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Annotated Bibliography (1990 – 2019): Knowledge, Skills, and Tests for Unmanned Aircraft Systems (UAS) Air Carrier Operations

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16. Abstract
The integration of unmanned aircraft systems (UAS) into the National Airspace System (NAS) requires a thorough understanding of the knowledge, skills, abilities, and other characteristics (KSAOs) needed for UAS operations. As UAS operations expand beyond Title 14 of the Code of Federal Regulations (14 CFR) Part 107, there is an increasing need for the Federal Aviation Administration (FAA) to standardize pilot requirements, certification requirements, and testing and training requirements, particularly for air carrier and commercial operations. Part 107 does not address air carrier operations; and existing air carrier rules, found in 14 CFR Parts 121 and 135, were not written with UAS in mind. As it stands, there is a gap in our understanding of the minimum knowledge, skills, and testing needed for various UAS operations, which poses a challenge for FAA rulemaking. This annotated bibliography seeks to bridge this gap by documenting the knowledge, skill, and testing requirements for pilots of unmanned aircraft operations based on a review of the research literature. This annotated bibliography will support FAA rulemaking efforts by the FAA's Flight Standard Service General Aviation and Commercial Division (AFS-800) for UAS operations over people, expanded operations, and non-segregated operations as well as efforts by the Air Transportation Division (AFS-200) for developing UAS air carrier regulatory requirements. Articles were collected from Google Scholar and FAA Technical Library databases. Eighty-eight articles were identified as relevant, including empirical studies, qualitative reviews, and regulation/guideline documents. This annotated bibliography is structured into four main sections: UAS Knowledge, UAS Skill, UAS Testing and Training, and UAS Operations. The documentation of KSAOs required of UAS pilots can inform FAA rulemaking by providing a foundation for the establishment of minimum pilot qualifications. Additionally, identifying minimum knowledge and skill requirements can inform UAS pilot training requirements. This research effort, in addition to other UAS research requirements (e.g., fatigue, crew and staffing), will support the FAA's rulemaking efforts that promote the safe and efficient integration of UAS into the NAS.

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unmanned aircraft systems, knowledge and skill requirements, testing requirements

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List of Abbreviations

4D	Four Dimensional
ACS	Airmen Certification Standard
ACU	Artificial Cognitive Unit
ADM	Aeronautical/Aviation Decision Making
AFOQT	Air Force Officer Qualifying Test
AGL	Above Ground Level
ALAADy	Automated Low Altitude Air Delivery
APEX	Automated Pilot Examination
ARM	Atmospheric Research Measurement
ASTB	Aviation Selection Test Battery
ASVAB	Armed Services Vocational Aptitude Battery
ATC	Air Traffic Control
AUVSI	Association for Unmanned Vehicle Systems International
AVO	Air Vehicle Operators
BUQ	Basic UAS Qualification
CAA	Civil Aviation Authority
CFR	Code of Federal Regulations
14 CFR	Title 14 (Federal Regulations on Aeronautics and Space)
CRM	Crew Resource Management
DoD	Department of Defense
DoE	Department of Energy
DSSQ	Dundee Stress State Questionnaire
ECAT	Enhanced Computer-Administered Test
ECG	Electrocardiography
EEG	Electroencephalography
EOG	Electrooculography
EP	External Pilot

FAA	Federal Aviation Administration
GCS	Ground Control Station
GPS	Global Positioning System
HALE	High Altitude Long Endurance
HSI	Human Systems Integration
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IP	Internal Pilot
ISR	Intelligence, Surveillance, and Reconnaissance
JASS	Job Assessment Software System
JTA	Job Task Analysis
KSA	Knowledge, Skill, and Ability
KSAO	Knowledge, Skill, Ability, and Other Characteristic
MALE	Medium Altitude Long Endurance
MFS	Medical Flight Screening
MOS	Military Occupational Specialty
MPO	Mission Payload Operator
MTOW	Maximum Take-off Weight
MUM-T	Manned and Unmanned Teaming
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAVAID	Navigational Aid
NOTAM	Notice to Airmen
Part 107	14 CFR Part 107 (Federal Regulation for sUAS)
Part 121	14 CFR Part 121 (Federal Regulation for Air Carriers)
Part 135	14 CFR Part 135 (Federal Regulation for Commuter Air Operations)
Part 61	14 CFR Part 61 (Federal Regulation for Certification: Pilots, Flight Instructors, and Ground Instructors)

PAS	Piloting Autonomous Systems
PBMB	Performance-Based Measurement Battery
PCSM	Pilot Candidate Selection Method
PIC	Pilot in Command
PO	Payload Operator
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft System
RPIC	Remote Pilot in Command
SA	Situation Awareness
SAA	Sense and Avoid
SAOC	Skill, Ability, and Other Characteristic
SIFT	Army Selection Instrument for Flight Training
SME	Subject Matter Expert
SO	Sensor Operator
SOP	Standard Operating Procedure
sUAS	Small Unmanned Aircraft Systems
sUAV	Small Unmanned Aerial Vehicle
TAPAS	Tailored Adaptive Personality Assessment
TBAS	Test of Basic Aviation Skills
TBS	Tethered Balloon System
TEM	Threat and Error Management
UA	Unmanned Aircraft
UAS	Unmanned Aircraft (Aerial) System
UAV	Unmanned Aircraft (Aerial) Vehicle
URT	Undergraduate RPA Training
USAF	United States Air Force
UTM	UAS Traffic Management
VFR	Visual Flight Rules
VLOS	Visual Line of Sight

VO	Visual Observer
WWI	World War I
WWII	World War II

Introduction

The safe and efficient integration of unmanned aircraft systems (UAS) into the National Airspace System (NAS) is a critical objective for the Federal Aviation Administration (FAA) given the rapid growth of UAS industries and technologies. A current barrier to the timely incorporation of UAS into the NAS is that UAS technology has far outpaced the regulatory guidelines surrounding UAS operations.[1] As such, there is not a complete set of regulations for current and future UAS operations. Current UAS rules permit the use of small UAS (sUAS) for commercial operations via Title 14 of the Code of Federal Regulations (14 CFR) Part 107. Under Part 107, aircraft must weigh less than 55 lbs., and the pilot must be at least 16 years old and hold a Remote Pilot Certificate with a sUAS rating. The operating rules defined by Part 107 require aircraft to be flown within visual line of sight (VLOS) below 400 feet Above Ground Level (AGL) in uncontrolled airspace unless a waiver on these restrictions is granted by the FAA. Current UAS regulations do not address UAS air carrier and commuter/on-demand operations as defined in 14 CFR Part 121 and 14 CFR Part 135, respectively. However, the FAA's plan for integrating UAS into the NAS will enable UAS operations over people, expanded operations (e.g., commercial air carrier operations), and non-segregated operations (i.e., outside of current UAS-permitted airspace). As operations prohibited by Part 107 expand, there is a need for the FAA to standardize the issuance of certifications, pilot and crew requirements, training and testing requirements, and duty and rest requirements for UAS operations in the NAS.

To standardize UAS pilot requirements, a comprehensive understanding of the knowledge, skills, abilities, and other characteristics (KSAOs) required for UAS operations is needed as requirements may differ by operation type (e.g., air carrier) and technology.[2] For example, requirements for sUAS pilots could include basic knowledge exams and age requirements, whereas requirements for large UAS (55 lbs. or larger) pilots in commercial operations could include professional pilot training and a minimum number of flight hours before qualification. The documentation of UAS pilot KSAOs can inform FAA rulemaking by helping establish the minimum qualifications necessary for safe operations. Identifying knowledge and skill requirements can also serve to inform UAS training requirements, which are mostly unstandardized and inconsistent across sectors.[3] In addition to the identification of KSAOs, documenting the current testing requirements for UAS operators can inform FAA rulemaking on future certification requirements.

Purpose

The purpose of this annotated bibliography is to document the knowledge, skill, and testing requirements for UAS pilots, including those outside of Part 107 regulations, or

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[1] Bennett et al., 2016
[2] Canis, 2015
[3] Carretta, Rose, & Bruskiewicz, 2016

operations under waivers to Part 107 such as operations over people, nighttime operations, instrument flight rule (IFR) operations, expanded operations, and non-segregated operations. In particular, this annotated bibliography provides a review of (a) UAS pilot/operator knowledge and skill requirements, (b) testing and training requirements for certifying and/or selecting UAS pilots, (c) differences and similarities between unmanned and manned KSAO requirements, and (d) commercial applications of UAS. Information presented in this document will support ongoing FAA rulemaking and regulations led by the FAA's Flight Standards General Aviation and Commercial Division (AFS-800) and Air Transportation Division (AFS-200) for UAS air carrier operations over persons, expanded operations, and non-segregated operations.

Method

All articles for this literature review were collected from the Google Scholar and FAA Library databases using the following keywords:

- Aeronautical decision making (ADM)
- Air carrier operations
- Air taxi
- Certification testing
- Cognitive task analysis
- Job task analysis for unmanned and manned pilots
- Manned and unmanned teaming (MUM-T)
- Package delivery operations
- Part 107 aeronautical knowledge test
- Part 107 certification test
- Pilot knowledge/qualifications
- Pilot skills
- Remotely piloted aircraft systems (RPAS)
- Risk assessment
- Risk mitigation
- Situation awareness
- Training
- UAS equipment knowledge
- UAS certification
- UAS knowledge requirements
- UAS personnel selection
- UAS pilot certification
- UAS skills
- UAS traffic management
- Unmanned aircraft systems
- Unmanned and manned operations
- Urban air mobility
- Workload analysis

The keyword list was developed by the first four authors and approved by the FAA primary investigator. Searches were conducted from November 7, 2019 to December 16, 2019. A general set of inclusion criteria was used to identify relevant articles to be included in this literature review. First, the article had to be relevant to either unmanned or manned aircraft operations in civilian, military, and/or commercial domains. Second, the article had to describe knowledge, skills, testing, or training requirements for individuals in unmanned or manned operations. This included a variety of positions, such as manned pilots, UAS pilots/operators, sensor operators (SOs), or payload operators (POs). Abstracts were inspected according to these criteria. If inclusion criteria were met, the full paper was analyzed further for possible inclusion.

After inspection of abstracts, 140 articles were examined for inclusion. Eighty-eight articles met the inclusion criteria. Annotations for the identified articles were completed by the authors and approved by the primary investigator who served as the subject matter expert (SME). The annotated bibliography is structured using the following primary headings: *UAS Knowledge*, *UAS Skill*, *UAS Testing and Training*, and *UAS Operations*.

Literature/Research Outcomes

The KSAO requirements of UAS and other remotely piloted aircraft (RPA) have been extensively studied in military operations. Job task analyses (JTAs) concerning UAS/RPA operators have identified several knowledge and skill areas that are critical to the operation of unmanned aircraft (UA).[4] Knowledge of airspace classifications, aeronautical charts, preflight procedures, recovery and landing, and aerodynamics appear to be critical for UAS pilot performance.[5] Important UAS pilot skills potentially include flight skill, hand-eye coordination, situation awareness (SA), crew resource management (CRM), mission planning, task prioritization, and active listening.[6] Other non-cognitive and cognitive characteristics identified as important for UAS pilots include dependability, stress tolerance, adaptability, and pattern recognition.[7] Appendices A-D present a list of the KSAOs identified in the literature review. It is important to note that the KSAO requirements for UAS pilots are likely to change as UAS technologies advance, which may influence the cognitive workload of pilots.[8] When comparing unmanned and manned operations, there appears to be slight differences in the requirements for unmanned and manned pilots. UAS operators may require less multi-limb coordination than manned pilots, but similar levels of aerodynamic principles and system operations knowledge are needed for performance. Currently, research on the KSAOs needed in commercial UAS operations is limited.

Literature on testing requirements is limited and was primarily drawn from research concerning the selection of UAS and RPA personnel in military. While limited tests have been developed strictly for the selection of UAS personnel, tests identified as relevant for selecting UAS operators include the Air Force Officer Qualifying Test (AFOQT), Armed Services Vocational Aptitude Battery (ASVAB), the ASVAB Surveillance and Communications Scale, Test of Basic Aviation Skills (TBAS), Army Selection Instrument for Flight Training (SIFT), and the Pilot Candidate Selection Method (PCSM).[9] Documents pertaining to the certification test for Part 107, the Remote Pilot – small Unmanned Aircraft Systems Airman Certification Standard (ACS), were identified as well.[10] However, several issues emerged following the

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[4] Mangos et al., 2014; Paullin et al., 2011; Williams et al., 2014

[5] Adams, 2010

[6] Triplett, 2008; Pavlas et al., 2009

[7] Mangos et al., 2014

[8] Carretta, & King, 2015; Ison, Terwilliger, & Vincenzi, 2013

[9] Howse, 2011; Rose, Arnold, & Howse, 2013

[10] Federal Aviation Administration, 2017

review of UAS selection and testing requirements including the lack of appropriate performance criteria and methodological issues in the measurement of UAS pilot performance.[11]

Findings

UAS industries are rapidly growing and the documentation of KSAOs will help determine testing, training, and certification requirements that can support FAA efforts to ensure the safe and timely integration of UAS into the NAS. Specifically, the identification of KSAO requirements provides the foundation for UAS certification procedures and can assist the FAA in standardizing UAS staffing and training processes. In addition, a comprehensive understanding of recommended KSAOs will be instrumental in the development of appropriate medical qualification standards for UAS operations. Nevertheless, given the proliferation of UAS, further research is needed to understand the knowledge, skill, and testing requirements for UAS pilots in this ever-changing landscape. As UAS technologies employ an increased number of automated systems, the role of the UAS pilot will evolve (e.g., change from controlling the aircraft's flight surfaces to managing multiple aircraft) and the knowledge, skill, and testing requirements for remote pilots will need to adapt as well.

Questions arose as a result of compiling this annotated bibliography as research results sometimes disagreed, highlighting gaps in knowledge. These questions are identified and discussed in the following sections.

Skills vs. Abilities

There is often confusion in the literature over the distinction between skills and abilities, as the difference between the two is not always apparent. In general, skills are proficiencies required to perform a task and are acquired through training and experience (e.g., instrument monitoring, map reading), whereas abilities are innate traits that are enduring and stable over time (e.g., long-term memory, hand-eye coordination). Skills and abilities are highly related, but a main difference between the two is that skills are viewed as more trainable than abilities. To illustrate this point, Pavlas et al. provide a taxonomy of attributes relevant to UAS training that includes knowledge, skills, and attitudes, but not abilities.[12] While abilities can be improved to some extent through developmental experiences, abilities are considered to have limited potential for improvement. Another important difference between skills and abilities is that abilities are believed to underlie one's capacity for skill development. Chappelle et al. state that a minimum level of abilities must be present to gain the level of skill needed to successfully operate as a UAS pilot.[13] For example, individuals with high levels of selective attention and memory may be better suited for developing skills in maintaining SA than individuals who are lower in those abilities. As such, assessing whether an individual possesses the necessary level of ability can

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[11] Carretta, & King, 2015; Schnell, & Engler, 2014

[12] Pavlas et al., 2009

[13] Chappelle, McDonald, & McMillan, 2011

help ensure that they are able to acquire critical skills during training.[14] Nonetheless, the overlap between skills and abilities leads to potential classification discrepancies within the research literature. For the purposes of this annotated bibliography, we relied primarily on how items were defined within the identified research.

Skill and Ability Testing Requirements

Regardless whether an item is classified as a skill or an ability, a more important concern is whether the skill or ability can be objectively measured and used as a basis for certifying UAS crewmembers. Tests that measure several of the skills and abilities identified as relevant to UAS pilots/operators have been developed and used for selection/placement purposes; examples include the AFOQT, ASVAB, and TBAS. However, while these tests are able to measure one's level of skill or ability, they do not on their own establish or define an acceptable level of proficiency for that skill or ability. Most research identifies KSAOs that are important and needed upon entry into a job, but does not specify criterion levels, or minimum levels of proficiency, for those KSAOs. As an exception, all U.S. Army RPA operators must achieve a minimum score on the ASVAB surveillance and communications scale.[15] However, whether such a criterion is effective in preventing lapses in safety of operations is not known. Establishing minimum levels for KSAOs would require further research. This research can consist of a longitudinal study where performance would be tracked across months or even years, or it could consist of a standard setting study in which SMEs are asked about minimum levels of KSAOs required of UAS pilots. For example, Barron et al. reviewed three years of performance ratings for UA pilots and found that certain aptitudes (e.g., perceptual speed) were related to first-year performance ratings, but that none of the aptitude measures predicted performance across the three-year span.[16] However, there were personality traits (i.e., neuroticism and conscientiousness) that were predictive of performance. These findings suggest that tests can be built on assessing these and other KSAOs determined relevant to UAS operations, and that these tests could in turn be validated by longitudinal testing or SME assessment.

Manned Aircraft Experience Requirement

In addition to a sparsity of studies looking at the long-term relationship of KSAOs to job performance, there is also limited research examining the potential differential effects of various KSAOs on job performance. One example illustrating these effects is the question of whether manned aircraft experience should be required as a part of training for the UAS pilots. As has been pointed out by Williams[17] and other recent research, some military services have required pilots of their UA to have experience flying manned aircraft, while other military services view their UA pilots as operators and do not require manned flight experience. Some research on UA pilots and operators argues that motor skills for UA should be learned independently of manned

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[14] Carretta et al., 2016

[15] Carretta et al., 2016

[16] Barron, Carretta, & Rose, 2016

[17] Williams, 2007b

piloting skills, which suggests that there might be possible negative effects (in regard to motor skills) when transferring skills from manned to unmanned aircraft environments.[18] Others suggest that specific KSAOs might be unique to various types of aircraft and mission operations.[19] From the standpoint of manned aircraft training, this might indicate that success in manned aircraft flight performance is not predictive of unmanned flight performance. It also means that some KSAOs that predict success with certain unmanned systems may not necessarily generalize to other unmanned systems. However, both of these claims will require additional empirical investigation.

The following section provides detailed notes on each of the research papers included in this document. In addition, there are four appendices (A-D) that provide a listing of all of the KSAO categories identified from the research papers.

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[18] Barnes et al., 2000
[19] Damos, 2011

Annotated Bibliography

UAS Knowledge

Blickensderfer, B., Buker, T. J., Luxion, S. P., Lyall, B., Neville, K., & Williams, K. W. (2012). The design of the UAS ground control station: Challenges and solutions for ensuring safe flight in civilian skies. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 56*(1), 51-55. https://doi.org/10.1177%2F1071181312561031

The growing demand for civil UAS operations calls for developing minimum standards and requirements for unmanned systems. This paper presents applied and academic perspectives on UASs and UAS Ground Control Stations (GCSs) with a focus on mid-sized and large UASs. The goal of the discussion is to identify the issues and possible solutions for the safe integration of UASs into the NAS. While the majority of the paper/discussion is focused on UAS design issues and solutions, valuable insight is also provided into the required Knowledge, Skill, and Ability (KSAs) of the UAS operators. UAS pilots must have the ability to navigate and maneuver the aircraft, communicate, and manage contingencies during operations. Managing the movement of the UAS and avoiding obstacles is particularly difficult because UAS pilots must know how the aircraft responds to movement with little feedback from the system or external environment. Therefore, given the lack of available environmental cues, UAS pilots likely need additional multisensory alerts and/or information displays to allow them to respond more proactively to contingency situations than manned pilots, or they must be assisted by the automation of aircraft guidance. Advances in automated systems will make it possible for faster and more accurate information processing and integration. Providing pilots with advanced training on these new sophisticated capabilities is challenging. Until pilots are adequately trained to understand the full capabilities and associated limitations with these new systems, they cannot be integrated into the NAS safely.

Carretta, T. R., & King, R. E. (2015, May). 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.

Human operators play a critical role in the safety and efficiency of UASs. This paper set out to determine what the best selection criteria is for predicting training completion and job performance for UAS operators. The paper reviewed the selection criteria used by the United States Air Force (USAF) for the Undergraduate RPA Training (URT) program. The selection criteria includes the AFOQT and the PCSM. The paper also outlines the physical and mental health minimum requirements required for entering the URT program. These minimum requirements are reviewed and determined by medical and psychological professionals. The authors argue that while the AFOQT and PCSM, have been carefully evaluated, the same standards have not been used when developing job performance criteria for RPA/UAS pilots.

Without having accurate and reliable measures for job performance, determining the best predictors of job performance is unreliable and biased. Future research should carefully consider the criteria used as measures of job performance and focus on developing sufficient and appropriate criteria for RPA pilots. Finally, the authors note that as technology advances the knowledge and skills required for good job performance will continue to change. In particular, it is likely that technological advances will reduce the cognitive workload currently required of UAS operators.

Carretta, T. R., Rose, M. R., & Bruskiewicz, K. (2016). Selection methods for operators of remotely piloted aircraft systems. In N. J. Cooke, L. J. Rowe, W. Bennett Jr., & D. Q. Joralmon (Eds.), *Remotely piloted aircraft systems: A human systems integration perspective* (pp. 137-163). West Sussex, UK: Wiley & Sons Ltd. http://dx.doi.org/10.1002/9781118965900.ch6

The demand for RPASs has increased the need to select and train RPAS operators with the necessary KSAOs. This chapter provides an overview on the selection of RPAS operators by discussing current selection and training processes for US military and civil aviation, reviewing RPAS JTAs, examining differences between pilots and SOs for RPAS, and more. The chapter focuses on the selection of RPAS pilots for medium and high altitude systems. In the USAF, selection methods for RPAS pilot training are similar to that of manned pilot training and involve medical screening and aptitude testing. Medical Flight Screening (MFS) includes completion of a FAA Class-III Medical Certificate and an USAF Flying Class IIU Medical Examination. Aptitude testing includes the AFOQT, TBAS, and PCSM. For SOs, selection is based on medical qualification, citizenship, security clearance requirements, and scores on the ASVAB. For the U.S. Navy, no testing requirements are made for RPAS crews. For the U.S. Army, Air Vehicle Operators (AVOs) and Mission Payload Operators (MPOs) are cross-trained and interchangeable. All U.S. Army RPA operators must achieve a minimum score on the ASVAB surveillance and communications scale, which is a composite of five subtests: word knowledge, paragraph comprehension, arithmetic reasoning, auto and shop information, and mechanical comprehension. In commercial aviation, several universities have UAS-specific majors such as the University of North Dakota and Kansas State University, Salina, which prepare students for careers as pilots/operators. The curriculum is tailored to make students familiar with critical UAS knowledge including airspace restrictions, FAA regulations, Air Traffic Control (ATC) requirements, and the capability and limitations of RPAS. In terms of JTAs, results from past studies have identified the following as important KSAOs: oral comprehension, vigilance, self-discipline, adaptability/flexibility, hand-eye coordination, selective attention, dependability, following rules, decision-making, handling crisis/emergency situations, and others (see Table 6-1 in this article for the complete list). Finally, in regard to KSAO differences between manned and unmanned, the authors report that several KSAOs were rated as more important to unmanned systems including assertiveness, followership, teamwork, leadership/delegation, interpersonal skills, and resourcefulness. Psychomotor ability/multi-limb coordination was the only KSAO rated as more important for manned than unmanned pilots. There were no differences between manned and unmanned pilots in terms of knowledge of aviation system operations, threat categories and indicators, and engagement procedures. Therefore, even though there might be slight skill differences, the knowledge requirements (i.e., aerodynamic principles, laws and rules of engagement) are similar.

Chappelle, W., McDonald, K., & King, R. E. (2010). *Psychological attributes critical to the performance of MQ-1 Predator and MQ-9 Reaper U.S. Air Force sensor operators* (Report No. AFRL-SA-BR-TR-2010-0007). Brooks City Base, TX: USAF School of Aerospace Medicine.

While pilots are central to the flying of RPA, SOs are critical to the identification, surveillance, and assessment of targets during RPA operations. The goal of this study was to determine the necessary psychological attributes that are needed for successful performance of RPA SOs for the MQ-1 Predator and M1-9 Reaper. The authors utilized Subject Matter Experts (SMEs) to identify the necessary attributes for success. The attribute categories reported as important to RPA SO training and performance were physical health (e.g., resilience to shift work, stamina), cognitive aptitude, personality traits, and motivation. The last category, motivation, was predictive of long term retention and job satisfaction. However, qualitative data indicated that individuals with low motivation could still achieve adequate performance. Future studies still need to be conducted to empirically test the predictive validity of these attributes.

Chappelle, W., McDonald, K., & McMillan, K. (2011). *Important and critical psychological attributes of USAF MQ-1 Predator and MQ-9 Reaper pilots according to subject matter experts* (Report No. AFRL-SA-WP-TR-2011-0002). Wright-Pattern Air Force Base, OH: Air Force Research Laboratory 711th Human Performance Wing School of Aerospace Medicine.

Understanding the knowledge and skill profile of RPA pilots is critical to the selection and staffing for RPA operations. This paper is similar to the previous paper published by Chappelle, McDonald, and King (2010); however, this paper identifies the KSAOs required of RPA pilots as opposed to SOs. The goal of this study was to determine the attributes believed to be critical to MQ-1 Predator and M1-9 Reaper pilot training as well as performance in the operational environment. The authors utilized SMEs to identify predictors of success. The attribute categories were cognitive ability, intrapersonal personality traits, interpersonal personality traits, and motivation. The authors also gathered preliminary validity evidence for these attributes by conducting a survey with SMEs. For each attribute, SMEs rated the extent to which they believed each attribute was critical to RPA pilot performance. Attributes that were rated as critical for RPA performance and had 90% agreement or higher were retained (see Tables 1-4 in this article for the complete list). In addition to identifying key predictors, the paper also outlines the duties and workflow of MQ-1 Predator and MQ-9 Reaper pilots to contextualize the attributes needed for performance.

Consiglio, M. C., Chamberlain, J. P., Munoz, C. A., & Hoffler, K. D. (2012, September). Concepts of Integration for UAS Operations in the NAS. In *28th International Congress of Aeronautical Sciences*. Brisbane, Australia: ICAS.

The lack of an onboard pilot is a major challenge to the integration of UAS in the NAS. This paper discusses a Sense and Avoid (SAA) concept for UAS currently being developed by National Aeronautics and Space Administration (NASA). SAA functions are (1) detect, (2) track, (3) evaluate, (4) prioritize, (5) declare an action, (6) determine the action, (7) command the action, and (8) execute the action. These functions are completed by either the automated system or crewmembers involved in the operation. The authors note that functions 6 and 7 are performed by the UAS pilot who evaluates the situation, communicates with ATC and commands action if needed. From a KSAO perspective, this requires UAS operators to have high SA of the surrounding airspace and be knowledgeable of the appropriate remediation if a potential collision is detected. When UA pilots receive information about potential threats they must consider the recommended maneuvers in the context of the mission, coordinate with ATC (if communicating with them), and engage in a maneuver to resolve the threat. UA pilots must be knowledgeable of the UAS equipment, the amount of time available to make a decision within the context of nearby traffic, and potential maneuvers for correctly navigating and resolving the threat.

Cook, S., Lacher, A., Maroney, D., & Zeitlin, A. (2012, January). 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. 1-10). Nashville, TN: AIAA. http://dx.doi.org/10.2514/6.2012-959

With the main difference between manned aircraft and UAS being the absence of a pilot in the aircraft, a primary area of concern is replacing the “See and Avoid” approach with a SAA system for UAS. A number of technical, operational, and policy issues are explored in this paper to understand best practices for implementing SAA systems. Operationally, pilots must be able to identify different types of targets and operate within a variety of conditions. Two interacting approaches that pilots must consider in SAA are self-separation (i.e., staying substantially far away from other objects) and collision avoidance (i.e., a last-minute maneuver). Avoidance decisions arise as a result of this approach, and pilots must possess the ability to detect, track, evaluate, and prioritize other objects and targets to make these decisions. Based on these decisions, a pilot must be able to declare that a maneuver must be made, select a specific avoidance maneuver, and then execute that maneuver.

Federal Aviation Administration. (2016). *Remote pilot - small unmanned aircraft systems study guide* (Report No. FAA-G-8082-22). Washington, DC: Flight Standards Service.

Pilots of sUAS can achieve their Remote Pilot Certification by passing the airman knowledge test. This study guide covers the knowledge areas of the airman knowledge test as required by Part 107. The knowledge areas covered in the test include sUAS regulations, airspace classification and restrictions, aviation weather sources and weather effects on sUAS, sUAS loading, emergency procedures, CRM, radio communication procedures, sUAS performance, physiological effects of substances, airport operations, and maintenance procedures. Each chapter in this guide covers relevant information needed for the airman knowledge test, and a brief overview of each chapter's content will be presented. Airspace classification covers information on (un)controlled airspace, restricted and special use airspace, ATC, and Visual Flight Rules (VFR). Weather sources cover weather observations and aviation weather reports. Effects of weather on sUAS covers atmospheric conditions, runway environments, wind effects, temperature, and visibility. Aircraft loading covers weight, stability, loading factors, and weight and balance. Emergency procedures cover inflight emergency maneuvers and plans. Radio communication procedures cover proper radio phraseology and communications with ATC. Aircraft performance covers the effects of temperature and humidity on density. Physiological factors cover the effects of drugs and alcohol on pilot performance and vision. ADM covers human factors, risk management, and pilot decision-making. Airport operations cover different types of airports and airport procedures. Maintenance procedures cover preflight maintenance requirements. Knowledge of each topic area is needed for remote pilots.

Federal Aviation Administration. (2017). *Remote pilot knowledge test guide* (Report No. FAA-G-8082-20). Washington, DC: Federal Aviation Administration.

Interested persons can achieve their Remote Pilot Certificate by successfully passing the airman knowledge test or by holding a pilot certificate under 14 CFR Part 61. For the knowledge test, there are 12 areas of knowledge covered on the sUAS airmen knowledge test: UAS application regulations, limitations, and flight operations, airspace classification, the influence of weather conditions on UAS, UAS loading, emergency procedures, CRM, radio communication procedures, determining the performance of UAS, drug and alcohol effects, ADM, airport operations, and maintenance and preflight inspection procedures.

Gertler, J. (2012). *US unmanned aerial systems* (Report No. R42136). Washington, DC: Congressional Research Service.

Military use of Unmanned Aircraft (Aerial) Vehicles (UAVs) has steadily increased due to the advanced navigation and communication technologies available within these systems and the decreased risk that UA provides troops. This report focuses on the current and future use of

UASs in the military. At the time of this report, UAS operations include Intelligence, Surveillance, and Reconnaissance (ISR) and combat (i.e., strike). Future UAS operations may include resupply, search and rescue, refueling, and air combat. In regard to unmanned pilot requirements, the USAF requires Predator and Global Hawk operators to be pilot-rated officers, whereas other services do not require that status of UAS operators (at the time of this report). The USAF maintains that their UASs require trained pilots due to the system's technology. However, the author notes that there are retention implications for requiring rated pilots to fly UAS and that this policy may change if requiring a manned aircraft rating is a barrier to adequate staffing. Some enlisted personnel may be interested solely in UA and have no desire to fly manned aircraft as well. As a future consideration, the author questions whether the Department of Defense (DoD) should consider using enlisted and civilian personnel for operating UAS, with civilians operating those not used for firing weapons. Personnel issues will remain a point of concern for UASs in the military given the need for well-qualified pilots for unmanned operations.

Gimenes, R. A., Vismari, L. F., Avelino, V. F., Camargo, J. B., de Almeida, J. R., & Cugnasca, P. S. (2014). Guidelines for the integration of autonomous UAS into the global ATM. *Journal of Intelligent & Robotic Systems*, 74, 465-478. http://dx.doi.org/10.1007/s10846-013-9945-0

Additional UAS requirements and certifications must be developed to establish safe operations of autonomous UASs in civil, non-segregated airspace. The authors of this report state that the responsibility of pilots is to fly, navigate, and communicate; however, the autonomous nature of UASs means that these responsibilities may be delegated differently for unmanned aircraft. A first step for allowing autonomous UAS to fly in non-segregated airspace is to compare the piloting skills between unmanned and manned aircraft. While the knowledge and skills for pilots of manned aircraft are well articulated in training and evaluation research, the challenge with autonomous UASs is that pilot proficiency is based on the electronic and programmable elements of the Piloting Autonomous System (PAS). The authors argue that knowledge of PASs should be modeled after human pilot requirements, which includes knowledge of (a) aeronautical regulations (e.g., communication protocol with ATC), (b) aircraft operation, (c) aircraft limitations, (d) good performance during take-off and landing, flight planning, and ATC procedures, (e) knowledge of human performance/limitations, (f) meteorological knowledge, (g) air navigation knowledge, (h) aeronautical operational procedures, (i) flight theory, and (j) telecommunication procedures.

Gupta, S. G., Ghonge, M. M., & Jawandhiya, P. M. (2013). Review of unmanned aircraft system (UAS). *International Journal of Advanced Research in Computer Engineering & Technology*, 2(4), 1646-1658. https://dx.doi.org/10.2139/ssrn.3451039

There is significant potential for UAS in both military and civilian applications. In reviewing the history, categories, types of functions, and applications of UAS, the authors identified areas requiring certain knowledge or skills. UAS pilots must be proficient in ground control (i.e., remote piloting) and balancing human intervention and automation for critical parts of the flight. Pilots must be able to delegate functions to automated systems and utilize network-centric communications for collaborative missions. UAS pilots must also be familiar with and practice detect and avoid techniques. Successful flight plans will depend on the mission specific knowledge (i.e., knowledge of the surroundings, traffic, and atmospheric conditions) and communication skills of the pilots and operators. Human oversight will be required for completely automated operations (e.g., mundane, low intensity jobs), and operators will be expected to monitor for errors/faults in the UAS in conjunction with the system.

Howse, W. R. (2011). *Knowledge, skills, abilities, and other characteristics for remotely piloted aircraft pilots and operators* (Report No. DAS-2011-04). Randolph Air Force Base, TX: Air Force Personnel Center Strategic Research and Assessment.

There has been little systematic investigation into the KSAO requirements for RPA operators. The goal of this report was to review the current KSAO requirements for RPA operators and compare them with future requirements. Out of the 200 articles collected by the author, only eight were viewed as relevant to the goal of this report. In his review, the author lists every KSAO identified within the literature relevant to operating RPAs. For a full list of KSAOs, see Table 11 in this article. The factors that relate to knowledge include: unit/command objectives, aviation principals, basic operation procedures, unmanned aerial system operations, communication procedures, threat categories and indicators, engagement procedures, meteorology, aeronautical terminology, and flight rules and regulations. The list of skills include: operation and maneuvering of unmanned aircraft systems, operation of communication systems and equipment, operation of navigation systems and equipment, operation of sensor/tracking systems and equipment, operation of weapon systems and equipment, performance of unmanned aircraft systems operational checks, map reading, photo interpretation, and communication procedures. The list of abilities include: oral comprehension/expression, written comprehension/expression, memorization, problem sensitivity, mathematical reasoning, deductive reasoning, inductive reasoning, information ordering, category flexibility, speed of closure, flexibility of closure, spatial orientation, visualization, perceptual speed, control precision, multi-limb coordination, response orientation, rate control, reaction time, arm-hand steadiness, manual dexterity, finger dexterity, wrist-finger speed, speed of limb movement, selective attention, time sharing, static strength, explosive strength, dynamic strength, trunk strength, far vision, visual color discrimination, depth perception, general hearing, auditory attention, sound localization, speech hearing/clarity, estimation of time to contact, SA, organization/time management, judgment/decision-making/problem solving, vigilance, cognitive task prioritization, adaptability/flexibility, stamina, visual perception, attention, and spatial processing. Finally the list of other attributes include: affinity for planning and logic, affinity for uncertainty, management of stressors, assertiveness, followership, self-regulation, work ethic, initiative, self-confidence, straightforwardness, helpfulness, teamwork, interpersonal skills, achievement striving, self-discipline, dependability, responsibility, stress tolerance, leadership, leadership motivation, attention to detail, general health, composure, resilience, self-certainty, conscientiousness, success oriented, perseverance, decisiveness, humility, cohesiveness, moral/occupational interest, extraversion, judgment, and team-oriented. The author explained that not all of the listed factors are well defined within the existing literature. Further, no validated instrument has been created for RPA selection. The author predicts that the physiological factors are likely to become less important in the future as systems continue to become increasingly automated. Table 12 in this article provides an overview of how KSAO demands may shift based on future requirements.

Ison, D. C., Terwilliger, B. A., & Vincenzi, D. A. (2013, July). Designing simulation to meet UAS training needs. In *International Conference on Human Interface and the Management of Information* (pp. 585-595). Berlin, Germany: Springer. https://doi.org/10.1007/978-3-642-39215-3_67

The use of UAS is growing rapidly across both civilian and military sectors. To ensure qualified individuals are operating UASs, it is necessary to identify the KSAO requirements for UAS operations, as well as best practices for selecting and training of UAS operators. The authors note that UAS platforms vary according to several factors such as takeoff weight, normal operating altitude, airspeed, and operational use (e.g., law enforcement, agricultural, surveying, photography, and infrastructure inspection). Despite these operational differences, there does appear to be a common set of KSAOs that are relevant across UAS operations. Based on a review of the literature, the KSAOs identified as critical for UAS pilots are communication (oral and written), spatial processing, control precision, selective attention, multitasking/task prioritization, SA, monitoring, and visual information processing. Key UAS tasks identified by the authors include takeoff, landing, surveillance, air traffic avoidance, and emergency procedures.

Mangos, P., Vincenzi, D., Shrader, D., Williams, H., and Arnold, R. (2014). *UAS cross platform JTA final report* (Report No. NAMRU-D-14-44). Wright-Patterson Air Force Base, OH: Naval Medical Research Unit Dayton.

UAS operations place a different set of demands on pilots than those traditionally experienced during manned flight. Therefore, understanding the aptitude and attribute requirements of UAS operations is important for identifying future pilots and operators. The purpose of this report was to summarize the task and competency requirements of UAS operations in the U.S. Navy and Marine Corps via a JTA. Additionally, this report sought to identify common and unique operator tasks, and KSAO differences across UAS positions. The different UAS platforms analyzed in this JTA include the (a) RQ-11 Raven, a tactical hand-launched UAS weighing 4.2 pounds, (b) ScanEagle, a long-endurance UAS for remote and ship-board operations, (c) RQ-7 Shadow, a large UAS (460 pounds), (d) MQ-8 Fire Scout, a large rotary-wing UAS that has a 600 ln lift capacity, (e) RQ-4A BAMS-D, a long-endurance UAS that operates up to 65,000 feet, (f) MQ-4C BAMS, a high-altitude long-endurance UAS for surveillance and reconnaissance , and (g) X-48 UCAS, a combat UAS that travels high subsonic speed. From the JTA, the authors produced a list of 256 task statements, which were sorted into 20 mission categories. These tasks were rated by SMEs on task importance, difficulty to learn, frequency, and level of mastery. The mission categories included preflight tasks, mission planning, system configuration/start-up, air vehicle launch and takeoff, in-flight operations (general, in-flight operations), safety and checks, communications, navigation, airspace and operating area management, crew task management, fuel and power management, payload operations, ISR, flight maneuvers, mission execution, missions (target management), emergency tasks, air vehicle approach and landing, post-flight tasks, and shipboard tasks. The KSAO list was drawn from prior JTAs and the final list consisted of 67 KSAOs organized into several categories (see Appendix C in this article for the complete list of KSAOs). Results show a consistent pattern of important tasks and KSAOs across and within platforms and positions (e.g., AVO, PO, mission commander). Almost all identified UAS tasks are important to most positions and platforms. Task categories with the highest importance ratings were (a) air vehicle launch and takeoff, (b) airspace area management, (c) ISR, (d) shipboard tasks, and (e) crew task management (see Appendix A in this article for the complete list of task categories). KSAO clusters that were consistently rated as most important include (a) conscientiousness, (b) communication skills, (c) multitasking and attentional skills, (d) development skills, (e) coping i with stress and emergencies, (f) social/interpersonal skills, (g) learning and memory, (h) motivation, (i) problem solving/reasoning skills, and (j) planning and organizing skills.

Pankok, C. Jr., & Bass, E. J. (2018). Information content requirements for remote pilot handover of control of unmanned aircraft systems in the national airspace. *Proceedings of the Human Factors and Ergonomics Society, 62*(1), 81-85. https://doi.org/10.1177%2F1541931218621018

A major consideration for the integration of UAS into the NAS is if UAS crews can safely handover control of the UA. Current FAA recommendations for handover between pilots in manned aircraft involve a three-step verbal process, but this does not adequately apply to the unique challenges presented by UAS operations as the crew receiving the UA may not be in the same GCS as transferring crew as well as the potential lag in communication between the transferring and receiving crews. ATC handover procedures can also serve as an analog for UA handovers, but it does not fully cover UAS procedures. Research has found that SA and background knowledge of the operation are keys to successful handover events. However, most research has focused on specific UAS operation contexts (e.g., crews located in same GCS versus different GCS), and focused on the receiving crew developing SA after the handover event. To overcome research gaps, seven SMEs reviewed UA handover control scenarios to identify information requirements for the safe handover of UA control. A seven-step procedure was developed for safe handover of UA control: 1) Establish communication, 2) Share procedure details, 3) Coordinate UA status, 4) Provide briefing to receiving crew, 5) Transfer positive control to receiving control station, 6) Confirm transfer, and 7) Backup the receiving crew by transferring crew. SME recommendations place all responsibility on the crews to establish and maintain verbal communication throughout each step of the procedure with the assistance of chat/real-time text-based software and visual indicators for key points in the flight route. Information elements that should always be available to both crews include uplink and downlink connection between the control station and UA, signal strength of the uplink and downlink, authority indicator for control station in command, indicator of handover point in flight route, and UA status information.

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

As the use of UAS in the military expands beyond ISR to tasks such as delivery and refueling, understanding the ideal profile of KSAOs for UAS pilots is critical for UAS selection. The goal of this paper was to review current selection practices in the U.S. Armed Forces for UAS pilots and operators. The aptitudes identified for RPA/UAS pilots include: cognitive abilities, domain specific knowledge, psychomotor abilities, prior experience, and personality. A similar set of aptitudes was found for RPA/UAS pilots across the U.S. Armed Forces. Additionally, the authors found that the personnel selection measures currently in use for RPA/UAS pilots demonstrate predictive validity evidence. Table 1 in this article describes the measures used and KSAOs assessed by current selection measures. However, even though studies on UAS/RPA selection show a relationship between the tests and job performance, this evidence is based on a small number of studies and a small sample size. Therefore, additional research is needed to examine new selection and scoring methods as well as the influence of contextual factors (e.g., team composition) on performance. The authors also note that as UAS technology continues to change and become more autonomous, the required KSAOs will evolve and change as well.

Selier, M., Stuip, M., & Verhoeven, R. P. M. (2008). National technology project 'outcast’ on UAS sense and avoid. *Proceedings of the 26th International Congress of the Aeronautical Sciences*, 1-10.

One of the main reasons UAS flights have yet to occur outside of segregated airspace is the lack of SAA capabilities in unmanned aircraft. The purpose of this paper was to outline potential

SAA requirements including strategic conflict management, separation provision, and collision avoidance. Adequate SAA needs to provide separation provision and collision avoidance under all environmental conditions. The authors identified the SAA processes for two crew roles: UAS pilots and POs. SAA processes for UAS pilots include conflict detection, classification and visual tracking, plan and initiate evasive maneuvers, and resume flight plan/mission. SAA processes for POs include establish visual contact with intruder, classify and visually track intruder, and resume payload mission. The pilot and PO need enough information from the SAA system in order to detect hazards, classify and visually track the hazard, and decide on and execute an evasive maneuver if needed. Good ADM with SAA requires the UAS operators to have adequate knowledge and SA about the SAA system. In addition to understanding the limits of the SAA system, UAS operators should also understand the limits of the human machine interface. With full information on the limits of these systems the probability of critical incidents is likely reduced.

Williams, K. W. (2007b). *Unmanned aircraft pilot medical certification requirements* (Report No. DOT/FAA/AM-07/3). Washington, DC: Federal Aviation Administration Office of Aerospace Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/200703.pdf

This research addressed the medical requirements necessary for UA pilots for successful flight in the NAS. Given that an existing medical certification was recommended, the question of which class of certification to propose was based on the perceived level of risk imposed by the potential incapacitation of the UA pilot. A second-class medical certification was judged to be the most acceptable, considering that there were several factors that mitigated the risk of pilot incapacitation relative to those of manned aircraft. First, factors related to changes in air pressure could be ignored, assuming that control stations for non-military operations would be on the ground. Second, many of the current UA systems have procedures that have been established for lost data link. Lost data link, where the pilot cannot transmit commands to the aircraft, is functionally equivalent to pilot incapacitation. Third, the level of automation of a system determines the criticality of pilot incapacitation because some highly automated systems (e.g., Global Hawk) will continue normal flight whether a pilot is or is not present.

UAS Skill

Barnes, M. J., Knapp, B. G., Tillman, Walters, B. A., & Velicki, D. (2000). *Crew systems analysis of unmanned aerial vehicle (UAV) future job and tasking environments* (Report No. ARL-TR-2081). Aberdeen Proving Ground, MD: Army Research Laboratory.

Two UAV crew positions (Air Vehicle Operator [AVO] and External Pilot [EP]) were assessed to determine what cognitive skills are necessary to serve in either position and if being a rated pilot increases performance (e.g., reduced the likelihood of a flight mishap or accident). The Job Assessment Software System (JASS) was used to collect ratings of cognitive skills (e.g., auditory, communication, psychomotor, reasoning, speed-loaded, and visual) that AVOs and EPs believed were important to their position. Results indicated that AVO cognitive skills are related to flight mishaps, and that AVOs do not consider flight-related tasks demanding for their position, except for communication-related tasks. Results also indicated that EPs require greater cognitive skills than AVOs across all skill categories. Enhanced Computer-Administered Test (ECAT) data indicated that psychomotor skills should be prioritized during training for EP crewmembers to prevent flight mishaps as they are primarily responsible for takeoff and landing, which has the highest likelihood for flight mishaps. Additionally, experienced EPs relied more on conceptual and reasoning skills in emergency scenarios than inexperienced EPs, who relied on psychomotor and visual skills. The results of the study suggests that motor skills for operating a UAV should be learned independently of manned piloting skills. This would eliminate the need for flight rated aviators in AVO positions. Additionally, the EP positions require unique motor skills that should be developed during training.

Cahillane, M., Baber, C., & Morin, C. (2012). Human factors in UAV. In P. Angelov (Ed.), *Sense and avoid in UAS: research and applications* (pp. 119-137). West Sussex, UK: John Wiley & Sons. http://dx.doi.org/10.1002/9781119964049.ch5

While UAVs are becoming more autonomous, it is likely that human operators will still play a significant role in UAS operations. Human control over UAVs extends beyond basic piloting duties, and there is need to shift UAS design from a supervisory control perspective (i.e., human manages the system) to a cooperative automation perspective (i.e., the human operator and autonomous system share SA responsibilities). The tasks required of pilots and operators will shift from physical to cognitive tasks as unmanned vehicles become more autonomous. Based on this anticipated shift, there are seven primary roles for humans in UAS operations: providing the capability to intervene if operations become risky, performing tasks that cannot yet be automated, providing ‘general intelligence’ for the system, providing liaison between the UAV system and other systems, acting as a peer or equal partner in the human-UAV partnership, repairing and maintaining the UAV, and retrieving and rescuing the damaged UAV. These roles will likely be distributed across team members as well. An interesting challenge facing operators as UAS become more autonomous is that humans are relatively poor at monitoring tasks, particularly for tasks with low base rate events. Three categories of UAS automation are substitution (i.e., system performs an operation outside the limits of human performance), addition (i.e., system performs functions that are demanding on human performance), and augmentation (i.e., system supports human performance where humans are limited). The advancement of UAS technology and automation will influence the responsibilities of UAS operators by impacting the number of UAVs to be controlled, task-switching and multitasking demand, and the types of interactions with UAVs (i.e., multimodal interaction). The authors note that several individual differences may influence an operator's ability to control/monitor UAVs such as attentional control, spatial ability, sense of direction, and video game experience.

Comstock Jr., J. R., McAdaragh, R., Ghatas, R. W., Burdette, D. W., & Trujillo, A. C. (2014). *UAS in the NAS: Survey responses by ATC, manned aircraft pilots, and UAS pilots* (Report No. NASA/TM-2014-218250). Hampton, VA: National Aeronautics and Space Administration, Langley Research Center.

Establishing requirements for UAS in the NAS is critical as the introduction of UA into civil airspace not only impacts UAS pilots, but manned aircraft pilots and ATCs as well. This study administered a survey to manned pilots, ATCs, and UAS pilots to get their perspective on future requirements for UAS operations. In general, most respondents reported that UAS rules and requirements for various classes of controlled airspace should be the same as that for manned aircraft. However, manned pilots and ATCs were more likely to report that UASs without ATC communication and large UASs may need separate airspace for their operations. The reasoning for this response was the lack of prior history for UAS operations in civil airspace. In terms of knowledge and skill, it was reported that the communication skills of UAS pilots is critical for safe UAS operations in the NAS. In particular, the communication between UAS pilots and ATC must be equivalent to that of manned aircraft pilots, so that manned pilots can also understand UAS pilot communication and maintain SA. Additionally, ATC respondents recommended that UAS pilots be able to navigate via Navigational Aid (NAVAID) and fixed points like manned aircraft to improve the predictability of flight patterns.

Cuevas, H. M., Kendrick, K. M., Zeigler, Z. A., & Hamilton, D. J. (2015). Investigating UAS operator characteristics influencing mission success. In *18th International Symposium on Aviation Psychology* (pp. 117-122). Dayton, OH: Wright State University. https://corescholar.libraries.wright.edu/isap_2015/87

Operator KSAs were investigated to see how they influence the success of UAS operations. Prior manned and unmanned experience, teamwork, and gaming experience were expected to be related to crew performance in a simulated UAS operation. Eighteen aeronautical university students participated in two-person UAS crews (Pilot and SO) in a simulated port security operation. The port security scenario involved navigating the UAS to a target location, identifying and surveilling the target, gathering intelligence, and returning to base. Prior to participation, participants completed a questionnaire that assessed their KSAs with respect to manned/unmanned flight experience, teamwork experience, and gaming experience. Mission success was measured using a behavioral checklist comprised of eight categories: spatial orientation, cue sharing, problem solving, information management, task management, task/equipment knowledge, CRM, and mission monitoring. This performance assessment is referred to as the Situation Awareness Linked Indicators Adapted to Novel Tasks methodology. Results indicated that the behaviors defined under these performance categories successfully discriminated crew performance. Manned flight experience had a positive relationship with CRM; team experience had a positive relationship with task management and problem solving; first person shooter gaming experience had a positive relationship with spatial orientation; and unmanned flight simulation experience had a negative relationship with task management. A proposed explanation for the negative relationship between unmanned flight simulation experience and task management was that without feedback to correct performance additional simulation time was detrimental for skill acquisition. These findings suggest that the identified KSAs predict UAS crew performance; however, additional research is needed to fully understand the causal factors underlying their relationship.

Guglieri, G., Mariano, V., Quagliotti, F., & Scola, A. (2011). A survey of airworthiness and certification for UAS. *Journal of Intelligent & Robotic Systems, 61,* 399-421. http://dx.doi.org/10.1007/s10846-010-9479-7

As UAS operations grow, the complexity of UAS missions and platforms grow as well. This paper discusses SMAT, an Italian project that will use UAS to monitor and surveil terrain in order to mitigate naturally occurring issues (e.g., fires, floods), and reviews current international pathways for UAS certification to derive useful guidelines from these existing regulations. Based on the authors’ review, important KSAOs for UAS pilots to possess include communication skills, transparency, experience with complex tasks, the ability to multitask, and knowledge of severe conditions, emergency procedures, target-level of safety, and flight rules. It is suggested that knowledge and certification required to operate a UAS must scale with the UAS classification and with the operations (e.g., Line-of-Sight vs. Beyond-Line-of-Sight). A classification system based on the type of UAS should consider three factors: ground risk (e.g., maximum take-off mass), air collision (e.g., altitude and airspace used for operation), and autonomy (e.g., remotely piloted vs. fully autonomous). UAS pilots also must understand and adhere to certification rules for launch and recovery.

Lennertz, T., Sparko, A. L., Cardosi, K., Yost, A., Kendra, A., Lu, J., & Sheridan, T. (2018). *Pilots' estimation of altitude of a small unmanned aircraft system* (No. DOT/FAA/TC-18/23). Washington, DC: Federal Aviation Administration. https://rosap.ntl.bts.gov/view/dot/36276

The use of sUAS for hobbyist and commercial operations is evolving quickly, and Part 107 requires that sUAS be flown using VLOS under 400 feet AGL in uncontrolled airspace. This study examined the ability of hobbyist and commercial sUAS pilots to estimate the altitude of their aircraft during a realistic flying task to determine if operators can accurately judge altitude. The authors suggest that it may be difficult for operators to maintain visual contact with a sUAS when other duties (e.g., scan for other aircraft) must be performed. Additionally, at the time of this report, altitude reporting capabilities are not required for sUAS under Part 107, which may further hinder the ability of operators to judge an aircraft's altitude. For the study, pilots were instructed to fly a sUAS to three altitudes: 50 feet, 200 feet, and 350 feet. Actual altitude was measured using a range finder, an inclinometer, and image analysis using photos taken from the sUAS. The participants in the study varied in experience: half were certified under Part 107 and half were hobbyists. Each participant was instructed to fly to each designated altitude three times. Participants' accuracy was measured by looking at the distribution of pilot altitudes estimates at each altitude level (50, 200, and 350 feet). The deviation from each prescribed altitude was calculated as well. Findings suggest that participants had relatively accurate altitude estimations for the 50 feet condition, but altitude estimations for the 200 feet and 350 feet conditions were significantly lower than the prescribed altitude. Specifically, as the altitudes increased, participant altitude estimates were more inaccurate. There were no significant effects for pilot experience suggesting that estimation accuracy was similar between commercial pilots and hobbyists. Also, most participants indicated that they felt "somewhat confident" in their performance regardless of altitude. These findings suggest that UAS pilots need a standardized way to judge altitude, and reliance on human judgment may not be sufficient.

Lin, J., Wohleber, R., Matthews, G., Chiu, P., Calhoun, G., Ruff, H., & Funke, G. (2015). Video game experience and gender as predictors of performance and stress during supervisory control of multiple unmanned aerial vehicles. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 59*(1), 746-750. https://doi.org/10.1177/1541931215591175

The increasing need for UAV pilots and operators necessitates that recruitment pools be expanded to meet workforce demands. The goal of this study was to determine if video game experience and gender were predictors of performance during a simulated multi-UAS task. Self-rated video game experience positively predicted performance during the multi-UAS task. For instance, individuals with higher levels of video game experience were more accurate, relied more on automation, and showed less task neglect in a Weapon Release task. One explanation for this finding is that the cognitive skills required for video games (e.g., task engagement) are similar to the cognitive skills required during the simulated multi-UAV task. This study provides some evidence on the value of video game experience for UAS operators. However, other possible explanations still exist. Gamers within this study were a self-selected group. Therefore, these gamers may already have a high aptitude for computer-based tasks. Without future experimental investigation it is still unclear whether a gamer population is an appropriate recruitment pool for UAV operators. The second factor under investigation was gender. Once video game experience was controlled for, there were no significant effects of gender on performance.

Matthews, G., Panganiban, A. R., Wells, A., Wohleber, R. W., & Reinerman-Joens, L. E. (2019). Metacognition, hardiness and grit as resilience factors in unmanned aerial systems (UAS) operations: A simulation study. *Frontiers in Psychology, 10*, 640. http://dx.doi.org/10.3389/fpsyg.2019.00640

UAS operators may face multiple stressors during operations, which has the potential to influence safety and performance. Characteristics such as hardiness and grit have shown to protect individuals from various stressors, and this study was conducted to investigate the effect of hardiness and grit on resilience among UAS pilots. Participants in this study experienced varying levels of cognitive demands and negative performance feedback during a multi-UAS control simulation task. The physical stress responses of participants were measured with electroencephalography (EEG), electrocardiography (ECG), and hemodynamic sensors. The Anxious Thoughts Inventory was used to assess worry. Results indicated that participants high in trait-level worry showed higher levels of stress, whereas participants high in hardiness and grit showed lower levels of stress. Negative performance feedback did not increase stress or worry; however, high cognitive demand increased stress and worry among participants. The authors recommended implementing interventions to improve motivation and task strategy to help UAS pilots with low levels of grit cope with cognitively demanding situations. The authors also recommended developing personalized training based on UAS operators' trait levels to improve individual resilience to stress and responses to stressful task environments.

McKinley, R. A., McIntire, L. K., & Funke, M. A. (2011). Operator selection for unmanned aerial systems: Comparing video game players and pilots. *Aviation, Space, and Environmental Medicine, 82*(6), 635-642. https://doi.org/10.3357/ASEM.2958.2011

The military is experiencing a shortage of qualified UAS pilots, and there is an expressed need to identify candidates and training practices not traditionally considered for UAS Predator or Reaper pilots. Past research suggests that video game players may be suited for UAS pilot positions because they have better cognitive skills, such as target tracking and response time, than non-video game players, and many of these cognitive skills appear transferable to UAS operations. Based on this research, the authors investigated whether non-UAS pilots such as video game and non-video game players could successfully operate an UAS and whether their skills meet the same efficiency as UAS pilots. Participants (UAS pilots, video game players, and non-video game players) completed eight performance tasks with a Predator landing simulation that assessed the skills and abilities identified by Triplett (2008): cognitive multitasking, fine motor coordination/control, judgement, memory, precise timing, SA, spatial awareness, and visual information processing. The Cambridge Neuropsychological Assessment Battery, multi-attribute task battery, G-PASS, and the Warship Commander tasks were used as performance tests. UAS pilots and video game players outperformed non-video game players on all tasks, and video game players performed nearly as well as UAS pilots for most tasks, except for the glide slope landing task. However, video game players outperformed both UAS pilots and non-video game players on the Warship Commander task. The overall findings from the study suggest that playing video games could improve the skills necessary to be a UAS pilot and could be beneficial for the SO position.

Panganiban, A. R. (2013). *Task load and evaluative stress in a multiple UAV control simulation: The protective effect of executive functioning ability* (Unpublished doctoral dissertation). University of Cincinnati, Cincinnati, OH.

Advanced UAV technology allows for the control of multiple vehicles at once. However, most research on UAV pilot skills and abilities is based on the control of a single UAV. The current study investigated the influence of controlling multiple UAVs on pilot's executive functioning (e.g., inhibition, task switching, and working memory) and its relationship to stress. Participants controlled multiple UAVs in a simulation and received negative performance feedback or no feedback to induce stress. The Positive and Negative Affect Schedule and Dundee Stress State Questionnaire (DSSQ) were completed before and after each simulation trial. Results found that high inhibitory control acted as a buffer for perceived stress and worry, while memory updating was negatively affected by perceived stress. Participants likely experienced a decline in executive function because cognitive resources were used to address and mitigate stress, and switch between UAVs throughout the simulation. The author argues that multi-UAV control should be implemented with caution because pilots will experience increased cognitive demand and perceived stress from having to divert cognitive resources across more than one UAV. However, the author also recommended using the DSSQ to evaluate pilot stress and workload as well as focusing on training that improves executive functions and stress response during UAS operations.

Paullin, C., Ingerick, M., Trippe, D.M., & Wasko, L. (2011). *Identifying best bet entry-level selection measures for U.S. Air Force remotely piloted aircraft (RPA) and sensor operator occupations* (Report No. AFCAPS-FR-11-64). Randolph Air Force Base, TX: Air Force Personnel Center Strategic Research and Assessment.

The demand for RPA personnel has grown to the point where demand cannot be adequately met in the military. The goal of this paper was to determine the best predictors of performance for RPA pilots and SOs to help the USAF identify potential RPA candidates. If predictors of performance are found, then recruitment can be targeted towards individuals who are the most likely to be successful in the position. USAF RPA SMEs reviewed a list of 10 skills, 25 abilities, and 12 work styles. The SMEs determined that 21 of the factors were the most critical for performance: initiative, assertiveness, decisiveness, self-control, stress tolerance, adaptability, oral comprehension, oral expression, number facility, working memory, task prioritization, selective attention, time sharing, perceptual speed, spatial orientation, visualization, pattern recognition, control precision, critical thinking, judgment and decision-making, and teamwork skills. Based on their review of existing measures, the authors recommend six measures which capture most of the important factors: ECAT Figural Reasoning or Abstract Reasoning Test, ASVAB Assembling Objects test, Tailored Adaptive Personality Assessment (TAPAS), TBAS Tracking subtests, and ECAT Mental Counters or Army SIFT. The authors also developed two additional scales to measure the factors not currently being measured by the existing instruments, a measure of time sharing ability and a measure of workplace preferences.

Renshaw, P. F., & Wiggins, M. W. (2017). The predictive utility of cue utilization and spatial aptitude in small visual line-of-sight rotary-wing remotely piloted aircraft operations. *International Journal of Industrial Ergonomics, 61*, 47-61. http://dx.doi.org/10.1016/j.ergon.2017.05.014

Cue utilization has been found to predict skill acquisition in simulated takeoff and landings of VLOS UAV and fixed-wing aircraft. Similarly, spatial aptitude may play a role in learning how to operate VLOS RPA because it shares similar neural mechanisms as cue utilization. To address this, the current study investigated the relationship between cue utilization, spatial aptitude, and skill acquisition in learning to operate a RPA while controlling for video game experience and motor vehicle driving experience. Ninety-five university students with no RPA experience participated in two simulated tasks. Task one required participants to successfully learn to hover an RPA in a limited space. Once successful, participants moved to task two, which involved maneuvering the RPA through a series of timed obstacles with increasing difficulty. The EXPERT Intensive Skills Evaluation Situational Judgement Test was used to assess cue-based processing (e.g., feature identification task, feature association task, feature discrimination task, feature prioritization task) and create a cue utilization score. Spatial aptitude was measured with the Mental Rotations Test variant C, Cube Comparisons Test, Map Planning Test, and the Perspective Taking Ability Test version 2.0. Results indicated that task one (hovering) was associated with higher levels of spatial visualization and video game experience. Task two (obstacle course) showed a relationship between cue utilization and performance. Specifically, higher levels of cue utilization were associated with more successful trials and better completion times than participants with low levels of cue utilization. Participant feedback suggested that directional control and stability were challenging for task one, but task two had greater challenges with power, altitude control, and vehicle control. Initial skill acquisition in task one appeared to support later skill acquisition for task two, but task two skills did not appear to benefit task one. General findings from the study suggest that cue utilization in skill acquisition may depend on the complexity of the task, and the individual's proficiency and stage of learning (e.g., gaming and driving experience).

Sticha, P. J., Howse, W. R., Stewart, J. E., Conzelman, C. E., & Thibodeaux, C. (2012). *Identifying critical manned-unmanned teaming skills for unmanned aircraft system operators* (Report No. 1962). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

The expansion of UAS in military aviation operations has produced the need for coordination between manned and unmanned aircraft. The purpose of this paper was to identify critical needed MUM-T skills for UAS aircrews to inform future training efforts. Following a review of relevant U.S. Army doctrine, the authors developed an initial list of MUM-T missions, tasks, and skills. These lists were subjected to SME review and revisions. This resulted in a list of 25 critical MUM-T skills, 20 of which were deemed important for training. Each skill was rated on performance level, importance for mission success, consequences of lack of skill, and training appropriateness. Based on these ratings, the top five most critical MUM-T skills were (a) deconflict munition trajectories from airframes, (b) utilize standardized execution commands to initiate attack, (c) transmit information about the method attack, (d) switch roles of laser designator and missile launch platforms, and (e) conduct call for direct fires. Behavioral indicators were created to support the measurement of these skills for MUM-T training purposes. As the operations for UAS expand in the military, as well as in the civil airspace, coordinated efforts between unmanned and manned aircraft are likely to become more common, pointing to the importance of MUM-T skills.

Triplett, J. E. (2008). *The effects of commercial video game playing: A comparison of skills and abilities for the Predator UAV* (No. AFIT/GIR/ENV/08-M22). Wright-Patterson Air Force Base, OH: Air Force Institute of Technology Graduate School of Engineering and Management.

The aptitudes required for video game players may be similar to the aptitudes needed for UAV operators. This articles focuses on the similarities in skills and abilities between video game players and operators for the Predator UAV. Based on the notion that pilots certified for manned operations may be overqualified or misplaced in UAS operations, the author looked at video game experience as a prerequisite for UA pilots in the USAF. First, the author describes several differences between manned and unmanned piloting. Key differences include that UAV pilots have to (a) deal with more sources of information when maintaining SA, (b) control the aircraft from the ground, (c) deal with the potential loss of data link, and (d) fly the aircraft with little sensory input. Through interviews with 9 participants (3 manned pilots, 4 video gamers, and 2 UAV pilot SMEs), the author compiled a list of skills and characteristics needed in Predator

UAV pilots. Example skills and characteristics include compensating for missing sensory cues, adapting to visual limitations, use of mapping and voice chat programs, mental acuity, attention to detail, knowledge of UAV aircraft/system, and awareness of airspace(see Tables 5-8 in this article for the complete list of skills). Furthermore, there was significant overlap in skills between video game players and UAV pilots, including hand-eye coordination, pattern recognition, rapid decision-making, SA, the ability to work in two-dimensional environments, and using various sources of information.

Tvaryanas, A. P. (2006). *Human factors considerations in migration of unmanned aircraft system (UAS) operator control* (Report No. HSW-PE-BR-TR-2006-0002). Brooks City Base, TX: USAF Performance Enhancement Research Division.

The nature of UAS missions creates situations where control may have to be transferred (i.e., control migration) from one operator to another due to temporal, physical, or functional demands of the operation. Examples of control migration include the transfer of control between operators at a single control station (e.g., crew changeover), between control stations (e.g., aircraft handoff), or among crewmembers in the execution of a task. The authors identify several operator skills that fall under the purview of control migration, including vigilance, multitasking, SA, situational problem solving, cognitive flexibility, endurance, alertness, stress management skills, target detection/recognition, image manipulation, and awareness of directions. Important knowledge for operators to possess includes familiarity with supervisory control, interfaces, and sensors. Control migration poses several advantages for UAS performance. First, the transfer of control can mitigate human factors issues related to fatigue or lapses in attention. Second, the idea of control migration suggests that functional specialization may be sufficient for UAS crews such that crewmembers should be experts in certain tasks to ensure that control can be efficiently transferred to another individual. Task specialization will allow operators to distribute duties among the crew accordingly to free up attentional resources for more complex demands. This specialization may lead to more efficient training programs as well. Third, control migration can prevent workload imbalances for UAS operators that are controlling multiple vehicles by allowing operators to transfer vehicles under conditions of high workload. The downsides of transferring control are that it may negatively influence operator SA as well as increase the complexity of a crew's workload and reduce teamwork efficiency. Accumulating training and mission experience with crewmembers can mitigate this potential degradation by enhancing teamwork knowledge.

Van Oijen, J, Pogginga, G., Brouwer, O. Aliko, A, & Roessingh, J. J. (2017, October). Towards modeling the learning process of aviators using deep reinforcement learning. In *2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*. Banff, Alberta, Canada: IEEE. http://dx.doi.org/10.1109/SMC.2017.8123162

Successful SOs typically have the following abilities: attention, cognitive proficiency, memory, reasoning, spatial processing, and visual perception. Arcade-style video games historically have been used to train pilots because many of the needed skills and abilities (e.g., visual tracking and spatial memory) generalize across platforms. A deep reinforcement learning model could be used to understand the learning process of SOs in RPASs and improve SO training by identifying and reducing the effect of human factors risks. To investigate this possibility, the authors used the game Space Fortress as a top-down approach to investigate skill acquisition. The components of Space Fortress were broken into 12 mini-games to investigate individual skill acquisition as a bottom-up approach. The deep reinforcement learning algorithm A3C+LSTM served as the learning agent for both approaches. The deep reinforcement learning agent was not able to successfully learn broad tasks in Space Fortress because it had to inhibit undesirable behavior to avoid negative rewards, rather positive rewards. The deep reinforcement learning agent was able to learn skills through the mini-games. However, learning was more effective when skills were learned incrementally over time, rather than at once. The findings from this study suggest that deep reinforcement learning could be used to improve training methods, but additional research is needed to understand the generalizability of deep reinforcement learning agents to human learning curves.

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, OH: Naval Medical Research Unit.

The selection and training of qualified individuals for UAS and RPA operator positions is critical to the military. This report details the selection and training process for UAS and RPA operators. First, a job analysis was conducted to identify the Skill, Ability, and Other Characteristic (SAOCs) needed upon entry into the job. The list of relevant SAOCs were reviewed by SMEs and a final list of 115 attributes was created. Critical SAOCs included task prioritization, management of stressors, vigilance, analytical ability, spatial orientation, working memory, mental rotation, risk perception, and mechanical comprehension. Next, SMEs identified several potential measures of the important characteristics required in UAS/RPA operators. Tests include the Aviation Selection Test Battery and Performance Based Measures, Self-Description Inventory+, Navy Computer Adaptive Personality Scales, Multi-Tasking Test, TBAS, ASVAB, AFOQT, and USAF RPA Work Interest Inventory. Seventy-eight SAOCs (see Table 2 in Williams et al.) received an average rating of 3.0 or higher on importance indicating that they were moderately important, and 57 of these SAOC items are judged to be measured by at least one of the identified selection measures.

Wheatcroft, J. M., Jump, M., Breckell, A. L., & Adams-White, J. (2017). Unmanned aerial systems (UAS) operators’ accuracy and confidence of decisions: Professional pilots or video game players? *Cogent Psychology*, 4, 1327628. http://dx.doi.org/10.1080/23311908.2017.1327628

UAS operations have outpaced current UAS training requirements, resulting in questions concerning the qualifications of unmanned pilots. The authors argue that trust and confidence are critical for UAS operations given the reliance on automation in UAVs and the need for pilots to make decisions based on what the system is saying. This study explores the suitability of three potential groups of UAS operators (video game players, private pilots, professional pilots [as well as a control group]), using a simulated civilian cargo flight. Participants were evaluated on accuracy, confidence, and confidence-accuracy correlations. In the experiment, participants engaged in a simulated UAS task that displayed pre-recorded vignettes of a civilian cargo flight, which included 21 events requiring a decision. Each decision provided the option to let the autonomous system control the UAV or to intervene and manually fly the UAV. Professional pilots and video game players showed higher decision confidence compared to the control groups. Professional pilots were more confident in manual decisions in both high and low decision danger conditions, but displayed higher confidence in automated decisions only in the low decision danger conditions. The authors argue that this may be partially explained by prior experience. Furthermore, all groups tended to display more confidence in a decision when they let the autonomous system control the UAS. In terms of confidence-accuracy correlations, correlations were the lowest under conditions of high decision danger. However, in general, there was a weak positive correlation between confidence and accuracy. Finally, professional pilots scored lower in neuroticism than the control group and scored higher in agreeableness than video game players. Neuroticism was negatively related to confidence, whereas conscientiousness was positively related to confidence.

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). Washington, DC: Federal Aviation Administration Office of Aerospace Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2010s/media/201409.pdf

Understanding the limitations of the human visual system is critical for the development of UAS regulations as pilots may be required to operate aircraft within VLOS. UAS operations may also use Visual Observers (VOs) to track aircraft and prevent mid-air collisions. VOs are trained personnel who assist the UA pilot in collision avoidance duties by visually tracking the vehicle and surrounding airspace. At the time of this report, VO requirements are outlined in FAA publication N8900.227. These requirements allow observers to operate via ground-based or airborne aircraft and prohibit the use of visual aids (e.g., binoculars, night vision devices) as the primary means of visual contact. The daisy-chaining of observers is also prohibited, but may be allowed under exemption. In this article, the authors review research on the human visual system to evaluate the appropriateness of current VO requirements. Evidence suggests that visual detection is problematic even under ideal conditions. UAS VO research suggests that an observer's ability to correctly identify aircraft is influenced by the size of the scan area, aircraft distance and altitude, and the movement of the aircraft (e.g., flying toward or away from the observer). SAA research finds that visual detection performance of manned pilots is influenced by aircraft speed, object contrast, background environment, and time availability. Compared to pilot of manned aircraft, VOs have several advantages for visually tracking aircraft, including the ability to devote 100% of their effort to visual scanning, being able to attain a better point of view for assessing the relative motion of aircraft, and the potential for less visual obstruction. Based on this research, the authors identify VO requirements that likely exceed actual observer abilities. This list includes maintaining visual contact with sUAS, maintaining visual contact with a UAS while scanning for traffic, judging collision potential of an intruding aircraft, and informing the pilot of impending loss of visual contact. Finally, the authors provide recommendations for the physical qualifications (e.g., 20/20 or better vision with or without correction, normal color vision, and normal hearing acuity) and training requirements (e.g., cardinal direction, scanning patterns, and phraseology) for VOs.

Wohleber, R. W., Matthews, G., Reinerman-Jones, L. E., Panganiban, A. R., & Scribner, D. (2015, September). Individual differences in resilience and affective response during simulated UAV operations. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 59, 751-755. http://dx.doi.org/10.1177/1541931215591176

UAS pilots, particularly in the military, are subjected to various sources of stress during operations, including multi-UAV control and high task load. This study sought to test whether resilience, the tendency to respond positively to challenging situations, was a predictor of stress responses during a simulated UAV task. Three factors were used to capture the construct of resilience: hardiness, grit, and anxious metacognitions. Hardiness is a trait that allows individuals to interpret stressful experiences as normal situations. Grit refers to an internal motivation to preserver in the face of difficulties. Anxious metacognitions reflects a style of thought that increases stress though ruminating on anxious thoughts. Participants in this study were undergraduate students with no prior UAS experience. The UAV simulation task required participants to control two UAVs during an ISR operation. Subjective and physiological measures were used to assess participants' stress response. While there was some variability in results, high scores on resilience were associated with lower stress levels. Hardiness and grit were the strongest predictors of stress response. Hardiness was positively related to engagement and negatively related to distress and worry. Similarly, grit was negatively related to distress and worry. The authors suggest that the assessment of resilience may be useful for identifying who is most fit to serve in these roles and that providing resilience training may be helpful for improving stress responses.

UAS Testing and Training

Adams, B. (2010). *Pilot skills and aerodynamic knowledge for operating smaller unmanned aircraft systems* (Unpublished master's thesis). University of North Dakota, Grand Forks, ND.

The skills and knowledge necessary to operate sUAS are a topic of significant importance given the impending integration of UAS into the NAS. The purpose of this effort was to determine the physical flying skills and aerodynamic knowledge needed to operate sUAS. A survey was used to assess UAS type-design, operational data, and training program information. The survey was sent to aviation professionals with experience with UAs of 500 pounds or less. A total of 58 valid responses were collected. Responses were collected from UAS/remote-controlled pilots, manufacturers, operators, researchers, trainers, and government employees. The majority of the respondents were familiar with 5 – 55 lbs. UASs, fixed-wing designs, and operations below 1,000 feet. The most commonly cited UAS use was recreational followed by military, government, research, and commercial uses, respectively. In regard to certification requirements, most respondents believed that a pilot certification was not necessary for type of sUAS operations they were involved in. Respondents who reported recreational UAS experience indicated that they had no formal training, whereas commercial or military UAS pilots had at least some formal training. The most common training topics were (a) takeoff/launch, (b) turns, (c) landing/retrieval/recovery, (d) climbs/descents, (e) remote control/GCS, and (f) emergency procedures/system malfunctions. The author reports that UA pilots operating aircraft weighing less than 5 lbs. and below 400 feet likely do not require specific training, but that regulations and certifications should be necessary for pilots operating UAS above 5 lbs. and above 400 feet. This suggests that a basic foundation of aerodynamics is needed for most levels of UAS operations. The author identifies the FAA knowledge test as a potential certification test as UAS pilots need to possess knowledge of airspace, ATC communication, aviation regulations, and basic aerodynamics.

Al Shibli, M. (2015). Towards global unification of UAS standardization: Regulations, systems, airworthiness, aerospace control, operation, crew licensing and training. *International Journal of Unmanned Systems Engineering*, 3, 32-74. https://doi.org/10.14323/ijuseng.2015.7

Even though the use of UAS has increased rapidly, a comprehensive set of regulations for UAS operations does not yet exist. This report summarizes the current set of regulations and requirements for UAS across the U.S. and international organizations (e.g., Civil Aviation Authority (CAA)) to provide recommendations for future UAS standards. In terms of pilot training requirements, the author describes the Aircrew Training Program of the U.S. Army as an example of UAS training standards. This program focuses on the different roles within an UAS crew (e.g., AVO, EP). In Aircrew Training Program, individuals are evaluated with a written exam that covers the entire UAV operator manual and a hands-on performance test that involves an oral evaluation and job position evaluation. Types of knowledge assessed in oral evaluation include (a) unit SOPs, (b) weather limitations, (c) UAV systems, (d) emergency procedures, and (e) preflight procedures. The author also describes the Flying Hour Program, which falls under the Aircrew Training Program. This program outlines required training hours, which are 30 hours for refresher training, 18 hours for mission planning training, and 50 hours for continuation training. CAA UAS regulations are also discussed. CAA standards for UAS operator qualifications are determined on a case-by-case basis and consider factors such as pilot experience, maximum air vehicle mass, flight control mode, and safety risk assessment. Under CAA regulations, pilots intending to use radiotelephony must hold a Flight Radio Telephony Operators' License. At the time of this report, there are no CAA approved training courses for UAS crews for the issuance of licenses or the issue of type/class ratings.

Barron, L. G., Carretta, T. R., & Rose, M. R. (2016). Aptitude and trait predictors of manned and unmanned aircraft pilot job performance. *Military Psychology*, *28*, 65-77. http://dx.doi.org/10.1037/mil0000109

The aptitude and trait measures predictive of success in USAF manned pilot training are also predictive of success in RPA pilot training. However, little research has examined if these aptitude and trait measures are predictive of on-the-job performance. Therefore, the purpose of this paper was to examine the predictive validity of aptitude and personality traits measures, specifically the AFOQT and Self-Description Inventory+, with supervisor ratings of performance. The first three years of performance ratings were gathered for the unmanned and manned pilots. In the first year performance reviews, perceptual speed and aviation knowledge were found to be positively associated with RPA pilot performance, whereas quantitative reasoning, instrument comprehension, perceptual speed, and aviation knowledge were associated with manned pilot performance. In terms of personality traits, neuroticism was negatively associated with RPA pilot performance and conscientiousness was positively associated with RPA pilot performance. For manned pilots, agreeableness and conscientiousness were positively associated with performance and extraversion was negatively associated with performance. For the three years of performance reviews, none of the cognitive aptitude measures were associated with RPA pilot performance. However, neuroticism and conscientiousness were still negatively and positively related to performance, respectively. The predictive validity of the measures remained similar for the manned pilot performance across the three years of performance ratings. However, it is important to note that the sample size of RPA pilots was substantially smaller than the manned pilot group.

Baum, M. S., Kiernan, K. K., Steinman, D. W., & Wallace, R. J. (2018). *UAS pilots code*. Aviators Code Initiative, University of Aviation Association.

The Aviators Code Initiative and University of Aviation Association established a living document to assist UAS pilots and operators with safely operating in civil aerospace and to provide supplemental knowledge outside certification and regulation requirements. They provide the following recommendations for UAS training and proficiency: receive equipment and operational training beyond those required by certification; incorporate manual flight, autonomous flight, and scenario training; incorporate flight simulators and related devices in training; incorporate weather and flight conditions protocol in their operations; include abnormal and emergency conditions like loss-of-control and traffic conflicts in training; practice obstacle and wire avoidance techniques; practice flight over harsh terrain that may impact the performance of the UAS (e.g., open water, remote areas); have knowledge of the mechanics, system, and unique risks and challenges posed by the type of UAS in operation; demonstrate and maintain mastery of ACS, flight skills, and aeronautical knowledge; and participate in continuing education UAS programs and related training programs provided by regulation and government agencies (e.g., FAA Pilot Proficiency Program).

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). Washington, DC: US Department of Energy.

Advances in UAS technology have increased the applicability of unmanned aircraft for atmospheric and climate research. This document describes the requirements and processes for obtaining approval for UAS and Tethered Balloon System (TBS) operations at Department of Energy (DoE) Office of Science Atmospheric Research Measurement (ARM) user facility observatories, ARM-supported training flights, atmospheric instrument development flights, and campaigns at non-ARM. Qualification and training requirements for Remote Pilot in Command (RPICs) and VOs involved in ARM are described in this document. To be approved as a RPIC, pilots must hold a Part 107 remote pilot certificate, complete the manufacturer's training program, complete site-specific training, and be 18 years of age or older. RPICs are also required to have performed at least three recoveries/landings within 90 days of the current operation. For sUAS RPICs, the training areas mandated in this document include airworthiness, flight characteristics, weight and balance, loss communication procedures, loss of Global Positioning system (GPS)/auto pilot, manual flight/control, GCS operation, initialization/checkout, frequencies and frequency mitigation/deconfliction, launch and landing/flight termination, normal and emergency procedures, and limitations. RPICs of sUAS must also complete 15 hours of manual control of each Small Unmanned Aircraft Vehicle (sUAV) (five of these hours may be logged via simulator), including 20 manual takeoffs and landings. UASs greater than 55 lbs. require increased training and must include the following content areas: airworthiness, set up and teardown of the aircraft, engine/motor, fuel/battery system, hydraulic system, control interfaces, normal and emergency procedures, weight and balance, payload and payload interfaces, launch and recovery procedures, limitations, autopilot and software (e.g., flight planning, lost communication), and GCS. Training requirements for VO are also described. VO training must include site-specific training, instruction on flight characteristics and limitations, identifying weather changes/trends, understanding cloud clearances, VFR minimums, and other airspace minimums, communications to the RPIC, radio procedures and discipline, identification of traffic and hazards, aircraft and traffic patterns, and one hour of directly observing UAS flights prior to acting as VO. Finally, in terms of fitness to perform duties, minimum qualifications for personnel participating in UAS operations at an ARM site include adherence to 14 CFR 91.17 and 91.19, which prohibits alcohol consumption within eight hours of an operation.

Bennett, W., Bridewell, J. B., Rowe, L. J., Craig, S. D., & Poole, H. M. (2016). Training issues for remotely piloted aircraft systems from a human systems integration perspective. In N. J. Cooke, L. J. Rowe, W. Bennett, D. Q. Joralmon (Eds.), *Remotely piloted aircraft systems: A human systems integration perspective* (pp. 163-176). West Sussex, UK: Wiley & Sons Ltd. http://dx.doi.org/10.1002/9781118965900.ch7

Current training for RPAS is inconsistent and unstandardized. The authors reviewed current training processes across UAS sectors and highlighted the usefulness of a Human Systems Integration (HSI) perspective for UAS training. The authors noted that the military, which traditionally required RPAS operators to be certified pilots, changed their policy to allow non-pilots to become RPAS operators. This policy change was based on research that found no significant differences in training performance between non-pilots, student pilots, and traditional pilots. Academic institutions have also started to offer training on RPAS. These institutions may train students to be knowledgeable of the systems for both small and large RPAS, sensor systems, and operation procedures. In terms of training development, the authors discussed the use of the Mission Essential Competency methodology for defining UAS training requirements. This methodology places the emphasis on proficiency rather than the number of times something has been performed (e.g., number of completed missions, flying hours) and has been applied to manned and unmanned pilot training. Training for RPAS should not only provide a realistic representation of the task environment, but accurately reflect the physiological and psychological experiences of RPASs as well. RPAS training should, therefore, be guided by the KSAOs underlying performance (e.g., control precision, time sharing, and spatial ability). Teamwork and collaboration skills should be covered in training as well given that multiple individuals are often involved in a RPAS operation at a given time.

Biggerstaff, S, Blower, D. J., Portman, C. A., & Chapman, A. (1998). *The development and validation of the unmanned aerial vehicle (UAV) external pilot selection system* (Report No. MANRL-1398). Pensacola, FL: Naval Aerospace Medical Research Laboratory.

The U.S. Navy employs the Pioneer UAV for RPA operations due to its versatility and adaptability to Navy environments; however, there is no screening criteria for potential Pioneer pilots prior to flight training. To reduce training costs and improve the quality of Pioneer pilots, the Naval Aerospace Medical Research Laboratory conducted a performance-based selection system to determine which EP candidate skills predict successful completion of training in less time and high performance after training. A secondary study was conducted with the Aeromedical Advisor Council to determine medical standards for screening potential EPs based on the unique operating environment of the Pioneer UAVs. The computer-based performance test was used to assess the aforementioned skills with the following test batteries: psychomotor and dichotic listening tests, horizontal tracking and digit cancellation tests, and the Manikin and time estimation task tests. Results reveal that the multitasking and tracking tests predicted both objective and subjective assessments of EP training success, and the Manikin test also predicted performance. However, the time estimation task did not predict EP performance. The following were identified as necessary EP skills for successful mission completion: hand-eye coordination, mental reversals and rotation, multitasking, selective auditory attention, and time estimation for approaching UAVs. These were not found to be important skills for IPs and mission commander/POs, and these positions were not investigated in the study because most flight errors occur under the EP's command. The Aeromedical Advisor Council recommended using similar medical requirements as ATCs for EPs with the addition of color vision and depth-perception screening to ensure EP candidates are able to discriminate UAV lights at night and accurately time the arrival of the UAV to the ship.

Blower, D. J. (1998). *Psychometric equivalency issues for the APEX system* (Report No. NAMRL-SR-98-1). Pensacola, FL: Naval Aerospace Medical Research Lab.

Ensuring that the proper testing instruments are in place is a crucial part of pilot selection. This work evaluates the ability of the Automated Pilot Examination (APEX) system, a computer-based version of the Aviation Selection Test Battery (ASTB) test. The authors investigated the psychometric equivalency of the pen and pencil test (i.e., conventional) and computer-based test using members of the Naval and Marine officers in waiting. Specifically, the authors were interested in examining whether transferring the test to a computer-based format would affect test scores. The authors were also interested in determining if changing test formats influenced the predictive validity of the ASTB. The ASTB tests examined included the mathematics and verbal subtest, mechanical comprehension subtest, spatial apperception subtest, and aviation/nautical interest subtest. The biographical inventory subtest was excluded. The results of the study showed that variances in the computer group were lower than the paper-pencil test, thus improving the reliability of test scores. However, test score averages and the predictive validity of the test was not different between the computer-based and paper-pencil format. These results support the APEX system as a reliable tool for improving methods of pilot selection.

Carretta, T. R., Rose, M. R., & Barron, L. G. (2015). Predictive validity of UAS/RPA sensor operator training qualification measures. *The International Journal of Aviation Psychology*, 25, 3-13. http://dx.doi.org/10.1080/10508414.2015.981487

Understanding the attributes needed for success in UAS and RPA operator positions is changing due to the growth of the UAS domain. Three courses that are used to train UAS/RPA pilots and SOs in the USAF were investigated to determine the validity of the ASVAB in predicting performance. UAS/RPA pilots should have high levels of hand-eye coordination, verbal communication, logic, patience, spatial reasoning, symbolic reasoning, high working memory, and SA. For SOs, utilizing one's senses for manual or automated tracking and monitoring of targets is an important skill, and a background knowledge in mathematics, geography, computer science, and chemistry is important as well. The requirements for RPA pilots are similar to those of manned aircraft pilots, which includes a medical screen (FAA Class III Medical Certificate, USAF Flying Class IIU Medical Examination, as well as a medical record review and psychological evaluation) and aptitude tests (AFOQT, TBAS, and PCSM). While the ASVAB was valid in predicting training course performance, it did not measure all KSAOs of interest such as logic, perceptual, spatial reasoning, verbal communication, or SA. Additional measures that assess these critical attributes should be identified for future selection purposes. Additionally, as the autonomous functions of UASs increase, the responsibilities of UAS/RPA pilots will shift from hands-on flying to supervisory control and human-automation balance. This change in job tasks will influence the manner in which UAS/RPA pilots are selected and trained.

Chubb, G. P. (2007). Simulating UAS: How much fidelity and why? In *International Symposium on Aviation Psychology* (p. 133-138). Dayton, OH: Wright State University. https://corescholar.libraries.wright.edu/isap_2007/114

Simulations can serve as a valuable tool for UAS pilot and operator training. When developing a simulation for training purposes, designers need to be aware of the physical, functional, and operational fidelity of the training device to get buy-in from stakeholders (i.e., pilots, operational personnel) and ensure the curriculum design is adequate. Physical fidelity reflects the degree to which the simulator mirrors the physical layout (e.g., control, display, and interface) of the system. Functional fidelity reflects the degree to which the simulator behaves like the actual system. Operational fidelity reflects the degree to which the scenario event within the simulation matches the task environment. Research on training and simulation fidelity, in general, suggests that physical fidelity is needed to support the face validity/user acceptance of the simulator to ensure that personnel view the device as valuable. Functional fidelity helps to support skill acquisition and ensure that the proper behaviors are taught in the training. Finally, the author discussed the Improved Performance Research Integration Tool as a tool for making predictions of training impacts to actual performance.

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*, 29-44. http://dx.doi.org/10.1109/MAES.2007.4408524

One of the biggest challenges facing the UAS industry is the integration of UAS into civilian airspace. A workshop on the future of UAS was held in Australia and focused on airspace integration problems by discussing existing standards and regulations, operational experience, and new technologies. In discussion the potential uses of UAS and regulations, the authors highlighted several key knowledge and skills that pilots should possess in order to operate UASs. The knowledge and skill areas identified include the ability to balance operations and technology for risk mitigation, understanding SAA techniques, and having background knowledge in aviation and UAS technologies. Communication and the ability to coordinate with team members are necessary skills as well. The authors suggest that a training program should consist of basic training (e.g., ground school and UAS theory), conversion training (e.g., flight training, GCS Standard Operating Procedures (SOPs)), basic operations training (e.g., instrument rating, target recognition), full mission training (e.g., mission planning, CRM training), and combat mission training (e.g., training with other platforms, close air support training).

Damos, D. L. (2011). *A summary of the technical pilot selection literature* (Report No. AFCAPS-FR-2011-0009). Randolph Air Force Base, TX: Air Force Personnel Center Strategic Research and Assessment.

A review was conducted on manned pilot selection criteria in the U.S. military from World War I (WWI) to the beginning of the 21st Century. Selection criteria in WWI focused on quickly screening applicants and establishing preliminary selection criteria. Most screening and test batteries focused on physical and psychiatric examinations, and non-medical examinations. Non-medical examinations included academic performance and intelligence, pilot performance in ground school and flight training, and personality traits associated with officer conduct. However, specific attributes and pass/fail criteria were not standard across recruitment facilities, and the items often varied by location. Most selection criteria focused on being physically capable of operating an aircraft and possessing basic motor skills. Research on pilot selection criteria stopped following WWI. Instead, military organizations began focusing on how to standardize selection and screening measures developed during the war so the same attributes were assessed across all locations. Additional research focused on developing measures for physical skills, such as response time and timesharing, vestibular function, and memory. Interest in personality and psychological traits were favored over pilot ability and skill, but it became apparent that personality traits were not predictive of pilot success during training. World War II (WWII) brought an organizational overhaul in the standardization of pilot selection criteria and test batteries. Researchers discovered that training success and pilot intelligence were better predictors than personality, and the military began implementing minimum education requirements and standardized test batteries like the Army Air Forces Qualifying Examination and the Aircrew Classification Battery. Pilots were typically removed from the screening process if they failed the following assessments during flight training: alertness and observations, communication and technique, intelligence and judgement, and personality and temperament. Research conducted after WWII shifted towards identifying specific KSAOs necessary for pilots. A human abilities taxonomy was developed by Fleishman and Reilly (2001) that is currently used in job analysis of civilian and military pilots. However, the review of past pilot selection criteria points to the necessity of continuing to identify KSAOs, especially for specific aircraft types and mission operations

Department of the Navy. (2012). *Group 1 unmanned aircraft systems (UAS) training and readiness (T&R) manual*. (Report No. NAVMC 3500.107). Washington, DC: Department of the Navy.

Adequate training for UAS operators is critical for the safety of unmanned operations. This manual focuses on training and readiness practices in the U.S. Navy and defines the roles and duties of sUAS team members for each class of sUAS. Training requirements are also highlighted throughout the manual in great detail. The overarching goal of the manual is to promote safety and efficiency. The minimum standards required to train individuals in UAS are explored. Some training prerequisites include Class I standards in visual acuity, color vision, and depth perception as well as completing a Basic UAS Qualification BUQ-I course. Introductory, intermediate, and advanced knowledge and skills that are mentioned include communication and coordination skills, tracking mobile targets, situation awareness, vigilance, preflight/launch/recovery operations knowledge, navigation skills, airspace knowledge, airspace surveillance skills, the ability to read and interpret maps (e.g., manipulating imagery from a mission video), range and distance estimation, knowledge of hand controllers and interfaces, and maintenance knowledge. Tables 2-5 in this article highlight all prerequisites and conditions to consider for sUAS operations of all types.

Dolgov, I. (2018). Establishing training and certification criteria for visual observers of unmanned aircraft systems. *Safety*, 4, 1-10. http://dx.doi.org/10.3390/safety4020015

In seeking to establish training methods and certification requirements for VOs of larger UAS, the authors identified three VO-related issues critical for safe UAS operations. These issues include identifying the skills needed for VOs, formal training requirements for VOs, and certification testing for VOs. For Phase 1, SMEs with either a manned or unmanned aircraft pilot license were interviewed in order to identify skills necessary to be a VO for larger UAS. These skills were categorized into three groups: visual tracking in various lighting and weather (e.g., maintain and reengage VLOS), visual scanning for traffic (e.g., adjusting visual depth of field), and communications with the pilot in command (PIC; e.g., cockpit discipline, appropriate terminology, global bearings and local landmarks for positioning, establishing flight patterns of traffic, and determining best course of action if forced to deviate from the flight plan). Phase 2 surveyed aviation stakeholders (e.g., pilots, frequent flyers, technicians) to identify the training and exam requirements necessary for the VO position. The respondents when asked if VOs of large UAS should be required to complete formal and hands-on training. Some respondents suggested online/print materials such as the sUAS ACS manual, ALC-451: sUAS online course, Aeronautical Information Manual, and commercially-available self-study guides.

Drasgow, F., Nye, C. D., Carretta, T. R., & Ree, M. J. (2010). Factor structure of the Air Force Officer Qualifying Test form S: Analysis and comparison with previous forms. *Military Psychology*, 22, 68-85. http://dx.doi.org/10.1080/08995600903249255

The AFOQT is an aptitude test that is used for role assignment and classification in the USAF. The authors analyzed the factor structure of Form-S of the AFOQT, which had already been implemented for operational use at the time of this report. However, the latent structure of the test had not yet been empirically tested. In addition to evaluating the factor structure of the test, measurement equivalence between ethnic groups and gender was also evaluated. Results from the analysis indicated that a bifactor model exhibited the best fit of the data. This model included general intelligence and then five specific factors: verbal, quantitative, spatial, aircrew, and perceptual speed. Measurement equivalence for race and gender was also supported by the analysis.

Driggs, J. B. (2017). *Towards predicting completion for United States Air Force (USAF) remotely piloted aircraft (RPA) training* (Unpublished master's thesis). Arizona State University, Tempe, AZ.

The proliferation of UAS in the USAF has led to a shortage of RPA pilots. Therefore, identifying competencies that distinguish well-qualified pilots can inform current selection and training practices for critical positions. The purpose of this effort was to determine if critical thinking skills distinguish performance between UAS trainees as well as identify competencies that discriminate successful and unsuccessful students in USAF MQ-9 Reaper Weapons School. The Weapons School consists of six phases: basic employment, surface attack, air interdiction, close air support, combat search and rescue, and integrated weapons. A sample of six active duty USAF RPA pilots enrolled in the Weapons School were administered the Halpern Critical Thinking Assessment, but no valid statistical conclusions could be drawn given the small sample size. However, the author also interviewed the seven training course instructors about characteristics that discriminate successful and unsuccessful trainees. The identified characteristics include transfer (generalization), problem solving, emotional self-regulation/competence, and evidence-based reasoning. Additionally, instructor comments on student performance during each training session (i.e., pre-brief, mission, and debrief) were reviewed for important attributes, which resulted in a list of 21 themes. The themes included topics such as organization, planning, error identification, collaboration, adaptability, and flight and area operations leadership.

Hall, E. M., & Tirre, W. C. (1998). *USAF air vehicle operator training requirements study* (Report No. AFRL-HE-BR-SR-1998-0001). Brooks Air Force Base, TX: Air Force Research Laboratory Human Effectives Directorate.

Establishing a training pipeline for current and future UAV needs is crucial for the USAF. This study was conducted to identify skills necessary to prepare an AVO for UAV training, how future UAV training may change because of system advancements, and whether enlisted personnel other than trained pilots could be trained as an AVO. Current AVOs completed a survey assessing skills in the Predator IQT, T-3 Enhanced Flight Screening Program, T-37 Instrument Training Maneuvers course, T-37 Navigation Training Maneuvers course, and the FAA Instrument Rating Practical Test Standards that are believed to be necessary to serve as an AVO and operate an UAV. After completing the survey, respondents reviewed the list of tasks and indicated which they believe would be necessary for combat and future UAVs. 70% of tasks from the Predator IQT (e.g., GCS), T-3 (e.g., flying), T-37 (e.g., instrument and training maneuvers), and FAA (e.g., instrument training) training courses were rated as “necessary” for AVO pilots, and 25% of the total tasks were rated as “nice to have but not necessary” (e.g., instrument and navigation training maneuvers). AVO respondents from the survey and focus groups found it difficult to predict skills for future AVO pilots and stated it largely depends on the type of UAV and mission. Although both groups agree that other enlisted personnel could be trained as AVOs, they argued that having manned aircraft experience is necessary for AVO pilots because AVO tasks involve responsibilities that are typically assigned to enlisted officers, such as making quick and accurate decisions during combat, communication with subordinates and supervisors, and ensuring their decisions are followed by others.

Hayhurst, K. J., Maddalon, J. M., Miner, P. S., DeWalt, M. P., & McCormick, G. F. (2006). Unmanned aircraft hazards and their implications for regulation. *Proceedings of the IEEE/AIAA 25th Digital Avionics Systems Conference*, 1-12. https://doi.org/10.1109/DASC.2006.313735

Recent progress in technology highlights the need for new a regulatory framework to address the unique hazards posed by UAS operating in (un)controlled airspace. The existing regulatory framework focuses on manned operations where crewmembers and passengers are physically onboard the aircraft; however, these regulations may not apply to unmanned operations with UAS because the hazards shift to personnel and individuals on the ground, and potential midair collisions with manned aircraft. Three hazards associated with UASs were reviewed: UAS design domain, UAS flight crew domain, and UAS operational domain. The design of UAS GCS should incorporate human factors issues, and additional consideration should be given to the potential for communication loss between the UAS and GCS. Security measures should be taken to protect communication between the UAS and GCS from unwanted interference or attacks, and crewmembers should be trained to appropriately respond to breaches in security or communication lapses with the UAS. Not all existing training requirements for manned operations will apply to unmanned operations (e.g., learning how to interpret physical cues during instrument training, cockpit resource management procedures). Because they are not physically onboard the UAS, pilots and crewmembers will need additional training on interpreting incoming data from the UAS and for increasing SA. Automated systems may take over these sensory duties, but the blending of pilot and automation duties has significant implications for pilot requirements. This is further impacted by the potential to operate more than one UAS at a time, which will require additional training and certification for the various UAS types. Training for UAS pilots should target topics such as equipment failure and GCS hazards/safety. Finally, UASs may operate in a variety of environments that require many specialized tasks. Regulations will have to be flexible enough to account for the range of potential UAS operations while not sacrificing safety to manned aircraft and individuals on the ground. At the time of this report, all regulations governing pilot requirements are based on the assumption that the pilot is located within the aircraft, which includes minimum medical requirements, passing the private pilot knowledge test, and certification for instrument flight rules (if necessary).

Held, J. D., & Wolfe, J. H. (1997). Validities of unit-weighted composites of the ASVAB and the ECAT battery. *Military Psychology, 9*(1), 77-84. https://doi.org/10.1207/s15327876mp0901_4

The ECAT test has been identified as a best bet selection measure for UAS/RPA operators in the military given that it measures psychomotor and spatial abilities. This paper examines the incremental validity of the ECAT subtest over the ASVAB and serves as an extension to the work covered by Wolfe (1997). The authors use the same dataset as Wolfe (1997), but focus on the operational validity of the test. The ASVAB uses around 20 selector composites, so the goal was to ensure that the additive test component was truly increasing the validity as opposed to merely appearing to do so through a redundant testing procedure. All of the tests were evaluated equally in regard to how they were weighted. One psychomotor test (Two-Hand Tracking) and two working memory tests (Mental Counters and Sequential Memory) demonstrated increased operational validity for recruit training performance in the Army, Navy, and USAF.

Hoepf, M., Middendorf, M., Epling, S., & Galster, S. (2015). *Physiological indicators of workload in a remotely piloted aircraft simulation* (Report No. AFRL-RH-WP-TR-2015-0092). Wright-Patterson AFB, OH: Air Force Research Laboratory 711th Human Performance Wing School of Aerospace Medicine.

Performance decrements caused by workload are a concern for UAS pilots given the demanding nature of their operations. As interest in RPA/UAS operations continue to increase, it is necessary to understand what constitutes high workload for pilots, how to measure it, and how to monitor that workload. This work draws on previous workload research to assess what physiological measures would best determine high workload for RPA pilots. The authors investigated physiological measurements of workload with six participants in a RPA simulation. The measurements included EEG (cortical), ECG (cardiac), and then vertical electrooculography (EOG) and eye tracking. Workload was manipulated by route (city vs. country), weather (hazy vs. clear), and the number of high value targets (one vs. two). The number of high value targets and the route were adequate manipulations of workload, and the results from the study indicated that the EEG data is difficult to interpret. However, the blink rate and duration decreased with increased workload, which is supported by previous research, and heart rate variability fluctuated as a result of workload as indicated by the ECG data. These results provide some support for the use of physiological measurements for monitoring the cognitive workload of RPA/UAS pilots.

James, L. Y. (2016). *An efficiency study on the US air force's consideration of allowing enlisted personnel to fly medium-altitude long-endurance (MALE) remotely piloted aircraft (RPA) or unmanned aerial systems (UAS)* (Unpublished master’s thesis). Army Command and General Staff College, Leavenworth, KS.

The USAF is facing a manning crisis due to the difficulties in retaining RPA pilots. To mitigate this issue, the USAF is considering permitting enlisted airmen to serve as RPA pilots. This report examines the qualifications and training of RPA pilots, and the benefits (downfalls) of allowing enlisted personnel to serve as RPA pilots. RPA pilot requirements for the USAF include being a commissioned officer, possessing a bachelor’s degree, and possessing a current aeronautical rating. Training requirements include successful completion of nine week officer training, completion of the URT or possession of an aeronautical rating of pilot or navigator/combat systems officer, and five months of undergraduate UAS training followed by a four-month flying course. While the USAF requires RPA pilots to be officers, the U.S. Army assigns enlisted personnel with no manned pilot training to the UAS operator role. UAS operator requirements for the U.S. Army include passing the Surveillance and Communications sub-test of the ASVAB, 10 weeks of basic combat training, and at least 25 weeks of advanced training with on-the-job instruction. This research discusses the utility (i.e., cost-benefit analysis) of allowing enlisted airmen to serve as RPA pilots and the potential changes to the USAF’s structure (e.g., officers managed enlisted RPA pilots).

Joint Staff. (2011). Joint unmanned aircraft systems minimum training standards. (CJCSI 3255.01).

Setting minimum training standards is important for ensuring that qualified individuals perform UAS operations. This work seeks to define the minimum training standards of joint unmanned aircraft systems, the minimum knowledge necessary for crewmembers, and any changes made to CJCSI Instruction 3255.01. A capabilities-based approach is suggested in the report, and five critical skill sets are addressed. Important skills include general aviation knowledge, mission crew skills, practical operation skills (e.g., SA), unique service skills, and general knowledge of objectives. The requirements and certification standards scale with the size and operations of the UAS. Training standards must include general aviation knowledge (e.g., airspace design, aerodynamics, navigation, and communication procedures), flight training, proficiency requirements, CRM, and certification. The report goes into detail for each level of Basic UAS Qualification (BUQ) requirements and training necessary for each level, as well as the expectations of understanding.

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

In addition to technical knowledge and skill, UAS pilots must maintain non-technical, CRM-related skills as UAS operations are often performed by in a team setting. CRM refers to the use of resources (e.g., crewmembers and systems) to achieve safety and efficiency involving concepts such as leadership, teamwork, and communication. CRM has been studied extensively in manned aircraft environments, which can serve as an analog to CRM in UAS contexts. Chapter 6 focuses on the training and development of CRM nontechnical skills in Europe. CRM training focuses on combined training among all flight crew, including cabin and technical crews. Training courses should include the following skills: principles of CRM and Threat and Error Management (TEM), SA, problem-solving and decision-making, workload management and task sharing, communication and assertiveness, leadership and teamwork, stress management, fatigue, and vigilance. Additional nontechnical skills should be incorporated to address technological advances and skill shortcomings identified in recent aviation incidents such as automation, monitoring skills and interventions, resilience, and surprise/startle effects. Training should be used as an opportunity for crews to learn from one another and should consist of evidence-based training methods. Chapter 9 reviews the evaluation and effectives of CRM training. Traditional methods of training evaluation have focused on reactions, learning, behaviors, and results. Evaluation of CRM training and effectiveness should include performing a needs analysis prior to implementation of training courses; identifying desired learning outcomes; acknowledging and mitigating limitations of evaluation assessments; collecting utility reactions (usefulness ratings) of training; incorporating multiple learning outcome dimensions; measuring the transfer of training skills; measuring transfer of individual, training, and organization characteristics; measuring training effectiveness at various stages of training; incorporating longitudinal assessments to assess training over time; allocating ample resources to training assessments; and referencing fields outside aviation for best practices. Chapter 16 reviews U.S. regulations concerning CRM and its application to CRM principles such as crew training and procedures, and the future design of aircraft equipment. For the purpose of this paper, only training is reviewed. The FAA's Advisory Circular AC120-51E describes the content of CRM training programs for Parts 121 and 135; however, Part 135 provides clear requirements for CRM training programs. CRM training should include the following topics: rights of pilot in command; crew communication and coordination with all involved individuals, such as ATC and passengers; formation of flight teams; workload and time management; SA; fatigue and fatigue countermeasures; stress and stress management; and decision-making and judgement specific to flight operations. Additional advisory circulars have been published by the FAA addressing crew procedures and SOPs that should be incorporated with CRM.

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). Netherlands: Springer. http://dx.doi.org/10.1007/978-90-481-9707-1_80

Effective training is critical for imparting the necessary knowledge and skills to UAS operators. The Portuguese Research and Technology Project in Unmanned Air Vehicles is described and evaluated in this paper. Training of UAS operators should address shortfalls in crewmember skills with regard to the operations. Requirements include hours in the simulator, supervised training, supervised UAS configurations, number of flights, and flight hours. These would scale up accordingly with operator category (i.e., pilot, systems operator, and instructor). The curriculum proposed in this training program includes knowledge of atmospheric behavior, aerodynamic fundamentals, flight stability, maneuvers, and flight performance. Operational training would cover chain of command, understanding autonomous flight, integration, platforms, rules of conduct, terminology, regular and critical situations, emergency procedures, concept of operations checklists, mission planning, and team coordination. Pilots will need to possess personal characteristics (e.g., honorable), technical, and professional qualities. They will also be trained in takeoff and landing procedures so they can take over flying the UAS if problems arise during operations.

Nye, C. D., Drasgow, F., Chernyshenko, O. S., Stark, S., Kubisiak, U. C., White, L. A., & Jose, I. (2012). *Assessing the tailored adaptive personality assessment system (TAPAS) as an MOS qualification instrument* (Report No. 1312). Fort Belvoir, VA: U.S. Army Research Institute for the Behavioral Social Sciences.

The TAPAS was evaluated to see if it could be used to improve candidate screening and performance for Military Occupational Specialty (MOS) positions, such as Infantry, Combat Medics, Military Police, and Motor Transport Operators. TAPAS assesses components of the Big Five personality factors such as achievement, adjustment, attention seeking, cooperation, dominance, even tempered, generosity, intellectual efficiency, non-delinquency, optimism, order, self-control, sociability, and tolerance. The TAPAS also assesses physical conditioning. Results from the study indicate that TAPAS predicted job knowledge test scores, performance ratings, and attrition outcomes. However, the predictive validity of the TAPAS varied across MOS and due to scoring methods. Overall findings from the study suggest that TAPAS can be used to supplement current candidature screening processes for the U.S. Army.

Ostoin, S. D. (2007). *An assessment of the Performance-based Measurement Battery (PBMB): The Navy's psychomotor supplement to the Aviation Selection Test Battery (ASTB)* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA.

Cognitive and psychomotor skills are critical for pilots as basic flight skills involve some form of hand-eye coordination. However, these skills are believed to be underrepresented in pilot selection methods (at the time of this report). The Performance-Based Measurement Battery (PBMB) was designed to supplement the ASTB for pilot selection in the U.S. Navy. This work assessed the validity of the PBMB as a pilot selection measure and examined the influence of flight experience on PBMB scores. Forty individuals, half with flight experience and half with no experience, took the PBMB which was comprised of three sections: Spatial Orientation, Listening, and Eye-Hand Coordinated Tracking. The Spatial Orientation section consisted of a Direction Orientation Test, the Listening section consisted of a Dichotic Listening Test, and the Eye-Hand Coordinated Tracking section consisted of a Vertical Tracking Test, an Airplane Tracking Test, and multi-task combination of the Vertical and Airplane Tracking tests. There were no significant differences in Spatial Orientation or Listening Skills based on flight experience. However, individuals with prior aviation experience performed significantly better than those without prior experience on several eye-hand coordinated tracking (i.e., multi-tracking) tests. The PMBM did prove to be a valid supplement to the ASTB. However, ongoing improvements and refinements will need to be made in order to fully understand the most crucial skills and characteristics necessary for pilots.

Pagan, J., Astwood, D., & Phillips, H. (2015, May). Optimizing performance of trainees for UAS manpower, interface and selection (OPTUMIS): A human systems integration (HSI) approach. In *18th International Symposium on Aviation Psychology* (pp. 554-559). Dayton, OH: Wright State University. https://corescholar.libraries.wright.edu/isap_2015/13

From a HSI perspective, understanding how humans interact with systems (i.e., UAS) is critical for safety. The authors note that research has attempted to define who should operate UASs, but less research has examined training requirements for UAS operators. This report discusses the KSAOs that should be used for the selection and the KSAOs that should be used for training. The authors note that prior research suggests that UAS mishaps can be attributable to issues with the selection, training, and design for UAS operations. For instance, research has found that UAS platforms operated by winged aviators experience more accidents due to human factors issues, whereas strictly unmanned pilots experience more mishaps due to training and procedural issues. The explanation for these findings may be the negative transfer of training from manned to unmanned platforms and that core manned skills (e.g., spatial, physical/perceptual) go unused in UAS. Based on a review of UAS JTAs, the authors identified 17 critical KSAOs for selection (e.g., mathematical ability, reaction time, finger dexterity) and 40 critical KSAOs for training, including navigation skills, disengagement, map reading, aviation principles, and systems comprehension. Aligning the KSAOs most appropriate for selection and training purposes can help ensure that UAS operators are well-qualified for operations.

Pavlas, D., Burke, C. S., Fiore, S. M., Salas, E., Jensen, R., & Fu, D. (2009). Enhancing unmanned aerial system training: A taxonomy of knowledge, skills, attitudes, and methods. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 53*, 1903-1907. http://dx.doi.org/10.1177/154193120905302604

There is misalignment between UAS use and current training requirements for UAS operators. In particular, there is a lack of standardization across UAS training and a deficiency in the knowledge, skills, and procedures being taught to operators. The authors attempt to bridge the gap between current UAS operations and UAS training by describing a taxonomy of UAS KSAs based on relevant literature. The authors describe UAS knowledge in terms of human-focused and equipment-focused items. Human-focused knowledge is comprised of 16 knowledge items including meta-task knowledge (e.g., workload, fatigue, distraction), SA (e.g., understanding the mission, understanding the tasks of team members), and knowledge of contingency behaviors (i.e., understanding how to deal with potential distractors). Equipment-focused knowledge includes 12 knowledge items such as the system's command set, operational threats, constraints, automation, and reliability which all differ based on the UAS system. Other equipment-focused knowledge includes the aircraft's feedback system and the four-dimensional (4D) state of the system. The authors identify 25 UAS skills which includes flight skill, long-term monitoring, target search, instrument/mission monitoring, risk assessment, visual scanning, and handoffs. Lastly, UAS attitudes comprise affective states deemed important for UAS operations and include eight general attitudes such as risk perception and risk taking, complacency, and trust in automation. Lastly, the authors discuss the applicability of several training methods for the KSAs on UAS operations, including event-based training, scenario-based training, team training, and self-correction training.

Phillips, H. L., Arnold, R. D., & Fatolitis, P. (2003). Validation of an unmanned aerial vehicle operator selection system. *Proceedings of the 45th Annual Conference of the International Military Testing Association*, 129-139.

The military is deeply invested in using UAVs for military operations, so selecting qualified pilots and operators is essential for missions using UAV systems. In this article, the authors validate selection standards for the screening of candidates into a UAV Pioneer Pilot training program in the U.S. Navy and Marine Corps. A Pioneer Pilot crew consists of an EP, Internal Pilot (IP), and mission commander/payload specialist. Each role is responsible for different duties. The EP is responsible for control of vehicles within visual sight, the IP is responsible for UAV control beyond visual sight, and the mission commander is responsible for the planning and execution of the mission. A sample of 39 students who received UAV training were administered a battery of five tests, a psychomotor test involving the use of a tick, throttle, and rudder, a dichotic listening task, a horizontal tracking, a digit cancellation task, and the Manikin task. Tests were aggregated to form five scores: an overall score, psychomotor ability, multitasking calculation, multitasking psychomotor, and visuospatial ability. All scores positively correlated with training performance and significant differences in scores were evidenced across students who completed and students who dropped out of training. However, the number of students dropping out of training was small.

Qi, S., Wang, F., & Jing, L. (2018). Unmanned aircraft system pilot/operator qualification requirements and training study. *MATEC Web Conference, 179*, 03006. https://doi.org/10.1051/matecconf/201817903006

As the demand for UASs increase, the role of UAS operators becomes increasingly critical to the safety of unmanned operations. This article examines the requirements and qualifications of UAS operators. Before discussing operator requirements, the authors discuss seven types of UAS: micro, mini, small, tactical, Medium Altitude Long Endurance (MALE), and High Altitude Long Endurance (HALE). At the time of this report, requirements for UAS operators by agency is as follows. For the FAA, UAS operators must hold a valid FAA private pilot license and valid second-class airmen medical certificate (Order 8130.34B), or UAS pilots must hold a pilot license, medical certificate, or valid driver’s license (under Section 333). For the U.S. Military, UAS operators must be trained and evaluated according to Regulation 95-23. For future UAS operator requirements, there are several recommendations made by the authors based on different requirement areas: professional quality, medical requirements, psychological evaluation, training requirements, operating experience, and coordination. Professional quality includes professional dedication, sense of duty, self-control, and enthusiasm for work. Additionally, UAS operators should be at least 18 years old, demonstrate proficient physical fitness, and know aeronautical theory and aviation regulations. For medical requirements, operators should have a medical certificate, but the type of certificate may vary depending on the type of UAS. For example, for sUAS, a driving medical license may be sufficient, whereas a Class-II or Class-III certificate should be required for a large UAS. For psychological evaluations, there is limited research on the use of psychological evaluations for UAS pilots, but the USAF has examined the use of personality testing for UAS selection. As UAS become more autonomous, the mental workload of UAS may change making psychological factors/problems a greater concern. For training requirements, sUAS operators should pass the Aviation Theory Test and participate in formal training to achieve certifications mandated by FAA regulations. For UASs above tactical, the authors recommend that UAS operators have a 4-year degree related to aviation or engineering, complete professional pilot training, learn aeronautical knowledge, and earn sufficient flight hours. For operating experience, prior training and experience is more critical for larger UAS (i.e., tactical and above) than sUAS. For coordination, UAS operators/pilots should be knowledgeable of other aircraft that will be in the same airspace. Lastly, the authors state that UAS training should include theoretical training, simulator training, small UAV operation, and specialized training.

Rodriguez, R. C. (2012). *Overmanned and Undertrained: Preparing UAS Crewmembers for Unmanned Close Air Support* (Unpublished master's thesis). Marine Corps Command and Staff College, Quantico, VA.

The advancement of UAS technologies has influenced the ability of the U.S. Marine Corps to adequately train and staff crewmembers for air vehicle squadrons. Noted issues with the current training procedures are a failure to address gaps in technical knowledge that arose with the advent of new technology, a lack of standardized training across crews, and the duplication of training efforts. The author provides several UAS training recommendations to address these training issues. First, UAS simulations should be relied upon for training procedures given the lower costs and risks, as well as the high degree of similarity across UAS simulations and actual UAS operations. Second, increased funding should be dedicated to simulation training devices. Third, special attention should be given to crew composition to ensure crews are assembled based on skill set and specializations to avoid redundancy in training, underutilization of aircrew, and miscommunication. The author also suggests consolidating crew positions to avoid potential understaffing.

Rose, M. R., Barron, L. G., Carretta, T. R., Arnold, R. D., & Howse, W. R. (2014). Early identification of unmanned aircraft pilots using measures of personality and aptitude. *The International Journal of Aviation Psychology*, *24*(1), 36-52. https://doi.org/10.1080/10508414.2014.860849

Pilot selection tests (e.g., PCSM 2.0 and AFOQT 2.0) that have been traditionally used for manned aircraft could potentially be used in the selection of pilots for unmanned aircraft. This article seeks to examine the validity of these tests as well as a personality measure (Self-Description Inventory+) for the identification and selection of RPA pilots. This work analyzed the following RPA training outcomes: (a) RPA Flight screening graduation/elimination, (b) Academic Average of RPA Instrument Qualification, (c) RPA Instrument Qualification daily flying and check flight average (i.e., flight experience), and (d) RPA Instrument Qualification total average. These training outcomes were compared to performance on the PCSM 2.0 and AFOQT 2.0 and both tests displayed positive correlations with training performance. This provides support for the use of cognitive and psychomotor tests for RPA selection. For the personality test, lower levels of openness predicted higher scores in RPA Instrument Qualification as well as higher scores on academic tests and check flight performance. This finding suggests that openness (i.e., the tendency to be drawn to new experiences and the inclination for introspection) has a negative relationship with pilot performance. As an explanation for this finding, the authors argue that the tendency to overthink situations would be detrimental to RPA pilots.

Schnell, T., & Engler, J. (2014). Entropic skill assessment of unmanned aerial systems (UAS) operators. *Journal of Unmanned Vehicle Systems, 2*, 53-68. http://dx.doi.org/10.1139/juvs-2014-0001

With the ongoing integration of UAS into the NAS, the authors note that there will be a need for skill assessments for licensure purposes for UAS operators such as AVOs and SOs. Current selection practices tend to rely on methodologies used in manned environments even though the requirements of UAS pilots are different. In this article, the authors present a method for automated skill assessment for UAS tasks in simulated environments. The methodology uses an entropic classification algorithm that allows operator skill (e.g., motion patterns) to be classified in real-time. In a study using 30 participants (15 teams of two), the authors examined the rating similarity of this classification method to instructor ratings of participant skill for the task. Instructors made their rating at the end of the simulation as opposed to the classification method which makes ratings throughout the simulation exercise. The authors found that the classification methods produced similar final ratings of instructor ratings of participant skill. This skill assessment methodology allows for continuous assessment during simulation exercises and has the potential to assist the testing and training of UAS operators for motion tasks.

Schreiber, B. T., Lyon, D. R., Martin, E. L., & Confer, H. A. (2002). *Impact of prior flight experience on learning Predator UAVF operator skills* (Report No. AFRL-HE-AZ-TR-2002-0026). Mesa, AZ: Air Force Research Laboratory Human Effectiveness Directorate Warfighter Training Research Division.

The rapid expansion of UAV operations and a pilot shortage in the USAF called for a review of the minimum requirements needed to successfully operate a Predator system. The authors investigated whether the number of flight hours could be a predictor of UAV pilot success. The authors did not assess attributes outside basic psychomotor and perceptual skills. Seven pilot groups were tested on simulated basic maneuvering, landing, and reconnaissance tasks: experienced Predator pilots (1,680-2,942 flight hours), Predator selectees (417-3,010), T-38 graduates (195-215), T-1 graduates (195-215), civilian instrument pilots (120-177), civilian private pilots (45-80), and Reserve Officers' Training Corps students (no flight hours). All participants participated in the simulated tasks using the same control method as Predator UAVs (e.g., stick, throttle, and rudder pedals). The basic maneuvering and landing tasks were conducted until participants met the criterion for proficiency. The reconnaissance task consisted of 30 trials. Results from the study revealed that flight experience (a) reduced the number of trials needed to reach proficiency in the basic maneuvering and landing tasks, (b) reduced the amount of root-mean-square error in the basic maneuvering and landing tasks, and (c) increased the time spent on target in the reconnaissance task. Experienced Predator pilots consistently performed better than the students, and the students consistently had the worst performance compared to the other pilot groups. Predator selectees, T-38 graduates, and civilian instrument pilots performed similar to one another across performance measures. The findings from this study suggest that once a certain amount of flight hours is reached, pilots have likely developed the necessary skills to perform basic maneuver and landing tasks for Predator UAV operations. The authors suggest 150-200 hours of flight experience is adequate for a pilot to learn how to operate a simulated Predator UAV. However, pilots with instrument ratings, T-38 graduates, and civilian instrument pilots should be considered as potential Predator UAV pilots due to their operational knowledge of combat/mission operations.

Stulberg, A. N. (2007). Managing the unmanned revolution in the US Air Force. *Orbis*, 51, 251-265. http://dx.doi.org/10.1016/j.orbis.2007.01.005

The success of UAS in the USAF has led to an expansion of their role in military operations. This work reviews the history of UAS in the USAF and highlights areas that have been successful, as well as areas that need improvement. One such area of improvement is the lack of consensus on what constitutes proper training. The author notes that those who have been making UAS-related staffing decisions have very little experience with or exposure to UAS, and it is suggested that more in-house knowledge is needed to improve this process. The author offers several recommendations for future UAS procedures in the USAF. First, operators should participate in a similar training curriculum as manned aircraft. Second, a healthy work-life balance is needed as missions may take a psychological toll – as they do in real combat – with the UAS pilot operating primarily from their home base. The author notes that those who possess adequate coping skills will be needed as military missions carry varying levels of stress. Third, human factor issues are often recognized as the source of error in manned aircraft incidents, but human oversight and training in launch, recovery, and flying of UASs are necessary skills for mission success. It is also suggested that implementing continuation training may mitigate shortfalls in SA and improve general UAS piloting skills.

Szabolcsi, R. (2016). UAV operator training – beyond minimum standards. *Scientific Research and Education in the Air Force, 18*, 193-198. http://dx.doi.org/10.19062/2247-3173.2016.18.1.25

Existing North Atlantic Treaty Organization (NATO) UAV skills and training requirement regulations are based on the STANAG 4670/ATP-3.37 and the Joint Minimum Training Standards. However, several NATO member-countries have been hesitant to adopt existing regulations, stating better minimum and upper limit requirements for UAV skills and training are needed. Belgium, Canada, Estonia, France, Great Britain, Italy, the Netherlands, and the U.S. each have different skill and training requirements, and UAV and UAS definitions, increasing the difficulty in standardizing NATO regulations for UAV pilot requirements. STANAG 4670 establishes four BUQs for minimum UAV pilot skills and training, and ATP-3.3.7 defines three UAS classes that are used to map the four BUQs of appropriate knowledge and skill minimums for UAV pilots. Class I includes UAS weighing less than 150 kg with operations up to 5,000 ft. AGL. Class II includes UAS weighing 150-600 kg with operations up to 18,000 ft. AGL. Class III includes UAS weighing more than 600 kg with operations up to 65,000 ft. AGL. BUQ Level 1 addresses minimum requirements for VFR International Civil Aviation Organization (ICAO) Classes E, F, and G, and below 3,000 ft. AGL of restricted/combat airspace (e.g., NATO Class I for micro and mini UAS). BUQ Level II addresses minimum requirements for VFR in ICAO classes D, E, F, and G, and below 5,000 ft. AGL of restricted/combat airspace (e.g., NATO Class I sUAS operators). BUQ Level III addresses minimum requirements for VFR for all ICAO Classes except A below 18,000 ft. AGL (e.g., NATO Class II tactical UAS operators). BUQ Level IV addresses minimum requirements for VFR and Instrument Flight Rules (IFR) in all airspace (e.g., NATO Class III UAS operations). UAV pilots must also pass a general aeronautical knowledge test that assesses the following items: airspace structure and operating requirements, ATC procedures and rules, aerodynamics, aircraft systems, performance, navigation, meteorology, ICAO communication procedures, and mission preparation. Other UAV pilot skill requirements focus on subject knowledge, task knowledge, and task performance, and UAV pilots are subject to periodic medical examinations by designated military examiners. Other UAV regulations exist in civil operations, specifically those created by the FAA, which has been the focus and scaffolding for other national efforts to establish skill and training requirements. However, the FAA regulations focus on UAVs weighing less than 25 kg and include accident reporting criteria (e.g., must report within 10 days if it resulted in injury or property damage). Additionally, the FAA regulations require UAV pilots to pass an aeronautical knowledge test, be vetted by TSA, obtain an UA operator certification, and pass a reoccurring aeronautical knowledge test every two years. Despite NATO and FAA regulations, there are gaps in minimum UAV skill and training requirements and differences in national regulations that must be addressed.

Warner, J. D., & Knapp, B. G. (2000). *Crew characteristics for common ground station applications* (Report No. ARL-TN-162). Aberdeen Proving Ground, MD: Army Research Laboratory.

The development of the common ground station of the future raise concerns about whether the current skillset required of ground station operators (i.e., MOS 96H) matches the skill requirements of future ground stations. Given the changes in ground station technology, it is possible that other MOSs possess similar skillsets (e.g., 96B and 96D) given their qualifications and training. SMEs were interviewed and asked to review key documentation on different MOSs (96H, 96B, and 96D). Job analysis data (i.e., skill-ability demands) were collected using JASS to assess overlaps in operator training and skill requirements, and to determine whether the 96H skill profile is adequate for the seven identified high level functions of ground station of the future. Results from the SME reviews revealed training differences in course content with 96H operators spending a greater proportion of training on non-military intelligence concepts for the ground station than 96B and 96D operators. JASS analysis of 96H skills revealed that 96H operators will have increased cognitive command for ground station and will need greater analytical skills, suggesting a need for increased training in intelligence analysis. 96B and 96D operators could be used to fill ground station positions as these MOSs receive more intelligence training than 96H operators. However, the authors recommended increasing intelligence analysis training for 96H operators as the rest of the training curriculum required of this specialty is adequate for the ground station of the future.

Wolfe, J. H., Alderton, D. L., Larson, G. E., & Held, J. D. (1995). *Incremental validity of enhanced computer administered testing (ECAT)* (No. NPRDC-TN-96-6). San Diego, CA: Navy Personnel Research and Development Center.

The ECAT has been identified as a relevant selection measure for the UAS/RPA operator role in the military as the measure assesses several KSAOs that underlie operator performance. This report documents the criterion-related validity of the ECAT and assesses the incremental validity of combined ECAT and ASVAB scores over the ASVAB test by itself. Test scores were validated using training performance. The ASVAB primarily measures facets of crystallized intelligence (e.g., verbal ability, math ability, technical knowledge, and clerical skills). However, this test content was believed to be a barrier for disadvantaged or less educated populations. The ECAT was developed to measure facets of fluid intelligence (e.g., nonverbal reasoning, spatial ability, psychomotor skills, and perceptual speed) in order to provide a more complete assessment of general intelligence. The ECAT’s working memory, spatial ability, and psychomotor tests showed the largest increase in validity over the ASVAB for training performance. Specifically, when ECAT tests were combined with the ASVAB, the predictive validity of the selection measures increased, on average, by two percent for schools’ grades and six percent for performance.

UAS Operations

Canis, B. (2015). *Unmanned aircraft systems (UAS): Commercial outlook for a new industry* (Report No. R44192). Washington, DC: Congressional Research Service.

The use of UAS for commercial purposes is prohibited unless the FAA grants an exemption (at the time of this report). However, the development and use of UAS in commercial industries is rapidly growing. As of the time of this report, 89 companies in the United States produce UAS ranging from hobbyist to high-endurance commercial level aircraft. This report reviews the industries granted exemptions by the FAA to forecast potential commercial uses of UAS. Exemptions made by the FAA were made to more than 20 industries with the top five industries being real estate, aerial surveying, aerial photography, agriculture, and aerial inspection. Organizations requesting an exemption included small businesses and large companies such as Chevron, Amazon, and Dow Chemical. The average weight of approved drones range from 5 lbs. for real estate to 12 lbs. for film and television purposes. The author notes that commercial UAS will be widely used in agriculture (i.e., pests and crop yield), real estate (i.e., large commercial properties), utilities (i.e., inspection of electrical systems), construction (i.e., infrastructure inspection), filmmaking, and law enforcement/public safety (i.e., surveillance and high-risk events). The growth of commercial UAS is dependent on regulations and testing plans by the FAA, privacy concerns, and improvements in SAA technologies.

Clauß, S., Aurich, P., Brüggenwirth, S., Dobrokhodov, V., Kaminer, I., & Schulte, A. (2012). Design and evaluation of a UAS combining cognitive automation and optimal control. *AIAA Infotech at Aerospace 2012*, 1-15.

Conventional automation alone is not enough to manage unforeseen events while operating an UAS. Therefore, quick and accurate human intervention is required to safely manage these events. When fast-paced decision-making is required, it increases the cognitive workload of UAS operators, making errors more likely. The proposed solution presented in the paper is a new automated technology, the Artificial Cognitive Unit (ACU). The ACU system provides task-based guidance and is designed to mimic human cognitive rationale to support the operator during unexpected events. The use of an automated system, such as the ACU, has the potential to decrease the cognitive workload of operators and reduce operational errors. The ACU requires the operator to insert the abstract goal of the mission. In order to select the correct input into the automated system the operator needs to have a comprehensive understanding of the objective of the mission as well as the situation. It should be noted that the automated system does not automate the takeoff and landing procedures and an UAS operator would still be required for those procedures. The planning and implementation of an optimized trajectory is also still required of the UAS operator. Flight testing shows promising results for the ACU. Some evidence provided in the paper suggests the ACU supports the operator and reduces their cognitive workload.

Clothier, R. A., Walker, R. A., Fulton, N., & Campbell, D. A. (2007). A casualty risk analysis for unmanned aerial system (UAS) operations over inhabited areas. *12th Australian International Aerospace Congress*, 1-15.

Integrating UASs into the NAS raises the potential risks for manned aircraft, people, and property. The paper presents a risk analysis tool designed to assist UAS operators in informed decision-making, which is valuable for reducing UAS related incidents. The risk analysis tool was created to assist the operator in gaining an objective view of UAS-related risks, particularly as the risks relate to the operation of UAS over highly populated areas. The acceptable level of risk for UASs should be roughly equivalent to the risk associated with manned aircraft flight. Therefore, when it comes to risk management, safety regulators propose utilizing and adapting the same procedures in place for manned aircraft. However, a number of differences exist between manned and unmanned operations that need to be taken into account when establishing procedures for UAS. The authors identify seven areas that differ between UAS and conventional manned aircraft: technology, performance, operations, human, sociological, market drivers, and integration. Based on these differences, this paper presented a new risk management system for UAS. The data presented in the paper showed some promising evidence on the value of the risk management system, with some notable limitations. However, the evidence from the paper strongly suggests the need for informed decision-making and accurate risk analysis.

Dalamagkidis, K., Valavanis, K. P., & Piegl, L. A. (2008). Current status and future perspectives for unmanned aircraft system operations in the US. *Journal of Intelligent and Robotic Systems, 52,* 313-329. http://dx.doi.org/10.1007/s10846-008-9213-x

Airworthiness standards must be met in order for aircraft to legally enter into the NAS. While the requirements and certification procedures are expected to be similar to manned aviation, regulations specific to UAS are still under development. This article focuses on the future perspectives and a potential roadmap of UAS regulations. The authors discuss two classification systems for UAS, one based on Maximum Take-off Weight (MTOW) and one based on system autonomy. MTOW classification has six categories: micro (0-1 kg), mini (1-10 kg), ultralight (10-100 kg), light (100-1,000 kg), normal (1,000-10,000 kg), and large (10,000+ kg). Classification based on UAS autonomy has three categories: remotely piloted, remotely operated, and fully autonomous. Remotely piloted UAS involve a certified pilot remotely controlling the system; remotely operated involves the UAS being monitored by a trained operator; and fully autonomous vehicles involves the system completing tasks and monitoring its own performance. The authors state that regardless of UAS's autonomous functions, airworthiness standards will require human override capabilities, compliance with ATC instruction, system failure handling, and collision avoidance strategies.

Dao, A. Q. V., Martin, L., Mohlenbrink, C., Bienert, N., Wolter, C., Gomez, A., Caludatos, L., & Mercer, J. (2017, July). *Evaluation of early ground control station configurations for interacting with a UAS traffic management (UTM) system*. Paper presented at the International Conference on Applied Human Factors and Ergonomics, Los Angeles, CA.

UAS have varied applications, including search and rescue, infrastructure inspection, delivery, recreation, and media/entertainment. If safety is to be achieved once UAS are integrated into civil airspace, the traffic management system dealing with increased air traffic must be safe. Data was reported in this paper to inform how to design future GCSs and UAS Traffic Management (UTM) procedures. Factors taken into consideration included UAS operator workload, SA, flight crew communication, coordination, and procedures. Among the responsibilities of the UAS crew are submitting flight geometries, sending/receiving communications, performing pre/post-flight checklists, generating flight plans, monitoring the aircraft, and visually observing the aircraft to avoid obstacles. Taking all these responsibilities into consideration, one of the major design recommendations includes display integration. With increased display integration, tasks currently subdivided between crewmembers can be consolidated and performed by one crewmember. The paper stresses the importance of assembling information requirements. Additionally, there needs to be an appropriate and ethical balance between the publics' privacy concerns and providing an adequate amount of information to the UAS operator needed for safe flight.

DeGarmo, M., & Maroney, D. (2008, September). *Nextgen and sesar: Opportunities for UAS integration*. Paper presented at the 26th Congress of International Council of the Aeronautical Sciences, Anchorage, AK. http://dx.doi.org/10.2514/6.2008-8925

The ongoing development of the Next Generation Air Transportation System may facilitate the integration of UAS in non-segregated, civil-managed airspace via the introduction of advanced systems and technologies. The authors provide an overview of the potential application of UASs in four segments: military, civil government, research, and commercial. The applications by market segment are listed in chronological order from 2005 to 2025 (with those past the time of this study being estimates based on market forecasts). Military applications are ISR, tactical strike, communications relay, signals intelligence, maritime patrol, penetrating strike, integrated strike, aerial refueling, air combat, and airlift. Civil government applications are border patrol, hurricane tracking, firefighting support, search and rescue, maritime surveillance, aerial imaging, law enforcement, infrastructure monitoring, humanitarian aid, communications relay, traffic monitoring, and port security. Scientific applications are atmospheric research, remote sensing, land use surveys, airborne pollution measurement, and near-space atmospheric monitoring. Commercial applications are aerial photography (sUAS only), crop monitoring, utility inspection, mining exploration, agricultural application, site security, news/media, aerial advertising, and cargo.

Dorafshan, S., Maguire, M., Hoffer, N. V., & Coopmans, C. (2017, June). Challenges in bridge inspection using small unmanned aerial systems: Results and lessons learned. *Proceedings of the International Conference on Unmanned Aircraft Systems*, 1722-1730. https://doi.org/10.1109/ICUAS.2017.7991459

Bridge inspection is one of several potential commercial applications for UAS, in addition to cinematography, agriculture, and cargo delivery. This article describes the application of UAS to bridge inspection. Specifically, the authors report case studies on the use of UAS for inspecting surface conditions and detecting surface cracks (case study 1) as well as the use of UAS for fatigue crack detection (case study 2). Studies used sUAS (i.e., 3DR Iris, DJI Mavic, and Goose) equipped with cameras. Results from these efforts suggest that surface inspection using UAS is comparable to human inspection. For fatigue crack detection, the sUAS performed best under normal lighting conditions, and inspection issues occurred under conditions of dark and bright lighting. Challenges for the use of UAS for bridge inspection include navigating in GPS-denied environments (e.g., under a bridge) and the potential for harsh, windy weather.

Gonzalez, F., Mcfadyen, A., & Puig, E. (2018). Advances in unmanned aerial systems and payload technologies for precision agriculture. In G. Chen (Ed.), *Advances in agricultural machinery and technologies* (pp. 133–155). Boca Raton, FL: CRC Press. http://dx.doi.org/10.1201/9781351132398-6

UAS represent a cost-effective and efficient solution for agricultural projects such as precision agriculture. The authors discuss the use of UAS for remote sensing in precision agriculture. This practice involves the use of spatial and temporal information of crops to perform site-specific management. UAS offer a cost-effective and flexible sensor platform for precision agriculture and can improve the safety and accuracy of these duties. The authors also discuss the most common UAS designs across the commercial industry and within agricultural applications. Across all commercial industries, the most common UAS designs are rotary-wing, 4-rotor (quadcopter), 8-rotor (octocopter), and 6-rotor (hexacopter) platforms. In the agriculture domain, rotary-wing and fixed-wing platforms are common. The authors discuss the current regulation and exemptions in the U.S. as it pertains to sUAS as well as the payload technologies currently available for drones.

Otto, A., Agatz, N., Campbell, J., Golden, B., & Pesch, E. (2018). Optimization approaches for civil applications of unmanned aerial vehicles (UAVs) or aerial drones: A survey. *Networks*, *72*(4), 411-458. https://doi.org/10.1002/net.21818

UAS can be used in a broad range of civil and commercial operations, yet integrating UAS into the NAS remains a challenge. This article discusses optimization approaches to the civil applications of UAVs, describing the mostly likely applications of UAVs for civil use and the characteristics of UAVs that are relevant to operations planning. The authors review and summarize 217 articles on UAS operations and regulations outside of military and security applications. The authors identify that the most promising applications of civil UAVs are physical infrastructure, agriculture, and transport (i.e., delivery) followed by entertainment and media as well as risk assessment following disasters. Next, the authors describe the characteristics/requirements of UAVs for civil use in relation to motion, payload, flight range, information processing and connectivity, and the use of a human operator. In this article, Tables 2-7 summarize the drone characteristics, operation type, and application of UAVs as reported in the research literature. Importantly, the authors note that the integration of UAVs into civil airspace will require the development of air traffic rules, management concepts, and additional collision capabilities as UAVs will be deployed in drone-only airspace and/or shared airspace with piloted aircraft. In terms of UAS operator concerns, the authors suggest that scheduling will be an important consideration to avoid cognitive under-loading and overloading by alternating the demanding nature of tasks and providing appropriate breaks.

Peinecke, N., Volkert, A., & Korn, B. (2017, April). Minimum risk low altitude airspace integration for larger cargo UAS. In *2017 Integrated Communications Navigation and Surveillance Conference*. Herndon, VA: IEEE. http://dx.doi.org/10.1109/ICNSURV.2017.8012027

Current initiatives for UAS integration are concerned with small-to-medium sized UAV. However, operations with large UAS are increasing in demand as well. This paper presents an integration concept for future air cargo systems in Germany that includes recommendations for airspace structure and communication infrastructure. The paper is framed within the context of Automated Low Altitude Air Delivery (ALAADy) vehicles which are drones that can carry up to 1000 kg payloads and are highly automated. The authors argue that in terms of current airspace classifications, Class G airspace is the most viable for ALAADy vehicles which usually has aircraft following VFR. However, in this airspace there are a variety of aircraft including general aviation aircraft, gliders, and unmanned/manned balloons that can interfere and pose a threat for UAS that cannot sense traffic. Therefore, the authors propose the classification of a new airspace, Class G+, which would provide a communication infrastructure and connect points of interest for unmanned vehicles. Risk mitigation for the use of ALAADy vehicles could involve avoiding inhabited areas by having G+ airspace be structured over less populated areas and having UAS establish a permanent data link before entering G+ airspace.

Valdovinos, M., Specht, J., & Zeunik, J. (2016). *Community policing & unmanned aircraft systems (UAS): Guidelines to enhance community trust.* Washington, DC: US Department of Justice Community Oriented Policing Services.

Emerging sUAS technology has the potential to transform several markets, including agriculture, energy, utilities, mining, construction, real estate, and media and film production. Additionally, the policing community and the way in which police officers complete their duties (e.g., search and rescue, process accident scenes, and aid in disaster relief) can be revolutionized by UAS capabilities. This report reviews various topics concerning the use of sUAS for policing activities, including the sUAV types, sUAV features, the benefits of sUAS, and regulations. The types of sUAS marketed toward police agencies include the basic features of portability, ground controller, avionics controller, and payload package. Given the public's concern over the use of sUAS by police, the report recommends that leaders be transparent about who will be involved in the operation of UAVs and how safety will be maintained. For example, as outlined in Part 107 regulation, the RPIC must maintain an airman certificate. Recommended standards for UAS operations put forth by the Association for Unmanned Vehicle Systems International (AUVSI) state that operations should address the following areas: weather conditions, anticipated failure modes, crew fitness for flight operations, compliance with aviation regulations, communication requirements, and reliability and airworthiness standards. Training protocols described in this report (e.g., sUAS pilot license, professional training) are stated to take up to 40 hours to complete. Training in remote areas is recommended until police teams can attain proficiency and additional training is recommended for video operators and SOs to maintain their proficiency.

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Appendix A: Knowledge List

Knowledge is a body of factual, technical, or procedural information an individual uses to perform a job. Knowledge is information that is acquired through formal and informal learning. For example:

1) Knowledge of aerodynamics.
2) Knowledge of equipment capabilities and systems.

Table 1. List of Knowledge Areas for UAS Pilots

Knowledge	**Definition**	**Reference**
Aerodynamics	Knowledge of air motion and other gaseous states, and the interaction between these properties and the aircraft.	Adams, 2010
Aeronautical terminology	Knowledge of the principles and practices of navigation, aviation phraseology, and standard crew terminology.	Bruskiewicz et al., 2007
Air traffic control requirements	Knowledge of air traffic control towers and facilities, and communication protocol related to ATC.	Gimenes et al., 2014
Aircraft limitations	Knowledge of aircraft limitations according to aircraft category including flight safety limits (e.g., maximum takeoff weight) and limitations of the aircraft systems (e.g., sense and avoid system).	Gimenes et al., 2014
Airport operations	Knowledge of airport types, special facility types (e.g., seaplane, heliports), and airport data (e.g., Notices to Airmen [NOTAMs]).	FAA, 2016
Airspace classification and requirements	Knowledge of airspace classifications, separation requirements, basic weather minimums, ATC authorizations and operating limitations, operations near airports, and potential flight hazards.	FAA, 2016

Knowledge	**Definition**	**Reference**
Airworthiness	Knowledge of aircraft airworthiness requirements, including installation, repair, and maintenance.	Bendure et al., 2019
Aviation principles	Knowledge of flight, force, gravity, speed, velocity, distance, motion, altitude, direction, and object rotation.	Bruskiewicz et al., 2007
Aviation/FAA rules and regulations	Knowledge of applicable regulations such as 14 CFR Part 107 and all Parts referenced within the regulation.	FAA, 2016
Collision avoidance	Knowledge of self-separation and collision avoidance thresholds and appropriate maneuvers for safe separation.	Consiglio et al., 2012
Communication procedures	Knowledge of proper radio procedures (e.g., selection of radio frequency) and radio phraseology including the phonetic alphabet and aircraft call signs.	FAA, 2016
Control interfaces	Knowledge of UAS control systems (e.g., joystick, yoke and rudder) and types of level of control (e.g., vertical, horizontal, speed).	Williams, 2007a
Crew resource management	Knowledge of all available resources for crew personnel to facilitate crew cooperation and decision-making.	FAA, 2016

Knowledge	Definition	Reference
Culture	Knowledge of the culture of the organization and crewmembers (e.g., professional background).	Pavlas et al., 2009
Engagement procedures	Knowledge of current rules of engagement, system control measures and operation, and target handover procedures.	Bruskiewicz et al., 2007
Equipment capabilities and systems	Knowledge of the UAS system and its command set, operational threats, constraints, performance envelope, automation level, reliability, system feedback, the spatial and temporal state of the system, and the latency rate in communication.	Pavlas et al., 2009
Flight plan and characteristics	Knowledge of procedures for administering a flight plan. This includes knowledge of flight plan, flight rules, takeoff weight, fuel consumption, and intended speed and altitude.	Bendure et al., 2019
Ground control station operation	Knowledge of ground control station interfaces and telecommunication procedures and the set up and tear down of the ground control stations.	Bendure et al., 2019
Maintenance	Knowledge of UAS-specific repair and modification procedures.	Bendure et al., 2019
Mathematics	Knowledge of numbers, their operations, and interrelationships, including arithmetic, algebra, geometry, calculus, statistics, and their applications.	Rose et al., 2013

Knowledge	**Definition**	**Reference**
Mechanical comprehension	Knowledge of physical relationships and practical problems in mechanics, and the operation of mechanical equipment.	Bruskiewicz et al., 2007
Mission awareness	Knowledge of the mission's objectives and progress toward mission completion.	Pavlas et al., 2009
Normal and emergency procedures	Knowledge of normal operational procedures such as loading/unloading, takeoff, landing, and recovery, as well as emergency procedures such as autopilot malfunction, loss of communication link, loss of GPS, loss of VLOS, and mishap response.	Bruskiewicz et al., 2007
Operational terms and graphics	Knowledge of map systems, chart and map reading, topography, and symbology.	Bruskiewicz et al., 2007
Payload and payload interfaces	Knowledge of payload systems including camera systems, reconnaissance equipment, radar, cargo and any equipment necessary for the UAS operation.	Al Shibli, 2015
Physiological effects	Knowledge of the physiological effects of medical factors (e.g., hyperventilation, stress), and drugs and alcohol on pilot performance.	FAA, 2016
Preflight procedures	Knowledge of preflight maintenance and inspection as well as preflight briefing processes.	FAA, 2016
Reconnaissance procedures	Knowledge of scanning assigned sectors, aerial observation, and route, zone, and area reconnaissance.	Bruskiewicz et al., 2007

Knowledge	Definition	Reference
Rights of pilot in command	Knowledge of the pilot in command's role and responsibilities of an aircraft and understanding that the pilot in command has the final authority throughout the operation.	Kanki et al., 2019
Runway setup procedures	Knowledge of runway or launching requirements for the takeoff and climb of aircraft.	Al Shibli, 2015
Shared situation awareness	Knowledge of team members' activity, characteristics, identities, and intentions as it relates to the operation.	Pavlas et al., 2009
UAS loading	Knowledge of the weight and balance requirements and restrictions of the aircraft.	FAA, 2016
UAS performance	Knowledge of operational and performance information related to the aircraft's capabilities and limitations for takeoff, climb, endurance, descent, and landing.	FAA, 2016
Unit and command objectives	Knowledge of the crew's functions and operations, and how current operations fit into the larger mission and commander's intent.	Pavlas et al., 2009
Unit standard operating procedures	Knowledge of the unit-specific standard operating procedures including, but not limited to, takeoff and landing, en route, loss of data link, and abort procedures.	Al Shibli, 2015
Weather	Knowledge of aviation weather sources (e.g., weather reports and weather charts) and meteorological concepts, such as analyzing	FAA, 2016

Knowledge	Definition	Reference
	meteorological conditions, understanding and interpreting operational risks, and appropriately responding to identified meteorological risks. This includes understanding weather/meteorological effects on aircraft performance.	
Workload and fatigue	Knowledge of factors contributing to workload, workload levels during operations, and the impact of workload on the degradation of attention and concentration (i.e., fatigue).	Pavlas et al., 2009

Appendix B: Skill List

A *Skill* is the capability to perform job tasks and is developed through training and/or practice. For example:

1) Skill at making high quality and timely decisions.
2) Skill at recognizing and coping with stress in oneself and others.

Table 2. List of Skills for UAS Pilots

Skill	**Definition**	**Reference**
Aircraft set up and teardown	Prepare an aircraft or GCS for takeoff and disassemble the aircraft or ground control station following landing.	Bendure et al., 2019
Altitude and distance estimation	Estimate the altitude of the aircraft or distance of the aircraft in relation to environmental surroundings.	Lennertz et al., 2018
Cockpit discipline	Obey rules and SOPs during operations.	Dolgov, 2018
Collision avoidance maneuvers	Maneuver clear of proximate air traffic to resolve threat situations.	Consiglio et al., 2012
Communication	Speak in a clear, concise, and persuasive manner, give clear directions and information, and ask questions to clarify and ensure understanding.	Carretta et al., 2016
Conflict resolution	Manage potential aircraft conflicts and maintain proper separation.	Pagan et al., 2015
Crisis management	Remain calm, analyze the situation, act appropriately, and make quick accurate decisions in emergency situations.	Mangos et al., 2014

Skill	**Definition**	**Reference**
Critical thinking	Use logic and reasoning to identify the strengths and weaknesses of alternative solutions, conclusions or approaches to problems.	Paullin et al., 2011
Disengagement	Avoid disruptive thoughts after making an error and refocus attention on a task after a disturbing situation.	Mangos et al., 2014
Flight	Control the aircraft during flight, including adjusting altitude, maintaining airspeed, and changing direction.	Gimenes et al., 2014
Handoff	Hand off or migrate control between UAV pilots and/or crews.	Pavlas et al., 2009
Instrument monitoring	Monitor the instruments of the aircraft or ground control station to check that the system is performing as expected.	Pavlas et al., 2009
Interpersonal and teamwork	Function effectively as part of a team and cooperate with other crewmembers to accomplish goals and solve problems.	Bruskiewicz et al., 2007
Judgment and decision-making	Make high quality and timely decisions. This includes assessing the level of risk associated with a given course of action, recognizing when additional information is required to make a decision or solve a problem, identifying potential and/or novel solutions to problems, and anticipating the consequences of decisions.	Bruskiewicz et al., 2007

Skill	**Definition**	**Reference**
Leadership	Motivate crewmembers to perform effectively under difficult circumstances, monitor crewmember performance and take action when performance is substandard, provide performance feedback and coaching to crewmembers as necessary, and resolve conflict among crewmembers to foster an environment of teamwork and camaraderie.	Bruskiewicz et al., 2007
Map reading	Understand a visual representation of an area and use information from a map to aid in navigation.	Mangos et al., 2014
Mission monitoring	Monitor the progress of the mission or operation objectives and monitor the path and navigation of the aircraft.	Pavlas et al., 2009
Multitasking and time-sharing	Shift back and forth between two or more tasks or sources of information.	Fleishman & Quaintance, 1984
Navigation	Navigate aircraft through an area to desired location.	Mangos et al., 2014
Operation of communication systems and equipment	Use proper radio/aircraft systems, intercom communication systems, and digital communication system procedures to communicate during operations.	Bruskiewicz et al., 2007
Operation of navigation systems and equipment	Use and monitor electronic systems, navigation radio, and other navigation devices during operations.	Bruskiewicz et al., 2007

Skill	Definition	Reference
Operation of sensor/tracking systems and equipment	Use laser, illuminators, and other sensor/tracking systems during operations.	Bruskiewicz et al., 2007
Operational checks	Perform security checks, engine checks, run-up and taxi checks, preflight checks, after takeoff checks, inflight checks, and post-launch checks.	Bruskiewicz et al., 2007
Organization and time management	Schedule and organize one's work activities, material, tools and equipment to complete tasks efficiently. Prioritize activities and determine which ones require immediate attention and to manage and allocate time effectively.	Bruskiewicz et al., 2007
Planning	Plan the sequence of actions needed to meet short-term and long-term work goals as well as develop backup plans for contingency scenarios.	Mangos et al., 2014
Prioritization	Perform multiple tasks in order of importance and direct attention to tasks when they change priorities (e.g., emergencies).	Mangos et al., 2014
Problem solving	Recognize problems, their potential causes and solutions, why they are likely to occur and create effective and innovative solutions to those problems.	Mangos et al., 2014
Risk assessment	Evaluate situations (e.g., safety-related hazards) and risk potential when making flight decisions.	Carretta et al., 2016

Skill	**Definition**	**Reference**
Risk mitigation	Take appropriate actions to reduce hazards and mitigate operational risks.	FAA, 2016
Role switching	Switch duties and responsibilities during operations, potentially with other crewmembers, in an effective and timely manner.	Sticha et al., 2012
Situational awareness	Extract information from the environment, integrate it with relevant internal knowledge to form a mental picture of the current situation, and use the information to direct further exploration in a continuous perceptual cycle to anticipate future events.	Carretta et al., 2016
Stress management	Recognize and cope with stress in oneself and others.	Bruskiewicz et al., 2007
System selection	Select appropriate aircraft and systems for operational purposes.	Sticha et al., 2012
Takeoff/launch and landing/recovery	Control the aircraft to perform the maneuvers required for takeoff and launch as well as landing and recovery.	Gimenes et al., 2014
Target detection and identification	Detect and identify location of threats, hazards, or obstacles in the airspace and surrounding environment.	Sticha et al., 2012
Technical troubleshooting	Use technical information to identify the source of a problem and potential solutions.	Mangos et al., 2014

Skill	Definition	Reference
Weather identification	Observe weather and visibility conditions as well as identify weather changes and trends that could affect UAS operations.	Bendure et al., 2019
Workload management	Use available resources to prioritize, reassign, and manage tasks in an efficient and timely manner.	Kanki et al., 2019

Appendix C: Ability List

An *Ability* is a general human trait possessed by an individual that gives them the capacity to complete mental and physical tasks required of the job. Abilities are innate rather than learned attributes. For example:

1) Ability to see close environmental surroundings.
2) Ability to identify or detect a known pattern that is hidden in other material.

Table 3. List of Abilities for UAS Pilots

Ability	**Definition**	**Reference**
Arm-hand steadiness	Keep one's hand or arm steady while making an arm movement as well as while holding the arm and hand in one position.	Williams et al., 2014
Attention	Sustain and divide attention to visual and auditory information.	Chappelle et al., 2010
Category flexibility	Produce many rules so that each rule tells how to group a set of things in a different way. Each group must contain at least two things from the original set of things.	Fleishman & Quaintance, 1984
Cognitive proficiency	Interpret and process information (e.g., verbal, numerical) quickly and accurately.	Chappelle et al., 2011
Control precision	Move controls of a machine, vehicle, or piece of equipment (e.g., joystick or yoke) quickly and repeatedly to exact positions.	Fleishman & Quaintance, 1984
Deductive reasoning	Apply general rules to specific problems to come up with logical answers.	Fleishman & Quaintance, 1984
Depth perception	Distinguish which of several objects is more distant from, or nearer to, the observer or to	Fleishman & Quaintance, 1984

Ability	Definition	Reference
	judge the distance of an object from the observer.	
Far vision	See distant environmental surroundings.	Fleishman & Quaintance, 1984
Finger dexterity	Make skillful, coordinated movements of the fingers of one, or both, hands and to grasp, place or move small objects.	Williams et al., 2014
Flexibility of closure	Identify or detect a known pattern (e.g., figure, word, or object) that is hidden in other material.	Fleishman & Quaintance, 1984
Fluency of ideas	Produce a number of ideas about a given topic.	Williams et al., 2014
General hearing	Detect and discriminate among sounds that vary in pitch and/or loudness.	Fleishman & Quaintance, 1984
Glare sensitivity	See objects in the presence of glare or bright ambient lighting.	Fleishman & Quaintance, 1984
Gross motor	Coordinate the movement of the arms, legs, and torso together in activities in which the whole body is in motion and regain one's body balance or stay upright in an unstable position.	Barnes et al., 2000
Hand-eye coordination	Make precise, coordinated movements based on visual information.	Mangos et al., 2014

Ability	**Definition**	**Reference**
Inductive reasoning	Combine separate pieces of information to form general rules or conclusions.	Fleishman & Quaintance, 1984
Information ordering	Follow a rule or set of rules to arrange things or actions (e.g., numbers, letters, words, pictures, procedures, sentences, and mathematical or logical operations) in a certain order.	Fleishman & Quaintance, 1984
Long-term memory	Retain and recall information (e.g., words, numbers, pictures, and procedures) after long time periods.	Mangos et al., 2014
Manual dexterity	Make skillful, coordinated movements of the hands to grasp, place, move, or assemble objects using those movements.	Mangos et al., 2014
Mathematical reasoning	Reason through math problems to determine possible operations and solutions, and apply mathematical formulas to problems.	Mangos et al., 2014
Mental rotation	Rotate an object (e.g., map) in one's imagination while maintaining an accurate sense of direction.	Mangos et al., 2014
Multi-limb coordination	Coordinate movements of the body or limbs.	Mangos et al., 2014
Near vision	See close environmental surroundings.	Fleishman & Quaintance, 1984
Night vision	See under low light conditions.	Fleishman & Quaintance, 1984

Ability	**Definition**	**Reference**
Number facility	Add, subtract, multiply, and divide quickly and correctly.	Fleishman & Quaintance, 1984
Originality	Produce unusual or clever ideas about a given topic or situation and invent creative solutions to problems or develop new procedures to situations in which SOPs do not apply.	Williams et al., 2014
Pattern recognition	Identify and detect a known pattern (e.g., numerical code) and combine and organize different pieces of information into a meaningful pattern quickly.	Mangos et al., 2014
Perceptual speed	Perceive or compare information (e.g., letters, number, symbols, or patterns) quickly and accurately, and notice or compare details about things quickly and accurately.	Mangos et al., 2014
Peripheral vision	See objects or movements toward the edges of the visual field.	Fleishman & Quaintance, 1984
Physical flexibility	Use of muscles to exert force repeatedly or continuously over a long time period, and the ability to bend, stretch, twist, or reach with the body, arm, or legs.	Williams et al., 2014
Physical strength	Use muscles to support part of the body repeatedly or continuously over time, and use short bursts of muscle force to propel oneself or an object.	Williams et al., 2014

Ability	Definition	Reference
Problem sensitivity	Identify when something is wrong and likely to go wrong, and able to identify the whole problem as well as the elements of the problem.	Barnes et al., 2000
Rate control	Adjust equipment control in response to changes in the speed and/or direction of a moving object and timing these adjustments in anticipation of changes.	Williams et al., 2014
Reaction time	Respond quickly and accurately to one signal with a manual or verbal response.	Mangos et al., 2014
Response selection	Choose between two or more possible responses quickly and accurately when two or more signals are given.	Mangos et al., 2014
Selective attention	Maintain high levels of performance on a task in distracting or repetitive conditions, and maintain focus despite interruptions.	Mangos et al., 2014
Sense of direction	Estimation of one's own spatial orientation ability.	Cahillane et al., 2012
Short-term memory	Retain and recall information (e.g., words, numbers, pictures, and procedures) after short time periods.	Williams et al., 2014
Sound localization	Identify the direction from which an auditory stimulus originated relative to the observer.	Fleishman & Quaintance, 1984

Ability	Definition	Reference
Spatial orientation	Know one's location in relation to the environment, maintain directional orientation when navigating an unfamiliar area, and accurately estimate direction or location after traveling for a certain amount of time.	Mangos et al., 2014
Spatial processing	Manipulate 2-dimensional information into 4-dimensional mental imagery.	Williams et al., 2014
Speed of closure	Combine and organize different pieces of information into one meaningful pattern quickly.	Williams et al., 2014
Speed of limb movement	Speed with which a single movement of the arms or legs can be moved.	Williams et al., 2014
Stamina	Exert oneself without getting out of breath and resilience to physical and cognitive fatigue.	Chappelle et al., 2010
Verbal comprehension	Understand spoken words and sentences (e.g., information, ideas, or instructions).	Williams et al., 2014
Verbal expression	Speak words or sentences so others will understand, and express information or ideas clearly.	Williams et al., 2014
Vigilance	Stay alert and be attentive to one's surroundings, including small details, recognize hazards and threats within one's environment, and perform repetitive tasks effectively.	Carretta et al., 2016

Ability	Definition	Reference
Visual color discrimination	Discriminate between different colors and levels of brightness or shades of the same color.	Mangos et al., 2014
Visual perception	Perceive, discern, and discriminate visual information in various lighting and meteorological conditions.	Chappelle et al., 2011
Visual tracking	Search and track visual stimuli in various lighting and meteorological conditions.	Dolgov, 2018
Visualization	Form a mental image of a pattern or figure and visualize how an object would look after changes are made.	Williams et al., 2014
Working memory	To hold information in memory while processing other information.	Mangos et al., 2014
Wrist-finger speed	Make fast, simple repeated movements of the fingers, hands, and wrists.	Williams et al., 2014
Written comprehension	Understand written sentences and paragraphs.	Barnes et al., 2000
Written expression	Use words or sentences in writing so others will understand.	Fleishman & Quaintance, 1984

Appendix D: Other Characteristic List

An *Other Characteristic* is an attitude, preference, or personality trait that influence the extent to which an individual can complete job tasks. Other characteristics include innate traits and learned preferences. For example:

1) Having the tendency to keep oneself focused on a task even when external factors make it difficult to do so.
2) Having the tendency to set ambitious goals for oneself and to work hard to attain a high level of work proficiency.

Table 4. List of Other Characteristics for UAS Pilots

Other	**Definition**	**Reference**
Achievement striving	Set ambitious goals for oneself and work hard to attain a high level of proficiency.	Carretta et al., 2016
Adaptability and flexibility	Adjust easily to changing situations or unexpected events, and flexibly change one's actions in response to changing task priorities.	Mangos et al., 2014
Adventure seeking	Prefer tasks that may involve danger or risks (e.g., high speeds) to boring or repetitive tasks.	Williams et al., 2014
Affinity for planning and logic	Enjoy the use of planning and logical reasoning to accomplish tasks.	Crumley & Bailey, 1979
Affinity for uncertainty	Comfortable working in uncertain, changing environments.	Crumley & Bailey, 1979
Assertiveness	Take charge, make decisions, and be persuasive, influential, and direct when dealing with others.	Mangos et al., 2014

Other	Definition	Reference
Attention to detail	Pay close attention to the details of one's work, to ensure work is accurate and complete, and to carefully review and scrutinize one's work.	Mangos et al., 2014
Calibrated trust	Display appropriate levels of trust in the autonomous functions of the aircraft.	Pavlas et al., 2009
Composure	Remain calm and composed under pressure.	Chappelle et al., 2011
Conscientiousness	Complete work in a deliberate, methodical, and organized manner.	Williams et al., 2014
Cooperation	Avoid interpersonal conflicts, reach solutions to problems in a cooperative manner, and avoid upsetting others.	Mangos et al., 2014
Decisiveness	Make decisions in real time, under pressure, and within operational deadlines and patient in making the right decision and committing to a course of action.	Williams et al., 2014
Dependability	Responsible, reliable, and punctual and to follow through on commitments.	Mangos et al., 2014
Dutifulness	Adhere to one's set of ethical principles and strictly follow rules and regulations.	Carretta et al., 2016
Emotional stability	Avoid feelings of anxiety, insecurity, depression, or worry, and control one's emotions in stressful situations.	Mangos et al., 2014

Other	**Definition**	**Reference**
Energy	Feel excitable and energetic, and show enthusiasm when performing work activities.	Mangos et al., 2014
Extraversion	Open and accepting of critical feedback from peers, subordinates, and leadership, receptive and approachable, and socially engaging and outgoing.	Chappelle et al., 2011
Followership	Follow requests or orders, and accept guidance from other crewmembers without being defensive.	Carretta et al., 2016
General health	No significant or chronic injuries or illnesses affecting performance and resilience to shift work adjustments.	Chappelle et al., 2010
Helpfulness	Have active concern for others' welfare, expressed through generosity, consideration of others, and a willingness to assist crewmembers in need of help.	Williams et al., 2014
Humility	Recognize the need and willingness to seek help from leadership and others.	Chappelle et al., 2011
Initiative	Initiate difficult tasks without excessive procrastination and to work independently, accomplish tasks without constant supervision, and take personal responsibility for completing work tasks.	Mangos et al., 2014
Intellectual efficiency	Process information quickly, and considered knowledgeable, astute, and intellectual.	Nye et al., 2012

Other	Definition	Reference
Moral interest	Personal beliefs and worldviews support operations.	Williams et al., 2014
Occupational interest	Possess a sense of duty as a pilot/operator, intrinsically appreciate UASs, enjoy duties of the position, and hold strong intrinsic interest in advanced UAS technology.	Williams et al., 2014
Perseverance	Stick with a task until completion in spite of obstacles.	Carretta et al., 2016
Resilience	Respond to situations (e.g., high stress, tiresome monotony) with hardiness and reliably to sustain emotional composure with an optimistic attitude.	Chappelle et al., 2011
Responsibility	Assume responsibility and accept consequences of one’s own decisions and actions.	Williams et al., 2014
Risk tolerance	Accept risk and engage in activities that involve a lack of certainty or fear of failure, but without being reckless.	Williams et al., 2014
Safety consciousness	Aware of safety hazards, take steps to protect oneself and others from harm, and avoid risky behavior that could lead to accidents.	Mangos et al., 2014
Self-confidence	Believe that one is capable of performing tasks in a wide variety of situations, and have confidence in one's skills and abilities.	Mangos et al., 2014

Other	**Definition**	**Reference**
Self-control	Maintain composure and keep emotions in check, even in difficult situations, and refocus attention on tasks after making an error.	Williams et al., 2014
Self-discipline	Perform difficult, repetitive, or boring tasks while avoiding distractions or alternative activities.	Mangos et al., 2014
Self-regulation	Keep oneself focused on a task or work activity when external forces make it difficult to do so.	Williams et al., 2014
Straightforwardness	Tendency to be frank, sincere, and genuine.	Bruskiewicz et al., 2007
Stress tolerance	Perform effectively under high workload, time pressure, or other stressful situations, and effectively handle stress under demanding situations.	Mangos et al., 2014
Success oriented	Self-motivated, driven to succeed, and committed to self-improvement.	Chappelle et al., 2010
Team oriented	Comfortable leading and working with crewmembers as a team, competitive disposition but does not jeopardize group and mission goals, interest in teaching others, and trusting of other crewmembers.	Chappelle et al., 2011
Work ethic	Strive for competence in one's work, willingness to work long hours when	Carretta et al., 2016

Other	Definition	Reference
	appropriate, and reliably complete one's work in a timely fashion.	