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Annotated Bibliography (1997 – 2021): Crew and Staffing Requirements of Unmanned Aircraft Systems in Air Carrier Operations

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16. Abstract
There is an increasing demand to utilize unmanned aircraft systems (UAS) for an array of new applications currently outside the scope of written regulation, including taxi services, package delivery, crop dusting, and more. Current Title 14 of the Code of Federal Regulations (CFR) Part 107 is restrictive to air carrier applications for UAS. In particular, 14 CFR Part 107 regulations do not explicitly address 14 CFR Part 121 (i.e., air carrier operations) and 14 CFR Part 135 (i.e., commuter air operations). Crew and staffing requirements have been extensively researched in unmanned operations, the annotating of which is the focus of this document, but recent and continuing developments in UAS applications and UAS automation have resulted in changing roles and responsibilities for crewmembers. This annotated bibliography will help inform future regulations from last-mile to high-altitude-long-endurance operations so that these novel applications of UAS can be integrated safely into the National Airspace System (NAS). This annotated bibliography is an effort to synthesize crew and staffing literature to inform future regulations concerning UAS operators in air carrier operations. It encompasses a selection of literature regarding crew and staffing, automation, training, testing, and duty and rest requirements. Articles were collected from PsycINFO, Google Scholar, and Federal Aviation Administration (FAA) Technical Library databases by searching keywords related to unmanned operations and crew and staffing requirements. Seventy-six articles were determined to be relevant for this literature review. Articles included empirical studies, meta-analyses, literature reviews, and organization guidelines. This annotated bibliography is structured into two primary sections: Unmanned Aircraft Systems and Manned Operations with relevant subheadings. These subheadings were generated based on the general findings that crew and staffing needs should be determined by operational needs, and the rapid pace of development in UAS automation is resulting in changing roles for crewmembers. Standardizing UAS operator crew and staffing requirements will support the safe and efficient integration of UAS into the NAS. This remains an important initiative for the FAA and industry stakeholders.

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Acronyms

A&P	Airframe and Power Plant
ADS-B	Automated Dependent Surveillance - Broadcast
AFOQT	Air Force Officer Qualifying Test
AFS-800	General Aviation and Commercial Division
AOS	Operational Support Service
ASIAS	Aviation Safety Information Analysis and Sharing
ASVAB	Armed Services Vocational Aptitude Battery
ATC	Air Traffic Control
ATM	Air Traffic Management
AVO	Air Vehicle Operator
CAMP	Continued Airworthiness Maintenance Program
CFR	Code of Federal Regulations
COA	Certificate of Operation
CRM	Crew Resource Management
CS	Control Station
DAA	Detect and Avoid
DEMPC	Data Exploitation, Mission Planning, and Communications
DoD	United States Department of Defense
EASA	European Union Aviation Safety Agency
ECAT	Environment-Conscious Aircraft Technology Program
ELOS	Equivalent Level of Safety
EP	External Pilot
FAA	Federal Aviation Administration
FDP	Flight Duty Period
GCS	Ground Control Station
GUI	Graphical User Interface
HALE	High Altitude Long Endurance
HF	Human Factors
HFACS	Human Factors Analysis and Classification System
HITL	Human-in-the-Loop

A&P	Airframe and Power Plant
HMI	Human-Machine Interaction
HSI	Human Systems Integration
HUVS	Human-Unmanned Vehicle System
IFR	Instrument Flight Rules
JASS	Job Assessment
JUSTAS	Joint Unmanned Surveillance and Target Acquisition System
KSAO(s)	Knowledge, Skills, and Other Characteristics
LAANC	Low Altitude Authorization and Notification Capability
MAP	Mobility, Acquisition, and Protection
MC	Mission Commander
MCE	Mission Control Element
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NOTAM	Notice to Airmen
PAC	Perceived Attentional Control
PACT	Pilot Authority and Control of Tasks
Part 27	Title 14 CFR Part 27
Part 107	Title 14 CFR Part 107
Part 121	Title 14 CFR Part 121
Part 135	Title 14 CFR Part 135
PCSM	Pilot Candidate Selection Method
PF	Pilot Flying
PIC	Pilot-in-Command
PITVANT	Research and Technology Project in Unmanned Air Vehicles
PM	Pilot Monitoring
PO	Payload Operator
RCO	Reduced Crew Operations
RESCU	Research Environment for Supervisory Control of Unmanned-Vehicles
RPA	Remotely Piloted Aircraft

A&P	Airframe and Power Plant
RPIC	Remote Pilot-in-Command
RTCA	Radio Technical Commissions for Aeronautics
SA	Situation Awareness
SAA	Sense and Avoid
SAOC(s)	Skills, Abilities, and Other Characteristics
SME(s)	Subject Matter Expert(s)
SO	Sensor Operator
SpA	Spatial Ability
SPO	Single Pilot Operation
sUAS	Small Unmanned Aircraft System
TBAS	Test of Basic Aviation Skills
TCAS	Traffic Collision Avoidance System
TCRG	Technical Community Representative Group
TIGER	Testbed for Integrated Ground Control Station Experimentation and Rehearsal
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
USAF	United States Air Force
USS	UAS Service Supplier
UTM	UAS Traffic Management
UV	Unmanned Vehicle
VFR	Visual Flight Rules
VO	Visual Observer

Background

There is a rapidly increasing interest in the use of unmanned aircraft systems (UAS) for commercial air carrier operations, and the Federal Aviation Administration (FAA) is working to standardize UAS regulations for air carrier operations. Current air carrier regulations primarily focus on manned operations, which could serve as the foundation for future UAS regulations. However, unmanned operations present a unique set of challenges for regulators that are not addressed adequately by the existing regulatory framework, particularly in the area of the crew and staffing requirements. The Code of Federal Aviation Regulations 14 CFR Part 121 (Air Carrier Operations)[1] and 14 CFR Part 135 (Commuter Air Operations)[2] do not directly address the novel use of UAS in air carrier operations. Although 14 CFR Part 107[3] regulates commercial UAS, there is a gap in the regulation because it does not address systems that weigh over 55 pounds. Currently, the FAA issues certificates of operation (COAs) that allow UAS operations in the National Airspace System (NAS). These COAs require applicants to follow the FAA's existing Part 135 certification process, with exemptions granted to sections of Part 107 and Part 135 that do not apply to UAS air carrier operations at this time.

The rapid pace of automation research concerning the role of human operators in unmanned operations, as well as the increasing number of applicants for Part 107 waivers,[4] suggest that there may be a regulatory and safety environment gap in pilot and crew requirements between unmanned and manned operations. Recent development in automation has resulted in new and changing roles for crew and staff, especially with UAS. For example, increased system automation opens the door for multiple Unmanned Aircraft (UA) to be monitored at once by a single pilot with multiple data inputs. Additional training and testing requirements may be needed to account for increased crewmember roles. This has the potential to influence how many personnel are necessary to monitor multiple UA safely and effectively. For example, Wing Aviation, LLC was granted recently a COA[5] requiring Part 135 certification; however, it limits a single pilot to flying no more than five UA at a time for delivery operations. Another factor that must be considered is duty and rest requirements for UAS crew and staff. Reduced personnel has the potential to increase fatigue and workload if a single pilot is expected to monitor multiple UA for extended time periods, and appropriate shift schedules will need to be established to reduce crew and staff fatigue.

[1] 14 CFR 121, Operating requirements: Domestic, flag, and supplemental operations. https://www.ecfr.gov/current/title-14/chapter-I/subchapter-G/part-121

[2] 14 CFR 135, Operating requirements: Commuter and on demand operations and rules governing persons on board such aircraft. https://www.ecfr.gov/current/title-14/chapter-I/subchapter-G/part-135

[3] 14 CFR 107, Small Unmanned Aircraft Systems. https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107

[4] See https://www.faa.gov/uas/commercial_operators/part_107_waivers/waivers_issued/ for an updated list of current Part 107 waivers issued.

[5] FAA Certificate of Waiver No. 107W-2019-01205A, 2019.

Purpose

This annotated bibliography aims to identify how crew and staffing needs are addressed in unmanned and manned operations with a focus on UAS to provide a framework for future UAS regulations with air carrier operations. Specifically, the goal is to identify the minimum crew and staffing requirements necessary to operate UASs successfully while providing an equivalent level of safety (ELOS) comparable to manned operations. It is likely that these crew and staffing requirements will differ by type of operation, and may additionally depend on other factors such as knowledge, skills, and other characteristics (KSAOs).[6] There is little distinction between "crew" and "staffing" requirements in the literature. For this report, crew requirements refer to individual roles necessary to successfully execute a UAS operation (e.g., pilot-in-command [PIC], launch and recovery, sensor operator [SO]). Staffing requirements refer to the number of crewmembers necessary to execute a UAS operation successfully, including multiple crewmembers at the same position. This annotated bibliography reviews the status of crew and staffing research for unmanned and manned operations in air carrier operations and related fields. It includes research on duty and rest requirements (e.g., fatigue, shiftwork) as it pertains to the minimum number of crewmembers needed to operate UAS. Similarly, the literature notes that training and testing requirements are related to crew and staffing requirements and are, therefore, included. Also included is research on automated control of UAS, which could allow one pilot to fly multiple UA at a time. Documenting crew and staffing requirements, duty and rest requirements, and automation research in UAS operations will support ongoing rulemaking efforts led by the FAA General Aviation and Commercial Division (AFS-800) for UAS operations over people, UAS expanded operations (e.g., commercial air carrier), and UAS non-segregated operations (i.e., beyond current UAS-permitted airspace) in the NAS. It will also support ongoing collaborations with various standards groups such as the Radio Technical Commissions for Aeronautics (RTCA) Special Committee 228, UAS Technical Community Representative Group (TCRG), and the UAS Matrix Team.

Method

All articles included were collected from the PsycINFO, Google Scholar, and FAA Library databases using the following keywords:

- air carrier operations
- air taxi
- airworthiness
- duty and rest requirements
- high altitude long endurance (HALE)
- package delivery operations
- shift work, urban air mobility
- UAS crew requirements
- UAS knowledge requirements
- UAS knowledge and skill requirements
- UAS pilot certification
- UAS Traffic Management (UTM)

[6] See Torrence et al., 2020.

The keyword search was supplemented by searching the reference sections of included articles to identify articles not otherwise found in database searches. Seventy-six articles discussed crew and staffing requirements (in both manned and unmanned operations) and were selected for annotation. Selected articles included empirical studies, meta-analyses, literature reviews, and regulatory guideline documents. Annotations for articles were drafted and refined by the authors and approved by the FAA principal investigator who is a UAS subject matter expert (SME). This annotated bibliography structured crew and staffing literature into two primary sections: *Unmanned Aircraft Systems* and *Manned Operations*. Relevant subheadings are included within both sections by topic.

Literature/Research Outcomes

Crew and staffing requirements have been studied extensively in both unmanned[7] and manned[8] operations. Although regulations currently exist for manned air carrier (14 CFR Part 121) and manned commuter air (14 CFR Part 135) operations, there are none for unmanned air carriers beyond those specified in Part 107 and FAA exemptions for current UAS regulations (e.g., the COA granted to Wing Aviation, LLC).[9] Recommendations from the literature review vary by several factors, including operational environment[10] and level of UAS automation.[11] Duty and rest requirements,[12] reduced crew operations (RCO),[13] and crew resource management (CRM) principles[14] for manned operations provide some regulatory suggestions for unmanned operations, especially given the pace of development in UAS automation and how it affects the roles of crewmembers. A small portion of the literature review focusing on training and testing requirements for UAS crews emerged as additional considerations for crew and staffing requirements.[15]

Several articles in the literature review recommend dynamic crew sizing,[16] where the number of crewmembers and their roles are staffed based on aspects of the operation and individual workload. For example, long-endurance operations may require larger crews and specialized staffing.[17] Meanwhile, operations such as commercial photography may split piloting and photographing duties[18] – but some operations may combine these roles. Some research suggests that an automated system can be considered a crewmember as it handles duties typically

[7] Hopcroft, Burchat, & Vince, 2006; Crandall, Cummings, & Nehme, 2008; Norton, 2016; Sprengart, Neis, & Schiefele, 2018.
[8] Samel, Wegmann, & Vejvoda, 1997; DuBose, 2011.
[9] FAA Certificate of Waiver 107W-2019-01205A, 2019.
[10] Dao et al., 2018; Bendure, Fadel, Ray, & Washburn, 2019.
[11] McColl et al., 2017; Gimenes et al., 2014.
[12] European Union Aviation Safety Agency, 2019.
[13] Lachter et al., 2017; Sprengart, Neis, & Schiefele, 2018.
[14] Kanki, Anca, & Chidester, 2019.
[15] Bendure et al., 2019; Gildea, Williams, & Roberts, 2017; Rodriguez, 2012.
[16] Tvaryanas, 2006a; Rodriguez, 2012; Matos et al., 2015; Dao et al., 2017.
[17] Hopcroft, Burchat, & Vince, 2006; Tvaryanas, & MacPherson, 2009.
[18] Pratt, Murphy, Stover, & Griffin, 2009.

assigned to a "human" crewmember, and should meet the same regulation and testing requirements as human crewmembers.[19] Workload further appears in the literature on automated UAS where a one-person crew monitors multiple automated UA in lieu of active piloting.[20] These staffing recommendations are supplemented with post-accident assessments[21] and recommendations from duty and rest research.[22] References cited here are not a complete list of articles included in this Annotated Bibliography.

Findings

Crew and staffing research can inform FAA rulemaking on UAS requirements in air carrier operations. Basic and applied research is necessary to fully measure and evaluate the effects of automation, duty and rest requirements, and training and testing requirements in UAS operations, especially with the dynamic crew and staffing requirements. Additionally, particular attention must be paid to the rapid pace of automation research and its effects on crew and staffing requirements. Automation changes the role of pilots from active to passive. Crewmembers must be both trained to work with the autonomous system functions, and prepared for the resulting cognitive demands. Challenges unique to monitoring multiple UA and sources of data are likely to evolve as automation continues to develop, and further research is necessary to standardize UAS crew and staffing requirements. The safe and efficient integration of UAS into the NAS will be supported by standardizing UAS operator crew and staffing requirements. For those reading through the annotated bibliography, please note that the inclusion of any individual document within the bibliography does not constitute an endorsement of any of the recommendations made in the document.

[19] Gimenes et al., 2014.
[20] Crandall, Cummings, & Nehme, 2008; Cahillane, Baber, & Morin, 2012.
[21] Manning et al., 2004.
[22] Goode, 2003; Strauss, 2006; Arrabito et al., 2010.

Annotated Bibliography

Unmanned Aircraft Systems

Crew and Staffing Roles

Agrawal, A. K., Hoomaan, E., Basile, T., & Kamga, C. (2021). NJDOT UAS/Drone Procedures Manual and Best Practices for Use in New Jersey (Report No. NJ-2021-001). New Jersey Department of Transportation, Bureau of Research. https://rosap.ntl.bts.gov/view/dot/58713

Considerations when operating UAS in compliance with state laws in New Jersey are discussed. Although the FAA provides regulations for UAS operations within the NAS, certain use cases are restricted or prohibited by state law. These include motor vehicle, privacy, insurance, and public records laws, which are discussed in detail. A division of responsibilities for the Remote Pilot in Command (RPIC) and Visual Observer (VO) are provided, which includes both legal compliance and completion of mission risk assessments. Sample assessment forms, instructions, and decision-making guidance (with examples) are provided.

Bendure, A. O., Fadel, G., Ray, J., & Washburn, P. J. (2019). *ARM-related unmanned aerial system (UAS) and tethered balloon system (TBS) operational requirements and approval* (Report No. DOE/SC-ARM-19-022). U.S. Department of Energy, Office of Scientific Atmospheric Radiation Measurement Program. https://www.osti.gov/biblio/1558925

Standards and processes for small unmanned aircraft system (sUAS) and UAS operation certification, were identified for several crew roles including training and the responsibilities for pilots, operators, observers, and mechanics. Important responsibilities for an RPIC included assuring safety and regulatory compliance, coordinating with the FAA (e.g., restricted airspace, Low Altitude Authorization and Notification Capability [LAANC] authorization, Notice to Airmen [NOTAM] issuance), coordinating with local and international aviation groups (as needed), maintaining communications with other aircraft (e.g., deconfliction), determining required crew, maintaining situation awareness [SA] of nearby aviation assets (e.g., airports, navaids, airways), verifying airworthiness, conducting flight crew briefings, and executing the flight. VOs assisted with watching the UAS location and for incoming aircraft, helping with vision, monitoring weather conditions, and effective communications). Maintenance Technicians were needed for sUAS repair and modification; Airframe and Power Plant (A&P) Technicians were required for all other UAS. Both Maintenance Technicians and A&P Technicians required site-specific training and mechanical training, as well as training specific to their respective vehicles.[23]

[23] Currently, the FAA handles sUAS maintenance requirements through the use of a Continued Airworthiness Maintenance Program (CAMP) to issue repairmen certificates for low-level tasks such as replacing batteries and

Dao, Q. V., Martin, L., Mercer, J., Wolter, C., Gomez, A., & Homola, J. (2018). Information displays and crew configurations for UTM operations. In J. Chen (Ed.), *International Conference on Applied Human Factors and Ergonomics Vol. 784* (pp. 64-74). Springer, Cham. https://doi.org/10.1007/978-3-319-94346-6_7

The UAS Traffic Management (UTM) system under development by the National Aeronautics and Space Administration (NASA) was used to assess how team configuration may affect performance and information sharing within UAS crews. Crewmember size varied per crew (e.g., two to 12 crewmembers) but included aspects of the following roles: PIC, Ground Control Station (GCS) Operator, UAS Service Supplier (USS) Operator (the UTM Operator), launch and software flight engineers, and VOs. Two team configurations were tested: integrated and distributed crews. Integrated teams had a single crewmember acting as the USS Operator for a single crew, while distributed teams had a single crewmember acting as the USS Operator for multiple crews. Integrated crewmembers could focus solely on the mission, but they likely experienced high workload if they were performing two or more roles at a time. In contrast, the distributed crewmembers acted as a specialist for multiple teams, reducing necessary labor. However, the distributed crewmembers had increased workload because of constant communication between the crews and managing multiple flights. Results from the study revealed that the role of the USS Operator influenced how crews obtained their information; integrated teams relied more on their tools and instruments to receive necessary information while distributed teams relied on communication with VOs. Integrated teams reported higher levels of workload compared to the distributed teams, likely due to the USS Operators having shared roles with some of the crews. The amount of information to attend to depended on the size of the team. Additionally, ease of finding information was an important factor in determining the workload for a crew and how many crewmembers are needed.

Dao, A. Q. V., Martin, L., Mohlenbrink, C., Bienert, N., Wolter, C., Gomez, A., Claudatos, L., & Mercer, J. (2017). Evaluation of early ground control station configurations for interacting with a UAS traffic management (UTM) system. In J. Chen (Ed.), *International Conference on Applied Human Factors and Ergonomics Vol. 595* (pp. 75-86). Springer, Cham. https://doi.org/10.1007/978-3-319-60384-1_8

NASA's UTM system was tested with different technical capabilities to explore human factors (HF) in the setup of a GCS, perceived crew workload, and crew configuration. Eleven crews, ranging in size from two to five crewmembers, participated in a range of live flight scenarios. Crewmember roles included PIC, client operator, GCS operator, on-site software engineer, and launch technician. Auxiliary crewmembers were available to crews depending on the flight scenario. Crews were either integrated (a single crewmember acting as GCS operator and client

other repetitive tasks that can be trained without the need for a certificated A&P Technician. The CAMP certificates are restricted to specific systems and specific tasks, leaving the possibility of a more generic certification that might be created at some point to cover a larger variety of systems and tasks.

operator) or non-integrated (separate crewmembers acting as GCS operator and client operator). Workload, difficulty of communication, and quality of communication did not appear to differ between integrated and non-integrated crews. Integrated crews reported higher SA and better integration of procedures than non-integrated crews. It is possible that because they did not have to coordinate efforts between multiple crewmembers and because the roles were similar, integrated crews were better able to perform than non-integrated crews. It should be noted that multiple data points were missing in the study due to unpredictable flight conditions and no significance testing was conducted. All data analysis performed was strictly exploratory.

Gildea, K. M., Williams, K. W., & Roberts, C. A. (2017). *A historical review of training requirements for unmanned aircraft systems, small unmanned aircraft systems, and manned operations (1997-2014)* (Report No. DOT/FAA/AM-17/15). Federal Aviation Administration, Office of Aerospace Medicine. https://rosap.ntl.bts.gov/view/dot/35550

Current training programs required for UAS operations were reviewed and compared to manned aircraft training programs. There are aspects of flying a manned aircraft that do not apply to UAS and vice versa. Therefore, while some of the training should overlap, there should still be unique training required for UAS operations. While several gaps in existing training programs were identified, one general finding was that the current training required for UAS operations were not tailored enough toward UAS. For example, VO training has not yet been established. This training is broken down into categories that include (1) Policy and Responsibilities; (2) Preflight Preparation; (3) Flight Authorization, Approval, and Clearance Authority; (4) Preflight Procedures; (5) Airport Operations; (6) General Flight Operations; (7) Takeoff and Departure; Maneuvers; (8) Emergency Operations; (9) Slow Flight and Stalls; (10) Navigation; (11) Landings and Approaches to Landing; (12) Postflight Procedures; (13) Visual Flight Rules (VFR); (14) Instrument Flight Rules (IFR); (15) Normal Operating Procedures; (16) Safety/Operational Risk Management; and (17) Reporting Procedures. Most of the training between manned and unmanned operations was found to have similar requirements. Based on their review, detailed recommendations for future training requirements based on existing gaps for manned and unmanned aircraft operation training are provided. A table of UAS and associated training requirements are also included.

McColl, D., Gagnon, J.-F., Banbury, S., Arrabito, R., Pavlovic, N., Williams, F., Charron, M., & Hou, M. (2018). Crew performance and situation awareness in three UAS GCS layouts. In J. Chen (Ed.), *Advances in Intelligent Systems and Computing Advances in Human Factors in Robots and Unmanned Systems Vol. 595* (pp. 195–204). Springer, Cham. https://doi.org/10.1007/978-3-319-60384-1_19

The Joint Unmanned Surveillance and Target Acquisition System (JUSTAS) is a collocated Canadian military UAS operations team where pilots and SOs work together in physical proximity to better use information gathered from Unmanned Aerial Vehicle (UAV) sensors.

The JUSTAS Concept of Operations defined a UAS crew as consisting of a pilot, SO, and intelligence analysts. Collocating these crewmembers was argued to facilitate mission effectiveness and performance. Results of a GCS simulation with a six-member crew configured into three workspace layouts are discussed: Distributed (physical separation using partitions), Classroom (desks facing the same direction, no partitions), and Boardroom (workspace arranged as if sitting around a mutual table). SME-rated performance and participant reports appeared to suggest the Boardroom layout as the best. In particular, results also found that SA measures were highest (best) in the Boardroom layout.

Covas-Smith, C. M., Grant, S.C., Hou, M., Joralmon, D. Q., & Banbury, S. (2016). *Training remotely piloted aircraft operations and data exploitation: Development of a testbed for integrated ground control station experimentation and rehearsal (TIGER)* (Report No. DRDC-RDDC-2016-P061). Defence Research and Development Canada. https://cradpdf.drdc-rddc.gc.ca/PDFS/unc240/p804390_A1b.pdf

The pace of operations in the military limits the amount of time available for training, both for Remotely Piloted Aircraft (RPA) crews and for Processing, Exploitation, and Dissemination (information processing) teams. These two halves of a crew traditionally are trained apart but must integrate closely in UAS missions. The Testbed for Integrated Ground Control station (GCS) Experimentation and Rehearsal (TIGER) simulator is used to provide a training environment for these crewmembers to work and train together on a simulated mission. In particular, TIGER crews consist of six members: an Air Vehicle Operator (AVO), a Payload Operator (PO), an image analyst, an image reporter, an intelligence analyst, and an intelligence reporter. Operator performance, SA, and workload were measured as outcomes; increased integration of crewmembers as a team is expected to improve these measures.

McColl, D., Banbury, S., & Hou, M. (2016). Test-bed for integrated ground control station experimentation and rehearsal: Crew performance and authority pathway concept development. In S. Lackeu & R. Shumaker (Eds.), *Virtual, Augmented and Mixed Reality Lecture Notes in Computer Science Vol. 9740* (pp. 433–445). Springer, Cham. https://doi.org/10.1007/978-3-319-39907-2_42

Two crews performed a simulated mission in a Canadian military HF experiment. While each crewmember performed well when judged individually, one crew was judged as performing poorly overall due to poor teamwork. Six-member crews were tested, where roles were the AVO, PO, Image Analyst, Image Reporter, Electronic Warfare Analyst, and Electronic Warfare Reporter. In one team, limited crew coordination resulted in poor SA, which further resulted in poor decision-making. The crews also demonstrated poor awareness of the UAS, resulting in the UAV being positioned improperly for mission objectives. The crews also violated Rules of Engagement and Law of Armed Conflict, leading to the recommendation of an "Authority Pathway" Graphical User Interface (GUI) that displays a live updated status of steps required to release a weapon. Overall, the results suggested that staffing and teamwork issues are important considerations when organizing UAS operations.

Neogi, N. A., Hayhurst, K. J., Maddalon, J. M., & Verstynen, H. A. (2016). Some impacts of risk-centric certification requirements for UAS. In *2016 International Conference on Unmanned Aircraft Systems (ICUAS)* (pp. 1003-1012). Arlington, VA: IEEE. https://doi.org/10.1109/ICUAS.2016.7502531

Some requirements for UAS are covered by current airworthiness standards, but these do not cover novel hazards and risks unique to UAS. The current study identified 15 different hazards under the purview of Title 14 CFR Part 27 (Airworthiness Standards) to determine which requirements applied to UAS as is, required some modifications, or were not applicable at all. Three primary issues were presented for UAS standards to consider: Controllability, Maneuverability, and Stability; Structural Integrity; and Power Plant and Supporting Systems. These issues highlight two areas not adequately covered by current practices: Detect and Avoid (DAA) and Containment (i.e., issues with fly-away), both of which contain important elements for crew and staffing purposes. Neogi et al. (2016) suggested a system that requires human operators on the ground to work in conjunction with automated functions for detection and avoidance. Also considered and discussed is a containment system that requires human observers at boundary points and a remote pilot to execute the containment function if a UAS threatens to perform a fly-away.

Hobbs, A., & Lyall, B. (2015). *Human factors guidelines for unmanned aircraft system ground control stations* (Working document). National Aeronautics and Space Administration. https://humanfactors.arc.nasa.gov/publications/GCS_HF%20_Prelim_Guidelines_Hobbs_Lyall.pdf

Equipment used to control UAS varies greatly, ranging from off-the-shelf consumer electronic components to purpose-built interfaces. While some UASs have aviation interfaces, many include point-and-click computer displays. Problems identified in previous research include error-provoking control placement, non-intuitive automation, reliance on text displays, and complicated menu sequences to complete tasks. Guidelines were provided in terms of pilot responsibilities, which were further broken down into pilot tasks, the information content of displays, control inputs, and properties of the interface. Special consideration must be made for UAS, in particular: loss of natural sensing, control via radio link, control station (CS) characteristics, in-flight control transfer, unique UAV flight characteristics, flight termination (e.g., in an emergency), reliance on automation, and widespread use of interfaces based on consumer products. The provided set of guidelines were intended to take these concerns into account and offer general guidance to the development of UAS control systems.

Matos, M. D. L. M., Caetano, J. V., Morgado, J. A., & Sousa, J. D. (2015). From research to operations: The PITVANT UAS training experience. In K. P. Valavanis & G. J. Vachtsevanos (Eds.), *Handbook of Unmanned Aerial Vehicles* (pp. 2525-2560). Springer.

The Portuguese Air Force Academy and the University of Porto collaborated to work on the research and technology project in unmanned air vehicles project (PITVANT), focusing on developing new UAS technology and related personnel training. For the purpose of the current literature review, only PITVANT training requirements are reviewed. Most UAV operations have at least seven crewmembers responsible for specific aspects of the UAV (e.g., takeoff and landing, in-flight monitoring, maintenance). However, the number of crewmembers may change, depending on the specific UAS and mission requirements. Crewmember training does not focus on combat readiness. Instead, it focuses on safety and UAS airworthiness, and training is typically tailored for each UAS to address gaps in actual crewmember skills and skills needed to successfully operate the UAS. Crewmember training is split into three areas: theory and principles of flight, UAV simulations, and supervised flight training. The following minimum requirements must be met for specific crewmember positions: simulator hours, supervised training hours, supervised UAS configurations (configurators and instructors only), number of flights, and real-time operational hours. Crewmembers also perform additional tests and must score 75% or higher to pass.

Stansbury, R. S., Robbins, J., Towhidnejad, M., Terwilliger, B., Moallemi, M., & Clifford, J. (2015). Modeling and simulation for UAS integration into the United States National Airspace System and NextGen. In J. Hodicky (Ed.), *Modelling and Simulation for Autonomous Systems Lecture Notes in Computer Science Col. 9055* (pp. 40–59). Springer, Cham. https://doi.org/10.1007/978-3-319-22383-4_4

Stansbury et al. (2015) focused on models and simulations in UAS research and training, but discussed issues of crew and staffing in doing so. In particular, the use of models and simulations allow researchers and policymakers to verify new technologies and procedures that would be impractical in the real world. In particular, Stansbury et al. (2015) note that HF training, such as remote pilots communicating with Air Traffic Control (ATC), can be modeled and simulated. Simulations are especially useful in training interactions with both semi and fully autonomous systems. Similarly, an opportunity exists to use simulation training in a “virtual laboratory” setting with students dispersed geographically.

Ambrosia, V. G., & Zajkowski, T. (2014). Selection of appropriate class UAS/sensors to support fire monitoring: Experiences in the United States. In *Handbook of Unmanned Aerial Vehicles* (pp. 2723–2754). https://doi.org/10.1007/978-90-481-9707-1_73

Due to safety concerns, the US Forest Service and NASA have begun efforts in using UAS for wildfire observation, coupled with an interest in other uses of UAS such as for firefighter communication (e.g., UAS acting as a radio repeater). Sensors must detect wavelengths of energy specific to fire and not due to other sources such as water vapor or reflected solar radiation; several example systems are discussed. In addition, this energy must be detected underneath obstacles such as tree canopy or smoke plumes. Incorporating UASs into the airspace above a fire may be seen as disruptive to other operations. However, UASs may be useful in nighttime hours, where the darkness makes manned operations more dangerous, although fires tend to be less severe at night. Because of operating conditions, it may be necessary to have crews qualified with training in emergency fire operations and safety.

Bilimoria, K. D., Johnson, W. W., & Schutte, P. C. (2014). Conceptual framework for single pilot operations. In *Proceedings of the International Conference on Human-Computer Interaction in Aerospace*. Santa Clara, CA: ACM. https://doi.org/10.1145/2669592.2669647

A framework for Single Pilot Operation (SPO) is being considered by NASA that examines the reduction of the crew and staff size in aircraft while maintaining safety levels of larger crews. This framework echoed the requirements being considered for UAS and identified three functions necessary for ground operators: conventional dispatch of multiple aircraft, distributed piloting support of multiple aircraft, and dedicated piloting support of one aircraft. A crew may be trained in all operations or highly specialized as a pilot or ground support and must work in conjunction with advanced automation tools. Ground stations requiring properly trained staff to oversee complex and valuable equipment for remote operations are needed. Overly relying on automation may inhibit human engagement and performance, so human operators must be trained to hand tasks back and forth to automated functions to capitalize on the unique capabilities of both. In light of an automation failure, properly trained staff would be necessary to land the aircraft safely. A progression towards smaller ground crews over time is likely as advancements in automation of complex tasks are made, but this will still be dependent upon the operations of the UAS.

Oncu, M., & Yildiz, S. (2014). *An analysis of human causal factors in unmanned aerial vehicle (UAV) accidents* [Master's thesis]. Naval Postgraduate School. http://hdl.handle.net/10945/44637

The role human error currently plays in UAS accidents is reviewed. To identify where human errors can potentially come from, it is valuable to review the various crew and staffing positions. The research identified crewmembers, maintenance technicians, and those who assess video and images as part of UAS. Within the UAS crew, there are UA operators and POs. UA operators are in charge of the operation of the aircraft from engine start to engine off. Their duties include (1) preflight, in-flight, and post-flight checks and procedures, (2) communicating with the ATC Tower, (3) performing any and all emergency procedures, and (4) coordinating with the crew. POs are in charge of the payload during all phases of flight. The POs assist the PIC by reading the checklist and attending/contributing to briefings, mission plans, mission executions, and debriefings. The Control Station technician is also part of the UAS crew, helping to ensure the functionality of the aircraft by performing pre-flight and post-flight checks and maintaining the functionality of the aircraft during flight. CS technicians are also on hand to assist in any emergencies during flight operations. Oncu and Yildiz (2014) estimate that approximately 65% of UAS mishaps involve human error. Fifty percent of these human errors are estimated to be the result of routine "habitual" violations. The Human Factors Analysis and Classification System (HFACS) method is recommended to help identify, and thereby provide the means to mitigate, human errors within UAS operations.

Williams, H. P., Carretta, T. R., Kirkendall, C. D., Barron, L. G., Stewart, J. E., & Rose, M. R. (2014). *Selection of UAS personnel (SUPer) phase I report: Identification of critical skills, abilities, and other characteristics and recommendations for test battery development* (Report No. NAMRU-D-15-16). Wright-Patterson Air Force Base, Naval Aeromedical Research Unit. https://apps.dtic.mil/dtic/tr/fulltext/u2/a613545.pdf

Williams et al. (2014) identified 115 Skills, Abilities, and Other Characteristics (SAOCs), with 78 items considered to be of moderate importance or higher; 57 of these items were measured by at least one existing military test. It is argued that cognitive abilities were well-assessed as a whole, and that new tests should be developed to assess the remaining SAOCs, such as oral expression, speech clarity, and leadership. Further recommendations were made to improve existing tests. In particular, Williams et al. suggested the development of a test to focus on complex verbal communication – a skill that is not covered by listening comprehension tests. Overall, the results indicate that particular attention must be paid to UAS crews' ability to communicate with each other effectively.

Williams, K. W., & Gildea, K. M. (2014). *A review of research related to unmanned aircraft system visual observers* (Report No. DOT/FAA/AM-14/9). Federal Aviation Administration, Office of Aerospace Medicine. https://rosap.ntl.bts.gov/view/dot/57171

The VO is a UAS crewmember who helps keep sight of the UAV to prevent mid-air collisions. Aspects of the human visual system are discussed, including research related to the VO role. For example, the resolving limit of human vision is 1 minute of visual arc, and research suggests a larger arc (object projected bigger on the surface of the eye) is required before an object will be seen. The ability to focus the eye at various distances (accommodation) is affected by age, and even the emptiness of the sky can result in VOs focusing their eyes at a close distance (empty-field myopia). Peripheral vision is another important consideration: it is sensitive to movement but imprecise location-wise. Vigilance decrements over time (e.g., over a shift), and is affected by several outside factors. Various models of human vision were discussed, but it is noted that such models do not incorporate all possible variables that affect human visual performance and thus may not reflect accurate behavior. A body of research on VOs is reviewed that focuses on forward observers observing from the ground and see-and-avoid (pilots seeing other aircraft). In general, the literature suggested that the human ability to detect aircraft is problematic even under ideal conditions. If the aircraft is detected, the ability of an observer to predict a potential collision is also poor. The findings are concluded with a set of guidelines and recommendations for the use of VOs in UAS based on the research.

Civil Aviation Authority. (2012). *CAP 722 - Unmanned Aerial Vehicle (UAV) Operations in UK Airspace - Guidance*.

Requirements for UAS in order for the aircraft to be integrated safely into the United Kingdom (UK) airspace are discussed; these included both airworthiness of the aircraft and operational standards. A general safety rule, identified by the Civil Aviation Authority (2012), is that UAS operators must ensure their aircraft can comply equivalently with the rules and procedures of manned aircraft. Of particular note is that there are unique challenges associated with flying an unmanned aircraft that do not apply to manned aircraft. These differences require future refinement to current policies and requirements. However, one equivalent rule is that the unmanned aircraft must be within the unaided direct visual line-of-sight of the pilot, or have an acceptable DAA system. UAS crew's roles and their duties are additionally discussed. Remote Pilots are categorized as a person in charge of manipulating flight controls during the flight. An RPA observer is someone who is in charge of visually observing the aircraft (i.e., a VO). Currently, there are no formal UAS requirements for Remote Pilots. Requirements are determined on a case-by-case basis. Certification for Remote Pilots depends on a number of risk-mitigating factors including restricted flight to segregated airspace, keeping the aircraft within visual line of sight, and operating a low mass aircraft. A designated point of contact will determine crew training on a case-by-case basis.

Gertler, J. (2012). *U.S. unmanned aerial systems* (Report No. R42136). Congressional Research Service. https://fas.org/sgp/crs/natsec/R42136.pdf

UAV topics of interest for Congressional rulemaking are discussed; of particular interest was the focus on different needs of the military, resulting in multiple UAV programs developed to meet those different operational requirements. The overall goals are similar: improve SA, support intelligence, improve targeting, and reduce hazards to both combatants and civilian noncombatants. Projected future needs for UAVs vary: Naval ship resupply, search and rescue, aerial refueling, and air combat are several highlighted examples. UAV systems remove the pilot from the aircraft, relocating crews to the ground, but UAVs do not eliminate the staffing that supports military operations. These operational goals are separate from cost considerations, where a common refrain is that unmanned aircraft are less expensive than manned aircraft. Lower costs cannot be taken for granted, given the costs of advanced sensors that unmanned systems must carry. Similarly, a UAV system moves the pilot from an on-board cockpit to a ground-based control station; the UAV system does not eliminate the pilot role, even when UAVs are used as "force multipliers" where one pilot simultaneously controls multiple aircraft.

Rodriguez, R. C. (2012). *Overmanned and undertrained: Preparing UAS crewmembers for unmanned close air support* [Master's thesis]. Marine Corps Combat Development Command and Staff College. https://apps.dtic.mil/dtic/tr/fulltext/u2/a601444.pdf

The Marine Corps' standard UAV Squadron for the RQ-7B Shadow UAV is discussed. Each crew consists of a UAS Aircraft Commander, a UAS AVO, a UAS Mission Payload Operator, and one Intelligence Marine. The UAS Aircraft Commander may be replaced by a UAS Mission Commander (MC), who performs the same duties but to multiple concurrent crews. Missions are to provide reconnaissance, surveillance, and target acquisition. Of particular note is that crews are drawn from a pool of officers with mixed aviation experience, resulting in a wide skill set among new Aircraft Commanders. Furthermore, each Squadron tour is 18-24 months, which results in an Aircraft Commander training that Rodriguez (2012) argues lacks depth. A new training requirement would increase training from 3 weeks to an additional 6 months, which includes flight instruction, RPA Instrument Qualification, and an RPA Fundamentals Course that focuses on countering threats to UAS. Rodriguez (2012) identifies several training gaps, among which include lack of training with the specific aircraft and insufficient trust between the Squadron and Forward Air Controllers. Simulators are available which allow different scenarios to be practiced, but appear to be underutilized. Recommendations include improving flight simulator operations and the surrounding culture against simulators, increased funding for simulators to reduce dependence on actual flight time for training purposes, combining and modifying staffing roles (e.g., giving the Aircraft Commanders some Mission PO duties, moving the Aircraft Commander in proximity with the AVO and Mission PO instead of communicating over radio), and assign a "tiger team" with tactical aviation experience to guide training. Although Rodriguez (2012) focused on issues specific to Marine Corps, the conclusions were more widely applicable. Care must be taken in filling crew roles, and training must be completed on the specific aircraft used in operations. Consideration must be given to training in simulators to reduce dependence on actual flight time.

Argrow, B., Frew, E., Houston, A., Elston, J., Stachura, M., Roadman, J., & Lahowetz, J. (2011). The tempest UAS: The VORTEX2 supercell thunderstorm penetrator. In *Infotech@Aerospace 2011*, (p. 1524). https://doi.org/10.2514/6.2011-1524

A new sUAS, the Tempest, was developed to collect data samples from within supercell thunderstorms. Argrow et al. (2011) reviewed the testing of the operations of the sUAS Tempest and its requirements. Three ground vehicles are required for the operation. The first ground vehicle is the Mobile Ground Station. Crewmembers for the Mobile Ground Station include a dedicated driver, the lead meteorologist, the PIC, the UAS operator, and a UAS technician. The second mobile vehicle is the Tracker. The crew for the Tracker includes a dedicated driver, a secondary meteorologist, a UA observer, and the assistant to the observer. The UA observer (i.e., VO) is required to maintain visual contact with the UAS at all times. The assistant to the observer is responsible for moving the orbit point. The third vehicle called the Scout has a crew of two: a dedicated driver and a third meteorologist. The Scout is responsible for collecting ground-level measures (e.g., wind velocity, pressure, temperature, and relative humidity). In addition, the Scout is responsible for reporting on road conditions in advance of the Mobile Ground Station and the Tracker. The findings help support a conclusion that Tempest not only can be used to collect data from supercell thunderstorms, but it can also be compatible with operations that conform to constraints in FAA COAs.

Howse, W. R. (2011). *Knowledge, skills, abilities, and other characteristics for remotely piloted aircraft pilots and operators* (Report No. AFCAPS-FR-2011-0006). Randolph Air Force Base, Air Force Personnel Center. https://apps.dtic.mil/dtic/tr/fulltext/u2/a552499.pdf

KSAOs developed for military UAV operators and discusses predictions for future requirements are reviewed. In particular, the review indicated an increased demand for analytical skills among pilots to help reduce reliance on imagery and intelligence analysts. Changes to the UAV interface, organization, manpower, and missions are expected to change KSAO requirements. These changes can result in decreased workload and reduced demand on perceptuomotor systems, but alternately can result in increased requirements elsewhere (e.g., when adding an additional weapon system to the UAS). Recent moves to place multiple UAVs under one crew require additional requirements on AVOs and Mission Package Operators for attention, spatial orientation, and time sharing. Manpower changes may result from transitioning to training that requires less hands-on flying. Changes may also result from UAVs taking on new roles such as attack missions. These changes are expected to result in increased demand in numerous areas, not limited to crewmembers' knowledge of each other's systems, communication skills, and SA. A cross-referenced list of KSAOs is provided.

United States Air Force. (2019). *Air Force officer classification directory (AFOCD): The official guide to the Air Force Officer Classification Codes*. U.S. Department of Defense, Air Force Personnel Center. https://www.afpc.af.mil/Portals/70/documents/07_CLASSIFICATION/20191031%20AFOCD.pdf?ver=2019-10-02-094009-730

A list of Duties and Responsibilities, as well as a list of Specialty Qualifications, are provided for each officer position in the United States Air Force (USAF). Positions of interest under the Remotely Piloted Aircraft Pilot Utilization Field (i.e., 18XX) include Attack Remotely Piloted Aircraft Pilot, Experimental Test Remotely Piloted Aircraft Pilot, Generalist Remotely Piloted Aircraft Pilot, Reconnaissance Remotely Piloted Aircraft Pilot, and Special Operations Remotely Piloted Aircraft Pilot. Also of interest under the Pilot Utilization Field (i.e., 11XX) is RPA Pilot.

Chappelle, W. L., McDonald, K., & King, R. E. (2010). *Psychological attributes critical to the performance of MQ-1 Predator and MQ-9 Reaper US Air Force sensor operators*

(Report No. AFRL-SA-BR-TR-2010-0007). Brooks City-Base, Air Force Research Laboratory Human Performance Wing (711th). https://apps.dtic.mil/dtic/tr/fulltext/u2/a525910.pdf

The goal of Chappelle, McDonald, and King's (2010) research effort was to identify the successful attributes that are predictive of SO training completion and job performance when operating the MQ-1 Predator and the MQ-9 Reaper. By identifying these attributes, more successful recruitment and selection of operators can take place, saving valuable resources such as time and money. The various uses of the MQ-1 Predator and the MQ-9 Reaper include gathering image and video intelligence, surveillance, close air support, and strike operations. Three crewmember roles identified are: (1) the ground-based pilot (controls the UAV movement), (2) a SO (in charge of reconnaissance and targeting), and (3) a mission intelligence coordinator (responsible for communicating sensitive intelligence information). Chappelle, McDonald, and King (2010) detailed the duties required of the SO, arguing that they must have high situational and spatial awareness, and have strong communication skills. The valuable attributes of an SO, as identified by SMEs, include: general health, stamina, cognitive proficiency, visual perception, attention, spatial processing, memory, reasoning, composure, resilience, self-certainty, conscientiousness, success-oriented, perseverance, decisiveness, humility, cohesiveness, assertiveness, adaptability, moral interest, and occupational interest.

Cooke, N. J., Gorman, J. C., Duran, J. L., & Taylor, A. R. (2007). Team cognition in experienced command-and-control teams. *Journal of Experimental Psychology: Applied, 13*(3), 146–157. https://doi.org/10.1037/1076-898x.13.3.146

Shared mental models, or team cognition, tend to have two different approaches, processes, or knowledge bases. A knowledge approach seeks the appropriate distribution of knowledge between team members to complete a task whereas a process approach focuses on the skills and functions necessary to execute a task. These processes were evaluated by examining the performance of teams in a UAV simulator. The teams were split between those with experience on a similar task (e.g., command-and-control task) and those without experience, based on the postulation that experience would lead to a more efficient performance and a quicker rate of task acquisition. The teams consisted of three members, each with a different role: an AVO who is responsible for airspeed, heading, altitude, and monitoring of the UAV, a PO who manipulates photos and settings while monitoring the camera equipment, and a Data Exploitation, Mission Planning, and Communications (DEMPC) who oversees the mission and determine the flight path. The primary areas of concern were team performance, team process (communication and coordination), and team knowledge (relatedness ratings to previous experience). The experienced teams exhibited higher performance scores, but there were no differences between experienced and inexperienced teams when it came to the rate of task acquisition. The interactions (e.g., coordination) appeared to differ between teams, but there were minimal differences in the knowledge metrics. It appears that the process of a task is modulated by experience. This improved performance emerges from team interactions and may be shaped by experience (e.g., knowledge of teamwork), which demonstrates a direct transfer of a skill and not an enhanced skill for acquisition. These findings may have implications for future training methods.

Hopcroft, R., Burchat, E., & Vince, J. (2006). *Unmanned aerial vehicles for maritime patrol: Human factors issues* (Report No. DSTO-GD-0463). Australian Government Department of Defence, Defence Science and Technology Organisation. https://apps.dtic.mil/dtic/tr/fulltext/u2/a454918.pdf

A review of HF in UAV operations identified multiple Human-Machine Interaction (HMI) concerns. For the purpose of this literature review, only crewing requirements are discussed. Reconnaissance UAV operations typically involve two crewmembers: an AVO and Mission PO. However, the size and complexity of the UAV can determine the number of crewmembers necessary to complete the mission and require multiple highly specialized member roles. Long-endurance Predator operations may require four AVOs, two operating per shift. A minimum of three crewmembers is required for Predator operations, which includes an AVO/MC, DEMPC Operator, and SO. However, Global Hawk operations require additional crewing from the Launch & Recovery Element and Mission Control Element (MCE). The MCE requires a minimum crew of MC, Command and Control Operator, Mission Planner, communications operator, imagery quality control technician, and maintenance technician.

DeGarmo, M. T. (2004). *Issues concerning integration of unmanned aerial vehicles in civil airspace*. MITRE Center for Advanced Aviation System Development. https://www.mitre.org/sites/default/files/pdf/04_1232.pdf

Initiatives and frames that are valuable for integrating UAVs into the NAS are discussed, with particular attention to the dangers associated with integration. New socio-economically friendly recommendations for safe integration are provided, including 10 proposed recommendations for UAS integration. Among them is the recommendation to establish regulations for UAV certification, operations, and controller qualifications. One major requirement for UAV pilots is Sense and Avoid (SAA). The pilot must be able to SAA all aircraft, both cooperative and non-cooperative, as well as any other collision hazards such as birds or towers. Discussed is how to determine a sensor's ELOS to a human observer, and the technologies that may be applied to UAS (e.g., optical sensors, cooperative surveillance such as transponders, Automated Dependent Surveillance – Broadcast [ADS-B], or Traffic Collision Avoidance Systems [TCAS]). Also discussed are technologies still in development. While these safety concerns exist and need to be addressed, DeGarmo (2004) additionally identified several positive outcomes associated with the expanding use of UASs; these positive outcomes include the technological advances in communication, automation, SAA systems, alternative fuels, and more for not only UAV but also for manned aircraft.

Williams, K. W. (2004). *A summary of unmanned aircraft accident/incident data: Human factors implications* (Report No. DOT/FAA/AM-04/24). Federal Aviation Administration, Office of Aerospace Medicine. https://rosap.ntl.bts.gov/view/dot/5920

The accident rate for UAVs is generally higher than for manned aircraft, and one way to mitigate the accident rate is to examine HFs related to UAV accidents and incidents. In particular, military UAV accidents are examined in terms of contributing to human errors. Several UASs are examined across military branches, with HF issues identified in accidents provided in tables for each UAS. While accidents due to mechanical failure occurred at a rate approximately equal to those caused by human error, it is noted that increasing mechanical reliability will likely increase costs; mitigating human errors by incorporating HFs during the design process (e.g., making sure a sequence of button presses to perform a function like lowering the landing gear is not easily confused with another sequence of button presses to stop the engine) is less likely to increase costs. Automation is noted as a potential way to overcome human error, but Williams (2004) further argues that proper application of automation is required to be effective and avoid other problems should the automation itself fail.

UAS Automation Level

American Aerospace Technologies (2021). *AiRanger™ UAS NASA SIO Program Final Report* (Report No. NASA/CR–20210018784). National Aeronautics and Space Administration. https://ntrs.nasa.gov/citations/20210018784

A new UAS platform was developed in cooperation with NASA to automate routine UAS operations that are anticipated for upcoming commercial uses. The platform, named AiRanger™, consists of a fixed-wing UAV with a payload capacity over 55 pounds that incorporates both cooperative and non-cooperative DAA systems. AiRanger includes ADS-B In and Out functionality, which allows for cooperative DAA with other similarly-equipped aircraft. For DAA of non-cooperative obstacles, the platform also incorporates onboard radar systems; onboard cameras are provided to the PIC for further SA during flight operations. A proof-of-concept flight is discussed, and a description of equipment used is provided.

Swieringa, K., Young, R., Vivona, R., & Hague, M. (2019, April). UAS Concept of Operations and Vehicle Technologies Demonstration. In *2019 Integrated Communications, Navigation and Surveillance Conference (ICNS)* (pp. 1-15). IEEE. http://doi.org/10.1109/ICNSURV.2019.8735203

A testbed UAS over 55 pounds performed proof-of-concept flights transiting through controlled space to a terminal environment and landing. The flights followed IFR under 14 CFR Part 91.[24] During lost-link situations, the UAS incorporated a voice synthesis system that could alert ATC

[24] 14 CFR Part 91, General Operating and Flight Rules. https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-91

and other pilots of its maneuvers; the UAS could also respond to verbal ATC commands (i.e., initiate a go-around). The UAS incorporated a system that allows it to taxi off an active runway when completing an emergency landing during a lost-link situation; an on-board lidar system provided obstacle avoidance during automated taxiing operations. Details of the test flights, which included lost-link exercises, are provided and discussed.

Lowry, M., Bajwa, A. R., Pressburger, T., Sweet, A., Dalal, M., Fry, C., Dalal, M, Schumann, J., Dahl, D., Karsai, G., & Mahadevan, N. (2018). Design considerations for a variable autonomy executive for UAS in the NAS. In *2018 AIAA Information Systems-AIAA Infotech @ Aerospace*, 1633. Reston, VA: AIAA. https://doi.org/10.2514/6.2018-1633

An Autonomy Executive that does not require human ground crews, yet is capable of communicating electronically with ATC (controller pilot data link communication) or through an artificial intelligence natural language capability, is discussed. In particular, the use of such an Autonomy Executive means that an operational support service (AOS) is not only capable of following a preplanned route, but also flexible enough to incorporate and follow new commands from ATC. The system is also intended to prevent additional burden on ATC, by communicating in the same way as manned aircraft pilots currently do. The AOS described also incorporates predefined emergency procedures, capable of executing checklists defined in the Pilot Operating Handbook. Human ground crews are defined as an automation fallback, which will not be necessary if an AOS is designed to identify and handle automation failures. The Autonomy Executive also provides a framework by which new features can be integrated.

McColl, D., Heffner, K., Banbury, S., Charron, M., Arrabito, R., & Hou, M. (2017). Authority pathway: Intelligent adaptive automation for a UAS ground control station. In (Eds.), *Engineering Psychology and Cognitive Ergonomics: Performance, Emotion and Situation Awareness Lecture Notes in Computer Science Vol. 10275* (pp. 329–342). Springer, Cham. https://doi.org/10.1007/978-3-319-58472-0_26

A new adaptive intelligence interface, called Authority Pathway, was developed to assist UAS GCS crews with SA, improve target engagement, and reduce overall workload. The Authority Pathway is one system working towards an adaptive, dynamic software to improve HMI and crew performance. It provides decision-making and judgement support to crewmembers, and it actively adjusts recommendations to reflect current mission status, crewmember position, and level of system automation. It is based on the Pilot Authority and Control of Tasks (PACT) taxonomy that is used to classify the level of pilot and computer control required for various levels of automation. Although it reduces overall workload and provides real-time data to support decision-making, there are several concerns about the Authority Pathway that need to be considered and improved. For example, it is conjectured that crewmembers may become too reliant on the system and be unwilling to identify and respond to problems not flagged by the system. Because the Authority Pathway provides various system information (e.g., SA view, crew view, commander view) and visual cues to the user, crewmembers may ignore and/or not be able to respond to all system notifications. These factors should be considered when implementing the Authority Pathway, but the development of adaptive and dynamic UAS GCS software will improve overall crew performance and reduce workload.

Norton, T. (2016). *Staffing for unmanned aircraft systems (UAS) operations* (Report No. P-5253). Institute for Defense Analyses. https://apps.dtic.mil/dtic/tr/fulltext/u2/1014109.pdf

The United States Department of Defense (DoD) investigated alternative staffing to cost options in an attempt to improve available manpower for UAS operations while reducing costs and increasing mission success. Specific mission duties and responsibilities can be separated (e.g., launch and recovery, surveillance, weapon employment) to alleviate staff workload. Additionally, a mixture of DoD workforce (active military, civilian, and contractor) may be used to alleviate staffing burdens and reduce costs. UAS operations range in crew size, from 14 to over 30 personnel, depending on the UAS and mission.

Sprengart, S. M., Neis, S. M., & Schiefele, J. (2018). Role of the human operator in future commercial Reduced Crew Operations. In *2018 IEEE/AIAA 37th Digital Avionics Systems Conference.* London, UK: IEEE. https://doi.org/10.1109/DASC.2018.8569803

Traditional commercial operations require two pilots: one aviates the aircraft while the other is in a supervisory role to ensure all systems are operational. Regardless of position, one pilot is in charge of the mission and makes the final decision. RCO drastically changes the role of a pilot to a supervisory role of an autonomous system, which is argued to redefine the pilot's role with the increase of cockpit automation. The idea behind RCO is that only one pilot would be needed to oversee the entire system and flight operation because the aircraft itself would be automated, taking responsibility off the pilot.[25] It is argued that the next generation of pilots will be "mission managers", focusing on the whole mission rather than monitoring specific aircraft systems. The mission managers will respond to mission goals as needed, using decision aids, and will be responsible for managing gaps between the automated system and outside events. One of the critical components to the new definition is that the mission manager will not be a backup or supplement to automated systems. Rather, the mission manager will act as the safety net for the systems.

Gimenes, R. A. V.,Vismari, L. F., Avelino, V. F., Camargo, J. B. Jr., de Almedia, J. R. Jr., & Cugnasco, P. S. (2014). Guidelines for integration of autonomous UAS into the Global ATM. *Journal of Intelligent & Robotic Systems, 74*(1), 465–478. https://doi.org/10.1007/s10846-013-9945-0

[25] The idea of transferring responsibility of flight safety to an automated system does not take into account potential regulatory and legal problems with this action and blurs the role of the pilot as pilot-in-command.

Pilots are responsible for three activities: flight, navigation, and communication. Stable flight takes priority over navigation, and both take priority over communication. However, these duties will shift away from human pilot responsibility with automatic and autonomous systems. An autonomous UAS was defined as consisting of an aircraft, an autonomously-piloted system, and flight procedures. One main obstacle to operation in the NAS is in providing evidence that UAVs provide the same levels of safety, reliability, availability, and performance as manned aircraft. For this, a comparison is needed between autonomous unmanned and manned aircraft following current civil aviation regulations. An autonomous UAS would need to meet all of the same flight requirements and skills that human pilots must meet. Several recommendations for the safe integration of autonomously-piloted UAVs are provided and discussed: (1) an autonomously-piloted UAV must be able to handle all foreseen scenarios (i.e., have functional completeness); (2) no fault combination can be allowed to bring the UAS into an unsafe state; and (3) a "safe state" must be provided to handle emergencies (i.e., landing at the safest and nearest location). The certification process for an autonomously-piloted system should be based on requirements for human pilots, and should include an equivalent knowledge test. A safety assessment should also be completed as part of certification, in reference to manned aircraft (details of the recommended certification process are provided). Overall, it is argued that autonomous pilots are capable of participating in non-segregated airspace, for which a minimum set of guidelines designed in reference to current manned aircraft are provided.

Cahillane, M., Baber, C., & Morin, C. (2012). Human factors in UAV. In P. Angelov (Ed.), *Sense and avoid in UAS: Research and applications* (pp. 119-142). Wiley & Sons.

Keeping the human-in-the-loop (HITL) is an important factor in UAV operations. A tradeoff occurs with highly automated UAVs: the pilot has less physical demand with highly automated UAVs but experiences high cognitive demand because they must monitor the system and incoming data to ensure it is functioning properly. However, the pilot is not completely eliminated from the system and must be able to efficiently and safely take control if the UAV fails. Previous research suggests a single pilot can successfully operate four to six UAVs at a time, but can operate eight to 12 UAVs depending on tasks in addition to monitoring (i.e., demanding a pilot to monitor multiple information sources will decrease the number of UAVs that can be operated at a time). Four UAVs is the suggested limit per one pilot based on a consensus reading of the literature. Moderate automation is recommended for UAVs to reduce task-switching speeds when the pilot has to take over the UAV. Additional concern should be given to the type and amount of alerts provided by the UAV because it can have a negative effect on pilot judgement and decision-making. The pilot may be distrusting of the system if apparently inaccurate or unnecessary warnings are being provided. Individual differences between pilot performance has been found when assessing Perceived Attentional Control (PAC) and Spatial Ability (SpA), suggesting that individuals high in PAC and SpA are more successful UAV pilots than those with average or low PAC and SpA.

Cook, S., Lacher, A., Maroney, D., & Zeitlin, A. (2012). UAS sense and avoid development-the challenges of technology, standards, and certification. In *50th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition* (pp. 959). Nashville, TN: AIAA. https://doi.org/10.2514/6.2012-959

The ability of an UAS to SAA obstacles while in flight is a major safety concern that must be addressed before UAS can be integrated into the NAS. Multiple committees have been formed to discuss challenges associated with UAS SAA. Multiple sub-functions were identified in SAA, beginning with detecting an obstacle or intruder, evaluating potential risk, prioritizing the potential risks, determining what maneuver is needed, and executing the maneuver. Manual decision processes could be used for SAA where the pilot assesses data from the UAS and takes appropriate action. This places additional cognitive demand on the pilot and assumes the pilot will accurately interpret data from the UAS. Many of the sub-functions could be automated and performed by the UAS itself, reducing cognitive demand on the pilot. However, this is further complicated by the variety of software systems used across UASs and limited research on the human/machine interaction. SAA should be developed with the human in mind, with the goal of reducing risks associated with SAA and collisions.

Wing, D., & Cotton, W. (2011). For spacious skies: Self-separation with "autonomous flight rules" in US domestic airspace. In *11th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference*. Virginia Beach, VA: AIAA. https://doi.org/10.2514/6.2011-6865

Wing and Cotton (2011) propose Autonomous Flight Rules in the context of Next Generation Air Transportation System (NextGen) improvements currently being implemented across the NAS. New changes to how instrumented aircraft (i.e., IFR) will result in more aircraft occupying less space and consequently on how many aircraft like UAVs will share the airspace. Wing and Cotton (2011) propose Autonomous Flight Rules to coexist with IFR and VFR). Automated systems will allow for coordination and mitigation of conflict (e.g., collision avoidance, right of way rules, priority). It is further recommended that pilots who use Autonomous Flight Rules when cruising at altitude act as monitors for radio communication in the sector they are flying, as radio contact would normally not be necessary except in emergencies. This allows crews to consist of as few as one pilot. A plan for implementation, divided into Current, Midterm, and Far Term proposals, is provided.

Lacher, A., Zeitlin, A., Maroney, D., Markin, K., Ludwig, D., & Boyd, J. (2010). Airspace integration alternatives for unmanned aircraft. In *AUVSI's Unmanned Systems Asia-Pacific 2010*. MITRE Center for Advanced Aviation System Development. https://www.mitre.org/sites/default/files/pdf/10_0090.pdf

With increased UAV use by both civilians and military, a way must be identified to integrate these uses into the NAS. Safety issues with integrating UAV operations into the same airspace as manned operations are discussed. One safety issue with UAVs is SAA of other aircraft. UAVs should practice Self-Separation (remaining well-clear of other aircraft) and Collision Avoidance. Another problem is disruptions in the link between the (remote) pilot and the aircraft. To address the lack of SAA, several alternatives are outlined: build on sUAS line-of-sight regulations, develop ground-based SAA, and develop airborne SAA (were traffic sensors are located on the aircraft). Alternatives for integrating command and control are also addressed. Options include standardizing lost link and contingency procedures, developing air traffic management (ATM) procedures and separation criteria for UAS, developing a radio spectrum reserved for UAV use to reduce the likelihood of lost link, developing automation to reduce or eliminate pilot input, and taking advantage of NextGen technologies.

Alexander, R., Herbert, N., & Kelly, T. (2009). The role of the human in an autonomous system. In *4th IET International Conference on Systems Safety 2009. Incorporating the SaRS Annual Conference*. London, England: IET. https://doi.org/10.1049/cp.2009.1536

Humans can monitor for problems and intervene, but cannot necessarily fill this role reliably. Humans can be incorporated into the mechanism of an autonomous system, providing functions that cannot be automated. Estimating safety requires interpretation and judgment abilities that current automated processes cannot accomplish. Humans may fill a mediator role, translating and ensuring that communications have resulted in a correct understanding. Because of shared resources, autonomous systems and humans must become partners. This includes not only detect-and-avoid procedures but also an ability for the system to interact and interoperate. In summary, some roles will be filled by humans even with autonomous systems, but those roles must be intelligently filled (parallels are drawn to the "Control Room Problem" faced in the nuclear and chemical industries) with interactions between humans and autonomous systems to be modeled and tested.

Liu, D., Wasson, R., & Vincenzi, D. A. (2009). Effects of system automation management strategies and multi-mission operator-to-vehicle ratio on operator performance in UAV systems. *Journal of Intelligent and Robotic Systems*, *54*(5), 795–810. https://doi.org/10.1007/s10

The US military intends to increase the use of UAVs while reducing the number of operators, resulting in a need for automation. Adaptive automation may help ensure maximum performance by varying operator-vehicle ratios. Humans must be kept as part of future UASs because of their superior ability to adapt to situations and exercise judgment, but the role must be tempered with adaptive automation to avoid high mental and workload demands that may reduce human effectiveness. Several methods that have been developed to measure automation are discussed; it has been found that "moderate" levels of automation are in use, and that lower levels of automation can overwhelm operators with high workloads. Additionally, higher levels of automation can remove the human from the operation entirely (resulting in the loss of a human's adaptability to situations and judgment making). It is also noted that automation does not necessarily reduce workload; increasing automation may change from operators flying a UAV to one operator monitoring multiple UAVs, resulting in the same or even increased workload. In an experiment examining operator-to-vehicle ratios, no difference was found in performance in 1:1 and 1:2 ratios. However, performance was significantly different between 1:4 and 1:1 ratios, as well as between 1:4 and 1:2 ratios. This suggests a nonlinear relationship exists between operator ratio and performance, which will require further research to understand.

Parasuraman, R., Cosenzo, K. A., & De Visser, E. (2009). Adaptive automation for human supervision of multiple uninhabited vehicles: Effects on change detection, situation awareness, and mental workload. *Military Psychology, 21*(2), 270–297. https://doi.org/10.1080/08995600902768800

Parasuraman, Cosenzo, and De Visser (2009) sought to understand the role of adaptive automation in supporting human operators flying multiple UAVs under high workloads. Automation can result in an unbalanced mental workload, reduced SA, biases in decision-making, etc. Adaptive automation, however, is designed to present information as needed given the environmental context. Automation triggers can include mission events, operator performance, or physiological state. Two experiments were conducted. In the first experiment, participants were asked to complete several concurrent UAV and communication tasks that varied in difficulty as they were measured on accuracy, reaction time, SA, and workload. This first experiment was used to develop baseline difficulty levels for the second experiment. In the second experiment, performance-based adaptive automation was introduced; operator performance was monitored in real-time to determine when help from automation was needed. Because the level of automation was set according to operator needs, the point in the operation when automation was invoked varied according to the individual operator. Results show that with adaptive automation, task accuracy increased and workload decreased. Compared to static forms of automation, the results indicate a comparatively larger increase in task accuracy and a decrease in workload with adaptive automation. No significant increase in SA was found for adaptive automation than static automation, which may be due to the insensitivity of the SA measure used in the experiment.

Pratt, K. S., Murphy, R., Stover, S., & Griffin, C. (2009). CONOPS and autonomy recommendations for VTOL small unmanned aerial system based on Hurricane Katrina operations. *Journal of Field Robotics, 26*(8), 636-650. https://doi.org/10.1002/rob.20304

Urban UAS operations are of particular interest to first responders and law enforcement, but these operations usually take place in a low-altitude environment cluttered with obstacles that are not necessarily well-mapped. Pratt et al. (2009) examined the use of urban UASs after Hurricane

Katrina for structural building inspections. Previous research in sUAS has resulted in bulky systems, such as laser systems used for detecting and avoiding obstacles. Other research has focused on crew models that do not fit the needs of tactical responses after disasters such as hurricanes. It is argued that a successful UAV operation deployment requires each team member have an understanding of the task (i.e., domain theory), which requires an understanding of the purpose of the operation. In the examined cases, this involves understanding the types of photographs needed for a structural building inspection. Pratt et al. (2009) found that it was difficult to reduce UAV teams to fewer than three operators, recommending a three-person flight crew for urban operations: a pilot responsible for flight, a mission specialist responsible for the payload (operating the building inspection camera), and a flight director responsible for overall safety and airspace regulations. Because of the working environment, a focus on semi-autonomy over full automation is recommended. A four-step operation procedure is provided: (1) site and landing zone safety review, (2) planning and identification of safety hazards, (3) flight review, and (4) data review.

Crandall, J. W., Cummings, M. L., & Nehme, C. E. (2008). *A predictive model for human-unmanned vehicle systems: Final report.* Massachusetts Institute of Technology, Department of Aeronautics and Astronautics.

Human-Unmanned Vehicle System (HUVS) models may be able to assist unmanned vehicle (UV) pilots in controlling multiple UVs by accounting for the workload demands and HF issues associated with UV operations. When a single UV pilot is controlling multiple UVs, the HUVS model must be able to account for interaction efficiency of human interactions with the UV, efficiency of a UV's performance without pilot input, and attention allocation efficiency for how the pilot allocates attention to multiple UVs in a single operation. Research Environment for Supervisory Control of Unmanned-Vehicles (RESCU) scenarios was used to compare the efficiency of HUVS with multiple UVs in operation per a single pilot. The number of lost UVs during scenarios increased as the number of UVs on the team increased. Optimal system performance was observed with teams of four to six UVs. The tested HUVS model was able to predict human performance in the RESCU scenarios and was able to identify when human users employed suboptimal selection strategies. Additionally, the tested model was able to provide decision support to human users to maximize performance. Additional research is needed to understand how model-provided decision support changes human user behavior, and how changes in human user behaviors affect model predictive performance. The design of the HUVS model is discussed in detail.

Cummings, M. L., Bruni, S., Mercier, S., & Mitchell, P. J. (2007). Automation architecture for single operator, multiple UAV command and control. *The International C2 Journal. 1*(2), 1-24. http://hdl.handle.net/1721.1/90285

The architecture of automation needed for UAS and how humans interact with that automation was reviewed to examine the requirements for a single pilot operation of multiple vehicles. Human supervisory control was identified as a key component for operating multiple UASs. This involves identifying when and where to use and not to use automation. Generally, automation was found to be most useful and necessary for navigation, status monitoring, and mainly motion control. Delegating tasks in those domains to automation frees up attentional resources for pilots and other crewmembers to perform higher-level decision-making and mission management. Decision support is an area identified requiring proper nuance that automation does not adequately cover. Overly relying on automation may decrease the performance of human operators, so it is important to train crews to use and trust an automated system, but not to solely depend on it. As automation increases, humans may control more vehicles with smaller crews, but too much may lead to decreased SA. It is suggested that training to avoid automation bias would be necessary. Human crews working with automation and overseeing multiple UAS is a shift towards network-centric operations to achieve the balance necessary between human operation and automation.

Williams, K. W. (2007a). *An assessment of pilot control interfaces for unmanned aircraft* (Report No. DOT/FAA/AM-07/8). Federal Aviation Administration, Office of Aerospace Medicine. https://rosap.ntl.bts.gov/view/dot/40496

While the goals of controlling a UAV are similar across operations (e.g., reach a specific destination), each offers different ways of controlling the UAV and different levels of automation. Williams (2007a) discussed the benefits of automation, such as providing automatic envelope protection where the aircraft cannot be flown outside of its flight-performance limits. Fifteen different UAS control systems from nine different manufacturers were reviewed to assess the level of aircraft control offered in each system. The control level was organized in a taxonomy that included three types of control: horizontal movement, vertical movement, and speed. Under the taxonomy, pilots could control the aircraft at different amounts of control. For example, a pilot could control speed by controlling thrust, adjusting airspeed, or entering waypoint time. The pilot's viewpoint was also split into two categories in the taxonomy: egocentric (view as if the pilot is onboard the aircraft) and exocentric (view the aircraft as if looking at it from outside). Of the reviewed control systems, the majority presented the pilot only with exocentric views, and a select set presented egocentric views only for certain operations. Only two of the systems provided direct control of flight surfaces; the other systems navigated by programmed waypoints. The level of control was generally selectable by the pilot, which may be a source of confusion in terms of SA. It is further argued that allowing the aircraft to formulate route deviations (autonomy) is a way to manage flight contingencies in future development. These deviations may be a temporary deviation to avoid a threat or developing a route deviation in service to a higher-level task or goal.

Hayhurst, K., Maddalon, J., Miner, P., DeWalt, M., & McCormick, G. (2006). Unmanned aircraft hazards and their implications for regulation. In *2006 IEEE/AIAA 25TH Digital Avionics Systems Conference* (pp. 1-12). Piscataway, NJ: IEEE. https://doi.org/10.1109/DASC.2006.313735

The unique requirements that are needed to safely and efficiently integrate UAS into the NAS are reviewed and discussed. Because of the differences between manned and unmanned aircraft, the same regulations that apply to manned aircraft, which mitigate risks, cannot easily apply to unmanned aircraft. Therefore, UAS needs different regulations for safety. Hayhurst et al. (2006) identified three notable hazards unique to UAS: (1) Controls for UAS are located on ground stations and not within the UAS. Currently, synchronization between controls is not ensured and therefore requires either automatic or manned additional safeguards. (2) Any issues regarding the shared resources between flight control and payload control should be mitigated. (3) Within UAS there is less capability for human intervention during autonomous operations. Hayhurst et al. define a UAS crew as the pilot and any other additional operators related to the UAS equipment and note that UAS crewmembers need to rely on different cues compared to manned pilots. Manned pilots experience physical cues while operating the aircraft, whereas UAS pilots need to find different environmental cues relevant to their decision-making. Unlike manned aircraft crews, UAS crews may be required to operate more than one UAV at one time. This creates an additional unique risk associated with UAS pilots that manned aircraft do not have. For all these unique requirements, there is a strong argument that the safe integration of UAS into the NAS would need new regulations and training.

Levinthal, B.R., & Wickens, C.D. (2006). Management of multiple UAVs with imperfect automation. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 50*(17), 1941–1944. https://doi.org/10.1177%2F154193120605001748

Levinthal and Wickens (2006) sought to understand how military UAV operators may be helped or harmed by imperfect target recognition automation systems. Generally, these systems can be imperfect in two ways: they can raise false alarms (i.e., cry wolf when nothing is there), or they can miss (i.e., not recognize a present target). The experiment tested three conditions: an automated system that had a reliability of 0.9, an automation system with a reliability of 0.6 that produced more false alarms, and an automation system with a reliability of 0.6 that produced more misses. The workload was varied by having the operator concurrently control either two UAVs (low workload) or four UAVs (high workload). The results showed that pilots could manage multiple UAVs, but performance decreased with more UAVs to control. The results showed that a system with more misses resulted in worse performance than a system with more false alarms. The system that made more misses yielded higher compliance (agreement with the system's messages) and lower reliance, with the opposite effect found for the system with more false alarms. These results suggested that pilots may be willing to over-rely on imperfect automation to reduce workload.

Duggan, G. B., Banbury, S., Howes, A., Patrick, J., & Waldron, S. M. (2004). Too much, too little, or just right: Designing data fusion for situation awareness. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 48*(3), 528-532. https://doi.org/10.1177/154193120404800354

Summarizing and cleaning up data before a presentation is one way to improve SA, but too much processing can reduce SA because necessary information has been removed. Related questions include how such information should be presented, and whether there are problems in how the presented data is used. "Just the right amount" of data fusion (i.e., summarizing and cleaning up) is not straightforward to achieve, as the needed amount of data varies by task, situation, and operator. Duggan et al. (2004) argue that targeting the optimal amount of data fusion should be done with an understanding of how tasks are completed, then designing the system to accommodate those needs. In other words, improving SA requires an understanding of "knowledge-in-the-world" in conjunction with an understanding of "knowledge-in-the-head". A framework is proposed for assessing future data fusions that are based on current psychological theory and takes into account the current understanding of SA.

Clough, B. T. (2002). *Metrics, schmetrics! How the heck do you determine a UAV's autonomy anyway?* Wright-Patterson Air Force Base, Air Force Research Laboratory. https://apps.dtic.mil/dtic/tr/fulltext/u2/a515926.pdf

Clough (2002) presented a review of existing models of robotic autonomy to develop a model capable of measuring levels of UAV autonomy. Three characteristics were deemed important in this construction: the measure must be easily visualized, be broad enough to adapt, and have a good resolution to track the technological impacts. The Mobility, Acquisition, and Protection (MAP) model of robotic autonomy and the Draper Three-Dimensional Intelligent Space model were identified for further consideration. The MAP model was found to have limited application to UAVs, as it could not address the type of autonomy found in UAVs and it could not address interactions between UAVs. It was also found that using the MAP model to discriminate between levels of automation was difficult. The Draper 3D Intelligence Space model did not have adequate resolution to describe multi-UAV systems, and it did not properly address system SA with high-level concepts and goals. This led to the development of a synthesis Autonomous Control Level model. The Observe Orient Decide and Act Loop model was updated and built into the new model. The new Autonomous Control Level model includes four descriptors: Observe (perception/SA), Orient (analysis/coordination), Decide (decision-making), and Act (capability). These four descriptors are measured using 10 levels of autonomy, described in detail. These metrics address operational issues while providing high resolution to discriminate between levels of autonomy.

Ruff, H. A., Narayanan, S., & Draper, M. H. (2002). Human interaction with levels of automation and decision-aid fidelity in the supervisory control of multiple simulated unmanned air vehicles. *Presence: Teleoperators and Virtual Environments, 11*(4), 335–351. https://doi.org/10.1162/105474602760204264

UAVs in an experiment were controlled through a simulated operation with varying levels of automation (manual control, where automation must be initiated by the operator; management-by-consent, where automation suggests an action; and management-by-exception, where the automation self-initiates can be turned off by the operator), decision-aid fidelity (100% accurate or 95% accurate), and the number of concurrently controlled UAVs (1, 2, or 4 UAVs). Mission efficiency, detection of incorrect decision aids, workload ratings, and SA ratings were measured. The management-by-consent level of automation showed performance advantages: highest overall mean mission efficiency, the highest rate of correctly rejecting decision-aid failures, and fewest/shortest total intrusion violations. Results suggest that when task complexity was high, pilots relied on management-by-exception automation, which lowered workload but also lowered performance. The workload increased when automation was incorrect (i.e., during 95% accurate decision-aid fidelity) as pilots had to double-check the automation. SA decreased with increasing UAVs to control. When decision-aid was 100% accurate, trust in management-by-consent increased as the number of UAVs increased. However, trust dropped when the pilot discovered a decision-aid error. The results indicate that workload does not always lower with increased automation. It is suggested that future systems allow pilots to focus on one vehicle to troubleshoot aspects of it while maintaining supervisory control of others.

Barnes, M. J., Knapp, B. G., Tillman, B. W., Walters, B. A., & Velicki, D. (2000). *Crew systems analysis of unmanned aerial vehicle (UAV) future job and tasking environment*s (Report No. ARL-TR-2081). Aberdeen Proving Ground, Army Research Lab. https://apps.dtic.mil/dtic/tr/fulltext/u2/a374230.pdf

The use of rated aviators as pilots in military UAS operations, the role of imagery specialists on a crew, and the use of automation are examined. The pilot positions are AVO and External Pilot (EP), where the AVO is seated in a GCS next to the Mission PO. The AVO reads flight instruments and maintains an understanding of the current flight status. However, the AVO does not fly the UAV in the same way a manned fixed-wing or rotary aircraft is. The EP handles takeoffs and landings and uses more hands-on control in doing so. A job assessment (JASS) and data from a computerized selection test battery (Environment-Conscious Aircraft Technology Program; ECAT) were collected from 30 Mission POs and AVOs, and their responses were rated by a group of SMEs. Results show little evidence requiring AVOs to have rated aviator skills. EP functions require motor and cognitive skills, which may be supported through training. It is suggested that having rated aviators as part of a UAV crew's decision chain may be useful, but it is not necessary to have the pilot be a rated aviator. Automation and workload modeling was completed to identify which tasks should be automated. Results suggest that pre and post-flight checks, system settings verification, and mission plan checks are strong candidates for automation. Monitoring tasks can be semi-automated, maintaining HITL. Operators did not prefer full automation, opting to maintain decision-making capabilities while reducing workload.

Duty and Rest Requirements

Qi, S., Wang, F., & Jing, L. (2018). Unmanned aircraft system pilot/operator qualification requirements and training study. In *MATEC Web of Conferences Vol. 179*. EDP Sciences. https://doi.org/10.1051/matecconf/201817903006

Qi et al. (2018) evaluated the differences between current UAS and manned aircraft pilot training and sought to determine best practices for the selection and training of future UAS pilots/operators. Qi et al. (2018) identify areas of required qualifications to consider for UAS pilots such as professional-grade (e.g., sense of duty, logical), medical requirements (e.g., good eyesight), psychological evaluation (e.g., emotional stability), training requirements (e.g., UAS education), operating experience (e.g., part of the training process), and coordination. To fully encompass challenges and demands presented by UAS operations, a tiered training method consisting of theoretical training, simulator training, sUAS operation, and specialized training is proposed. It is also suggested that training in psychological health and HF involved with UAS operations is necessary for adequate certification. HF worth considering includes the limitations of a human crew, ergonomic influences, human error prevention, and flight and operation safety.

Cerreta, J., Bruner, T., & Snyder, P. (2017). *A10–Human factors considerations of UAS procedures and control stations: Tasks PC-1 through PC-3, pilot and crew (PC) subtask, recommended requirements and operational procedures.* Federal Aviation Administration, William J. Hughes Technical Center. https://rosap.ntl.bts.gov/view/dot/37381

Minimum procedures and practices required of UAS pilots are examined. While similarities were noted between manned and unmanned platforms, UAS operations allow for crew changeovers where relief pilots were not responsible or present for previous phases of flight. This results in unique requirements for UAS, such as handoff procedure briefings. A minimum of a one pilot crew with no required support crew is recommended, and minimum operational requirements and procedures for this minimal staffing are proposed. The PIC should have final authority in safe operation, communicate using standard aviation phraseology, and be knowledgeable of emergency procedures. Also proposed is that flight time be limited according to existing regulation 14 CFR Part 91.1059, where a duty period may not exceed 14 hours in a 24-hour period, and that flight time for a pilot may not exceed 12 hours within a 24 hour period. Rest periods are also proposed to follow existing regulations as well. PICs are also proposed to possess a current UAS airman certification, ratings appropriate to the UAS, currency (and proficiency) in the UAS category being operated, and instrument currency. Additional recommendations include minimum operational requirements and procedures for each phase of flight, including abnormal flight operations (e.g., emergencies).

Pankok, C. Jr., Bass, E. J., Smith, P. J., Bridewell, J., Dolgov, I., Walker, J., Anderson, E., Concannon, R., Cline, P., & Spencer, A. (2017). *A7—UAS human factors control station design standards (plus function allocation, training, and visual observer)*. Federal Aviation Administration, William J. Hughes Technical Center. https://rosap.ntl.bts.gov/view/dot/36213

In identifying areas necessary for UAS operation, Some of the key training guidelines for pilots and observers are highlighted and discussed, as there are no current standards that are uniform across UAS pilots or observers. A work system that parallels manned aircraft procedures by distributing the planning among pilots, observers, dispatch, schedulers, and traffic managers is suggested so as to mitigate workload with flight planning for a UAS crew. As operations emerge specifically unique to UAS, training methods should be implemented to reflect those while focusing on two types of certification: commercial and private. Private certification would encompass least-risk entry-level certification, and commercial certification would encompass operations; commercial certification would encompass compensation and for-hire operations. VOs should receive training in tracking UAS, scanning airspace, and coordinating with the pilot and GCS. An EP may be needed for takeoff before passing control to an RPIC, and subsequently having control returned to the EP before landing. This would require training programs specifically for takeoff and landing because it is one of the more difficult procedures. The size of the UAS and mission will dictate the workload and size of the crew necessary to carry out operations.

Carretta, T. R., & King, R. E. (2015). The role of personnel selection in remotely piloted aircraft human system integration. In *18th International Symposium on Aviation Psychology* (pp. 111-116). Dayton, OH: Wright State University. https://corescholar.libraries.wright.edu/isap_2015/88

Important factors for personnel selection with RPAs that would mitigate increased costs resulting from poor training, selection, and methodology, are considered. Current selection standards for Undergraduate RPA training are examined to determine best practices for these areas. The curriculum for potential pilots and operators includes aptitude testing (e.g., Air Force Officer Qualifying Test [AFOQT], Test of Basic Aviation Skills [TBAS], and Pilot Candidate Selection Method [PCSM] test battery), medical screening (e.g., FAA Class III Medical Certificate and USAF Flying Class IIU Medical Examination), and an interview with a licensed psychologist. Examples of relevant cognitive abilities that have been rated as “most important” for RPA pilots (e.g., spatial orientation) and personality traits (e.g., dependability) were provided for reference. It is mentioned that these traits and abilities will vary for occupations like pilots or engineers.

The resulting automation of functions will dictate the requirements of the crew and the size as well.

Joslin, R. (2015). Synthesis of unmanned aircraft systems safety reports. *Journal of Aviation Technology and Engineering*, *5*(1), 2-6. https://doi.org/10.7771/2159-6670.1117

Mainstream UAS implementation is currently exceeding the pace of developing proper safety regulations. UAS accidents and incidents reported in the Aviation Safety Information Analysis and Sharing (ASIAS) database were reviewed to evaluate the general cause of these mishaps and identify ways to mitigate them. Many of the reports were attributed to equipment failure, but nearly a third were the fault of pilot/operator error. Out of the instances due to human error, the majority of them were the result of deviating from procedural operations. Other examples concerned the general operation of the UAS, such as rough landings or in-flight encounters or loss of link to command centers. Identifying the root cause of the human error in UAS mishaps may shed light on areas to focus future training efforts for pilots/operators.

Mirot, A. (2013). The future of unmanned aircraft systems pilot qualification. *Journal of Aviation/Aerospace Education & Research, 22*(3), 19-30. https://doi.org/10.15394/jaaer.2013.1317

Current UAS definitions and requirements are examined to determine proper qualification standards for UAS pilots and observers. Pilots will need training in areas like launch and recovery, normal operations, emergency protocol, and loss of control link. In a study where pilots (UAS, civilians, and non-UAS military pilots) and non-pilots flew a UAS, the performance of the formally trained pilots was significantly better than those not trained, suggesting formal training is indeed necessary for the particular UAS being flown. An amended version of the DoD's group of categories for UAS pilot certification is proposed that divides UAS by weight, altitude, and top speed. Each category would then necessitate specific requirements for that class (i.e., Level 1 requirements are not as stringent as Level 4). The medical requirements for pilots and crew members would scale accordingly. Observers and more crew members are needed until adequate technology can account for proper SAA procedures. As commercial use will be more prevalent and require caution for public safety, the level of qualification for pilots and crews must be the most stringent.

Rose, M. R., Arnold, R. D., & Howse, W. R. (2013). Unmanned aircraft systems selection practices: Current research and future directions. *Military Psychology*, *25*(5), 413–427. https://doi.org/10.1037/mil0000008

The development of selection criteria for UAS operators, and whether such criteria should be uniform across the U.S. military is of interest. The focus is on pilots in the MCE phase that starts after takeoff and ends shortly before landing; pilots involved with takeoff and landing are expected to be eliminated with automation. Selection for USAF UAS pilots includes the Medical Flight Screening and the PCSM which consists of the AFOQT Pilot composite, parts of the Test of Basic Aviation Skills (TBAS; Carretta, 2005), plus a flying experience measure. Sensor operators are selected on the basis of Armed Services Vocational Aptitude Battery (ASVAB) scores and additional measures of technical knowledge. Cited studies suggest that cognitive and psychomotor abilities, personality, aviation knowledge, and flying experience are useful predictors of success in USAF UAS pilots as well as SOs. The U.S. Navy does not have a formal UAS crew selection testing process, but a recent job analysis with SMEs found that teamwork, communication skills, and decision-making abilities were the highest-rated attributes. In the U.S. Army, soldiers are required to have a score of 105 or higher on the ASVAB surveillance and communications scale. In a recent job analysis, communication skills were deemed most important for AVOs. However, other research has identified psychomotor abilities as strongly related to training completion. Overall, predictors of success include tests of cognitive abilities, knowledge, psychomotor abilities, and experience. Additionally, the focus should also be placed on personality measures in the selection process as well.

Arrabito, G., Ho, G., Lambert, A., Rutley, M., Keillor, J., Chiu, A., Au, H., & Hou, M. (2010). *Uninhabited aerial vehicles: Preliminary findings in support of the Canadian Forces joint unmanned aerial vehicle surveillance target acquisition system project* (Report No. TR 2009-043). Defence Research and Development Canada. https://apps.dtic.mil/dtic/tr/fulltext/u2/a543186.pdf

Canadian Forces reviewed HF associated with UAV operations, specifically the role of HF in UAV accidents, operator performance, shift work, pilot experience, and data displays of GCS. Only shift work and crew staffing requirements are addressed here. Decreased mood, alertness, and performance are common across all shifts during shift rotation, and are amplified during rapid shift rotations for day and night shifts compared to evening shifts. To reduce the negative effects of extended shift work, it is recommended that a UAV crew consists of nine personnel to support the mission. This allows for UAV personnel to take vacations, use sick leave, and provide days for rest and other personal activities. Fewer than nine personnel increases the number of rotating shifts and overall work demand. Additional fatigue countermeasures can be implemented, such as bright lighting, shift breaks, and prophylactic naps, to reduce the strain of extended shift schedules.

Johnson, C. W. (2009). The safety research challenges for the air traffic management of unmanned aerial systems (UAS). In *Proceedings of the 6th EUROCONTROL Experimental Centre Safety Research and Development Workshop.* Munich, Germany. https://publish.eurocontrol.int/eec/gallery/content/public/document/other/conference/2009/safety_r_and_d_Munich/day_1/Chris-Johnson-(Glasgow-University)-Paper.pdf

The novelty of introducing UAV into controlled airspace has led to a double-edge challenge: strict regulation has limited the usability of UAV in controlled airspace because of unknown hazards presented by their use. However, little information is available about hazards presented with UAV operations because so few are allowed to operate in controlled airspace. Documented UAV accidents could be used to close the knowledge gap in unknown UAV hazards, and a review of five UAV accidents was done to identify potential hazards. In a comparison between Canadian Defense Forces and US Customs and Border Patrol accident cases, the discussion was categorized in terms of eight "safety challenges": (1) Hazards from the Spirit of Innovation, (2) The Complexity of Ground Movements, (3) ATM Communications and UAS Task Allocation, (4) Risk Erosion and the Loss of First Person Liability, (5) Human Factors and the Complexity of Remote Situation Awareness, (6) Accurate Assessments of UAS Airworthiness, (7) ATM Interaction with Lost Link Profiles, and (8) ATM Emergency UAV Interaction. Importantly, lack of sufficient operator training is a major consideration because most UAV pilots do not receive sufficient UAS training and are unable to respond to system failures. Also, many of the reviewed UAV accidents did not have proper procedures or manuals in place for certain events, resulting in an inadequate response from crewmembers and ultimately UAV loss. Improved UAV pilot training and procedure/manuals are required to reduce hazards and increase the efficient integration of UAV into controlled airspace.

Tvaryanas, A. P., & MacPherson, G. (2009). Fatigue in pilots of remotely piloted aircraft before and after shift work adjustment. *Aviation, Space, and Environmental Medicine, 80*(5), 454-461. https://doi.org/10.3357/ASEM.2455.2009

Shift work in long endurance RPA operations is known to increase crewmember fatigue, and a follow-up study was conducted to see if changing to a 6W:3F (six days working, three days free) schedule reduced crewmember fatigue. Fatigue scores did not improve with an extra day free for rest, suggesting the quality of sleep is more important than the quantity. Rotating shift schedules depend upon crewmembers maintaining wake and sleep schedules on days off and is difficult, if not impossible, to enforce. Additionally, no alternative shift schedule models were found showing decreased fatigue scores because of inadequate staffing; these findings highlight issues of "doing more with less". One suggestion to overcome inadequate staffing is to hand off RPA control between two or more crews working in different time zones to keep crewmembers working in their local time, thus reducing the need for rotating shifts in a single crew.

Cork, L., Clothier, R., Gonzalez, L. F., & Walker, R. (2007). The future of UAS: Standards, regulations, and operational experiences [workshop report]. *IEEE Aerospace and Electronic Systems Magazine*, *22*(11), 29-44. https://doi.org/10.1109/MAES.2007.4408524

A workshop was held in Brisbane, Australia, to review challenges posed by UAS integration to the airspace. One outcome of the meeting was the development of a "roadmap" to guide the development of regulations for UAS integration in the NAS and crewmember training. Discussed was a previous finding that 16% of all accidents and incidents were due to human error, and subsequent research noted that crew resources, training, and HIS contributed to some of the incidents. Improved operator training and redesign of data displays were implemented to reduce the frequency of accidents and incidents. Additional research focused on UAS technology, recommending that training should also focus on basic training, conversion training, basic operations training, full mission training, and combat mission training, rather than training specific to the UAS platform.

Williams, K. W. (2007b). *Unmanned aircraft pilot medical certification requirements* (Report No. DOT/FAA/AM-07/3). Federal Aviation Administration, Office of Aerospace Medicine. https://rosap.ntl.bts.gov/view/dot/58437

UAS pilot medical certification requirements are necessary for three reasons: compliance with the Americans with Disabilities Act, mitigation of public safety risks (e.g., risks due to pilot incapacitation from a medical condition), and mitigation of the perception of safety risk. A third-class medical certification with the use of Authorization of Special Issuance waivers for exceptions is recommended. However, there are other competing recommendations to note, such as requiring a second-class medical certification for 20/20 vision among pilots flying line-of-sight operations. Williams argued that these requirements are subject to waivers, so handicapped persons may still receive a certification if they demonstrate the ability to fly an unmanned aircraft – which is different than the ability to fly a manned aircraft.

Thompson, W. T., Lopez, N., Hickey, P., DaLuz, C., Caldwell, J. L., & Tvaryanas, A. P. (2006). *Effects of shift work and sustained operations: Operator performance in remotely piloted aircraft (OP-REPAIR)* (Report No. HSW-PE-BR-TR-2006-0001). Brooks City-Base, Air Force Research Laboratory 311th Performance Enhancement Research Division. https://apps.dtic.mil/dtic/tr/fulltext/u2/a443145.pdf

The effects of shift work on fatigue in USAF MQ-1 Predator UAS crews in a sustained-operations environment are discussed. Results found decreased mood and cognitive performance across shifts and rotation schedules. Fatigue was found to be pervasive in the sampled crews; chronic fatigue is known to cause stress, burnout, and emotional exhaustion. Results suggest inadequate opportunities for recovery sleep for crews operating on a shift system compared to crews working only day shifts. Sleep quality was also low among night-shift and rapid-shift-rotation crews, which may suggest lower work effectiveness for those crews. Alertness (attentional lapses) appeared to be more prevalent at certain times of day, suggesting early-morning or mid-afternoon times may be prone to issues. Furthermore, flying time limits did not seem to be useful in limiting fatigue among crews scheduled on a shift system.

Tvaryanas, A. P. (2006a). *Human factors considerations in migration of unmanned aircraft system (UAS) operator control* (Report No. HSW-PE-BR-TR-2006-0002). Brooks City-

Base, Air Force Research Laboratory 311^{th} Performance Enhancement Research Division. https://apps.dtic.mil/dtic/tr/fulltext/u2/a444925.pdf

Tvaryanas (2006a) reviewed the advantages and disadvantages of the migration of UAS control operations. UAS operations can be migrated physically, temporally, and functionally. During a single flight, there could be changes in team tasking, changes between teams, and movement between control stations. These migrations likely increase operator workload and therefore risks associated with operating UAS. While there are risks associated with migration, it is likely necessary. UAS military operations are reviewed to gain a better picture of the advantages and disadvantages associated with functional migration. Within military UAS operations, there are two operators: one vehicle control and the other payload control. The vehicle operator controls the movement of the UAS and the payload operator controls target acquisition functions. The reviewed data strongly suggests one single operator cannot perform both functions without significant risks. This is one example of many that suggests there are limitations associated with human capabilities and/or technology that make migration a necessity, despite their being increased workload/risks involved. Some advantages were also discussed. For example, migration may be valuable for mitigating the negative effects of fatigue by having an appropriate work-rest shift schedule. Tvaryanas (2006a) concluded that future HF research should be conducted to optimize current migration operations.

Tvaryanas, A. P. (2006b). Human systems integration in remotely piloted aircraft operations. *Aviation, Space, and Environmental Medicine*, *77*(12), 1278-1282. https://www.researchgate.net/publication/6616379_Human_Systems_Integration_in_Remotely_Piloted_Aircraft_Operations

Challenges unique to RPA operations were reviewed with the Human Systems Integration (HSI) model. The HSI model identified multiple human domains affected by RPA operations, specifically in pilot training and awareness, shiftwork and manning, and ergonomic design failures of GCSs. Unmanned operations give the illusion that less demand is placed on pilots; however, pilots are subjected to equal, if not longer, shiftwork for unmanned than manned operations. RPA pilots will need additional training to interpret data from visual instruments and training to increase/maintain SA. Although fewer crewmembers are required for a single RPA operation, more demand could be placed on an individual RPA pilot because they have additional items to focus on, especially if they are flying in non-ideal conditions. Additionally, RPAs designed for long-endurance missions still require shiftwork so as not to fatigue crewmembers over time.

United States Air Force. (2005). *The U.S. Air Force remotely piloted aircraft and unmanned aerial vehicle strategic vision*. U.S. Department of Defense, Air Force. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1000&context=usafresearch

Operations and capabilities planning are discussed, with extended time aloft, aircrew fatigue mitigation, network integration (communications), and versatility (e.g., capable of different tasks, such as a combat mission concurrent with weather data collection), as main attributes of interest. One problem noted in the document was the challenge of maintaining maximal SA under these conditions; future research will be required to identify appropriate displays and controls, staffing, and levels of automation (i.e., what procedures should or should not be automated). Organizational issues include vehicle operator qualification, operator-to-UAV staffing ratio, and weapon system support. With the move from rated pilots serving three-year tours to a career field with RPA training, the USAF may supplement uniformed crew with civilian employees and contractors. Functions will require future determination on whether they may be "contracted out". The degree of command authority, as well as the level of training, will also require future determination. While the operator responsible for the aircraft will be the PIC, this role may encompass the control of multiple aircraft or one aircraft depending on future software development, the mission itself, airspace, and aircraft capability. Up-to-date training will be required for both pilots and system maintainers.

Manning, S. D., Rash, C. E., Leduc, P. A., Noback, R. K., & McKeon, J. (2004). *The role of human causal factors in US Army unmanned aerial vehicle accidents* (Report No. USAARL-2004-11). Fort Rucker, Army Aeromedical Research Lab. https://apps.dtic.mil/dtic/tr/fulltext/u2/a421592.pdf

There has been little investigation of what HF may have played a role in USAF UAV accidents. Manned flight hours outnumber unmanned flight hours in the USAF, but UAV operations have a significant accident rate, 10 to 100 times more than manned operations. Crew coordination, ergonomics, and system design, fatigue, SA, training, and workload have consistently been identified as HF in UAV accidents. To investigate the role of HF in UAV accidents, 56 military UAV accidents were analyzed using HFACS and the U.S. Army's DA PAM 385-40 methods. Similar results were found with both methods. Human error was determined to be a factor in 32% of examined UAV accidents, either as a sole or compounding factor. Specifically, unsafe acts or failures by the individual, ineffective training, ineffective policies and standards, and ineffective leadership were identified as contributing factors to the UAV accidents. Recommendations include training programs that focus on preventing human errors to reduce UAV accidents; training should focus on environmental effects upon the UAV, such as wind, and how to successfully operate the UAV in those conditions. Emergency procedure training (e.g., engine failure) was also noted, and improved training and policies focusing on UAV emergency procedures should be implemented.

Manned Operations

Crew and Staffing Roles

Kanki, B. G., Anca, J., & Chidester, T. R. (Eds.). (2019). *Crew resource management* (3rd ed.). Elsevier Academic Press.

The history, philosophy, and implementation of CRM are analyzed to derive concrete guidelines for future aviation regulation. CRM is an essential area of focus for determining proper crew size, allocation of members and duties, and for efficient UAS operations as training in CRM principles is vital for crewmembers. In particular, the focus of CRM is on training at the crew level, as opposed to training at the individual level. Doing so would improve not only individual-to-computer interactions but performance in interpersonal activities as found on aircraft crews. Proper CRM involves crew coordination, communication, monitoring, and error management. Additionally, CRM also includes a focus on the individual and the role of leadership in a team. Distributing the duties effectively amongst crewmembers is a cornerstone of crew coordination. The text stressed the importance of continually evaluating the current understanding of CRM and that recurrent training is needed as effective improvements are made and new information comes to light. Developing training for efficient and reliable CRM assessment is also of top priority. Methods such as Line Oriented Flight Training as tools for developing CRM training are discussed. Successful CRM implementation with UAS may emerge once there is a consensus on best practices, grading scales, methodologies, and procedures for measuring and teaching CRM. It is noted that as the number of rules and regulations increases then so will the complexity that goes into proper compliance. Aspects of CRM, such as lessons learned from other industries and other cultures, are also discussed.

Beveridge, S. D., Henderson, S. T., Martin, W. L., & Lamb, J. B. (2018). Command and control: The influence of flight crew role assignment on flight safety in air transport operations. *Aviation Psychology and Applied Human Factors*, *8*(1), 1.

The roles assigned to the Pilot Flying (PF) and to the Pilot Monitoring (PM) are examined in a meta-analysis for their effects on flight safety. Thematically, the 16 selected articles discussed monitoring, situational awareness (SA), and decision-making. *Monitoring*. Errors made by PMs were found unlikely to be challenged. Junior first officers' attempts at appearing competent led to taking on higher workload, which in turn led to degraded PM performance. Relative inexperience may also contribute to first officers' failures as PM. Although both PF and PM are both considered pilots, an imbalance of status and authority was found; a number of the studies found that a lack of assertiveness or corrective actions from the first officer was a significant factor in accidents. *Situational Awareness*. Crews appeared more likely to lose SA when the captain lost SA, particularly in situations where the captain was under high workload. Similarly, high situational complexity was found to reduce SA when the captain was PF. First officers were found to lose SA due to inexperience. *Decision-Making*. Contributing factors include task overload, first officers' lack of expertise, and PF ineffectiveness at selecting information requiring further SA. Increased decision-making time among captains as PF may indicate increased cognitive burden, and the perceived skill of captains may allow them to pilot the aircraft into unsafe states. However, the increased engagement in control processes may be a factor in increased takeoff performance among captains as PF. Overall, the effect of crew roles on performance and safety can be observed through the interacting themes of monitoring, SA, and decision-making. Analyses indicated that workload and experience may inhibit monitoring; status may reduce SA by inhibiting communication; and the combined lack of monitoring and SA may result in poor decision-making. Further research is recommended for improving performance of first officers as PM, practices that might sometimes inappropriately place captains as PF, and guidance for appropriate delegation of roles.

Vu, K.-P. L., Lachter, J., Battiste, V., & Strybel, T. Z. (2018). Single pilot operations in domestic commercial aviation. *The Journal of the Human Factors and Ergonomics Society*, *60*(6), 755–762. https://doi.org/10.1177/0018720818791372

A review of previous research on crew size for commercial aviation indicated that crew size has been reduced as technological advances have been made over the years with the current goal striving for SPOs. This transition will greatly reduce costs across many areas, so the incentive for research is there. The research into SPOs may inform regulations and decision-making surrounding UAS/RPA crew needs as a functional balance between human operators and automation is necessary. Aside from pilots, other crewmember roles include ground operators for support (a role to replicate the responsibilities of a co-pilot to increase SA and decision-making), a first officer on the ground, dispatcher roles, and automation is proposed as a crewmember from a human-autonomy teaming perspective. Ground support may be split between general roles (hybrid) that support many aircraft to dedicated support for specific aircraft (specialists). One specialized role that is mentioned is that of a Harbor Pilot. A Harbor Pilot would have a deeper understanding of the proximate area conditions such as airspace, weather, traffic, and scheduling to assist with crew needs. Technological advances will continue to shape the roles required for SPO and UAS as they evolve over time with further research. Once automation is properly developed and standardized, then it may dictate crew size and requirements.

Lachter, J., Brandt, S. L., Battiste, V., Matessa, M., & Johnson, W. W. (2017). Enhanced ground support: Lessons from work on reduced crew operations. *Cognition, Technology & Work*, *19*(2-3), 279–288. https://doi.org/10.1007/s10111-017-0422-6

Recent advances in automation technology have the potential to further reduce manned aircraft operations to a SPO/RCO. Lachter et al. (2017) argued that, with increased automation and the presence of a ground operator, an aircraft can be safely operated with a single pilot on board. Four HITL simulations that built-in complexity were reviewed to assess the efficiency and effectiveness of a single onboard pilot with a ground operator (either a dispatcher or ground pilot). The first HITL simulation investigated crew communication between collated or separated pilots, and it found a slight preference for separate pilot locations (e.g., pilots in separate rooms rather than in the same room), although pilots reported they preferred operating together in the same location. One identified challenge was a reduction in SA, such that separated pilots were unsure of the other pilot's actions and who was in command of the aircraft. The second HITL simulation investigated differentiated pilot roles (e.g., captain onboard the aircraft or ground operator [dispatch and first officer roles]) on crew communication and workload. It also addressed the challenge of reduced SA by incorporating CRM indicators to notify pilots of the other's actions and who was operating the aircraft. It found that both pilots communicated more often and responded more with the CRM indicators, suggesting the added tools help direct attention to appropriate safety decisions. However, it was recommended that the ground operator only focus on one task rather than two when having to assist an aircraft. The third HITL simulation investigated SA and whether awareness of an aircraft's system and flight information before an emergency is necessary for the ground operator to efficiently intervene and provide support. Lack of SA before intervening did not affect the ground operator's workload, SA, or performance. The final HITL simulation added an alerting system, augmented route re-planning tool, and voice interactions in the ground station to increase automation available to the ground operator. Ground operators and pilots found the increased automation and tools valuable and helpful for integrating information between the aircraft and the ground station. However, both the ground operators and pilots preferred standard inputs over voice controls, and the pilots expressed additional concern about interruptions from the ground station.

Comerford, D., Brandt, S. L., Lachter, J., Wu, S. C., Mogford, R. H., Battiste, V., & Johnson, W. W. (2013). *NASA's Single-pilot operations technical interchange meeting: Proceedings and findings* (Report No. NASA/CP-2013-216513). National Aeronautics and Space Administration, Ames Research Center. https://ntrs.nasa.gov/search.jsp?R=20140008907

Comerford et al. (2013) provide a meeting summary regarding SPOs, particularly in air carrier operations. Issues identified include but were not limited to: authority between agents (e.g., human-automation conflict), changes in the nature of communications within the NAS, requirements and certification, aircraft ergonomics (e.g., development of a single-pilot cockpit), automation and decision support, accountability, workload, pilot availability (e.g., pilot steps away from control station), and teamwork. The discussion primarily focused on a pilot on board, but recognized the role of automation. To support the single onboard pilot, recommendations ranged from relying on onboard personnel as a backup pilot to relying on a ground-based support team or relying on automation. Against moves to reduce pilot staffing, issues include acceptability to the general flying public, whether automation may fail, and whether there are cost savings if crewmembers are simply moved from the aircraft to a ground station. However, evidence is also provided in favor of reducing pilot staffing. For example, General Aviation pilots have already been flying SPOs, where pilots with adequate training can handle emergencies. It is further noted that manufacturers are already in the process of designing aircraft in anticipation of SPOs.

Duty and Rest Requirements

European Union Aviation Safety Agency. (2019). *Effectiveness of flight time limitation (FTL)*. https://www.easa.europa.eu/document-library/general-publications/effectiveness-flight-time-limitation-ftl-report

The European Union Aviation Safety Agency (EASA; 2019) conducted a review of European Union requirements for flight and duty time, and rest requirements. Night operations had a higher probability of elevated fatigue levels towards the end of late Flight Duty Periods (FDPs) and at the top of descent compared to all recorded FDPs. Fatigue levels did not differ for night FDPs ranging more or less than 10 hours, suggesting night operations, in general, are associated with elevated fatigue levels compared to other flight operation times. Current regulations emphasize crewmembers receiving adequate rest for FDPs greater than 10 hours. However, it is recommended that regulations should include adequate rest before all-night operations. Taking naps during or resting prior to night FDPs can reduce fatigue levels, but napping during FDPs is a short-term remedy and generally only accepted for unexpected fatigue levels experienced late into an FDP. The EASA recommended adjusting the definition of night FDP to account for different types of night FDPs, recommending that operators implement appropriate fatigue risk management for late finish and all-night FDPs, and amending current regulations to emphasize adequate sleep and rest prior to all-night FDPs.

DuBose, N. N. (2011). Flightcrew member duty and rest requirements: Does the proposed legislation put to rest the concern over pilot fatigue? *Journal of Air Law and Commerce, 76*(2), 253-288. https://scholar.smu.edu/jalc/vol76/iss2/3

The 2011 Airline Safety Act was reviewed. The FAA proposed new FDP schedules that reduce day-flight operations from 16 to 9-13 hours maximum, and night operations to no more than nine hours of flight operations. However, an alternative FDP schedule was adopted that limits flight operations from 8-10 hours, with night operations being restricted to 8-9 hours. This was expanded to cargo, international, and passenger operations. Daily rest requirements were also changed, requiring at least nine hours of rest prior to beginning a flight, beginning when the crewmember reaches their hotel or other relevant residences. However, the proposal drastically affects rest requirements for international travel, reducing the rest period from the length of the flight times to between 2 and 9 hours. The FAA proposal also placed additional responsibility on the carrier itself to determine whether a crewmember is fit for duty. Augmented flights were also proposed for passenger flights, allowing total flight time to increase, depending on the number of available crew and flight characteristics. However, additional requirements for rest facilities and pilot commutes to work should be taken into consideration with future duty and rest requirements.

Strauss, S. (2006). *Pilot fatigue*. Johnson Space Center. http://aeromedical.org/Articles/Pilot_Fatigue.html

Fatigue is a known threat to flight safety that can occur from lack of sleep, circadian rhythm disruptions, and shift work. Sleep loss can lead to sleep debt, where an individual does not receive adequate hours of sleep for optimal function for consecutive days. Pilots with any sleep debt may suffer from fatigue and have poor judgement and performance. Additionally, they may experience bouts of microsleep and other involuntary episodes of sleep that range from seconds to minutes during operations. The FAA established flight time and rest rules for commercial carriers to combat pilot and crewmember fatigue. The maximum flight time for crewmembers cannot exceed 30 hours in seven consecutive days and eight hours between periods of rest. However, current regulations do not allow for adequate sleep nor address the range of sleep an individual may require. Regulations should incorporate additional factors such as time to check out of hotels and travel to the airport prior to scheduled shifts to increase rest periods and limit the effects of fatigue on pilots and crewmembers.

Goode, J. H. (2003). Are pilots at risk of accidents due to fatigue? *Journal of Safety Research, 34*(3), 309-313. https://doi.org/10.1016/S0022-4375(03)00033-1

Extended flight schedules are generally believed to increase fatigue and the probability of aviation accidents. A comparison of 55 accidents and pilot duty activities under Part 121 air carrier operations was done to investigate the relationship between the length of duty and the occurrence of aviation accidents. An incremental increase in accidents was observed as the length of duty increased. Flight operations of 13 or more hours had the highest proportion of all accidents compared to operations with fewer hours, suggesting long schedules increase the odds of an accident occurring. There was no indication of when the length of duty significantly affected the probability of accidents occurring. However, length of duty with 10 or more hours of operations had high proportions of aviation accidents compared to fewer than 10 hours. Regulations regarding duty schedules should be adjusted to shorten pilots' length of duty to reduce the odds of aviation accidents.

Samel, A. Wegmann, H. M., & Vejvoda, M. (1997). Aircrew fatigue in long-haul operations. *Accident Analysis and Prevention, 29*(4), 439-452. https://doi.org/10.1016/S0001-4575(97)00023-7

Modern advancements in aircraft design, such as the glass-cockpit, and the reduction of minimum crew requirements for flight operations drastically affects pilot workload and performance. Two-pilot crew performance was investigated for long-haul operations to see whether current duty and rest regulations should be adjusted. Results indicate that crews operating fewer than 12 hours a day did not report critical levels of fatigue, despite operating longer than regulation (e.g., 10 hours of duty time is standard in German regulations; however, it can be extended to 14 hours under specific circumstances). However, night operations are at risk for fatigue due to the natural disruptions of the circadian rhythm, and crew members reported less sleep and higher fatigue levels with night operations. It is recommended that long-haul operations with a two-pilot crew be limited to no more than 12 hours for day operations and 10 hours for night operations. At least 48 hours of rest should be provided to crews between long-haul operations to provide adequate rest between extended long-hauls to reduce sleep deprivation.

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