NASA/TM–20250002531

Personnel Selection, Roles, and Training for sUAS

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February 2025

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February 2025

Acknowledgements

In addition to the listed key authors, this paper could not have been developed without the assistance of the entire sUAS working group. sUAS working group members are part of NASA, FAA, DoD, industry, and academia. With a mission to advocate for small unmanned aircraft systems (sUAS) in the national airspace system (NAS) the sUAS working group tackles topics including use cases, requirements, certification, training, and public acceptance. For 2024 the working group came together to develop this white paper titled "Personnel Selection, Roles, and Training for sUAS". The hopes of the paper are to provide government, industry, academia, and the various associated standards committees with information on how best to move forward in terms of best practices for personnel, roles, and training pertaining to sUAS.

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Acronyms and Definitions

1:N ....One Operator supervising several UAS
AAM ....Advanced Air Mobility
ADM ....Aeronautical Decision Making
AFD ....Austin (Virginia) Fire Department
AGL ....above ground level
AI ....Artificial Intelligence
AR...Augmented Reality
ATC ....air traffic control
Au ....Anzen Unmanned
BCF.......................................Big City Fire
BUQ ....Basic UAS Qualifications
BVLOS ....beyond visual line of sight
C2..Command and Control
CALFIRE..............................California Department of Forestry and Fire Protection
CFR.......................................Code of Federal Regulations
CISA ....Cybersecurity and Infrastructure Security Agency
COA ....Certificate of Airworthiness
CONOPS...............................Concept of Operations
CRM ....crew resource management
DAA......................................Detect and Avoid
DFR.......................................Drones as a First Responder
DHS ....Department of Homeland Security
DoD.......................................Department of Defense
DPD ....Denver Police Department
EASA ....European Union Aviation Safety Agency
EOPS....................................Emergency Operations
eVTOL..................................electric vertical takeoff and landing
FAA ....Federal Aviation Administration
FAR.......................................Federal Aviation Regulation
FDNY ....Fire Department of the city of New York
FEMA ....Federal Emergency Management Agency
FLD.......................................flight lead
FSTD.....................................Flight Simulation Training Device
ft ....feet
FTN.......................................federal tracking number
HALO ....High Activity Location Observation
HF ....human factors
IACP ....International Association of Chiefs of Police
IACRA ....integrated airman certification and rating application
IMU.......................................Inertial Measurement Unit
IQ ....intelligence quotient
JARUS ....Joint Authorities for Rulemaking on Unmanned Systems
JFC ....Joint Force Commander
JIT ....Just-in-Time
JMQ ....Joint Mission Qualification
JMTL ....Joint Mission Task List

JUMTS..................................Joint Unmanned Aircraft System Minimum Training Standards
KSAs.....................................knowledge, skills, and abilities
LAANC.................................Low Altitude Authorization and Notification Capability
LAFD....................................Los Angeles Fire Department
lbs..pounds
m:N ....One or a few Operators supervising several (or more) UAS
mph ....miles per hour
NAS ....National Airspace System
NASA ....National Aeronautics and Space Administration
NASA-TXL ....NASA Task Load Index
NIST ....National Institute of Standards and Technology
NOTAM................................Notice to Air Mission
NSP ....National Simulator Program
NYPD ....New York City Police Department
ORM ....Operational Risk Management
PIC ....Pilot-in-Command
PII ....Personally Identifiable Information
QR...Quick Response
RDC ....rapidly deployable camera
RPIC ....Remote Pilot in Command
RTCA....................................Radio Technical Commission for Aeronautics
RTCC....................................Real-Time Crime Center
SA ....situational awareness
SLA.......................................Service Level Agreement
SME ....subject matter expert
SMS ....Safety Management System
SOAR....................................Special Operations Aviation Regiment
SOP ....Standard Operating Procedure
sUAS.....................................Small Unmanned Aircraft System
SWAT ....Special Weapons and Tactics
SWAT ....Special Weapons and Tactics
TECH....................................technician
TESU ....Tactical Enforcement Support Unit
TLX.......................................Task Load Index
UAG......................................Unmanned Aircraft General
UAS ....Unmanned Aircraft System
UAS-CTI...............................UAS-Collegiate Training Initiative
UASC....................................UAS crewmember
UASFCA...............................UAS Flight Crew Skills
UASMCS..............................UAS Mission Crew Skills
UTM ....UAS Traffic Management
VLOS ....visual line of sight
VO...Visual Observer
VR...virtual reality
WOPHA................................Warrant Officer Performance Health Assessment

Personnel Selection, Roles, and Training for sUAS

Scott Scheff[1], Garrett Sadler[2], Meghan Saephan[2], Phillip Walker[3], Chris Schupp[4], Timothy Beglau[5], Wendy Ljungren[6], Robert Owen[7], Vernol Battiste[8], Rese Drucker[9], Brittany Duncan[10], Edwin Sanchez[11], Christine Arboleda[1], and Gita Hodell[2]

1. Introduction

The rapid advancement of Advanced Air Mobility (AAM) technologies, coupled with the growing integration of small Unmanned Aircraft Systems (sUAS) into commercial, defense, and public safety operations, has fundamentally transformed the aviation landscape. These innovations promise significant benefits, including enhanced efficiency, expanded accessibility, and new opportunities for transportation, logistics, and emergency response. However, they also introduce complex challenges, particularly in the areas of personnel selection, training, and role definition.

As automation capabilities increase and operational demands grow, traditional concepts of piloting and crew responsibilities are being reimagined. Managing multiple UAS in diverse operational contexts requires not only technical expertise but also a nuanced understanding of human factors, workload management, and crew resource coordination. Developing standardized approaches to address these needs is essential to ensure safety, efficiency, and scalability.

This paper explores these challenges and opportunities by synthesizing insights from existing practices, lessons learned, and expert recommendations. Through a comprehensive review of industry trends, case studies, and human factors research, the paper highlights critical considerations for sUAS personnel selection, training, and role development. The findings aim to support organizations in preparing for the safe and effective integration of sUAS into the National Airspace System (NAS) while laying the groundwork for future regulatory and technological advancements.

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1.1. Advanced Air Mobility and sUAS Integration

Advanced Air Mobility (AAM) is the concept of air transportation using various types of aircraft as well as sizes of aircraft ranging from sUAS to large shuttles. Aircraft include electric, hybrid, combustion-powered, and potentially hydrogen fuel cell-powered systems, to move people and cargo between places either not currently or not as easily served by surface transportation or existing aviation modes. Additionally, while electric vertical takeoff and landing (eVTOL) aircraft are a key component of AAM, other means of takeoff and landing can also be implemented within this framework.

The goal of AAM is to bring accessibility not only to cities, underserved communities, and geographically distant regions but also to a wide range of industries and applications—positioning AAM as a versatile solution for transportation, logistics, healthcare, and more. AAM is expected to become an increasingly important part of our transportation system in the next several years. sUAS are a component of AAM and the sUAS domain is already seen as becoming a critical part of city infrastructures worldwide.

The advent of AAM will introduce the need to properly identify the roles, personnel types, and training needed to make all this happen. The discussions in this paper focus on the factors influencing personnel selection, roles, and training specific to sUAS within the AAM framework. Many of these considerations also extend to larger UAS operations, highlighting common challenges and opportunities across the broader AAM ecosystem.

1.2. Importance of Personnel Selection, Roles, and Training

Due to the complexities of the envisioned AAM airspace, there is a need to clearly define the types of personnel needed, develop required credentials, and ensure traceability of prior work experience and education. This clarity will enhance the effectiveness of the hiring process and help ensure that qualified individuals are selected. Facets of such hiring and training techniques can be extrapolated from other industries that revolve around complex systems.

An example of this can be seen with the streaming company Netflix. When training people on complex systems, Netflix uses a tool called "Chaos Monkey" (Hochstein & Rosenthal, 2016). This training tool randomly disables features for the programming team to be able to see how the system responds and creates situations that they might not have previously planned. The tool helps the team develop resilience and adaptability by simulating unexpected failures. Random algorithmic software then disables, creates latency, and generally scrambles normal functions so that the team can learn and develop new tools and safeguards.

Training needs to be proactive—designing instruction before bad things happen, not after. Automation in highly autonomous systems can reduce operator proficiency (Büchel, 2024), as seen in various industries where the need for human intervention becomes less frequent. However, the more complex the system, the more challenging the decisions that are not automated can become, particularly during automation failures. Leveraging automation as much as is reasonable may enhance efficiency and reduce cognitive demands on operators—yet this increased automation can sometimes hinder users from responding effectively. Users may sometimes feel compelled to override automated actions, even when the automation might be correct; this can occur due to factors such as uncertainty, limited transparency of the system's decision-making process, or a lack of trust in the automation (Fallon & Blaha, 2018).

At the same time, training should also be reactive, adapting to conditions or scenarios encountered in the field that may not have been captured in the original training design. For example, updates based on lessons learned from real-world operations can help address gaps in understanding, particularly regarding automation failures or unexpected system interactions. By combining proactive and reactive approaches, organizations can ensure that personnel are equipped to respond effectively to both anticipated and emerging challenges.

To help keep personnel prepared and engaged in the wake of automation, training and simulation are essential. With high levels of automation, however, personnel may lose their skills if daily operations run smoothly without issues (Skybrary, n.d.). Additionally, the right type of people for these operator roles often seek jobs that challenge them. Thus, if a job becomes monotonous, it can be challenging to attract and retain skilled workers. The human brain can struggle with risk assessment, especially if there is a lack of consistent training; this is pertinent as automated systems become more robust. Ongoing training, simulation, and exercises such as Chaos Monkey could help improve user performance and retention.

In high-automation environments, organizations often keep personnel engaged by involving them in system improvements, such as interface enhancements and alerting systems. This approach serves dual purposes: 1) it keeps personnel actively involved and engaged throughout the day, and 2) it ensures they are well-prepared to handle advanced events due to their continuous interaction with the system.

When selecting individuals for operator roles in such settings, it's beneficial to identify personnel who seek challenges and possess a broad skill set. For systems where long operational durations are standard, operators often need to manage scenarios that prevent operational bottlenecks, such as simultaneous landings or data overloads. As a result, these organizations often seek generalist engineers—individuals familiar with automation and coding, with a general understanding of various subsystems. These individuals can then receive specialized training in specific operational concepts and tasks, such as communication with air traffic control (ATC).

Discussions with first responders and law enforcement (see Section 3 of this paper) indicate that many UAS operators do not have traditional pilot backgrounds. Instead, these operators are often tech-savvy individuals with a personal interest in technology and prior experience with drones for recreational use. This trend suggests that in the context of UAS, technical aptitude and adaptability may be more important than traditional aviation experience for certain operational roles.

1.3. Purpose

This paper aims to provide a comprehensive review of best practices, lessons learned, and actionable recommendations for sUAS personnel selection, training, and role development. By synthesizing insights from industry, government, and academia, this paper seeks to support the development of standardized approaches that balance the need for safety, efficiency, and scalability in diverse sUAS applications.

Through case studies, lessons learned, and proposed guidelines, this paper highlights critical areas such as human factors, operator workload, crew resource management, and training methodologies. The overarching goal is to advance the safe integration of sUAS into the National Airspace System (NAS) and ensure readiness for future regulatory and technological advancements.

2. Background and Context

We leveraged the use cases outlined herein to help identify current research, organizations in the sUAS domain to speak with, and applicable lessons learned (not only from the sUAS domain but from other domains that have integrated advanced automation). The authors of this paper represent government (NASA, FAA, and DoD), industry (including UAS manufacturers), and academia, providing a comprehensive and holistic perspective.

As an example, sUAS members from Anzen Unmanned (Au), a private drone and aviation consulting firm, conducted recent research that helped inform this paper (Federal Aviation Administration, 2023). Au developed the minimum criteria and open-source flight control software for a sUAS operator to supervise multiple sUAS simultaneously (1:N). Au's research was part of an FAA UAS Broad Area Announcement project examining standards for piloting multiple, simultaneous UAS beyond visual line of sight (BVLOS). The project successfully included defining, developing, and testing the:

- safety cases to obtain 107.31 (BVLOS) and 107.35 (m:N) waivers needed for flight test
- minimum UAS performance and behaviors for normal and off-nominal conditions, including the flight control modes and levels of automation necessary to support operator responses
- operator interfaces (e.g., display, alerts, controls) needed to maintain m:N situational awareness and enable timely, correct operator responses
- minimum sUAS equipage needed to support the m:N safety case
- operational pre-flight and flight procedures
- location-specific checklist that can be scaled nationwide
- minimum operator qualifications and training needed
- organizational practices, including safety management, quality management, configuration management, and training programs

These safety risk controls, established using the Safety Management System (SMS) process, effectively identified the human factors (HF) hazards associated with the m:N BVLOS UAS operation and mitigated the risks to acceptable levels by implementing automation, crew resource management (CRM), and task analysis, which were validated through simulation and flight tests (Federal Aviation Administration, 2023). The acceptable levels of risk were defined by ensuring the operator could manage up to six UAS without exceeding workload thresholds or compromising safety during both normal and contingency operations.

These criteria were critical as the first codification of operational factors necessary to ensure safe ongoing operation of multiple sUAS by one operator, particularly in situations where multiple operators were supervising a fleet of sUAS. The importance of these guidelines is even more evident when any or all sUAS are operating BVLOS of the operator. BVLOS could be one mile or 1,500 miles away, so the ramifications of remote operations need to be carefully considered. Findings from the Au report could directly inform this paper as many of the findings pertained to personnel types, roles, and training requirements for sUAS.

While this research focuses on an operator managing multiple UAS through individual ground station devices (one per UAS), future research and experimentation may consider scenarios where Command and Control (C2) software for multi-drone operations is used. In these cases, a single interface is used to control many UAS, introducing an entirely different set of ergonomic and cognitive load challenges. The dynamics of the operation, including the user interface, cognitive demands, and overall system efficiency, change significantly with the shift from one-to-one to one-to-many interface designs. Exploring these differences will be crucial to refining operator training and interface design for multi-drone operations in m:N settings.

2.1. Part 107 FAA Broad Area Announcement Project: Standards for Piloting Multiple, Simultaneous UAS BVLOS

Au's research worked in conjunction with the FAA's existing Federal Aviation Regulations (FARs) 14 CFR Part 107 (Federal Aviation Administration, n.d.-d). Part 107 controls the operation of sUAS within the United States and provides regulations for (1) the issuance of a remote pilot certificate as well as (2) operating rules for drone operators including line of sight, weighing under 55 lbs, flying with a speed of less than 100 mph, and flying below 400ft above ground level (AGL) (Federal Aviation Administration, n.d.-g). However, Part 107 does not provide guidance on establishing a sUAS organization, selecting the proper personnel, identifying necessary roles beyond a sUAS operator, or outlining training requirements that exceed those specified in Part 107. Additionally, to date, Part 107 does not cover BVLOS—a capability that is essential for m:N operators to reach the full impact of how sUAS can support operations such as those detailed in this and anticipated use cases.

For the organizations interviewed for this paper, all sUAS operators were, at a minimum, Part 107 certified. In some cases, the organizations included Part 107 certification as part of their training. In other cases, the organization required personnel to already be Part 107 certified before joining their sUAS program.

As noted, there are current requirements for Part 107. While it does not require instrument flight training and is considered "lightweight" when compared to general aviation, Part 107 does require awareness of altitude and airspeed. Further information on Part 107 certification requirements can be found here (Federal Aviation Administration, n.d.-b).

Beyond the basics, which include a government-issued identification, a candidate for Part 107 must be able to pass the "Unmanned Aircraft General (UAG) - Small Test," which includes areas of knowledge such as:

- applicable regulations relating to small, unmanned aircraft system rating privileges, limitations, and flight operations
- airspace classification, operating requirements, and flight restrictions affecting small, unmanned aircraft operation
- aviation weather sources and effects of weather on small, unmanned aircraft performance
- small unmanned aircraft loading and performance
- Emergency procedures
- crew resource management
- radio communication procedures
- determining the performance of small, unmanned aircraft
- physiological effects of drugs and alcohol
- aeronautical decision-making and judgment
- airport operations
- maintenance and pre-flight inspection procedures
- operation at night

2.2. Use Case to Frame the Challenges

To help frame the challenges, demonstrate the potential uses of sUAS, and further understand the critical importance of proper personnel selection, role definitions, and training, the following use case is provided. This scenario was developed by a larger, NASA-sponsored m:N working group (NASA, n.d.).

2.2.1. Use Case Overview

Drones-R-Us is a company contracted by California Department of Forestry and Fire Protection (CALFIRE) to survey northern California during fire season. The company uses infrared sensors to find hot spots as well as Artificial Intelligence (AI) analysis to identify potentially dangerous fire areas. The human operators set routes, monitor compliance, and review highlighted areas from the surveys before passing information over to CALFIRE.

Automated planning tools may be used to improve efficiency. Each operator typically commands 10 sUAS (under 55 lbs.) which fly under 400ft AGL. Five operators (50 sUAS total) work together to survey a designated area. Each individual sUAS mission is approximately 30 minutes in length. UAS Traffic Management (UTM) corridors provide strategic separation.

2.2.2. Event One

At mission time 00:11, a non-cooperative general aviation aircraft flies through two operators' survey areas. The operators are alerted by a ground-based Detect and Avoid (DAA) system.

Operator 1 Tasks

Re-route three sUAS during incursion by loitering in a safe area. (Note: due to battery performance, loiter times may be low; however, the sUAS could land and serve as a ground sensor, which would help reduce coordination burden).

Coordinate with Operator 2 to determine the most efficient way to recover the mission. Following coordination and incursion, re-route to complete the survey.

Operator 2 Tasks

Re-route four sUAS during incursion (loiter in safe area). Coordinate with Operator 1 to determine the most efficient way to recover the mission. Following coordination and incursion, re-route to complete the survey.

Estimated Task Time

10 minutes to reroute to avoid conflict (from alert to completion of re-routes to complete survey).

2.2.3. Event Two

At mission time 00:05 (e.g., not simultaneous with Event One) a sUAS commanded by Operator 1 develops a battery problem and must scrub its mission and return to base. The aircraft alerts the operator to the unusual battery drain rate.

Operator 1 Tasks

Provide expedited route to affected sUAS back to base. Re-configure remaining sUAS to cover the survey area (extending the mission time by 3 minutes but completing the mission). Automation provides potential new path solutions, but the operator must review and approve prior to execution.

Estimated Task Time

3 minutes from aircraft alert to new route(s) approval.

2.2.4. Key Challenges Illustrated

These use cases highlight several critical challenges inherent in sUAS operations. First, operators face significant workload management demands, as they must rapidly execute time-sensitive tasks such as re-routing sUAS while simultaneously monitoring multiple aircraft. The ability to maintain situational awareness across a dynamic operational environment is essential to ensuring mission success. Additionally, effective coordination and communication between operators are critical when recovering from disruptions like airspace intrusions. Collaboration enables operators to optimize resources and maintain coverage despite unexpected events. Furthermore, these scenarios highlight the importance of decision-making under pressure, as operators must evaluate automated recommendations, account for system constraints, and implement solutions that balance efficiency and safety. Finally, the events emphasize the need for comprehensive training programs to equip operators with the skills required to handle complex situations, leverage automation effectively, and adapt to off-nominal conditions without compromising mission objectives.

2.3. Automation Levels and Human-Machine Interaction

As systems scale, the traditional pilot tasks—flight planning, route navigation, pre-flight inspections, aircraft health monitoring, contingency management, and airspace aircraft avoidance, etc.—are becoming increasingly automated. This trend is supported by frameworks that classify levels of automation and their impact on human-machine interaction. According to a document published in 2023 by the Joint Authorities for Rulemaking on Unmanned Systems (JARUS), automation in UAS operations can be categorized into different levels. The document, titled "JARUS Methodology for Evaluation of Automation for UAS," provides a detailed framework for evaluating these levels of automation.

The automation levels as defined by JARUS are:

1. *Level 0: Manual Operation.* The human is fully responsible for function execution with no machine support.
2. *Level 1: Assisted Operation.* The machine supports the human by providing relevant information.
3. *Level 2: Task Reduction.* The machine reduces human workload by managing specific tasks, such as conflict alerts.
4. *Level 3: Supervised Automation.* The machine executes tasks under human supervision, who must monitor and intervene if necessary.
5. *Level 4: Manage by Exception.* The machine performs tasks and alerts the human only if an issue arises, allowing for non-real-time monitoring.
6. *Level 5: Full Automation.* The machine fully controls the function, with the human unable to intervene in real-time.

While the UAS industry aspires to reach level 4 automation soon, we are currently between levels 2 and 3 in terms of automation capabilities. The challenge, felt by some within industry, is that regulations prevent us from fully adopting level 4. Level 5 is even further away from implementation. As organizations transition from legacy systems to increasing autonomy, challenges such as operator workload, automation bias, and transitioning complexities must be addressed (Sanchez, 2024a).

Considering these challenges, it's crucial to consider how automated systems handle failures and the changing role of human operators. Considering the following factors can help guide the development of such systems:

- The increased information volume and system interdependencies make timely adequate human decisions more challenging.
- Staffing for rare, simultaneous multiple aircraft failures negates the benefits of automation scalability and introduces additional opportunities for human error.
- The potential gains in efficiency, including time, cost savings, resource management, and risk reduction.
- Simplification of training, as automation reduces the complexity of tasks that operators need to master.

As a result of these factors, the traditional concept of a "pilot" is evolving. Human roles are shifting from individuals ("Pilots") controlling and monitoring aircraft, to organizations ("Operators") supervising and managing advanced integrated systems and automation. This shift aligns with other highly automated industries as well.

In this new paradigm, an operator's system management organization becomes responsible for configuring automated systems, imposing system constraints, responding to incidents, maintaining historical records for auditing, traceability, and analytics, and ensuring all systems operate within safe bounds and Service Level Agreements (SLAs). This organization may be composed of several system-specific roles, teams, subject matter experts (SMEs), and subsystem experts.

For example, a large-scale sUAS operator may have a small team dedicated to monitoring weather and imposing geographical restrictions accordingly, which are then automatically enforced by automation (thus removing the proportionality of workload to the number of aircraft). When weather restrictions are automated, human responsibilities evolve to the configuration and maintenance of the weather automation system, rapidly restoring systems to their nominal operating state in case of outages, and ensuring they operate within SLAs (Zipline, n.d.).

Another critical area of automation includes DAA functions, which could potentially remove the need for humans to monitor traffic (Wing Blog, 2024). If DAA fails, an automated health-monitoring system can trigger a contingency landing without needing human intervention. In this scenario, human responsibilities evolve to:

- configuring the automated failure response
- handling the aircraft recovery
- investigating the failure
- improving the system to prevent future occurrences or mitigate their impact

Clear protocols are necessary to define when and how human intervention is required during automation failures. For example, in scenarios where operators are alerted by a ground-based DAA system, careful consideration is needed for the software managing deconfliction between the DAA and the operator, as well as for operator reaction time. Without appropriate measures, human errors and delayed reactions risk contributing to accidents.

Similarly, when the system provides recommendations, the human operator is expected to review and validate them. Protocols are essential to guard against poor recommendations and to provide a backup plan for revising automated suggestions that are suboptimal.

Each system's unique automation, Concept of Operations (CONOPs), and approach necessitate both standardized and tailored roles and tasks. While current regulations (Part 135 and Part 107) define standardized "Pilot" roles with specific knowledge and skill requirements, future regulations for large-scale sUAS, such as the anticipated Part 108 (Federal Aviation Administration, 2022), could benefit from including compulsory roles with standardized requirements, while also allowing for customization and additional roles based on system-specific needs and SMS systems. Operators will need to define system-specific roles, responsibilities, knowledge, and required skills, as well as develop and implement their own system-specific training programs accordingly.

Today, manufacturers outline their plans for implementing these systems, which the FAA then validates. As an example, the sUAS company Wing currently operates with a 1:16 operator-to-vehicle ratio, supported by waivers and a special class type certificate under 14 CFR 21.17(b) for its Model Hummingbird UAS (Federal Register, 2024). The Hummingbird's high degree of automation and the use of smaller sUAS enable Wing to achieve its high operator-to-vehicle ratio, but there is a desire to increase this ratio in the future. It is important to note that these ratios are highly dependent on operator workload and what happens when an exception occurs (i.e., when a UAS encounters problems and requires human intervention).

From a human factors perspective, the relationship between operator workload and the number of UAS under supervision is critical (Monk et al., 2019). If the operator is monitoring overall aircraft conditions with no contingencies or exceptions, a higher number of UAS could be controlled by the same operator. However, if additional workload is added to the monitoring job, such as having to replan routes or assist with an off-nominal asset, then the operator's cognitive load increases. In this type of situation, the number of UAS under that operator's supervision would need to be reduced to help ensure safety.

The FAA expects manufacturers to have a highly automated system by the time a company evolves from having an operator supervise one UAS to having the operator supervise many UAS. As a result, sUAS operators likely do not need in-depth knowledge of aerodynamics as the system would be controlling those functions (for example, pitch and yaw). The core tenants of Digital Flight Rules further substantiate this position.

Recently, the Radio Technical Commission for Aeronautics (RTCA) published a Member Report discussing future-facing modes of operation (RTCA, 2023). The report highlights how advances in automation for flight controls and path planning could democratize aviation, enabling individuals with different or evolved knowledge to operate these systems. However, as autonomy scales, it might still be important for today's operators to understand the fundamental principles of flight, such as lift, weight, drag, thrust, and concepts like the "power curve." Grasping environmental concepts such as relative wind components and how the aircraft interacts with terrain, buildings, and airflow (to include ground effect) would also be important to understanding how the aircraft behaves in various flight envelopes.

While automation may reduce the need for certain technical skills, it introduces new requirements for operators. These include:

- the ability to monitor and interpret complex automated systems
- quick decision-making skills when intervening in autonomous operations
- understanding of system limitations and potential failure modes
- capacity to manage cognitive load effectively, especially during high-stress situations

Over time however, and similar to other industries where automation is increasingly present, software systems will gradually reduce the need for understanding the underlying technologies, shifting the operator's focus to higher-level understanding and decision-making. For example, in an automobile, users are not required to understand the underlying mechanics of how a car works to successfully drive it from one point to another. However, it should be noted that understanding essential operational components like brakes and steering remains vital for safe vehicle operation. As technology advances, the user does not necessarily reduce their overall knowledge; rather, they evolve with a different knowledge set.

3. Lessons Learned from Existing Practices

The integration of UAS into high-pressure, mission-critical environments offers valuable lessons for scaling and optimizing operations in various sectors. From defense to public safety, organizations have employed UAS to enhance situational awareness, streamline operations, and mitigate risks. These applications demonstrate the potential of UAS technology to improve safety, efficiency, and decision-making in complex scenarios.

In public safety, for instance, UAS are deployed to assess scenes, identify risks, and provide critical information to first responders before they arrive. UAS can enhance community safety through applications such as search and rescue, crowd management, and infrastructure protection. Additionally, sUAS are increasingly used to respond to AMBER alerts (helping locate missing individuals; U.S. Department of Justice, n.d.) and shotspotter alerts (identifying the location of gunfire; SoundThinking, n.d.), thereby enhancing response times to critical incidents.

Currently there are sUAS programs for public safety across the United States. As of 2024, there are approximately 1,500 police departments in the U.S. that utilize sUAS. Some of the largest and most advanced sUAS programs for public safety in the U.S. are in major cities including New York City, Los Angeles, and Phoenix. These programs emphasize the value of using sUAS technology for enhancing situational awareness, improving response times, and ensuring safety for first responders and the public. In the future, the number of sUAS programs is expected to grow even further as more agencies recognize their benefits and as advancements in technology make them increasingly accessible and effective for public safety operations.

This section explores key insights from both defense and public safety sectors, presenting case studies and expert interviews that summarize best practices for personnel selection, training, and operational protocols. The examples of the Department of Defense, DRONERESPONDERS, the Denver Police Department, the Los Angeles Fire Department, and the U.S. Army's 160th Special

Operations Aviation Regiment highlight how UAS programs have evolved to meet diverse operational needs.

3.1. Department of Defense

UAS is not only used within the civilian airspace; the Department of Defense (DoD) has employed UAS for years as well, with technologies and usage rapidly evolving. As such, the DoD has also published guidance on UAS training. From the Joint Chiefs of Staff, most recently distributed on 04 September 2012, there is a document titled "Joint Unmanned Aircraft Systems Minimum Training Standards." The purpose of this document is to define Joint Unmanned Aircraft System Minimum Training Standards (JUMTS) and identify the minimum knowledge required for a UAS crewmember (UASC) to support Joint Force Commanders' (JFC) objectives.

The instruction called out in this document helps to prepare aircraft crew members to perform in a joint environment by standardizing training and certification. The document goes on to state that the qualification standards meet or exceed existing manned aircraft FAA standards to facilitate UAS access in the NAS.

3.1.1. DoD Critical UAS Skill Sets

There are five skill sets seen as critical within the DoD for operating UAS, regardless of operational environment. They are as follows:

- *Basic UAS Qualification (BUQ):* Operators shall possess general aviation knowledge as well as UAS knowledge-based skills to operate UAS safely. This includes ground instruction equivalent to aircrew comparable to civil or military aircraft operating in similar airspace. This also includes an understanding of weather/meteorology, aerodynamics (including effects of controls), human factors, aircraft systems and emergency procedures (including operational risk management), performance, navigation, communication procedures, air traffic control (including procedures, rules, and regulations), mission preparation, and flight regulations for the types of airspace in which the UAS will operate.
- *UAS Flight Crew Skills (UASFCS):* Operators shall possess practical skills to operate UAS with situational awareness (SA) and the ability to execute tasks during flight operations. This includes an approved flight training program (flight and/or simulator training). The operator will be able to demonstrate control of a specific UAS throughout its performance parameters and potential operating conditions, including responding to an emergency or system malfunction during a mission.
- *Joint Mission Qualification (JMQ):* Operators shall have general knowledge of the UAS mission/objective. This includes mission support with capabilities defined in other DoD materials such as the Joint Mission Task Lists (JMTL).
- *UAS Mission Crew Skills (UASMCS):* Operators shall have the necessary skills required to ensure accomplishment of the assigned task. Skills include mission skills to execute joint tactics, techniques, and procedures to meet UAS employment mission objectives.
- *Unique Service Skills:* Operators shall have the knowledge and understanding of specific mission types and their associated requirements. This includes JUMTS certification by maintaining currency via established minimum recurring training and assessment. This also includes staying current on event orchestration which includes mission briefing and actual or simulated missions.

3.1.2. DoD UAS Training Requirements

UAS operators in DoD service must demonstrate satisfactory knowledge of both ground and flight/simulator operations through examinations and flight checks, as outlined in the JUMTS (Joint Chiefs of Staff, 2012). These checks ensure that operators are proficient and capable of handling both routine and emergency situations.

To qualify as a UAS operator one must demonstrate they have the knowledge, skills, and abilities (KSAs) as well as the responsibility to operate a UAS. Operators are also expected to show sound judgment and decision-making in real-world scenarios, as specified in the JUMTS.

The DoD acknowledges that, due to the wide diversity in UAS design, mission, and technology architecture, it is difficult to prescribe a standard set of universally applicable training certification requirements. However, as noted in the JUMTS, regardless of the type of controls, technologies, or platforms involved, UAS operators must be capable of safely conducting missions, to include proper response to emergency situations. This applies when operating the UAS within both unmanned and manned aircraft scenarios.

UAS training criteria must consider CRM techniques, as detailed in the JUMTS. CRM is seen as being essential for UAS operations and the operator must be able to communicate effectively to ensure safety. This includes knowing how to coordinate with Air Traffic Service Providers when required, as well as understanding applicable national and international controlling authorities' flight regulations.

3.1.3. DoD Minimum Knowledge Areas

The DoD also breaks down mission preparation and aircraft operations areas of knowledge for operators. These are the minimum recommended training levels for operators, including:

- Mission preparation
  - aviation weather
  - communications
  - emergency procedures
  - checklists
  - charts
  - flight information publications and procedures
  - aircraft performance data and limitations
  - publications
  - departure and arrival planning

- Aircraft operations
  - weather hazards
  - general flight rules
  - fuel planning
  - integrated navigation systems
  - aviation principles
  - time and course control
  - manual navigation
  - low level flying
  - aircraft systems
  - emergency procedures

3.2. DRONERESPONDERS

When speaking with DRONERESPONDERS' (DroneResponders.org; DRONERESPONDERS, 2023) founder, Charles Werner, he explained that today there are many resources to help develop UAS programs. With the increase in UAS operations, various organizations are forming to support this growth. In addition to DRONERESPONDERS, these other organizations include:

- National Institute of Standards and Technology's (NIST), which focuses on research and development to enhance the safety and reliability of unmanned aircraft systems
- Unmanned Safety Institute, which provides training and certification programs for UAS operators to promote safe operations
- National Wildfire Working Group, which is working to standardize training for wildfire management
- the FAA, which establishes essential UAS safety regulations and operational standards

3.2.1. DRONERESPONDERS Personnel

There is a growing demand and interest in the field of sUAS. Charles Werner is currently working on developing an international training group for firefighters and incorporating sUAS into its programs, demonstrating the expanding role of drones in emergency services.

Charles Werner cited that both the New York City Fire Department (FDNY) and police department (NYPD) require personnel to complete Part 107 testing as an initial step, followed by psychological assessments for those who pass Part 107.

3.2.2. DRONERESPONDERS Training

DRONERESPONDERS is advancing efforts to establish a unified standard for remote pilots, alongside a comprehensive training program set to launch soon (i.e., hopefully sometime in 2025). This initial program will provide a foundational framework for remote pilots across various sectors. Following its release, DRONERESPONDERS will introduce targeted modules designed to address specific areas within remote piloting, enhancing skills and knowledge as the field continues to evolve.

3.3. Public Safety Innovation in Virginia

Chris Sadler, director of the Virginia Innovation Partnership Corporation Public Safety Innovation Center, provided context for how Virginia runs its UAS programs today. According to Mr. Sadler, Virginia Polytechnic Institute and Austin Fire Department (AFD) were among the earliest public entity UAS locations. Working with the FAA, they both created their own programs, collaborating closely. Currently in Virginia, the fire departments and law enforcement agencies share the costs of UAS programs.

3.3.1. York County Fire Department Personnel

In York County's Fire Department, Chris Sadler found that some individuals who struggled with traditional firefighting roles discovered a passion for operating sUAS. Operators typically perform dual roles, serving as both UAS operators and fulfilling their regular duties as law enforcement officers or firefighters. Usually, sUAS teams consist of four or five operators, with responses spanning both law enforcement and fire-related calls.

3.3.2. York County Fire Department Training

The York County Fire Department requires all personnel to obtain Part 107 certification and complete the Remote Pilot 101 prep course (Drone Launch Academy, n.d.) within a month. The team trains twice a month for eight hours each session—one day and one night—and often collaborates with the Special Weapons and Tactics (SWAT) team.

According to Sadler, although operating a UAS is relatively straightforward, skills such as understanding the rules and requirements, determining the best location for the sUAS, and effectively tracking individuals require more advanced training, which cannot rely solely on textbooks.

3.3.3. Future Challenges

Sadler predicts an increase in automated drone responses over the next five to ten years, including further deployment to rural areas. He anticipates that in the future, 911 dispatchers could launch drones, potentially delivering a defibrillator or Narcan in a much shorter time frame than a ground based delivery could.

However, challenges remain, including the limited availability of U.S.-manufactured drones, which does create cybersecurity concerns. If Congress proceeds with passing legislation that bans the buying of drones from certain countries, there will be insufficient funding to replace entire fleets of existing sUAS. Another concern is the recurring costs of replacing batteries and parts that get worn out through routine use. Note that law enforcement, first responders, and the DoD are all facing similar issues related to the International Traffic in Arms Regulations with sUAS procurement.

Sadler believes when developing a sUAS program, it is crucial to allow law enforcement and first responders to experiment and learn from their failures swiftly. This approach can provide valuable insights that inform rulemaking for both civil and commercial applications.

3.4. Denver Police Department

The Denver Police Department (DPD) has embraced small Unmanned Aircraft Systems (sUAS) as part of its broader effort to enhance public safety, operational efficiency, and community engagement. Through the launch of its UAS program, DPD aims to integrate sUAS technology into its existing infrastructure to improve situational awareness, reduce response times, and strengthen its capabilities across a wide range of operations. This section outlines DPD’s approach to implementing sUAS, including its goals, personnel selection criteria, training protocols, operational procedures, and deployment strategies.

3.4.1. Approach to sUAS Usage

The DPD initiated a sUAS program with a 12-month rollout starting in April 2024. DPD has put together a “Drones as a First Responder” (DFR) team comprised of personnel from special operations, strategic investigations, strategic initiatives, Crime Lab, SWAT, Real-Time Crime Center (RTCC), Inertial Measurement Unit (IMU), Tactical Enforcement Support Unit (TESU), bomb unit, research and policy, and a dedicated individual for FAA Part 107 licensing.

The goals of the Drones as a First Responder program include:

- improving public and officer safety
- reducing response times
- assisting with various investigations (including traffic, persons, property, SWAT, and crime lab cases)
- providing live visual interaction
- promoting community engagement and transparency
- protecting civil liberties and privacy
- establishing common operating procedures
- ensuring clear oversight and accountability
- supporting DPD cybersecurity

The DFR program utilizes sUAS to respond to calls for service before officers arrive on scene to develop a better understanding of the situation on the ground. The early visuals provided by the sUAS can include information on potential unanticipated hazards to officers and public such as weapons, or the need for special capabilities or equipment. This may include the fire department, medical assistance, SWAT teams, co-responders, and mental health professionals. This increased situational awareness allows the department to more effectively allocate personnel and resources to incident scenes. It also helps the department anticipate potential challenges and tailor the response appropriately to avoid unnecessary escalation.

As part of the DFR program, DPD is working with several manufacturers specializing in various aspects of drone technology and operations: DroneSense provides software for managing missions, DJI supplies the drone hardware, Skydio offers advanced autonomous flight capabilities, and Motorola delivers communication solutions. To date, DPD has conducted demonstrations for the city council and has begun deploying sUAS. sUAS operators are selected from the DPD officer pool and are all Part 107 certified. The official DPD deployment is scheduled for December 2024 as a pilot program, with an anticipated go-live date for all sUAS in January 2025. Note that during the pilot program, sUAS were not operated BVLOS, but DPD is actively working towards BVLOS operations.

3.4.2. DPD Policy

DPD published its sUAS policy on April 11, 2024. The purpose of this policy was to provide guidance for the DPD in the responsible and effective use of overt cameras in public areas for safety and security, and the use of rapidly deployable cameras (RDCs) for the surveillance related to investigations. The sUAS program is designed to integrate with and enhance Denver's existing surveillance capabilities, specifically by providing mobile and flexible aerial support to the High Activity Location Observation (HALO) system.

Denver's existing HALO surveillance program is used for crime detection and prevention throughout Denver, with fixed cameras that provide video surveillance to police headquarters in real time. HALO targets public areas of high crime and disorder, and areas where the safety and security of the community is at risk. The principal objectives of the HALO project include:

- enhancing public safety in areas where the safety and security of our community is at risk
- preventing and deterring crime
- reducing the fear of crime
- identifying criminal activity

- identifying suspects
- gathering evidence
- documenting police actions to safeguard both the community and police officer rights
- reducing the cost and impact of crime to the community
- improving the allocation and deployment of law enforcement resources

Once the DFR program is fully launched in January 2025, sUAS will be deployed from strategic docking stations in high-crime areas. This initiative aims to significantly cut down response times to under three minutes for high priority 911 calls, which is a substantial improvement over the current 14.5 minute average. The sUAS program will complement the HALO system by providing mobile and flexible surveillance capabilities, allowing DPD to respond rapidly to incidents in areas beyond the reach of fixed cameras.

3.4.3. DPD Personnel Selection

Currently, sUAS operators are selected from volunteers among current officers who are interested in the sUAS program. DPD wants to recruit approximately 10–15 officers to serve as sUAS operators. While prior experience as a pilot—whether in manned or unmanned aircraft—is not a requirement, candidates must meet the following key criteria detailed in the JUMTS (Joint Chiefs of Staff, 2012):

- be in good standing with the department
- demonstrate a strong interest in sUAS technologies
- maintain a record of professionalism and responsibility when using department assets

In addition to these criteria, operator applicants must establish a federal tracking number (FTN) by creating a profile in the integrated airman certification and rating application (IACRA) system. They must also pass the “Unmanned Aircraft General - Small” exam, with a mandatory 14-day waiting period for retesting in the event of a failed attempt. Prior to deployment, the operator must hold a valid and current Remote Pilot Certificate from the FAA, as required by Part 107 (Federal Aviation Administration, n.d.-g).

sUAS operations in DPD will only be conducted by trained and authorized personnel. Once certified, the operator has the final authority and responsibility for the operation and safety of a sUAS operation. Each operation would involve two operators per sUAS. DPD is not currently operating BVLOS.

3.4.4. DPD Training

DPD conducts weekly training sessions to get their sUAS team up and running. Personnel assigned to operate a sUAS for DPD must complete the agency-approved training program (Joint Chiefs of Staff, 2012) to ensure proper use. All agency personnel with sUAS responsibilities, including command officers, will receive training in the policies and procedures governing their use. This training will cover legal aspects such as search and seizure laws, as well as privacy regulations. Additional training will be required at periodic intervals to ensure operators continue to use equipment effectively and safely, perform proper calibrations, verify equipment performance, and stay up to date with changes in policy and technology.

3.4.5. DPD Deployment and Procedures

DPD must obtain applicable authorizations, permits, or certificates required by the FAA prior to deploying or operating the sUAS, and all must be maintained and current (Joint Chiefs of Staff, 2012). Any deployment of a sUAS must comply with all relevant FAA requirements and the following operational procedures:

- sUAS will only be operated by licensed remote pilots (Part 107).
- sUAS will only be operated by personnel who have completed the agency-approved training program.
- A sUAS may not be deployed for any purpose beyond those explicitly authorized without the knowledge and prior approval of the chief of Police, Deputy Chief, Division Chief of Investigations or designee(s).
- All sUAS will comply with any mandatory specifications required by the FAA. These include obtaining proper authorization for operating BVLOS of ground observers and implementing lost link procedures.
- Any sUAS operation that is conducted entirely indoors is not considered to be within the NAS and is therefore not subject to FAA regulation.
- An operator who deploys the sUAS will properly document each deployment on a form designed for that purpose and all flight time will be accounted for on the form, including in an individual pilot log. Such documentation must include at a minimum:
  - purpose of the deployment
  - date, time, duration, and location of the flight
  - name, date, and time of approving authority if deployed for any purpose other than that of a criminal investigation
  - sUAS flight crewmembers
  - summary of actions taken, activities, and outcomes from deployment
  - if relevant, brief description of recorded images and storage location
  - whether a search warrant was sought and obtained for the deployment, and if required, name of District Attorney who was consulted
  - if a warrant was not obtained, a written explanation as to why it was not sought and who approved the decision to use the sUAS without a warrant
- The operator is directly responsible for the operation of the sUAS during a deployment. No member, regardless of rank, will order a pilot to make a flight when, in the opinion of the operator, it cannot be done safely or is in violation of this policy. Any conflicts in utilization will be reported in writing, via the chain of command, to the Commander of the officers involved, as soon as possible.

3.5. Los Angeles Fire Department

The Los Angeles Fire Department’s (LAFD) sUAS policy was developed with input from the Department of Homeland Security's (DHS) Big City Fire (BCF) Working Group and published as the “Recommended Small Unmanned Aerial System Program Documentation” April 30, 2024. This document represents a collective effort by senior leaders from 12 of the nation’s largest fire departments. The primary purpose of the LAFD policy is to guide fire departments in developing, advancing, or refining their sUAS programs. It emphasizes collaboration with sUAS SMEs, ensuring that the implementation of these programs is grounded in both practical experience and technical expertise.

LAFD’s sUAS policy outlines that sUAS deployment is strictly limited to specific public safety missions and must comply with all applicable laws (Los Angeles Fire Department, 2024). The policy specifies that only personnel who have been properly trained and authorized can operate sUAS. The mission of the sUAS program is to provide increased operational capability and efficiency in support of safe fire department missions and operations.

3.5.1. LAFD Approach to sUAS Usage

LAFD has utilized sUAS for a wide range of mission support and operational activities since 2017. Table 1 summarizes the key missions and activities supported by sUAS in LAFD operations (DRONERESPONDERS, 2023).

Table 1. sUAS Mission Support and Activities

Mission	*sUAS Support*
Structural fire	Overwatch Identification of heat signatures
Wildfire	Overwatch Fuel load assessments Incendiary drops for backfire operations
Search and rescue	Access to dangerous terrain or inaccessible areas Coverage of larger search areas Thermal imaging to locate lost persons Delivery of floatation devices or ropes for water rescue
HazMat response	Overwatch Identification of substances and materials Identification of direction of spill Detection/viewing of invisible plumes, gas clouds or flames Determination of content levels in containers
Suspicious package investigation	Monitoring suspicious packages in support of bomb squad activities and under direction of the bomb squad
Emergency management	Pre-incident facility planning and 3D modeling Post-incident damage survey
EMS	Delivery of medical supplies (e.g., blood and blood products in response to trauma, rescue medications)
Forensics	Fire cause and crime investigations with 3D modeling
Training	Capture of training activities for subsequent review and lessons learned
Traffic	Traffic flow analysis Accident reconstruction

3.5.2. LAFD Personnel

This section describes the program roles and their responsibilities within the LAFD sUAS program. Note that for the LAFD, a single individual may be assigned to more than one role.

sUAS Unit Commander/Program Manager

The Program Manager is responsible for understanding FAA regulations and agency policies and managing the sUAS program to ensure operations, requirements, and documentation are done in accordance with department policy and procedures.

Air Coordinator (Optional)

The Air Coordinator is responsible for airspace deconfliction and management, coordination between manned and unmanned aviation assets (such as department sUAS and helicopters, rogue sUAS, press helicopters, other public safety sUAS and helicopters, and all commercial aviation) coordination of sUAS operations at large incidents, and managing radio frequency communications and interference.

Remote Pilot in Command (RPIC)

An FAA Part 107 certified sUAS pilot shall serve in this role, which is responsible for flight operations and safety and holds the appropriate category, class, and type rating (if appropriate) to conduct the flight.

Visual Observer (VO)

The VO is a trained member of the flight crew and is responsible for assisting the Remote Pilot in Command (RPIC) with aircraft setup and operations, communications, and avoiding other air traffic or obstacles.

Property Officer

The Property Officer is responsible for ensuring that the aircraft and accessories are stored and maintained properly when not deployed. This role may also be filled by an active Remote Pilot.

Training Officer

The Training Officer is responsible for implementing, managing, and documenting training for personnel involved in sUAS operations, as well as recommending training modifications based on lessons learned. The Training Officer may also serve as an active Remote Pilot.

Records Manager

This role is responsible for implementing the records management system for sUAS administration and operations, including ensuring that records are kept current and that reports are generated and submitted to the proper point of contact when required. The Records Manager may also be an active Remote Pilot.

Public Relations/Press Coordinator (Optional)

This role handles communications with the public or media regarding the sUAS program and its activities. Duties include drafting press releases, preparing media summaries, and coordinating with department leadership to deliver messaging.

3.5.3. LAFD Training

The LAFD has established a comprehensive, tiered certification process for personnel involved in sUAS operations. These training and certification requirements, adapted from the International Association of Chiefs of Police (IACP) Small Unmanned Aircraft Systems Model Policy, ensure that all personnel maintain the necessary skills and knowledge to safely and efficiently manage sUAS operations. This section outlines the specific training levels, required competencies, and certification process that LAFD personnel must complete to operate within various operational contexts. Descriptions are taken from the IACP Small Unmanned Aircraft Systems Model Policy (2019).

To provide a clear foundation for the program, LAFD requires all personnel involved in sUAS operations to undergo rigorous training. The following key guidelines outline the essential training expectations:

- All sUAS program personnel shall receive training necessary to safely, efficiently, and effectively manage or operate sUAS, to include initial and recurrent training.
- All RPICs and VOs shall hold the appropriate credentials and retain proficiency prior to any flight operations.
- All sUAS program personnel shall receive training in the regulatory requirements for sUAS operations.
- All sUAS program personnel shall receive annual training on the policies and procedures governing the use of the equipment.

These core training principles form the baseline for sUAS operations and are further enhanced through a tiered certification process that provides additional layers of specialized training. The process not only ensures personnel are qualified for their roles but also enables them to meet evolving challenges in complex operational environments.

All LAFD UAS pilots are required to maintain flight proficiency by demonstrating completion of a refresher exercise with a certified LAFD UAS instructor pilot at least once annually. This can be accomplished through the annual night training or quarterly training. In addition, every pilot must have a minimum of 30 minutes of flight time logged with the current air management software quarterly. Additionally, intermediate and advanced level pilots must complete an annual night training operation. If any LAFD pilots do not meet these minimum requirements, he/she must become current before accepting any future missions.

To ensure all members have a clear understanding of this policy, Commanding Officers are responsible for reviewing this departmental bulletin with all members in their command. Officers use Vector Solutions to document the training of assigned members.

3.5.4. LAFD Certification Process

The LAFD certification process is a tiered process consisting of three levels (Los Angeles Fire Department, 2024). Any LAFD member may begin the UAS certification process by showing up to a UAS pilot-provided training. Members need not obtain an FAA Part 107 Remote Pilot Airmen Certificate prior to beginning the process. However, they must obtain one prior to requesting level one certification. The UAS levels of certification must be completed in the following listed order.

Level 1: Initial Training and Certification

Before members assume any UAS pilot duties, they must complete their "Level 1 UAS Training," also known as "initial training." Initial training consists of learning the fundamentals of operating as a UAS pilot within the City of Los Angeles. Initial training will give members the basic UAS skills, including introduction to LAFD UAS policies, basic manipulative skills, pre-flight requirements, and knowledge surrounding the Certificate of Airworthiness (COA).

Level 1 competency procedures create the foundation of a successful UAS pilot. Once a pilot completes the "Level 1 UAS certification," he/she becomes deployable to all Level 1 flights.

According to LAFD policy, the following competencies must be achieved:

- Ten total documented flight hours within the Department's current flight management software (four hours must be performed in supervision of the LAFD "Lead Pilot").
- Complete and understand of all Vector Solution assignments.
- Obtain FAA Part 107 certification (member obtains on his/her own).
- Demonstrate a working knowledge of policies and procedures surrounding the use of drone aircraft, including but not limited to:
    - – LAFD COA
    - – FAA required notifications
    - – LAFD Operations Manual
    - – FAA pre-flight checklists
- Achievement of the required NIST "Basic Maneuvering Trials" or open lane tests
- Complete the UAS Practical Examination (the practical scenarios are detailed in Section 3.5.5.) .
- Successfully pass the LAFD UAS Operator's written examination, administered on the same day as the flight test.
- Demonstrate proficiency in streaming video using department-approved flight management software.
- Understand the sensitive nature of video data acquired during UAS operations; all Personally Identifiable Information (PII) is highly regulated and UAS pilots must operate within a framework that minimizes risk to the department and the city.
- Produce a pre-flight plan that demonstrates the member understands the airspace in which they are operating, required to be filled out before the examination begins.

Upon completion of Level 1 training, the UAS section commander will approve the member's certification. The section commander will then write an F225 form, a document used to track personnel actions or certifications, to Emergency Operations (EOPS) for approval. EOPS refers to the structured management of resources and response efforts during emergency situations, ensuring effective coordination and planning. Upon EOPS approval, the F225 will be uploaded into Vector Solutions, a learning management system that supports training and compliance, and a copy will be filed in the member's personnel file.

Level 2: Intermediate Skills Training and Certification

UAS pilots who have successfully passed Level 1 certification are eligible for intermediate level training. Intermediate skills include operating UAS indoors and at nighttime. During "Level 2 UAS

Training," members will complete the National Institute of Standards and Technology's (NIST) basic maneuvering trials at night. Additionally, the member must demonstrate safety and competency in UAS indoor flying in accordance with LAFD policy.

Level 2 competency procedures enhance the foundational skills of a successful UAS intermediate-level pilot. Once a pilot completes the "Level 2 UAS Certification," he/she becomes deployable to all Level 1 and Level 2 flights.

According to LAFD policy, the following competencies must be achieved:

- Complete night and indoor training.
- Demonstrate proficiency in the required "NIST Basic Maneuvering Trials."
- Exhibit indoor UAS pilot competence.

Upon completion of Level 2 competencies, UAS Lead Pilots will handle the member's certification and documentation.

Level 3: Advanced Skills Training and Certification

UAS pilots who have successfully passed Level 2 certification are eligible for advanced level training. "Level 3 UAS Training" consists of payload operations and HAZMAT skills. A payload generally refers to anything carried by UAS to obtain data for diagnostic purposes (e.g., a thermal imaging camera or HAZMAT sensor).

Note that members can become deployable after "Level 1 UAS Certification" as long as the incident requirements are within the initial level training. An example would be providing situational awareness for an Incident Commander at events such as daytime festivals.

Building upon the intermediate-level training, Level 3 competencies develop a successful UAS advanced level pilot. Once a pilot completes the "Level 3 UAS Certification," he/she becomes deployable to all LAFD flight requests.

According to LAFD policy, the following competencies must be achieved:

- Complete UAS hazmat standardized training.
- Demonstrate proficiency of payload operations.

Upon completion of Level 3 competencies, UAS Lead Pilots will handle the member's certification and documentation.

3.5.5. Standard Flight Evaluation Practical Exam

According to LAFD policy, pilots must complete and pass all parts of the evaluation on the day of certification to qualify as a LAFD UAS Pilot.

Certification is comprised of the following components:

- Passing the written exam with a minimum score of 80%. All study materials can be found in Vector Solutions "Level 1 Pilot Certification."
- Demonstration of NIST "Man 1" and "Man 2" tasks. Members have twenty minutes to complete both evolutions.
- Passing a practical flight test. This test consists of three separate events or scenarios. As part of these scenarios, members must provide proper flight plans prior to evaluation. Flight planning includes airspace considerations. Additionally, the flight test includes the following components:
  - Filing of a Notice to Air Mission (NOTAM) or Low Altitude Authorization and Notification Capability (LAANC), which must be performed depending on the location of the examination or any time one is required.
  - Crew member documentation to be provided by the candidates; documentation should include all participating crew members, including the Pilot-in-Command (PIC), VO, and UAS Data Technician (TECH).
  - Demonstration of effective communications and notifications to participating agencies when appropriate.
  - Demonstration of effective CRM, Aeronautical Decision Making (ADM), and Operational Risk Management (ORM) with regards to safe operations throughout all scenarios.
- Completion of a pre-flight inspection of the aircraft prior to every launch and a post-flight inspection after every landing during the evaluation process.

The following scenarios are included in the evaluation:

- Provide situational awareness for an incident commander at a structure fire.
- Provide an orthomosaic map for the incident commander at an emergency operation.
- Capture and organize imagery for an LAFD event, such as an arson investigation or training exercise, while adhering to chain of custody protocols.

If, at any time, a pilot's behavior or piloting skill is identified and deemed unsafe by the LAFD Lead Pilot, the member is asked to ground the aircraft. A review of the critical failure is immediately discussed by the proctor. A failure or unsuccessful attempt to complete certification is defined as one of the following:

- Any portion not completed safely.
- Failure to complete the NIST lane proficiency for "Man 1" and "Man 2" in a controlled flight pattern or within the required time limit of 20 minutes per lane.
- Inability to live stream data through the Department approved data management software in an expeditious manner.
- Failure to create an orthomosaic map when utilizing a mapping program to fly missions and gather data.
- Inadequate securing of sensitive data in a manner required by LAFD UAS Policy.

- Failure to complete a written exam in the allotted time of 120 minutes or fails to pass with a score of 80% or better.
- Lack of understanding of the synchronization process.
- Failure to provide a flight plan that clearly demonstrates his/her understanding of the local airspace.
- Omission of any mandatory items from the LAFD UAS Program Remote Pilot Evaluation/Qualification Checklist.

Candidates are counseled immediately following an unsuccessful attempt at certification. Areas of concern are identified and a plan for remediation is discussed and signed by the pilot member and the LAFD Lead Pilot. Members must wait a period of one week to schedule another attempt. Before rescheduling the exam, the pilot must schedule and participate in one practice session with a UAS instructor pilot.

3.5.6. U.S. Army 160th Special Operations Aviation Regiment (SOAR)

As we progress towards more complex multi-operator scenarios—ranging from small teams, such as 1:1 or 1:10+, to large-scale operations involving m:N or even m:1000 teams—personnel selection, training, and role development will need to evolve accordingly. A critical factor in this evolution is fostering a safety culture where issues are promptly reported and managed. Building this culture involves clarifying who handles reports when things go wrong and ensuring proper procedures are in place for managing these situations efficiently.

Selecting the right personnel is key to creating and sustaining this culture. A question that arises is whether an organization should adapt its culture to the people it hires or select individuals who align with its established values. Specialized operations, like the U.S. Army's 160th Special Operations Aviation Regiment (SOAR) for example, have tackled this challenge by focusing heavily on optimal personnel selection. In SOAR, every officer volunteers and undergoes a rigorous screening process, which includes a comprehensive application review by command and staff. Each application is voted on and scored collectively, with the possibility for certain leadership members, such as the commanding officer, to override decisions if necessary. Although this method can introduce some bias, the benefits of this thorough vetting process generally outweigh the drawbacks.

After the initial review, candidates typically undergo a week-long assessment. Those who successfully complete this stage proceed to a board interview, where they are evaluated by leaders, HR personnel, medical professionals, and SMEs. Importantly, SMEs undergo specialized training to ensure they can effectively assess the candidates.

Flexibility plays a crucial role in this evaluation. SMEs may tailor events during the assessment to better understand a candidate's strengths, weaknesses, and ability to learn in real time. These evaluations often occur under conditions of uncertainty, with no feedback given to the candidate throughout the process. Candidates may also schedule an appointment with a psychologist and review aspects such as intelligence quotient (IQ), personality, and ethics.

Even after successfully completing the selection process, candidates are subject to continuous training and professional development. Each role within the organization comes with ongoing training requirements, and failure to meet these standards can result in reassignment to general duties or even dismissal. Leadership plays a key role here, helping underperforming personnel develop improvement plans to address any deficiencies. However, if personnel fail to improve, those in leadership roles may be recommended for reassignment or release. For example, flight leads (FLDs)—typically two per company—are held to high performance standards and can be dismissed on short notice if they make critical mistakes.

In addition to organizational evaluations, personnel are also encouraged to self-assess. For instance, commanders may recommend personnel for the Warrant Officer Performance Health Assessment (WOPHA), an annual review that serves as a "compass check" for self-awareness and performance. This assessment provides an opportunity for individuals to evaluate their fit within the organization and identify areas for improvement.

If a team member feels they are no longer a good fit, they are encouraged to have open discussions with their leadership to explore how the organization can better support their success. This emphasis on mutual benefit ensures that both the individual and the organization gain from their relationship. Ultimately, leadership plays a decisive role in navigating these personnel challenges, with their actions directly influencing team cohesion and operational success.

4. Recommendations and Proposed Guidelines

As complex m:N BVLOS operations grow, particularly in the commercial domain, ongoing, top-level training and systematic operational safety are critical for all personnel involved in the sUAS operation—including managers, supervisors, operators, safety pilots, and technical maintenance personnel. Fostering a culture where safety is the priority and serving as an integral part of operations can enhance overall effectiveness; with this commitment reinforced at all organizational levels.

Solid, defined, and actionable practices are essential for maintaining safety and operational integrity. Each operation benefits from thorough analysis to determine the number of sUAS that can be safely managed by typical operators with reasonable training and experience. A clear chain of command is also vital for addressing unexpected situations effectively. Defining the roles of typical operators helps ensure smooth operations, particularly as these roles may diversify into sub-roles. For instance, one operator might supervise telemetry, another might oversee streaming, a third manage might handle sensor control, and a fourth could handle collateral support or safety systems.

This section provides a set of recommendations and proposed guidelines designed to support the safe and effective implementation of sUAS operations. Drawing on lessons learned from existing practices (see Section 3), human factors research, and regulatory considerations, these recommendations aim to establish best practices for training programs, workload management, crew resource management, and system design. The goal is to ensure that operators and organizations are prepared to meet the demands of increasingly complex sUAS missions while maintaining safety, efficiency, and scalability.

4.1. Organizational Structure and Management

As AAM grows and the use of UAS becomes more prevalent, the need for different organizations to collaborate in resolving operational issues or conducting joint efforts will increase significantly. This includes scenarios such as disaster management, where the Federal Emergency Management Agency (FEMA) may assist with hurricane relief in coordination with multiple public and private organizations. Law enforcement agencies may work together on criminal pursuits or joint operations, while the DoD could involve various forces in collaborative efforts. Additionally, private organizations will need to coordinate workflows, such as package delivery over long distances versus the last mile.

To help ensure safety as AAM expands, several proposed guidelines relating to organizational structure and management are presented in the subsections that follow.

4.1.1. m:N Organizational Structure

Establishing an effective organizational structure is crucial for optimizing operations involving multiple UAS. Addressing the unique challenges associated with CRM, scheduling strategies, and regulatory requirements is key to ensuring safe and efficient m:N operations.

4.1.2. CRM in m:N Organizations

CRM plays a pivotal role in m:N operations, fostering teamwork, communication, and situational awareness among operators managing multiple UAS. Enhancing CRM effectiveness involves the development of tailored training programs specifically designed for m:N operations. Taking insights from existing practices (discussed in Section 3), these programs should emphasize effective communication protocols, decision-making processes in complex scenarios, teamwork dynamics unique to multi-UAS management, and stress management techniques for high-pressure situations.

Equally important is the establishment of a well-defined organizational hierarchy with clearly delineated roles and responsibilities for each team member. This structure incorporates structured communication channels to minimize confusion and protocols for escalation and decision-making authority. By clearly defining roles and responsibilities, organizations can ensure smooth coordination during missions and minimize the risk of errors or miscommunications.

To maintain comprehensive situational awareness, operators can benefit from leveraging advanced tools. These may integrate real-time data displays for multiple UAS, intelligent alert systems for critical events, and decision support systems to facilitate rapid response to changing conditions. Such tools are essential in helping operators manage the complexity of overseeing multiple UAS simultaneously.

4.1.3. Scheduling Strategies

Efficient scheduling is essential for maintaining high performance in m:N operations. Developing a robust scheduling framework that accounts for operational demands, mission requirements, personnel availability, and regulatory limitations on operator flight time is key to ensuring operators are available when needed and missions are appropriately staffed.

Workload management is a critical component of effective scheduling. Implementing measures to prevent operator fatigue and maintain peak performance involves designing shifts with regular breaks, incorporating task rotation, and establishing clear policies on maximum continuous operation time. This includes designing shifts with regular breaks and task rotation and establishing clear policies to maximum continuous operation time.

Organizations can improve operational capabilities by forming teams that integrate diverse skill-sets to enable comprehensive problem-solving during m:N operations. Rotating team compositions can promote knowledge sharing and skill development across the organization.

4.1.4. Framework Flexibility

A flexible framework is also essential for m:N operations, allowing real-time adjustments based on operational needs. Dynamic adjustment protocols are recommended for rapidly modifying personnel assignments and operational plans as circumstances change. This may involve pre-defined criteria for reallocating resources based on factors such as weather conditions, mission priority, or equipment availability.

Collaborative tools, such as shared dashboards, messaging applications, and task management systems can allow operators to quickly and easily share real-time information regarding operational status, potential risks, and resource needs. These tools facilitate effective communication and decision-making during missions.

Additionally, encouraging a culture of open communication empowers team members to propose changes that enhance flexibility and operational efficiency. Regular debriefs after missions can help identify areas for improvement and highlight successful adaptations to unforeseen challenges.

4.1.5. Points of Friction

When managing multiple sUAS, organizations may encounter several key friction points within their structure that can affect operational efficiency and safety. These challenges include:

- miscommunication among team members or between different operational roles, leading to misunderstandings about mission objectives and procedures
- ambiguity regarding roles and responsibilities, resulting in ineffective coordination
- increased operational demands, which can lead to overload, reducing situational awareness and decision-making capabilities
- ineffective allocation of personnel, equipment, or technology resources, leading to inefficient or delayed mission execution

4.1.6. Regulatory Considerations

Understanding the regulatory frameworks governing UAS operations is vital for developing an effective m:N organizational structure. Different regulations apply depending on the nature and scope of the operations, each with its own set of requirements and implications for organizational structure.

Part 107 of the FAA sets the baselines for many UAS m:N operations. Key considerations for organizational structure under Part 107 include:

- incorporating additional personnel such as visual observers or ground crew to maintain visual line of sight (VLOS) or assist in waived (BVLOS) operations
- establishing a team or role dedicated to applying for and managing operational waivers (e.g., BVLOS or night operations; Zoldi, 2024)
- implementing operational safety protocols and ensuring crew training aligns with regulatory requirements

Under Part 107, operators are only required to designate a RPIC who holds a remote pilot certificate to oversee compliance with regulations (Federal Aviation Administration, n.d.-g). This limited personnel requirement allows organizations to adopt a relatively flexible structure, focusing on minimal staffing and operational simplicity.

In contrast, Part 135 operations must meet stricter requirements, including the implementation of a formal SMS, comprehensive crew training programs, and detailed operational manuals (Federal Aviation Administration, n.d.-a). Therefore, Part 135 operations require a more formalized structure to ensure compliance with these rigorous standards.

Military UAS operations are governed by even more rigorous protocols and a hierarchical structure designed to ensure mission success across various defense and security contexts.

Accounting for the specific constraints and requirements set by the applicable regulations—whether Part 107, Part 135, or military protocols—is essential to achieving compliance, operational efficiency, and safety across different UAS operational contexts.

4.1.7. Feedback and Continuous Improvement

Organizations are encouraged to foster a culture and system that values continuous improvement by providing employees with opportunities to learn new skills, adopt new methods, and deepen their understanding of emerging technologies. These initiatives can enhance operational capability and contribute to employee retention. It is also advisable to thoroughly document learning objectives alongside all training records.

Incorporating feedback from team members across all phases of mission operations is critical for maintaining a safe and efficient work environment for sUAS operations. Conducting detailed post-mission debriefs as a team helps capture lessons learned and identify areas for improvement.

4.2. Training

The increasing complexity of m:N operations necessitates the evolution of training programs to equip operators with the skills required for safely and effectively managing multiple UAS simultaneously. The objective of m:N training is to ensure that operators are proficient in supervising these complex systems while maintaining situational awareness and responding swiftly to any irregularities or failures. The recommendations outlined in this section are informed by the existing practices detailed in Section 3, which highlight how organizations such as LAFD, DPD, and the DoD have successfully developed training protocols to enhance operator proficiency and mission effectiveness.

Effective training programs can utilize a combination of:

- ground school “classroom” sessions covering the relevant rules and regulations, as well as the roles/responsibilities, m:N specific policies, BVLOS operations, and waiver conditions
- m:N simulator training for familiarity and more challenging m:N scenarios without the flight risk (there are companies building UAS flight simulators today)
- flight training designed to expand pilot competency to comfortably maintain situational awareness and control of multiple UAS during simulated normal, abnormal, and emergency operations

Training is essential for sUAS implementation, especially at scale. Where m:N BVLOS operations are concerned, proper training enhances system safety, efficiency, and overall human performance. To date there is not an officially approved training program outside of Part 107, and Part 107 does not cover all aspects of m:N UAS operations. With regard to AAM operations, implementing a training program that includes BVLOS training before incorporating m:N operations is crucial.

Drawing on lessons learned from existing practices detailed in Section 3, the training should be designed to provide a comprehensive understanding and hands-on experience with every aspect of the flight operations.

Beyond BVLOS considerations, additional m:N training requirements can include simulator and then flight proficiency checks for:

- positive transfer of aircraft control between safety pilot (if applicable), operator, and supervisor
- supervisor recognition and response for operator issues (e.g., health, excessive workload, errors, fatigue; see subsection on safety and fatigue management in Section 4.5.)
- understanding and acknowledging when workload is high
- acceptable response times for warnings needing immediate response
- m:N communications standards
- simulated normal, abnormal, and emergency operations to ensure operators can safely recover and/or land up to the maximum number of allowed UAS
- awareness of automation bias and complacency, ensuring operators do not overly rely on automated systems or overlook potential system-generated errors

Operational training is critical, and these aspects outlined here remain valid for m:N operations. However, when operating at scale, operational complexity increases significantly, introducing additional vital considerations. Proficiency in reporting and analytics becomes crucial, as does understanding cybersecurity and data protection. Operators are also expected to excel in teamwork and multidisciplinary interactions, as many roles within an operation extend beyond piloting.

In addition, training programs benefit from addressing the integration of various subsystems, such as UTM, DAA, and environmental monitoring systems. Operators need to grasp how these components interact and impact overall system performance. With the rapid advancement of technology, incorporating elements that facilitate continual learning and regular updates ensures personnel remain aligned with the latest developments and best practices.

4.2.1. School

The initial phase of m:N training begins with classroom sessions that establish foundational knowledge. These sessions cover essential topics such as FAA regulations for BVLOS operations and waiver conditions, as well as the specific roles and responsibilities within m:N operations. CRM is a crucial part of this training, emphasizing the importance of effective communication and coordination between operators and supervisors. Ground school also focuses on the development of emergency response protocols and communication standards, ensuring that operators can effectively collaborate with their teams and subsystems in real time.

4.2.2. Simulator Training

Simulator training plays an indispensable role in m:N operations, providing operators with hands-on experience in managing multiple UAS under both normal and abnormal conditions without the risks associated with actual flight operations. Simulators replicate real-life scenarios, such as loss of communication or automation failures, allowing operators to practice managing contingencies and recoveries. Simulator training also reinforces the importance of managing cognitive load and mitigating automation bias, such that operators remain engaged and prepared to intervene when necessary.

Where possible, operators should be training using a simulator in addition to live training, as recommended by the Au report (Federal Aviation Administration, 2023). Operators should receive m:N specific training in the classroom and on the simulator (or representative environment). The training should encompass both knowledge assessments and performance evaluations to ensure comprehensive understanding and skills application.

The simulator should also mimic the actual UAS platform in terms of capabilities and user interface design. This consistency helps to avoid confusion and errors that can occur when features are introduced to the cockpit before they are reflected in the simulator, as evidenced by the challenges faced in manned aviation.

As part of a testing standard, and as detailed in the Au report (Federal Aviation Administration, 2023), the following requirements should be met:

- A simulator (or a comparable experiential training environment) shall use the same UAS software and user interface that will be used in actual operations. Additionally, updates to the UAS software and user interface should be aligned with what is taught in the simulator (i.e., same capabilities, features, and look and feel).
- If simulation testing is not viable, then a representative environment may be substituted if available, such as at a UAS test range that has an m:N authorization or another alternate environment with an m:N flight authorization.
- All the m:N and supporting BVLOS requirements (including CRM/operational) shall be verified and validated in the simulator, with a subset tested on a physical UAS in a 1:1 operation.

Note that even today, simulation can be implemented using real-life UAS platforms in the field with software assisting the operation and remotely operated or assisting in a sim-to-real environment.

4.2.3. Flight Training

Flight training further expands the operator's capabilities by providing real-world experience in managing multiple UAS during live operations. Operators will focus on maintaining situational awareness and controlling UAS through complex scenarios, including emergency situations. The ability to transfer control between safety pilots, supervisors, and other personnel will be evaluated through flight proficiency checks. These tests will ensure that operators can effectively manage real-time operations.

Part 107 Operations

Training for Part 107 emphasizes operator skills, such as maintaining VLOS, adhering to airspace restrictions, and managing UAS during standard commercial operations (Federal Aviation Administration, n.d.-g). Operators must demonstrate proficiency in handling UAS under the constraints of Part 107, including emergency responses like loss of control or battery failures.

Part 135 Operations

Part 135, also known as the Air Carrier and Operator Certification Process, is the only regulatory path for UAS to carry another party's property for compensation under/in BVLOS conditions (Federal Aviation Administration, n.d.-a). Similar to private aircraft certification, Part 135 comes with specific operating limitations, but offers greater operational flexibility than Part 107, such as the ability to fly over people and BVLOS. Advanced training is required for Part 135 operations, including:

- developing proficiency in role-based team operations
- practicing complex scenarios, such as transferring control between operators, supervisors, and safety pilots
- implementing and adhering to a SMS that ensures operational compliance and safety standards

4.2.4. Crew Resource Management

In addition to Part 107 training, Part 107 certification, and the aforementioned recommendations, there are still other training requirements that should be considered. CRM is a set of training procedures for use in environments where human errors can have devastating effects. CRM is primarily used for improving aviation safety and focuses on communication and decision making. CRM provides many risk mitigations needed for complex multi-crewed m:N BVLOS UAS operations. Complex UAS operations require communication, situational awareness, and leadership skills to optimize decision-making based on the effective use of all available resources.

CRM skills should be considered to enhance crew coordination and teamwork to successfully and safely operate in the complex UAS m:N BVLOS environment. The rules and standards in CRM are robust and solid for an operation on-site or where a supervisor has direct and present contact with operators in a command center or tower. However, decentralized command centers will be common. Similarly to what happened during the pandemic, when teachers and students were unprepared to transition from in-school instruction to fully digital courses, significant challenges emerged. It has taken several years to address these challenges, and some believe that educational institutions are still working to regain lost progress. If CRM protocols are not revised with the forethought to handle these new UAS environments, a similar scenario could occur. Evaluating digital and decentralized scenarios for CRM effectiveness is an important step in mitigating such issues.

Safety Management System (SMS)

Within the context of the larger safety culture, effective CRM is an attribute of an organization’s commitment to safety. During Au’s m:N BVLOS tests, all required crew members were qualified under the organization’s voluntary SMS. In addition to the FAA SMS guidance, there were human factors, personnel, and training related requirements which included:

- safety culture with open and honest communication
- active engagement in identifying emerging hazards
- management commitment to addressing safety risks
- role-based training

More information on SMS systems can be found under Section 4.5.2.

4.2.5. Continuous Training

Continuous training is necessary to keep operators updated on the latest technologies and best practices. Regular proficiency checks and annual refresher courses will ensure that operators maintain their skills in managing multiple UAS, including emergency and contingency handling.

Proficiency checks should include both simulator-based scenarios and actual flight operations to validate their real-world application (Federal Aviation Administration, 2023). This continuous learning approach will help operators stay current as systems evolve.

4.3. Personnel Selection

Building on insights from existing practices detailed in Section 3, operator selection is recommended to focus on identifying a representative set of capable operators. The representative operators would ideally reflect the range of "typical" operators given proper training and experience, as opposed to expert or above average operators. Research suggests that experience with fast-action video games may enhance cognitive skills, multitasking abilities, and proficiency in managing automated systems (Wright, 2017) and ultimately predict positive UAS operator performance (Ferraro et al., 2022). Research has also shown that familiarity with automation, whether through gaming or previous UAS experience, can also improve an operator's ability to trust, manage, and effectively leverage automated systems during operations (Zhang et al., 2024). Additionally, exposure to structured and high-pressure environments, such as military operations, are likely to develop strong decision-making and problem-solving skills under stress.

The example of the 160th SOAR, detailed in Section 3.5.6., provides valuable insights into personnel selection, which can be applied to UAS operations. The following key takeaways from SOAR can help guide the development of personnel selection strategies as we move towards m:N and larger team operations:

- UAS operators should undergo a thorough screening process to evaluate their fit for the role. This includes evaluating both technical competencies and personal attributes that align with the organization's values and mission.
- Personnel selection should include flexible evaluations of an individual's ability to adapt to complex and evolving environments. These evaluations should be conducted by a diverse panel to ensure that candidates are assessed on both technical skills and mental resilience, adaptability, and judgment.
- UAS operators should engage in continuous training and professional development. Regular assessments, such as annual performance checks, can ensure personnel remain prepared for new challenges.
- Leaders should be actively involved in identifying performance gaps and offering support for improvement through personalized development plans. However, there should be clear criteria for reassignment or release if personnel are unable to meet expectations to ensure that standards are maintained across the organization.

4.4. Operational Procedures

Developing and refining operational procedures is essential to ensure safety, efficiency, and regulatory compliance. Effective task analysis, comprehensive training, and standardized operating procedures (SOPs) are critical components of this effect. These processes aim to optimize operator performance, manage cognitive load, and address the unique challenges posed by managing multiple UAS simultaneously.

This section outlines recommendations for task analysis, training validation, and SOP development, drawing from insights detailed in the Au report (Federal Aviation Administration, 2023). Key considerations include establishing safety protocols, creating communication standards, and integrating lessons learned from analogous high-stakes environments such as ATC.

4.4.1. Task Analysis

A task analysis is essential in determining the maximum feasible number of UAs that can be safely operated by a single operator (1) or a few (m) operators in a one to many (1:N) or a few to many (m:N) UAS operation. This number would be expected to fluctuate based on the level of automation and the number of exceptions experienced by the UAS. For example, in a fully autonomous setting with no issues, an operator would be able to supervise more UAS than in a setting with less automation and/or multiple issues across several aircraft. A matrix may be needed to assess and quantify the cognitive load associated with different operational scenarios, ensuring that workload remains within safe limits.

Test data can be collected to validate the task analysis timing, occurrence of errors, and operator perception of workload. This can be done subjectively via surveys such as the NASA Task Load Index (NASA-TLX).

As detailed in the Au report (Federal Aviation Administration, 2023), operators should successfully complete the following validation test cases on a simulator or in the representative environment:

- normal 1:1 operations to gather timing data to confirm the task analysis and to establish baseline performance
- 1:1 testing of all manual contingencies (note that this can be done in conjunction with testing the requirements, but the operator needs to make sure data is gathered for baseline timing)
- normal operations with mid-point number of UAS (i.e., N/2)—optional test case to confirm the infrastructure, performance, and procedures can scale
- normal N UAS operations to check timing, performance, and adherence to procedures
- N UAS handling all manual contingencies
- N UAS handling representative/critical automatic contingencies
- N UAS response to realistic common mode failures (e.g., internet connection, area outages, computer failure, etc.)
- N UAS with transfer of control to supervisor (e.g., sudden health issue)
- N UAS with multiple realistic events—combination auto and manual contingencies
- additional scenarios could include highly congested airspaces or full N operation

In addition to the simulator, operators should also perform training flights with actual UAS (Federal Aviation Administration, 2023). In accordance with the Au report, flight testing shall not proceed until:

- The timing and sequences in the m:N task analysis are confirmed. This ensures the number of UAS flown in a physical environment is supported by the theoretical maximum number of UAS "N."
- Data from the operator's perception of workload is determined to be acceptable, aiming to maintain workload levels comparable to those of today's ATC personnel.
- The cause of any potentially hazardous conditions detected during simulation or previous flight testing is identified (e.g., software anomalies, confusion, inadequate response times, etc.).
- Regression testing is done on any updates from simulation testing.

- Regulatory authority operating approvals are obtained using the simulator data prior to flight test (unless testing is performed at a UAS test site with an m:N approval or other alternate environment with a m:N flight authorization).

In addition to establishing the initial BVLOS m:N operations, the organization should also implement annual training that includes proficiency checks from the most challenging simulation and flight test cases (e.g., low battery during intruding aircraft on one UAS with C2 loss and intruder on another) and lessons learned. A monitoring program focused on continuous improvement that proactively evaluates the effectiveness of the safety mitigations and implements correct actions, such as a SMS, should also be established to prevent future incidents (Federal Aviation Administration, 2023).

4.4.2. Standard Operating Procedures (SOP)

The operational procedures and training should be updated to reflect operations with "N" UAS, in accordance with the guidance given by Au (Federal Aviation Administration, 2023). This could include leveraging training, techniques, and lessons learned from ATC, as many tasks—such as supervising multiple aircraft within a specified airspace—are similar. Revising operational procedures to address the increased scale and complexity of operations could include developing protocols for efficient task delegation, real-time monitoring, and response strategies for abnormal or emergency situations involving multiple UAS.

SOPs should also be considered and these can be driven by m:N BVLOS operations. As part of Au's research (Federal Aviation Administration, 2023), the following recommendations were made for SOPs:

- Establish clearly defined roles, responsibilities, and authorities between the operator, supervisor, and safety pilot (if applicable).
- Define minimum qualifications for each role, which included prior BVLOS experience and training.
- Establish flight operations standards, including transfer of displays/controls to/from the operator, supervisor. and safety pilot (if applicable).
- Define the frequency of briefings and use of checklists. In the case of the Au research, for example:
    - All operators are to meet with a supervisor at the beginning of the shift.
    - A full pre-flight inspection is to be performed on each UAS by the on-site safety pilot.
    - An abbreviated pre-flight inspection is to be performed before successive flights.
- Establish communications standards.

As an example, in a remote operating center, a supervisor may be overseeing multiple operators flying (or overseeing) multiple UAS. The following phrases identified, through research conducted by Au, could be implemented to minimize communications:

- "Call and response" communication style, similar to traditional ATC towers and ARTCCs. For example:
    - Operator (RO): "SUP, your controls"
    - Supervisor (SUP): "RO, my controls"
- Use callsigns to distinguish the different operators that are unique, consistent, easy to pronounce, and easy to distinguish via voice communications.

- Use location or UAS identifiers that are unique, consistent, easy to pronounce, and easy to distinguish via voice communications.
- Terminology standards that cover:
  - all modes of operations, including contingencies
  - current UAS status conditions
  - transition of control
  - phraseology consistent with FAA Order 7110.65 to minimize misunderstanding between the operator, supervisor, and safety pilot (when applicable)

4.5. Safety and Fatigue Management

The effective management of safety and fatigue is critical in the evolving landscape of UAS operations, particularly as m:N BVLOS operations introduce unique challenges not present in traditional aviation. Ensuring operator readiness, maintaining situational awareness, and mitigating risks associated with fatigue are essential in maintaining high safety standards and operational efficiency. This section explores strategies for addressing fatigue and workload management, including the implementation of a SMS to identify, assess, and mitigate risks in aviation operations.

4.5.1. Fatigue and Workload Management

Fatigue should also be considered, especially given the added complexity of an m:N environment, where the concept of pilot workload will differ from traditional aviation. Additionally, as automation capabilities advance, the distribution and duration of workload will shift. Further research on workload and fatigue could explore the similarities between m:N operations and today's ATC practices.

Fatigue-related work scheduling requirements refer to guidelines designed to mitigate fatigue through structured scheduling practices and safety risk controls. These include setting limits on work hours, ensuring adequate rest periods, and incorporating regular breaks into operational schedules to reduce fatigue-related risks.

Ultimately, fatigue assessments should be based on a safety assessment of the operational complexity. However, it is important to recognize that fatigue assessments are dependent on the complexity of the operation and resulting levels of workload. For example, the following list outlines possible operational limitations aimed at managing fatigue for m:N BVLOS operations:

- Scheduled shifts should not exceed 10 hours.
- Where operational work exceeds 10 hours, it must be approved by the Safety Leader on a case-by-case basis.
- Operators must have a minimum of 15-minute break every two hours.
- Operators must have a minimum of 9–11 consecutive hours off duty before a shift starts, depending on the operational workload and complexity, to ensure sufficient rest.
- A regular day off is required after working 6 consecutive days.

These measures are based on existing fatigue guidance developed by the FAA for air traffic controllers and adapted to address the unique demands of UAS operations. While some research in pilot fatigue points to similarities to manned aviation, (Federal Aviation Administration, 2021), the nature of UAS operations introduces unique scenarios that warrant further investigation. For instance, as remote BVLOS operations become more common, mobility considerations, device factors, and operational context and ergonomics may negatively affect how a remotely operated mission will be executed and how operators will be subject to stress and fatigue.

As part of the Au study, to mitigate risk of fatigue for UAS operations, operators adopted the "I'M SAFE" program for all required crew members during the initial pre-flight and when mission requirements extended operations beyond 2 hours. Though voluntary for UAS operations, embedding a similar checklist into standard procedures is recommended to help mitigate risks with complex UAS operations.

- *Illness*: Do I have any symptoms?
- *Medication*: Did I take prescription or over-the-counter drugs that could affect my performance?
- *Stress*: Am I worried about financial matters, health issues, or family discord?
- *Alcohol*: Have I consumed alcohol within the last 8 hours?
- *Fatigue*: Am I tired and not adequately rested?
- *Emotion*: Am I emotionally upset?

If operators answer "yes" to any of the "I'M SAFE" checklist questions, it could indicate that they are not fit for duty, jeopardizing the safety of operations. This unfitness may lead to impaired cognitive function, slow reaction times, and decreased situational awareness, increasing the risk of errors in judgment or decision-making. As a result, it is advisable to relieve an affected operator from duty.

4.5.2. Safety Management System (SMS)

A SMS in aviation is a systematic approach to managing safety, including the necessary organizational structures, accountabilities, policies, and procedures. It encompasses a set of principles, processes, and tools designed to ensure that risks associated with aviation activities are identified, assessed, and effectively controlled. Key components of an SMS typically include:

- Safety Policy: Outlines the organization's commitment to safety and defines the overall objectives and responsibilities for safety management.
- Safety Risk Management: Involves the systematic identification, assessment, and mitigation of safety risks associated with aviation operations. It includes processes for hazard identification, risk assessment, and the implementation of risk controls.
- Safety Assurance: Ensures the ongoing monitoring and measurement of safety performance to ensure that safety objectives are being met. It includes processes for safety audits, inspections, and performance monitoring. Safety assurance also involves feedback mechanisms to improve safety practices and rectify identified issues.
- Safety Promotion: Focuses on promoting a positive safety culture within the organization through training, communication, and safety awareness programs.

SMS is a proactive approach to safety management, emphasizing continuous improvement and the involvement of all stakeholders, including management, employees, regulators, and other relevant parties. It is mandated by aviation regulatory authorities such as the International Civil Aviation Organization (ICAO) and is required for all aviation organizations to enhance safety performance and minimize risks in aviation operations.

4.6. Technological Integration and Automation

The integration of advanced technologies and automation has become a cornerstone for enhancing efficiency, safety, and operator performance. Innovations such as multimedia-based learning tools and the adoption of digital flight rules are transforming traditional training paradigms and operational procedures. At the same time, the increasing reliance on digital systems highlights the need for robust cybersecurity measures to protect data integrity and mitigate risks associated with evolving threats. This section explores key technological advancements and their implications for UAS operations, with a focus on improving training methodologies, incorporating human factors principles, and addressing emerging regulatory requirements.

4.6.1. Just-in-Time Training

The FAA plays a vital role in highlighting the need for flexible and responsive training programs that equip operators with the necessary skills to adapt to changing operational demands. Just-in-time (JIT) training, a concept borrowed from other industries (such as manufacturing and healthcare), is gaining traction in the UAS domain. JIT training for UAS operators offers on-demand access to critical learning materials, enabling them to adapt to emerging technologies, new operational environments, and unexpected challenges in real-time.

For instance, JIT training can deliver quick refreshers on crucial UAS systems, airspace regulations, or emergency procedures immediately before a flight. As UAS operations grow in complexity, especially in BVLOS and m:N scenarios, JIT training ensures operators remain current with the latest safety protocols, risk mitigation strategies, and regulatory updates without requiring extensive time away from operations for traditional classroom learning.

4.6.2. Multimedia and UAS Training

The integration of multimedia in UAS training programs has emerged as a powerful tool for improving knowledge retention and skill development. The FAA plays a significant role in highlighting the potential of these tools to enhance learning outcomes and operational safety. Video tutorials, interactive simulations, virtual reality (VR), and augmented reality (AR) modules offer engaging, immersive experiences that can accurately replicate real-world UAS operations and complex scenarios. These technologies are particularly valuable for training in situations that would be challenging or hazardous to practice in live environments.

Interactive simulations, for instance, provide operators with hands-on experience in UAS controls, airspace management, and emergency procedures without the associated risks of live flights. Similarly, VR and AR environments facilitate full-scale training on navigation, obstacle avoidance, and coordination with multiple UAS in m:N operations, giving operators practical exposure in a safe, controlled setting.

The FAA's approach to incorporating these technologies into UAS training is evolving. While there are no specific regulations solely dedicated to multimedia training technologies for UAS, there are some relevant points to consider:

- The Unmanned Aircraft Systems Collegiate Training Initiative (UAS-CTI) acknowledges the use of drones and related technologies in educational settings, potentially paving the way for more advanced training methods (Federal Aviation Administration, n.d.-h).
- In the broader aviation context, there's a growing push from flight training officials to incorporate VR and AR technologies. The European Union Aviation Safety Agency

(EASA) has already approved VR technology for flight simulation training, and the FAA is expected to follow suit (European Union Aviation Safety Agency, 2021).

- While not specifically addressing UAS, the FAA's National Simulator Program (NSP) establishes standards for Flight Simulation Training Devices (FSTDs) (Federal Aviation Administration, n.d.-e). This framework could potentially be adapted or expanded to include UAS training simulators in the future.

4.6.3. Cybersecurity and Data Privacy

As UAS operations evolve, there is a growing recognition of the need for operators to be equipped with the skills necessary to manage digital threats and ensure data integrity within their systems. The FAA plays a crucial role in shaping the regulatory framework surrounding UAS operations, highlighting the importance of cybersecurity training as an essential component of comprehensive operator education. While there are currently no specific guidelines solely dedicated to cybersecurity training for UAS operators, the FAA does recognize the need for operators to develop competencies in safeguarding against potential vulnerabilities. Additionally, the Cybersecurity and Infrastructure Security Agency (CISA) provides resources to increase awareness of UAS cybersecurity risks (Cybersecurity and Infrastructure Security Agency, n.d.).

As a result, there is a pressing need for UAS training programs to address the legal implications surrounding data collection, storage, and transmission. Incorporating robust cybersecurity components into training initiatives can help address potential vulnerabilities associated with UAS operations. This includes best practices for securing communication links and safeguarding sensitive data against unauthorized access, ensuring that operators can effectively mitigate risks.

4.6.4. Digital Flight Rules

The introduction of digital flight rules (RTCA, 2023) is reshaping the regulatory landscape and corresponding training requirements for UAS operators. Digital flight rules leverage digital communication and automation to improve airspace management, facilitating BVLOS and m:N operations by reducing manual input and decision-making burdens on operators. As these rules become more prevalent, UAS training programs will need to incorporate new modules that focus on understanding and applying them in daily operations.

Operators will require training on interacting with digital systems governing UAS flights, such as automated airspace authorization, real-time traffic alerts, and adaptive route planning systems. Training will emphasize the operator's role in overseeing these digital processes, ensuring they can monitor and intervene when necessary. Moreover, the shift to digital flight rules is expected to bring a need for updated human factors training, equipping operators to balance trust in automated systems with their own manual oversight and intervention skills.

5. Gaps Identified

As the landscape of m:N sUAS operations continues to evolve, several critical gaps have emerged across key areas of personnel selection, training, and operational readiness. These gaps pose significant challenges to the safe scaling of m:N operations and the establishment of consistent performance standards across the industry.

One of the most pressing issues is the lack of standardized training programs specifically designed for m:N operations. While general training frameworks exist, there is no universally accepted program that adequately prepares operators for the complexities of managing multiple UAS simultaneously. Most current training focuses on single-operator, single-UAS scenarios, leaving a significant gap in preparing personnel for the demands of m:N environments. Furthermore, existing FAA training standards, such as those outlined in Part 107, fall short of addressing the requirements of BVLOS and m:N operations.

Closely related to this is the inadequate training in automation management. As UAS operations become increasingly dependent on automation, operators often find themselves ill-equipped to handle high levels of automation effectively. This gap in training can lead to automation bias, as well as over-reliance on autonomous systems, potentially compromising safety, especially in abnormal scenarios. There is a clear need for structured training that focuses on maintaining situational awareness and readiness to intervene when automated systems fail or behave unpredictably.

The unique cognitive demands of m:N operations have also highlighted a significant gap in fatigue and workload management training. Current programs often fail to address the strategies needed to prevent cognitive overload and manage the increased mental strain associated with supervising multiple UAS. This gap could be addressed by incorporating research and best practices from related fields, such as air traffic control, which have extensive experience in managing high-stakes, cognitively demanding tasks over extended periods.

Another critical area of concern is the insufficient training for BVLOS operations. Despite the growing prevalence of BVLOS scenarios, training for these operations remains inconsistent and often inaccessible. This gap in BVLOS-specific training covers several crucial areas, including:

- communication protocols specific to BVLOS operations
- understanding and compliance with waiver requirements
- emergency management in BVLOS scenarios
- navigation and spatial awareness without visual reference

The lack of comprehensive BVLOS training could significantly hinder the scalability and safety of m:N operations as they expand into more complex and diverse environments.

Furthermore, there is a notable gap in training that integrates various subsystems and orchestration software. While technologies such as UTM and DAA systems are essential for the success of m:N operations, operators are not consistently trained to manage these technologies in conjunction with UAS control. This lack of integrated training can lead to:

- inefficient use of critical subsystems
- increased risk of errors in complex operational scenarios
- reduced ability to respond effectively to system anomalies or failures

Lastly, the rapid evolution of m:N operations has outpaced the development of clear operational role definitions and personnel selection criteria. Many organizations struggle to define new roles and responsibilities that reflect the operational complexity of m:N UAS supervision. This gap in role definition and personnel selection can lead to:

- mismatched skill sets for operational requirements
- inefficient task allocation and team dynamics
- increased risk of human error due to role ambiguity

Addressing these gaps will require a holistic approach to m:N training and personnel selection, drawing lessons from other highly automated industries. Industry-wide collaboration will be crucial in developing standardized training programs, robust automation management protocols, and clear criteria for personnel selection that reflect the evolving nature of UAS operations.

6. Next Steps

The development of standardized m:N training programs benefits from collaboration between industry stakeholders, regulatory bodies, and human factors experts. These programs should draw from established practices in complex, high-stakes environments such as air traffic control. From a human factors perspective, training programs are most effective when they go beyond technical skills to address the cognitive and psychological aspects of m:N operations. Key components to consider include:

- BVLOS-specific training
- CRM skills adapted for the m:N environment
- fatigue management protocols that account for the increased cognitive load of monitoring multiple UAS
- stress management techniques to help operators maintain performance under high-pressure situations

Simulation-based training offers an initial focus, providing realistic scenarios that enable safe learning across a wide range of operational conditions.

Establishing robust personnel selection criteria is equally crucial. Drawing from military operations such as SOAR, the selection process should include psychological and cognitive assessments to evaluate aspects such as stress resilience and adaptability. Additionally, once a candidate has been selected, assessments and training updates should be ongoing to meet evolving demands.

Expanding collaboration with academia and industry is another crucial step in refining best practices for m:N operations. This collaboration should focus on:

- conducting targeted research on human factors issues specific to m:N operations, such as:
  - optimal interface design for managing multiple UAS
  - workload management strategies for prolonged m:N operations
  - assessing the cognitive load limits of operators when supervising multiple UAS, and establishing benchmarks for operator-to-UAS ratios
- improving human-machine collaboration in m:N operations
- exploring the potential of new technologies, such as AI assistants and adaptive automation systems, to support operators in m:N environments

These research efforts should be guided by a human-centered design approach, ensuring that technological advancements enhance rather than hinder human capabilities in m:N operations. Additionally, regulatory bodies should work with industry and human factors experts to develop performance-based standards focused on measurable outcomes related to safety, efficiency, and operator performance.

By implementing these steps, the industry can create a robust framework for m:N sUAS operations that enhances safety and unlocks the full potential of this transformative technology. The path forward requires sustained commitment, collaboration, and an unwavering focus on the human element of these complex systems.

Appendix A. Excerpt from FAA Order JO 7110.65AA - Air Traffic Control

For the full document, visit the FAA's Air Traffic Control Manual or view the specific Appendix A in that document. Relevant excerpt:

1. Purpose

This appendix prescribes the method and step-by-step process for conducting a position relief briefing and transferring position responsibility from one specialist to another.

Discussion

Position relief unavoidably provides workload for specialists at the time of relief. The intent of this SOP is to make the transfer of position responsibility take place smoothly and to ensure a complete transfer of information with a minimum amount of workload. The method takes advantage of a self-briefing concept in which the relieving specialist obtains needed status information by reading from the Status Information Area/s to begin the relief process. Up to the moment information related to the control of aircraft or vehicular movements requires verbal exchanges between specialists during the relief process. The method also specifies the moment when the transfer of position responsibility occurs.

Step-by-Step Process

Assumption of Position Responsibility

Relieving Specialist	*Specialist Being Relieved*
1. Make a statement or otherwise indicate to the specialist being relieved that position responsibility has been assumed.	2. Release the position to the relieving specialist and mentally note the time.

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