m:N WORKING GROUP

MEETING SUMMARY

November 2022

EXECUTIVE SUMMARY

On November 29th and 30th, 2022 the m:N UAS working group and its subgroups [small Unmanned Aircraft Systems (sUAS), Large UAS, High Altitude Platform Systems (HAPS), and Urban Air Mobility (UAM)] met at the NASA Ames Research Center in Mountain View, CA for an in person meeting. The option to dial in remotely and use Conference.IO to engage with questions was offered as well.

The subgroups meet multiple times throughout the year, virtually. Twice a year however, participants from all the subgroups come together to brief each other on progress, challenges, and path forward ideas for incorporating UAS into the airspace.

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 FAA and RTCA's SC-228 Detect and Avoid. Each subgroup is run by a government/industry team (see below).

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

Large UAS Subgroup
Conrad Rory (NASA)
Brandon Suarez (Reliable Robotics)

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

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

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?

To meet that statement, topics discussed included lessons learned from today's autonomous and semi-autonomous operations, current research, and a discussion of what the roadmap might look like for incorporating UAS into the civilian airspace. The subgroups also discussed near term, mid term, and long term use cases, what technologies would be needed, and what these timelines looked like.

At the culmination of the two-day meeting each subgroup briefed the larger m:N UAS working group on the status of use cases, definitions, and assumptions.

The full workshop recording including presentations can be found here.

NOVEMBER 29TH BRIEFINGS and PANEL DISCUSSIONS

The November 29th briefings included representatives from Industry, NASA, FAA, and the US Army. Panel discussions regarding Safety Cases and Ongoing Research were also presented.

A summary of the briefings is included in the following pages.

NOVEMBER 29TH BRIEFINGS

Welcome & Introduction | Mike Rogers [PM, Transformational Tools and Technologies (T3)]

Mike Rogers discussed the T3 program with a focus on communications, navigation, and surveillance. He explored the concept of controlling a large number of Autonomous Vehicles (AVs) with minimal human operators.

The m:N roadmap was presented to outline the developmental path for the program. The program is scheduled to continue until FY ’27 with the goal of building an operational roadmap in collaboration with communities such as the m:N working group.

Working Group Purpose | Andy Thurling (m:N co-lead)

Andy Thurling emphasized the importance of interdisciplinary discussions to address the command and control of AVs. He reviewed lessons learned from other industries, and the concept of cross pollination was also explored.

FAA | Tim Beglau, UAS Air Carrier Operations

The FAA discussed the current state of affairs in the AV industry, specifically mentioning companies such as UPS Flight Forward, Amazon Prime, Zipline, and Wing Aviation. Among these, Wing Aviation was highlighted for having 1:5 control where the Remote Pilot in Command (RPIC) can:

- Activate and deactivate system(s)
- Land now
- Return for landing
- Reroute
- Monitor each aircraft
- Access an RPIC station in another location

Currently, these operations are solely conducted with sUAS below 400 feet, but this may change in the future.

Other questions and considerations that were discussed by the FAA include:

- How can an m:N control system be achieved?
- Who will the “many” (m) be in this context? This could involve pilots, operators, dispatchers or other personnel.
- What qualifications will be required of individuals involved, such as certificates, ratings, training, and medical exams?
- What will the “many” (m) be able to control? Examples of relevant control capabilities include activation, deactivation, landing, returning, and rerouting.
- Who communicates with ATC in an m:N system?
- Who is responsible for the platform? As you get into the regulations every flight needs a person who is responsible.

Tim Beglau also identified potential obstacles to m:N implementation, specifically focusing on challenges associated with Detect and Avoid (DAA) systems and emergencies. For example, the question was raised - Will a DAA-equipped m:N system be robust enough to detect and avoid other aircraft even when the behavior of human pilots is uncertain? Additionally, how would multiple emergencies be feasibly handled? In this context, the scenario of a mandate to land all aircraft, similar to the events of 9/11, was brought up. Also the question of liability was mentioned; who is liable if an incident, accident, or violation occurs?

Mr. Beglau also discussed terminology, such as “Pilot in Command (PIC)” which he defined as the person who 1) has final authority and responsibility for the operation and safety of the flight, 2) has been designated as pilot in command before or during the flight, and 3) holds the appropriate category, class, and type rating, if appropriate, for the conduct of the flight. The PIC of an aircraft is directly responsible for, and is the final authority as to, the operation of that aircraft.

U.S. Army | Grant Taylor (Program Lead, Technology Development Directorate), Advanced Teaming Program Overview

Advanced teaming especially in the context of the Army’s Future Vertical Lift (FVL) is the symbiotic effort of manned rotary wing and fixed wing aircraft, unmanned aircraft systems (UAS), ground vehicles, and air launched effects (ALE) to accomplish the full range of multi-domain operational missions with enhanced and distributed situational awareness, greater lethality, and improved survivability.

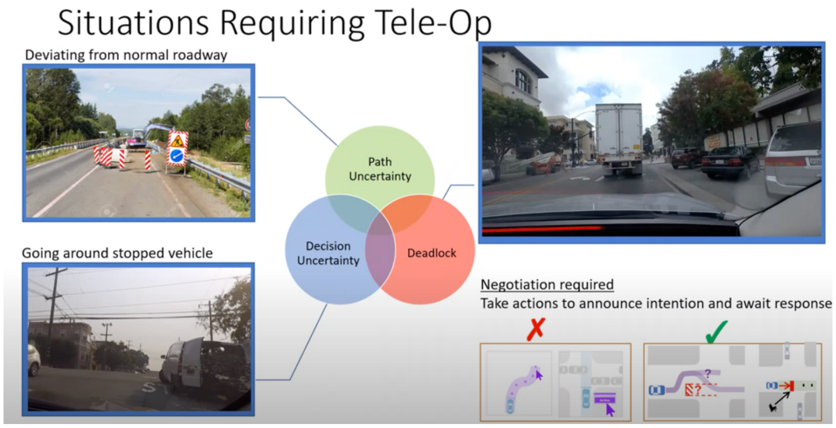
Dr. Taylor focused this discussion on FVL and the future of advanced teaming between manned rotorcraft and ALEs on the battlefield. The integration of these elements is expected to bring about significant advancements in military flight operations.

However, there are numerous challenges associated with advanced teaming, such as airspace deconfliction and autonomous algorithms. Furthermore, all aircraft involved in advanced teaming should be capable of detecting and tracking each other, including working successfully in GPS- and communications-degraded environments that are in the commercial airspace.

Nissan | Liam Pedersen, Remote Tele-Operation for Autonomous Vehicles

Liam Pedersen discussed with the group how Nissan’s CEO envisions a future for 2030 where joint research is conducted with NASA on how Autonomous Vehicles (AVs) can operate more efficiently with the assistance of Cloud AI.

Teleoperations becomes relevant in various urban scenarios, such as deviations from normal roadways (path uncertainty), maneuvers around stopped vehicles (decision uncertainty), or negotiations are required around an obstacle.



Situations Requiring Tele-Op

Deviating from normal roadway

Going around stopped vehicle

Path Uncertainty

Decision Uncertainty

Deadlock

Negotiation required

Take actions to announce intention and await response

✗ ✓

Figure 1. Teleoperation continues to be necessary as all possible environments continue to be modeled

Even today, AVs must operate in uncertain and unmodeled environments. Autonomous cars are improving at avoiding collisions, but there is still an ongoing effort in determining how to handle unusual or unknown situations. For example, currently, teleoperators are contacted to act as a driving instructor to help the vehicle navigate through such scenarios. The aim over time is to minimize reliance on teleoperators, only keeping a few on standby in case of unexpected situations that require their intervention.

Sensor technology such as Light Detection and Ranging (LiDAR) uses a lot of bandwidth and may not provide a comprehensive understanding of the situation in certain circumstances. Consequently, using LiDAR with High Definition (HD) video is considered necessary for adequate teleoperation.

Reliable Robotics | Chad Healy, Remote Voice Communication in the NAS

Chad Healy outlined a plan to retrofit existing aircraft with autonomous systems and ultimately scale to an m:N style operation that runs 24/7.

The FAA is expected to require a not-to-exceed pilot-to-controller latency of 390 milliseconds in the National Airspace System (NAS), as outlined in DO-377A. Additionally, the International Civil Aviation Organization (ICAO) expects a 10-second transaction time, as outlined in the ICAO Manual on Required Communication Performance.

Currently, there are limited design solutions available to address these requirements. The deployment of text based communication, such as Controller-Pilot Data Link Communications (CPDLC), is limited. Radio Line of Sight (RLOS) datalinks with terrestrial network systems are in early development. Satellite relay systems are currently being used and explored, and greatly exceed the requirements.

From a pilot's perspective, there are three basic use cases for the voice communication system:

- Pilot initiates communications with ATC for initial contact or to request changes in flight plan. This can be inefficient as it may interrupt other calls, or workload if done in the middle of an exchange.
- Pilot responds to directions from ATC, such as revectoring or clearances. This could lead to too long of a lag in response, making this inefficient.
- Pilot initiates or responds to ad hoc communication flow, including pausing or repeating a call and handling emergencies.

As traffic density increases, the duration of communication calls is shortened and consequences of a miscommunication are greater. To help mitigate communication errors, especially with regard to voice latency, certain requirements should be considered:

- Pilot should not inadvertently talk over ATC or other aircraft, which requires sensing a channel is quiet and knowledge of ongoing conversations.
- Pilot should promptly respond to ATC in a timely manner, which requires comprehension of ATC's instructions.
- Design should be robust to human errors and contingencies.

Reliable Robotics is currently developing a system to address these considerations (see Figure 2).

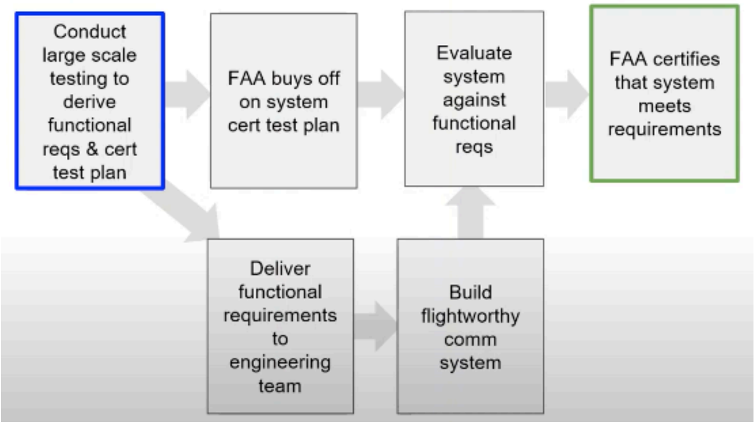


Figure 2. Derive Functional Requirements through Human-in-the-Loop Testing

Panel Discussion | Safety Case

Wes Ryan (NASA and panel moderator), Autumn Alderdice (FAA), Mark Blanks (Wing), Delbert Christman (Autonodyne), Derek Hufty (FAA), Dan Ridgeway (FAA), Harrison Wolf (Zipline)

Lessons learned from sUAS in package delivery, HAPS, and DoD demonstrations need to be applied to civil aviation for m:N operations. This panel was formed to help bridge the gap between industry and FAA.

Wing currently conducts operations under Part 135 regulations with a one-to-many ratio of 1:5 in the US and 1:15 in Australia. Ultimately, the goal is to have various UAS working in the same airspace, necessitating a transition from segregated operations to integrated airspace. Close to 1 million operations have been conducted between Wing and Zipline, generating statistical safety data that demonstrates the viability of these operations.

Testing in a sterile environment is becoming increasingly more difficult; the FAA requires data and demonstrations, for which vendors require FAA approval. The expansion beyond the current operational scope will become more challenging.

Research efforts are underway to address these gaps, involving collaborations between NASA, industry partners, and other government agencies. The FAA is working with research partners to understand the operations and human factors influences that impact operations for one to many operations. Additionally, the FAA is working with international aviation authorities, including the International Civil Aviation Organization (ICAO); although the structure of US airspace differs.

Critical issues which have yet to be addressed include the impact of granting or denying operations, as well as the shorter lifecycle of these aircraft compared to manned aircraft. The UAS being certified today may differ from those developed in the future, especially with software lifecycles.

Autonomy is crucial to scale operations to many aircraft. However, there is no consistent standard on what an autonomous system should look like and its necessary functionalities.

When trying to control multiple (10-100 UAS) by a single operator, the following requirements arise:

- Multi-UAS autonomous behaviors
- Autonomous obstacle detection

- Teaming mechanisms (interface)
- Pipeline for developing multi-UAS behaviors

When teaming with autonomy, the following considerations should be taken into account:

- Situation awareness (SA) of autonomy should be maximized
- Task load on the system operators should be minimized
- Interface should be intuitive to reduce training and provide positive transfer
- Adaptive machine behaviors should be incorporated to foster trust in autonomy
- Transparency should be offered to give insight on future actions
- Safety-enhancing visual cues and autonomous/interactive emergency handling should be implemented

Co-development of interfaces, behaviors, and tactics, techniques, and procedures (TTPs) allows for optimization and scalability.

There is a need to define the pilot as it pertains to unmanned platforms in integrated airspace. Depending on performance of the aircraft, mission requirements, and the number of aircraft managed, the roles and responsibilities of the pilot (or operator) may change.

Quantum AI | Tracy Lamb, Considerations and References to Support One to Many m:N sUAS Commercial Operations: Lessons & Observations From The Field 2014-2022

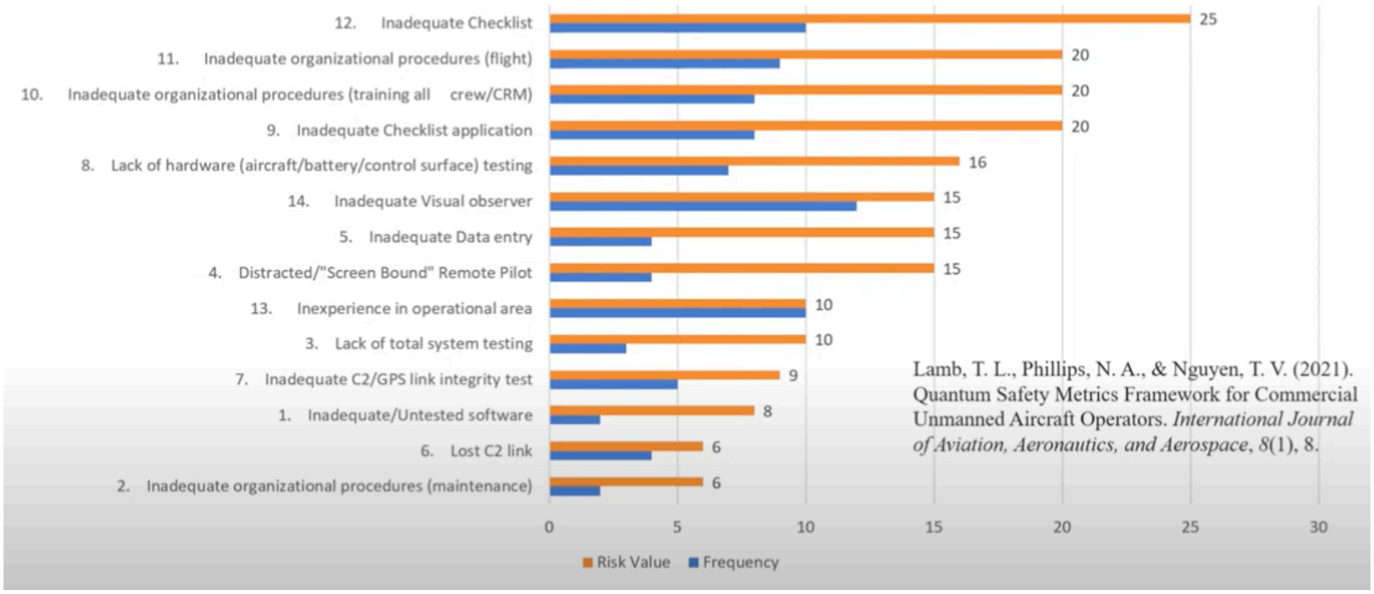
Tracy Lamb discussed human factors and safety issues (Figure 3) in the context of m:N operations, including observations, lessons learned, and considerations.

Commercial off the shelf (COTS) displays vary widely in their format, presentation, functionality, and configurability. While COTS displays may be user friendly, they are not designed for m:N operations and may not adequately support pilot SA, trust, or operational safety in that context (Politowicz et al., 2021). COTS pilot control stations are not usually developed with the application of human factors design principles (Hobbs & Lyall, 2016). Some existing research and standards are relevant and should be considered and applied in COTS m:N displays, including 14 CFR Part 23, 25, Military Standard 203G, Department of Defense, 1991, and RTRCA SC-228 Detect And Avoid. Workarounds should be avoided, as they indicate latent hazards in the processes, training, and trust of the system.

There is significant merit in developing initial m:N operations from normal workflows as a first step, using data from everyday operations (Hollnagel, 2018; Kiernan, 2019; Kiernan, et al, 2020; Flight Safety Foundation, 2021; Homann, et al., 2022). An incremental approach in scaling up (1:2 – 1:3 – 1:4) while gathering safety data in each step while introducing non-normal/off nominal situations should be considered (Flight Safety Foundation, 2021; Hollnagel, 2018; Hollnagel, E., Woods, & Leveson, 2006; Kiernan, 2019; Kiernan, et al, 2020; Lamb et al., 2021; Levenson, 2014, 2015). Distributed Cognitive model.

Operational safety will likely increase if formal human factors studies with recommendations are incorporated, and non-technical skills and teamwork training is delivered to operators and teams. This can improve morale, worker engagement, and trust in leadership (Flin, et al., 2008; Homann, et al., 2022).

Leadership and industry culture have a significant impact on operational safety and culture as well. (Blair & O'Toole, 2010; Helmreich, 2000).



Lamb, T. L., Phillips, N. A., & Nguyen, T. V. (2021). Quantum Safety Metrics Framework for Commercial Unmanned Aircraft Operators. *International Journal of Aviation, Aeronautics, and Aerospace*, *8*(1), 8.

Figure 3. Unsafe Control Themes Occurrence Frequency and Risk Value (N=22 UAS Accidents)

Because UAS and m:N is so different than civil aviation, there is an opportunity to start fresh and implement new approaches and practices.

*Select references included in Tracy Lamb's presentation can be found in Appendix A of this report.

Nuro | Ben Carrol, Nuro m:N Challenges and approach

Nuro is a robotics company working on a fully autonomous robot for last-mile goods delivery and utilizes a 1:N approach with their autonomous cars. They are the first AV company to receive a National Highway Traffic Safety Administration (NHTSA) exemption for low speed driverless vehicles. Mr. Carrol spoke of the requirement for human assistance in rare events when a robot needs help. In such cases, a human operator can supervise and take control of the vehicle. If the human operator cannot help, an operator is dispatched to the scene in person.

A crucial requirement for Nuro's system is the ability for the robot to identify when it cannot resolve a situation and to reach out to a human operator for assistance. Ensuring the safety of the system while driving in residential areas requires comprehensive validation of human system components.

Currently, there is no readily available off-the-shelf teleoperation hardware solution; therefore, off-the-shelf parts must be fabricated and/or customized.

Building a system that best reflects the roles of human and system is a challenging task. Humans excel at understanding and adapting to context, quickly adapting to anomalies, situation understanding, and improvising with flexible procedures. On the other hand, machines are proficient in tasks involving vigilance, memory, multitasking, sensing beyond human capabilities, routing tasks, and controlling a network of devices.

There are several technical challenges to be considered; for example, sensors, hardware, software, etc. are the foundational elements that enable m:N, and cannot be replaced with human operators. There is no m:N without the capabilities that these technologies offer. Additionally, teleoperation requires custom built hardware and software to provide safe, secure, and failsafe operations.

Building a system that enables the strengths of humans and machines is nontrivial, and sometimes requires revisiting previous assumptions about technical abilities. Validating that system and proving its safety is almost as challenging as building it.

Panel Discussion | Ongoing NASA Research Panel, Garrett Sadler (moderator/NASA), Meghan Chandarana (NASA), Eric Chancey (NASA), Rich Coppendbarger)

HAT m:N Activity - Meghan Chandarana (NASA) and Garrett Sadler (NASA)

The m:N Human-Autonomy Teaming (HAT) conducted human-in-the-loop (HITL) simulation research at NASA Ames, focusing on how human performance can be augmented by increasingly autonomous systems. The relationship between human operator and autonomous systems should replicate a teammate relationship. The goal is to test and enhance the safety and efficiency for novel, proposed operations within the NAS (see Figure 4).

Multiple studies have been conducted thus far on m:N operations including food delivery with sUAS, Ground Control Station (GCS) design, and Urban Air Mobility (UAM) air taxis. The latest GCS designs are highly configurable and can support/simulate UAM, large UAS, sUAS, and low Size, Weight, and Power (SWaP) scenarios.

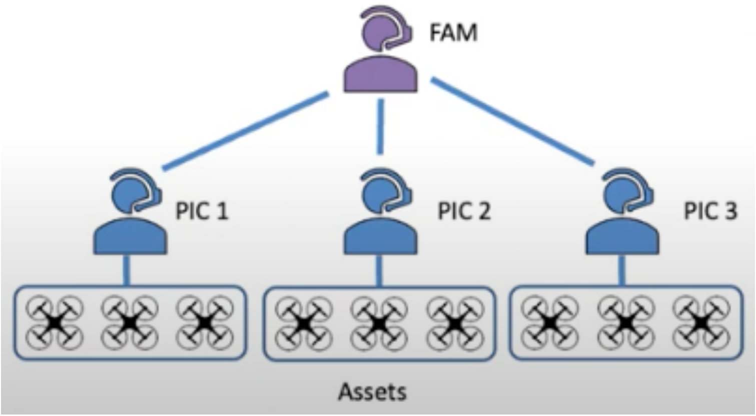


Figure 4. Multiple Operators collaboratively managing multiple vehicles

Study 1 investigated the effect of automation support level on pilots' performance and workload while controlling multiple (up to 12) vehicles. Findings concluded that with the GCS designs and automation, pilots were able to support the control of multiple vehicles. Automation significantly decreased subjective workload and improved efficiency.

Study 2, the Handoff Simulation, explored how remote operators utilized the handoff capability in an m:N UAM context. Participants were tasked with managing unplanned handoffs, such as if one or more vehicles in their fleet experienced an emergency. Results showed that participants successfully diverted emergency aircraft to appropriate landing sites (i.e., hospitals, helipads, and open fields). In Figure 5, an alert queue is shown and affected aircraft, as well as diversion options, are annotated.

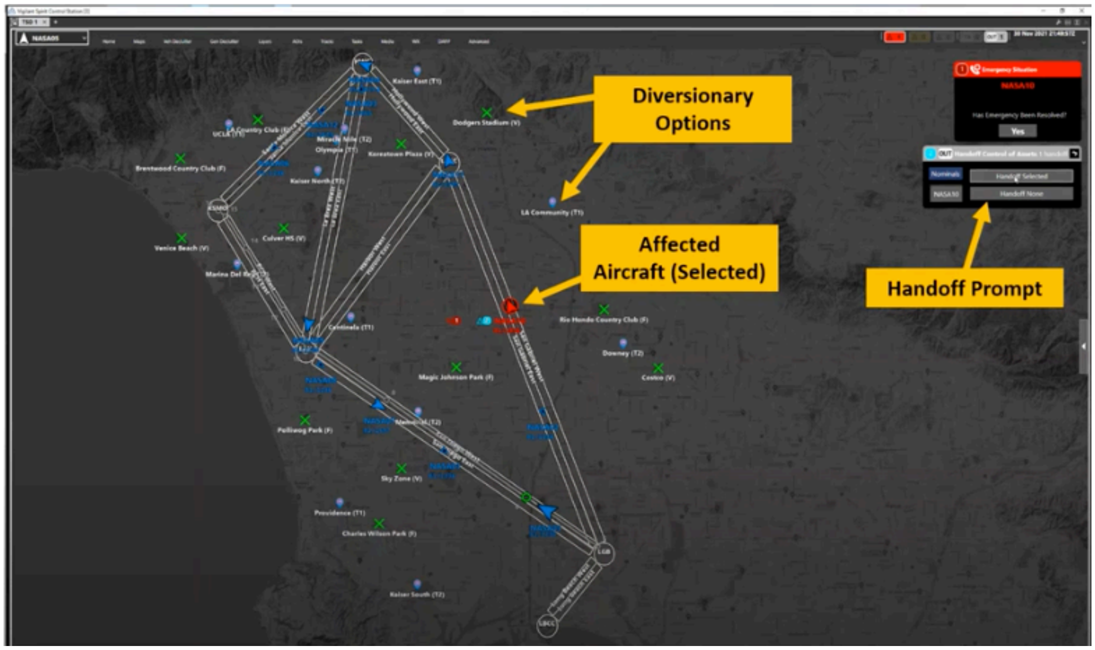


Figure 5. Contingency and Handoff Prompt as part of GCS

Note that in this second study, most of the time, participants chose to handoff either no vehicles or only nominal vehicles, allowing them to concentrate on the off-nominal vehicles. Time to resolve a contingency was longer in the assisted automation condition.

Study 3, the UAM Communications Simulation, aimed to determine effects of a communication system and vehicle load on pilot coordination with air traffic control (ATC). Participants were asked to coordinate flight activity for multiple, simultaneous flights in a hypothetical air taxi service. Pilots were required to request departure, arrival, and transition clearances and comply with ATC instructions while supervising up to 12 vehicles at a time. Participants had voice, datalink, and hybrid (combining voice and datalink) for communications options. The analysis considered factors such as communications transaction time, accuracy in addressing the correct person, whether clarification is needed, and workload.

No effect of communication system on subjective workload ratings (via NASA-TLX) was observed in Study 3; however, participants expressed a preference for voice communication systems, followed by the hybrid system, then the datalink system. Moreover, vehicle load had a significant effect on subjective workload ratings.

Note that a sUAS GCS HITL is upcoming in partnership with Zipline. The goal will be to explore different GCS configurations and their impact on RPIC ability to manage vehicles under their control. This will ultimately flow into a high complexity simulation, enabling testing and evaluation of a high-fidelity, fully-integrated m:N capability operation.

Human-Autonomy Teaming (HAT) Foundational Activity – Eric Chancey (NASA)

Eric Chancey and Mike Politowicz lead the HAT Foundational Activity group from NASA Langley, which focuses on the human aspect of upcoming Advanced Air Mobility (AAM) operations rather than regulations and technologies. Their primary objective is to perform basic research and explore HAT approaches to help facilitate the m:N concept. They specifically focus on UAM maturity level 4+ (UML4+) operations and leverage their MPATH GCS in their research.

Upcoming research with Old Dominion University includes:

- Using mental models to predict trust and automation dependence
- The role of mental models in predicting multi-vehicle management performance
- Attentional limitations in multi-vehicle management

Pathfinding for Airspace with Autonomous Vehicles (PAAV) Multi-Vehicle Operations with Digital Trajectories – Rich Coppenbarger (PAAV Technical Co-lead)

There is growing interest in automating regional cargo operations using large UAS to handle missions up to 500 miles, carrying up to 10 tons of cargo. Cessna Caravan is a typical platform used for such operations today. This interest is partially motivated by the pilot shortage in the industry, and the desire for scalable and efficient operations that optimize pilot and aircraft utilization (m:N).

There are a variety of research activities within Public Airspace Automation and Validation (PAAV) including:

- Collaborations with Stakeholders
- Fast-time Simulations
- Concept Development
- Prototype Development
- HITL simulations for flight testing

One of the objectives of PAAV is to combine trajectory solutions with data link for m:N operations to reduce reliance on voice-based communications. An important tool in this regard is the AutoResolver capability, which acts as a trajectory-based solution engine. It strategically solves problems involving multiple constraints simultaneously, reducing the number of communications (see **Figure 6**). AutoResolver prevents conflicts, manages traffic flow, avoids weather and other restricted airspace, and optimize energy-efficient flight paths. Trajectory solutions provided by AutoResolver are issued as dynamic flight plan modifications affecting a UA's route, speed, or altitude profile as needed. In the future, AutoResolver may be extended to help avoid regions of poor command and control (C2).

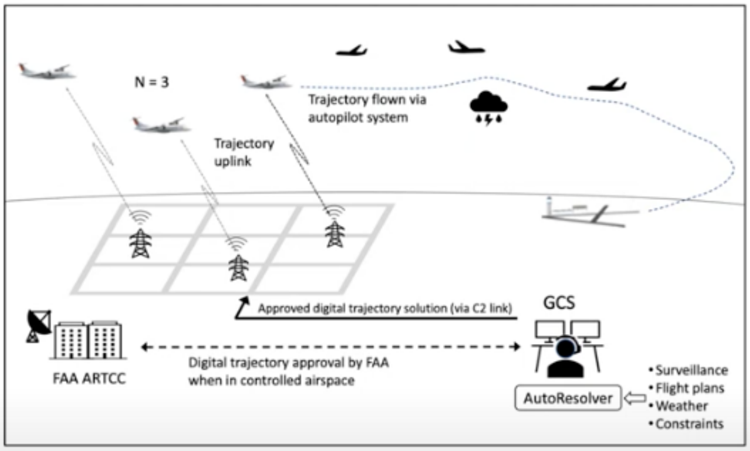


Figure 6: AutoResolver Solution

The overarching goal is to provide safe, efficient, seamless, and scalable operations within an integrated air environment. Additionally, efforts are being made to utilize numerous underutilized airports in the US rather than relying on specialized airports that can only serve unmanned aircraft. The current focus is on integrating the research prototype of AutoResolver with a testbed and adapting it for operations at the cargo feeder hub located at Fort Worth Alliance Airport (KAFW).

Wisk | Erick Corona, Wisk Overview & ConOps for Uncrewed Urban Air Mobility

The industry's goal is to move to digital flight rules, as increased digitalization paves the way for a higher number of m:N operations. The focus is on defining a system rather than just an aircraft. The proposed ConOps framework serves as a starting point to test all the elements necessary to achieve digital flight rules, but with a controlled and supervised approach. Wisk has developed six generations of aircraft; the latest generation is planned for market deployment and can accommodate four passengers (see Figure 7).

Figure 7. Wisk Aircraft Timeline

The AAM Ecosystem aims to increase predictability within the system. The proposed ConOps envisions a fixed route network of urban taxis, moving continuously between points. The fixed, consistent route structure helps to define and understand the environment and contingencies. This system would rely on surveillance data to support operations.

What makes AAM possible now is the convergence of technology, infrastructure, and regulations that are ready to deliver a new means of transportation. This includes:

- Advanced sensing and automation
- Electrification and battery technology
- C2 links and data infrastructure
- Regulations/Standards

In autonomous operations, the aircraft handles all aspects of flight, including left/right/up/down movements and throttle control, without human oversight. The argument for autonomy in AAM operations is based on safety and scalability. With regards to safety, avionics have achieved levels of reliability that exceed human capability, while SA on the ground exceeds the SA of an individual in the flight deck. AAM autonomy also provides scalability by mitigating the pilot shortage and reducing at-scale operating costs. The self-flying aviate capability is provided by on-board avionics, and navigation behavior is supported by human-over-the-loop Multiple-Vehicle-Supervisor (MVS) as the final authority.

Generation 6 is being adapted to the FAA UAM ConOps V2.0, (Figure 8), with an illustrated evolutionary timeline shown in

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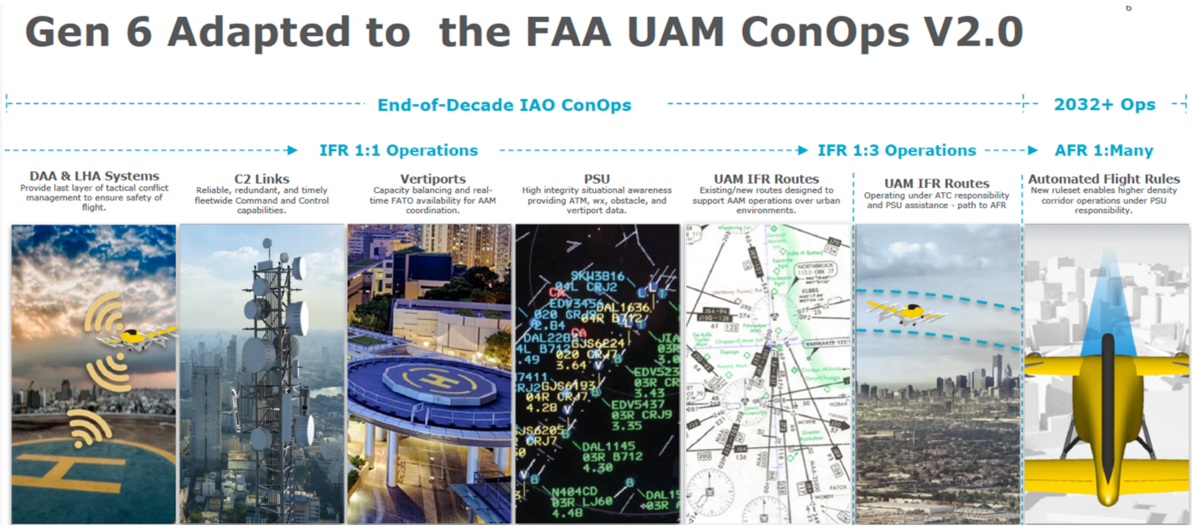


Gen 6 Adapted to the FAA UAM ConOps V2.0

End-of-Decade IAO ConOps

2032+ Ops

IFR 1:1 Operations

IFR 1:3 Operations

AFR 1:Many

DAA & LHA Systems
Provide last layer of tactical conflict management to ensure safety of flight.

C2 Links
Reliable, redundant, and timely fleetwide Command and Control capabilities.

Vertiports
Capacity balancing and real-time FATO availability for AAM coordination.

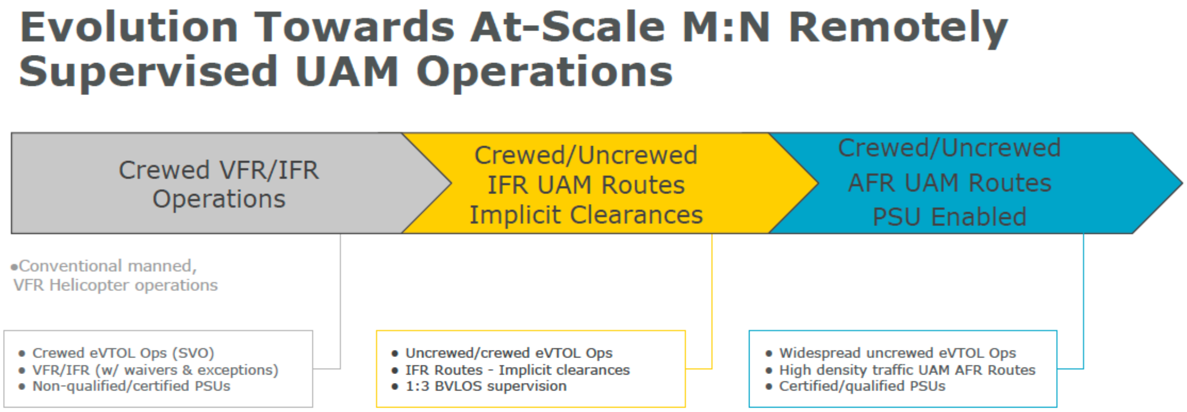
PSU
High integrity situational awareness providing ATM, wx, obstacle, and vertiport data.

UAM IFR Routes
Existing/new routes designed to support AAM operations over urban environments.

UAM IFR Routes
Operating under ATC responsibility and PSU assistance - path to AFR

Automated Flight Rules
New ruleset enables higher density corridor operations under PSU responsibility.

Figure 8 ConOps for Uncrewed UAM



Evolution Towards At-Scale M:N Remotely Supervised UAM Operations

Crewed VFR/IFR Operations

Crewed/Uncrewed IFR UAM Routes Implicit Clearances

Crewed/Uncrewed AFR UAM Routes PSU Enabled

•Conventional manned, VFR Helicopter operations

- Crewed eVTOL Ops (SVO)
- VFR/IFR (w/ waivers & exceptions)
- Non-qualified/certified PSUs

- Uncrewed/crewed eVTOL Ops
- IFR Routes - Implicit clearances
- 1:3 BVLOS supervision

- Widespread uncrewed eVTOL Ops
- High density traffic UAM AFR Routes
- Certified/qualified PSUs

Figure 9. UAM Timeline

Workshop and Subgroup breakouts | Wes Ryan

In preparation for the next day's activities, Wes Ryan from NASA provided an overview of workshop and discussion breakouts at the end of the day on November 29th.

The primary goal was to identify the technological and regulatory context of existing m:N operations and identify gaps and barriers to expansion into larger, more integrated operations in non-segregated airspace. These gaps would then be addressed through research and development efforts and collaboration between government, industry, and academia.

The desired outcome was to create a roadmap with tangible steps for safe expansion of m:N operations. Emphasis was placed on addressing the unique needs for each CONOP or use case; this includes considering technical, regulatory, operational challenges that must be solved.

This roadmap would outline the necessary actions to transition from modern operations to envisioned future states. The overarching objective was to guide the transition from sUAS to AAM, delineating the path from one epoch to another.

Marching orders for the groups: Define the near term and far term vision. What does a mature operating system look like? What does success look like?

NASA | Andy Lacher, Digital Flight Rules: Proposed Research into a New Cooperative Operating Mode to Complement VFR and IFR

> *"New and adapted flight rules and procedures will be required to efficiently manage these increasingly dynamic operations of differing priority and types."*
>
> *– Airbus and Boeing, 2020*

The future of aviation mobility calls for capacity, flexibility, and access. However, today's Visual Flight Rules (VFR) and IFR operations are limited in their ability to adapt to greater flight diversity, scale to high tempos and density, support self-piloted aircraft, ensure operational predictability, and facilitate regional growth.

To address these challenges, NASA introduced Digital Flight (DF), a proposed cooperative operating model in which flight operations are conducted by reference to digital elements. With DF, the operator would ensure flight-path safety through cooperative practices and self-separation enabled by digital technologies and automated information exchange. Digital Flight Rules (DFR) are regulations that would govern sustained Digital Flight operations as an alternate means of separation in Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC), in lieu of employing visual procedures (VFR) or receiving ATC separation services (IFR).

DF is proposed to be applicable to all airspace user categories and accepted in potentially all airspace classes. DFR is designed to be compatible with the emerging concepts of Unmanned Traffic Management (UTM), Enhanced Traffic Management (ETM), and UAM, and could serve as the mature-state operating mode in each of these concepts and other similar derivatives.

NASA is developing technologies that are already building toward digital flight, including Traffic Aware Strategic Aircrew Requests (TASAR).

After Jay Shively gave the charge for the meeting, groups were asked to develop two to three consensus "Visions" for near-term, mid-term, and mature use cases within the context of m:N operations, which could include:

- m:N ratios
- PICs role
- Environment (density)
- Assumptions
- Technologies
- Functions
- Automation
- Timeline

Each discussion should also identify functions, barriers, research needed, and data needed to establish a safety case.

Participants were then broken out into the following groups, reflecting the m:N subgroups:

1. Large UAS – Moderated by Brandon Suarez and Conrad Rorie
2. Small UAS – Moderated by Meghan Chandarana and Garrett Sadler
3. HAPS – Moderated by Andy Thurling and Jeff Homola
4. UAM – Moderated by Igor Dolgov and Mike Politowicz

Breakout groups discussed use cases relevant to their respective subgroups (large UAS, sUAS, HAPS, and UAM) and then met back as the larger m:N group to debrief.

Large UAS Debrief

The large UAS breakout group created two use cases, one for near-term and one for mid-term (intermediate).

<u>Large UAS Near-Term Use Case</u>

In the near-term use case, the assumptions include point-to-point cargo operations under IFR with minimal ATC interaction, normal 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, one remote pilot can handle two aircraft enroute under nominal conditions. The m:N ratio entails two remote pilots 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 regards 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, which is estimated to take approximately 3 years.

Large UAS Key Takeaways

The first major key takeaway from the large UAS breakout group’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 Intermediate Use Case

In the intermediate use case for large UAS, the goals are to increase m:N ratio and relax operational tempo constraints, which can be achieved with new certified hardware at a lower cost per unit. The 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 Aircraft Collision Avoidance System (ACAS) Resolution Advisories (RA) execution, and automated checklists with resolutions.

The timeline for implementing these operations is estimated to be 5+ years after initial operations, approximately 10 years from now.

sUAS Debrief

The sUAS breakout group identified a list of key takeaways, including the need for regulatory mechanisms that can accommodate small system updates without requiring certification. They emphasized that the specific m:N ratio is not as important as the capability and reliability of the system, but there is 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. In the view of the military, the “m” component is more involved with decision-making than flying. On the other hand, 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 farm-term.

Remaining questions revolve around aligning regulatory timescales 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.

UAM Debrief

The UAM breakout group 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 Debrief

The HAPS breakout outlined several key takeaways. Firstly, they stressed the international nature of HAPS operations and the need to adhere to ICAO rules in governing these operations.

The HAPS breakout group 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
- A DAA solution is accepted for up and down transit, involving the PIC on the loop
- Cooperative Traffic Management (CTM) 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

The HAPS breakout group also defined a few key terms and concepts associated with HAPS:

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.

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 Control Environment (CCE) enabled by ICAO Standards and Recommended Practices (SARPs).

Heterogenous operations are conducted in CCE 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 CCE.

Roles, and the concept of the human *over* the loop, are depicted in Figure 10 where the PIC role is over the loop at a strategic objective level:

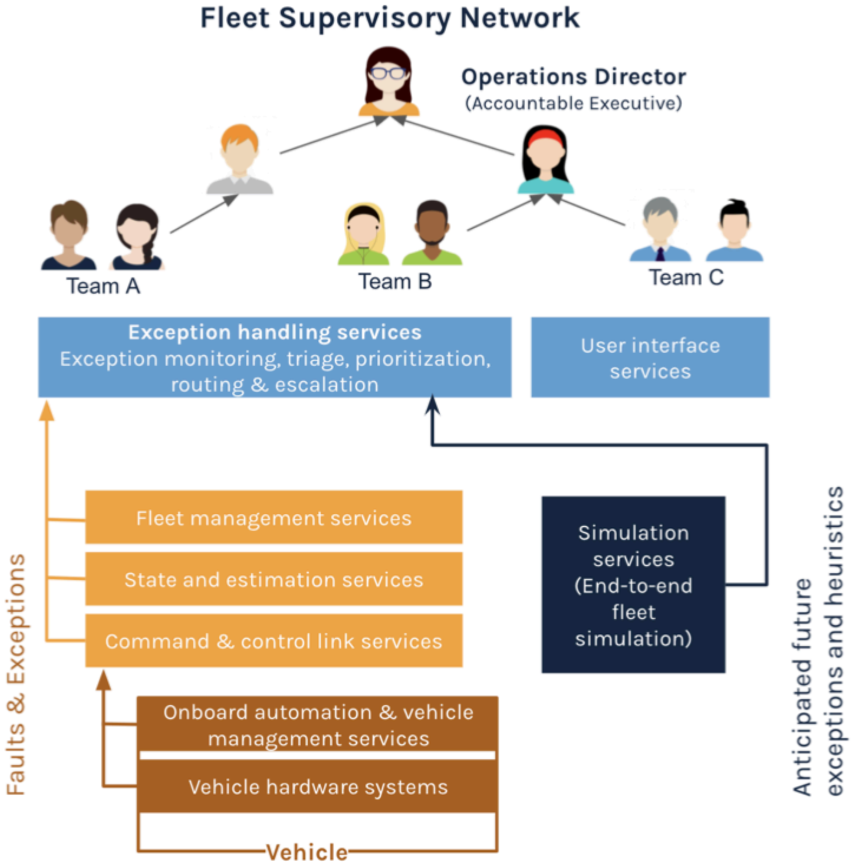


Figure 10. Fleet Supervisory Network, used with permission

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 CCE can be established, enabling dynamic deconfliction between operators

- Operations within the CCE are heterogeneous, but do not include super or hypersonic vehicles
- The infrastructure supports multiple operators within the CCE, such as having Essential Support Systems (ESS) in place

The environment for these operations is limited to the national context, meaning there are no ICAO SARPs governing the operations. Additionally, the airspace density is low.

The m:N ratio in this mid-term use case is dependent on the platform being used. It is determined based on the breakeven point and the demonstrated safety of the operations. Currently, the focus is on expanding the operational envelope.

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 CCE 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 CCE are homogenous, with each CCE 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 regulated outlined in Annex 1 (part 61 commercial instrument) are applicable.

Next Steps

Next steps include a face-to-face kickoff Jan 24-27, 2023 with RTCA's SC 228 working group on Detect And Avoid (DAA). Meeting will be held at RTCA headquarters in Washington, DC. The outcome of our m:N work can directly help 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).

While large UAS, sUAS, HAPS, and UAM working groups will continue to meet virtually throughout the next year, the next in-person m:N working group will be in conjunction with AUVSI's Xponential May 8-11, 2023 in Denver CO.

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.

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

Appendix A: Select References from Tracy Lamb's Presentation, *Considerations and References to Support One to Many m:N sUAS Commercial Operations: Lessons & Observations From the Field 2014-2022*

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