A NEW CONTROL PARADIGM: MULTIPLE AIRCRAFT CONTROLLED BY MULTIPLE OPERATORS

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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). This is a new control paradigm that raises multiple issues in various areas. The issues include regulatory, technical, safety, community acceptance and Human Factors. Human factors issues include displays, pilot workload, pilot situation awareness just to name a few.

This panel brings together researchers, developers and operators that have been working in the area of m:N. They will discuss the need, the issues and some potential solutions.

PARTICIPANT POSITIONS

Garrett Sadler, Human Autonomy Teaming (HAT) research

Since 2019, the NASA and industry partners have been involved in research focused on a novel paradigm for operations of remotely piloted aircraft. This paradigm involves multiple people sharing a fleet of multiple vehicles between them. Referred to as m:N (pronounced “em-to-en”), this configuration describes a ratio where m is the number of operators and N is the number of vehicles. Through force and asset multiplication, the m:N concept seeks to enable a scalable and resilient operation of remotely crewed vehicles. The primary means of obtaining such a robust operation is through allowing a flexible crew of variable size to dynamically attend to the needs of assets in while performing real-time operator workload management. It is in that sense that assets are shared between operators: as needed (such as in events of elevated workload) an operator in an m:N context can “handoff” the responsibility for some amount of assets, $n_h < N$, to be absorbed by the $m - 1$ crew members on staff. At some time later, these n_h assets could be returned to their original owner or they may be further distributed to other crew if called for by the mission. During this panel, I will elaborate on the research activity undertaken by the Human-Autonomy Teaming (HAT) Laboratory at NASA Ames Research Center over the previous three years. The studies conducted by the HAT Lab range from interviews with subject matter experts, a cognitive walkthrough, a task analysis, and two simulation experiments to-date. During experimentation, pilots made use of an advanced Ground Control Station developed by the HAT Lab and industry partners to simulate m:N operations in two large, metropolitan areas of Southern California: Los Angeles and San Diego. Further experimentation planned over the next few years. Results from our research to-date indicates that pilots of a moderately sized fleet of about a dozen remotely crewed aircraft adequately maintained safety performance and situation awareness of their aircraft, even when presented with unexpected situations of heightened workload.

Scott Scheff, Designing for UAS management on the future battlefield, lessons learned for envisioned world military programs

Many of today’s military unmanned aircraft systems (UAS) come complete with sensor suites and are connected to advanced software interfaces managed by teams of flight and payload operators typically working from elaborate ground control stations (GCS). Fast forward to the next decade and there is a concept of an envisioned world battlespace which pits forces against near-peer threats. To help challenge these threats, there is a desire to increase the capabilities of next generation UAS while also reduce the number of operators needed. In fact, in some future scenarios, the idea of the GCS is moved to inside the cockpit where those managing UAS can be closer to the fight for better situational awareness and combat power. To take this to the next level, there is even a desire in some scenarios to have operators performing crucial tasks of today such as piloting or copiloting a manned aircraft while also managing not one, but several UAS on the battlefield. Incorporating UAS management and control in an oftentimes already overburdened cockpit has the potential to overload the end user without the proper automation technologies, interfaces, and training. How do we design for these use cases of the future and what are some of the current lessons learned we can share out?

This presentation will discuss findings from speaking with today's UAS operators and manned aircraft pilots. This presentation will also discuss the lessons learned from human performance modeling and how it can be used to identify areas of high workload for UAS operators as well as evaluate how different technologies and training aids can help reduce workload and fatigue in these complex environments.

Igor Dolgov. Gradually stepping toward m:N control to enable Urban Air Mobility at scale

On-board pilots will be the norm in the domain of Urban Air Mobility (UAM) for the immediate future. Yet, as with UAS, achieving m:N remote control of UAM aircraft enables the business to scale efficiently. Luckily, researchers and practitioners alike will be able to rely on solutions to common challenges posed by m:N remote control across domains (e.g., Smith et al., 2021). So, while this control paradigm is not feasible or practical in this domain yet, it is important to the proliferation of UAM and AAM across the globe.

Progressing from pilot-on-board UAM operations to remotely piloted operations will require new rulemaking and the maturation of numerous technologies that can meet a wide array of challenges. For instance, along with known complexities with ensuring safe remotely-piloted operations, removing the pilot from the cockpit introduces the need to monitor passengers' well-being while on board. Moreover, it will require the development of procedures for on-board emergencies. Passengers will need the ability to communicate with the remote pilot to convey details about in-flight hazards or emergencies that are not automatically detected by the aircraft's sensors. While this requirement presents technological challenges, there are a host of other cultural and procedural hurdles as well. For instance, one can envision communication breaking down between the remote pilot and passengers if they happen to be foreign travelers and do not speak the local language.

While research on m:N control in UAM is truly in its nascence, NASA has led the way in identifying the major challenges our field faces. Holbrook et al. (2020) identified several operational objectives that must be met before m:N becomes a reality, including:

- Enabling aircraft without an onboard pilot to routinely operate in the NAS
- Revising the current regulatory paradigm that requires a pilot for every passenger aircraft
- Achieving an order of magnitude more vehicles than operators
- Enabling an order-of-magnitude increases to airspace system capacity without employing huge numbers of additional air traffic controllers
- Simplified training and certification procedures
- High-levels of autonomy on board the vehicle and in the airline operation center, paired with appropriately facilitated human-autonomy and human-human teaming

Accomplishing each of the above objectives will require programmatic research and technological development. Some of the vital paths to success have already been sketched out and include:

- Advanced simplified vehicle operations (SVO) and remote supervisory operations (RSO) (Holbrook et al.,2020)
  - Traditional SVO will reduce the workload of onboard UAM in the near future (Wing et al., 2020).
  - Advanced SVO will allow for the remote supervisory operation of one or more UAM aircraft (Chiou et al., 2020).
- Advanced airspace management (Holbrook et al.,2020) and digital pilot-controller communications
  - While traditional air traffic technologies and procedures are not scalable to the point of accommodating UAM, the use of corridors initially and, eventually, highly-automated, digital pilot-controller communications can enable UAM operations at scale.
- Effective human-autonomy teaming (HAT) and communication (Demir, McNeese, & Cooke, 2016) and appropriate human-autonomy trust (Chancey, Politowics, & Le Vie, 2021; Chiou et al., 2020)
  - Since automated technologies are imperfect, human operators tend to misuse or underuse them (e.g., Dolgov, 2018). Thus, approaches like Adaptive Calibrate Trust (Chancey, Politowics, & Le Vie, 2021) must be employed to continuously track and augment the relationship between intelligent assistive technologies and their human teammates.
- Appropriate type and degree of system transparency (Kaltenbach & Dolgov, 2017)
  - Human operators must be able to see into and through the system. Specifically, must be presented with the right information at the right time in order to maintain an accurate mental model of the system and have adequate situation awareness.
- Adaptive and adaptable automated aids and decision systems (Kaltenbach, Dolgov, & Trafimow, 2016)
  - The systems we build to support UAM operations in scale will need to be sensitive to human workload and while also retaining the ability for human operators to adjust their level of autonomy.
- Effective human-human communication and teaming (e.g., Cooke et al., 2007)

- There will be a plethora of human actors in the system that must work and communicate with each other seamlessly to ensure safe and efficient UAM operations. Their communication architectures must be seamless.

The aforementioned advances in research and development will also require an unprecedented level of integration among actors in the National Airspace System (NAS). To facilitate this coordination, NASA and the FAA have reached out to NAS stakeholder to develop community-based rules (CBRs). While these efforts are also in their nascency, standards setting organizations like ASTM have begun investigations into these themes.

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Harrison Wolf, Small Autonomous Drones

Scaling drones for viability will require entirely new approaches when it comes to human machine integration. Already, at Zipline, we're operating at a scale of on average 23 drones per operator with the expectation that very soon we'd be able to manage an infinite number of drones per Operator. This requires some unique assumptions when it comes to Human Factors – the belief that systems must be reliable and safe at a vehicular level without operator input, that the system must be reliant up on multiple fail-safe networks, and that the less human interaction with the aircraft flight the better. Zipline has learned a lot operating at national scale in Rwanda and Ghana and we're eager to share those at HFES as part of this panel.

PARTICIPANT BIOGRAPHIES

Jay Shively is a NASA research Psychologist currently leading the Human Autonomy Teaming lab at NASA-Ames. He previously led the Detect and Avoid element NASA's UAS Integration into the NAS. Jay has studied workload for many years and was on the original NASA-TLX development team. Jay's focus has been on automation in unmanned systems for several years including supervisory control of multiple, heterogeneous systems by a single operator. He is the HSI lead for RTCA SC-228 on airspace integration as well as the ICAO Human Factors lead. After graduate study at Purdue University, Jay has been at NASA-Ames (in one capacity or another) for 33 years.

Dr. Dolgov is currently a Human Factors Engineer for Joby Aviation as well as the Program Chair of the Aerospace Systems Technical Group for the Human Factors and Ergonomics Society (HFES). Prior to this role he was the lead Human Factors Engineer for Uber Elevate and a tenured associate professor of Engineering Psychology at New Mexico State University, where he led the Perception, Action, and Cognition, in Mediated, Artificial, and Natural Environments (PACMANe) laboratory.

Scott Scheff is Founder, CEO, and a principal Human Factors Specialist at HF Designworks, Inc., in Boulder, Colorado. With over 20 years' of applied experience, Mr. Scheff has formal training in human factors design, user experience research, user interface design, human computer interaction, and human performance modeling. Mr. Scheff has been involved with technology assessments, workload evaluations, and the development of learning management systems in support of various Army and Navy Future Vertical Lift programs, especially when exploring the challenges of UAS management. Mr. Scheff is also part of several UAS and human performance modeling groups including co-chairing a working group that looks at requirements and challenges of incorporating small UAS (sUAS) into the civilian airspace.

Garrett Sadler is a social scientist and human factors researcher at NASA Ames Research Center. Mr. Sadler's formal training is in mathematics and cultural anthropology and has been involved in interdisciplinary teams of researchers investigating aviation human factors. Mr. Sadler's work has focused on the interaction between human trust and transparent automation/autonomy. Prior to investigating m:N operations, Mr. Sadler made contributions to the UAS Integration into the NAS project, the Reduced Crew Operations project, and fieldwork studying pilot trust in the Automatic Ground Collision Avoidance System (Auto-GCAS) on the F-16 platform.

Harrison Wolf is the Director for Global Aviation with Zipline. Prior to Zipline he led aerospace and drone projects with the World Economic Forum focused on advancing progressive regulations that enable a risk-based approach. Harrison co-founded and continues to teach the Safety Management Systems for Remotely Piloted Aircraft course at the University of Southern California Aviation Safety & Security Program which uses the text book he wrote entitled Drones: Safety Risk Management for the Next Evolution of Flight.