, where and how sUAS are used in the public sector. Education on sUAS use and best practices. Advertising campaigns with honest, accurate information about sUAS in regions where they will go into initial service. Community engagement (public forums?) prior to and after going into operation.	Developing a testing/modeling methodology, sharing out safety data.	Widespread use and implementation of the developed and approved processes, shareout of safety data.	Regulatory/Policy Likely influenced by experience as well
Public acceptance of automation and trust	Rigorous testing + time. Transparency, reliability, repeatability. Increasing levels of partnership/lessons learned/evaluations/observations between FAA and industry.	Coordinating so that the operator/organization and regulatory bodies work together, which includes the behind the scenes work (what goes into everything, "behind the curtain to see the wizard")	Developing a testing/modeling methodology, sharing out safety data.	Widespread use and implementation of the developed and approved processes, shareout of safety data.	Ensuring calibrated trust between system/operator and regulatory bodies Could be a generational issue