



Routine Autonomous Multi-Aircraft Operations Working Group

MEETING SUMMARY

MARCH 2026



CONTENTS

THE CHARGE FOR THE WEEK..... 3

Presentations and Panels..... 4

Welcoming Remarks..... 5

Air Traffic Management & Safety (ATMS) Project 5

Autonomy Challenges & Enablers 7

Joint NASA-Wisk Aero ATC-in-the-Loop Simulation of Multi-vehicle Operations Air Traffic Management & Safety (ATMS) Project 9

TRANSCEND NASA ULI: Ensuring the Trustworthiness of Learning-Enabled Safety Assurance Systems 11

Explorational Study of Human Factors in Autonomous Multi-Aircraft UTM Operations..... 12

Defining the Path Forward: Industry Standards & Safety Frameworks for Multi-Aircraft Operations..... 14

Keynote and Fireside Chat with Robert Rose 19

Subgroup Breakout Sessions 23

Interventions & Exceptions (I&E)..... 24

Small Unmanned Aircraft Systems (sUAS) 27

Scalable Remote Crew Design Considerations for Multi-Aircraft Operators and Original Equipment Manufacturers (OEMs)..... 29

System of Systems Design for Multi-Aircraft Operational Integration in Non-Segregated Airspace..... 33

Assurance, Verification, & Validation (AV&V) 37

Tours 40

NASA Ames Research Center Tours..... 40

Zipline Tour 42

Conclusions..... 44

Open Conversation..... 45

Closing Remarks..... 46

Next Steps..... 47

Appendix A: sUAS Breakout Session – Cross-Comparison Tables 49

Appendix B: *Potential Weaknesses in Future Scalable Remote Crew White Paper Identified by the Subgroup* 53

Appendix C: Attendee List..... 54

Appendix D: List of Acronyms..... 56

Compiled by Aptima, Inc. staff:
Samantha N. Emerson
Ramisha Knight

Stephanie Fussell
Sylvain Bruni

Jordan Coker

EXECUTIVE SUMMARY

From March 3 through March 5, 2026, the newly rebranded Routine Autonomous Multi-Aircraft Operations (RAM-AO) Working Group and its subgroups met at the NASA Ames Research Center in Mountain View, CA for their biannual, in-person meeting.

Late in 2025, the Working Group came under new oversight by the recently established Air Traffic Management & Safety (ATMS) Project in NASA's Airspace Operations & Safety Program (AOSP), and Summer Brandt (Deputy for Safety, ATMS) joined co-leads Andy Lacher (ASTM, FSF) and Andy Thurling (DroneUp) to help guide the direction of the Working Group.

Along with the new oversight came the new name, RAM-AO, which

- better reflects the Working Group's focus on issues broader than just identification of ideal ratios, and
- highlights the alignment between the Working Group's current set of goals with those of ATMS

Although the name has changed, the Working Group still seeks to join stakeholders from government, industry, and academia in a mission to identify and reduce barriers to autonomous, multi-aircraft operations.

Toward this end, the Working Group published two white papers, with a third to be released shortly. During the July 2024 meeting at NASA Langley Research Center, the Working Group solidified its plans for five new papers. The Interventions & Exceptions (I&E) subgroup continued its path forward on a modeling and simulation approach to validate operations; the small unmanned aircraft system (sUAS) group identified a new topic to pursue; and three new subgroups coalesced.

THE CHARGE FOR THE WEEK

The RAM-AO Working Group focus was on advancing the five white papers.

Major themes of the meeting included industry perspectives on barriers to autonomy, cutting-edge research, and cross-sector collaborations, including presentations on

- NASA's new Air Traffic Management & Safety (ATMS) Project,
- Joby's perspective on the challenges and enablers to autonomy,
- upcoming research between NASA and Wisk on air traffic management (ATM),
- a collaborative effort on trust in learning-enabled tools for safety assurance,
- the results from a study of human factors in UAS traffic management (UTM),
- standards and safety bodies working towards autonomous operations, and
- insights on the future of autonomous operations from Reliable Robotics.

Attendees were also able to tour NASA's Human-Autonomy Teaming (HAT) and Airspace Operations (AOL) laboratories, as well as Zipline's operations in South San Francisco, CA.

Five subgroups made progress towards distinct white paper topics during the meeting. The subgroups and their champions included the following:

- **Interventions & Exceptions (I&E)** – Andy Thurling (DroneUp)
- **Small Unmanned Aircraft Systems (sUAS)** – Scott Scheff (HF Designworks) & Garrett Sadler (NASA)
- **Scalable Remote Crew Design Considerations for Multi-Aircraft Operators and Original Equipment Manufacturers (OEMs)** – George Gorospe (NASA) & Husni Idris (NASA)
- **System of Systems Design for Multi-Aircraft Operational Integration in Non-Segregated Airspace** – Srikanth Gururajan (St. Louis Univ.) & Mark Shikerman (Wisk)
- **Assurance, Validation, and Verification (AV&V)** – Adrian Agogino (NASA)

Presentations and Panels

The 3-day bi-annual face-to-face meeting of the RAM-AO Working Group featured presentations and panels from representatives of government, industry, and academia, including a Fireside Chat with ATMS Project Manager, Shivanjli Sharma, and keynote speaker Robert Rose, Chief Executive Officer (CEO) of Reliable Robotics.



Welcoming Remarks

Summer Brandt | NASA

Andy Lacher | ASTM

Andy Thurling | DroneUp

The Working Group Meeting opened with Ms. Summer Brandt discussing the history of the NASA m:N Working Group and its transition into the Routine Autonomous Multi-Aircraft Operations (RAM-AO) Working Group in early 2026 (Figure 1). The name change reflects the scope and direction of NASA's Air Traffic Management & Safety (ATMS) Project, including the broad goal of identifying barriers to RAM-AO, technological innovations, and directional insights to advance operational outcomes, rather than focusing solely on the m:N ratio. The oversight of Mr. Jay Shively, Mr. George Gorospe, and Mr. Michael Politowicz as the previous NASA sponsors was recognized as laying the foundation for the current phase.

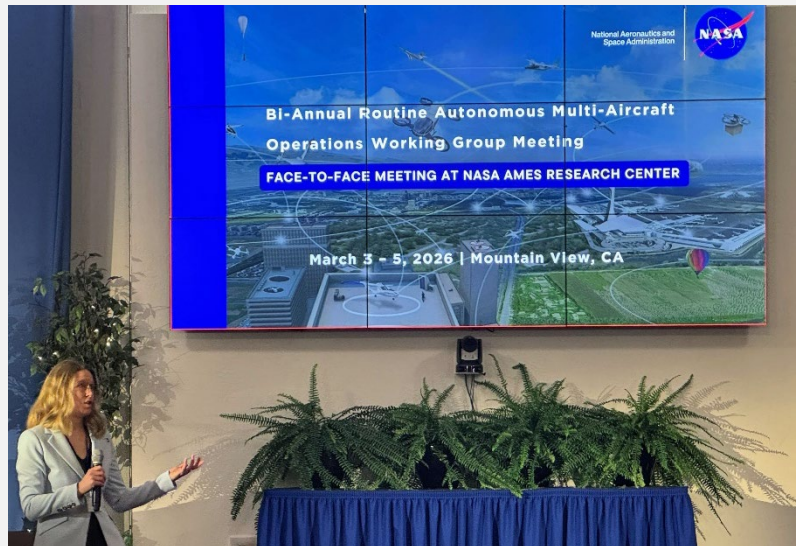


Figure 1. Ms. Summer Brandt welcoming meeting attendees

Mr. Andy Lacher and Mr. Andy Thurling, co-leads of the Working Group (Figure 2), continued the conversation by introducing the Working Group's new website (<https://nari.arc.nasa.gov/ram-ao>) and reiterating that the purpose of the Working Group aligns with the name change: to explore the problems, issues, and solutions associated with autonomy and multi-aircraft operations that interact to advance the state of the art and create mechanisms for sharing knowledge



Figure 2. Mr. Andy Thurling (left) and Mr. Andy Lacher (right) providing welcoming remarks

with others (e.g., white papers). The discussion then highlighted the work of the subgroups, emphasizing their importance in understanding autonomy and human requirements needed to scale RAM-AO across the National Airspace System (NAS). Mr. Lacher and Mr. Thurling drew parallels among the issues faced by the different groups, reiterating how these groups can help establish the foundation for industry consensus standards that the FAA and other stakeholders can use to implement operational outcomes. The remarks concluded with confirmation that in-person conversations and networking will benefit the outcomes of each subgroup and the Working Group as a whole.

Air Traffic Management & Safety (ATMS) Project

Summer Brandt | NASA

Ms. Brandt shared the core elements driving the ATMS Project's mission, including national strategic initiatives, global innovations, and the need to increase automation to achieve scalable operations with less human intervention. As she reviewed some of the Project's research goals, she emphasized that predictable, verifiable, and safe behaviors from

the aircraft system are needed to shift the NAS from its current human-centric control structure to a future in which human management will move toward being *on* the loop rather than having to be *in* it. Ms. Brandt then transitioned into the strategic direction of ATMS (Figure 3), which aims to transform the aviation system of today and tomorrow by enabling faster, safer, and more resilient operations through automation. The ATMS vision includes empowering humans in the system by reducing cognitive workload, improving the predictability and resilience of airline operations, reducing costs and delays, providing value to passengers, and improving terminal safety and operational efficiency. She acknowledged that several key barriers must be overcome. Achieving these aims include, for example, moving from voice-based communication to digital information systems, understanding the shifting role of the human operator, and defining the specific capabilities and assurance required for increasing levels of automation.



Figure 3. Vision and objectives for ATMS in fiscal years 2027 through 2032

In discussing research needs, Ms. Brandt emphasized that NASA will leverage partnerships and national initiatives, such as Federal Aviation Authority (FAA) regulatory changes, to take a scoped, parallel approach to the safe, routine operations of increasingly automated aircraft. The project intends to take both evolutionary and revolutionary steps: Evolutionary steps were presented for aircraft with onboard pilots and certified airframes, including digital clearances, using voice-to-text to reduce workload, exploring new technologies to keep runways clear and advance sensor performance, and automating taxiing with pilot supervision. Revolutionary steps for remote pilot operations for new entrants included air traffic control (ATC) interactions with remotely supervised operations, integrated detect-and-avoid (DAA) technology and processes for cooperative and non-cooperative traffic, autonomous capabilities for degraded states, and advanced avionics and aircraft systems. Digital clearances were highlighted as a common theme across the parallel approaches to ensure an integrated airspace with safe, routine, autonomous, multi-aircraft operations. Although the current NAS is very safe, adding multi-aircraft operations must be just as safe as the current one-to-one traditional operations, and the need to verify and demonstrate an equivalent level of safety was emphasized.

Autonomy Challenges & Enablers

Craig Milliard | Joby

Mr. Craig Milliard, Joby's Caravan Program Lead and Flight Test Lead, presented Joby's perspective on airworthiness and remote operations for their aircraft, detailing their collaboration with the local Flight Standards District Offices (FSDOs) and air traffic controllers to understand challenges and opportunities (Figure 4). The discussion began with what autonomy means for Joby aircraft, which he described as self-sufficient and capable of safely conducting all phases of flight—including taxi, takeoff, landing, and maintaining safe separation from other traffic. This capability allows Joby to shift the pilot's role and location to that of a remote operator supervising the flight from a control center. Eventually, Mr. Milliard said this role will evolve to a remote operator supervising multiple aircraft. A goal for Joby is to have aircraft that can operate in all classes of airspace; however, this will not occur until equipment is sufficient both on the ground and in the air, and additional operational approvals have been granted.



Figure 4. Mr. Craig Milliard describing the five challenges and three enablers of autonomy

The overview included how Joby addresses the replacement of traditional human functions, specifically, the eyes, brain, hands, and voice. Replacing human eyes involves an approved suite of technologies and technical capabilities that perform all pilot functions, achieved through aircraft sensors that identify and classify hazards and determine positioning, among other tasks. The human brain is replaced by computing and algorithms that analyze data, make decisions, and modify flight plans in real time. Hands refer to aircraft control, which is already in use in traditional flight operations via autopilot systems that follow flight plans (Figure 5). Finally, voice pertains to communications with ATC, dispatch, passengers, etc. The current NAS and ATC structure is heavily dependent on voice communications, generally involving direct pilot-ATC communications, and was noted as a slower change that must occur through collaboration with the FAA.

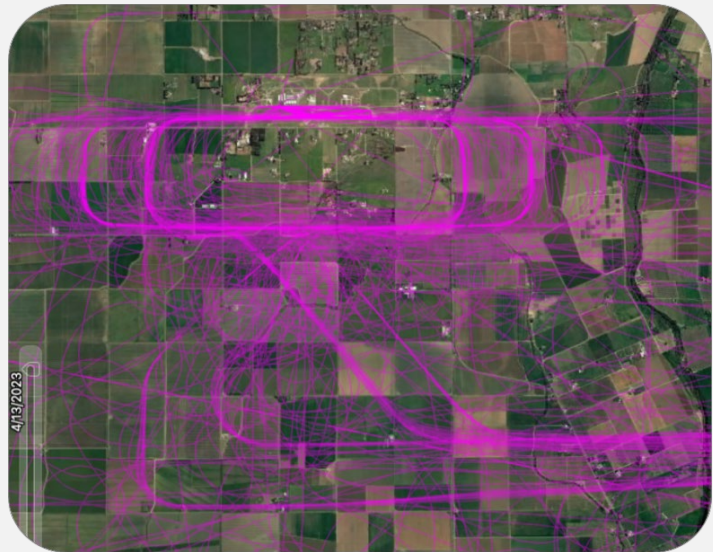


Figure 5. Although Joby's autopilot capability allows for highly consistent flight trajectories (dark pink lines), real-world flight conditions require a high degree of adaptation from planned routes

Mr. Milliard then discussed how Joby divides these functions and duties between remote supervisors and onboard autonomy. The remote supervisor holds operational control, communications, mission planning, and updates. Onboard autonomy manipulates controls and switches to aviate, navigates the mission plan, detects and avoids hazards, and manages system failures. Additionally, any time-sensitive or time-critical decisions are made onboard the aircraft.

This overview of Joby's approach to increasingly autonomous operations set the stage for the crux of Mr. Milliard's presentation, which focused on the five "hard problems" for autonomy: (1) the NAS as a system of systems, (2) airspace access for testing new and emerging aircraft, (3) ATC communications, (4) defining the role of the remote operator, and (5) loss of communication.

Hard Problem 1. First, the NAS comprises numerous interconnected systems and agents working together toward the common goal of safe and efficient aircraft movement, relying on Federal Aviation Regulations (FARs) and the Aeronautical Information Manual (AIM). Mr. Milliard described the FARs as providing the things that you *must* do. But more critically, the AIM tells you what things you *should* do. Although the FARs provide "rules and math" to guide the development of operations, complying with the AIM is more complicated and hence where Joby spends much of its time. However, by aligning with the FARs/AIM, a "new" type of autonomous aircraft can be introduced into this complex system while maintaining overall safety. Mr. Milliard emphasized that Joby is focused on solving the problem of integration into the NAS, not just flying without a human pilot onboard.

Hard Problem 2. Testing in actual airspace was discussed as a critical but challenging element due to the NAS's complexity. Joby is working with local FSDOs and air traffic controllers to integrate their aircraft into certain airspaces using Certificates of Authorization (COAs) or experimental operating limits and to obtain airworthiness certification with operational limits. Although these sandboxes allow limited testing, more work is needed to address integration challenges.

Hard Problem 3. The third challenge, ATC communication, was broken down by the ability of onboard autonomy to comply with strategic, tactical, urgent, and immediate interaction requirements. Strategic and tactical interactions were noted as easier to comply with through automation using data links and communication protocols, supported by optimized user interfaces onboard and on the ground. However, urgent and immediate interactions are more difficult: Urgent interactions require simple, quick user interfaces that minimize human error whereas immediate interactions require full automation as there is no time to wait for human input or validation. The role of voice was also discussed. Traditional communications include a confirmation-correction loop with readback functioning as a critical safety net. Humans can use emotional intelligence and intonation, whereas digital text is flat. Mr. Milliard also described the "party line effect," which enhances situational awareness by allowing pilots to listen to radio chatter and instructions to other aircraft. Voice communication also allows greater speed in time-critical situations; although digital communications are effective for routine cruise flight, they are often too slow for the terminal environment.

Hard Problem 4. The next challenge identified was the shifting of duties between roles in traditional NAS operations and future routine autonomous multi-aircraft operations. Mr. Milliard discussed the mental models of the pilot in a manned aircraft, the air traffic controller, and the remote operator, including similarities and differences in situational awareness, systems understanding, environment, human factors, flight progression, and emergency anticipation and planning. The pilot was characterized as making decisions to take actions; the air traffic controller as making decisions to provide guidance; and the remote operator as one who monitors before making decisions to execute limited actions.

Hard Problem 5. The final challenge was communications and supervision. Notably, connections may be lost, as latency and outages are typical, not exceptions. Workload, alarm fatigue, and mode confusion are hazards that must be mitigated. Cybersecurity was discussed as safety-relevant, and graceful degradation and exception-based supervision are required to ensure safe integration of routine autonomous multi-aircraft operations.

Although autonomy faces these significant challenges, Mr. Milliard also presented three autonomy enablers: (1) Proliferated Low Earth Orbit (pLEO) constellations; (2) electric vertical takeoff and landing (eVTOL) and the Advanced Air Mobility (AAM) Integration Pilot Program (eIPP); and (3) special authority for advanced UAS, along with partnerships with the Department of Defense (DoD). pLEO and satellite communications, such as Starlink, were credited with bridging the "connectivity gap" for operational autonomy by enabling real-time remote supervision, increasing data exchange, reducing the "authority lag" in human-machine handovers, providing ubiquitous coverage, and transforming aircraft from isolated "islands of autonomy" into nodes within a high-uptime, distributed system.

An audio clip of a conversation between ground control in Hawaii and an operator in Guam provided convincing evidence of the advantages of pLEO, ending with ground control stating, “those were the cleanest comms I’ve heard on frequency all day.” The second enabler discussed was Executive Orders “Unleashing American Drone Dominance” of 2025 and “eVTOL and AAM Integration Pilot Program” (eIPP, 2025). These initiatives were described as having great potential to enable many use cases, alongside the FAA granting exemptions for UAS operations that exceed the limitations of 14 Code of Federal Regulations (CFR) Part 107, specifically under 49 U.S.C. § 44807: Special Authority for Advanced UAS. Finally, Mr. Milliard described how DoD partnerships can accelerate autonomy by incentivizing early commercial investment. Additionally, partnerships can provide access to test conditions not achievable in civilian airspace. Increased airspace access, coupled with a higher operational tempo, will yield faster risk retirement, higher sortie rates, and quicker iteration. However, stressors such as variable communications, austere testing sites, and mixed traffic will also be challenges. Partnering with the DoD has allowed Joby to demonstrate the utility, maturity, and flexibility of autonomous aircraft operations.

Mr. Milliard concluded his presentation by highlighting Joby’s exploration of how autonomous systems can enhance the ability to operate in new environments, reduce reliance on fixed infrastructure, and strengthen the ability to respond quickly and effectively—all of which are needed for safe, seamless integration into the NAS.

Joint NASA-Wisk Aero ATC-in-the-Loop Simulation of Multi-vehicle Operations Air Traffic Management & Safety (ATMS) Project

Vicki Dulchinos | NASA

Michael Johnson | Wisk

Ms. Vicki Dulchinos of NASA and Mr. Michael Johnson of Wisk (Figure 6) introduced their experimental design to explore an ATC-in-the-loop simulation of multi-aircraft operations, an effort aligned with the ATMS Project’s research objective of enabling safe, routine autonomous operations. The research will investigate the impacts of high levels of automation on pilots, ATC, and other users in the context of multi-aircraft control in near-term airspace. The study will utilize multiple facilities, including the Future Flight Central (FFC) at NASA Ames and Wisk’s Autonomy Lab. These facilities have simulation environments designed to explore the role of humans in emerging operations; validate the concept of operations (CONOPS); and improve user interfaces, human tasking, and autonomy. Wisk is pioneering the future of autonomous flight with its electric vertical takeoff and landing (eVTOL) air taxi, aiming to make safe, everyday flight a reality for everyone. Although these air taxis are designed to fly themselves, human involvement remains a critical component of the system’s safety and operational success. Designing a safe, human-centered system requires a deep understanding of how these supervisors interact with the technology and how this interaction affects their workload. Together, NASA and Wisk will conduct rigorous testing using simulations that replicate specific control scenarios, including the number of aircraft, their activities, and departure schedules. Mr. Johnson played a video that discussed the Wisk efforts in the project, detailing how the integrated ecosystem of autonomous technology and human oversight will help create a future in which safe, reliable, and accessible autonomous air transportation is a reality.



Figure 6. Mr. Michael Johnson (left) and Ms. Vicki Dulchinos (right) detailed an upcoming collaborative research effort

The goal of the research is to understand the impacts of higher levels of automation in multi-vehicle operations on ATC and to assess the viability of 1:3 multi-aircraft operations in the near term. The team anticipates that lessons learned will drive future research building upon the outcomes of this study, which is expected to begin in May 2026,

with results anticipated for the RAM-AO Working Group meeting in August 2026. The researchers will measure the impacts of one operator controlling multiple, highly automated aircraft on current-day ATC performance and workload, including different communication strategies and both nominal and off-nominal conditions. NASA will oversee the simulation and utilize retired tower and Terminal Radar Approach Control (TRACON) air traffic controllers to respond to traffic including legacy and highly automated Gen 6 Wisk aircraft in a designated area, with emphasis on handoffs between sectors. Wisk Aero will be responsible for flying simulated aircraft and providing multi-vehicle supervisors (MVSors) and other elements to support up to 1:3 operator-to-vehicle operations. Air traffic controllers will be blind to whether they are managing one or three aircraft per operator, ensuring unbiased feedback. Participants will exchange traffic and voice data while contending with background traffic and pseudo-pilots (confederates in the study) to emulate average daily traffic. The simulated scenarios will compare how MVSors and air traffic controllers navigate the environment and respond to nominal and scripted events, such as traffic conflicts, missed approaches, lost-link procedures, and diversions. Measures will include collecting objective and subjective data to capture controller efficiency and safety, interactions between ATC and MVSors, and acceptability from both sides (Table 1). Finally, the design will compare results from both 1:1 and 1:3 operations.

Table 1. Primary Outcome Metrics for ATC and MVSors

	Metric Type	Metrics
ATC Metrics (NASA-led)	Efficiency	Total traffic managed
		Number of Wisk operations
		% Time of communications/average call duration
	Safety	Losses of separation
	MVSor Interactions	Response times, rate of incorrect/repeated calls
MVSor Metrics (Wisk-led)	Acceptability	Surveys on workload, procedures, interactions
	ATC interactions	Response times, compliance with ATC calls
	Acceptability	Surveys on workload, situation awareness, procedures, user interface

During the Q&A with the audience, Ms. Dulchinos and Mr. Johnson clarified several critical aspects of the MVSor role, particularly regarding the intersection of human performance and regulatory requirements. Under current frameworks, MVSors are treated as pilots in command with associated responsibilities, though their duties focus on high-level mission supervision and ATC communication rather than having direct control over the aircraft or performing typical pilot tasks such as “see and avoid.” This regulatory status carries significant liability and accountability even as the physical tasks evolve, and Wisk continues to comply with these regulations while continuing discussions on how they may evolve in the future. To ensure safety under these requirements, the team is moving beyond nominal operations to satisfy FAA mandates for performance under worst-case conditions. They are actively investigating the probability and impact of emergency events, such as missed approaches or traffic conflicts, to ensure that supervision ratios such as 1:3 can be safely achieved.

The discussion also included a focus on managing operator workload, another essential component of both safety and liability. The MVSor role can involve long periods of low activity during nominal flight that lead to a recognized risk of complacency. Conversely, workload can spike rapidly during off-nominal events, and the study aims to monitor these fluctuations to design systems that maintain an optimal level of engagement. The goal is to design a system that will keep the operator sufficiently engaged without overburdening them. With this in mind MVSor complacency and workload will be monitored during the study.

While there was significant audience interest in the future of these operations, the speakers clarified that while the long-term intent is to scale beyond current limits, the present study is strictly focused on establishing a baseline at 1:1 and 1:3 ratios. Similarly, the current focus is on integrating novel autonomous aircraft into today’s NAS without overburdening controllers, though this work is intended to serve as a necessary stepping stone toward a future, fully digital airspace environment.

TRANSCEND NASA ULI: Ensuring the Trustworthiness of Learning-Enabled Safety Assurance Systems

Meredith Carroll | Florida Tech

Dr. Meredith Carroll presented on Trustworthy Resilient Autonomous ageNts for Safe City transportation in the *Evolving New Decade* (TRANSCEND): a NASA University Leadership Initiative (ULI) that Florida Tech is leading with other academic, industry, and government partners including the FAA (Figure 7). The group is investigating how learning-enabled tools can increase the effectiveness of online and offline safety assurance to be more robust and faster, ensuring that a learning-enabled safety assurance system results in safe outcomes. Dr. Carroll characterized the theoretical problem as understanding what it means for a safety assurance system to be “trusted” or “trustworthy,” a timely issue given the evolving nature of learning-enabled and traditional systems. The 3-year project aims to produce methods and tools to allow practitioners developing learning-enabled safety assurance system to emulate similar outputs. This will allow others to study the ability of the tools and approaches to assess system trustworthiness, believability, and reliance. The ULI will address four research gaps that are mapped to their technical challenge (TC) areas outlined in Table 2. The group distinguishes system trustworthiness as an engineering focus and perceived trust/belief and reliance are considered human factors focuses. Addressing the three variables of system trustworthiness, believability, and reliance will require a multidisciplinary approach to collecting distinct measurements that combine objective metrics, behavioral data, and subjective assessments, thereby bridging the gap between operator and engineer.



Figure 7. Dr. Meredith Carroll introducing her NASA ULI, TRANSCEND

The project will involve working with flight students in human-in-the-loop simulations, created by engineers to simulate and mathematically model machine-learning algorithms to explore their limitations. The aims are to better understand how to communicate trust and reasoning and to develop safety and integrity analysis tools. Two scenarios will be used to validate these tools: one focused on sUAS cargo operations and the other on a passenger air taxi. The scenarios will vary in terms of operator involvement, decision making based on weather and route changes, aircraft routing, traffic management, and flight monitoring. The team will evaluate how the tools provide safety assurance functions that are trustworthy, believed in, and relied upon, as scenario participants determine whether their vehicles can complete the flight (considering energy levels relative to wind, rerouting around weather) and make decisions based on whether the traffic flow is safe and sustainable.

Table 2. TRANSCEND Scientific Contributions

Research Gap	Research Outcomes
Gap 1. Definitions and models of trust vary across disciplines. A shared approach must include common terminology and quantitative measures.	TC 1. Develop an integrated definition, model, and measures of trust that account for the human factors, organizational, and technology perspectives.
Gap 2. Lack of tools and methods to establish that learning-enabled systems are trusted within safety-critical organizations	TC 2. Develop and empirically validate cross-disciplinary methods and tools to establish trust in learning-enabled system-wide safety assurance systems.
Gap 3. Current approaches for assessing learning-enabled trustworthiness are insufficient for technology transition	TC 3. Integrate cross-disciplinary methods, tools, and simulations into relevant testbeds to facilitate transition to industry stakeholders.
Gap 4. Lack of an integrated approach and tools for proving safe integration of learning-enabled systems into ISSA	TC 4. Develop a safety case toolkit for providing learning-enabled systems that are trustworthy, believed, and relied upon.

TC, technical challenge

Additionally, the use cases will include a learning-enabled safety assurance system that monitors (collecting available data), assesses, detects, and alerts or queries as a redundant safety contribution. Dr. Carroll emphasized that the effort is not focused on developing the learning-enabled safety assurance system itself. Rather, they are emulating its outputs to study the ability of the created tools and approaches to assess system trustworthiness, believability, and reliance, as well as the system characteristics that influence these constructs. In addition, the TRANSCEND ULI will include workforce development efforts to inspire K-12 students in science, technology, engineering, and mathematics (STEM) through afterschool and summer programs, engage college-aged students through research experiences and internships, and educate additional potential workforce members through partnerships with a local community college.

During the Q&A, a concern was raised that trust can be lost if a tool loses its predictability due to a learning element; Dr. Carroll responded that part of the development will ensure transparency regarding why the tool's behavior changed to aid user understanding. This led to a brief discussion on the use of artificial intelligence (AI) in the system and how the impact and outcomes may change if the system is adapting and learning but the pilot still does not trust the tool. Dr. Carroll concluded her overview by inviting members of the RAM-AO Working Group, including industry leaders, technology innovators, safety experts, and government partners, to engage with the project as stakeholders.

Explorational Study of Human Factors in Autonomous Multi-Aircraft UTM Operations

Bhoomin Chauhan | NASA

Dr. Bhoomin Chauhan reported on behalf of his team (Figure 8, including co-authors Dr. Nadia Fox, Ms. Gita Hodell, and Mr. Brian Petty) regarding their research study investigating the effect of control level and task complexity on an operator's ability to use a ground control station (GCS) to manage autonomous UAS operations. A future NAS will include UAS Traffic Management (UTM) to support strategic deconfliction, conformance monitoring, and priority assignment, complementing traditional airspace management by ATC. In anticipation of the projected increase in Beyond Visual Line of Sight (BVLOS) operations, adoption of autonomous UAS operations, and UTM services, this research addresses anticipated gaps related to standardized GCS information presentation and varying degrees of automation capabilities. The team aimed to evaluate UTM-enabled GCS interfaces and human performance. The research utilized a simulation that varied the level of control the participants had over the aircraft: One condition, *full control*, included both manual and automated vehicle commands (e.g., GoTo, speed and altitude changes, land, terminate). The full control condition allowed the participant to choose between manual and automated responses. The *partial control* condition included automated commands only (e.g., Hold, Hold and Descend, onboard automation, terminate). The study design included a variety of human performance measures (Table 3).



Figure 8. Dr. Choomin Chauhan describing the results of autonomus multi-aircraft UTM operations study

The simulation sessions reflected real-world, multi-aircraft UAS operations (1:1 to 1:7 aircraft-to-operator ratios) in nominal settings with injected off-nominal events such as strategic deconfliction, high-priority conflicts, non-conforming or contingent operators, crewed traffic avoidance, GPS outages, and lost-link scenarios. Each event was assigned a complexity score to capture operational demand across nominal and off-nominal events with the goal of creating a standardized, quantitative complexity score comparable across conditions, vehicle loads, and event types.

Dr. Chauhan shared preliminary findings from their ongoing analyses. No significant effect of fatigue was found between level-of-control conditions (full vs. partial), time (pre vs. post), or their interaction. However, a nonsignificant trend showed fatigue increasing from pre- to post-simulation in both conditions, with a steeper increase in the full control

condition. A significant effect of level-of-control condition was found for the vigilance task: the partial control condition showed more attentional lapses than full control, though no effect of time or interaction was observed. Vigilance reaction times showed no significant effects although reaction times slowed slightly post-simulation in both conditions with a larger increase in the partial control condition. Participants' perceived workload did not differ between full and partial control conditions; however, predicted workload ratings increased with event complexity in both conditions. Usability assessments revealed a preference for the partial control condition, indicating participants favored a system with more automation. This preference was mirrored in situational awareness measurements, though effects were not significant. The system display was deemed acceptable in both conditions.

Table 3. Human Performance Constructs, Measures, and Administration

Construct	Measures	Administration
Fatigue & Vigilance	- Self-reported sleep quantity - Psychomotor Vigilance Test (PVT) - Visual Analogue Scale for Fatigue (VAS-F)	Pre-study Post-study
Workload	- NASA-TLX - Modified single-item NASA-TLX - Cooper-Harper Rating Scale	During study Post-study
Situational Awareness	- Eye tracking (duration, fixations, saccades, and area of interest) - SART questionnaire	During study
System Use & Trust	- System Usability Scale (SUS) - Trust in Automation (Performance, Process, Purpose, Faith) - Perceived Risk of Automation - System Familiarity	During study Post study
Cognitive Models	Pathfinder Mental Model	During study

Eye-tracking analyses showed that fixation durations and average number of fixations varied in the full control condition with priority events having the highest averages and automatic dependent surveillance – broadcast (ADS-B) events the lowest while partial control events were similar on average. Saccade velocity was higher in the full control condition indicating that participants using manual control shifted attention and scanned the interface more rapidly. Areas of interest heat maps showed primary focus on the central area. Although patterns were similar between conditions, differences emerged during non-conforming events. During priority events, heat maps showed the highest number of fixations and greater areas of interest, appearing darker compared to other event types. In the partial condition, the highest levels of interest shifted to the left of the visual interface, whereas in the full condition, the greatest concentration remained in the center (Figure 9).

Participants also provided extensive feedback through an open-ended discussion with the researchers. The interface and system were new to participants, and the learning curve likely influenced performance and self-reports. After gaining familiarity, participants reported increased confidence and improved understanding of system functions. Participants, furthermore, suggested that managing seven UASs was difficult with limited capacity to respond to emergencies, use different control options, and monitor vehicles directly. Participants heavily relied on automation due to time pressure and the complex environment, perceiving differences in control level as irrelevant under sustained high workload. Participants felt comfortable supervising no more than two vehicles in real-world operations. Situational awareness was negatively impacted by elevated workload, leading to reduced awareness and limited ability to recall vehicle states and specific aircraft behaviors. Participants relied on pre-loaded flight plans and automation decisions without verification. To aid situational awareness, it was suggested that nominal tasks such as scheduling and takeoff be automated and that the user interface be enhanced to support monitoring. Additional feedback on interface design and usability included that spatial dispersion of controls increased workload. Suggested improvements included adding visual cues, grouping controls by task, using larger fonts, and color-coding vehicles. Participants also requested alternative path suggestions.

During the question-and-answer session, the audience first commented on participants' limited attention to certain instruments, such as the attitude indicator, and asked if the research team was reviewing similar trends to assess the usefulness of such instruments for UAS operators. Dr. Chauhan confirmed that although they had not explicitly analyzed these trends, fixation heat maps could be used to identify preferred information during non-conforming events. He added that heat map trends should be complemented by questionnaires to better capture user interface elements most used in such events. The audience also inquired whether the team had explored participant suggestions to automate more tasks and whether there was insight into how many tasks could be automated to reduce operator workload under extreme conditions. Dr. Chauhan explained that the study's design and variable manipulation did not allow exploration of automation to that extent, but future studies could address this. Mr. Michael Politowicz, NASA, who was involved in the research, commented that the level of automated nominal tasks depended on system capabilities and agreed that some tasks could be automated and adjusted in future studies. He also mentioned a study led by Dr. Carroll on user needs assessment that addressed instrumentation questions such as the attitude indicator and encouraged the audience to review those results regarding display content.

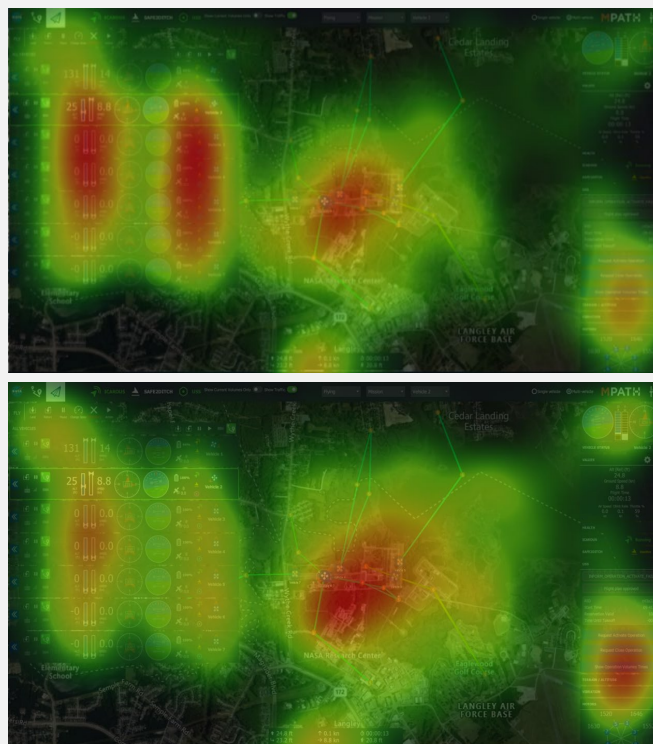


Figure 9. Eye tracking for priority events in the partial control condition (top) and full control condition (bottom)

Defining the Path Forward: Industry Standards & Safety Frameworks for Multi-Aircraft Operations

Harrison Wolf | FSF, Advanced Aviation

Brandon Suarez | RTCA, SC-228

Mallory Graydon | SAE, S-18

Andy Lacher | ASTM, AC377

Anna Dietrich (Moderator) | AUVSI

The panel, *Defining the Path Forward: Industry Standards & Safety Frameworks for Multi-Aircraft Operations*, aimed to foster collaboration among representatives from various standards organizations and safety foundations (Figure 10). Its goal was to provide an overview of ongoing efforts to establish industry standards and safety frameworks that support the advancement of multi-aircraft operations.

Panel moderator Ms. Anna Dietrich, Association for Uncrewed Vehicle Systems International (AUVSI), brought her expertise in certification, strategy, and regulatory affairs to guide the discussion and share insights from her work on the [Blueprint for Autonomy](#), published by AUVSI in 2023. She emphasized the importance of industry collaboration in developing performance-based standards and warned of the risks of reverting to prescriptive regulatory environments if these efforts falter. Ms. Dietrich provided an overview of the blueprint, which outlines five foundational areas for advancing autonomous aircraft operations (Figure 11), along with actionable steps categorized by immediate, near-term, and mid-term priorities. She noted that, although



Figure 10. Ms. Anna Dietrich, Mr. Andy Lacher, Dr. Mallory Graydon (virtual), Mr. Brandon Suarez, and Mr. Harrison Wolf (left to right) discussing whether current barriers are more technological or societal in nature

progress has been made, significant work remains, particularly in generating standards for m:N (human to multi-aircraft) operations. Ms. Dietrich encouraged attendees to engage in these efforts and announced upcoming workshops to refine and update the blueprint, underscoring its relevance to the future of autonomous aviation.

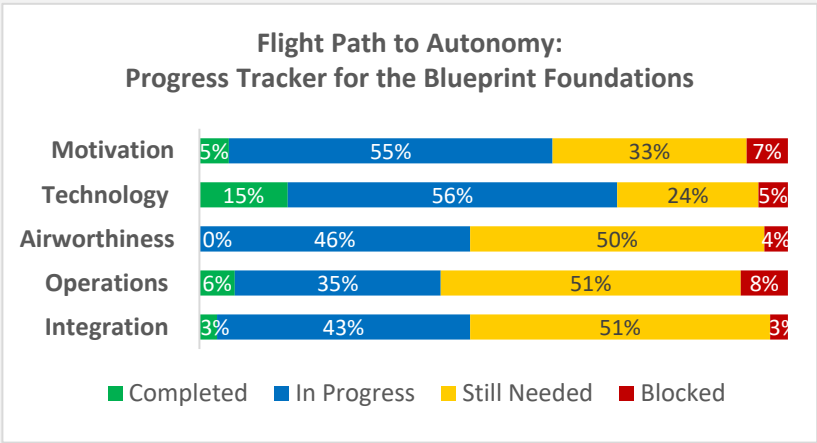


Figure 11. Blueprint for Autonomy progress tracker

safety of autonomous systems, and a white paper on roles and responsibilities for increasingly autonomous systems, which addresses policy and accountability issues (see other publications in Figure 12). He encouraged engagement in ASTM's activities, such as steering committees, quarterly meetings, study panels, and an annual symposium, as opportunities to shape future studies and foster collaboration within the autonomy and aviation community.



Figure 12. Relevant publications from ASTM include the following:

- [TR1-EB Autonomy Design and Operations in Aviation: Terminology and Requirements Framework](#)
- [TR2-EB Developmental Pillars for Increased Autonomy for Aircraft Systems](#)
- [TR3-EB Regulatory Barriers to Autonomy in Aviation](#)
- [White Paper - Roles and Responsibilities for Operational Control in the Age of Increasingly Autonomous Flight](#)
- [White Paper - A Safety Intent-Based Application of Part 23 "Pilot" and "Flightcrew" Requirements for Uncrewed Aircraft](#)

rotorcraft, and emerging eVTOL applications, culminating in the development of Airborne Collision Avoidance System X for UAS (ACAS Xu) and for Rotorcraft (ACAS XR). He also highlighted his work leading an RTCA ad-hoc committee that produced [The Forum for Digital Flight](#), building on foundational research from NASA. The report proposes a new operating mode in the NAS that combines the flexibility of visual flight rules (VFRs) with the all-weather accessibility of instrument flight rules (IFRs), addressing the needs of emerging markets such as urban and regional air mobility. He stated that the technologies developed for UASs over the past two decades not only advance highly automated aircraft but have broader applications across all aviation, paving the way for a safer airspace. Mr. Suarez encouraged

The first panelist, Mr. Andy Lacher, representing ASTM and the Flight Safety Foundation (FSF), emphasized the importance of cross-pollination between various industry groups to advance autonomy and m:N; discussed ASTM's Administrative Committee 377 (AC377), which focuses on autonomy across aviation technical committees; and highlighted its role in framing problems and proposing solutions instead of writing standards directly. He shared key achievements, including the award-winning [TR1 technical report](#), which established a functional framework for demonstrating the

Mr. Brandon Suarez, co-chair of RTCA Special Committee 228 (SC-228), provided an overview of the committee's work in developing standards for UAS and DAA technologies over the past decade. He highlighted the committee's origins, driven by military needs to integrate large UASs into civilian airspace, and its early achievements, including the creation of technical standards for DAA systems and C-band data links, which were quickly adopted by the FAA as technical standard orders. Mr. Suarez emphasized the critical role of NASA's UAS-in-the-NAS project in advancing these standards through extensive hardware development and flight testing. Over time, the committee expanded its scope to address diverse use cases, including smaller UASs,

continued collaboration to address evolving industry needs and leverage the momentum for innovation in autonomous and highly automated aviation.

The next panelist was virtual attendee, Dr. Mallory Graydon, representing SAE's S-18 (Figure 13), who introduced the group's focus on best practices for development assurance, primarily addressing [14 CFR 25.1309](#), which mandates that catastrophic failure conditions in aircraft systems must be extremely improbable and not result from a single failure. Although the committee's work primarily targets transport category aircraft, it is expanding to address gaps related to new and emerging aviation technologies such as eVTOLs and remotely piloted systems. Dr. Graydon highlighted ongoing efforts to adapt traditional safety standards such as [SAE ARP4754B](#) (development assurance) and [ARP4761A](#) (safety analysis), to these novel use cases, emphasizing the importance of understanding these standards as they represent the gold standard for FAA compliance and provide a structured approach to addressing safety concerns in aviation system design.

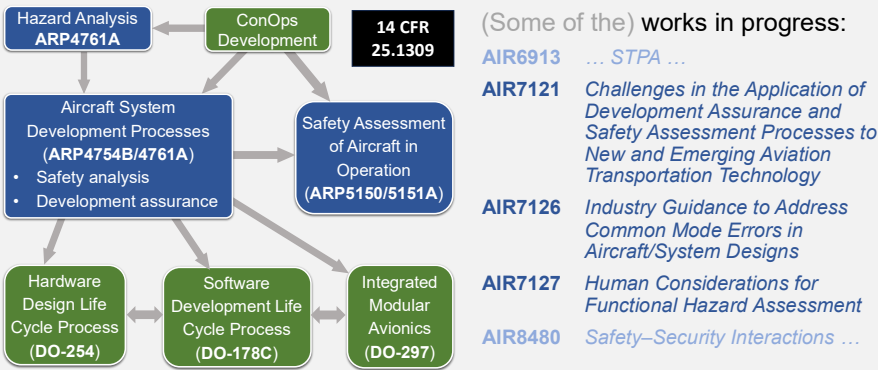


Figure 13. Overview of recent publications and works in progress from SAE-18's Aircraft and System Development and Safety Assessment Committee



Figure 14. FSF's 2026 - 2028 working groups

The final panelist, Mr. Harrison Wolf from FSF Advanced Aviation, highlighted his organization's long-standing commitment to aviation safety since its founding in 1945. He emphasized the Foundation's impartial, independent, and internationally representative approach to addressing emerging technologies in aviation. Mr. Wolf outlined the Foundation's current efforts, which include three key working groups for the 2026–2028 term: regulatory alignment, human factors in increasingly autonomous operations, and airspace of the future (Figure 14). He described the regulatory alignment group's work on reconciling the Basic Aviation Risk Standard (BARS) and the Specific Operational Risk Assessment (SORA) methodologies to address challenges faced by organizations such as the World Food Program in global operations. Lastly, he introduced a new initiative to analyze and compare international roadmaps for AAM and AI safety assurance, using a tool to assess domain readiness and capability timelines.

During the Q&A portion of the panel, the first discussion centered on key roles in the automated flight ecosystem and how collaboration is shaping its development. Mr. Wolf highlighted the success of UTM collaborations, particularly ASTM's data-exchange standards, which have enabled industry test sites supported by the FAA. He emphasized the importance of documenting these successes as case studies to replicate across other technologies. Mr. Lacher reinforced the idea of grounding future advancements in the successes of current innovations, noting that regulators are already approving innovative solutions. Mr. Wolf agreed, adding that learning from what works is as important as analyzing past failures. Mr. Suarez reflected on the evolution of the UAS and advanced aviation ecosystem, noting that the technologies have become integral to aviation as a whole, rather than being niche or isolated. He emphasized the value of diversity within the ecosystem, cautioning against attempts to unify all frameworks under a single model. He also shared insights on the challenges of bridging specialized domain expertise, such as data link experts and system safety professionals, to foster productive collaboration. Dr. Graydon addressed the differences in vocabulary and approaches between communities focused on smaller aircraft and those working on larger transport category aircraft. She emphasized the importance of applying lessons learned from larger aircraft development assurance

processes, which represent the "gold standard" for safety. Dr. Graydon noted that although smaller aircraft have unique challenges, the rigorous safety frameworks developed for larger aircraft provide a benchmark for addressing emerging technologies.

The next topic of discussion was the challenge of developing standards for new aviation technologies without the benefit of decades of operational experience found in conventional aviation. To this point, the panelists emphasized the importance of prototyping, testing, and learning from limited operational deployments. The panelists emphasized the need for collaboration, thoughtful integration, and maintaining safety.

Ms. Dietrich then noted the challenge of aligning diverse stakeholders and having standards and requirements that reflect a unified direction for the industry. Mr. Suarez highlighted the need for newcomers to the aviation industry to understand the complexity of the existing ecosystem and how their use cases fit into the broader aviation landscape. He emphasized the importance of humility and collaboration in aligning with the larger vision, noting that the challenge lies in helping stakeholders see their role in the pathway forward. Mr. Lacher added that although a single unified vision may not be necessary, the focus should be on creating enablers and addressing barriers to progress. He stressed the need for a new operating mode, such as digital flight or automated flight rules, that is native to autonomous operations and better suited to the future of aviation. Mr. Wolf framed the future of aviation as both a technical and societal revolution, with the potential to democratize low-altitude airspace and expand access to aviation for a larger portion of the global population. From the FSF's perspective, maintaining the safety of the airspace is critical to preserving public trust in aviation as a safe and reliable mode of transportation. He also reflected on how future generations may perceive aircraft differently, noting that his young son already views all flying vehicles as UASs. This shift in perception highlights the need for thoughtful and intelligent management of the transition to autonomous and uncrewed aviation systems. If mishandled, the transition could foster fear rather than hope, underscoring the importance of integrating these advancements in a way that inspires confidence and safety. Dr. Graydon focused on the need to ensure that new systems do not compromise the safety of existing airspace operations. She highlighted the importance of rigorous testing and collaboration to confirm that traditional systems can coexist with new technologies without degrading performance. Together, the panelists underscored the need for a balance between innovation, safety, and collaboration to realize the vision of an automated aviation future.

Next, Ms. Dietrich touched on whether a dedicated m:N standard is needed or if it is an emergent property of existing autonomy-related standards. The panelists offered nuanced perspectives. Mr. Lacher opined that m:N and autonomous flight operations are inherently interconnected, as there is no economic incentive for autonomy without m:N. He suggested that although a standalone, overarching m:N standard may not be necessary, a family of standards addressing specific components, such as ground control station design for m:N situational awareness, might be required. These standards could include m:N as part of their scope but would focus on enabling specific aspects of the broader vision. Mr. Wolf agreed, stating that m:N is an emergent property of the broader work being done on autonomy and related standards. He highlighted the need to evolve the roles and responsibilities of pilots and supervisors to account for the complexities of managing multiple vehicles. He pointed to ongoing research, such as NASA's work on human mental models and supervisory capacity, as critical to informing future guidance materials, whether they take the form of standards, regulations, or other frameworks. However, he expressed that the field is not yet ready to define m:N as a separate standard. Dr. Graydon noted that although m:N is not directly a development assurance issue, the human factors aspects of m:N could be addressed by liaising with the SAE G-10 community, which focuses on human factors in aviation. Rounding out the discussion, Mr. Suarez agreed with Mr. Lacher and Mr. Wolf, reflecting on past efforts within SC 228 to develop a white paper on m:N for DAA operations. He noted that the community struggled with defining m:N as a standalone concept because, operationally, it often boiled down to specific issues, such as how information is displayed to a ground-based supervisor and the interactions that person has with the aircraft and other system actors.

Ms. Dietrich also asked the panel discussion about electronic conspicuity. The panelists noted its critical role in the safety of both manned and unmanned aviation, as it enables real-time awareness of aircraft locations. They highlighted the need for a machine-readable, universal system to track and identify aircraft, noting that current technologies such

as ADS-B and Remote ID have significant limitations such as a lack of authentication, encryption, and robustness for safety-critical applications. The panelists stressed the urgency of addressing these gaps to support the evolution of aviation, particularly as autonomous operations and higher-density airspace become more prevalent, and Mr. Wolf noted that electronic conspicuity is currently under the *Special Projects* section in Figure 14. They warned that delaying action could constrain future advancements in both manned and unmanned aviation. Ms. Dietrich followed up on her electronic conspicuity in the context of human-piloted aircraft and Dr. Graydon highlighted the importance of informing pilots about nearby aircraft in a way that neither disrupts their workflow nor creates additional risks, especially during critical phases such as landing. Dr. Graydon also pointed to the growing collaboration between system safety and cybersecurity experts in the airliner industry to address issues such as data spoofing and asked how much of this type of work has been applied to the development of electronic conspicuity devices. She referenced European efforts to develop portable electronic conspicuity solutions but noted her limited familiarity with their progress.

The final moderated question from Ms. Dietrich asked the panelists to provide concise insights on the role of standards in advancing digital flight and automated flight rules. Mr. Lacher emphasized the need for a clear CONOPS as a foundation for developing technical standards, suggesting that the aviation community and organizations such as the International Civil Aviation Organization (ICAO) must first align on future operating concepts. Mr. Wolf highlighted the importance of establishing a universal communication language and format, noting that agreement on how to communicate is a critical first step, albeit a challenging one. In contrast, Mr. Suarez advocated for the United States to resume its position of being the global leader in aviation, i.e., for the United States to lead by developing and deploying solutions domestically, focusing less on international groups such as ICAO, and setting the stage for the rest of the world to catch up. Dr. Graydon stressed that standards play a crucial role in ensuring a shared understanding of technology but reiterated that standardization must be informed by real-world deployments and testing, citing digital clearance delivery in oceanic sectors as an example of a precursor to broader standardization efforts. In general, the panelists underscored the importance of collaboration, testing, and leadership in shaping the future of digital and automated flight.

Question 1. The first audience question came from Mr. Joe Darden (Iridium), who raised the idea of expanding the concept of m:N to a broader, cross-domain perspective in which operators manage not only aircraft but also ground vehicles, surface vehicles, and other assets within a unified network. In response, the panelists discussed the evolution of connectivity concepts, from vehicle-to-vehicle (V2V) communication to broader frameworks such as vehicle-to-infrastructure (V2I) and ultimately "anything-to-anything" (A2X) communication. They noted that although the aviation regulatory landscape is among the most complex, solving autonomy challenges in aviation, particularly in low-altitude, high-interaction environments, could provide a foundation for addressing similar problems across other domains. The panelists also touched on the importance of sharing surveillance and intent data across domains to simplify these challenges. They mentioned underutilized aspects of existing technologies, such as ADS-B, which already includes specifications for obstacles and ground vehicles but has not been fully implemented. The discussion underscored the need to revisit and implement the visionary concepts developed 25+ years ago to fully realize the potential of cross-domain autonomy.

Question 2. The second question from the audience came from Mr. Jake Buurma (CCS STEM), who proposed using a hub-and-spoke model to optimize the integration of technologies such as ADS-B and Remote ID for aviation operations. The idea is to cluster more advanced and expensive technologies, such as ADS-B in, ADS-B out, radar, and sonar, at centralized hubs, while equipping spokes, such as drones, with simpler, cost-effective systems like ADS-B out. This approach would allow drones to communicate essential information to the hub without requiring the full suite of capabilities. In response, panelists discussed the challenges of data sharing within the hub-and-spoke model, highlighting industry concerns about losing competitive advantages if operational data, such as routes and patterns, are shared openly. It was proposed that the US government could be leveraged as a central repository for surveillance data, enabling two-way data sharing between private entities and government systems, an approach that would allow operators to contribute ground-based surveillance data, such as radar at non-towered airports, while gaining access to broader surveillance data from the government.

Question 3. Mr. Nelson Brown (NASA) inquired about the potential role of the insurance industry in encouraging data sharing within the aviation community. The question suggested that participation in a data-sharing ecosystem could lead to lower insurance rates for operators, creating an incentive for collaboration. To this question, Mr. Suarez quipped, "Have you met any aviation insurance adjusters?" The panelists acknowledged that although the insurance industry has historically driven safety improvements in general aviation, its engagement with the sUAS and autonomous aviation sectors has been limited. They noted that insurance requirements, such as mandatory training for pilots operating more complex aircraft, have contributed to enhanced safety. However, efforts to involve the insurance industry in data-sharing initiatives have met with lukewarm interest so far.

To conclude the panel discussion, Dr. Katie Constant-Coup (Constant Technology & Research Solutions, LLC) asked the panelists to suggest a single homework assignment for each breakout subgroup that would support their respective standards development activities. Mr. Wolf stated the importance of articulating the "why" behind every standard. He suggested that committees begin each meeting by clearly defining the purpose of their work, as this clarity is essential for gaining buy-in from stakeholders, regulators, and contributors. Mr. Lacher echoed Mr. Wolf's point and noted that understanding the value of a standard makes the effort worthwhile, particularly for groups such as AC 377, which are still determining their next study focus. Dr. Graydon recommended aligning subgroup efforts with the FAA's existing safety framework, which revolves around three key questions: (1) How could what you are creating harm people? (2) What is being done to mitigate that harm? and (3) How to determine when enough has been done? Mr. Suarez encouraged subgroups to review foundational documents, such as RTCA's DO-304A and the report on digital flight, to identify gaps or areas for improvement. Finally, Ms. Dietrich, as moderator, emphasized leveraging existing standards and frameworks rather than creating new ones from scratch. She urged subgroups to "shrink the change" by building on established foundations, such as Part 23-type certification requirements, which already address autonomy-related functions.

Keynote and Fireside Chat with Robert Rose

Robert Rose | Reliable Robotics
Shivanjli Sharma | NASA

Mr. Robert Rose, CEO of Reliable Robotics, delivered a keynote focused on operationalizing autonomy in aviation and the future of dense airspace operations (Figure 15). He began by sharing his professional background, which includes experience at SpaceX and Tesla working on autonomous systems before transitioning to aviation, a field he is deeply passionate about. Mr. Rose expressed his lifelong enthusiasm for flying and his belief that expanding access to air travel has the potential to make the world a better and more connected place. He referenced his recent presentation at the ASTM Autonomy Symposium, where he discussed Reliable Robotics' approach to operationalizing autonomy in the near term. He noted that his perspective on m:N operations, specifically the concept of a single pilot or a collection of operators managing multiple aircraft, was met with some controversy due to his expressed cynicism. This viewpoint, he suggested, may have contributed to his invitation to speak at the RAM-AO Working Group, allowing him to delve deeper into the topic and share his insights with the audience.

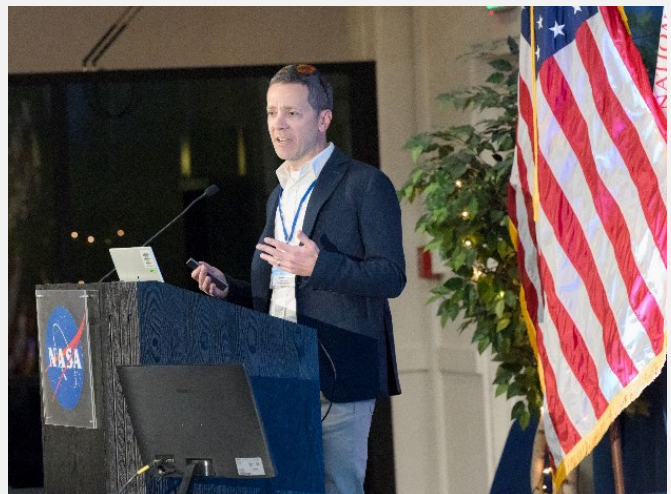


Figure 15. Mr. Robert Rose discussing operationalizing autonomy

Mr. Rose introduced the concept of "minimum viable autonomy," or in other words, "the absolute simplest thing that you can put into the airspace right now that you can label autonomous". To this end, Reliable Robotics is pursuing

two Supplemental Type Certificates (STCs) for the Cessna Caravan: one enabling end-to-end autonomous operation with continuous autopilot engagement and another moving the pilot to a ground-control station. Mr. Rose highlighted three key enabling technologies for remote operations: (1) certified DAA systems, (2) robust communications data links, and (3) ground-control stations (Figure 16).

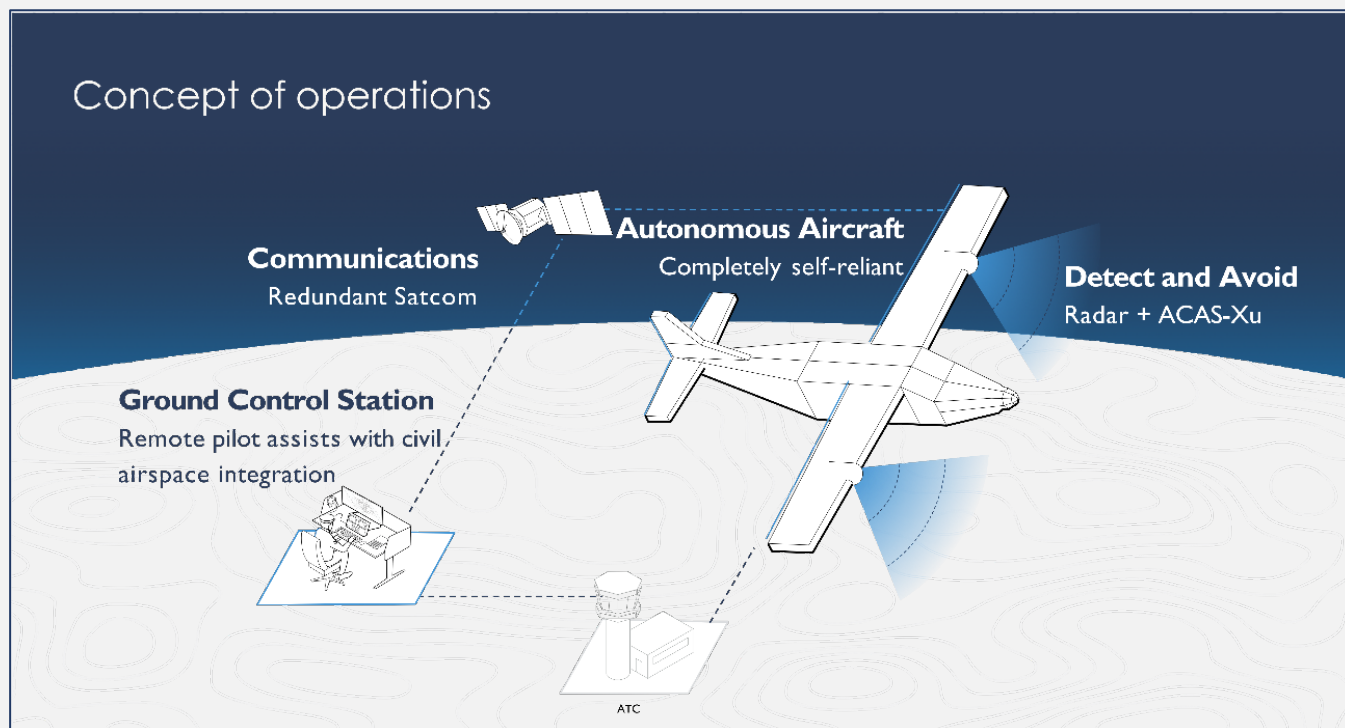


Figure 16. Concept of operations demonstrating three key enabling technologies for remote operations: (1) certified DAA systems, (2) robust communications data links, and (3) ground control stations

While discussing the importance of compliance with FAA regulations and standards, Mr. Rose referenced the recently published Technical Standard Orders (TSOs) [TSO-C211a](#) and [TSO-C212a](#), to maintain safe and scalable integration of autonomous systems into the airspace. Mr. Rose also shared his perspective on the challenges of m:N operations, expressing skepticism about their economic and operational feasibility based on personal experience and research.

To illustrate the challenges of envisioning the future of autonomy, Mr. Rose shared a series of AI-generated images depicting high-density airspace operations. He noted that even advanced AI tools struggle to imagine such a future, as they are limited by the data they are trained on. By presenting these images, Mr. Rose encouraged the audience to consider how the industry can better educate and inspire the public about a future with significantly more aircraft in the skies: a future that remains difficult for many to conceptualize.

Mr. Rose then returned to his original topic of why he is cynical about m:N operations. He suggested that there is an economic reason to pursue autonomous 1:1 operations, especially for cargo delivery. Decoupling the pilot from the aircraft already results in a tremendous amount of savings. However, transitioning from 1:1 to m:N does not provide significant amounts of additional improvements to those savings. As such, m:N operations have not been a major focus of Reliable Robotics. Mr. Rose continued his critique with insights from a research study conducted by Andrew Dassenville, a Reliable Robotics employee, who explored the challenges of multi-aircraft operations in his 2025 master's thesis, [Limitations of pilot-ATC communication in multi-UAS operations](#). Using a simulator, Mr. Dassenville developed a simplified user interface for remote pilots, featuring a top-down moving map, a timeline view, a radio panel, and a list of managed aircraft. Although the system streamlined many tasks, the study revealed significant stress and complexity as the number of aircraft increased, particularly in terminal areas with overlapping trajectories and weather data. Mr. Rose recounted his own experience with the simulator, noting that managing a single aircraft was

straightforward, but adding a second aircraft introduced overwhelming cognitive demands and communication challenges. The study found a correlation between the number of aircraft and the frequency of misinterpreted instructions. Mr. Rose concluded that if pilots are to manage multiple aircraft simultaneously or operate within any m:N system, it is essential to digitize aircraft management processes, as voice communication is not scalable.

To address this issue, Mr. Rose proposed a phased approach to implementing digital communications, starting with restricted access to certain airspaces for non-digital systems. He advocated for leveraging technologies such as Controller-Pilot Data Link Communications (CPDLC) and DAA radar to improve safety, reduce pilot workload, and enable higher traffic densities. Mr. Rose concluded by urging the aviation community to focus on integrating new technologies into existing operations, particularly for the large Part 121 commercial aviation sector, in an effort to achieve widespread adoption and long-term safety improvements.

The Fireside Chat, led by Ms. Shivanjli Sharma, next explored Mr. Rose's philosophy on testing, regulatory collaboration and the challenges of advancing autonomy in aviation (Figure 17). Ms. Sharma first asked Mr. Rose to share the origins of his company's philosophy and how it has shaped his approach, particularly in his interactions with the FAA and the direction of his work. In his response, Mr. Rose highlighted the tension between Reliable Robotics' ultimate goal of certification and the practical need for flight testing. Whereas an idealized process would focus solely on documentation and presenting a fully conformed system to regulators, flight testing plays an important role in solidifying requirements, demonstrating real-world functionality, and building trust with the FAA. He explained that prototyping and testing help clarify formal system requirements, provide tangible proof of functionality to regulators, and inspire confidence among stakeholders, including investors and team members. This hands-on approach not only advances technical development but strengthens relationships and credibility within the aviation community.

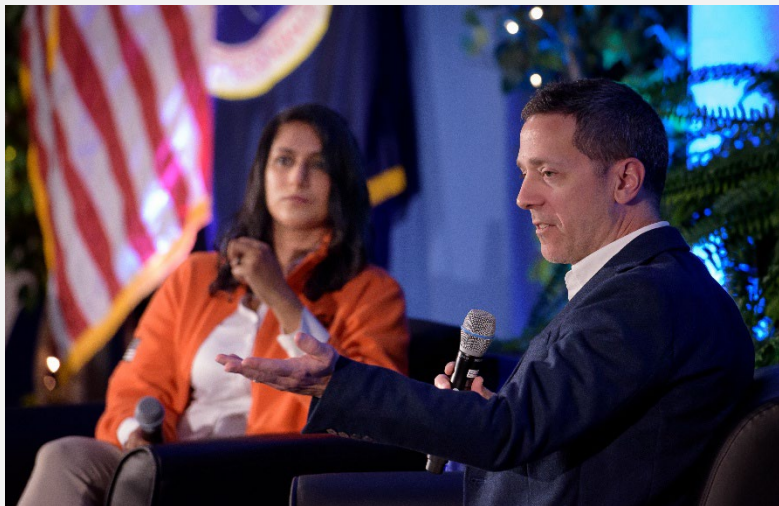


Figure 17. Ms. Shivanjli Sharma (ATMS Project Manager; left) and Mr. Robert Rose (Reliable Robotics CEO; right) during the Fireside Chat

Ms. Sharma next asked Mr. Rose to reflect on any surprising findings from his company's assessments that influenced decisions about developing capabilities in-house versus purchasing them. She specifically inquired about how these insights have shaped their approach to addressing key challenges, such as DAA systems and other critical problem areas limiting routine operations. In response, Mr. Rose used the development of radar systems as an example of unexpected challenges and decisions his company faced. Initially, Reliable Robotics pursued a strategy of leveraging ground-based radar systems for scalable collision avoidance, working with the FAA and the US Air Force to access existing radar infrastructure. They conducted demonstrations and analyses, showing that although the system was not perfect, it could work effectively in many areas of US airspace. However, their access was eventually revoked due to national security concerns and the overwhelming demand from other applicants seeking similar access. Faced with this roadblock, Reliable Robotics pivoted to onboard radar systems, which the FAA had begun to accept for collision avoidance. Despite preferring not to develop radar themselves, the company approached multiple aerospace manufacturers, asking them to build the radar, but none was willing to invest due to skepticism about the near-term market for such technology. After 18–24 months of lobbying unsuccessfully, Reliable Robotics decided to take on the challenge themselves, underscoring the difficulty of advancing innovative solutions in an industry hesitant to invest in emerging technologies.

When asked by Ms. Sharma whether the development and testing of Reliable Robotics' air-to-air radar (ATAR) system has been a solid decision from a design, architectural, and business standpoint, Mr. Rose confidently responded, "Well, of course, no regrets." He expounded on this by reflecting on the challenges and successes of developing Reliable Robotics' radar system, emphasizing the complexity of the project and the importance of hiring the right team and granting them autonomy to make key decisions. Within 12 to 18 months, the team achieved their first flight test and began collaborating with government entities to demonstrate the technology's viability and advance its certification process. Looking ahead, Mr. Rose shared a vision for potentially redefining pilot certification, including the possibility of obtaining a private pilot's license without learning manual landing, and eventually creating a new class of remote pilots for larger autonomous vehicles. He acknowledged the implications of these ideas and the need for careful regulatory engagement as the company collects data and explores future milestones.

The Fireside Chat concluded with Ms. Sharma (Figure 18) asking Mr. Rose to reflect on the most pressing challenges, including political and cultural obstacles, that impact the success of Reliable Robotics' operations. She specifically inquired about what concerns him most. Mr. Rose replied that safety is his core motivation and a key factor in enabling aviation to reach its full potential, with higher frequencies of smaller aircraft and greater operational density. He expressed concern about Reliable Robotics being one of the few companies actively working closely with the FAA to push regulatory boundaries forward, noting a lack of competition in the industry. Additionally, he touched on the growing advancements in autonomous aviation by China, warning of potential national security and economic risks if Western nations fail to keep pace. He stressed the importance of building systems for the next 70 years to maintain US leadership in aviation, describing this as an existential challenge that keeps him up at night.



Figure 18. Ms. Summer Brandt (ATMS Deputy for Safety; left), Mr. Robert Rose (Reliable Robotics CEO; middle), and Ms. Shivanjli Sharma (ATMS Project Manager; right)

During the audience Q&A, Mr. Rose addressed several questions about the future of autonomy, airspace management, radar systems, and Reliable Robotics' vision for aviation. On airspace management, he explained that Reliable Robotics avoids tackling this issue directly but sees potential in automating certain aspects, such as enroute operations, while maintaining human oversight for safety-critical decisions. He stated the importance of protocols and interoperability to allow seamless integration with existing systems. He also spoke about the versatility of radar systems, including their collision-avoidance, weather-detection, and ground-alerting capabilities, noting that although safety improvements are desirable, cost remains a barrier for widespread adoption. He also discussed the FAA's gradual acceptance of radar systems for compliance and encouraged the development of alternative sensors such as LiDAR.

Looking ahead, Mr. Rose shared his vision for Reliable Robotics in 2035, focusing on incremental advancements that align with regulations and deliver immediate business value. He noted the importance of collaborative research, experiments, and exemptions to address future challenges. Finally, he described a future of frictionless travel enabled by autonomous aircraft and ground transportation, where smaller airports become major hubs, and travel planning is reduced to a simple push of a button.

Subgroup Breakout Sessions

Each RAM-AO subgroup held four breakout working sessions on site to further advance their efforts, especially those directed to releasing white papers by September 2026. Starting with ongoing work (for the I&E and sUAS subgroups) or their thesis statement (from the previous bi-annual meeting, for the new subgroups on Scalable Crew Design, System of System Design, and Assurance, Verification, & Validation), each team briefed new participants, conducted interactive discussions and brainstorming, and adopted impact statements and roadmaps to guide the subgroups forward. Each team debriefed the whole RAM-AO working group on the last day of the event, summarized as follows and expanded upon in the following pages:

- The I&E subgroup clarified the structure of their safety assessment framework, refined their intervention taxonomy, and initiated the mapping of operational scenarios to their modeling approach.
- The sUAS subgroup worked to expand their three use cases (humanitarian aid, agriculture, and package delivery), generated cross-comparison tables to assess commonalities across these use cases in five areas, and adopted a writing plan to complete their white paper.
- The Scalable Remote Crew Design subgroup leveraged the pre-mortem technique to identify key content to research, devised an outline and writing plan for their white paper, and adopted an impact statement focused on consensus-building across stakeholder groups.
- The System of Systems (SoS) Design subgroup employed a brainstorming technique to create thematic clusters for consideration in an SoS framework, identified critical SoSs to be included, and fleshed out a white paper outline and writing plan.
- The Verification & Validation (V&V) subgroup adopted a new name with the addition of Assessment (anchoring its work in safety as a foundational architecture for the m:N paradigm) and discussed the creation of a position paper for the architects of the future airspace.



Interventions & Exceptions (I&E)

Andy Thurling (Champion) | DroneUp
Jordan Coker (Moderator) | Aptima

Across the breakout sessions, the Interventions & Exceptions (I&E) subgroup advanced the development of a framework for evaluating safe human to aircraft (m:N) ratios in multi-aircraft operations. The framework integrates CONOPs and hazard inputs, human intervention modeling, and Monte Carlo simulation-based analysis to assess whether proposed supervisory ratios can operate safely. Figure 19 illustrates the overall workflow proposed by the group to translate operational concepts and hazard analyses into simulation-based safety evaluation.

Impact Statement: Develop a framework that will enable scalable autonomous aviation by providing a repeatable method to evaluate how humans supervise large fleets of aircraft safely. By quantifying intervention demands and operator workload, the approach supports operational design, safety case development, and eventual certification for future multi-aircraft operations.

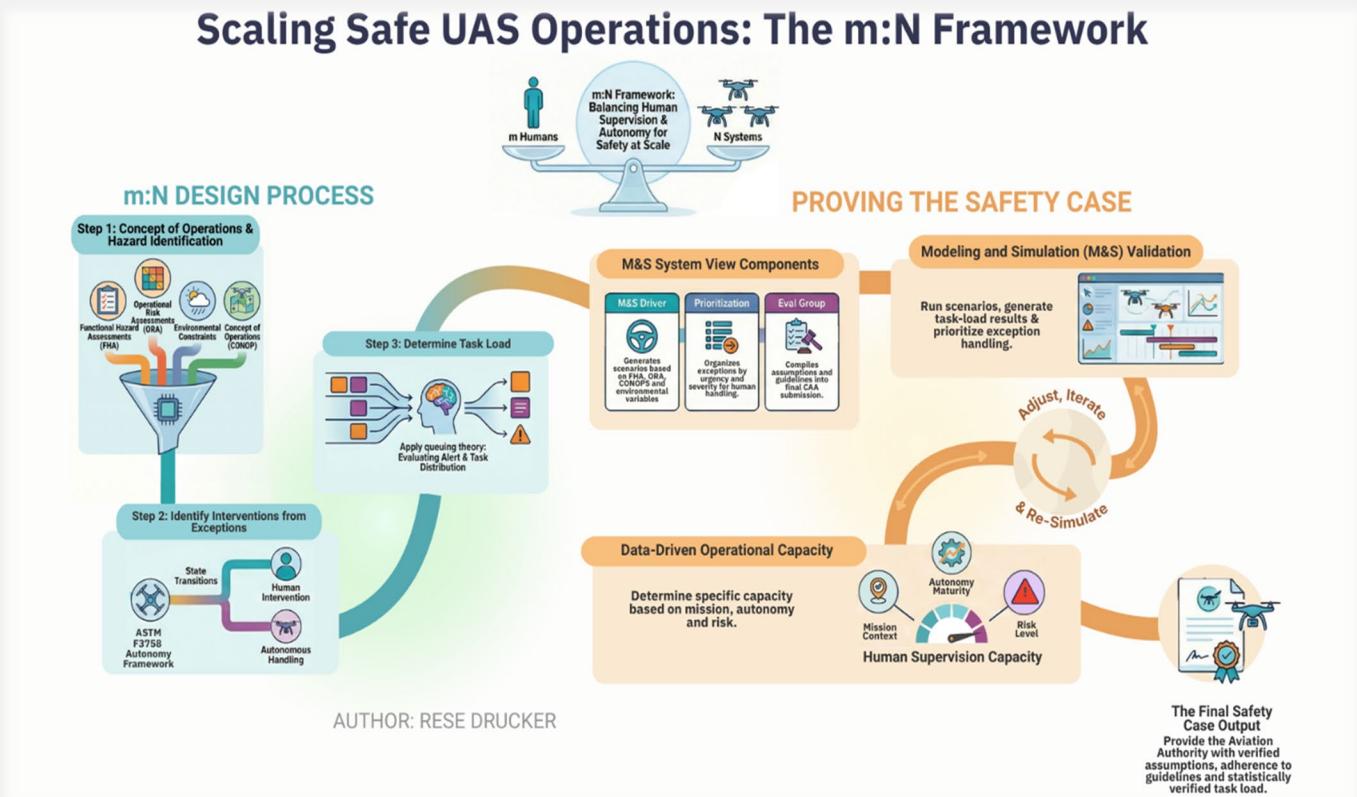


Figure 19. m:N Framework workflow showing the integration of CONOPs, hazard identification, intervention modeling, and simulation-based validation used to evaluate safe supervisory ratios (baseline image created with NotebookLM then modified)

The group aligned on using the CONOPs (what am I doing, with what vehicle, in what environment, with which humans) and a functional hazard assessment (FHA) as inputs to the framework. The FHA hazards were pulled from Coldsnow and colleagues' 2023 [Safety Case for sUAS BVLOS Operations at NASA Langley Research Center](#) and included primary, secondary, and contributory hazards relevant to the operational concept (summarized in Table 4). Hazards identified in the FHA will be analyzed with the (currently in ballot) ASTM F3758 [Standard Guide for Exercising a Contextual Framework for Increasingly Autonomous Aviation Systems](#) to describe the human interventions required to prevent these hazards from escalating into unsafe outcomes. These interventions are likely contingency procedures that take place when automation reaches its operational limits.

Table 4. FHA Hazards used as Inputs to the I&E Framework, including Primary, Secondary, and Contributory Hazards

ID	Description
Primary Hazards	
PH1	Midair collision with manned aircraft
PH2	Midair collision between UA
PH3	UAS flies off the CERTAIN range
PH4	GPS Failure
Secondary Hazard	
SH1	UA impacts people/structures on the ground
Contributory Hazards	
CH1	Degradation of ground surveillance system
CH2	Loss of all command and control links
CH3	Unrecoverable failure of UA or GCS during flight
CH4	Human factors events, e.g., loss of situational awareness, crew miscommunication, crew fatigue
CH5	Loss of voice communications
CH6	Lithium battery fire

Adapted from Coldsnow et al. (2025). Safety Case for sUAS BVLOS Operations at NASA Langley Research Center, Technical Memorandum

Discussions clarified the distinction between routine operator tasks and exception-driven interventions, with the framework focusing on modeling the latter but still recognizing that, although the “peak” cannot be overwhelming, the “nominal” needs to be engaging enough. The group also emphasized the importance of representing how quickly hazards degrade toward unsafe conditions and capturing variability in intervention timing through a structured taxonomy of parameters. An example of the intervention parameter taxonomy used to characterize exception events is provided in Figure 20.

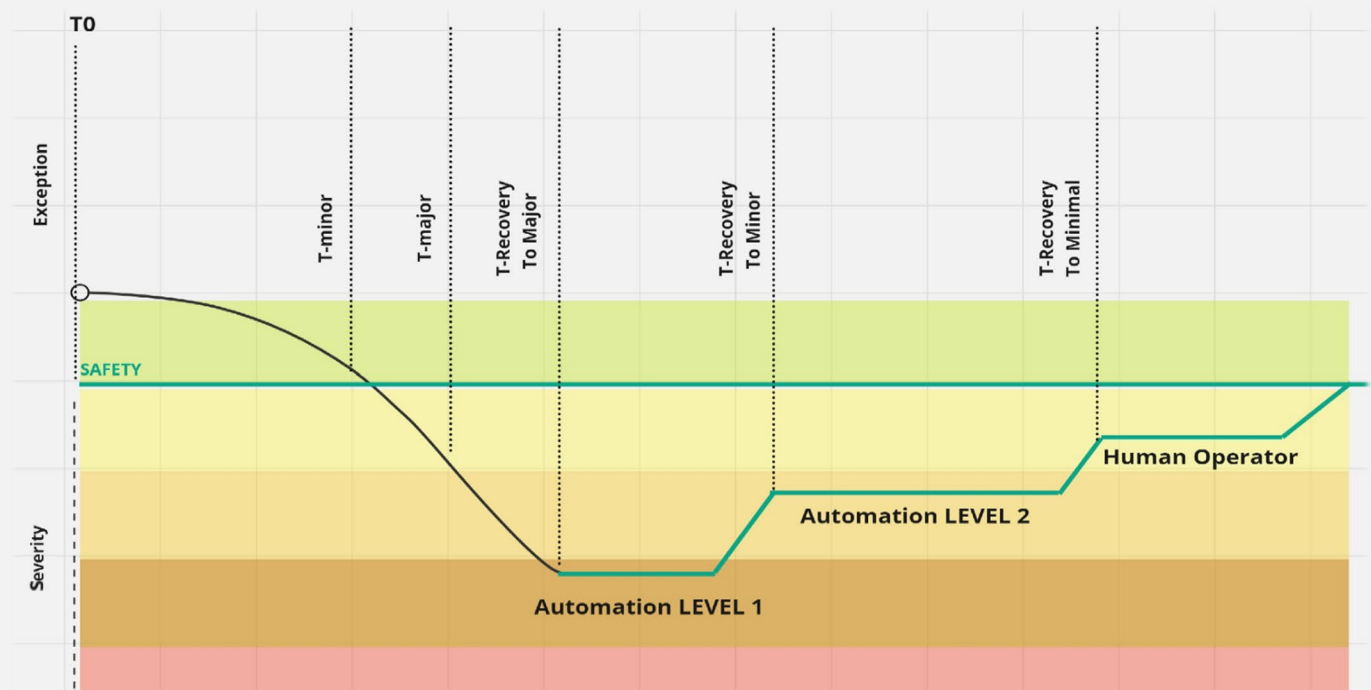


Figure 20. Example intervention taxonomy parameters used to characterize exception events, including severity progression, intervention timing, recovery timing, and operator response characteristics

Human supervisory performance was a central theme. The group discussed how operators must manage both steady-state monitoring and bursts of intervention activity and how system design can support rapid acquisition of situational awareness when exceptions occur. To evaluate these dynamics, the framework will use Monte Carlo simulation to model overlapping intervention events, variability in response times, and potential task surges. This approach will allow the team to evaluate whether proposed supervisory ratios can safely manage real-world operational variability.

The group also began applying the framework to the NASA Remote Operations for Autonomous Missions (ROAM) laboratory BVLOS training scenarios, including a non-cooperative manned aircraft intrusion event, to test how real operational events can be translated into taxonomy parameters for simulation (Table 5). This reinforced the importance of data from part-task simulations in properly modeling the interventions.

Table 5. Representative BVLOS Training Scenarios used to Map Operational Events to Intervention Taxonomy Parameters

Category	Parameter	Description	Example Value
Event Characterization	Severity	Worst credible outcome if event not mitigated	Catastrophic
	Safety Priority	Priority relative to aircraft safety (scale 1–5)	1
	Mission Priority	Priority re: mission objectives (scale 2–7)	Not applicable
Hazard Escalation Timeline	T_minor	Time to minor severity level after detection	0 s
	T_major	Time to major severity level after detection	0 s
	T_hazardous	Time to hazardous severity level	~10 s (assuming closure rate ≈120 kts at ~2000 ft separation)
	T_cat	Time to catastrophic severity level	~13 s (assuming closure rate ≈120 kts at ~1400 ft separation)
Human Intervention Timing	Recognition Time	Time required for operator to detect that an intervention is required	0 s
	Switching Time	Time required for the operator to orient and initiate action	~5 s
	Service Time (Touch Time)	Avg. time required to execute intervention	~34 s
	Neglect Time	Maximum allowable delay between event detection and service initiation	0 s
	Verification Time (T_verify)	Additional time required for confirmation by another operator, if applicable	Not required
Recovery Timeline	Resolved Severity	Best achievable outcome following successful intervention	No Safety Effect (NSE)
	T_R_NSE	Time to recover to no-safety-effect condition	~34 s
	T_R_minor	Time to recover to minor severity	Not applicable
	T_R_major	Time to recover to major severity	Not applicable
	T_R_hazardous	Time to recover to hazardous severity	Not applicable
	T_R_cat	Time to recover to catastrophic severity	Not applicable
Operational Constraints	Specific Re-source Needed	Whether only one specific operator can resolve the event	Not applicable
	Environmental Sensitivity	Environmental effects influencing event	Addressed upstream in FHA; not modeled here
	Maximum Queue Time	Maximum time the exception may remain unserved	TBD
	Operator Bandwidth	Maximum workload capacity for handling simultaneous exceptions	TBD

Overall, the breakout sessions clarified the structure of the framework, refined the intervention taxonomy, and began mapping operational scenarios into the modeling approach that will ultimately support quantitative safety evaluations for scalable multi-aircraft operations.

Small Unmanned Aircraft Systems (sUAS)

Scott Scheff (Champion) | HF Designworks

Garrett Sadler (Champion) | NASA

Ramisha Knight (Moderator) | Aptima

Mr. Scott Scheff and Mr. Garrett Sadler led the sUAS subgroup (Figure 21). Prior to the March 2026 RAM-AO Working Group, the sUAS team began drafting a white paper entitled “Use Cases, Emerging Technologies, and Part 108: Needs, Gaps, and Understanding Processes for sUAS Operating Beyond Visual Line of Sight (BVLOS)” and used the breakout sessions to further flesh out three identified use cases: (1) humanitarian aid, (2) agriculture, and (3) package delivery.

Humanitarian Aid. The humanitarian aid use case centers on the potential to deliver critical supplies (e.g. baby formula, oxygen, insulin, water) during emergencies and disaster relief efforts, exemplified by the response to the 2025 flooding in North Carolina following Hurricane Helene. sUAS offer unique advantages in these situations, including rapid deployment, access to remote or inaccessible areas, and ability to bypass traditional infrastructure that may be damaged or overwhelmed. However, the group identified several challenges, such as having proper prioritization of deliveries (e.g., distinguishing between routine and emergency medical supplies); coordinating multiple operators and sUAS in high-stakes environments; and maintaining clear communication among stakeholders including dispatchers, emergency responders, and airspace managers. Technologies such as Starlink were highlighted as potential solutions for establishing reliable communication networks in disaster zones, enabling efficient coordination of sUAS operations. The discussion also addressed edge cases, such as sUAS inadvertently entering restricted areas or interfering with other emergency operations (e.g., via helicopter). Public perception was another key consideration, as drones and sUAS used for humanitarian aid may face scrutiny regarding privacy and safety. The group noted that although the public is generally accepting of sUAS delivering life-saving supplies, concerns about surveillance or misuse of these aircraft could still arise.

Agriculture. The agriculture use case focused on leveraging sUAS to enhance precision farming practices including spraying crops, monitoring fields, and optimizing resource usage. The subgroup explored operational considerations such as payload types (liquid [water, fertilizers] or solid [seeds, fertilizers] materials), flight patterns, runtime limitations, and the need for fleet management software to coordinate multiple sUAS. Precision agriculture demands high levels of accuracy, such as using a real-time kinematic (RTK) global positioning system (GPS) for precise application of chemicals and to minimize runoff or waste. The group also discussed the importance of mitigating risks such as fire hazards when operating under power lines, and verifying that sUAS can adapt to diverse environments (e.g., rural farms, forestry, urban parks, golf courses).

Impact Statement: Develop a technical memorandum that will inform the FAA, OEMs, and general public of the feedback, needs, and gaps from sUAS operations in a BVLOS environment. We hope to be able to further disseminate this information through other industry publications, including technical journals and trade magazines.

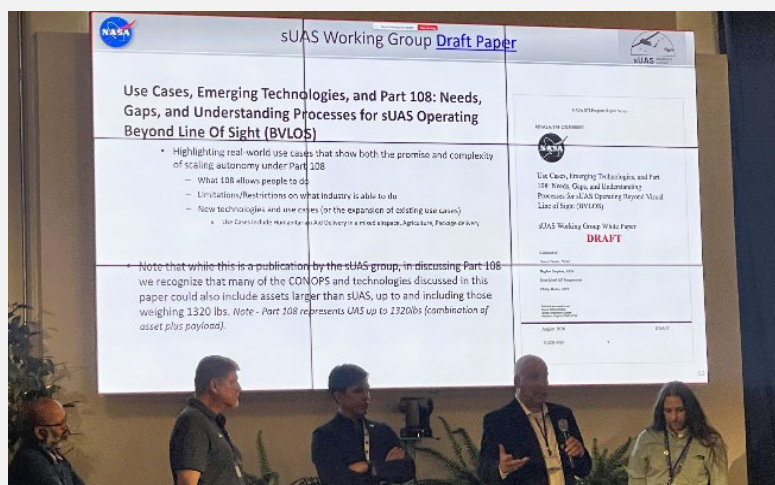


Figure 21. Mr. Scott Scheff (second from right) and Mr. Garrett Sadler (right) providing an overview of the sUAS white paper and their objectives for the week

Package Delivery. For the package delivery use case, the sUAS subgroup discussed considerations such as public perception and prioritization of deliveries. Public concerns about privacy and job displacement were also discussed, with many in the subgroup expressing apprehension about sUAS collecting imagery or replacing human delivery drivers. However, it was noted that public acceptance tends to increase when sUAS are used for high-priority deliveries (e.g., for medical supplies or emergency items) or during public crises (e.g., the Covid-19 lockdowns in 2020, where it was encouraged for the public to stay at home and package delivery was an attractive alternative to venturing out to the supermarket). Regarding prioritization of deliveries, the subgroup explored the idea of creating emergency corridors in urban areas, where sUAS could operate with minimal interference during critical missions, supported by unified communication systems (exact systems still to be determined) to keep all stakeholders informed.

In addition to expanding on the three use cases, the subgroup created five cross-comparison tables to systematically evaluate the use cases against various operational requirements, including: (1) infrastructure needs, (2) technologies, (3) how BVLOS operations are performed today, (4) personnel requirements; and (5) gaps under Part 108. Each table featured the use cases as columns and the requirements as rows, allowing the group to assess whether each requirement was/was not applicable to a given use case, and how/why not. This structured approach provided clarity on the unique and overlapping needs of each use case. Three of the five tables were completed during the breakout sessions and the fourth table on personnel requirements was partially completed. The fifth table, addressing gaps under Part 108, is scheduled for completion during the sUAS group's April 2026 meeting. Cross-comparison tables 1-4 can be found in Appendix A.

The sUAS subgroup concluded its breakout sessions by defining a clear roadmap for advancing its white paper and disseminating its findings (Figure 22). The group outlined immediate next steps, including continuing the development of the white paper and providing updates on the outcomes of the March 3–5 RAM-AO Working Group during the next sUAS meeting in April 2026. In addition to the publication of a NASA Technical Memorandum (TM) in September 2026, the subgroup anticipates additional opportunities to share insights through trade magazines such as American Institute of Aeronautics and Astronautics (AIAA) Aerospace America (Summer 2026), press releases targeting industries such as general aviation and agriculture, and technical journals such as the UAS College Training Initiative's (CTI's) resource repository. The group also plans to leverage social media platforms such as LinkedIn, and newsletters, as well as local newspapers, to broaden its outreach. Finally, the subgroup aims to present its findings directly to the FAA, either informally or through high-level briefings to key offices such as Air Traffic Organization (ATO) and the Office of Integration.



Figure 22. Dr. Ramisha Knight, Mr. Garrett Sadler, and Mr. Scott Scheff (left to right) debriefing the Working Group on the results of the sUAS breakouts

Scalable Remote Crew Design Considerations for Multi-Aircraft Operators and Original Equipment Manufacturers (OEMs)

George Gorospe (Champion) | NASA

Husni Idris (Champion) | NASA

Sylvain Bruni (Moderator) | Aptima

Autonomous aircraft are advancing quickly, but the human systems needed to manage them at scale remain poorly defined. As multiple autonomous aircraft begin operating simultaneously in shared airspace, the question is no longer whether humans will remain in the loop. The real question is how remote crews will be structured, coordinated, and supported so that safety, efficiency, and accountability scale with the technology. The work of the *Scalable Remote Crew Design Considerations for Multi-Aircraft Operators and OEMs* subgroup addresses this challenge directly by examining how future crews will allocate tasks, manage responsibilities, and coordinate across increasingly complex operations.

Impact Statement: Develop stakeholder consensus (across industry, academia, and government) on (1) critical principles and best practices in scalable crew design and management; (2) key enablers needed for scalable routine autonomous multi-aircraft operation end-state related to crew matters (e.g., “digital machine-to-machine comms to replace human voice”); and (3) gaps in standards and policy needs related to crew design and management in RAM-AO, and of the research/testing to be conducted to close these gaps and address these needs.

Over the course of four working sessions held across 3 days, the subgroup advanced the early foundations of a white paper intended to support the goals of NASA’s ATMS project. Participants from government, academia, and industry collaborated to identify the key considerations involved in scalable crew design and management for routine autonomous multi-aircraft operations. Through structured brainstorming, prioritization exercises, and collaborative planning, the group produced several core artifacts: a shared impact statement, a structured white paper outline, and a detailed writing plan that will guide the work through the summer. These outcomes provide a clear path toward producing a consensus document that can inform both operational practices and system design across the emerging ecosystem.

Mr. George Gorospe of NASA opened the initial breakout session with participant introductions and an overview of the subgroup’s purpose. The central thesis guiding the effort is to identify considerations for allocating and distributing tasks, roles, responsibilities, and handoffs among remote crew members in multi-aircraft operations. These considerations are intended to inform the design of operator procedures, original equipment manufacturer (OEM) systems, and services provided by third-party organizations. Next, participants reviewed the overall timeline for producing the white paper and discussed several guardrails for the work. The group agreed to focus on broad principles rather than prescriptive recommendations, avoid narrowing the analysis to specific use cases, and maintain a scope that allows the paper to be completed by the targeted late-summer timeline.

The remainder of the session launched an interactive pre-mortem exercise designed to anticipate potential weaknesses in the future white paper (Figure 23). The process began by asking participants to imagine what failure would look like for the document. From there, the group worked backward through several layers of analysis: identifying types of failure, defining specific failure scenarios, describing the underlying antecedents that could lead to those failures, and finally identifying the gaps or research topics that would need to be addressed to prevent them. This collaborative brainstorming took place on a shared Figma board (Figure 24) that allowed participants to contribute and refine ideas in real time. The group began populating the board during Session 1 and continued the work in the subsequent session. The exercise identified five major categories of potential failure for the white paper (light red stickies), i.e., failure (1) to consider key problem dimensions, (2) of accountability, (3) based on incorrect or incomplete assumptions, (4) of scope, and (5) of relevance to stakeholders. Across these categories, participants identified 22 specific failure scenarios and documented 33 antecedents explaining how such failures could occur.

These insights were then organized into 14 clusters of gaps and research topics that represent the issues the white paper must address (see Appendix B for details).

The failure scenarios identified by the group (pink stickies) largely revolved around risks of ambiguity, incomplete scope, and lack of alignment with prior work and stakeholder needs. Several scenarios pointed to confusion around fundamental concepts such as what constitutes a “crew,” which aircraft and operating rules apply (e.g., Visual [VFRs] vs. Instrument Flight Rules [IFRs]), and who ultimately holds responsibility for the airspace. Others highlighted the possibility that the white paper could overlook critical interaction types, including communication with external stakeholders and interactions among humans, machines, and mixed human-machine teams. Additional risks concerned gaps in conceptual rigor or relevance, such as weak cognitive models, duplication or omission of existing work, insufficient differentiation between good and poor design approaches, or failure to clearly explain the motivation behind the work. Finally, the list reflected concern that the paper might be overly narrow or poorly targeted, either by focusing only on current or future operations, failing to generalize across use cases, or not addressing the needs of the intended audience and stakeholders.

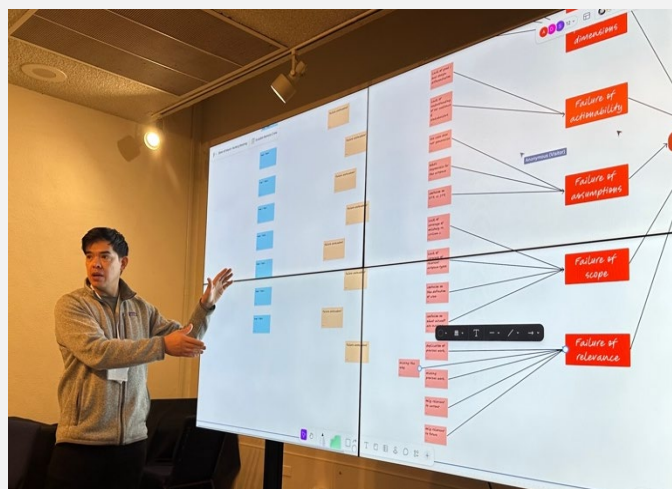


Figure 23. NASA's Mr. George Gorospe introduces the interactive pre-mortem exercise

From these antecedents, the group inferred several key gaps and topics (blue stickies) that the white paper should address. A central theme is task allocation in distributed and scalable crews, including how tasks are dynamically assigned, transferred, or shed across operators and systems under nominal and off-nominal conditions.

Closely related are issues of cognitive workload and confusion that may arise in complex, distributed teams, particularly when boundaries between crew members, automation, and external entities such as air traffic control or third-party services become unclear. The topics also highlight the need to understand how situational awareness, communication, and data dependencies are maintained as operations scale, and how design choices affect workload, coordination, and safety. Finally, methodological considerations are also emphasized, including literature reviews, research interviews, surveys, and other evidence-building activities to support the framework.

From these antecedents, the group inferred several key gaps and topics (blue stickies) that the white paper should address. A central theme is task allocation in distributed and scalable crews, including how tasks are dynamically assigned, transferred, or shed across operators and systems under nominal and off-nominal conditions.

Closely related are issues of cognitive workload and confusion that may arise in complex, distributed teams, particularly when boundaries between crew members, automation, and external entities such as air traffic control or third-party services become unclear. The topics also highlight the need to understand how situational awareness, communication, and data dependencies are maintained as operations scale, and how design choices affect workload, coordination, and safety. Finally, methodological considerations are also emphasized, including literature reviews, research interviews, surveys, and other evidence-building activities to support the framework.

Pre-Mortem Board

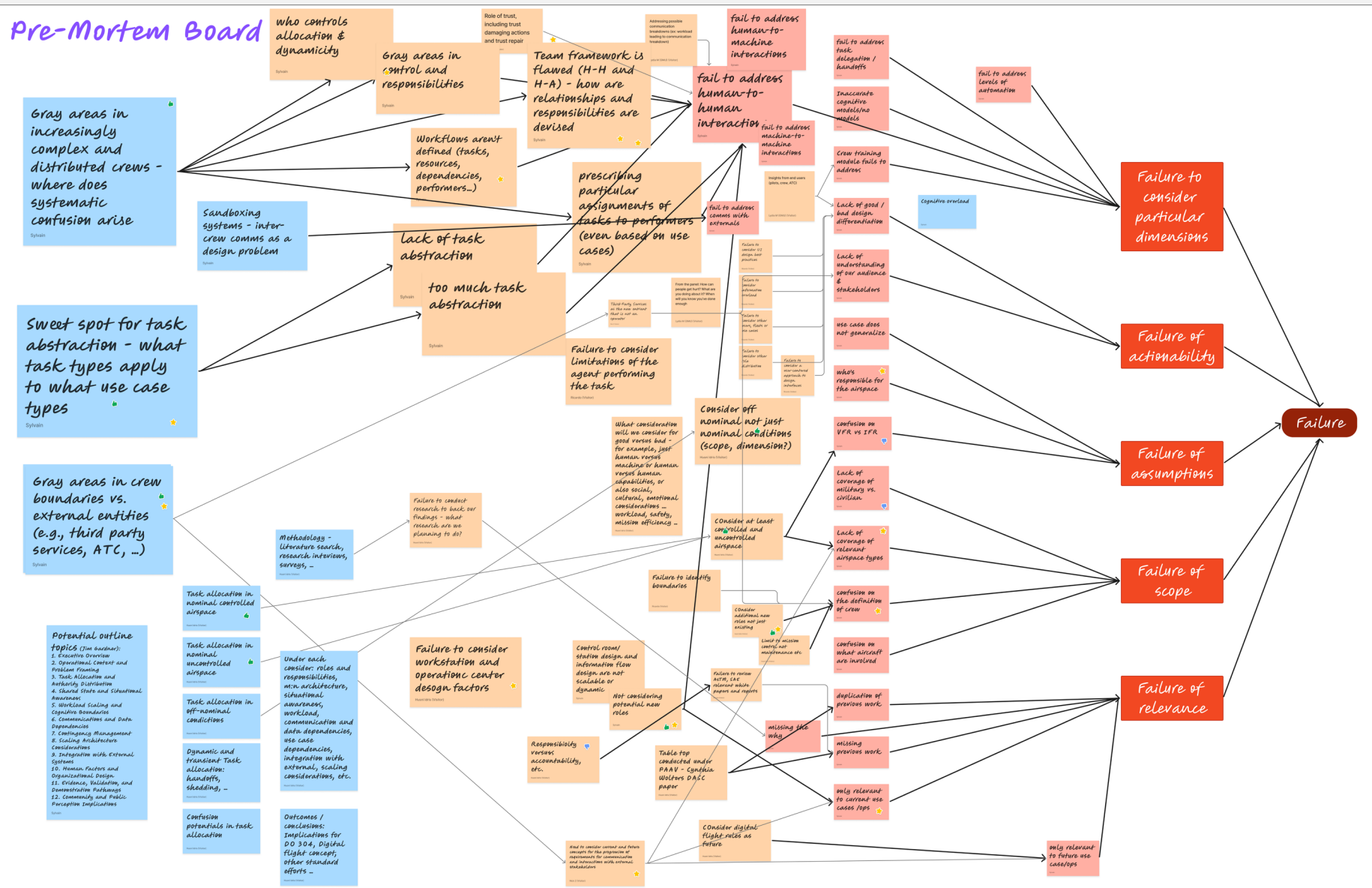


Figure 24. Full board of networked sticky notes detailing potential failure scenarios, antecedents, and gaps/research topics

To refine the results, the group conducted a two-stage dot-voting process. First, participants reviewed each element on the Figma board and indicated agreement or disagreement with how it had been categorized. When participants disagreed with the consensus placement of an item, they explained their reasoning through discussion with the group. This step helped clarify definitions and ensure that the emerging structure reflected a shared understanding. Second, participants used star votes to highlight the topics they considered most important for the white paper. Voting remained open overnight to allow additional reflection before the next session.

The third session was led by Dr. Husni Idris of NASA and shifted the focus toward defining the intended impact of the white paper and building its structure. Participants collaboratively drafted an impact statement describing the outcomes the work should deliver to the aviation community. During this session, the group also refined the terminology guiding the effort. The original phrase “crew design” was expanded to “crew design and management” to reflect the broader operational considerations associated with coordinating distributed teams responsible for multiple aircraft. The group then developed a preliminary outline for the white paper (Figure 25, top), identifying ten main sections and several key subsections. The discussion also addressed the research methods that will support the analysis over the coming months. One important decision was to organize the discussion of crew principles around progressively more complex operational contexts. The analysis will begin with nominal operations in controlled airspace and expand to uncontrolled environments, off-nominal conditions, dynamic states, and situations involving ambiguity or confusion. Participants also identified the need for a dashboard that tracks research progress and highlights areas where additional data or analysis will be required.

The final session, co-led by Mr. Gorospe and Dr. Idris, focused on finalizing the main artifacts produced during the workshop. The agreed impact statement (above) emphasizes the creation of stakeholder consensus across industry, academia, and government in three areas, i.e., identifying (1) critical principles and best practices for scalable crew design and management; (2) enabling capabilities required to support routine autonomous multi-aircraft operations, such as increased use of digital machine-to-machine communication in place of human voice communication; and (3) gaps in standards and policy, along with the research and testing needed to address them. Participants also finalized the white paper outline (Figure 25, bottom).

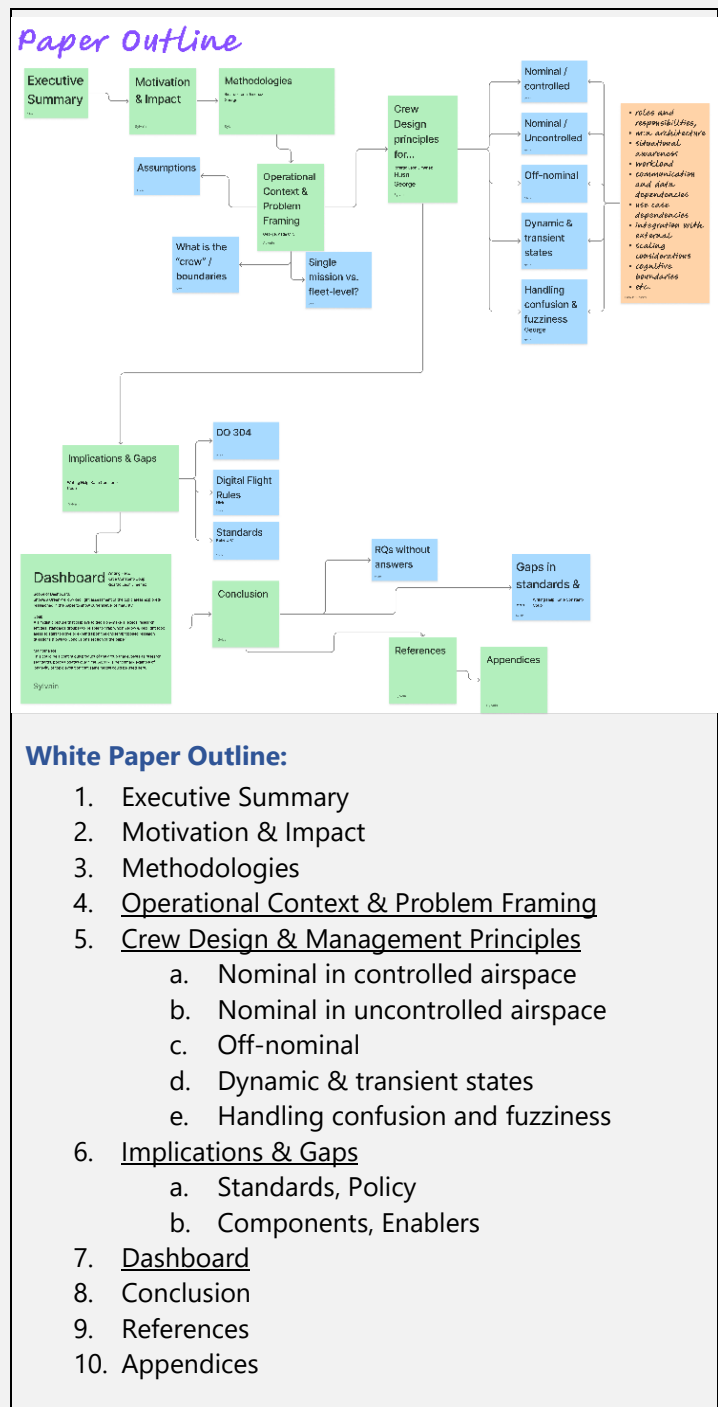


Figure 25. Conceptual (top) and final (bottom) outline for the Scalable Remote Crew Design Considerations for Multi-Aircraft Operations and OEMs white paper

Finally, the group agreed on a detailed writing plan. Work will proceed through biweekly check-ins beginning in March 2026. Early efforts will focus on author assignments, shared terminology, and drafting the early contextual sections. Section outlines and research completion are planned for April, followed by a first full draft in May. Cross-section review will take place in June, with revisions continuing through July and August. A progress report will be shared during a working group event, followed by independent review and final revisions before submission to NASA in September.

The four-session workshop established a strong foundation for the subgroup's work. Participants clarified the scope of the effort, identified key research gaps, defined the impact the white paper should achieve, and created a structured plan for producing it. The next phase will focus on drafting the early sections, developing a shared vocabulary for the field, and conducting targeted research on the prioritized topics identified during the pre-mortem exercise. Through continued collaboration and regular progress reviews, the subgroup aims to deliver a consensus document that supports NASA ATMS efforts to safely scale autonomous operations in the NAS.

System of Systems Design for Multi-Aircraft Operational Integration in Non-Segregated Airspace

Srikanth Gururajan (Champion) | St. Louis Univ,
Mark Shikerman (Champion) | Wisk
Stephanie Fussell (Moderator) | Aptima

Dr. Srikanth Gururajan represented the group leadership in place of Mr. Mark Shikerman, who was unable to attend. The subgroup is still in the early stages of its work, having met only a few times prior to the Working Group meeting. Many participants in the in-person breakout sessions were new to the group.

Impact Statement: Develop a white paper that explores an efficient path from the current system of systems to accommodate normalized multi-aircraft operations in non-segregated airspace to provide a "big picture" framework of considerations to the aviation community interested in advancing RAM-AO by exploring gaps through three use cases.

Day 1. Day 1 began with introductions, followed by Dr. Srikanth Gururajan outlining the overarching goal of the sessions: to create a white paper presenting a framework describing systems of systems (SoS) relevant to multi-aircraft operations. The white paper would feature use cases to illustrate how the SoS evolve and interact as operational considerations change. The group reviewed NASA ATMS directives and research objectives to align their plan of action, and Dr. Gururajan presented a timeline for producing the white paper. A preliminary "seed" framework, including some SoS examples and use cases, was introduced to initiate discussion. The session concluded with a review of breakout session goals: agreement on the objective and audience, identification of SoS and use cases, discussion of the framework's structure, outlining the white paper, and commitment to writing assignments.

The main activity on Day 1 involved silent generation of potential SoS to include in the framework. Some participants used a dedicated Figma board while others took notes manually. The group then discussed their inputs, leading to conversations about common themes, the placement of regulations (e.g., FAR Part 108) and higher-level requirements within the framework, and clustering related ideas. Integration into non-segregated airspace was emphasized as a critical consideration. The session ended with consensus that the suggestions should be broadly categorized—a task assigned to Dr. Stephanie Fussell. This resulted in 11 thematic clusters, including operations, safety, aircraft/vehicle, and communications, shown in Figure 26.

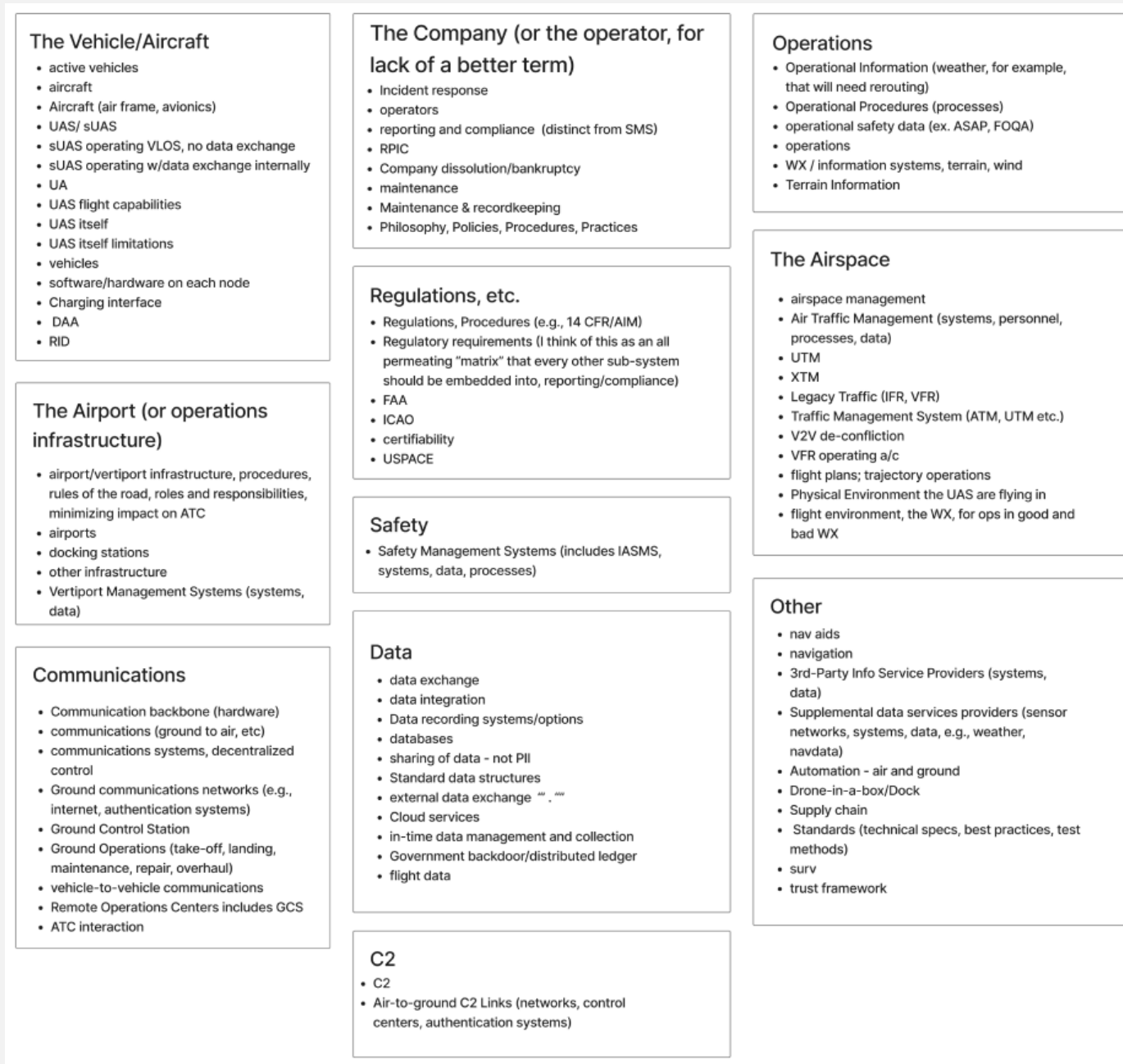


Figure 26. Broad categories of systems of systems relevant to normalized multi-aircraft operations in non-segregated airspace

Day 2. Day 2 focused on discussions regarding the audience, scope, and final product. The group reviewed the efforts under Part 108 for BVLOS operations as well as the work of the sUAS subgroup and noted that industry has largely driven conversations within existing regulations and limitations. This was identified as a potential concern, emphasizing that safe operations must be prioritized independently of profit motives. The discussion also clarified the meaning of non-segregated airspace, providing examples such as airspace with or without ATC and constraints below 400 feet. The group considered how operations might differ in various contexts, such as urban environments with specific right-of-way rules, and how the introduction of Part 108 would influence future developments. A shared mindset emerged around adding value alongside BVLOS operations under Part 108.

Regarding the audience, the subgroup distinguished between stakeholders and curious individuals who might read the white paper and use the framework. To maximize impact, the group agreed to focus on higher-level SoS with big-picture takeaways that support safe operations in non-segregated airspace. They also discussed how management and operations would shift when aircraft transition from segregated to non-segregated airspace, noting that the prominence of certain SoS may vary depending on immediate operational needs. The envisioned final product is a resource enabling users with specific use cases to understand relevant SoS and recognize commonalities and differences across use cases. The framework will feature established SoS while allowing room for growth as routine autonomous multi-aircraft operations evolve. Although safety, risk assessment, and other frameworks may help describe SoS interactions, the goal of the white paper is not to prescribe operational procedures. Instead, it aims to bridge the knowledge gap created by the breadth of information in the FARs and AIM, effectively codifying considerations and SoS necessary for successful normalized multi-aircraft operations in non-segregated airspace.

Day 3. On Day 3, the group returned to SoS discussions for inclusion in the white paper. Brainstorming yielded a bucket of systems comprising 14 categories (Figure 27, top), which were consolidated into six higher-level SoS essential for enabling multi-aircraft operations (Figure 27, bottom). Three SoS—SMS, security (particularly regarding data transmission), and current regulations—were identified as critical but potentially requiring consideration at an even higher level or within a similar architectural tier, given their interactions with lower-level SoS.

The group explored the transition from single to multi-aircraft operations, emphasizing the need to consider not only current operations but also how future autonomous multi-aircraft environments may evolve. The path forward is broad and influenced by organizations such as NASA, the FAA, and industry stakeholders: all shaping the operational environment and airspace in which remote operators function. The group acknowledged that historical operations continue to influence the current and future NAS and thus normalized multi-aircraft operations in non-segregated airspace. It was also noted that the sUAS subgroup is addressing BVLOS considerations, necessitating coordination to avoid overlap.

Regarding the framework's structure, Dr. Gururajan initially proposed a tiered visualization (Figure 28), which evolved in discussion toward a more dynamic matrix concept. The subgroup considered how the white paper and framework could address the "connective tissues" that span and interact across SoS boundaries.

The tier concept—still requiring further definition—would encompass SoS that cannot be overlooked for a given use case. Safe multi-aircraft operations require multiple interacting SoS, which may scale depending on technology and operational context. The tiers could represent levels of interaction or the impact of adding/losing a system or be organized by safety criticality. The specific tier structure remains undecided (to be addressed in future meetings). The scope was defined to help individuals with specific use cases consider different SoS and their interconnections to enable their operations. Although the white paper may speculate on future evolution, its primary focus will be on operating multiple aircraft within the current NAS.

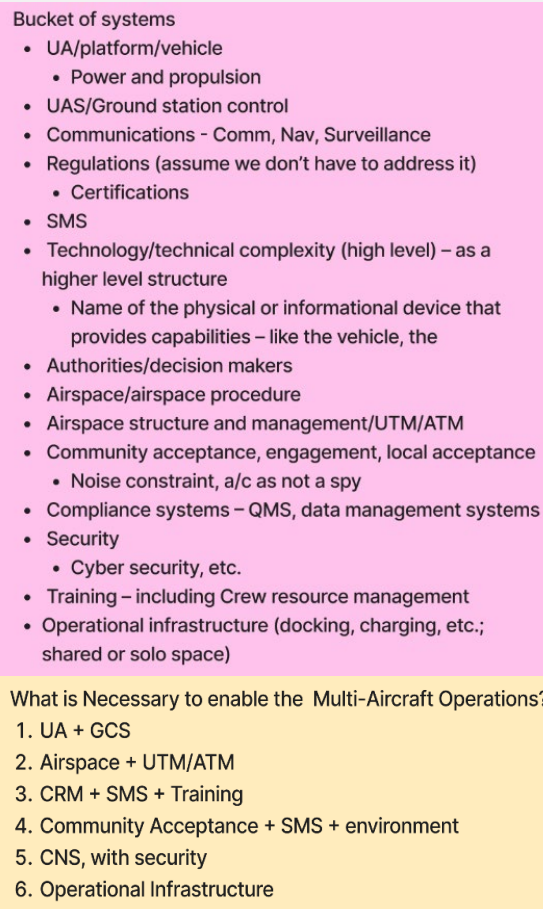


Figure 27. Broad "bucket of systems," based on Day 1 clustering (top) and consolidated list of SoS (bottom)

Having established the audience, identified essential SoS, and agreed on the scope, the subgroup discussed use cases. An initial broad list was narrowed by removing items that overlapped with other subgroups' work. The final use cases were selected based on operational context, including takeoff and landing environments (e.g., airport type and usage), movement through airspace (e.g., point-to-point or airport operations), airspace systems in place, priority (e.g., emergency transport), and third-party service utilization. The agreed-upon use cases are cargo/package delivery, emergency services, and air taxi operations.

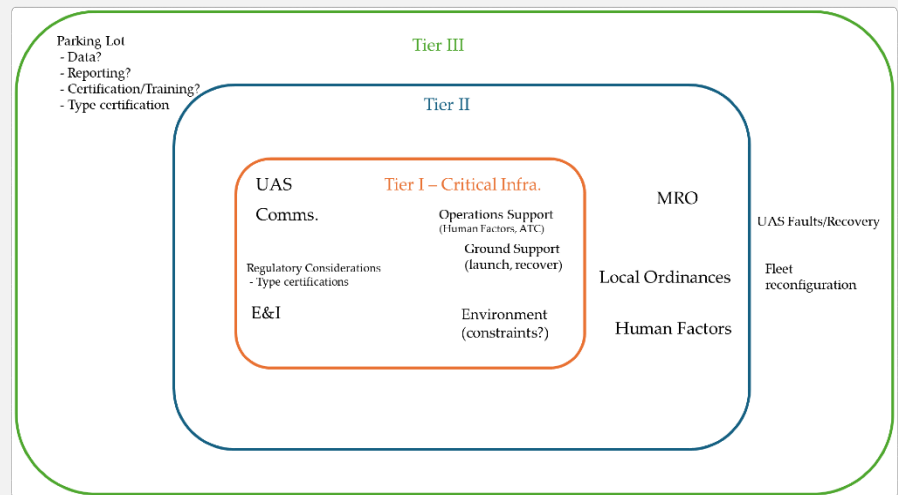


Figure 28. A visual created by Dr. Gururajan to seed conversation on how SoS could shift for different use cases

The breakout sessions concluded with creation of the white paper outline (at right) and assigning writing sections. The group agreed that these would remain flexible to accommodate input from subgroup members unable to attend in person. Although the paper will focus on SoS considerations as of 2026, it will also address how the framework, operational context, and considerations might evolve with advancing technology and changing airspace (e.g., noisy UAS may become quieter in the future, potentially altering their operational environments).

Finally, the subgroup agreed on the following next steps: (1) establish meeting cadence, (2) convene with other subgroups, (3) debrief to larger subgroup, (4) identify additional systems, (5) establish visualization of the framework, and (6) have assigned authors outline sections (by March 19), start writing, and present to the subgroup at the next online meeting.

Dr. Gururajan debriefed the Working Group attendees, highlighting the subgroup's key accomplishments and next steps. He described the subgroup's role as acting as a "glue" that connects various efforts into a cohesive whole. To ensure that the white paper comprehensively addresses the SoS needed for normalized multi-aircraft operations in non-segregated airspace, Dr. Gururajan will arrange meetings with other subgroups.

In summary, the subgroup made significant progress in defining the scope, audience, and essential systems of systems for multi-aircraft operations in non-segregated airspace. With a clear framework and targeted use cases established, the group is well-positioned to develop a comprehensive white paper that will guide safe and effective integration of autonomous aircraft. Continued collaboration with other subgroups and stakeholders will be key to ensuring that the framework remains relevant and impactful as the operational environment evolves.

White Paper Outline:

- Executive Summary
- Introduction
- The System of System Framework
- Case Studies
 - a. Cargo/Package Delivery
 - b. Emergency Services
 - c. Air Taxi Operations
- Conclusion
- AI Statement
- Acknowledgments
- References
- (Appendices)

Assurance, Verification, & Validation (AV&V)

Adrian Agogino (Champion) | NASA
Samantha Emerson (Moderator) | Aptima

Impact Statement: Develop a position paper for the architects of the future airspace (e.g., regulators, relevant government agencies, OEMs) that identifies assurance, verification, and validation gaps for the safe integration of increasingly autonomous airspace operations and aircraft systems in an m:N paradigm.

Autonomous multi-aircraft operations are no longer in the distant future, but are a fast-approaching reality that is drastically changing both the character of the airspace and the complexity of the aircraft within it. This shift, however, requires robust verification and validation (V&V) procedures and tools to ensure the safety and predictability of the autonomy that enables it. Designing V&V for autonomous capabilities that are still in development poses a significant challenge, which is compounded by a persistent perception that V&V activities should be considered only after a system has been developed, rather than during the conceptualization and inception of that system. Despite this view, it is vital to treat V&V as a foundational element of the design process. Integrating these processes during the inception phase allows for identification and mitigation of problems at the requirements level—ensuring that they are precise, correct, and non-conflicting—before transitioning to costly, complex designs. Catching errors early prevents them from propagating down to the system level, ultimately creating a more resilient architecture for autonomous flight. The primary goal of this subgroup is to convince all relevant stakeholders that V&V and assurance need to be considered when conception and design of the system begin, as well as throughout its life cycle, rather than after the fact, especially in safety-critical and burgeoning domains such as autonomous, multi-aircraft operations.

Perhaps due in part to this “V&V-last” perception, the breakout sessions for the subgroup were predominantly attended by members of NASA’s Intelligent Systems Division, as well as by one academic. Two additional factors conspired against broader breakout attendance: (1) breakout sessions for all subgroups were held concurrently meaning that topics were competing for attendees’ attention and (2) V&V processes and tools are frequently perceived as esoteric or inaccessible. When presented with a choice between subgroups, some of the other topics may have seemed more approachable. Despite this, the RAM-AO Working Group members do acknowledge the key role of V&V as an enabling factor. During the subgroup’s inception at the July 2025 Working Group meeting, V&V was widely agreed upon to be one of the biggest challenges that the RAM-AO group should tackle. Further, the subgroup’s virtual meeting the preceding week (when not competing with other subgroups) was well attended and widely representative of the interdisciplinarity seen in the fuller RAM-AO Working Group’s membership.

With the perceived “V&V-last” impenetrability in mind, the subgroup decided to broaden its scope by integrating the concept of “assurance” into its purview, rebranding from the *m:N V&V* subgroup to the *Assurance, Verification, and Validation (AV&V)* subgroup.

Subgroup member Dr. Ganesh Pai, NASA Ames Research Center (Figure 29) defined “assurance” as being concerned with providing justified confidence that a system or service can be relied upon and that it meets the safety intent of the applicable regulations. “Validation and verification” activities were defined as important sources of evidence that system requirements meet stakeholders’ intent and that system implementation meets the validated requirements. Thus, rather than focusing on specific techniques for V&V, the subgroup is interested in exploring the fuller system involved in multi-aircraft operations and where assurance is required. Critically, this requires integration of AV&V early in the concept and design process. By identifying them at the outset, requirements can be propagated through subsequent levels of development—even through deployment and retirement—ensuring that safety and performance are integral to the system throughout its entire life cycle.

Automation is at the heart of the issue for AV&V specifically applied to multi-aircraft operations. Scaling the concept and operations from a human operator controlling a single aircraft to multiple aircraft is shifting the role of the human from pilot to more of a supervisory role. Automation is helping to bridge the gap where humans may no longer be

able to perform the tasks safely. In multi-aircraft operations, these distributed points of automation—whether on board the aircraft, remotely broadcast from a ground station, or coordinated across shared airspace—operations are the primary focus of the AV&V subgroup. The immediate goal of the position paper will be to identify the AV&V gaps in m:N operations. However, the longer term goal of this gap analysis is to contribute to the eventual development of a system-level framework that regulators (or third-party providers) can use as a reference to provide a level of rigor and confidence that the automation replacing or augmenting human performance is at least maintaining, if not exceeding, current levels of safety.

Although automation is the focus, humans are still deeply ingrained within m:N operations. The ideal state for multi-aircraft operations would be to have fully autonomous aircraft without the need for human intervention. This end state, however, may be untenable in the immediate future. A human must be in the loop to some extent, e.g., for edge cases in which automation and autonomy-enabling technologies may not have been designed and for which human intervention is necessary to maintain operational safety. Thus, it is important to ensure that the human is calibrating trust appropriately.



Figure 29. Dr. Ganesh Pai describing the concept of “assurance”

Dr. Meredith Carroll (previewing her upcoming talk on the second day of the meeting) shared with the group that to build trust, autonomous systems must (1) act as they are designed to act, (2) be used appropriately by the operator, and (3) react the way that the operator thinks it should (concepts tightly coupled with the intent of the V&V process). Without all three, trust breaks down. To balance these three aspects to appropriately calibrate trust in the system, it is necessary to (1) build explainability into the model, e.g., by identifying the parameters under which a model performs well versus sub-optimally and (2) optimize the user interface to provide the “right” amount and type of information for the operator to vet the quality of the output. The latter may be complicated because “right” likely looks different across various operations and scenarios and operator preferences vary from wanting deep insight to “just the answer.” Thus, although the focus of AV&V will be on assurance of the automation aspects, the ways in which humans interact with and trust these capabilities cannot be ignored in the overall concept.

The AV&V group ended their session by deciding that they wanted to develop a position paper for the architects of the future airspace (e.g., regulators, relevant government agencies, OEMs) that identifies assurance, verification, and validation gaps that need to be filled for the safe integration of increasingly autonomous airspace operations and aircraft systems in an m:N paradigm. However, to achieve this end, they will need two things from the rest of the RAM-AO Working Group: (1) use cases and (2) domain and technical experts.

Because the majority of the AV&V breakout attendees were new to the domain of multi-aircraft operations, they decided to spend the second of the four breakout sessions sitting in on other subgroups to better understand the various use cases that the other groups were tackling. As an initial starting place, the AV&V subgroup relied heavily on a vignette borrowed from a 2026 white paper by Skygrid and Wisk entitled [Enabling Scalable Urban Air Mobility Through Automated Flight Rules](#). This paper includes a proposed conflict management framework for increasingly autonomous operations in low-altitude airspace (see upper right quadrant of Figure 31). In this vignette, as operations move in time from the flight planning stage to the seconds before a potential conflict, greater amounts of the decision-making process become automated, enabling greater levels of aircraft autonomy. However, this is just one CONOPS and to make forward progress on the position paper, the AV&V subgroup would like to leverage the use cases being developed by the subgroups as well as the real-life use cases of the OEMs in the Working Group to identify the relevant points of automation and potential gaps. Further, the subgroup needs greater domain and technical expertise

from the subject matter experts in the Working Group on ATMS, regulatory bodies, and the individuals responsible for developing the use cases to ensure that they are asking the right questions and looking at the right problems.



Figure 30. Mr. Adrian Agogino debriefing AV&V subgroup discussion

The debrief was led by Mr. Adrian Agogino, NASA (Figure 30), who used the quad chart in Figure 31 to help summarize the sessions and clarify future needs.

Ultimately, viewing assurance and AV&V together is a commitment to viewing safety not as a final hurdle but as a foundational element for the m:N paradigm. The subgroup’s shift toward a holistic, system-level perspective will ensure that autonomous capabilities are not treated as isolated components to be checked at the end of development but instead verified and validated as integrated elements of a resilient system through a continuous life-cycle-based assurance process. By integrating the diverse use cases and deep domain expertise of the broader RAM-AO Working Group, the

AV&V subgroup aims to transform AV&V considerations into a collaborative framework for justified trust. Success in drafting the position paper depends on this cross-pollination, ensuring that the future of autonomous flight is assurance-centric.

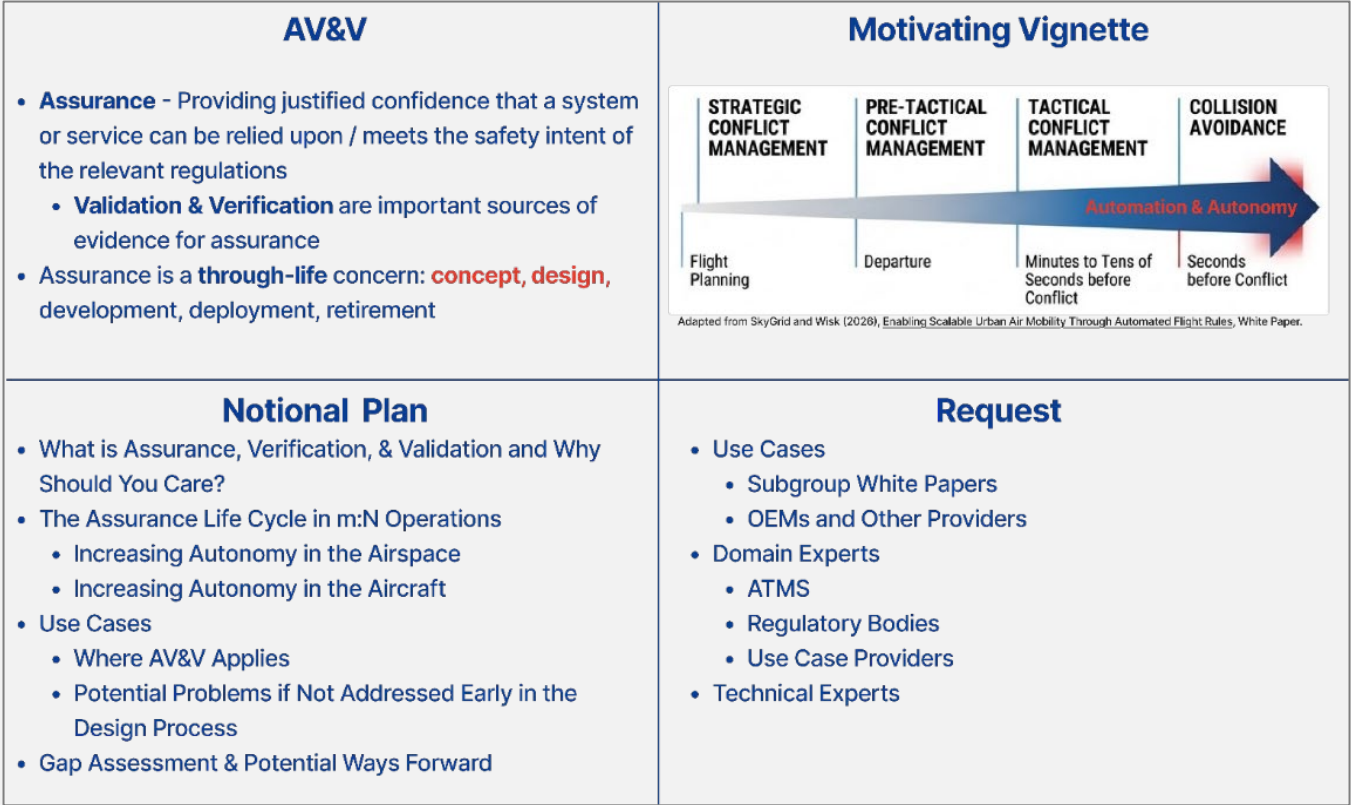


Figure 31. Quad chart used by the AV&V subgroup during the debrief for the breakout sessions (top right quadrant created with Gemini 3 Flash)

Tours

Three tours were offered to the RAM-AO Working Group during this bi-annual meeting. Participants had the opportunity to participate in two onsite visits at NASA Ames Research Center—at the Human-Autonomy Teaming (HAT) Laboratory and the Airspace Operations Laboratory (AOL)—and one off-campus tour of Zipline’s UAS delivery operations in South San Francisco. All tours were held at maximum capacity and participants shared their appreciation for our NASA and Zipline hosts.



NASA Ames Research Center Tours

Airspace Operations Laboratory (AOL)

Jeffrey Homola | NASA

The participants visited the NASA Airspace Operations Laboratory (AOL), where (1) research focuses on integrating new aviation technologies into the NAS and (2) studies on how emerging vehicle types, including UAS and AAM vehicles, can operate safely alongside traditional aviation traffic are conducted.

Mr. Jeffrey Homola (Figure 32, with help from Ms. Latha Balijepalle) described the lab's research on the interaction between human operators, automated systems, and the broader airspace environment, noting that much of the work examines how automation can support air traffic management while maintaining the high safety standards required in aviation operations.

In the AOL (Figure 33), simulation studies are conducted that evaluate how new operational concepts may affect air traffic controllers and other system users. Researchers examine topics such as traffic sequencing, automated decision-support tools, and the integration of unmanned aircraft into existing ATC workflows. Another area of focus is the development of systems that support BVLOS operations. NASA researchers are working with industry partners and regulatory stakeholders to evaluate how UAS and other autonomous aircraft can operate safely, at larger scales, and in more complex airspace environments. The laboratory also supports research into high-altitude platforms and emerging aviation technologies that may operate for extended durations above conventional commercial air traffic. These platforms could enable new communications, sensing, and surveillance capabilities while introducing new operational challenges for airspace management.

Through simulation environments and collaborative research efforts, the AOL plays an important role in developing the operational frameworks and technologies needed to support future autonomous aviation systems.

Human-Autonomy Teaming (HAT) Laboratory

Garrett Sadler | NASA

The group also toured the NASA HAT Laboratory, where the focus is on understanding how humans interact with increasingly autonomous aviation systems. The laboratory supports research into supervisory control, multi-aircraft operations, and the human factors challenges associated with integrating autonomous systems into complex operational environments.



Figure 32. Mr. Jeffrey Homola providing an overview of the research conducted at the AOL lab



Figure 33. AOL operating stations

The HAT Lab includes human-in-the-loop simulation environments designed to replicate real operational scenarios. During the tour, Dr. Casey Smith and Mr. Garrett Sadler exhibited their simulation setup consisting of a simulation manager station and multiple pilot stations that allow researchers to monitor and analyze operator behavior in controlled experimental conditions (Figure 34).



Figure 34. Dr. Casey Smith (far left) and Mr. Garrett Sadler (far right) describing the simulation stations of the HAT lab

Mr. Jacob Pfeiffer (Figure 35, with help from Mr. Conrad Rorie, Mr. Vern Battiste, Mr. Jeremy Marquis, and Mr. Dominic Wong) discussed how they use these simulations to study how operators respond to disruptions and off-nominal events during multi-aircraft operations. The simulation manager can control a wide range of experimental variables, including the number of aircraft being managed, environmental conditions, and injected disruptions designed to test operator response. Dr. Alisa Braun and Ms. Katie Homer explained that a key area of research in the lab involves measuring human workload and situational awareness during supervisory control tasks. Physiological monitoring techniques, including eye tracking, are used to collect data on operator behavior. Measurements such as pupil dilation and eye movement patterns help researchers understand how operators respond to increasing task complexity and unexpected events.

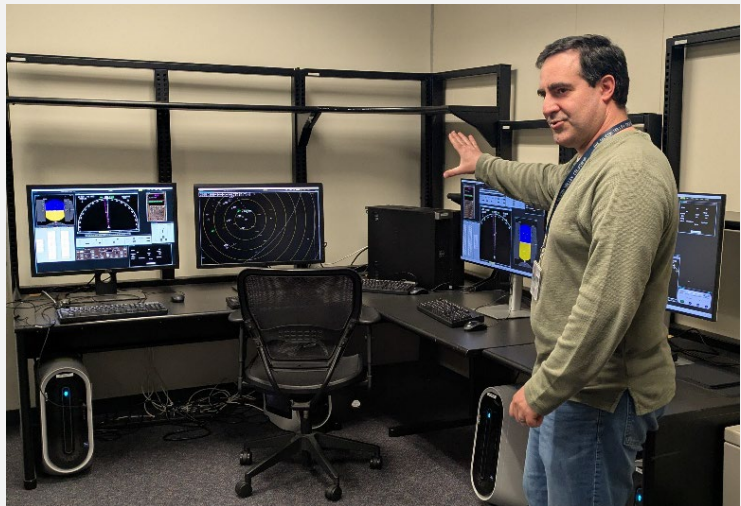


Figure 35. Mr. Jacob Pfeiffer describing research conducted in the HAT lab

The research conducted in the HAT Lab contributes to a better understanding of how operators interact with automated systems and how interface designs and operational concepts can be improved to support safe and scalable multi-aircraft operations.

Zipline Tour

Peter Sachs | Zipline
Gene McGuinness | Zipline
Chris Lyons | Zipline
Arvind Sathe | Zipline
Ava Everett | Zipline

Participants visited Zipline's headquarters (Figure 36) to learn about the company's autonomous UAS delivery system and its operational approach to scaling autonomous logistics. Zipline currently operates the world's largest UAS delivery network, with deployments in North America (United States), Africa (Rwanda, Ghana, Nigeria, Kenya, Côte d'Ivoire), and Asia (Japan). The company focuses primarily on small-package, instant delivery in the US for retail, food, and health partners and continues to provide critical healthcare and community deliveries across global locations.



Figure 36. Mr. Peter Sachs (right) and other panelists describing Zipline's m:N operations

The tour began with a presentation and panel discussion describing Zipline's operational concept and long-term vision for scaling autonomous aerial logistics. Their US delivery platform, known as the P2 system, operates at relatively low altitudes (approximately 300 feet), during delivery operations, and is designed to perform the majority of mission functions autonomously. Aircraft can launch, navigate to delivery locations, and complete deliveries without continuous pilot control.

Zipline described their transition from a human-in-the-loop operating model toward a human-on-the-loop supervisory model, where operators act as fleet supervisors rather than individual pilots. Although operators retain the ability to intervene when necessary, the system is designed to handle most routine operations autonomously. Current operational ratios are approximately one operator supervising 40 aircraft (1:40), with capabilities deployed so that one operator can supervise up to 100 aircraft (1:100).

The company emphasized the importance of human factors considerations in these operations. Monitoring systems are designed to present operators with clear cues and alerts so that interventions can be made when necessary without overwhelming the operator. Human workload and engagement are actively monitored to avoid both overload and under-stimulation during long monitoring periods.

Zipline's airspace management approach relies on a reservation-based strategic deconfliction using UTM services. Aircraft make four-dimensional reservations for airspace along their routes, allowing the system to strategically deconflict operations before flights begin. If conflicts arise, routes can be adjusted. If no alternate route is available, aircraft must wait until the reserved airspace becomes available.

Participants were also shown Zipline's extensive testing and validation infrastructure. The company conducts thousands of test flights per day and operates multiple testing environments, including environmental chambers, wind tunnels, and hardware-in-the-loop laboratories. These facilities allow engineers to validate both hardware and software systems under a wide range of operational conditions before deployment.

The hardware portion of the tour provided insight into the aircraft and delivery mechanisms themselves. The aircraft incorporate redundant propulsion systems and safety features such as parachute recovery systems. Rather than landing at delivery sites, the aircraft deploy a smaller delivery unit, referred to as a "droid," which lowers the package to the ground using a winch system. This approach allows deliveries to be completed without requiring landing infrastructure at the destination.

The docking system used for aircraft launch and recovery was also demonstrated. The docking mechanism stabilizes the aircraft during takeoff and landing operations, reducing turbulence and improving reliability. Extensive testing is conducted to validate docking performance and ensure consistent operation under varying environmental conditions.

Overall, the Zipline tour (Figure 37) provided a practical example of how autonomous aviation systems are currently being deployed in real-world operations and the technical and operational considerations required to scale such systems safely.



Figure 37. Group photo of attendees after the Zipline tour

Conclusions

To conclude the activities for the week, the floor was open to final thoughts, questions, and recommendations from the RAM-AO Working members. Conversation centered on the role of the Working Group with respect to the regulatory, standards, and safety bodies that it intends to impact. Following this open discussion, Ms. Summer Brandt provided closing remarks, thanking the RAM-AO members for the productive week.



Open Conversation

Samantha Emerson (Moderator) | Aptima

Following the subgroup debriefs on the final day, the floor was opened to RAM-AO members to ask questions and provide final thoughts on the event. The main theme that emerged from conversation was the desire to better understand how the Working Group's white papers would impact regulators, standards bodies, and safety organizations; what the role of the Working Group should play relative to these bodies; and how best to interact with them.

The first question from the Working Group members was focused on identifying who the audiences would be for each of the white papers. As part of the subgroup breakout sessions, each group created an impact statement to formalize a shared vision of the intended outcomes for the white paper (see *Subgroup Breakout Sessions* section, above). Many groups chose to include a specific audience in their impact statement, and some, e.g., the Scalable Remote Crew Design subgroup, went as far as to create explicit connections between their white paper and documents, standards, and frameworks that had been discussed in presentations and panels earlier in the meeting. It was agreed that as "homework," the subgroups would continue to refine their definition of who the intended audience of the white paper should be. Ms. Summer Brandt offered the services of the RAM-AO Steering Committee to work with the subgroup Champions to refine the scope and intended audience as they continued to refine the concept of their white papers.

It was suggested, though, that a critical limitation to generating linkages between the RAM-AO white papers and with other regulatory, standards, and safety bodies is that many of the important documents that have been published are inaccessible to the general public, often ranging from \$60 to more than \$1000 for a single document. This paywall poses a significant barrier to the RAM-AO Working Group's ability to effectively collaborate with these organizations. Although the relevant documents may not be available to all, many members of the Working Group belong to organizations (including NASA) that do have subscriptions that enable access, so this barrier might be overcome with better intra-group collaboration in which members with access to these documents disseminate relevant information within and among the subgroups.

Another challenge posed was defining precisely what the Working Group gives to these other organizations. Although the Working Group definitely wants to influence regulatory, standards, and safety bodies, because it is not one of these types of institutions itself, it cannot provide rules, recommendations, or requirements (the "big Rs"). Instead, it was clarified that the Working Group should provide the following:

- Considerations to inform rule-, recommendation-, and requirements-making
- Research questions that need to be explored and answered
- Opportunities for improvements to help mature the overall system

Mr. Andy Thurling concluded the group discussion with an example of how that collaboration might look based on his own subgroup, I&E. The FAA is in the process of publishing the Part 108 rule, which states that operators must set their own m:N ratios. However, one gap that the I&E subgroup has identified is that this regulation does not provide OEMs with guidance on how to set that ratio. To fill that gap, his group is developing a method to help identify what a safe m:N ratio looks like given that OEM's operations. The goal of the I&E group is to hand this method to researchers to validate and then to standards bodies as a potential input to be considered for future standards. In this context, the output of the Working Group is not a recommendation, but rather an input for other groups in a collaborative effort to advance multi-aircraft operations.

Closing Remarks

Summer Brandt | NASA

Ms. Summer Brandt (Figure 38) closed out the meeting by emphatically thanking all of the RAM-AO Working Group attendees. She stated that the goal of the Working Group is to bring stakeholders from government, industry, and academia together in the same room to address challenging problems that will better enable autonomous, multi-aircraft operations. Such advancements would not be possible without the dedicated time and support given to the Working Group by its many members. The subgroups will continue to meet virtually over the next 6 months to continue progress on their white papers with a goal of publication in September 2026 at the end of the fiscal year. She encouraged members to remain engaged in those efforts and welcomed them to attend the next in-person meeting in August 2026. With those final remarks, the meeting was adjourned.



Figure 38. Ms. Summer Brandt thanking RAM-AO Working Group attendees for their participation

Next Steps

The primary focus of the March 2026 meeting of the RAM-AO Working Group was to make progress toward the development of white papers for each of the five subgroups. This goal was achieved with the creation of impact statements for each group as well as the development of refined scopes, outlines, action plans, and other products.

Subgroups will continue their forward progress on the white papers by meeting virtually to continue writing activities, with an ultimate goal of publishing the papers in September 2026.

The next in-person meeting of the full RAM-AO Working Group will be held in August 2026 to report out on the progress of the white papers and seek input from other members of the full Working Group.

Additional information on the RAM-AO Working Group and its subgroups can be found on the RAM-AO website or by reaching out to one of the members below.

<https://nari.arc.nasa.gov/ram-ao/#/>

RAM-AO Working Group

Andy Lacher alacher@gmail.com

Andy Thurling andy.thurling@droneup.com

Summer Brandt summer.l.brandt@nasa.gov

Samantha Emerson semerson@aptima.com





RAM-AO WORKING GROUP

The RAM-AO Working Group (previously known as the *m:N Working Group*) was formed in March 2021 by researchers from NASA in collaboration with partners in industry. A central goal of the Working Group is to bring together a broad collective of interested stakeholders from government, industry, and academia to identify and reduce barriers to routine, autonomous, multi-aircraft operations such as technical, regulatory, safety assurance, and community acceptance factors (e.g., better enabling multiple operators [m] to safely control multiple aircraft [N] simultaneously [m:N operations]). Identified barriers are considered across a variety of multi-aircraft control contexts (e.g., urban/advanced air mobility, delivery, infrastructure inspection, disaster response and recovery, high-altitude pseudo-satellite operations), forming the basis for future research to confront operational, technical, and regulatory gaps. Ultimately, the Working Group will produce technical insights and operational data needed to inform the evolution of future standards and regulatory frameworks for routine, autonomous, multi-aircraft operations.

<https://nari.arc.nasa.gov/ram-ao>

Appendix A: sUAS Breakout Session – Cross-Comparison Tables

<u>Infrastructure Needs</u>	Humanitarian Aid Delivery	Agriculture	Package Delivery
DAA	Mixed airspace, manned and unmanned aircraft	On-board DAA, laser, lidar, computer vision, ADS-B/remote ID	Ground based DAA/RADAR solutions?
Airspace	Implementation of priority of traffic UVRs/TFRs / Mobile TFRs???	UTM Mobile TFRs???	UTM / strategic deconfliction
Weather	UTM / strategic deconfliction Supplemental Data service Urban corridors	Micro climates	Supplemental Data service Urban corridors
Communications	Talking with emergency medical services / first responders / pilots (manned and unmanned) / ATC / ADSPs / public agencies like FEMA / complex crews/ teams Service recipient	Talking to people within the internal operation Other proximal drone operators / crop dusters Payload specialist Service recipient	Distribution center FAM / supervisor Ground operations Meteorologist Restaurant/walmart/supplier Service recipient
Personnel	Operator Payload specialist Medical response teams Public agencies / public safety Other operators ATC	Operator Payload specialist Proximal operators	RPIC/ operator Ground operator Manager/supervisor Contingency team Restaurant/walmart/supplier?
Population Density			

Technologies (future facing to be Part 108 compliant) (What we hope to do)	Humanitarian Aid Delivery	Agriculture	Package Delivery
DAA Is ADSB a solution for DAA? Ground DAA is important too (planes clipping each other).	2X, it might be over more densely populated areas, and more drones/companies delivering	0X, you need it a little bit. You shouldn't hit a plane over a field, but you may have two sprayers over a farm	3X, they have to talk to each other. This will occur over the most densely populated areas
Airspace UTM, Strategic deconfliction	X, UTM	X, UTM	X, UTM
Weather	X	X	X
Communications	X, ATC Will use ADSB in, not ADSB out X, via radio to communicate with other internal operations	X, via radio to communicate with other internal operations; via digital comms in urban areas	X, Will use ADSB in, not ADSB out X, via digital comms
Documentation See which technologies the documents call out	X EASA, JARUS, ASTM	X EASA, JARUS, ASTM	X EASA, JARUS, ASTM
Satellite	3X, you'd need more satellites for major operations	2X	1X
Cybersecurity	X	X	X

<u>How are BVLOS operations performed today?</u>	Humanitarian Aid Delivery this will get split into two: 1) disaster response and 2) routine medical supplies	Agriculture	Package Delivery
Waivers	X	X	X
Part 135	X hospitals delivering to each other	X If a company wants to sell services to a farm	X Zipline is a chartered airline
Part 107 with waiver	depends on the mission	X until 108 is in effect	O
Future Part 108	depends on the mission	X	X
Special Use Airspace	X	O	O
Experimental Aircraft	X	X	X mentioned by Reliable Robotics during Fireside Chat
COAs	X for public agencies	O	O
LAANC	X	O for rural areas, as they are not in a controlled airspace X in urban parks X Ag land next to an airport *population density will affect this one	O Zipline has 135, they don't need a LAANC

<u>Personnel Requirements</u>	Humanitarian Aid Delivery	Agriculture	Package Delivery
Training (short-term, <5 years)	Current standards	Current standards	Constantly evolving
Training (long-term, >5 years)			
Certifications (short-term)			
Certifications (long-term)			
Roles (short-term)	1. Operations supervisor 2. Flight coordinator 3. Ground maintenance 4. Dispatch (human)	1. Operations supervisor 2. Flight coordinator 3. Ground maintenance 4. Payload specialist	1. Operations supervisor 2. Flight coordinator 3. Ground maintenance 4. Dispatch (software, digital)
Roles (long-term)	1. Operations supervisor 2. Flight coordinator 3. Ground maintenance 4. Dispatch (human)	1. Operations supervisor 2. Flight coordinator 3. Ground maintenance 4. Payload specialist	1. Operations supervisor 2. Flight coordinator 3. Ground maintenance 4. Dispatch (software, digital)

Appendix B: Potential Weaknesses in Future Scalable Remote Crew White Paper Identified by the Subgroup

Failure Scenarios	Antecedents/Possible Reasons for Failure	Gaps/Topics
1. Confusion re: definition of crew 2. Confusion re: VFR vs IFR 3. Confusion re: which aircraft are involved 4. Crew training module fails to address 5. Duplication of previous work 6. Fails to address comms with externals 7. Fails to address human-to-human interactions 8. Fails to address human-to-machine interactions 9. Fails to address levels of automation 10. Fails to address machine-to-machine interactions 11. Fails to address task delegation/handoffs 12. Inaccurate cognitive models/no models 13. No coverage of military vs. civilian 14. No coverage of relevant airspace types 15. No good/bad design differentiation 16. No understanding of audience & stakeholders 17. Missing previous work 18. Missing the "why" 19. Only relevant to current use cases/ops 20. Only relevant to future use case/ops 21. Use case does not generalize 22. Does not indicate who is responsible for the airspace	1. Possible communication breakdowns (e.g., caused by workload) not addressed 2. Additional new roles (not just existing) not added 3. Controlled vs. uncontrolled airspace not considered 4. Digital flight rules as future not considered 5. Off-nominal conditions (scope, dimension?) not considered 6. Control room/station and information flow design not scalable or dynamic 7. Failure to conduct re-search to back findings. Research planned? 8. Failure to consider a user-centered approach to design interfaces 9. Failure to consider information overload 10. Failure to consider limitations of agent performing task 11. Failure to consider other role distribution 12. Failure to consider other users, fleets, use cases 13. Failure to consider UI design best practices 14. Failure to consider work-station and operation center design factors 15. Failure to identify boundaries 16. Failure to review ASTM, SAE relevant white papers and reports 17. From panel: Failure to consider how people can be injured, potential mitigations, evidence of success 18. Control and responsibilities unclear 19. Insights from end users (pilots, crew, ATC) not gleaned 20. Lack of task abstraction 21. Limited to mission control, not maintenance etc. 22. Current and future concepts for progression of requirements for communication and interactions with external stake-holders not considered 23. Failure to consider potential new roles 24. Particular assignments of tasks to performers (even based on use cases) not prescribed 25. Responsibility vs. accountability unclear 26. Role of trust, incl. trust damaging actions, trust repair not considered 27. Tabletop conducted under PAAV - Cynthia Wolters DASC paper 28. Flawed team frame-work (H-H and H-A) – unclear how relationships and responsibilities are devised 29. Third-party services as new entrant, i.e., not operator 30. Too much task abstraction 31. Unclear what to consider for good vs. bad (e.g., human vs. machine or human vs. human capabilities), also social, cultural, emotional considerations, workload, safety, mission efficiency 32. Unclear who controls allocation and dynamicity 33. Workflows not defined (tasks, resources, dependencies, performers)	1. Cognitive overload 2. Confusion potential in task allocation 3. Dynamic and transient task allocation: handoffs, shedding. 4. Gray areas in crew boundaries vs. external entities (e.g., third-party services, ATC) 5. Gray areas in increasingly complex and distributed crews - where does systematic confusion arise? 6. Methodology - literature search, research interviews, surveys 7. Outcomes/conclusions: Implications for DO 304, digital flight concept, other standard efforts 8. Sandboxing systems - inter-crew comms as a design prob. 9. Sweet spot for task abstraction - what task types apply to what use case types? 10. Task allocation in nominal controlled airspace 11. Task allocation in nominal uncontrolled airspace 12. Task allocation in off-nominal conditions 13. Under each consider roles and responsibilities, m:N architecture; situational awareness; workload; communication, data, and use case dependencies; integration with external; scaling considerations, etc. 14. Potential outline topics: Executive overview, operational context and problem framing, task allocation and authority distribution, shared state and situational awareness, workload scaling and cognitive boundaries, communications and data dependencies, contingency management, scaling architecture considerations, integration with external systems, human factors and organizational design, evidence, validation, and demonstration pathways, and community and public perception implications.

Appendix C: Attendee List

Name	Organization
Adrian Agogino	NASA
Paul Albuquerque	FAA
Barth Baron	San Jose State University Research Foundation @ NASA Ames
Vernol Battiste	San Jose State University Research Foundation @ NASA Ames
Timothy Beglau	FAA
Tanumaya Bhowmik	American Delivery Drone Company
Dorrit Billman	NASA
Gregory Blaize	Boston Drone School
Summer Brandt	NASA
Alisa Braun	NASA
Nelson Brown	NASA
Sylvain Bruni	Aptima, Inc.
Vishwanath Bulusu	Crown Innovations, Inc.
Gerald Buurma	CCS STEM
Meredith Carroll	Florida Institute of Technology
Michele Cencetti	San Jose State University Research Foundation @ NASA Ames
Bhoomin Chauhan	NASA
Annie Cheng	Wisk Aero
Jordan Cohen	Boeing, SkyGrid
Jordan Coker	Aptima, Inc.
Katie Constant-Coup	Constant Technology & Research Solutions, LLC
Quang Dao	NASA
Joe Darden	Iridium
Anna Dietrich	AMD Consulting for AUVSI
Igor Dolgov	Reliable Robotics
Eric Dong	SB Flight Training
Victoria Dulchinos	NASA
John Dwyer	Boeing
Samantha Emerson	Aptima, Inc.
Shawn Engelland	Aerial Vantage
Greg Feldman	Cavan Solutions
Jolene Feldman	NASA
Pete Frank	Censys Technologies
Stephanie Fussell	Aptima, Inc.
Vimmy G	NASA
Jim Gardner	Mosaic ATM
Max Gariel	Joby
Divya Gopinath	KBR Inc., NASA
George Gorospe	NASA
Mallory Graydon	NASA

Andrew Guion	NASA
Srikanth Gururajan	Saint Louis University
Benjamin Hargis	NASA
Alan Hobbs	San Jose State University Research Foundation @ NASA Ames
Katie Homer	NASA
Daniel Hulse	NASA
Husni Idris	NASA
Devin Jack	Adaptive Aerospace Group
Michael Johnson	Wisk Aero
Liza Josias	Wisk Aero
Ramisha Knight	Aptima, Inc.
Rob Knochenhauer	Protocol UAS
Andy Lacher	Flight Safety Foundation
Joel Lachter	NASA
Paul Lee	NASA
Ricardo Leon Jimenez	Pactica
Rebecca Lurie	Boeing
Samantha Magill	NASA
Anastasia Mavridou	KBR Inc., NASA
Dominic McConnachie	Cavan Solutions
Lydia Melles	George Mason University
Craig Milliard	Joby Aviation
Jon Murakami	FAA
Jonathan Nguyen	NARI
Yuki Niwa	PwC Consulting Japan
Ganesh Pai	KBR Inc., NASA
Bryan Petty	NASA
Mike Politowicz	NASA
Conrad Rorie	NASA
Robert Rose	Reliable Robotics
Garrett Sadler	NASA
Meghan Saephan	NASA
Jordan Sakakeeny	NASA
Scott Scheff	HF Designworks
Christine Serres	MIT Lincoln Laboratory
Shivanjli Sharma	NASA
Brandon Suarez	Reliable Robotics
Hayato Takaoka	ANA HOLDINGS Inc.
Andy Thurling	DroneUp, LLC
Takatoshi Usui	ANAHD
Harrison Wolf	Flight Safety Foundation
Huafeng Yu	US Department of Transportation
Mykyta Zhyla	Wisk Aero

Appendix D: List of Acronyms

Acronym	Meaning
A2X	Anything-to-Anything
AAM	Advanced Air Mobility
AC	Administrative Committee
ACAS XR	Airborne Collision Avoidance System X for UAS
ACAS Xu	Airborne Collision Avoidance System X for Rotorcraft
ADS-B	Automatic Dependent Surveillance-Broadcast
AI	Artificial Intelligence
AIAA	American Institute of Aeronautics and Astronautics
AIM	Aeronautical Information Manual
AOL	Airspace Operations Laboratory
AOSP	Airspace Operations & Safety Program
ASTM	ASTM International, (formerly American Society for Testing and Materials)
ATAR	Air-to-Air Radar
ATC	Air Traffic Control
ATM	Air Traffic Management
ATMS	Air Traffic Management & Safety
ATO	Air Traffic Organization
AUVSI	Association for Uncrewed Vehicle Systems International
AV&V	Assurance, Verification, & Validation
BARS	Basic Aviation Risk Standard
BVLOS	Beyond Visual Line of Sight
CEO	Chief Executive Officer
CERTAIN	City Environment Range Testing for Autonomous Integrated Navigation
CFR	Code of Federal Regulations
COA	Certificates of Authorization
CONOPS	Concept of Operations
CPDLC	Controller-Pilot Data Link Communications
CTI	College Training Initiative
DAA	Detect and Avoid
DoD	Department of Defense
eIPP	eVTOL Integration Pilot Program
eVTOL	Electric Vertical Takeoff and Landing
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FFC	Future Flight Central
FHA	Functional Hazard Assessments
FSDO	Flight Standards District Office
FSF	Flight Safety Foundation

GCS	Ground Control Station
GPS	Global Positioning System
HAT	Human-Autonomy Teaming
I&E	Interventions & Exceptions
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
LiDAR	Light Detection and Ranging
LLM	Large Language Model
m:N	Human (m) to autonomous aircraft (N) ratio
MVSor	Multi-Vehicle Supervisor
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
OEM	Original Equipment Manufacturer
pLEO	Proliferated Low Earth Orbit
Q&A	Question & Answer
RAM-AO	Routine Autonomous Multi-Aircraft
ROAM	Remote Operations for Autonomous Missions
RTCA	RTCA, Inc. (formerly Radio Technical Commission for Aeronautics)
RTK	Real-Time Kinematic
SAE	SAE International (formerly Society of Automotive Engineers)
SC	Special Committee
SORA	Specific Operations Risk Assessment
SoS	System of Systems
STC	Supplemental Type Certificate
STEM	Science, Technology, Engineering, and Mathematics
sUAS	Small Unmanned Aircraft Systems
TC	Technical Challenge
TM	Technical Memorandum
TR	Technical Report
TRACON	Terminal Radar Approach Control
TRANSCEND	Trustworthy Resilient Autonomous ageNts for Safe City transportation in the Evolving New Decade
TSO	Technical Standard Order
UAS	Uncrewed Aerial Systems / Unmanned Aircraft Systems
ULI	University Leadership Initiative
UTM	UAS Traffic Management
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V&V	Validation and Verification
VFR	Visual Flight Rules