m:N Working Group Status

OUTLINE

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Background

Remotely piloted aircraft systems (RPAS) are becoming more and more prevalent in the aerospace operations. This is true in a number of diverse domains; urban air mobility, medical product delivery, infrastructure inspection, high altitude pseudo-satellites, search and rescue, auto cargo and several other applications. One aspect that all of these share in common is the need for scalability to be viable and continue to grow. The Association of Uncrewed Vehicle Systems International (AUVSI) develops an annual economic report. They project that in the first three years of integration more than 70,000 jobs will be created in the US alone, with an economic impact of more than $13.6 billion. This benefit will grow through 2025 when we foresee more than 100,000 jobs created and economic impact of $82 billion. For many of these domains to reach these levels and have the scalability needed, they will require a remote pilot to control multiple aircraft (1:N) or the extension of that multiple pilots controlling multiple aircraft (m:N).

Working group

Because of the need to address barriers for entry for m:N operations, an industry, NASA, DoD & FAA working group was started. The goal is to bring together operators, researchers and regulators interested in m:N. Andy Thurling, NUAIR, and Jay Shively, NASA, co-chair this working group. An executive steering committee was also named: Conrad Rorie, NASA, Igor Dolgov, Joby, and Garrett Sadler, NASA. The initial kick-off meeting was held virtually 25-26 March 2021. Over 100 attendees heard talks from leaders in this community. The talks and recordings of the meeting are archived at this site: https://nari.arc.nasa.gov/node/18490. Since that initial meeting, the overall group has met twice more, culminating in a face-to-face meeting hosted by AUVSI, Xponential 2022.

Status

The working group has made significant progress and has brought the issues of m:N to mainstream. It became clear, early on, in the general sessions that while there are many issues that are common across domains, there are many specific issues as well. Therefore, we decided to break into domain-specific working groups. These are co-chaired by an industry and government representative:

Group	Government	Industry
Large UAS	Conrad Rorie	Brandon Suarez
Urban Air Mobility	Mike Ploitowicz	Igor Dolgov
High Altitude Platform Stations (HAPS)	Jeff Homola	Andy Thurling
Small UAS	Garrett Sadler	Scott Scheff
Swarms	Meghan Chandarana	Phil Walker

These domain specific working groups have held several meetings over the course of the last year. The initial and primary focus has been on identifying barriers to entry to their particular domain. These have been documented and disseminated to the larger community and revised as needed. They are included in Appendix A.

A second effort undertaken was development of a use-case for detect and avoid. Use cases for large UAS, UAM and small autonomous drones were developed and briefed to RTCA SC-228. These use cases are documented in Appendix B.   These use-cases highlighting many of the critical issues were briefed to RTCA SC-228; communication, different ATC sectors, potential loss of party-line information, etc. It was decided that it would be useful to mature the concept by developing a white paper and periodically briefing SC 228 on the progress, with the intent to possibly include in future MOPS.

As mentioned earlier, the domain-specific working groups have all held multiple individual meetings and progressed their efforts. The status reports from the working groups are included in Appendix C.

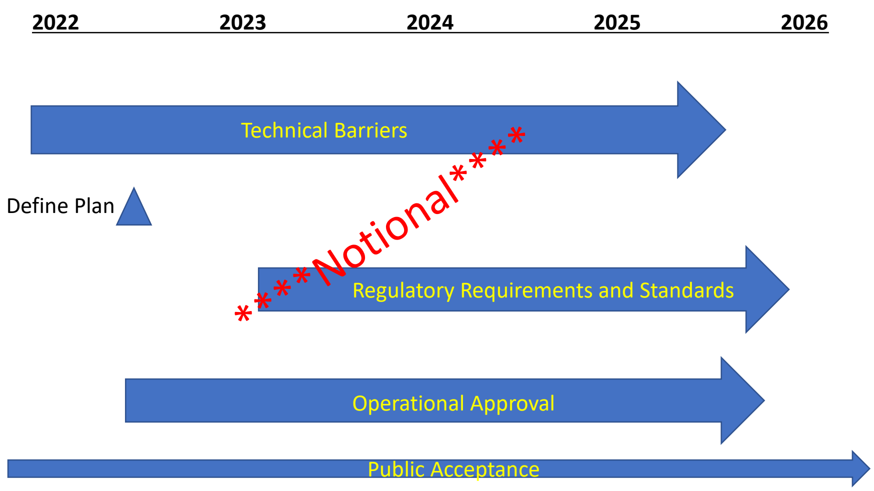
Next Steps

The domain specific working groups will continue to hold periodic meetings. They will continue to refine and update the barriers/issues. The next step in this activity will assess the state of each barrier, potential solutions, research activities and potential gaps in coverage.

Secondly, we will be soliciting authors to help write the DAA working paper. This needs to be planned, staffed and actively developed.

Third, each of the groups will begin working on development of a roadmap to operational approval. This will build on the work done and take it further into actionable content and timelines.   A notional roadmap is shown below. These will be needed for each working group and potentially (depending on the level of detail) for each barrier.

Notional Roadmap



Appendix A. Barriers

Technical Barriers

Type	Barriers
sUAS	1. How do you keep Staff trained on technical systems where taking over is infrequent? 2. Identify what info operator needs 3. Ensure calibrated operator trust 4. Scaling from lower number of vehicles to higher numbers 5. How do you certify autonomous systems?
Large UAS	1. SA for pilot 2. Managing multiple voice channels (w/latency) 3. Contingency management capabilities 4. How to demonstrate pilot's ability to work in m:N framework?
UAM	1. Battery management 2. On demand operators to handle exceptions 3. Crew to vehicle ratio 4. Comms 5. DAA systems (vision, sensor fusion)
HAPS	1. Identify appropriate time horizons relevant to m:N interactions 2. Identifying how SA needs to change in nominal vs contingency situations? What to display? When? To whom to display?
Swarms	1. SA of swarm state due to emergent behavior 2. Supervisory control 3. Impact of environmental and geo. Restrictions 4. Hardware failures

Operational Barriers

Type	Barriers
sUAS	1. What level of automation is needed? 2. How much workload can a single operator handle? How do you staff for spikes in workload?
Large UAS	1. In-flight changes 2. Pilot response time 3. New/increased human error under new paradigm 4. Identify correct level of pilot involvement
UAM	1. Handoff conops 2. Enough funding for infrastructure 3. Integration of ATM/UTM/etc. 4. Corridors
HAPS	1. Standard/Accepted method for demonstrating that an organization's HAPS operations are "safe" and don't degrade safety of NAS 2. Justification of how many vehicles an operator can control
Swarms	1. Define operating environment and procedures 2. Operator roles: across boundaries, when swarm splits/mergers, when failures occur 3. How many operators is enough?

Regulatory Barriers

Type	Barriers
sUAS	1. How do you show that your operations are safe enough and do not degrade the safety of the national airspace?
Large UAS	1. Identify pilot role 2. Certification with less human involvement 3. What data is needed to support regulatory changes?
UAM	1. Liability 2. Certification 3. Noise
HAPS	1. Certification of highly automated systems 2. Identifying what policies need to change
Swarms	1. Certification for non-deterministic behavior 2. Defining airspace restrictions

Public Acceptance Barriers

Type	Barriers
sUAS	1. Is the general public willing to accept sUAS flying over homes, etc.? 2. Public acceptance of automation and trust (could be a generational issue)
Large UAS	-
UAM	1. Generational differences 2. Credibility 3. Noise 4. Emissions
HAPS	1. How to weigh perceived societal value against third-party risk 2. Lack of ability to understand and quantify risk associated with upscaling HAPS operations
Swarms	1. Explanability 2. Reduce fear factor, immediate fear factor

Common Barriers

Type	Barriers	Timeline (near/mid/long term)
Technical	1. Determining and maintaining adequate/appropriate SA, depends on many things: vehicle class, risk posture, LOA, scale, operator role 1. Is the level identified by the breakdown of roles and responsibilities?	

Operational	1. Centralized (or decentralized) management system for task/work/airspace allocation
	2. If you have an operator who is managing multiple assets
	   1. How many can they manage?
	   2. Is it shared? If shared, how to split the responsibilities?
	3. Should there be a distinction in operational barriers between RPAS and fully autonomous (e.g., Loon-like) operations?	

Regulatory	1. Certification: automation, non-determinist system, airframe	
Public Acceptance	1. Transparency, explanability, trust	

Appendix B.

DAA Use Cases for Small Package Delivery m:N Operations

Use Case 1.

Seven small (under 55 lbs) UA traveling along individually differentiated predefined flight paths, are en route to a single landing area and under the authority of a single remote pilot in command (RPIC). The RPIC has no direct flight responsibilities other than monitoring for mission related causes for flight termination or airspace wide emergencies. The RPIC is responsible for the operations and safety of the aircraft. They are flying through class G airspace at an altitude of 300ft (AGL). The flights were all approved by a digital UTM system that assigned these aircraft to their routes. The aircraft are operating BVLOS Cellular network datalink with intermittent signaling at 1 packet per second. GPS (used for positioning of the aircraft and navigation) latency lasting no more than 5 seconds at 5 – 10 minutes intervals occurs regularly along these routes. All the aircraft are equipped with a class 2 DAA system which includes a cooperative (V2V) system along, ADS-B in for strategic deconfliction, a DAA system and on-board sensor. The system does not allow for RPIC input for avoidance, relying exclusively on strategic and tactical deconfliction as well as onboard decision making in the event of off-nominal conditions.

Event 1: Cooperative (ADS-B out) intruder that would lead to loss of well-clear for 3 of the aircraft

Event 2: non-cooperative intruder leading to a loss of well clear for 3 of the aircraft

Event 3: System-wide failure in the GPS network

DAA Use Cases for Auto-Cargo m:N Operations

Use Case 1.

Five UAS regularly scheduled, large cargo aircraft are en route and under the authority of a single remote pilot in command (RPIC). Weather conditions at the airport are CAVOK (Clear and visibility OK). The RPIC is responsible for the operations and safety of the aircraft. They are flying through class A airspace at an altitude of 24000 ft (MSL) along the same route. They have filed and are flying IFR flight plans. Two aircraft are flying in ZZZ sector 1, two in ZZZ sector 4, and one in ZZZ sector 7. The aircraft are operating LOS terrestrial C- band datalink with minimal latency. All of the aircraft are equipped with a class 2 DAA system which includes a TCAS II system along with a DAA system and on-board non-cooperative sensor (in this case a RADAR).

DAA Event 1.
Multiple corrective alerts.

Three of the aircraft sense intruders by ADS-B, which are then validated by active surveillance. These intruders will cause a loss of well clear, if no action is taken, representing multiple corrective Remain Well Clear (RWC) alerts (caution level). The RPIC's displays show the corrective level alerts and a range of maneuvers that each aircraft can execute to avoid a loss of well clear. The RPIC contacts the appropriate ATC for each aircraft and requests a deviation for traffic specific to each maneuver. The first call goes to the controller in sector 1, who approves the requested deviation and asks the remote pilot to report when they want to return to their clearance. The remote pilot acknowledges the clearance and commands a 10 degree right heading change on that UA. The remote pilot then calls the controller in sector 4, asking for an altitude change to avoid traffic. That ATC denies the request, telling the remote pilot that the traffic at 12 o'clock will expedite their descent and be "no factor". The remote pilot then turns their attention to the third RWC corrective alert and calls sector 7 to request a deviation for traffic. Noting other potential conflicts further ahead, ATC amends the clearance of that UA to begin a turn left of course early with new waypoints to join back to the STAR that they have in their filed flight plan. The remote pilot acknowledges the new clearance and uploads the new waypoints to the UA. The DAA system gives a "clear of conflict" message for each aircraft, when appropriate. The RPIC coordinates the return to course maneuver for the first UA with ATC, and then executes.

Issues:
Timeline. Will the RPIC be able to coordinate with (possibly different) ATC and maneuver all the aircraft in time to avoid loss of well clear? Since the remote pilot can only coordinate with one ATC at a time, does possibility of multiple simultaneous RWC alerts mean that the RWC timeline needs to be reexamined? Or, is the likelihood of this "worst case" scenario of 3 simultaneous alerts so small that it doesn't need to impact the requirements and the community is comfortable just handling it in real life, if it ever occurs.
Pilot workload. Will RPIC workload be too high? Are there additional UA automation requirements that would be needed to enable the remote pilot to turn their attention away from the other 4 UA for so long a period of time?
Situation Awareness. Will the RPIC's SA be high enough to correctly choose avoidance maneuvers without impacting other aircraft (their's or other). Will other constraints (e.g. STAR waypoints) make it too difficult for the remote pilot to quickly request a deviation that corresponds to all of the other objectives that ATC has, such as traffic flow management?
Displays/alerts. How do the displays depict the alert status and maneuver options for all the aircraft (and does this scale to 10 or 50)? Does the remote pilot need a pop-up ownship-centric display or can they handle it all from an airspace-centric display?
Crew Interaction: If there are more than 1 remote pilots working as a team, does the presence of a RWC or CA alert impact how the crew interacts? Would one crew member focus all of their attention to resolving the RWC alert while the other crew member(s) continue to monitor the other N-1 aircraft.

(1) Is coop v. non-coop another use case?

DAA Event 2.
RWC evolves into TCAS RA

Three of the aircraft sense intruders by ADS-B , which are then validated by active surveillance. These intruders will cause a loss of well clear, if no action is taken, representing multiple corrective Remain Well Clear (RWC) alerts (caution level). The RPIC's displays show the corrective level alerts and a range of maneuvers that each aircraft can execute to avoid a loss of well clear. The RPIC contacts the appropriate ATC for each aircraft and requests a deviation for traffic specific to each maneuver. The first call goes to the controller in sector 1, who approves the requested deviation and asks the remote pilot to report when they want to return to their clearance. Before the remote pilot can command the maneuver, a resolution advisory (RA) is issued by the TCAS II system on the UA that the pilot had initially determined to be the lowest priority. The RA includes direct guidance consistent with TCAS II;
Aircraft 3: *Descend. Descend.* The UA begins to automatically perform a 1500 fpm descend consistent with TCAS performance assumptions so the remote pilot calls the ATC in sector 7 to notify them that the aircraft is executing a TCAS RA. The RPIC then turns their attention back to the first UA to finish commanding the right turn, which was approved by ATC. While UA 3 continues to perform the TCAS RA, the remote pilot turns their attention to UA 2 to request a flight level change from ATC in sector 4. That ATC denies the request, telling the remote pilot that the traffic at 12 o'clock will expedite their descent and be "no factor". The TCAS system onboard UA 3 issues a "clear of conflict" message, the UA levels out to hold its present altitude, and the remote pilot contacts ATC in sector 7 to coordinate the next move. The RPIC coordinates the return to course maneuver with ATC, and then executes.

Issues:
Latency. Will the RPIC be able to execute maneuvers for all three aircraft to avoid a loss of separation? Will the RPIC be able to coordinate with ATC in an acceptable time frame?
Pilot workload. Will RPIC workload be too high?
Situation Awareness. Will the RPIC's SA be high enough to correctly execute avoidance maneuvers without impacting other aircraft (their's or other).
Displays/alerts. How do the displays depict the alert status and maneuver advisory for all the aircraft (and does this scale to 10 or 50)?

Use Case: DAA Three UAM eVTOL aircraft inbound City Vertiport, RPIC m = 1, Aircraft *N* = 3
Assumptions:

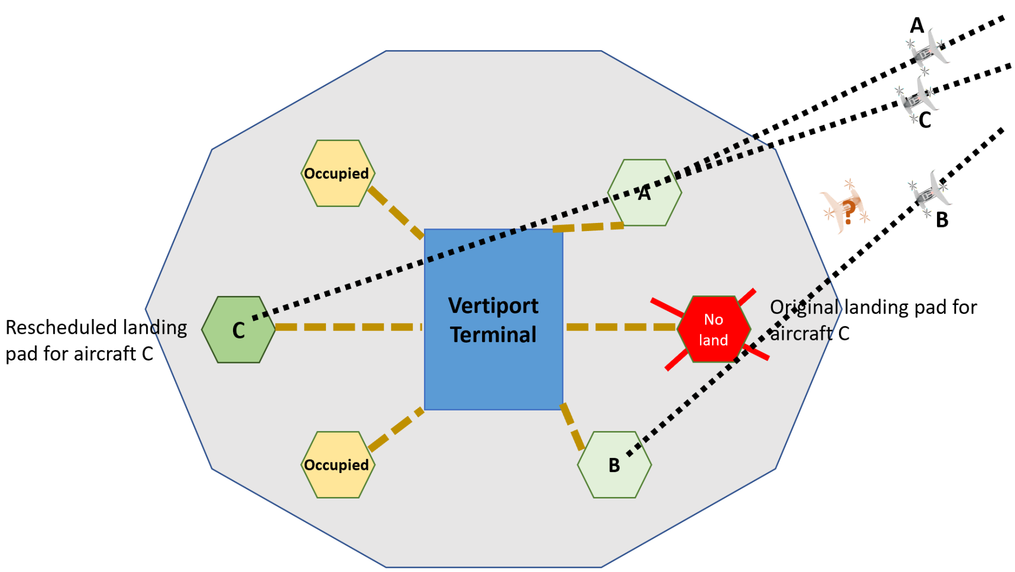
- UAM technologies have matured to meet NASA's TCL Level 4 or higher.
- The pilot is remote
- There is a high level of autonomy on board the aircraft and in the pilot's supervisory control tooling
- The pilot is responsible for supervising multiple aircraft at the same time

Scenario UAM Variation: Remote pilot in command (RPIC) has monitoring control of three company aircraft inbound to a city vertiport (or skyport) with six landing pads. The aircraft are all the same type of eVTOL with the same performance and equipage including TCAS II/ACARS coupled to the auto flight system. The RPIC has the ability to execute direct manual control of each of the aircraft independently if needed. Functionality of CNS is transparent to the Provider of Services to UAM (PSU), and Vertiport Manager through the Vertiport Automation System (VAS) as outlined VAS architecture in NUAIR (2021)[1].

On initial approach to a city vertiport, the PSU notifies the fleet operator and flight crew (RPIC) of a surface issue closing one of available vertiport pads. The RPIC must conduct an inflight replan and maneuver for one of the three aircraft to approach and land at a pad on the other side of the vertiport. Figure 1 depicts the surface scenario and vertiport layout.

During the maneuver the RPIC receives an expected TCAS Traffic Advisory (TA) alert from the closest company (cooperative aircraft) as the flight trajectory momentarily comes within the point of closest approach envelope; seconds later a TCAS Resolution Advisory (RA) is activated by the presence of an uncooperative aircraft (possibly a UAS). The RPIC must execute the following:

- In-flight replan of aircraft Alpha (A) communicate trajectory with ATC and PSU
- Execute new flight trajectory
- Maintain control of the three company aircraft and respond to TCAS TA appropriately (Communicate first).
- Correctly identify TCAS RA alert and execute TCAS RA maneuver to ensure separation between the company aircraft, and the intruder aircraft (Aviate first).
- Finally RPIC must recover and communicate with ATC/PSU to confirm flight inbound flight status, and landing pad clearance.



[1] Northeast UAS Airspace Integration Research Alliance (NUAIR). (2021b). *Vertiport automation software architecture requirements* (Doc. NND15SA83B). NTRS – NASA Technical Reports Server. https://ntrs.nasa.gov/citations/20210019083

m:N HAPS Working Group Status

Andy Thurling (Industry Lead)
Jeffrey Homola (Government Lead)
May 2022

Background

The demand for the use of High-Altitude Platform Systems (HAPS) is projected to increase in the coming years due to their unique capabilities in areas such as communications and remote sensing. Given that there are many different types of vehicles intended to be operated in the stratosphere, there are likewise many different approaches to the control and management of those vehicles. Operations at scale for certain vehicle types and use cases will depend on the ability to manage multiple simultaneous operations as a team rather than a 1:1 mapping of vehicle to operator. This working group is dedicated to understanding the path forward and driving the research in the evolution from 1:1 to m:N operations for HAPS in the nation's airspace.

Members

The HAPS WG is made up of approximately 10 members from Government, Industry, and Academia. The WG members are located across the US and internationally as well.

Stated Goals

Through discussion with working group members, the following goals have been stated early on for pursuit:

- Focus is on High Altitude Platform Systems and the m:N aspects of diverse operations (i.e., not about broader airspace management or its associated systems)
- Identify major technical and Regulatory barriers to m:N operations at scale
- Explore ongoing Operations and Research in the domain as well as completely outside but with lessons to be learned
- Identify potential areas and organizations for collaboration
- Find high-priority gaps to be addressed in potential follow-on research and testing

Meetings

The HAPS WG has held approximately 6 internal meetings since the initial m:N kickoff. The meetings are held remotely and sometimes involve individuals from outside the group to provide insight into particular areas of interest.

Early WG Efforts to Identify Barriers

After initial discussions, an effort was undertaken to get input from the broader group collective on their perceptions regarding key barriers to scalable m:N HAPS operations in the National Airspace System (NAS). Table 1 below reflects the top results from that poll with respect to perceived Operational, Technical, Regulatory, and Public Acceptance barriers.

Table 1. Top responses from poll on barriers to m:N HAPS operations in the NAS

Barriers	
Operational	**Standard/Accepted method for demonstrating that an organization's HAPS operations are "safe" and do not degrade safety of the NAS**
	Justification of how many vehicles a single operator or team of operators can safely control
Technical	**Identifying appropriate time horizons relevant to m:N interactions**
	Identifying how situation awareness needs change in nominal vs contingency situations? What to display? When to display? To whom to display? …
Regulatory	***Certification of highly automated systems***
	Identifying what policies need to change before adopting m:N CONOPS in the civilian airspace
Public Acceptance	How to weigh perceived societal value against third-party risk
	Lack of ability to understand and quantify risk associated with upscaling HAPS operations

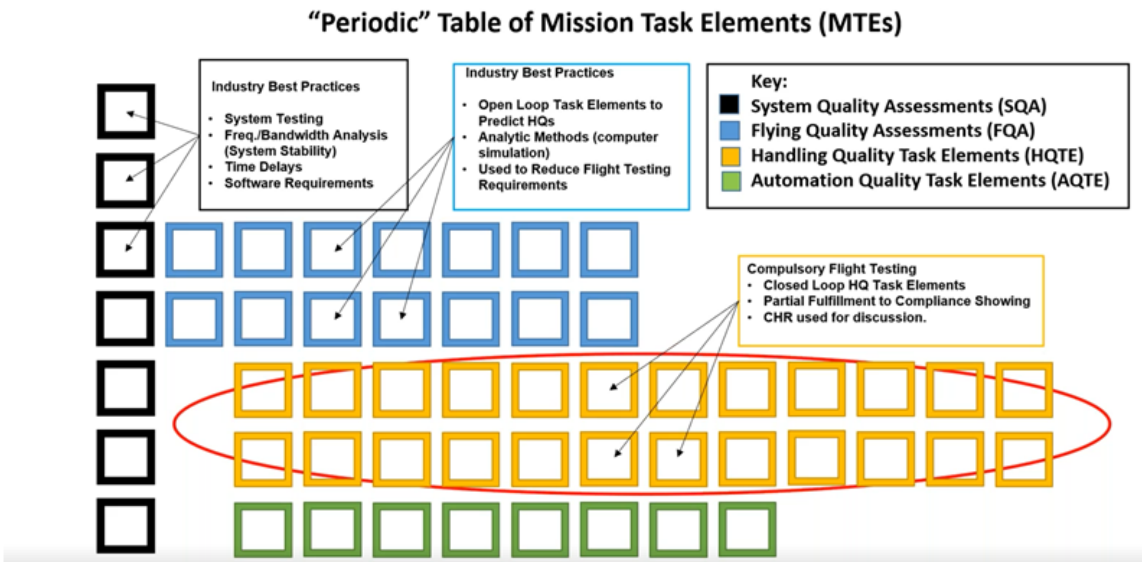
Application of Mission and Organizational Task Element Constructs to HAPS m:N

To begin addressing the identified barriers, the HAPS WG discussed possible approaches and decided to look toward Mission Task Elements (MTEs) and how HAPS operations can be broken down accordingly. The initial guiding problem statement in which to apply MTEs was how a potential m:N HAPS operator can show how their management approach is as “safe” as traditional 1:1 Pilot in Command-to-Aircraft mapping. The MTE approach has worked well in complex rotorcraft certification and takes a holistic approach for demonstrating compliance. Meetings were held with NASA and FAA personnel external to the WG that were experienced in the application of MTEs for guidance and discussion.

From the initial MTE discussions, the follow-on question was whether an approved set of MTEs or Exception Task Elements could be established for the m:N environment and how they could be used as test cases for an operator’s design, training, and organization needed to respond “safely.” Through discussion of these questions, it became evident that the concept and related MTEs needed to include the organization and its response in operating in a HAPS m:N environment. Rather than focusing on individuals within the larger whole, the focus was shifted to look at how the organization as a team collective can adapt to meet specific needs of Exception Task Elements (ETEs) and MTEs. In looking at the problem through an organizational lens, the WG arrived at exploring the concept of Organizational Task Elements (OTEs) that are similar to MTEs and looks at how the “m” humans work to resolve exceptions or accomplish tasks involving the “N” vehicles being managed.

Next Steps

Having settled on the application of MTEs, ETEs, and OTEs as a potential method of addressing key barriers for HAPS m:N operations, the next steps are to continue with the breakdown of relevant task elements for HAPS and the methods and means of compliance. An approach being developed within the FAA and AAM industry to show a more holistic approach to means of compliance is through the establishment of a "Periodic Table" of MTEs (see below for reference).



Future discussions in the HAPS WG will focus on the further breakdown of OTEs, how to incorporate those elements into a periodic table with other task elements (if applicable), and what approach stakeholders can take to conduct the necessary research, testing, and demonstration to move the m:N concept forward for the HAPS industry.
Next HAPS WG meeting scheduled for June 6, 2022.

SWARMS Update

The m:N Swarms Subgroup has met regularly to identify the primary barriers to deploying swarms in real world environments, as well as mitigations to those barriers (and remaining research questions to be solved before implementing those mitigations). We have discussed technical, operational, regulatory, and public acceptance barriers and mitigations, with a primary focus first and foremost on technical barriers.

The primary technical barriers identified include unreliable operation due to the emergent nature of swarm algorithms and behavior, uncertainty between true failure vs. new emergent behavior, and how to handle hardware failures, which will be more numerous with the larger numbers of vehicles inherent in swarms. Operational and regulatory barriers include ambiguity about different roles for swarm control--e.g., are roles spatially distributed over different swarm operating areas, or hierarchically distributed?--how to hand off control between different operators in these roles when the transition criteria are difficult to define due to the distributed nature of swarms, how to quantify the number of operators required to achieve an objective with a swarm, and the difficulty in certifying non-deterministic behaviors for deployment in the national airspace. Finally, public acceptance barriers include reducing or eliminating panic in the public when seeing large, coordinated groups of UASs in public places, and determining the resources required for educating and informing the public in advance of, and during, swarm operations.

The team has already developed general mitigation strategies and to-be-answered research questions for some of these problems, which broadly include strictly defined bounds for swarm behaviors that supersede the control laws on the robots, explainable AI for swarm algorithms, different possible operator hierarchy schemes and protocols for hand-offs, educational programs and online resources or public announcements for swarm operations, and phased introductions of increasingly large numbers and more complex behaviors.

Our future work in the m:N Swarms Subgroup will more concretely define some of these mitigation strategies and research questions and document them in a technical report that can be disseminated to the wider m:N working group, businesses, and researcher institutions in the field. We hope that this report can help guide future research and development.

sUAS Working Group Status

SUMMARY

The sUAS Working Group is a 34 member organization comprised of government, industry, and academia. Note that a complete list of members along with their organization can be found in Appendix A of this document.

The primary goals of the sUAS Working Group is to help identify, discuss, and resolve sUAS barriers under the m:N paradigm.

Barriers discussed include technical, operational, regulatory/policy, and public acceptability.

The sUAS Working Group also works with the FAA, RTCA's special committee on detect and avoid (SC-228), and is helping to support SC-228's Operational Services and Environmental Definition (OSED) documentation. We are currently developing sUAS based use cases which focus on encounter scenarios, traffic displays, DAA alerting and guidance, and ATC interactions for the OSED.

Challenges currently under discussion by working group members:

Technical

- Training
- Informational needs
- Trust in automation
- Scaling from operating one or a few sUAS to managing many
- Certification

Operational

- What levels are automation are needed, and when
- Workload management

Regulatory/Policy

- Safety
- Speed at which policies are created and requirements are made

Public Acceptability

- Acceptance of sUAS flying in civilian airspace
- Public acceptance of automation and trust

Use case topics currently under discussion by working group members:

- Defining requirements for flying in certain environments/airspace
- Definition of well clear
- Are today's sUAS capable enough to meet the needs of our use case
    - Do today's sUAS house the necessary sensors for our use cases? Perhaps consider smaller sensors or a combination of air and ground sensors
    - Understand the flight profiles and capabilities of various sUAS (leveraging our working group members' platforms)

PAST MEETINGS

- June 16, 2021 (kickoff)
  - sUAS group context/definition
  - Identification of barriers
- November 3, 2021
  - Member survey results (survey developed and administered to members to further deep dive on sUAS barriers)
- February 24, 2022
  - Use case generation
  - sUAS performance specifications from our members who build sUAS
- April 26, 2022
  - AUVSI panel discussion with other m:N working groups

UPCOMING MEETINGS

- June 23, 2022 (virtual)
- September 29, 2002 (virtual)