m:N WORKING GROUP

MEETING SUMMARY

JULY 2025

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EXECUTIVE SUMMARY

From July 8 through July 10, 2025 the m:N Working Group and its subgroups met at the NASA Langley Research Center in Hampton, VA for their biannual in-person meeting. Although the subgroups of the m:N Working Group meet virtually year-round to make progress on their individual goals, the in-person meeting serves to pull the full group together to further identify and discuss challenges and paths forward for incorporating uncrewed aircraft systems (UAS) into the airspace.

After the retirement of Jay Shively (Adaptive Aerospace), Andy Lacher (NASA) and Andy Thurling (DroneUp) took over as the leads of the m:N Working Group, with assistance from Aptima, Inc. The group comprises members of government, industry and academia who endeavor to identify and reduce barriers to m:N operations. This includes identifying requirements, use cases, and metrics, and developing white papers to support organizations including the Federal Aviation Administration (FAA), Radio Technical Commission for Aeronautics (RTCA), SAE International, and Advancing Standards Transforming Markets International (ASTM).

Following the previous in-person meeting in October 2024, significant progress was made in achieving the objectives of the existing subgroups. The Airspace Integration and small UAS (sUAS) subgroups completed their white papers; the sUAS subgroup began identifying new topics to pursue; the white paper for the Evaluation Methodologies subgroup entered its final stages of drafting; and the Interventions and Exceptions (I&E) subgroup began drafting a version of their white paper. With the initial goals of these subgroups nearing completion, the m:N Working Group shifted its attention toward identifying new topics of interest during the July 2025 meeting.

THE CHARGE FOR THE WEEK

This meeting of the m:N Working Group focused on developing new subgroups, defining the scopes, and identifying champions to lead the visions of the new groups.

The biannual meeting commenced with tours of the UAS research laboratories at NASA Langley Research Center. The second half of the first day and first half of the second day then focused on presentations from government, academia, and industry. Topics discussed included the following:

- Multi-vehicle operations at Langley
- Effects (or lack thereof) of N on workload and situational awareness
- US Army challenges in UAS operations
- International UAS regulations
- Updates on the 14 CFR Part 108 release
- An in-ballot standard on autonomy
- Authority, responsibility, and accountability

For the remainder of the meeting, the Working Group divided into various breakout groups to identify new topics of interest, culminating in the identification of three new breakout groups. Work moving forward will continue in the following subgroups:

- **Interventions & Exceptions Subgroup**
  Andy Thurling (DroneUp)
- **sUAS**
  Scott Scheff (HF Designworks)
- **Scalable Remote Crew Design Considerations for Multi-Aircraft Operators and OEMs**
  George Gorospe (NASA) & TBD
- **m:N Validation and Verification**
  Wendy Ljungren (Anzen Unmanned) & TBD
- **Design Considerations for m:N**
  Srikanth Gururajan (Saint Louis University) & Mark Shikerman (Wisk)

JULY 8 TOURS AND PRESENTATIONS

Day 1 of the 3-day bi-annual face-to-face meeting of the m:N Working Group began with a tour of research laboratories at NASA Langley Research Center followed by presentations from representatives of government, industry, and academia.

NASA Langley Research Center Tours

Prior to the official start of the m:N Working Group meeting, attendees were given the opportunity to tour NASA Langley Research Center's uncrewed aircraft systems (UAS) and autonomy research laboratories (Figure 1), coordinated by Mr. Mike Politowicz and Ms. Victoria Chung. The tour included the Mission Operations & Autonomous Integration Center (MOSAIC), Research Collaboration Facility (RCF), Air Traffic Operations Laboratory (ATOL) and Remote Operations for Autonomous Missions (ROAM) facilities.

Figure 1. Tours of the NASA Langley Research Center laboratories including MOSAIC (upper left), RCF (upper right), ATOL (middle left), the Langley Flyer simulators (middle right), and the ROAM/CERTAIN Command Centers (lower left and right)

Mission Operations & Autonomous Integration Center (MOSAIC)

James Nicholson | NASA

Mr. James Nicholson led the tour of the MOSAIC. The long-term objective of MOSAIC is to provide a centralized location for managing remote, multi-fleet, live or simulated UAS flight operations—including beyond visual line of sight (BVLOS) operations. This is conducted using NASA Langley Research Center's City Environment Range Testing for Autonomous Integrated Navigation (CERTAIN) capability, which supports both research and center operations and safety missions, including LiDAR inspections, perimeter surveillance, and locating and monitoring activities. The facility is used to remotely monitor uncrewed aircraft (UA) performance data, issue commands for controlling the vehicles, and view live feeds from onboard cameras.

Research Collaboration Facility (RCF)

Lon Kelly | NASA

Mr. Lon Kelly provided an overview of the RCF's capabilities. The RCF partners with researchers to provide live, virtual, and constructive (LVC) capabilities to support research on UAS operations. Its technologies include the UAS Mission Analysis Tool (UMAT) and Traffic Awareness and Ubiquitous Real-time Airspace Surveillance (TAURAS). UMAT contains a high-fidelity visual model of an area (like the NASA Langley facility) and provides users with capabilities such as replaying missions, adding waypoints to create mission paths, and integrating live data such as radio frequency and weather. The TAURAS system ingests data from multiple sources, e.g., radar, Automatic Dependent Surveillance-Broadcast (ADS-B), and direct vehicle feeds to provide real-time BVLOS airspace surveillance.

Air Traffic Operations Laboratory (ATOL)

Neil O'Connor | NASA

Mr. Neil O'Connor guided attendees through ATOL's facilities and discussed the laboratory's capabilities and objectives. ATOL is a flexible airspace operations simulation facility designed to prepare for a paradigm shift in air traffic demand. It conducts research to enable the transition from a homogeneous to a heterogeneous traffic mix, addressing the potential unprecedented increase in traffic numbers due to the proliferation of urban air mobility (UAM) vehicles. ATOL aims to mitigate growing delays from increasing traffic and facilitate the easy assimilation of new categories of vehicles with dramatically different performance characteristics. By simulating a representative portion of the National Airspace System (NAS), ATOL supports research and development to ensure the efficient and safe integration of diverse air traffic. ATOL hosts ten Langley Flyers, low-cost, flexible simulators configured for large-fleet advanced air mobility (AAM) operations. These simulators are used for research on human-in-the-loop operations and air traffic management (ATM) procedures.

Remote Operations for Autonomous Missions (ROAM)

Bryan Petty and Nadia Fox | NASA

Included in the ATOL are ROAM and the CERTAIN Command Center—a tour of which was provided by Mr. Bryan Petty and Dr. Nadia Fox. This facility conducts small UAS (sUAS) research and BVLOS flight operations at NASA Langley and other remote locations. ROAM is designed to enable future multi-vehicle operations (m:N) by providing an LVC environment as a test ground. The command center includes multiple workstations including ones for the Ground Control Station (vehicle) Operator, Vertiport Manager, Range Safety Officer, and Flight Test Manager/Sim Director. The facility supports the maturation of AAM technology and concepts through comprehensive end-to-end hardware and human-in-the-loop simulation and flight testing.

Welcome

Andy Lacher | NASA
Andy Thurling | DroneUp
George Gorospe | NASA

Figure 2. Mr. Lacher (left) and Mr. Thurling (right) welcoming meeting attendees

Kicking off the m:N Working Group meeting, Mr. Andy Lacher and Mr. Andy Thurling (Figure 2) shared the goals of the in-person meeting: to exchange information about m:N operations, identify knowledge gaps for m:N operations, and plan future tasks for the Working Group. Dr. Samantha Emerson from Aptima then stepped in to share the meeting agenda and outline the activities that would be taking place over the course of the meeting to achieve these goals. Mr. George Gorospe emphasized the importance of the conversations and work of the Working Group meeting and how they will be vital for paving the future trajectory of the m:N Working Group. Mr. Gorospe closed out the welcoming remarks by introducing Mr. Mike Politowicz and his work on m:N operations.

CONOPS for Multi-Aircraft Flights from ROAM

Mike Politowicz | NASA

Mr. Mike Politowicz, Research Aerospace Engineer at NASA Langley Research Center, discussed an upcoming publication from NASA's ROAM UAS Operations Center on the concept of operations (CONOPS) for multi-aircraft flights. The publication will provide the blueprint for conducting multi-aircraft flights at the NASA Langley Research Center, using the CERTAIN concept for sUAS. The goal of the paper is to enable researchers and operators to understand how to scale from 1:1 to 1:N to m:N and to mitigate risks as operations scale.

Mr. Politowicz discussed how the Langley m:N CONOPS incorporates the ROAM Operations Center and Measuring Performance of Autonomy Teaming with Humans (MPATH) Ground Control Station software to operate uncrewed aircraft (UA) in the CERTAIN range. The CONOPS publication includes comparison of 1:1, 1:N, and m:N operations in terms of technology, team structure, communications, and contingencies. The presentation included adapted decision flow diagrams for 1:1 to m:N operations for generic, off-nominal operations as well as 1:1 and m:N operations in which handoff may be required. Mr. Politowicz highlighted that the Langley m:N CONOPS handoff philosophy is to mitigate risk by handing off "unhealthy" aircraft between operators so that one person may focus on the safe operation and risk mitigation of the unhealthy aircraft, assuming that tasks can be done quickly while also considering if the tasks require sustained attention. Figure 3, above, shows representative changes between the operations to align with the risk mitigation philosophy.

		1:1 Operations CURRENT OPERATIONS	1:N Operations MULTI-AIRCRAFT OPTION	m:N Operations MULTI-AIRCRAFT OPTION
Technology	GCS		Updated MPATH Ground Control Station UI for improved multi-aircraft control	
	Traffic		*Optional:* NASA IoT Platform or USS	
	Handoff			Vehicle handoff capability
Team Structure			*Optional:* Airspace Manager (AM) and Radar Operator (RO) roles collapsed into Range Safety Officer (RSO)	
Communication (within Teams)			*Optional:* Integrated text-based chat capability	
			Optional: Co-location of roles to minimize digital comms	
				GCS-to-GCS (digital) comms for handoffs
Contingencies (General)			*Optional:* Reconsider "knock-it-off" response actions to potentially allow healthy UAS to continue on flight paths	
Contingencies (Specific)		*See 1:1 decision flow diagrams (Appendix B in ConOps Document)*	Similar to *1:1*, but need to account for handling of remaining healthy UAS when one UAS has an issue	*See m:N decision flow diagrams (Appendix B in ConOps Document)*

Figure 3. Representative changes from single- to multi-aircraft operations

Using SME expert input, the paper can be used by other operators to set a groundwork to take to their review boards. The authors will be defining new procedures; identifying contingency scenarios; and creating transparent, accessible, reality-based examples with input from stakeholders, including the research community and external organizations. The published paper will also include handoff implementation recommendations, including options for team configuration and communications link configurations.

OSU-Wing PIC Phase I Evaluation: Baseline Workload and Situation Awareness Results

Julie A. Adams | Oregon State University

Figure 4. Dr. Adams presenting OSU-Wing experiment and results

Dr. Julie A. Adams (Figure 4), Associate Director of Research in the Collaborative Robotics and Intelligent Systems Institute as well as the College of Engineering's Dean's Professor at Oregon State University, presented on her research on flight evaluations as part of the FAA's Center of Excellence (COE) for UAS Research Alliance for System Safety of UAS through Research Excellence (ASSURE) program. The research team is collaborating with Wing to assess the use of UAS for disaster response using multi-aircraft operations with a pilot in command (PIC) performing detect and avoid (DAA) tasks. Dr. Adams discussed the research goals and the hypothesis that PIC performance and workload are not negatively impacted by an increased number of UAS or nests. To assess the hypothesis, PICs complete manual single and double DAA operations while addressing tactical weather in multiple trials.

The presentation included a review of the experimental design and instrumentation, how situation awareness was measured, variables associated with workload and how they were measured, and other elements of the research. Overall, the study revealed several key insights, as follows:

- The overall objective workload was similar between trials and stayed in the low to moderate range, as shown in Figure 5, below.
- There were no major differences in workload and situation awareness when PICs controlled a nest range of 10-24, although interaction counts increased.
- PICs had slightly improved situation awareness with an increased number of UAs but no change in workload; although fixation and duration counts decreased, the change was not significant.
- During single DAA conditions, situation awareness did not change although PICs had higher fixations on the ADS-B than the Wing interface, resulting in more interactions and a moderate increase in workload due to the DAA event. The change was not impacted by the number of nests or UAs.
- During double DAA conditions, PICs had the lowest measures of overall workload but also decreased situation awareness. The participants fixated on relevant ADS-B areas and the increased number of active UAS resulted in fewer interactions.
- Tactical weather conditions did not significantly impact the area or duration of fixation, the interaction level, or overall workload as compared to nominal tasks. The PICs experienced the lowest situation awareness initially, but this improved with better briefings.
- Manipulation of the number of nests and active UAS did not impact performance.

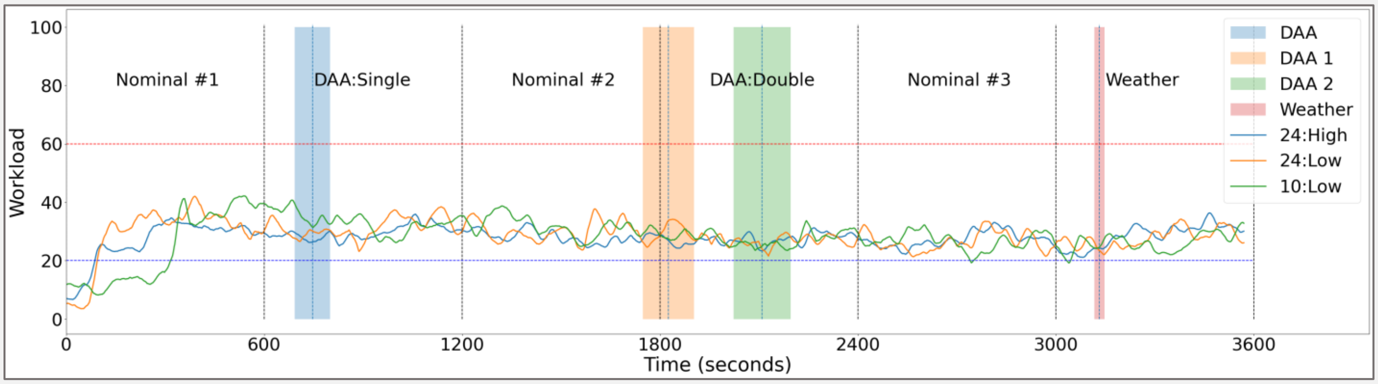

Figure 5. Overall objective workload

J. A. Adams, C. A. Sanchez, V. Mallampati, J. Bhagat Smith, E. Burgess & A. Dassonville. (2024) OSU-Wing PIC Phase I Evaluation: Baseline Workload and Situation Awareness results

The findings indicate that manipulating the number of nests and active UAS may not impact PIC performance, and that PICs were actively engaged in the tasks with very good situation awareness and normal workload regardless of the type of trial. The researchers found that unexpected events slightly changed PIC actions but did not negatively impact PIC performance. Dr. Adams concluded by discussing factors that impact m:N operations, such as the human-robot interaction role, environmental complexity, the spatial operational area, and communication requirements through the lens of three use cases. She highlighted that although swarm operations add complexity, communications requirements were the drivers of performance and workload change as opposed to the number of UAS a PIC must control. Finally, Dr. Adams discussed the algorithms that were created using this research to predict workload.

US Army m:N Challenges

Chris Lyman | US Army, Aviation and Missile Center, Technology Development Directorate

Mr. Chris Lyman (Figure 6), the Autonomy and Teaming Branch Chief for the Army's Aviation and Missile Center’s Technology Development Directorate, presented a military perspective on advanced teaming for tactical aviation operations and using science and technology to create requirements that industry can use to generate solutions. A critical challenge faced by the military is that issues are time sensitive and operators use the system from various locations and by means of different user interfaces. Mr. Lyman discussed the challenge of meeting different missions and roles while contending with jamming, active disruptions, and multiple systems operating at various ranges with varying complexity, depicted in Figure 7, below.

Figure 6. Mr. Lyman discussing the US Army's use of artificial intelligence and machine learning in human-machine integration for UAS operations

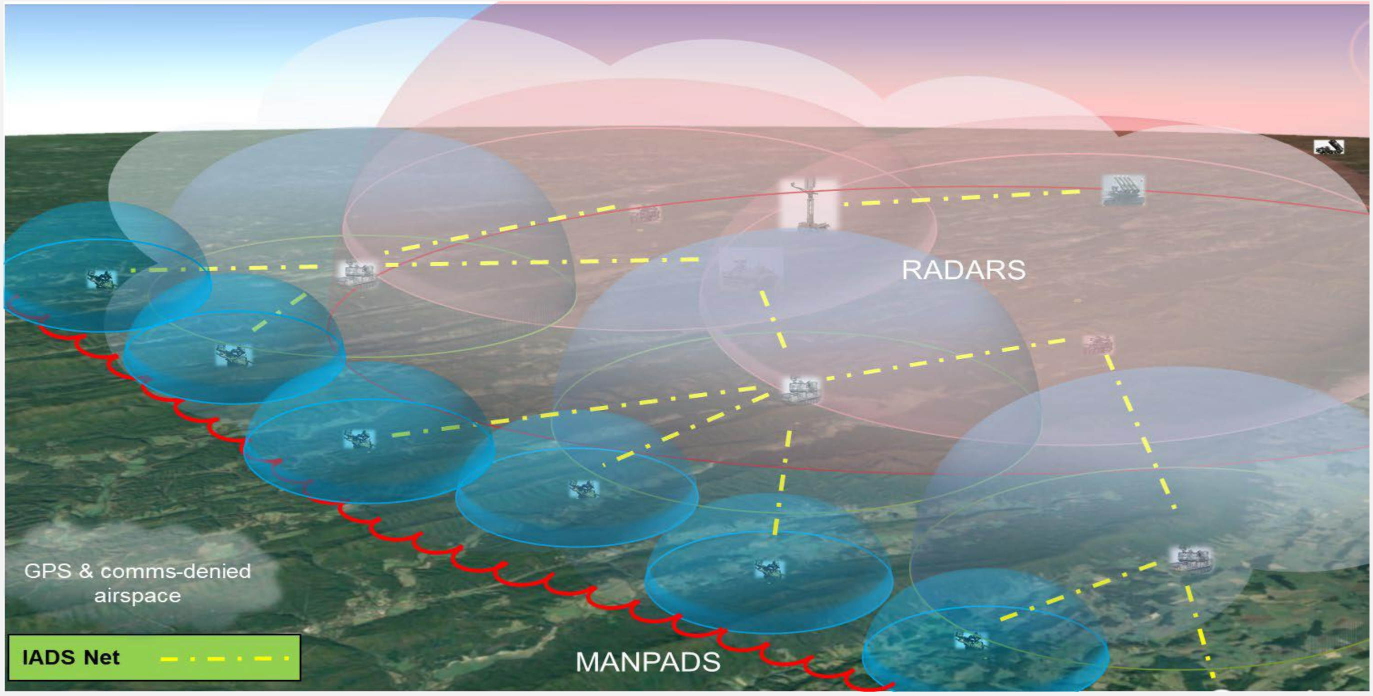

Figure 7. A visual depiction of advanced teaming for tactical aviation operations in the US Army

He posed the following series of questions that the military must consider to meet these and other challenges and for the audience to consider:

- How can solutions be leveraged for effective handover while soldiers are also performing other roles?
- How do the various systems interact?
- How are data shared across multiple systems that must be managed?
- What must occur when there are limited communications and inconsistent status updates?
- How can autonomy and automated aspects be leveraged?

To address these questions, Mr. Lyman discussed how some systems are created onsite, live from the field, when the airspace, systems, and individual UA in active engagement must be managed. The challenges of handoffs were presented, such as authenticating and verifying that a person can control a given asset and determining if the system is compromised even as operation authority and cybersecurity concerns must also be addressed. The presentation also included the use of artificial intelligence (AI) and machine learning (ML) in human-machine interfaces with a philosophy of "AI to do things right, so humans can do the right things." Mr. Lyman discussed the Army's application of these technologies to execute tasks and actions, sharing that they discovered that 16 tasks/actions was the maximum integration level that could be accommodated at that time. The concept of "graceful degradation" of autonomous systems as things change was described.

Mr. Lyman discussed how the role of human in the control loop shifted in current operations (e.g., in/on/over the loop). In the field, these roles will change with the mission, the operator's ability to shed capabilities, and if the asset must be retained (i.e., an "exquisite" asset) or can be abandoned (i.e., an "attributable" asset). The perspective considered the different levels of risk versus reward and how skill identifiers may be needed for some levels of UAS to execute a certain engagement type.

Mr. Lyman concluded that the Army's far-term vision is one in which the human and agent operate as peer to peer. He outlined where the Army is going, reviewing exploration of autonomy architecture, autonomy component technology, end-user engagement, safety and security management, collaboration ontology and interoperability profiles, and the use of AI and ML to enhance capabilities.

International Regulators Panel

Tim Beglau | FAA
Craig Bloch-Hansen | Transport Canada
Scott Griffith | CAA New Zealand
Andrew Hately | Eurocontrol
Conrado Klein de Freitas | ANAC Brazil
Andy Thurling (Moderator) | DroneUp

Figure 8. Panelists discussing regulations for UAS operations in their respective countries.

Mr. Andy Thurling moderated a panel of five representatives of international regulators (Figure 8) to discuss the regulations needed, and status thereof, to enable m:N operations. After introducing the panelists, Mr. Thurling opened the floor to Mr. Tim Beglau of the FAA to discuss how the United States is approaching this subject. Mr. Beglau stated that currently, there are two ways to approach operations based on the size of the UAS. sUAS (less than 55 pounds at takeoff) operations may occur following the guidance of 14 CFR Part 107 and entities can request a waiver to conduct m:N operations. Larger UAS can operate under 14 CFR Part 135 with an exception approved through the FAA. Mr. Beglau noted how these regulations were not written for UAS, but exceptions may be granted as operators demonstrate their control center set up and maintenance. He highlighted that seven operators are conducting delivery activities under Part 135 operations in the United States with approved standard operating procedures (SOPs). Mr. Beglau discussed the FAA's approach of reviewing the research regarding the handling of emergencies by human and system, how information is shared among systems and humans, and to what extent a human must monitor each uncrewed aircraft. From this research, the FAA has created a data-driven checklist that will be incorporated into the upcoming 14 CFR Part 108 and made available to guide operators.

Mx. Craig Bloch-Hansen then presented on behalf of Transport Canada, sharing that the regulations on BVLOS operations had been approved in Canada and would begin on November 4, 2025. Transport Canada is working with pilots and original equipment manufacturers (OEMs) to prepare the industry for routine operations. They discussed how the regulations reflect the importance of human accountability for flight safety, even as the role of "pilot" is changing. Mx. Bloch-Hansen discussed Transport Canada's graduated method, starting with research, followed by specific operational approach with special approvals for some operators, then standardizing operations, and finally approving new regulations. It is expected that experimental operations will mature and can be used to scale operations between the steps. Mx. Bloch-Hansen also reviewed Transport Canada's novel CONOPS approach considering people, procedures, and product functions to guide methodologies and technologies along the way, working through a loop and then iterating for the next set of regulations as well as updates. The approach is shown in Figure 9.

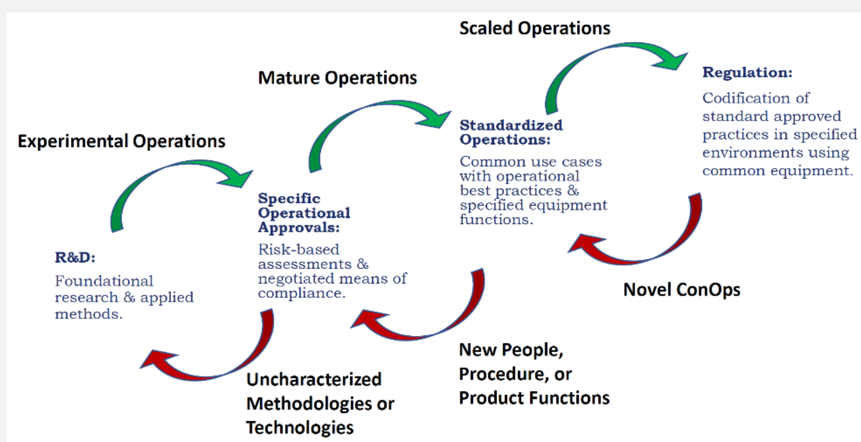

Figure 9. Transport Canada's approach to regulatory maturity

Mr. Scott Griffith spoke next on behalf of the Civil Aviation Authority (CAA) of New Zealand. He shared that New Zealand is still in the early stages, encompassing m:N operations in light shows and agrichemical applications. The latter have limited instances of BVLOS, utilize pre-flight automation and alerting technologies, have a maximum m:N ratio of 1:3, and are low-level operations (i.e., close to the ground). Mr. Griffith shared a proposed m:N instrument flight rules (IFR) trial, depicted in Figure 10. The trial includes three conditions: two UAs on the same route with vertical separation and then reduced lateral separation, two UAs on the same route with a vertically separated overtake, and two UAs on opposite routes with vertical separation. The goal of the trial is to test the boundaries of what can be done in controlled airspace under IFR with escalating complexity and eventually higher m:N ratios.

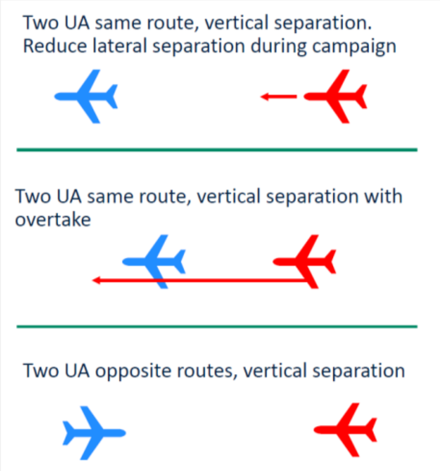

Figure 10. CAA New Zealand's proposed m:N IFR trial (Q1 2025)

Next to present was Mr. Andrew Hately of Eurocontrol. Mr. Hately discussed the status of delivery and inspection flights in Europe and that, because operations are not yet completely autonomous, the regulations require a pilot or operator in command to be responsible for the flight. The m:N ratio is determined based on the certificate issued and the Specific Operations Risk Assessment (SORA). He stressed that the regulator must be convinced that the SORA and proposed operations are safe before granting approval. Although operations have begun, there is a limit on flights that is determined by the expected workload including contingencies. Typical operations feature a ratio of 1:4, although some operators are achieving ratios of 1:10 with BVLOS. Mr. Hately shared an anecdote that in some operations, increasing the operator number from one to two had led to confusion when roles were less defined. He shared another example of a successful UAS swarm-type show using an approved SORA with two pilots flying 600 UAs and a team of four observers and one project manager.

Mr. Conrado Klein de Freitas then presented on the regulations of the National Civil Aviation Agency (ANAC) of Brazil. The current Brazilian standard enables BVLOS above 120 meters (400 feet) above ground level (AGL), established Remotely Piloted Aircraft Systems (RPAS) operations, and created the ANAC System for Unmanned Aircraft (SISANT) registration UA weighing more than 250 grams (0.55 pounds), regardless of whether they are used for recreational or professional purposes. Mr. Klein de Freitas described that there are currently three levels of UAS under ANAC standards which are based on UAS size and the altitude at which operations occur. ANAC regulators are discussing new levels that will be classified as Open, Specific, and Certified and that rules will be changing based on risk level (i.e., low, medium, high) using the SORA methodology.

Following the overviews, the panelists engaged in a question-and-answer session. Mr. Thurling began the discussion by noting that all regulations referenced the responsibility of a human "in command." He asked how the scaling of automation and autonomy will affect accountability, authority, and responsibility of the human in command and impact the regulations. Mr. Griffith responded by sharing a graph (Figure 11) of responsible parties in traditional aviation operations and a potential representation of future UAS operations with the expected shift in amounts of authority for each role, describing how the general theme of accountability will shift within the value chain of stakeholders. The panelists discussed how the historical view of the pilot was also that of the main operator, but that these roles are also distinguished from each other using SOPs; the panel recognized that revised SOPs for UAS operators will need to stay in a general zone of safety and foundational responsibility. This point was emphasized by how a safety management system (SMS) will identify areas of accountability and responsibility and that although SOPs will shift with increasingly automated equipment and technology-enabled operations, accountability will still reside with the person who put the aircraft in the air as well as the business in operation. It was concluded that safety must be ensured to drive SOPs, separate roles and levels of responsibility, and prioritize the testing and defining of limitations.

Figure 11. Mr. Griffith's depiction of shift in responsibility and accountability from traditional to highly autonomous aviation

The group was asked how to ensure that the human is not in a "moral crumple zone," which prompted a conversation about who has the ultimate authority and responsibility in traditional aviation as compared to UAS operations. The panelists noted how UAS operations have more automation, which shifts other roles and operations based on certification, and thus the levels of authority and responsibility.

The conversation flowed to the topic of who is making decisions, with an example of how software development includes a level of requirements for coding and decision making within the software programming. The panelists discussed how a PIC can, traditionally, break the rules if safety demands it. In high levels of automation, however, the person/PIC must take over as required, meaning that they also need to monitor, have good situation awareness, and be ready to act. Higher automation levels also mean that the person must have regular tasks to ensure that they maintain situation awareness, which translates to the m:N ratio. The panelists concluded that the role of the human is not changing much but there has been a slight shift in scope.

Finally, the group discussed terminology consistency, how it influences regulations and standards, and how terminology impacts users. Although there is a call for "harmonized regulatory standards" and consensus within standards, the panelists agreed that the consideration of standardization will come with maturation.

Part 108 Update

Tim Beglau | FAA

Mr. Tim Beglau (Figure 12), one of the authors of the new FAA rule, delivered an informative talk on the upcoming 14 CFR Part 108 regulation. Part 108, which addresses BVLOS operations for UAS, has been accelerated by a recent Executive Order aimed at "Unleashing American Drone Dominance." Although the rule had not been publicly released at the time of the meeting, Mr. Beglau provided valuable updates and insights into what to expect, summarized as follows:

Figure 12. Mr. Beglau explaining what to expect from the upcoming Part 108 rule

- **Request for Comments**
  Mr. Beglau emphasized the importance of the public comment period, urging participants to provide legitimate and detailed feedback. He noted that the rule is extensive, spanning 900+ pages, and highlighted the need for specific comments that address particular issues rather than general discontent. He explained that comments should not only state what is disliked but also provide reasons why. He mentioned that many comments are often disregarded if they do not add value or if they repeat points already addressed in the preamble.

- **Public Comment Period and Timeline**
  Mr. Beglau discussed the timeline for the rule's finalization, referencing the Executive Order that had pushed for the rule to be released for public comment by July 6, with a final version expected by February 1, 2026. He acknowledged the challenges in meeting this timeline but assured that efforts were ongoing to adhere as closely to the timeline as possible. The public comment period could range from 30 to 90 days, during which stakeholders are encouraged to read, analyze, and provide feedback. Mr. Beglau highlighted that the final rule could differ from the initial publication based on the comments received and the input from other agencies, including the Department of Homeland Security.
- **Implications for UAS Operations**
  Mr. Beglau explained the implications of the new rule for various operators. For those flying under Part 135 with exemptions or as agricultural operators under Part 137, the new rule would eliminate the need for exemption renewals. He stressed the importance of reading and understanding the rule, especially for operators intending to conduct BVLOS operations. He emphasized that although some aspects of the new rule may make operations easier, other operations could become more challenging. He also mentioned that other regulations, such as Part 1, would be updated in conjunction with Part 108, necessitating a thorough review by operators. Additionally, operators who are not under Part 135 but engage in activities such as research, flight schools, or photography would also need to comply with the new rule if they conduct BVLOS operations.

Mr. Beglau also provided insights into the current state of Part 135 operations, noting that there are seven operators who can transition to supervisory roles and continue to manage their operations. He highlighted the differences between Part 135 and Part 137, emphasizing that Part 135 requires a higher certification level. He also discussed the importance of maintaining security during off-nominal situations, such as off-field landings, and the role of supervisors in managing these scenarios.

Mr. Beglau concluded by expressing his willingness to provide a virtual follow-up talk to brief the m:N Working Group once the rule is publicly released. He reiterated the importance of stakeholder engagement during the public comment period and encouraged participants to stay informed and provide meaningful feedback. Mr. Beglau's talk provided a comprehensive overview of the upcoming Part 108 rule, its implications, and the importance of thorough review and engagement by all stakeholders.

Day 1 Concluding Remarks & Introductions

Andy Lacher | NASA
Andy Thurling | DroneUp

Mr. Andy Lacher's and Mr. Andy Thurling's closing remarks wrapped up the Day 1 presentations, provided a preview of Day 2 discussions, and primed the Working Group on some of the topics and aims for the following day. Mr. Lacher informed the group that one of the discussions for Day 2 would concern the definition of the "system" within a UAS, pointing out that this is likely to surface gaps and points of discrepancy when incorporating m:N operations. He added that such gaps will be a main focus of the Working Group over the next 2 days, with several activities and discussions focusing on which gaps the Working Group should prioritize addressing in the future. Mr. Thurling noted that definition discrepancies are one of the reasons that standards are important, alluding to the presentation and discussion on standards that would take place on Day 2.

JULY 9 PRESENTATIONS AND BREAKOUTS

Day 2 of the 3-day m:N Working Group meeting began with additional presentations from representatives of government and industry. Presentations were followed by breakout groups to brainstorm new ideas for the group to pursue. The day ended with a debrief session to synthesize the ideas across groups into concrete themes for new m:N subgroups.

ASTM Proposed New Standard – Guide for Exercising a Contextual Framework for Increasingly Autonomous Aviation Systems

Pranav Nagarajan | DLR

Mr. Pranav Nagarajan, Research Scientist, German Aerospace Center (DLR), presented an insightful talk on the Advancing Standards Transforming Markets International's (ASTM's) proposed new standard, "Guide for Exercising a Contextual Framework for Increasingly Autonomous Aviation Systems." The session was moderated by Mr. Andy Lacher, who provided an introduction to the standard and its development process. The standard, currently in ballot, aims to address the rising tide of autonomy in aviation by providing a contextual framework rather than prescriptive levels of autonomy.

Mr. Lacher began by explaining the background and motivation for the standard. He noted that the effort originated from a need to establish clear definitions related to autonomy, as there is currently no consensus on terms such as "uncrewed aircraft" or the roles of individuals who operate them. Recognizing the growing importance of autonomy in aviation, ASTM formed an administrative committee (AC377) to explore the issue comprehensively. Unlike the SAE J3016 standard, which defines levels of autonomy for automated driving, the framers of the ASTM standard chose to develop a more flexible contextual framework instead of fixed levels of autonomy. This approach was initially outlined in a white paper and has since evolved into a standards development activity.

Mr. Nagarajan, who now leads the effort, provided an overview of the standard's content and development process. He explained that the standard is designed to offer a guide for exercising a contextual framework for increasingly autonomous aviation systems. It includes analysis methods for redistributing tasks among pilots and automated systems, a standardized framework and vocabulary, and recommendations rather than prescriptive requirements. The standard does not claim explicit relation to other standards but references them within the document.

The core of the task group responsible for developing the standard, ASTM WK76044, includes representatives from various organizations such as Reliable Robotics, Joby, Honeywell, MITRE, Collins Aerospace, DroneUp, the FAA, NASA, and DLR. The group has worked collaboratively to ensure that the standard addresses safe autonomy and facilitates the exchange of ideas. Although the effort is mostly complete, the group continues to meet periodically to refine the standard and are currently in the ballot resolution process. The standard guide is expected to be published in Fall 2025.

Mr. Nagarajan highlighted the scope of the standard guide, which follows the typical ASTM structure. The procedural section is the largest part, detailing what is conceptually required without being prescriptive in how requirements are achieved. An appendix provides a non-prescriptive example to help users understand the standard. The scope of the standard ranges from fully autonomous flight from point A to point B to specific functions such as geofencing. The standard does not make ethical or moral statements about what should be automated but takes a technical, rational approach to analyzing autonomy.

The terminology section of the standard introduces concepts such as "agent-in-the-loop," agent-on-the-loop," agent-over-the-loop," and "agent-out-of-the-loop" to describe the varying levels of human interaction with autonomous systems. It also defines "command authority" and "final authority" to clarify the roles and responsibilities within the system. The procedural section includes a detailed analysis of the risks and safety benefits of including automation, emphasizing the importance of understanding the operational context and system description.

Mr. Nagarajan walked the group through an example use case for the standard, focusing on an automatic ground-collision-awareness system. This fictional system was used to illustrate how the standard can be applied to real-world scenario systems. The example included a detailed description of the system's functions, interfaces, and safety analysis, demonstrating how the standard can help users understand and implement autonomous systems.

The talk concluded with a Q&A session, where participants discussed various aspects of the standard and its application. Questions covered topics such as the relationship to model-based systems engineering (MBSE) techniques, cognitive task analysis, workload assessment, and the potential for applying the standard to m:N operations. Mr. Nagarajan and other participants emphasized the importance of considering the human role in autonomous systems and the need for tools to assess and manage workload effectively.

Overall, Mr. Nagarajan’s talk provided a comprehensive overview of ASTM's proposed new standard for contextualizing increasingly autonomous aviation systems. The standard aims to provide a flexible, contextual framework for analyzing and designing autonomy, addressing the complexities and challenges of integrating autonomous systems into aviation. The discussion highlighted the collaborative effort behind the standard and the ongoing work to refine and improve it, ensuring that it meets the needs of the aviation community.

Accountability for Autonomous Flight Operations

Andy Lacher | NASA

Mr. Andy Lacher, Chief Technologist for Future Airspace Operations at NASA Langley Research Center, presented on how the shift of decision making from human-centric to automated means that clarity is needed for accountability. He noted that the evolution of automation and autonomy in the aviation landscape has resulted in a reexamination of the accountability, authority, and responsibility of traditional roles and responsibilities, defining these terms for the audience as follows:

- **Authority**: the power to give orders and/or make decisions
- **Responsibility**: the obligation or duty to carry forward an assigned task to its successful conclusion (closely coupled with authority)
- **Accountability**: the obligation to answer for an action taken by a responsible entity

Currently, automation has limited authority and responsibility and it is often revokable by a human. However, a future state will feature automation with greater responsibility and authority to make decisions and act, as delegated by humans. Mr. Lacher noted that the extent of responsibility and authority may be limited during the design phase, and that accountability can only be assigned to a human or human-based organization. He went on to discuss an example of an operational framework for OEMs and operators, which has set responsibilities for type certification, production approval, operational control, and training (among others), and that there can be debate on whether the manufacturer or user of a product should be held accountable when issues arise.

The conversation then turned to accountability for conflict management, which has historically been operator- and provider-centric. An example pertaining to airspace was provided as follows:

> In a visual flight rules (VFR) environment, the operator is accountable, and in an IFR environment in which separation services are provided by Air Traffic Control, the provider (ATC) is held accountable. However, the operator can be held accountable for failure to perform an action from the provider.

Mr. Lacher discussed a future that is more operator-centric and emphasized that research must focus on how to automate the operator-centric model of conflict management. The concepts to be explored shift the roles in conflict management to include eXtensible Traffic Management (XTM). In this case, the operator has responsibility for conflict management, with shared information services, automated decision making, and cooperative operating practices (Figure 13). Mr. Lacher acknowledged that this could necessitate shifting the existing operating modes that depend on human situation awareness and procedures to a digitally-enabled operating mode. This new mode would require information services and connectivity, cooperative practices, shared traffic and intent awareness, and automated conflict management capabilities.

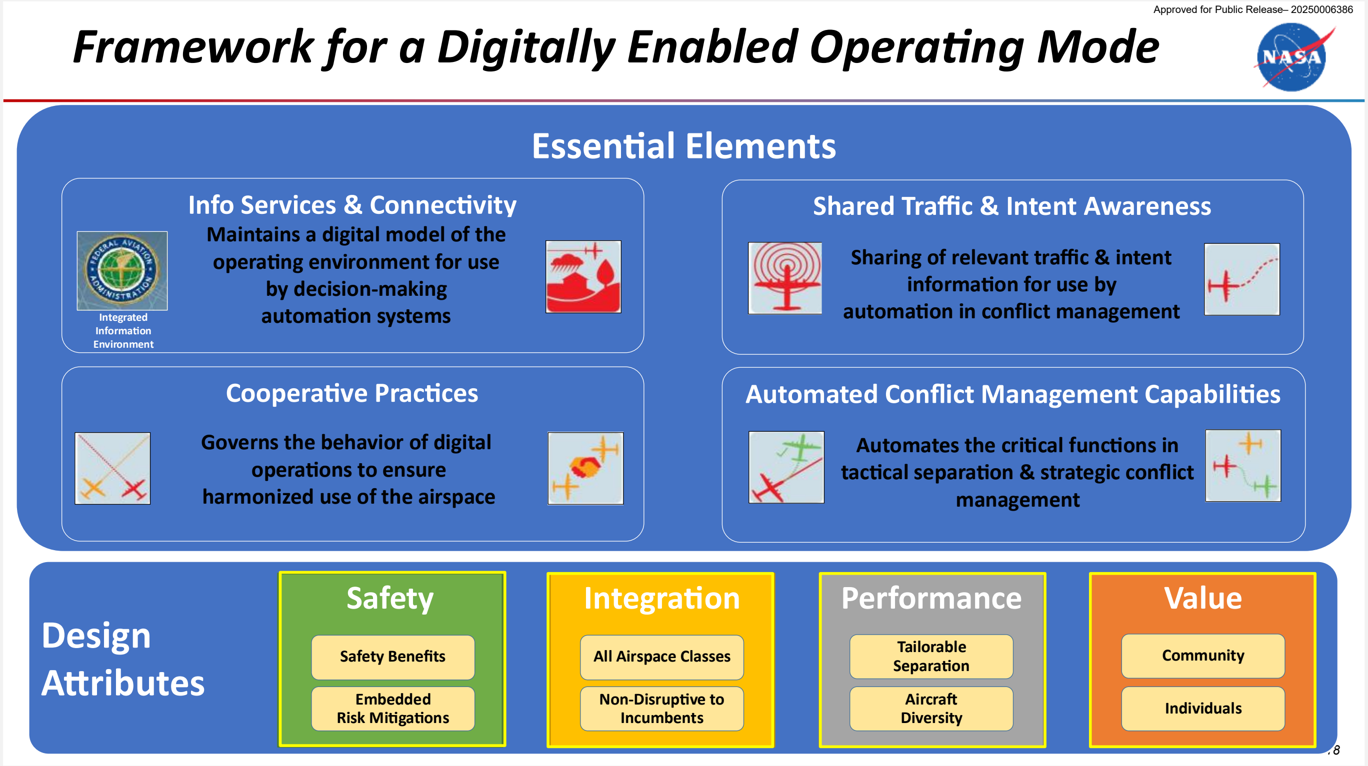

Figure 13. A framework for a digitally enabled operating mode presented by Mr. Lacher

The presentation then focused on accountability and how aviation has a history of "just culture," i.e., one that seeks to understand what causes issues and facilitate an atmosphere of trust. He noted that accountability is hierarchical and has structure to determine who is accountable, to whom, and for what. However, a mechanism is needed to clearly articulate the who and what, such as regulations, standards, and SOPs. Mr. Lacher noted that there can be dual lines of accountability and in the future, third-party service providers may be accountable to the operator and the regulator. This discussion was followed by a delineation between explicit accountability (defined in laws, regulations, etc., with defined consequences) and implicit accountability (inferred from procedures, training, etc. with inferred consequences), emphasizing that accountability is a separate issue from legal liability. Safety assurance was also discussed as a component of accountability, as it can be part of the safety management system and internal processes.

Mr. Lacher concluded that the increasing automation in flight operations, coupled with the need for accountability in aviation operations, will move the accountability model to a new operating mode, noting that a new accountability structure will need to consider required system performance as well as hierarchical accountability. He emphasized that the clarity of accountability is imperative for the viability of a distributed and automated conflict-management operating mode.

m:N Subgroup Debriefs

Airspace Integration

Andy Lacher | NASA

Mr. Andy Lacher debriefed the results of the Airspace Integration subgroup, sharing that the subgroup successfully published their white paper, "Considerations for Airspace Integration Enabling Early Multi-Aircraft Operations." He noted that the white paper presents conceptual propositions, not regulations or standards, which are intended to start discussions about the barriers that airspace integrations pose to m:N operations. In the paper, the subgroup identified that a major limitation for integrating m:N operations into current air traffic management is the need for voice communication with air traffic control. Traditional IFR, which requires a 1:1 ratio between pilots and ATCs, would limit m:N operations because they scale the numbers of remote PICs and aircraft being operated. Acknowledging the need to develop solutions that circumvent this human-centric ATC need for air traffic management, the subgroup posed three major approaches: (1) use VFR-like technology-enabled operations, (2) arrange ATC pre-approved terminal airspace areas for technology-enabled operations, and (3) allow transition between m:N and 1:1 as needed. With the publication of the white paper, the Airspace Integration subgroup has no future to-do items on their agenda and has concluded their work as a subgroup.

Interventions & Exceptions

Andy Thurling | DroneUp

Mr. Andy Thurling debriefed the results of the Interventions & Exceptions (I&E) subgroup, sharing that the subgroup's paper is currently in a late-stage draft undergoing revisions. Recent I&E subgroup discussion have focused on an m:E:N ratio to highlight the importance of the role that exceptions (E) play in impacting human workload and safety during m:N operations. In light of this, the group has developed a taxonomy of exceptions on seven different characteristics to begin identifying and quantifying the impact an exception will have on the human. Currently, the I&E subgroup is working on developing analytical techniques, such as Monte Carlo simulations, to quantify the impact of exceptions and exception stacks on humans. Drawing from the subgroup's exception taxonomy and recent NASA work on queueing, the goal of these analytical techniques would be to simulate how exceptions stack and sequence to impact humans. In sum, the I&E subgroup has made significant progress on setting up the elements that will feed the simulation, with next steps focusing on finalizing those elements (i.e., including other previously unaccounted for characteristics of exceptions, such as likelihood) and then preparing for the actual modeling and simulation of the queueing of exceptions.

Evaluation Methodologies

Mike Politowicz | NASA

Mr. Mike Politowicz debriefed the results of the Metrics subgroup, noting that it was previously led by Mr. Jay Shively before he retired, and Mr. Politowicz has since taken it over alongside Mr. Scott Scheff. The Metrics subgroup is currently in the final stages of revisions for their white paper, which is focused on providing tools for evaluating m:N operations. The white paper is intended to identify holistic indicators that an m:N operation is functioning well. Whereas much of the extant discussion on m:N operations focuses on workload and situational awareness, the Metrics subgroup aims to look at the larger set of metrics that measure the vitality of the m:N operation. Their white paper identifies these metrics, and details how an evaluation strategy can be built using these metrics. They describe two vignette cases and demonstrate possible evaluation strategies. Mr. Politowicz concluded the debrief by highlighting the utility of the Metrics subgroup's decision diagrams, which can be used to help evaluators prioritize which metrics should be measured when evaluating their operations. As with the Airspace Integration group, there are currently no future to-do items on this subgroup's agenda.

sUAS

Scott Scheff | HF Designworks

Mr. Scott Scheff debriefed the results of the sUAS subgroup, noting that the subgroup's efforts have been co-led by himself, Dr. Meghan Saephan, Dr. Phillip Walker, and Mr. Garrett Sadler. Mr. Scheff noted that the sUAS subgroup has been active since 2021 and brings in sUAS stakeholders from academia, industry, and government each year to examine different sUAS-related issues. Instead of focusing on a single problem like other subgroups, the sUAS subgroup tackles many different issues across the variety of sUAS operations. They published a recent white paper, "Personnel Selection, Roles, and Training for sUAS," in which they presented sUAS use cases across a diverse landscape of operations to showcase the variety of sUAS challenges and lessons to be learned from each. The sUAS subgroup is working on two papers for 2025. Their first in-progress paper, focused on emerging technologies and operational approval of autonomous systems, aims to convert the work presented at sUAS subgroup quarterly meetings into a paper on the problems and technologies that are emerging across sUAS stakeholders from academia, industry, and government. They have also begun working on a second white paper, focused on public outreach and community acceptance. Mr. Scheff noted that this paper has gotten grassroots momentum, and that a strong group of members are passionate about this initiative and willing to share documentation from their own organizations to push this effort forward.

m:N Framework and Breakout Sessions

Samantha Emerson | Aptima

The m:N framework session started with a review of the framework created by the Aptima team (Figure 14; Appendix B) led by Dr. Samantha Emerson. The framework was a synthesis of Working Group white papers and relevant publications and documents identified by the steering committee. The crux of the framework was the human component, with recognition that although the m:N Working Groups have identified ways to optimize the m:N ratio, additional factors can be discovered, especially as technology, the National Airspace System (NAS), and the use cases evolve.

Figure 14. Dr. Emerson presenting the framework synthesized from the Working Group white papers and relevant publications

The goal of the overview was to help attendees identify gaps and areas of interest for new subgroups and continued work. It included figures related to defining the multi-vehicle operations use case and determining an appropriate m:N ratio in multi-vehicle operations. The attendees engaged in discussion, asking questions and exploring the concepts and relationships presented within the framework.

After the framework was reviewed, the attendees were divided into three pre-assigned groups. The groups were charged with discussing gaps in the framework, identifying topics that could be expanded upon, and exploring ideas for creating new subgroups. The breakout sessions, which lasted approximately 2 hours, were led by the Aptima team and included silent generation of ideas by each participant, discussion of the topics to identify similar ideas, and consolidation of themes into potential subgroup topics. A list of the topics generated by each group is provided in Appendix C.

Breakout Group 1

Samantha Emerson (Moderator) | Aptima

Figure 15. Breakout Group 1 discussing identified themes

Breakout Group 1 (Figure 15) identified six key themes during the workshop, each addressing different aspects of m:N system design and operation, as follows:

1. **m:N System Design**
   This theme focused on the fundamental aspects of designing m:N systems, including the taxonomy and task definitions, autonomy definitions, and information flow and responsibilities. It also covered systems management, robust system health monitoring, weather considerations, user interface design for problem identification, common modes prevention, software/hardware assurance, understanding a UA's place in the world, system logging and assessment, distributed operational sites, and UA-to-UA data exchange.
2. **Organizational Considerations**
   This theme addressed the organizational aspects necessary for effective m:N operations. It included the content of operational specifications and manuals, crew member roles and responsibilities, safety management practices, m:N-specific training and qualifications, underload management, time variance, people interactions, workforce development, organizational maturity, and optimizing the number and distribution of personnel across multiple sites.
3. **System Validation and Safety**
   This theme emphasized the importance of validating and ensuring the safety of m:N systems. It included considerations for common modes such as C2, hacking, software/hardware, operations center, GPS, DAA, weather, and unmanned traffic management (UTM). It also covered the effects of edge-cases and off-nominal scenarios, the role of simulations in safety and certification, criteria for validation, and the relationship to digital twins.
4. **Artificial Intelligence**
   This theme explored the implications of AI in m:N systems. It included the FAA's upcoming autonomy Aviation Rulemaking Committee (ARC) and its AI roadmap; the differences between autonomy and m:N; the relationship between AI and autonomy; and the taxonomy of automation, AI, and machine learning. Despite its few distinct associated ideas, this topic generated a lot of passion among members of the group toward exploring ways in which AI can intersect with and alter nearly every level and component of UAS operations.
5. **CONOPS Demands and Constraints**
   This theme focused on the demands and constraints of CONOPS for m:N systems. It included the taxonomy for m:N CONOPS, the definition of the operating environment, where humans add value, ways of categorizing m:N operations, and the impact of distributed operation/control on m:N systems.
6. **Parking Lot**
   This theme included additional considerations that were identified but not fully explored during the workshop, including (1) implications of Part 108 once the new rule was released and (2) airspace, including the role of ATC in highly automated m:N operations, inter-airspace operations impacts, compliance with existing airspace regulations, and the implications of mixed operations and uncooperative vs. cooperative airspace considerations. Although the group identified some new and exciting ideas to explore in the latter topic, they felt that the theme was too close to issues covered in the “Considerations for Airspace Integration Enabling Early Multi-Aircraft (m:N) Operations” white paper that the m:N Working Group had published earlier in the year.

Breakout Group 2

Sylvain Bruni (Moderator) | Aptima

Figure 16. Members of Breakout Group 2 silently generating ideas

Group 2 (Figure 16) identified the following 14 areas of further exploration for the m:N Framework, listed a few additional topics for the existing I&E and sUAS subgroups, and added a few items to the Parking Lot list for future consideration:

1. **Complexity Dimensions**
   This theme addressed several angles to understanding the dimensions of complexity that impact m:N. Participants discussed whether "system complexity" may be a better term than "ratio." Discussions held about the particulars of "N" included questioning whether each "N" is an interchangeable UA (are they all the same or not) or whether the locality associated with "N" is similar across systems. It was determined that not all m:Ns are equal in that the same numbers in m:N may refer to vastly different constructs for different missions. Expanding on this idea were the expectations of "mixed traffic" vs. "sterile airspace" for m:N operations, the fact that multiple dimensions of the UAs (e.g., speed, size, level of autonomy, reliability) impact system complexity, and that interoperability considerations among independent systems was also a factor.
2. **Weather and Environment**
   This theme focused on characteristics related to weather and the operational environment that affect m:N and are not represented explicitly in the framework (e.g., How is area-wide vs. localized weather considered, both in terms of situation awareness and modeling? Does the framework need to represent urban sub-region weather/micro-climates and related predictions?). The group discussed micro-climate and high-intensity radiation fields (HIRFs) for interference prediction and contingency management, as well as the role of third-party services. Questions arose related to the need for standardization vs. variability of external data feeds for weather and environment information, and how the quality of the data provided can be ensured.
3. **Cooperative Operating Practices**
   This theme explored a range of matters related to cooperation and conflict management. A "separation concept" based on uncertainty or assurance vs. accuracy was discussed. The need for sensitivity analyses (both at the local and global level) was mentioned. Reliability levels across UASs and cooperative practices were discussed as foundational considerations for this theme. Participants discussed automating conflict management at the strategic and tactical levels. The following questions were considered: Are there airspace constraints that need to be defined or modeled to envelop complex operations? How would that exist? What about stakeholders' gaming system capacity with one m and multiple vehicles? How is overload controlled? Who defines (and enforces) such policies? The underlying multifaceted concept of reliability (human, system, and technology) was also discussed.
4. **External Communications**
   This theme emphasized communication between N and ATC. Participants discussed the ability to automate ATC communications from the vehicle and vice-versa. The team highlighted the need for a support infrastructure to operationalize this concept (e.g., data links, radar, GPS). The potential issues of integration and interaction with traditional operations was mentioned (IFR/ATC and communications without ATC involvement).
5. **Internal Human-Machine Interactions (HMIs)**
   This theme covered the need for an HMI framework for autonomy management and automating communications in the "human system." Participants debated how the control spectrum ignores differing types of information required for humans to exercise that level of control.

6. **Roles and Crew Composition**
   This theme highlighted the large range of considerations related to the role of m and the potential composition of a human crew. A key question when considering human-in/on/over-the-loop is “what loop?” Participants wondered if a PIC is always necessary and whether automation may be elevated at any level. The human factors of split attention were mentioned as a driver to limit the number of m in the system. Team composition and roles were extensively debated, starting with the core human role(s) in the control loop. The latter seemed to focus on “SAE-like” levels of autonomy and, as such, seemed rooted in a functional basis. This raised the question of which loop is being considered. The group further discussed the levels of control for human team roles and role types with respect to the loop (in, on, out, over, with) and about task-variable human in/over/out of the loop assignments. The group concluded with a discussion on how to characterize some human dimensions to inform role assignments, such as personnel cards, knowledge/skills/abilities (KSAs), team cohesion, and team-building factors.
7. **Tasks, Skills, and Training**
   This theme explored dynamic task allocation to optimize workload. It was determined that a focus on routine human tasks (i.e., those under nominal operation) should be taken and that the required skills should be analyzed. Cognitive task analyses (CTAs) were mentioned as an approach to cover this area.
8. **Operational Optimization**
   This theme focused on leveraging automation and AI to optimize formation operations (whether homogeneous or heterogeneous), to generate and validate plans, or to define sequencing requirements (e.g., if m is variable based on phases and effective sequencing, what is the lower m across phases?).
9. **Use Case Evolution for Auto***
   This theme emphasized novel aspects brought on by automation and autonomy (grouped under the moniker of “auto*”). The group discussed the need to devise new use cases to cover the evolution of the loops (see earlier discussions); safety assessment; technology advancements; and evolution of human situation awareness, decision making, and autonomy levels.
10. **HAT Performance and Metrics**
    This theme covered human-auto* teaming performance and metrics. Participants brought up the need for consistent and uniform training, as well as manpower and personnel consideration (e.g., qualifications, training, KSAs, experience) and reflected that having better-qualified people does not always mean that fewer people are needed. The group discussed how overall human team performance should include the “quality of the resolution” (with the added complexity of defining who judges such quality) as well as the “delays and suboptimal resolution” that may be indicators of unsatisfactory performance. Participants zeroed in on the definition of “optimality” and what influences it vs. who defines it. Finally, under- and over-tasking in the framework was mentioned.
11. **Public Outreach**
    This theme addressed the absolute need for the m:N Working Group to conduct public outreach, specifically to grow public acceptance of m:N. One participant suggested that noise abatement via vehicle design is a promising approach to showing how the m:N community is addressing public concerns.
12. **Relations with Other Groups and Standards**
    This theme explored how the m:N Working Group needs to engage with external stakeholders. The group suggested building deeper connections with ASTM, ATCA, JARUS, and others. Topics of engagements were brainstormed, such as certification bases (e.g., for vehicles, data, people, power supply units [PSUs]), terminology and level of authority (LOA) understanding (because the same LOA number may mean something different across multiple organizations), and practical test standards for supervisory roles.

13. **Handoffs**
    This theme focused on hand-off procedures, safe modes, decisions, situation awareness and orientation. Participants discussed specific cases in which m / humans may or may not have different roles simultaneously, and how that may impact hand-offs.
14. **Accountability**
    This theme highlighted the need to dive further into accountability and legality matters. Flight rules were discussed insofar as they define roles and responsibilities applicable to m:N. Accountability-related suggestions for several subgroups were made as follows:

    - **I&E Subgroup**
      The following items were identified for consideration by the I&E subgroup: failure modes and effects analysis (FMEA); the definition of human tasks in terms of time, probability, and reliability; real-time safety and performance monitoring; functional safety; safety integrity levers; and fail-safe modes (particularly for unknown unknowns, especially if m:N is optimized for nominal and known off-nominal situations). The group also suggested that the I&E subgroup consider additional system vignettes with examples of automation and contingencies.
    - **sUAS Subgroup**
      The following items were identified for consideration by the sUAS subgroup: minimum requirements for UAS, workloads' profile, payload-related details (minimum requirements, optional, plug & play), and flight/mission departure pre-check.
    - **Parking Lot**
      Finally, cybersecurity, hacking, and software vulnerabilities were placed on the "parking lot" board for future consideration by the m:N Working Group.

Breakout Group 3

Daniel Nguyen and Stephanie Fussell (Moderators) | Aptima

Figure 17. Breakout Group 3 members discussing and capturing ideas

Breakout Group 3 (Figure 17) identified the following three main themes to bring to the debrief session for discussion, as well as a variety of themes and items for further exploration of the m:N framework:

1. **Delegation and Distribution of Tasks**
   This theme addressed multiple aspects concerning the m side of the equation. First, participants noted that the problem space thus far has focused on the relationship between m and N, but not as much attention has been paid to how multiple m should work together in m:N operations. The group discussed (1) how roles and responsibilities can also change with knowledge, skills, and experience, encompassing training and certifications earned as well as skills brought to the position; (2) that roles, responsibilities, and the ability to delegate may shift based on use case and operator experience; and (3) that some individuals have more capacity than others. Several questions were identified in regard to the interactions between multiple m, including how tasks and roles should be configured to optimize workload, safety, and situational awareness; how many operators are desirable to staff these roles; and how m-to-m coordination should occur (e.g., handoffs, communications).
2. **Roadblocks of One to Many (1:Many) Operations**
   In this theme, the group first asserted that before considering m:N operations, several barriers in 1:Many operations need to be resolved before effectively tackling multiple m including uncooperative detect-and-avoid (DAA) systems, unpredictable weather, communications in a busy airspace, and

uncontrollable aircraft events. The group discussed the need to refine solutions to these problems for 1:Many operations first, because these problems exist not only for m:N operations but likely scale in complexity with multiple m operating multiple N. Existing gaps in testing and research were acknowledged; although some entities, including NASA Langley ROAM, academia, and industry (e.g., Wing) can push certain areas of research, many topics will emerge as the aviation industry, UAS environment, and technology evolve.

3. **Clarity of Purpose and Context**
   This theme addressed concerns regarding ambiguity around the m:N contexts. Participants raised several areas of ambivalence re: exploration of m:N operations including how goals shift based on mission and context; the missing clarity of context; and limits of authority, responsibility, and accountability for multiple m in a system.

Although the above were the final themes decided on by the group, four additional concepts arose during the breakout discussion, as follows:

1. **Pipeline of Factors Between "m" and "N" Areas of Framework**
   Some participants re-emphasized a point made earlier in the Working Group that there are likely many other letters in between m and N that account for more nuanced factors influencing the m:N relationship. Participants thus discussed that a pipeline of factors between m and N, and that further explorations of the m:N Working Group could focus on identifying, classifying, and explaining the relationships among these factors as they influence m, N, or the m-to-N interaction.
2. **Human Skills (KSAEs) Needed in m:N**
   Related to the discussion about the impact of knowledge, skills, abilities, and experiences (KSAEs) on how roles and responsibilities may be delegated for multiple m, specific inquiries were raised by the group about KSAE gaps in m:N operations, including (1) determining which humans need which KSAEs (i.e., KSAEs for regulating authorities, different roles in the operation); (2) identifying the KSAEs needed for humans in each capacity and mapping them to operational needs; and (3) pinpointing qualification and certification needs for these KSAEs, including common qualification requirements across scenarios and specialized requirements for specific scenarios or contexts.
3. **Metrics & Evaluation**
   Given the importance placed on several outcomes in m:N operations, several participants highlighted the value of being able to further measure abilities for these outcomes. For example, if live evaluations of human performance during operations could be implemented with reasonable granularity and accuracy, this would have meaningful impacts for identifying tasks, phases, or other contexts in which human performance tends to be off-nominal and go out-of-bounds. Relatedly, several participants expressed enthusiasm for the idea of developing models that forecast human workload to determine if an operator is experiencing phases of exceptionally heavy/light workload.
4. **Parking Lot**
   Group 3 brought up additional valuable ideas related to other aspects of m:N operations that would serve as meaningful future points of consideration, which spanned the following concepts:
   - Airspace policy differences across 1:1, 1:Many, and m:N operations
   - Autonomy infrastructures, such as value structures and operational architectures for autonomy
   - The role of backup operators, including elaborations on the takeover process and detailing cues for takeover (e.g., visual/voice indicators to take over)
   - Elaborating on handoff parameters, such as identifying the maximum number of allowable handoffs, system safety bounds to prevent situations without a PIC, and the minimum and maximum length of time a person can be a remote PIC (RPIC) before handing off
   - Protecting m:N operations, such against willful disruption, developing resiliency to threats, and establishing protocols when a UA is unrecoverable

Debriefs on Breakout Sessions

Samantha Emerson (Moderator) | Aptima

Once the three breakout groups reconvened, one or two attendees from each group took turns sharing the topics that their breakout group had generated, with the Aptima team compiling the topics on a Figma board displayed to the room. After each breakout group presented and all 22 topics were compiled across the three breakout groups, the Working Group proceeded to categorize and consolidate the list of 22 topics. This process resulted in the formation of the following three topic areas that reflected emerging themes across breakout group topics:

Topic Area 1.
m:N Considerations for Ops Manual (focused on factors related to m at multiple levels)

Topic Area 2.
System Validation (described by the group as “the means to evaluate system design”)

Topic Area 3.
System Design (described by the group as “provisioning for future growth”)

Day 2 thus concluded with the identification of these three topic areas that would serve as the basis for potential new subgroups.

JULY 10 BREAKOUTS AND NEXT STEPS

Day 3 of the 3-day m:N Working Group meeting began with new breakout sessions to identify the goals of each of the new subgroups and to identify champions for each vision. The meeting concluded with a debrief from each of the three new subgroups and a discussion of next steps for the m:N Working Group as a whole.

Breakouts on Goals for New Subgroups

On Day 3 of the Working Group meeting, participants had the opportunity to select which of the three themes they wanted to discuss: "m:N Considerations for Ops Manual," "System Validation," or "System Design." This approach differed from that of the first day, where members were assigned to groups. The purpose of these breakout sessions was to set the foundations for the new subgroups that will guide the Working Group's efforts over the next year. Each breakout group was tasked with three specific objectives: (1) develop a thesis statement to determine the aim of the new subgroup, (2) create a title to rename the subgroup, and (3) identify one or two champions to lead the vision of the subgroup. The over-arching goal was to establish clear objectives and leadership for the subgroups, although the focus of each group remains flexible and subject to change. This collaborative effort aimed to ensure that the Working Group's initiatives are well-defined and effectively championed, setting the stage for productive and goal-oriented activities in the coming year.

Breakout Group 1: Scalable Remote Crew Design Considerations for Multi-Aircraft Operators and OEMs

George Gorospe (Champion) | NASA
Co-Champion TBD
Stephanie Fussel and Daniel Nguyen (Moderators) | Aptima

The group of 12 participants began by reviewing the topics and bulleted subtopics (shown in Figure 18) gathered from the Wednesday breakouts. The group confirmed the need to explore and define the allocation and delegation of human tasks from a human-centered perspective, emphasizing the importance of human-to-human (m-to-m) coordination and the variability of crew composition based on operational methods. They highlighted the significance of ensuring that task delegation aligns with individual qualifications and regulatory requirements, particularly in the context of handoffs, where situation awareness and context-specific information are crucial.

Thesis Statement: Identify considerations for the allocation and distribution of tasks, roles, responsibilities, and handoffs among remote crew members in multi-aircraft operations, including lessons learned and potential solutions, for the design of operator processes/procedures, OEM systems, and third-party service providers.

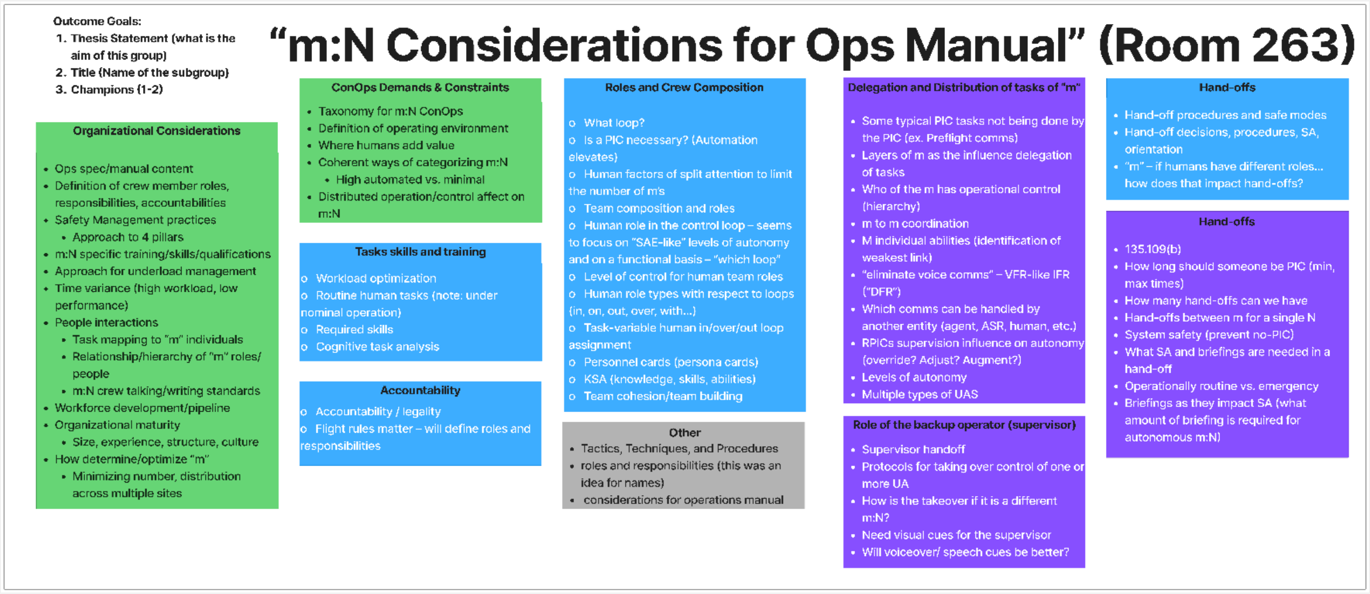

Figure 18. Prompt for conversation about "m:N Considerations for Ops Manual" that ultimately led to the formation of the Scalable Remote Crew Design Considerations for Multi-Aircraft Operations and OEMs subgroup topic.

The implications of regulations such as 14 CFR Part 135.109(b) were discussed in relation to UAS and m:N operations, with a proposal to evaluate the pros and cons of these regulations in a white paper that would (1) be a straightforward guide for operators; (2) provide high-level guidance on qualifications, roles, and responsibilities, especially for PICs and other crew members; and (3) be non-prescriptive, as many aspects of human roles and tasks vary by system, use case, and mission. The overarching goal is to develop a resource that addresses the complexities of human roles in evolving operational environments and benefits a range of stakeholders including organizations at different stages of operation and standards groups. The emphasis will be on handoffs and lessons learned from operators, while also considering the design of human crews to guide system development, ensuring that the human remains central to the m:N issue.

The group also determined that the subgroup would need to review the efforts of others to preclude duplication of efforts and creation of conflicting documentation. Another consideration was to ensure that a future white paper does not focus on airspace but acknowledges it as a constraint. The group concluded the conversation by discussing construction of a system that resists fragility in a distributed human system, requiring a level of flexibility based on who is physically available to do a task, and having redundancy and adaptability. These discussions evolved into the name of the group, which was debated for several minutes before "Scalable Remote Crew Design Considerations for Multi-Aircraft Operators and OEMs" was agreed upon (although the group acknowledged that this name could shift with the formation of the subgroup). The proposed name captures the group's belief that the subgroup should focus on human-centered task assignments and distribution in operations that range from 1:1 through 1:Many and m:N, with the expectation that operations for a given entity may need to shift dynamically. The subgroup would (1) concentrate on the design of the human side, as it impacts roles, not system design, and (2) provide solutions to consider, not recommend, for operators and OEMs as they create the human-machine interface. A goal should be to create a white paper that large, medium, and small operators could find helpful. "Operator" in this case refers to the parent entity, not to the person controlling an aircraft, although both designations would need to be addressed.

After reviewing the prompt, a member presented an outline reflecting his understanding of the conversation and goal of the potential subgroup. The discussion included the concepts of authority, responsibility, tasks, and the intended audience for the future white paper. It was agreed that identifying the constituent group of "m" and the associated tasks and roles in multi-aircraft operations is essential. After some deliberation, the focus was determined to shift from "m:N" to "multi-aircraft" operations, with the final choice emphasizing the roles of individuals completing tasks rather than the ratio of m to N. The outline was discussed and refined as follows:

m:N Considerations for Ops Manual Outline

- When seeking cert or authority to operate N aircraft under XX part doing YY task/mission you must validate or certify (assuming accountability):
    - Task
    - Conditions
    - M crew requirements (assuming a training and qualification standard, human and digital processes)
    - Standards
    - If used in future papers, this part can include uses cases and lessons learned; standards could be a review of current and missing (gaps)
- Assumes operator has approved procedures (by whom?) for management or organizational processes and procedures for activities including but not limited to:
    - Handover
    - Shift change
    - Infrastructure anomalies
    - SOP for XYZ events based on operator, situation, mission, etc.
    - If used in future papers, this can include challenges to consider and items to discuss, nominal and non-nominal events, airspace management coordination, and airspace integration procedures

m:N Validation and Verification

Wendy Ljungren (Champion) | Anzen Unmanned
Co-Champion TBD
Samantha Emerson (Moderator) | Aptima

Thesis Statement: Develop an evaluation framework for safe m:N operations, concepts, and tools.

The Systems Validation breakout group consisted of five participants who were guided in discussion by the prompt in Figure 19. To determine the scope of their section, the group decided to develop a rough outline of topics they felt were relevant. This outline, which is subject to change, served as a starting point for their discussions and helped to identify key areas of focus.

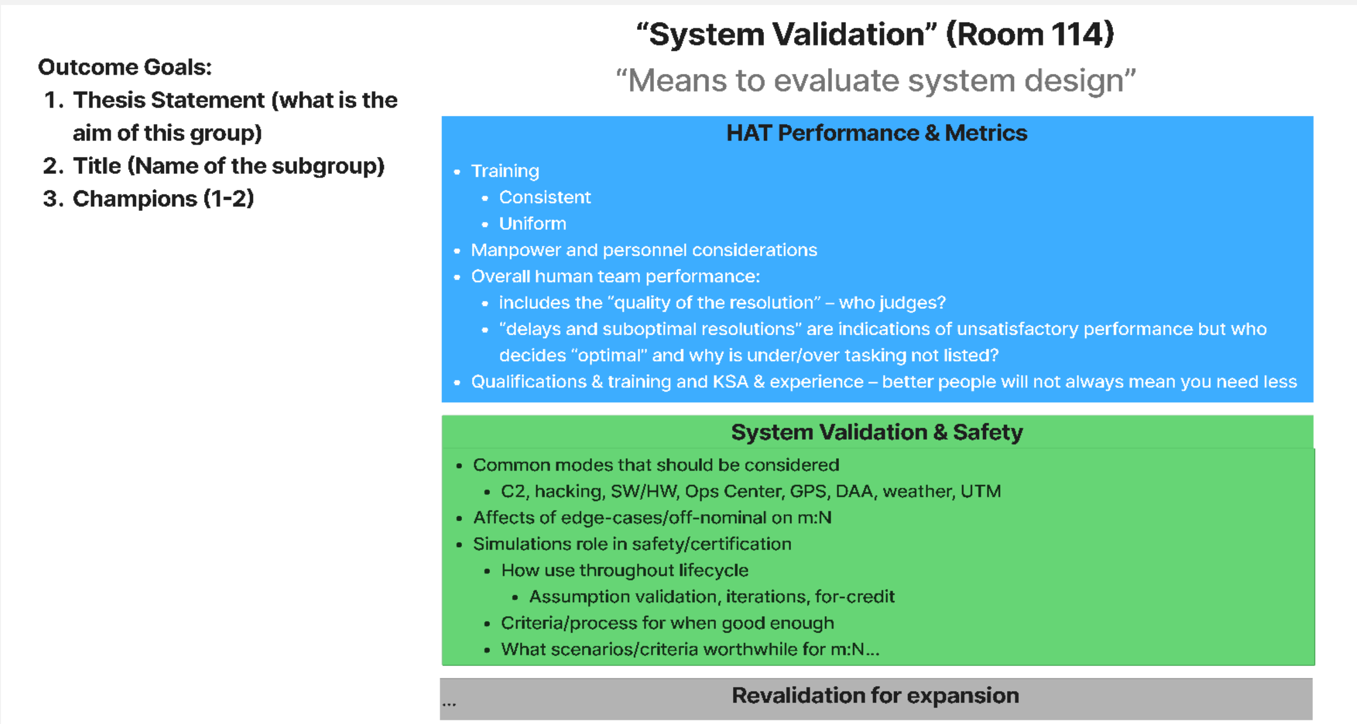

Figure 19. Prompt for conversation about system validation that led to formation of the m:N Validation and Verification subgroup

One of the primary discussions centered around the theme of "Nonhuman Workload," which the group felt might fall within the scope of the "System Design" topic, later renamed to "Design Considerations for m:N." Additionally, there was some debate about the full breadth of components that should be included in the scope of Systems Validation. One proposal was that the scope should include integration, organization, training, processes, and software whereas validation and verification (V&V) of the UA component would be included in the airworthiness certification, and the approval of weather supplemental data service providers (SDSPs) and detect and avoid (DAA) services would be covered by the Near-Term Approval Process (NTAP; Figure 20).

The group also discussed how this subtopic intersects with the I&E subgroup, which is examining analytical techniques, such as Monte Carlo simulations, to quantify the impact of exceptions and exception stacks on humans. It was suggested that the results of the I&E group might feed into the m:N V&V paper or that the two groups might combine to form a single product. This collaborative approach would ensure that all relevant aspects of system validation are thoroughly addressed.

Although there is still work to be done to refine the topic, the m:N Validation and Verification breakout group made significant progress in outlining the key topics and areas of focus for their section. By developing a comprehensive outline, they set the stage for a detailed exploration of the V&V processes necessary for m:N systems. The group's discussions highlighted the importance of refining the scope of the various components and processes to be included in the topic, as well as the need for collaboration with other subgroups, especially Interventions & Exceptions. As the group moves forward, they will continue to refine their outline and ensure that all relevant aspects of system validation are thoroughly addressed, ultimately contributing to the safe and efficient operation of m:N systems.

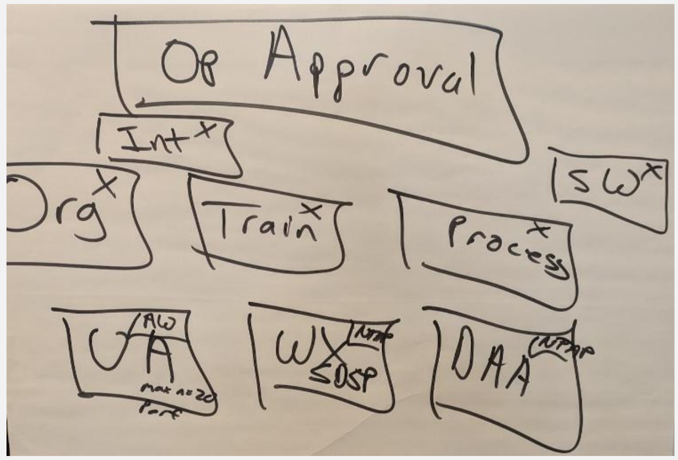

Figure 20. Proposal of components to be within scope for the m:N Validation & Verification subgroup.

m:N Validation and Verification Outline

- Introduction & Background
  - V&V: Validation = Having the right requirements; verification = Meeting the requirements
  - Includes
    - System Design
    - Environment: Weather, location (including emergency zones), EMI/HIRF, spoofing/jamming, appropriate mission
    - Assumptions: Focusing on operational environment; assuming are V&Ved & declared elsewhere
- Methods/Process
  - Safety Analysis
    - m:N Common Mode Analysis
  - Live vs Simulations
    - How do you know your simulation is good enough?: Providing some threshold for the simulator fidelity; ensuring match between live and simulated flight performance
    - Representativeness of I&E
  - Defining the m:N “envelope”
    - The team of humans (m) and team of UA/systems (N)
    - An input that needs to be checked against other metrics
    - Proving an “envelope” versus incremental increases from 1:1
- Metrics
  - Workload
  - Nonhuman workload? (possibly a system design question): Handling qualities, bandwidth, saturation of ground radar
  - Conformity to Desired/Required Mission Parameters
    - Planned landing zones
    - Conformance volume: spatial, temporal
    - Number of: “Well clear” violations (from other aircraft, internal system separation); ground risk (geofence violations, crashes)
  - Task Performance
- Outputs
    - V&V Report: Test & Analysis
    - Safety Report: Compliance to FAA 8040.6A or similar regulations: Few “yellows,” no “reds”

Design Considerations for m:N

Srikanth Gururajan (Champion) | Saint Louis University
Mark Shikerman (Champion) | Wisk
Sylvain Bruni (Moderator) | Aptima

Thesis Statement: Define baseline considerations for robust system management in fully integrated airspace.

The System Design breakout group included ten participants across government, academia, and industry. The group first reviewed the prompt of Figure 21 with a walkthrough of the relevant items identified during Day 2 brainstorming breakouts. Participants in those breakouts contextualized the discussion with additional details in the areas of System Design, System Validation and Safety, AI, Clarity of Purpose, Operational Optimization, Complexity, Weather and the Environment (Third-Party Services), and Use Case Evolution for Autonomy and Automation.

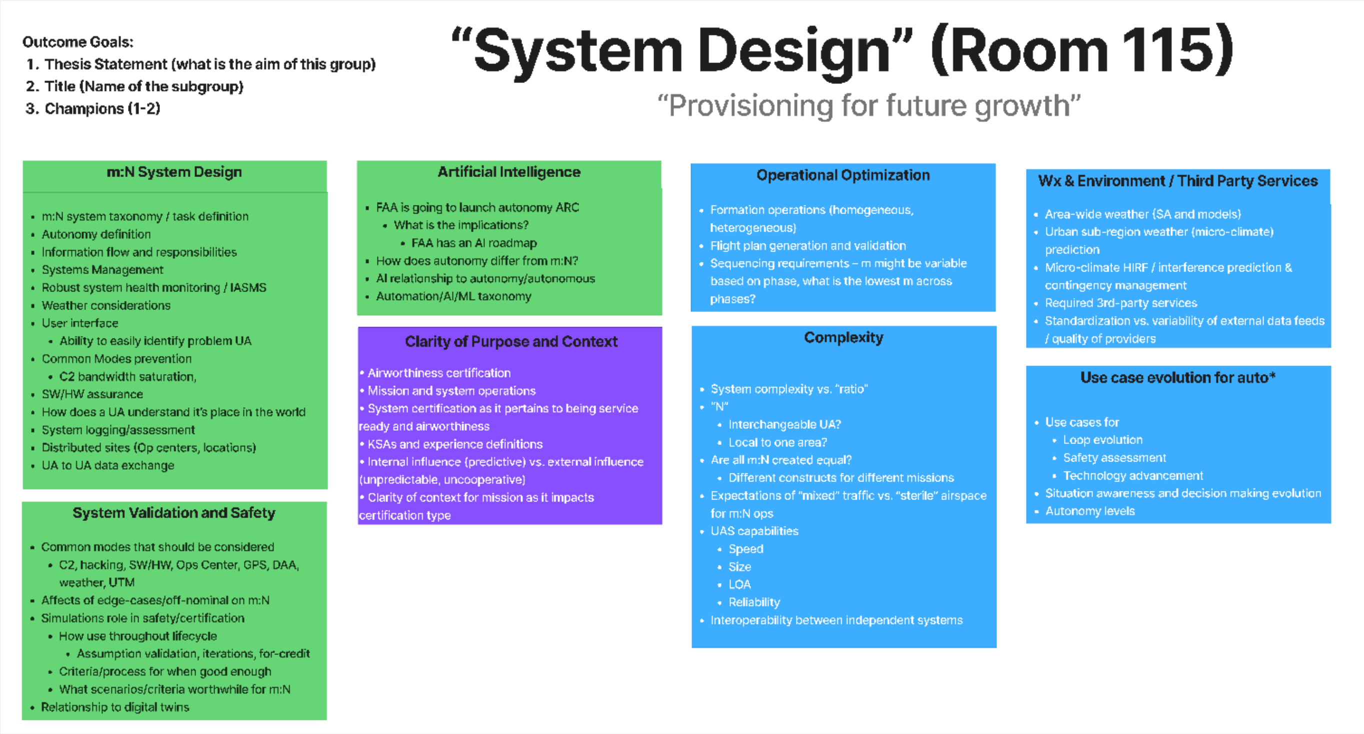

Figure 21. Prompt for conversation about system design that ultimately led to the formation of the Design Considerations for m:N subgroup topic

The discussion rapidly centered on the characterization of system design considerations toward the intended airspace for integrated m:N operations (i.e., the end state). Participants insisted on the need to research the system design dimensions that would enable a path from the present to the expectations of a fully integrated, mixed airspace, operating in nominal and off-nominal conditions.

Participants highlighted that a key characteristic of the intended airspace will be its complexity, including both the complexity of the UASs themselves and the complexity of N UASs operating together, further adding the complexity of multiple sets of N UASs operating in the same airspace, and the complexity of the range of behaviors and missions associated with all systems, and their likely dynamicity over time.

Following this lengthy discussion, the group was prompted to identify other design dimensions beyond complexity. One participant suggested AI as a key driver of change, and the discussion organically evolved toward the consideration of breakthrough technologies that may surface in the next decade and similarly drive considerable changes in system design. Participants insisted that solely focusing on AI would be too restrictive, and that the aperture for the new subgroup should be opened and afford a systemic look at the impact of new technologies on system design.

Next, the group held an insightful conversation about behavioral considerations related to the future intended airspace, i.e., how the system design should account for the wide range of behaviors to be adopted or anticipated in an integrated airspace. Participants quickly focused on the need to define a proto-scale of behaviors along a dimension of cooperativeness, thereby identifying categories of system behaviors for which system design should account. The group settled on the following scale: cooperative, non-cooperative, negligent, and nefarious.

Finally, participants discussed which individuals such system design considerations should be leveraged to inform a range of stakeholders, particularly in the regulatory space.

In conclusion, the group laid out a simple four-step roadmap defining the steps that the potential subgroup should take:

1. Address a generalizable scope and compilation of use cases across various dimensions of complexity (i.e., including both “known knowns” and uncertainty [e.g., weather]).
2. Account for the injection of future technologies (including but not limited to AI).
3. Consider the range of behaviors in a mixed airspace, from cooperative to nefarious.
4. Deliver system design considerations that will inform regulatory requirements, standards, operators, and manufacturers.

Debriefs and Closing Remarks

George Gorospe | NASA
Andy Lacher | NASA
Andy Thurling | DroneUp

Mr. George Gorospe started the closing remarks, acknowledging both the accomplishments of the week and the uncertainty ahead. Despite this uncertainty, Mr. Gorospe affirmed a strong commitment and passion for advocating for the group’s continuation, emphasizing the clear value of and impacts demonstrated by the Working Group—through their time, contributions, and support. To help shape next steps, Mr. Gorospe urged attendees to complete the post-event survey, which will provide critical evidence of the group’s impact and help inform how it may evolve. Mr. Andy Lacher and Mr. Andy Thurling echoed these sentiments, expressing appreciation for the conversations held throughout the Working Group meeting. They emphasized that the efforts of the group yielded tangible outcomes in the form of the three new subgroups, which will play a key role in shaping the future of the m:N Working Group and what it has to offer. Mr. Lacher reminded participants that although the in-person meeting is ending, the work continues virtually, and he encouraged attendees to continue identifying key contributors to the m:N Working Group.

In closing, the group recognized the energy and uniqueness of this community. Although change may be ahead, including the potential for a new name or structure of the Working Group, the commitment to advancing this important work remains strong.

Next Steps

As part of this meeting's outcomes, three new subgroups were identified:

1. Scalable Remote Crew Design Considerations for Multi-Aircraft Operators and OEMs
2. m:N Validation and Verification
3. Design Considerations for m:N

Each of these three groups will reach out to the m:N community to identify additional members to contribute to the topics. Additionally, the Scalable Remote Crew Design Considerations for Multi-Aircraft Operators and OEMs and m:N Validation and Verification subgroups are looking for co-champions to help lead the vision for these groups moving forward. Following recruitment, subgroups will hold regularly scheduled virtual meetings to refine their scope and develop white papers or other relevant products.

The existing sUAS and I&E subgroups will continue to meet virtually on a regular basis to further their current objectives. Conversations will be held to determine whether the I&E subgroup's efforts will feed into the m:N Validation and Verification subgroup or whether the two groups will merge. Finally, Mr. Mike Politowicz and Mr. Scott Scheff will solicit feedback from the Metrics subgroup as they bring the Methodology white paper to a close.

For additional information or to join the m:N Working Group or its subgroups, please reach out to the individuals listed below.

m:N Working Group
Andy Lacher
Andy Thurling andy.thurling@droneup.com
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Samantha Emerson semerson@aptima.com

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

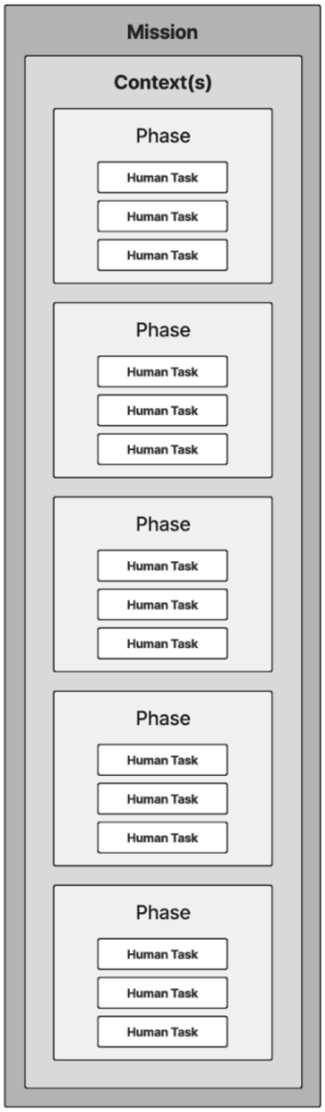
Appendix A: Attendee List

Name	Organization
Julie A. Adams	Oregon State University
Paul Albuquerque	FAA
Natalia Alexandrov	NASA Langley
Igor Alvarado	Collins Aerospace
Vanessa Aubuchon	NASA
Bryan Barmore	NASA
Timothy Beglau	Federal Aviation Administration
Radhika Bhopatkar	Purdue University
Ryan Bird	Boeing Global Services
Mark Blackwell	SkyDrive
Gregory Blaize	The Boston Drone School
Timothy Bleakley	General Atomics Aeronautical Systems, Inc
Craig Bloch-Hansen	Transport Canada
Angela Bowes	NASA
Sylvain Bruni	Aptima, Inc.
Eric Chancey	NASA's Langley Research Center - Crew Systems and Aviation Operations Branch
Sheila Conway	Boeing
Rese Drucker	DroneUp
John Dwyer	Boeing
James Eanes	Daniel H. Wagner Associates, Inc.
Samantha Emerson	Aptima
Melanie Flavin	FAA UAS R&D Portfolio Branch
Nadia Fox	NASA AMA
Stephanie Fussell	Aptima, Inc.
Ken Goodrich	NASA AMP Project
George Gorospe	NASA
Scott Griffith	Civil Aviation Authority of New Zealand
Srikanth Gururajan	Saint Louis University
Benjamin Hargis	NASA's Langley Research Center
Husni Idris	NASA Ames Research Center
Devin Jack	Adaptive Aerospace Group
Sophie Jantz	Merlin
Michael Johnson	Wisk Aero
Rob Knochenhauer	Censys Technologies
Andy Lacher	NASA Langley Research Center
Wendy Ljungren	Anzen Unmanned
Chris Lyman	AvMC TDD
Benjamin Magocs	MosaicATM
Daniel Nguyen	Aptima, Inc.
Jonathan Nguyen	NARI

Robert Owen	USASOC
Bryan Petty	NASA Langley
Mike Politowicz	NASA
Sandro Salgueiro	SkyGrid
Scott Scheff	HF Designworks, Inc.
Chris Sebastian	DroneUp
Mark Shikerman	Wisk Aero
Will Stavanja	DroneUp
Marius Sterk	The Longbow Group
Liang Sun	Baylor University
Kurt Swieringa	NASA
Andy Thurling	DroneUp
David Wing	NASA (retired)

Appendix B: m:N Framework

Defining the Multi-Vehicle Operations Use Case



Mission: The overarching objective of purpose and goals that guides the multi-vehicle operation.
Examples
- *Delivery*
- *Taxi*
- *Fire Fighting*
- *Public Safety*
- *Police Activity*
- *Military Applications*

Context(s): The various situational factors in addition to the mission type (such as those included in the Operational Design Domain) that influence and define the environment in which multi-vehicle operations are conducted. These factors are not mutually exclusive and must be collectively considered to ensure safe and effective multi-vehicle operations.
Examples
- *Airspace Type*: Controlled, Uncontrolled, Preapproved Terminal Airspace Areas
- *Operating Mode*: Instrument Flight Rules (IFR), Visual Flight Rules (VFR), Technology-Enabled Operations
- *Ground Risk Environment*: Urban, Rural
- *Environmental Complexity*: Terrain, Weather, Traffic Congestion
- *Communications Availability*: Available, Denied, Disrupted, Intermittent, Limited
- *Time of Day*: Day, Night

Phase: The temporal component of the mission, representing distinct segments of multi-vehicle operations that are characterized by specific tasks, especially those performed by the human operator. Phases should be determined by the Operator based on their relevance to the tasks that the human operator will perform and may vary depending on the mission type. Phases can be combined or eliminated if they do not involve distinct human tasks.
Examples
- *Cargo Delivery*: Preflight, Hover, Takeoff, En Route, Approach & Landing, Postflight
- *Package Delivery*: Morning Check, Deliveries In Progress, End-of-Day Check
- *First Responder Phases*: Pre-Deployment, Dispatch, Inbound Flight, On Scene, Return-to-Base, Post-Base

Human Task: Based upon the system design, the specific responsibilities and actions that the human must, should, or will be able to perform during a mission depending upon the context, situation, environmental conditions, and other circumstances. These include both nominal, off-nominal, and reversionary tasks.
Examples
- *Set Next Waypoint*
- *Define a No Fly Zone*
- *Use VHF Radio to Communicate with ATC*

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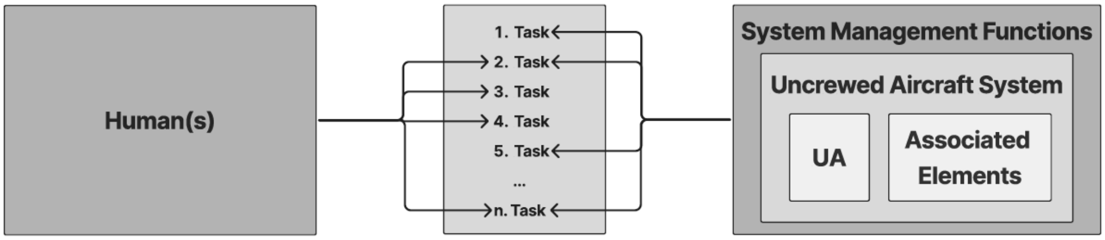
Defining Roles in Multi-Vehicle Operations



Human(s): The individual or team of people who are responsible for performing specific tasks as part of a team with the uncrewed aircraft system (UAS). Each human or team is assigned a role, which is a set of tasks that they are responsible for completing. The number of tasks that each human can complete simultaneously or in quick succession to safe levels of performance are constrained by cognitive and physical limitations.

Example Human Roles

- *Pilot/Operator*
- *Mission Planner*
- *Communications Specialist*
- *Safety Officer*
- *Team Leader*

System Management Functions: The comprehensive set of functions and services required to manage and support the operation of Uncrewed Aircraft Systems (UAS). It includes not only the UAS themselves, but also additional systems and services that facilitate safe, efficient, and coordinated UAS operations.

Uncrewed Aircraft System: The **uncrewed aircraft (UA)** themselves as well as all other **associated elements** in the broader system within which the UA operate. The UAS includes all the necessary hardware, software, communication systems, and support infrastructure required for the operation of the UA.

System Management Functions:

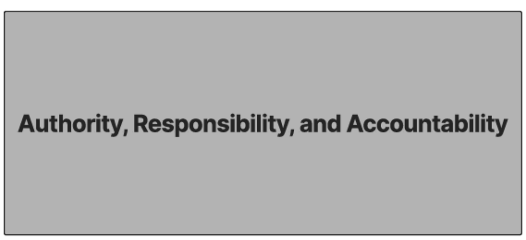
- UAS Traffic Management System (UTM)
- Information Services
- Third-Party Providers
- Regulatory Compliance Systems
- Operational Coordination Systems
- Uncrewed Aircraft System (UAS)

Uncrewed Aircraft System (UAS)

- Uncrewed Aircraft (UA)
- Associated Elements
  - Control Station
  - Communication Systems
  - Navigation and Sensor Systems
  - Support Infrastructure

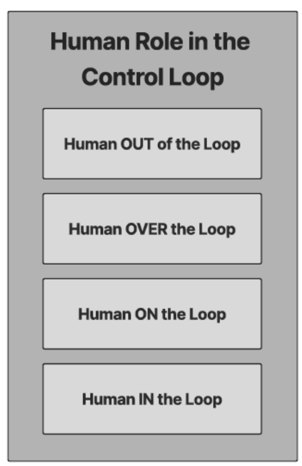
Type of Control: Operations vary in the amount and type of control that the human has over their tasks. Human tasks can range from high-level strategic control to low-level tactical control

- **Strategic Control**: Tasks where the human directs the outcome of a situation either through predetermined actions or real time high-level system direction
- **Tactical Control:** Tasks where the human directs the behavior of the system in real time through low-level inputs to affect a desired outcome



Roles: Roles are set of tasks that are assigned to either a human, team of humans, or UAS to complete. Allocation of tasks into roles should balance who has the authority for a task, who has the responsibility for the task, and who has the accountability for the task.

- **Authority**: The power to give orders and/or make decisions
- **Responsibility:** The obligation or duty to carry forward an assigned task to its successful conclusion; this is closely coupled to the authority
- **Accountability:** The obligation to answer for an action taken by a responsible entity



Human Role in the Control Loop: The varying levels of human involvement and interaction with the UAS during operations. It defines the degree to which human operators are engaged in the control and decision-making processes, ranging from complete autonomy to direct manual control.

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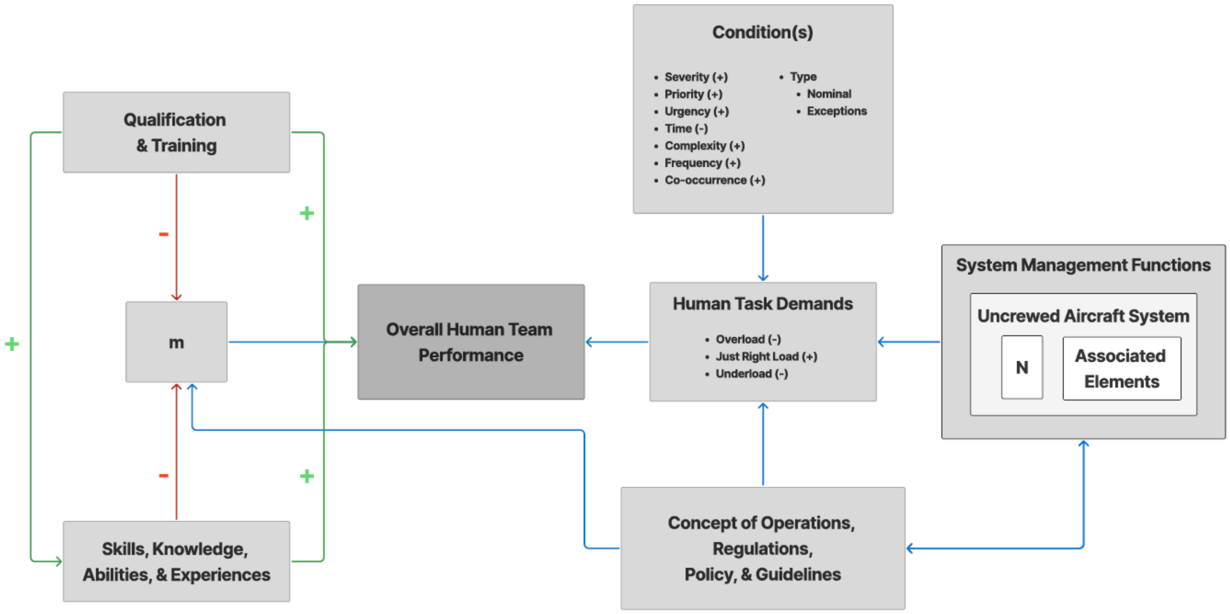
Determining Appropriate m:N Ratio in Multi-Vehicle Operations



Overall Human Team Performance: The effectiveness and efficiency with which the human team completes their assigned tasks during multi-vehicle operations. It evaluates both the time taken to resolve conditions and the quality of the resolution, including the resulting severity level. If the performance metrics indicate that the m:N operations do not meet satisfactory criteria—either through delays or suboptimal resolutions—it suggests the need for adjustments to the task distribution, team composition, UAS design, or operational procedures.

Human Task Demands: The requirements of the particular tasks to be completed across all co-occurring conditions, including both nominal duties and "interventions". Both overloading and underloading the of the human task demands are generally associated with decreases to overall human team performance, but appropriate loading levels are generally associated with increases in performance.

m: The total number of humans included in the multi-vehicle operations. Humans may differ in the roles that they take.

Qualification & Training: The specific qualifications and training on the tasks that the human receives for their role. Improvements to training are generally associated with increases to skills, knowledge, abilities, and experiences; decreases in the total m necessary; and increases in human performance.

Skills, Knowledge, Abilities, & Experiences: The capabilities that the human brings with them including but not limited to those gained in training. These are often shaped by experiences or innate cognitive or physical capabilities and may be included as selection criteria. Higher quality skills, knowledge, abilities, and experiences are generally associated with decreases in the total m necessary and increases in human performance.

Concept of Operations, Regulations, Policy, & Guidelines: The strategic framework, regulatory requirements, policies, and operational guidelines that govern the deployment and use of multi-vehicle operations. It defines how multi-vehicle operations should be conducted, ensuring compliance with legal and safety standards while optimizing performance and efficiency. This component influences the design and implementation of System Management Functions, including the UAS and UA design. In turn, the capabilities and limitations of these systems inform the development and refinement of policies and guidelines. It also influences the decision on how tasks should be designed, queued, and managed, directly affecting the human task demands. Finally, it determines the assignment of roles to human operators, influencing the total m required for the multi-vehicle operations.

N: The total number of uncrewed aircraft (UA) included in the multi-vehicle operations and a subcomponent of the fuller uncrewed aircraft system (UAS). N is a limiting factor in multi-vehicle operations only to the extent that it impacts task demands (e.g., increases the number of human "interventions").

System Management Functions: The comprehensive set of functions and services required to manage and support the operation of Uncrewed Aircraft Systems (UAS), including the UAS themselves as well as the uncrewed aircraft (UA) and all associated elements. The design of the System Management Functions, UAS, UA (including N, the number of UA), and associated elements will each have variable impacts on human task demands. This system also has a bidirectional relationship with the concept of operations, regulations, policy, and guidelines wherein the system informs the development of these policies and guidelines, which in turn influences the design and implementation of those systems.

Condition(s): The specific circumstances or triggers (during both nominal conditions and exceptions) that necessitate the human operator to perform a task. Conditions are the factors or events that prompt action and can vary widely depending on the mission, context, and phase. Increases in the condition's severity, mission/safety priority level, and complexity generally increase task demands while decreases in the time required to resolve the condition generally increases the task demands. Conditions that require a human action often do not occur in isolation. Thus, frequency of occurrence and of co-occurrence of conditions results in the need to queue tasks for completion and generally increases task demands.

Version 0.1 (July 8, 2025)

Appendix C: Day 2 Breakout Groups – Candidate Subgroup Topics

Group 1

1. **m:N System Design (TOPIC 1)**
    - m:N system taxonomy/task definition
    - Autonomy definition
    - Information flow and responsibilities
    - Systems management
    - Robust system health monitoring/IASMS
    - Weather considerations
    - User interface
        - Ability to easily identify problem UA
    - Common modes prevention
        - C2 bandwidth saturation,
    - Software/hardware assurance
    - How does a UA understand its place in the world
    - System logging/assessment
    - Distributed sites (ops centers, locations)
    - UA-to-UA data exchange
2. **Organizational Considerations (TOPIC 2)**
    - Ops spec/manual content
        - Definition of crew member roles, responsibilities, accountabilities
        - Safety management practices
            - Approach to four pillars
        - m:N-specific training/skills/qualifications
        - Approach for underload management
        - Time variance (high workload, low performance)
        - People interactions
            - Task mapping to "m" individuals
            - Relationship/hierarchy of "m" roles/people
            - m:N crew talking/writing standards
    - Workforce development/pipeline
    - Organizational maturity
        - Size, experience, structure, culture
    - How to determine/optimize "m"
        - Minimizing number, distribution across multiple sites
3. **System Validation and Safety (TOPIC 3)**
    - Common modes that should be considered
        - C2, hacking, SW/HW, Ops Center, GPS, DAA, weather, UTM
    - Effects of edge-cases/off-nominal on m:N
    - Simulations role in safety/certification
        - How use throughout lifecycle
            - Assumption validation, iterations, for-credit
        - Criteria/process for when good enough
        - What scenarios/criteria worthwhile for m:N
    - Relationship to digital twins
4. **Artificial Intelligence (TOPIC 4)**
    - FAA is going to launch autonomy ARC
        - What are the implications?
            - FAA has an AI roadmap
    - How does autonomy differ from m:N?
    - AI relationship to autonomy/autonomous
    - Automation/AI/ML taxonomy
5. **CONOPS Demands & Constraints (TOPIC 5)**
    - Taxonomy for m:N CONOPS
    - Definition of operating environment
    - Where humans add value
    - Coherent ways of categorizing m:N
        - High automated vs. minimal
    - Distributed operation/control effect on m:N
6. Parking Lot
    - Part 108 Implications
    - Airspace – previous Working Group covered
        - Role of ATC in highly automated m:N
        - Inter-airspace ops impacts on m:N
        - Implications of mixed operations
        - M:N compliance with existing airspace
        - Uncooperative vs. cooperative airspace considerations

Group 2

1. **Complexity (TOPIC 1)**
    - System complexity vs. "ratio"
    - "N"
        - Interchangeable UA?
        - Local to one area?
    - Are all m:N created equal?
        - Different constructs for different missions
    - Expectations of "mixed" traffic vs. "sterile" airspace for m:N ops
    - UAS capabilities
        - Speed
        - Size
        - LOA
        - Reliability
    - Interoperability between independent systems
2. **Weather and Environment (TOPIC 2)**
    - Area-wide weather (situation awareness [SA] and models)
    - Urban sub-region weather (micro-climate) prediction
    - Micro-climate HIRF/interference pre-diction and contingency management
    - Required third--party services
    - Standardization vs. variability of external data feeds/quality of providers
3. **Cooperation and Conflict Management (TOPIC 3)**
    - "Separation concept" based on uncertainty or assurance vs. accuracy
    - Sensitivity analysis
        - Local
        - Global
    - Reliability levels for UAS
    - Cooperative practices
    - Automating conflict management: strategic to tactical
    - Airspace constraints enveloping "complex" operations (how)?
    - Gaming system capacity with m + vehicles?
        - Control overload
        - Whose policy?
    - Reliability
        - Human
        - System
        - Technologies
4. **External Interactions (TOPIC 4)**
    - Air traffic communication automation
        - Minimize necessity (4D trajectory)
    - UAS comms with ATC
    - Support infrastructure (data links, radar, GPS, etc.)
    - Interaction with "traditional" ops:
        - IFR/ATC
        - Without ATC involvement
5. **Human-Machine Interactions (TOPIC 5)**
    - HMI framework for autonomy management
    - Communication human system automation
    - Control spectrum ignores differing types of information required for humans to exercise that level of control
6. **Roles of the Human (TOPIC 6)**
    - What loop?
    - Is a PIC necessary? (automation elevates)
    - Human factors of split attention to limit the number of m's
    - Team composition and roles
    - Human role in the control loop – seems to focus on "SAE-like" levels of autonomy and on a functional basis – "which loop"
    - Level of control for human team roles
    - Human role types with respect to loops (in, on, out, over, with…)
    - Task-variable human in/over/out loop assignment
    - Personnel cards
    - Knowledge, skills, abilities (KSAs)
    - Team cohesion/team building
7. **Tasks and Skills (TOPIC 7)**
    - Workload optimization
    - Routine human tasks (note: under nominal operation)
    - Required skills
    - Cognitive task analysis
8. **Operational Optimization (TOPIC 8)**
    - Formation operations (homogeneous, heterogeneous)
    - Flight plan generation and validation
    - Sequencing requirements – m may be variable based on phase, what is lowest m across phases?

9. **Use Case Evolution for Auto* (Autonomy & Automation) (TOPIC 9)**
    - Use cases for
        - Loop evolution
        - Safety assessment
        - Technology advancement
    - Situation awareness and decision-making evolution
    - Autonomy levels
10. **Human-Auto* Teaming Performance & Metrics (TOPIC 10)**
    - Training
        - Consistent
        - Uniform
    - Manpower and personnel considerations
    - Overall human team performance:
        - Includes the "quality of the resolution" – who judges?
        - "Delays and suboptimal resolutions" are indications of unsatisfactory performance but who decides "optimal" and why is under/over tasking not listed?
    - Qualifications, training, KSAs, and experience – having better-qualified people does not necessarily mean fewer people are required
11. **Public Outreach (TOPIC 11)**
    - Public acceptance of m:N
    - Noise abatement via vehicle design
12. **Standards and External Groups (TOPIC 12)**
    - Practical test standards for "supervisor" roles
    - Certification bases for
        - Vehicle
        - Data
        - People
        - PSU
        - Other
    - Connecting with other groups in this space
        - m:N Working Group
        - ASTM
        - ATCA
        - JARUS
    - Terminology and LOA understanding (LOAs may have different meanings in various organizations)
13. **Handoffs (TOPIC 13)**
    - Handoff procedures and safe modes
    - Handoff decisions, procedures, SA, orientation
    - "m" – If humans have different roles, how does that impact handoffs?
14. **Accountability (TOPIC 14)**
    - Accountability / legality
    - Flight rules matter – will define roles and responsibilities

Group 3

2. **Distribution and Delegation of m tasks (TOPIC 1)**
    - Some typical PIC tasks are not being done by the PIC (e.g., preflight comms)
    - Layers of m as the influence delegation of tasks
    - Who of the m has operational control (hierarchy)?
    - M-to-m coordination
    - M individual abilities (identification of weakest link)
    - "Eliminate voice comms" – VFR-like IFR ("DFR" digital flight rules)
    - Which comms can be handled by another entity (e.g., agent, ASR, human)?
    - RPICs supervision influence on autonomy (override? adjust? augment?)
    - Levels of autonomy
    - Multiple types of UAS
3. **Roadblocks of 1-to-Many (1:Many) Operations (TOPIC 2)**
    - Uncooperative DAA
    - Unpredictable weather
    - Uncontrollable aircraft event
    - No communication
    - Infrastructure
    - Integration
    - Interoperability
    - Uncontrolled/busy airspace
    - Understanding the status of the UA
4. **Clarity of Purpose and Context (TOPIC 3)**
    - Airworthiness certification
    - Mission and system operations
    - System certification as it pertains to service readiness and airworthiness
    - KSAs and experience definitions
    - Internal influence (predictive) vs. external influence (unpredictable, uncooperative)
    - Clarity of context for mission as it impacts certification type (e.g., drone as first responder)
5. **Parking Lot/Miscellaneous Ideas**
    - Future fully integrated NAS
    - Regulations
        - How to scale m:N w/out ATC (amended TC)
        - Aircraft TC, allowable configurations and supervisions (like engines)
        - System, supersystem, etc.
    - Associated elements: infrastructure for autonomy
    - Several operations and autonomy value structures
    - PIC acceptable handoffs
        - 135.190(b)
        - How long should someone be PIC (minimum and maximum durations)?
        - How many handoffs can we have?
        - Handoffs between m for a single N
        - System safety (prevent no-PIC)
        - What SA and briefings are needed in a handoff?
        - Operationally routine vs. emergency
        - Briefings as they impact SA (what amount of briefing is required for autonomous m:N)
        - Role of the backup operator (supervisor)
            - Supervisor handoff
            - Protocols for taking over control of one or more UA
            - How is the takeover if it is a different m:N?
            - Need visual cues for the supervisor
            - Will voiceover/ speech cues be better?
    - Protecting m:N operations
        - Against willful disruptions
        - Threat resilience
        - Protocols for CFIT in case UA is unrecoverable
            - Need to have a good description of the boundaries of UA capabilities
    - Role definition
        - Today vs tomorrow (future)
        - Pilot vs. RPIC vs. autonomy
        - Operational architectures

Appendix D: List of Acronyms

Acronym	Meaning
AAM	Advanced Air Mobility
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
AI	Artificial Intelligence
ANAC	National Civil Aviation Agency
ARC	Aviation Rulemaking Committee
ASSURE	Alliance for System Safety of UAS through Research Excellence
ASTM	Advancing Standards Transforming Markets International
ATC	Air Traffic Control
ATCA	Air Traffic Control Association
ATM	Air Traffic Management
ATOL	Air Traffic Operations Laboratory
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
CAA	Civil Aviation Authority
CERTAIN	City Environment Range Testing for Autonomous Integrated Navigation
COE	Center of Excellence
CONOPS	Concept of Operations
CTAs	Cognitive Task Analyses
DAA	Detect and Avoid
DLR	German Aerospace Center
FAA	Federal Aviation Administration
FMEA	Failure Modes and Effects Analysis
GPS	Global Positioning System
I&E	Interventions & Exceptions
IFR	Instrument Flight Rules
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
KSA	Knowledge, Skills, Abilities
KSAE	Knowledge, Skills, Abilities, and Experiences
LiDAR	Light Detection and Ranging
LOA	Level of Autonomy
MBSE	Model-Based Systems Engineering
ML	Machine Learning
MOSAIC	Mission Operations & Autonomous Integration Center
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NTAP	Near-Term Approval Process
OEMs	Original Equipment Manufacturers

PIC	Pilot in Command
PSUs	Power Supply Units
RCF	Research Collaboration Facility
ROAM	Remote Operations for Autonomous Missions
RPAS	Remotely Piloted Aircraft Systems
RPIC	Remote Pilot in Command
SDSPs	Supplemental Data Service Providers
SOPs	Standard Operating Procedures
SORA	Specific Operations Risk Assessment
sUAS	Small Unmanned Aircraft Systems
TAURAS	Traffic Awareness and Ubiquitous Real-time Airspace Surveillance
UA	Uncrewed Aircraft
UAM	Urban Air Mobility
UAS	Uncrewed Aerial Systems / Unmanned Aircraft Systems
UMAT	UAS Mission Analysis Tool
UTM	Unmanned Traffic Management
V&V	Validation and Verification
VFR	Visual Flight Rules
XTM	eXtensible Traffic Management