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Literature Review and Annotated Bibliography (1990 – 2019): Duty Time, Shift Work, and Operator Fatigue for Consideration of Unmanned Aircraft Systems in Air Carrier Operations

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16. Abstract

There is a rapidly increasing interest in the use of unmanned aircraft systems (UAS) for commercial operations. Title 14 of the Code of Federal Aviation Regulation (14 CFR) Part 121 and 135 do not take into consideration air carrier operations with small UAS (sUAS), and Part 107 mandates a maximum weight limit for sUAS. UAS exceeding this weight limit are not permitted in civil operations unless directly involved in military operations or granted a waiver by the Federal Aviation Administration (FAA). This literature review and annotated bibliography is an effort to consolidate and centralize the duty time, shift work, and fatigue literature to inform future policy and regulation concerning UAS operators in air carrier operations. It encompasses a selection of literature regarding duty time, shift work, fatigue, and fatigue risk management related to both unmanned and manned operations from 1990 to 2019. Also discussed are human factors (HF) and ergonomics considerations that may affect operator experiences of fatigue. Articles searched were from PsychINFO, Google Scholar, and FAA Technical Library databases using keywords related to unmanned and air carrier operations and fatigue. In addition, forward searches using the Google Scholar 'cited by' feature helped identify additional literature relevant to the topic. One hundred and five articles (59 literature reviews/organization guidelines, 46 empirical studies) discussed duty time, shift work, and fatigue in unmanned and manned operations. The associated annotated bibliography structured the research literature into three primary sections (Unmanned Aircraft Systems, Manned Operations, and U.S. Military Pilot Duty Time Regulations) with relevant subheadings. Duty time, shift work, and fatigue have been extensively researched in manned operations, but less so in unmanned operations. Duty time, shift work, and fatigue in UAS have been primarily investigated in military aviation and maritime operations, while research outside of those two types of operations has focused more generally on how humans interact with an unmanned system. This highlights the need for further duty time, shift work, and fatigue research in UAS operations, as well as the need for additional consideration to UAS definitions and classification standards and UAS integration into the National Airspace System (NAS) to minimize risk and maximize operational safety to people and property. This research task is provided in conjunction with a broader research portfolio supporting the FAA's efforts to inform future policy and regulation on duty time, shift work and fatigue in UAS air carrier operations.

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Acronyms

14 CFR	Title 14 (Federal Regulations on Aeronautics and Space)
ACM	Airworthiness Certificate Matrix
ANSI	American National Standards Institute
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATS	Air Traffic Service
BFI	Brief Fatigue Inventory
CAMI	Civil Aerospace Medical Institute
CFR	Code of Federal Regulations
COA	Certificate of Waiver or Authorization
CPA	Conventionally Piloted Aircraft
DoD	United States Department of Defense
EASA	European Union Aviation Safety Agency
ELOS	Equivalent Level of Safety
EMS	Emergency Medical Services
EU	European Union
FAA	Federal Aviation Administration
FAST	Fatigue Avoidance Scheduling Tool
FDP	Flight Duty Period
FMT	Fatigue Monitoring Tool
FRMS	Fatigue Risk Management Systems
FTL	Flight Time Limitation
HEMS	Helicopter Emergency Medical Services
HF	Human Factors
HFES	Human Factors and Ergonomics Society
HMI	Human-Machine Interface
HSI	Human Systems Integration
HVT	High Value Target
ICAO	International Civil Aviation Organization

KSA	Knowledge, Skills, Abilities
KSAO	Knowledge, Skills, Abilities and Other Attributes
LOA	Loss of Alertness
MRAB	Mini-cognitive Rapid Assessment Battery
NAS	National Aerospace System
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NATOPS	Naval Air Training and Operating Procedures Standardization
NPRM	Notice of Proposed Rule Making
OED	Operational Error and Deviation
OSS	Operator Support Systems
Part 107	Title 14 Part 107 (Federal Regulation for sUAS)
Part 121	Title 14 Part 121 (Federal Regulation for Air Carriers)
Part 135	Title 14 Part 135 (Federal Regulation for Commuter Air Operations)
PTSD	Pots-Traumatic Stress Disorder
PVT	Psychomotor Vigilance Test
RPA	Remotely Piloted Aircraft
sUAS	Small Unmanned Aircraft Systems
UK	United Kingdom
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
USAF	United States Air Force
UTM	UAS Traffic Management
USS	UTM Service Provider
UVS	Unmanned Vehicle Systems

Issue

The Federal Aviation Administration (FAA) has an initiative to standardize (a) the issuance of UAS air carrier operating certificates, (b) UAS remote pilot and crew requirements, (c) training and testing requirements, and (d) duty and rest requirements. Current Title 14 of the Code of Federal Aviation Regulations (14 CFR) on Unmanned Aircraft Systems (UAS) does not include air carrier (Part 121) and commuter and on-demand (Part 135) operations. Small UAS (sUAS; less than 55 pounds) regulations for commercial and government use (Part 107) set strict limitations on UAS operating requirements. Large UAS are defined as greater than 55 pounds and are only permitted in civil operations following FAA authorization with operational restrictions and flight exemption. However, large UAS are exempt if they involve military operations or if a certificate of waiver or authorization (COA) is granted by the FAA. Operations over populated areas may be inevitable for UAS air carrier operations. As an initial step to enabling UAS air carrier operations, the FAA has granted exemptions for part 135 operators for package delivery operations with unmanned aircraft, including: Wing Aviation, LLC (Docket No. FAA-2018-0835) and UPS Flight Forward, Inc. (UPS; Docket No. FAA-2019-0628).[1]

With the increasing interest and prevalence of UAS in air carrier and civil operations, examining how duty time, shift work (i.e., changing schedules) and operator fatigue will affect the performance of UAS operators and operational safety while flying over people and property is of paramount importance. There are standardized scheduling and duty and rest requirements in manned operations based on empirical evidence in circadian rhythm, fatigue, and sleep sciences. However, research concerning duty time, shift work, and fatigue in UAS operations is limited. Further examination of how duty schedules and operator fatigue affect UAS performance in order to standardize pilot and crew training, testing, duty time, and rest requirements is recommended. Standardizing UAS operator requirements will certainly support the integration of UAS into air carrier operations and the National Airspace System (NAS), and improve overall safety in performance.

Purpose

The purpose of this report is to identify how duty time, shift work schedules, and fatigue are addressed in manned and unmanned operations, with a focus on air carrier UAS operations, to provide a framework for future UAS requirements and regulations in air carrier operations. This report includes a focused literature review and an annotated bibliography providing the status of duty time, shift work, and fatigue research for consideration of UAS in air carrier operations, as well as a discussion on current UAS duty time regulations observed by the U.S. military. Duty time, shift scheduling, and fatigue research in UAS operations related to the FAA initiatives will support ongoing FAA policy and rulemaking efforts led by the Air Transportation

[1] For additional details, search the associated docket numbers at: www.regulations.gov

Division (AFS-200), and, UAS expanded operations and UAS non-segregated operations in the NAS led by the General Aviation and Commercial Division (AFS-800).

Methods

All articles included were collected from the PsychINFO, Google Scholar, FAA Library databases, and subject matter experts using the following 30 keywords/phrases:

- Air Carrier Duty and Rest Requirements
- Air Carrier Fitness Requirements
- Air Carrier Staffing Requirements
- Air Carrier Testing Requirements
- Air Carrier Training Requirements
- Drone
- Duty and Rest Requirements
- Exhaustion
- Fatigue
- Operational Risk
- Operator Fatigue
- Remote Operator
- Remote Operator Fatigue
- Remote Pilot
- Remote Pilot Certification Requirements
- Remote Pilot Fatigue
- Remote Pilot Operation
- Remote Pilot Training
- Risk
- UAS Air Carrier Operations
- UAS Air Carrier Remote Pilot and Crew Requirements
- UAS into the NAS
- UAS Operations
- UAS Operator Certification
- UAS Regulation
- UAS Rulemaking
- UAS Standards
- Unmanned
- Unmanned Operations
- Unmanned Transportation

This initially resulted in 122 articles. Following a review of the collected articles, a total of 105 articles (59 literature review/organization/government guidelines and documents, and 46 empirical studies) discussing shift work and fatigue in unmanned and manned operations were selected and annotated. The annotated bibliography was structured with three primary headings: Unmanned Aircraft Systems, Manned Operations, and U.S. Military Pilot Duty Time Regulations. Relevant subheadings are included within each of the three sections by topic.

Literature/Research Outcomes

The identified fatigue-related literature and research demonstrates that **Manned Operations** in aviation-specific and non-aviation fields has been examined extensively.

Specifically, shift work and fatigue in air traffic controllers,[2] flight attendants,[3] flight crews,[4] and aviation maintenance technicians[5] have been historically studied at the Aerospace Human Factors Research Division of the FAA's Civil Aerospace Medical Institute (CAMI). Other aviation research has explored fatigue risk management,[6] fatigue factors in air medical operations,[7] pilots,[8] and military operations[9]. However, research directly investigating the effects of duty time, shift work schedules, and fatigue in UAS operations has a very limited history.

There has been an ever increasing interest in **Unmanned Aircraft Systems** for commercial and civil operations. Much of the literature suggests a need for standard definitions and classification of UAS,[10] safety considerations for NAS operations,[11] and UAS regulation for integration into the NAS[12]. Achieving these needs requires a better understanding of how to maximize safety and minimize risk during actual UAS operations. This, in turn, requires thorough examination of fatigue factors associated with duty time and shift work schedules, for example. Duty time, shift work and fatigue research in unmanned operations has been almost exclusively conducted in military aviation operations[13] and maritime operations[14]. Other research in UAS operations take human-system interaction and workload into consideration[15]. The needs identified in the literature cannot be met without a holistic approach that incorporates considerations from all of these areas. References cited here are not a complete list of the selected articles included in the annotated bibliography (see References for a complete list of all annotated articles).

Conclusions

Duty time, shift work scheduling, and fatigue research can inform the FAA with recommended best practices, requirements, policy development, and possibly rulemaking for UAS air carrier operations. Further, basic and applied research is necessary to fully measure and evaluate the effects of shift work, fatigue, pilot and crew training, and duty time and rest requirements on UAS operator performance and safety. Future research directions will be introduced in follow-up reports outlining procedures to test the effectiveness of fatigue

[2] Cruz et al., 2002; Della Rocco, 1999; Krishnan et al., 2014; McCauley & Nesthus, 2017; Orasanu et al., 2012; Schroeder et al., 1995; Schroeder et al., 1994.
[3] Avers et al., 2009, 2011; Nesthus et al., 2007; Roma et al., 2010.
[4] Bryant et al., 2016.
[5] Hobbs et al., 2011.
[6] Brown et al., 2014; Caldwell, 2005; Caldwell et al., 2009.
[7] Gregory et al., 2010; Nix et al., 2013.
[8] DuBose, 2011; Goode, 2003; Samel et al., 1997; Strauss, 2006.
[9] Caldwell & Caldwell, 2005; Miller & Melfi, 2006; Thompson & Tvaryanas, 2006.
[10] Clothier et al., 2011; Maddalon et al., 2013; Washington et al., 2017.
[11] Cook et al., 2012.
[12] Cork et al., 2007; Hayhurst et al., 2006.
[13] Chappelle et al., 2011; Hardison, 2018; Thompson et al., 2006; Tvaryanas et al., 2008.
[14] Hopcroft et al., 2006; Man et al., 2015.
[15] Coppin et al., 2009; Crandall et al., 2008; Hoepf et al., 2015; Narayan et al., 2007.

countermeasures and fatigue risk models in various types of UAS operations to achieve an equivalent level of safety found in all air carrier operations.

Annotated Bibliography

It should be noted that articles in the various subsections might fit well under more than one subsection heading, including the Shift Work, Fatigue, and Fatigue Risk Management, the Military and Maritime, and the Human Factors/Ergonomics subheadings. Much of the early work with UAS was conducted by the military for defense purposes and has only been recently adapted for commercial applications. For this reason, the rationale for selecting the most appropriate section for each article included evaluating the subject matter and theme, and not only the organization conducting the research. The UAS Airworthiness Certification Categories and Regulations section follows the above mentioned subsections. The expressed purpose of this literature review and annotated bibliography was focused on operator fatigue and associated issues.

Unmanned Aircraft Systems

Shift Work, Fatigue, and Fatigue Risk Management

Center for Robot-Assisted Search and Rescue. (2019). *Best practices to reduce fatigue in small unmanned aerial systems pilots.* http://crasar.org/just-in-time-guides-consultation/

Addressed are suggested practices to reduce fatigue, particularly among robot-assisted search and rescue personnel. Increased human error in relation to fatigue is highlighted. That is, human errors result in lower quality work, violated regulations, and accidents. For search and rescue operations, fatigue comes from various sources, including lack of sleep, required personal protective equipment that must be worn during such operations, physiological stress, and work schedules. Recommendations for fatigue management include training squads together to allow individuals to be comfortable in communicating concerns and problems, conducting risk assessments (and cancelling operations that do not meet threshold for need), avoiding the effects of alcohol use on sleep and work, alternating sorties to “change up” cognitive demands, and empowering safety officers to step in as needed.

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

As the rapid developments of technologies continue to advance, the possibility for a single operator to control multiple unmanned aerial vehicles (UAVs) is becoming more feasible. Computationally intensive models have become a necessity to understand how different operations affect the operators' performance during duty-time. These models should have metrics to adequately describe limits in the system as a whole (i.e., human and UAV). To reduce difficulty of operations, some portions of the flight system should be automated. Reducing the amount of work an operator must complete when recalculating flight plans or performing evasive maneuvers can assist in lessening the burden of operating multiple UAVs. These computationally intensive models can help predict what portions of the system should be automated or when decision-making support to the UAV operator might be necessary. Since the decision process slows as an effect of fatigue, an increase in decision aids may be required; these models would require some adjustment to accurately predict automation requirements during time of operator fatigue.

Manning, S. D., Rash, C. E., Leduc, P. A., Noback, R. K., & McKeon, J. (2004). *The role of human causal factors in US Army unmanned aerial vehicle accidents* (Report No. USAARL-2004-11). Army Aeromedical Research Lab.

The human brain responds to sunlight and darkness to maintain a natural circadian rhythm. However, as increased UAS capabilities allow for long-range and increased mission duration, there is an increasing concern that fatigue may jeopardize UAS operations. Thus, operators and regulators must consider the effects of fatigue as an imposing concern for UAS pilots. A mitigating effect to UAS operators compared to manned aircraft pilots is that they do not have to adjust to multiple time zone changes as they fly to their destinations. Conversely, the long hours at a UAS workstation may pose certain fatigue issues related specifically to UAS pilots. For example, long periods of continued workload, especially after times of sleep loss or fragmented sleep, may put pilots in a higher accumulated sleep debt, which can affect wakeful performance. During times of sleep loss, the dark environment in which UAS workstations are commonly kept may make staying alert more difficult. Reports suggest that fatigue was a contributing factor for up to 25% of United States Air Force (USAF) night fighter Class A accidents between 1974 and 1992. Four underlying factors of fatigue include sleep loss and cumulative sleep debt, continuous hours of wakefulness, circadian rhythm, and possible sleep disorders. During the period spanning FY95-FY03, 56 UAS accidents were reported in the United States Army Safety Center accident database. Human error was to blame for about 20% of these accidents with fatigue being a contributing factor in the error in judgement category.

Norton, T. (2016) *Staffing for unmanned aircraft systems (UAS) operations* (Report No. P-5253). Institute for Defense Analyses.

The widespread use of UAS has led to a lack of synchronization between government programs and private industry, resulting in inadequate staffing and manpower. As UAS technology expands to encompass more applications, it is necessary to synchronize these programs to avoid a strained UAS workforce within the Department of Defense (DoD), while also maintaining mission cost and success. The current article investigates alternative staffing-to-cost to effectively perform UAS related operations. Three classification requirements (system complexity, risk assumed, and operational environment) are provided to help set requirements for staffing UAS pilots. These classification requirements provide unique staffing methodologies and criteria that are tailored to demands of a mission, allowing for better resource allocation (i.e., staffing) to meet the mission's unique needs. For example, rather than using enlisted personnel for all UAS missions, it may be more feasible to have civilians complete the mission so that enlisted personnel can be allocated towards high stakes missions.

Ouma, J. A., Chappelle, W. L., & Salinas, A. (2011). *Facets of occupational burnout among US Air Force active duty and National Guard/reserve MQ-1 Predator and MQ-9 Reaper operators* (Report No. AFRL-SA-WP-TR-2011-0003). Air Force Research Lab.

UAS crew occupational burnout is a matter of concern as crews usually work long rotating schedules. To better understand factors involved for occupational burnout, a comparison of active duty Air Force operators and National Guard UAS crews was conducted. Of particular focus was identification of top factors leading to occupational burnout. The Pilot and Sensor Operator positions entail numerous duties which demand splitting attention to cover multiple visual and auditory data sources while maintaining spatial and situational awareness. Pilot and Sensor Operators must also work closely together to achieve operational goals. Current USAF policy dictates that crews must be healthy, with the concern that any physical or psychological condition can result in degraded performance, which ultimately can lead to unintended threats on human life, national security, foreign relations, military operations, and the UAV equipment itself. Occupational burnout is defined here as consisting of three parts: (1) emotional exhaustion, (2) cynicism (a sense of indifference), and (3) personal efficacy (i.e., sense of accomplishment). Effects of burnout range from impaired ability to complete tasks to difficulty relating to people. Air Force and National Guard UAS crews are susceptible to operational stressors such as available manpower, equipment, and general resources needed; they are also susceptible to combat stressors outside the scope of civilian or commercial UAS operations. Air Force and National Guard UAS crews were asked to complete the Maslach Burnout Inventory-General Schedule. Results indicate active duty operators were 2.2 times more likely to report high levels of emotional exhaustion, 2.62 times more likely to report high levels of cynicism, but are not more likely to report low levels of professional efficacy, when compared with National Guard/Reserve operators. Qualitative analysis also revealed that Air Force crews were more likely to report stressors regarding career progression, geographical location, and assignment concerns. Both National Guard/Reserve and Active duty operators attributed shift work, shift changes, and hours worked as contributing to burnout levels. In addition, the unique job requirement of serving as a warfighter during the day and returning home to a domestic life at night also contributed to burnout levels. Recommendations for reduced operational hours, reducing the frequency of shift changes, improving human-machine interfacing, and increased social and psychological support systems were made.

Paullin, C., Ingerick, M., Trippe, D. M., & Wasko, L. (2011). *Identifying best bet entry-level selection measures for US Air Force remotely piloted aircraft (RPA) pilot and sensor operator (SO) occupations* (Report No. AFCAPS-FR-2011-0013). Human Resources Research Organization.

UAS pilots are extremely task saturated, possibly more so than the average manned aircraft pilot. UAS pilots may experience higher levels of task saturation because they have to monitor flight data from instruments that manned aircraft pilots may perceive from other senses while in the aircraft. For example, visual information usually available to manned aircraft pilots through natural sight (e.g., ocular depth perception) is presented to UAS pilots through maps, images, text, and numerical information. The lines of communication for UAS pilots also include higher amount of task saturation because manned aircraft pilots often have only headset communication through radio; UAS pilots might communicate by means of instant messages, landline phones, emails, and also radio communication. As the higher demand for task saturation is present with UAS operators the adequate completion of these tasks become increasingly more difficult as UAS crews are working shifts opposite of the natural cycles (e.g., night shifts) or if the crew is fatigued in general. A test battery for being able to work under high task saturation was suggested as a selection criteria for entry-level UAS pilots. The paper identified the following skills, abilities, and other characteristics important for UAS pilots and sensor operators to have: Adaptability, Assertiveness, Control Precision, Critical Thinking, Decisiveness, Initiative, Judgement and Decision Making, Number Facility, Oral Comprehension and Expression, Pattern Recognition, Perceptual Speed, Selective Attention, Self-control, Spatial Orientation, Stress Tolerance, Task Prioritization, Teamwork Skills, Time Sharing, Visualization, and Working Memory.

Scheiman, T., Chappelle, W., & Sanford, E. (2018). *U. S. Air Force special operations command remotely piloted aircraft operator fatigue levels and compensatory strategies* (Report No. AFRL-SA-WP-TR-2018-0013). Air Force Research Lab.

The working environment of long-range UAS pilots, such as those flying Reaper systems, present a unique set of operator requirements. Contributing factors to fatigue include long work hours, shift work schedules, workstation design, and geographically remote assignments. Many Reaper crews in the USAF work a cycle of five days on with two days off due to a staff shortage. Days on consists of 12-hour rapidly shifting duty times – all well-documented factors that contribute to prolonged fatigue. Seventy-two crewmembers (including pilots and sensor operators) participated in a series of pre-mission, during, and post-mission fatigue assessments. Greater than 50% of respondents reported fatigue levels ranging from moderate to extreme when they just arrive for duty. When examining post-mission scores, it appears that more than 60% of pilots and 37% of sensor operators experience very high to extreme levels of fatigue. In summary, operators are arriving to work already fatigued, and leaving their shift with extreme fatigue, putting their health at risk. Inadequate rest between shifts is a probable contributor. Operators also indicated that fatigue is time-dependent, becoming more pronounced at the end of the shift and end of the workweek. Operators reported that they began to "fall off a cliff" at approximately six hours into a 12 hour shift. High levels of workload, lulls in activity (i.e., long duration vigilant attention operations), additional administrative duties, shift work, stress, extended hours, irregular meal times, ergonomic issues with workstation design, and lack of recovery time contribute to feelings of fatigue. As a fatigue countermeasure, approximately 70% of participants indicated positive results from use of blue light at their workstations. The paper recommended that crew rest requirements outlined in the Air Force Instruction 11-202 be enforced to ensure that all operators have a 12-hour period prior to their scheduled duty in which no flight or job related duties may be performed. The paper also recommended that a senior detachment officer should be given the responsibility of synchronizing all operator work schedules to ensure adequate rest periods are provided between shifts and crews, and to enforce crew rest periods. Additional recommendations include facilitating opportunities for physical exercise on-site, educating operators about proper sleep hygiene, providing access to healthy food during a shift, and improving access to psychological care.

Thompson, W. T., Lopez, N., Hickey, P., DaLuz, C., Caldwell, J. L., & Tvaryanas, A. P. (2006). *Effects of shift work and sustained operations: Operator performance in remotely piloted aircraft (OP-REPAIR)* (Report No. HSW-PE-BR-TR-2006-0001). Air Force Research Laboratory.

The effects of shift work on fatigue in USAF MQ-1 Predator UAS crews during sustained operations were examined. Results indicated decreased mood and cognitive performance across shifts and rotation schedules. The effects of shift work were greater on day and night shifts compared to evening shifts and greater on rapid versus slow shift schedules. Moreover, crews reported increased fatigue and decreased mood compared to the control group. Results suggest inadequate opportunities for recovery sleep due to ineffective fly time restrictions increase fatigue, despite being in compliance with USAF fatigue management policies. These results are likely due to USAF fatigue management policies focusing primarily on the length of duty time, rather than how fatigue fluctuates throughout the day, affecting sleepiness, mood, and performance. Recommendations include using science-based scheduling techniques when developing duty and rest requirements to account for the dynamic nature of fatigue which includes educational and training programs about alertness management, fatigue coping strategies, and sleep hygiene for all crew and personnel, including supervisors and managers.

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

Shift working schedules can pose many issues, such as increased error rates and circadian rhythm disturbances due to fatigue. The research used well-validated fatigue surveys to collect baseline data on shift-working UAS pilots and sensor operators. The study experimentally manipulated the shift schedule to emphasize consecutive days off to improve recovery time (6W:3F). Results indicated an increase in duration of shift work, decreased sleep quality, and impaired relationships were contributing factors to increasing fatigue. Furthermore, quality of sleep was found to be more important than the quantity of sleep, especially for morning and evening shifts. Recommendations include better education of circadian rhythms, more consecutive night shifts, and exposure to bright light early in a night shift.

Tvaryanas, A. P., Platte, W., Swigart, C., Colebank, J., & Miller, N. L. (2008). *A resurvey of shift work-related fatigue in MQ-1 Predator unmanned aircraft system crewmembers* (Report No. NPS-OR-08-001). Naval Postgraduate School. http://hdl.handle.net/10945/759

After changes to UAS crew schedules were made to address fatigue, concerns arose regarding the effectiveness of the changes as well as interest in further changes that could be made. MQ-1 Predator UAS pilots were moved from a 5W:1F:5W:3F, weekly rotating schedule to a 6W:3F, monthly rotating schedule to provide greater sleep recovery. The series of studies was initiated due to the current nature of UAS operations as being chronic and periodic, and due to known risks of fatigue from the timing, length, frequency, and regularity of work shifts. The study consisted of a 51-item online questionnaire completed by pilots and sensor operators. Fatigue questions were based on the Fatigue Scale, Checklist Individual Strength Concentration subscale, Fatigue Assessment Scale, World Health Organization Quality of Life Assessment Energy and Fatigue subscale, and Maslach Burnout Inventory Emotional Exhaustion subscale. These questions measured mental and physical fatigue, reduced concentration, chronic fatigue, and emotional exhaustion. When comparing new (post-modified schedule) participants with old (pre-modified schedule) participants, fatigue scores were generally unchanged except for Checklist Individual Strength Concentration subscale, where mental fatigue increased post-modified schedule. However, the unchanged scores between test periods indicate continued chronic fatigue. The research suggests that fatigue issues may be due to inadequate opportunities for restorative sleep, problems with adjusting circadian rhythms with work schedules, or diminished sleep quality. The results also identify possible task-related factors, given different fatigue scores for Predator pilots and the control group (E-3B Sentry crewmembers). Recommendations include educating crewmembers, supervisors, and their spouses on circadian rhythms and sleep disorders, the impacts shift work may have on family and social lives, alertness strategies and coping with stress, and ensuring medical staff is kept up to date on sleep disorders while providing medical surveillance for fatigue. Additional recommendations suggest providing organization sponsored car pools and napping stations to prevent post-shift fatigue and exposing crewmembers to bright light in the ground control station during night shifts.

Van Camp, R. O. (2009). Zolpidem in fatigue management for surge operations of remotely piloted aircraft. *Aviation, Space, and Environmental Medicine*, *80*(6), 553-555. https://doi.org/10.3357/ASEM.2460.2009

Many UAS operators are on a rotating shift work schedule. Shift work schedules interrupt circadian rhythm making it difficult to fall asleep at the appropriate time. Zolpidem (Ambien) was prescribed to UAS operators during rest times to explore the potential benefits for UAS crewmembers. Previous studies have indicated Zolpidem is more effective than melatonin in relieving symptoms of jetlag. Conversely, extensive and severe side effects of Zolpidem are a concern, especially for UAS operators, as the side effects include decreased cognitive functioning, sleepwalking, and sleep driving. Of the 43 crewmembers recruited for the study, 27 (63%) took the medication, 19 crewmembers reported good sleep with no side effects, four crewmembers reported a drug hangover after two hours of waking, and four crewmembers reported poor sleep. Additionally, five crewmembers considered the use of Zolpidem to be critical to duty performance. None of the crewmembers self-reported extreme side effects or sleep disturbances.

Military and Maritime

Armour, C., & Ross, J. (2017). The health and well-being of military drone operators and intelligence analysts: A systematic review. *Military Psychology*, *29*(2), 83-98. https://doi.org/10.1037/mil0000149

The health and well-being of American military drone operators are reviewed. The review noted that certain stressors are anecdotally known to be unique to military UAS operators; that these operators "commute" to a war zone suggest they are subjected to family stressors while being susceptible to combat stressors. Previous research indicates that Post-Traumatic Stress Disorder (PTSD) can be precipitated from visual images, which may relate to the types of visual images monitored by military UAS operators. The results of the review suggest that top sources of occupational stress were operational (e.g., hours, staffing, shift work) rather than combat-related. This does not necessarily reduce the importance of combat-related stress as a factor of well-being, but highlights the importance of understanding operational stress. Also identified was a low rate of mental health diagnoses. Among those diagnoses, adjustment disorders, depressive disorders, relationship problems, and life circumstances requiring counseling were common. Risk factors for PTSD varied by role within a UAS crew, but may include time on station over 24 months, working over 50 hours per week, shift work, or scheduling. The Maslach Burnout Inventory-General Survey was used in several studies on military UAS operators as a measure of occupational burnout; it measures emotional exhaustion (i.e., fatigue), cynicism (i.e., indifference), and professional efficacy. Results from this area of research show the measure to be sensitive in identifying occupational burnout among groups, and that occupational burnout is a continuing issue. One study found that over half of tested UAS crewmembers met Diagnostic and Statistical Manual of Mental Disorders-IV edition criteria for Shift Work Sleep Disorder. Other findings include high scores on the Epworth Sleepiness Scale. One study noted a reported increased use of alcohol and tobacco respectively since beginning Predator/Reaper UAS duties. Additionally, participants reported increased use of medical services, prescription drugs, and over-the-counter drugs since beginning their duties. The review concludes that the number of studies related to the health and well-being of UAS operators is low and that more studies are required. The review also suggests that reported mental health issues may be low, due to stigma or the possibility of pilots losing their jobs due to a diagnosis. Furthermore, several of the cited studies require reassessment to better understand the effects of policy changes that have occurred since.

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

Mechanical and technical issues were the leading cause of Class A mishaps during the early years of UAS operations (1997-2003). Recently, human error has become a leading factor in Class A mishaps. Increased endurance capabilities of UAS consequently increase operator fatigue and human error.

Burmeister, H. C., Bruhn, W. C., Rodseth, O. J., & Porathe, T. (2014, April). Can unmanned ships improve navigational safety? In *Proceedings of the Transport Research Arena 2014* (pp. 1-10). Paris, France.

There are benefits for using autonomous marine vessels to reduce human error and consequently reduce fatalities at sea. Among these, human errors contributed to high fatality rates, and fatigue was listed as a top contributing factor to human error related accidents. The article discusses how the use of autonomous shipping vessels may reduce crew fatigue levels. The functions of the autonomous features of the ship could relieve mariners of various tasks and help keep the ship on course. UAS and manned aircraft have autopilot to compensate for tasks such as these. However, the possibility exists that automated maritime vessels can distribute fatigue by allowing multiple crews to operate the vessel remotely (instead of one crew on board continuously). The same possibility exists between manned aircraft and UAS crews as well, whereby pilots inflight have less rest or sleep on the aircraft during long duration operations but switch crewmembers mid-flight.

Caid, S., Hauret, D., Wolff, M., & Mollard, R. (2016). Fatigue study and discourse analysis of French Uninhabited Aerial Vehicle (UAV) operators to understand operational issues. In *Proceedings of the 15th Ergo'IA Conference.* ACM.

The consideration of fatigue as an influence for risk-taking behavior is assessed in UAS crews. Fatigue risk was measured through the Iowa Gambling Task, commonly used to measure risk-taking behavior; the Iowa Gambling Task has previously been used to show a link between increased risk-taking and sleep deprivation. Sleep and wake activity were measured via wrist actigraphy and the Self-Assessment Manikin questionnaire. Results show highly variable bedtimes (from 9:17 pm to 1:53 am), self-reported good work performance with low difficulty and little difference between roles. However, an increase in effort was observed on days with more than three duty turnovers and with shortened time periods between turnovers. Analysis suggests the existence of a subset of individuals who are considered “risky”: these individuals underestimate their need for sleep, go to bed too late, accrue sleep debt, and let a state of chronic fatigue imperceptibly settle. Participant crewmembers were also interviewed; their responses were analyzed using Tropes discourse analysis software (commonly used to analyze political speeches). The software generated a set of 12 reference fields from which several associations could be made: Tactical Coordinators, whose role is to coordinate between the Pilot and Picture Analyst to the Control Center, tended to discuss workload, communication, national operations, situation awareness, synergy and system. UAS pilots tended to discuss assignment, workload, overseas operations and stress. Picture Analysts (who process image data and select onboard sensor usage) tended to discuss communication, fatigue, human-machine interface (HMI), and operators. While sleep data show all crewmembers were impacted by fatigue issues, they were not discussed evenly across roles. The analysis also identified a potential deficiency in work conditions and training for Picture Analysts beyond fatigue management. The study suggests that in addition to interviews, physiological measures such as actigraphy can provide insight into the content of interviews, and that interview statements processed by discourse analysis software can provide insight into sleep data findings.

Chappelle, W. L., Goodman, T., Reardon, L., & Thompson, W. (2014). An analysis of post-traumatic stress symptoms in United States Air Force drone operators. *Journal of Anxiety Disorders, 28*(5), 480-487. https://doi.org/10.1016/j.janxdis.2014.05.003

The prevalence of PTSD among USAF UAS operators was investigated. Results revealed that PTSD rates among drone operators are lower than rates reported by returning military personnel after deployment (4.3% compared to 10-18% respectively). Many of the reported symptoms did not meet clinical criteria for diagnosis, but a large number of respondents reported subclinical symptoms. Difficulty concentrating, falling/staying asleep, and aggressive outbursts were reported by 76-89% of respondents who met clinical criteria for PTSD, and 12-32% who did not meet clinical criteria for PTSD. The rate of reported symptoms raises safety concerns for drone operations because distracted or sleep deprived operators are more like to commit errors that could lead to injury, financial loss, or mission compromise. Furthermore, PTSD symptoms could exacerbate these safety concerns in drone operators. Recommendations included providing and promoting self-disclosure programs to identify personnel suffering from distress so early prevention measures can be taken, and having experienced mental health providers available to observe and consult with personnel so that personnel are able to express concerns about their mental health with a trained professional.

Chappelle, W. L., McDonald, K. D., Prince, L., Goodman, T., Ray-Sannerud, B. N., & Thompson, W. (2014). Symptoms of psychological distress and post-traumatic stress disorder in United States Air Force "drone" operators. *Military Medicine, 179*(8), 63-70. https://doi.org/10.7205/MILMED-D-13-00501

There is limited research on the occurrence of PTSD symptoms among USAF UAS operators, and previous studies assessing PTSD among UAS operators were time consuming and disruptive to military operations. A web-based survey based on Chappelle et al.'s (2011) Outcome Questionnaire was administrated to 1,094 Predator/Reaper drone operators to assess PTSD and other symptoms related to operational stressors. A smaller percentage of Predator/Reaper UAS operators reported high distress (11%) and PTSD symptoms (2%) more than those surveyed by Chappelle et al. (2011) (20% and 5% respectively). Shift work (specifically night/swing shifts), working over 50 hours a week, and 24 month or longer duty assignments were significant predictors of distress scores, and operators were twice as likely to report high distress levels. UAS operators working more than 50 hours a week were also four times more likely to report severe PTSD symptoms. Results indicate shift work, long hours, additional duties and administrative tasks, and low staff are operational stressors for distress and PTSD symptoms. The decline in reported symptoms and recommendations are also discussed.

Chappelle, W. L., Salinas, A., & McDonald, K. (2011). *Psychological health screening of remotely piloted aircraft operators and supporting units* (Report No. RTO-MP-HFM-205). USAF School of Aerospace Medicine.

To provide insight on the psychological effects of combat on UAS operators, 600 Predator/Reaper operators, 264 Global Hawk operators, and 600 Noncombatant Airmen supporting UAS operations were surveyed using the Malasch Burnout Inventory - General Scale. Results indicated 19.5% of Predator/Reaper operators experience high emotional exhaustion compared to 33% of Global Hawk operators, and 15.67% of Noncombatant Airmen. Predator/Reaper operators experience significantly less burnout than Global Hawk operators and significantly more than Noncombatant Airmen. Predator/Reaper operators experience significant less occupational cynicism than Global Hawk operators and Noncombatant Airmen. Predator/Reaper operators had the least occurrences of low professional efficacy (3.7%) followed by Global Hawk operators (4.6%) and Noncombatant Airmen with the highest rate of professional efficacy (7%). Those reporting high levels of stress were 16.5 times more likely to report high emotional exhaustion and 5.3 times more likely to report a negative work attitude. Those who reported shift work affecting their stress level were 11.3 times more likely to report high levels of emotional exhaustion and 2.9 times more likely to report having a negative work attitude. The results suggest the majority of Predator/Reaper operators do not experience occupational burnout, although about one in five operators experience emotional exhaustion/fatigue. Results may suggest operator stressors are more highly related to occupational stressors (shift-work, long hours, operational demands, career progression) rather than combat-related stressors (deploying weapons, exposure to live video feed of combat operations). The paper concludes by suggesting policy and line commanders are the best defense against occupational burnout in Predator/Reaper operators, because they reduce factors found to increase burnout risk (e.g., shift-work, long hours, operational demands, career progression).

Hardison, C. M. (2018). *Stress and dissatisfaction in the Air Force's remotely piloted aircraft community: Focus group findings* (Report No. RR-1756-AF). Rand Corporation.

UAS and the personnel who operate them are crucial to successful operations in today's military environment, especially in intelligence, surveillance, and reconnaissance–critical special operations. The staff manning the UAS include those in two of the newest career fields in the USAF. As these career fields mature and demand for skilled operators continues to grow, Air Force Special Operations Command leadership has recognized the need to address workforce issues facing the UAS career fields to ensure these career fields' health. Results of surveys administered during focus groups indicated that manning, tasking, and scheduling concerns were at the top of the list of issues raised by participants. Greater than 70% of respondents indicated that task load was disproportionate to manning, and that "mission creep" was a concern. Greater than 50% of participants indicated that schedule issues, such as shift work, rotation schedules, and unpredictable scheduling were a concern. Further, greater than 50% of respondents thought that they were not given enough time to complete tasks, they did not receive enough breaks (i.e., to eat or use the restroom), and were given too many additional administrative and training duties. Of note, more than three-quarters of respondents indicated that the minimum number of operators needed to perform the work was not clearly defined and was not realistic. In terms of HF issues, respondents indicated that more attention should be paid to ergonomic design of workstations, equipment upgrades, and climate control (i.e., rooms were kept very cold to keep the electronic equipment cool).

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). Air Force Research Lab.

The possibility for a single pilot to operate multiple UAS from a centralized location and the reduction in pilot-per-aircraft cost are discussed. People perform the best at an optimal level of workload; the research presented here questions whether operating multiple UAS will impose too large a demand on mental resources. One advantage to operating a UAS is the high availability for automation, which suggests the human-in-the-loop may be more of a supervisor than a traditional pilot. For the current study, the research focused on four indicators of cognitive load from eye tracking: blinks, saccades, fixation, and pupillary response. The ocular measures were recorded while the participants were in a UAS simulator performing two objectives (one primary and one secondary objective). Manipulations included visibility (clear versus hazy), the number of high value targets (HVT) the participants were to track (1 or 2), and the HVT route (e.g., a country road consisting of traveling on a straight open road with no obstructions from an aerial viewpoint). The visibility manipulation (weather conditions) did not have a significant effect on performance or measures of workload except for pupil diameter. The presence of one or two HVT(s) had a significant effect on performance and all measures of workload except for heart rate. The route the HVT took (country or city) had a significant effect on performance and measures of workload except in pupillometry and heart rate. Cognitive load was found to modulate blink rates. Unsurprisingly, the research concluded that flying multiple UAS requires more mental effort than flying a single UAS. The condition of the planned flight may also effect the mental effort required to fly the UAS. Any policy regulating fatigue for UAS pilots will need to be dynamic and flexible to the conditions and number of UAS the pilot is operating, while also considering the possibility of weather and the difficulty of the task during the missioned flight.

Hopcroft, R., Burchat, E., & Vince, J. (2006). *Unmanned aerial vehicles for maritime patrol: Human factors issues* (Report No. DSTO-GD-0463). Australian Government Department of Defence, Defence Science and Technology Organisation.

High altitude long endurance UAS involve many HF considerations for maritime patrol and response operations. A review of known HF concerns resulted in three general categories for considerations: automation, air traffic management and crewing, and the human-machine interface. A completely automated UAS decreases the odds of a human error and operator workload, thus increasing the success of the mission. However, complete automation puts the operator in a supervisory role and reduces overall situational awareness, and humans are typically known to perform poorly in observational, supervisory roles over extended time periods. Rather than a passive role, operators should be prompted to direct resources towards tasks where humans excel, which requires additional research for UAS operations (traditional manned flight operations require pilots to continually shift attention and interpret complex incoming data; automated UAS operations decrease the opportunity for such behavior and force the UAS operator to rely on incoming data from multiple sources). Additional HF issues arise when there is overreliance on UAS automation and the operator is not able to respond effectively and quickly to system errors, or if the operator does not trust that the automated system is providing accurate data. Human error is also possible in other UAS components, such as in maintenance and mission planning. The HMI separates the operator from available sensory information and instead forces them to rely on data input from the UAV, thus creating "sensory isolation" when operating a UAS. To overcome these HF issues, the operator should have better display systems based on basic graphic design principles that clarify and provide easy access to the most used data. Operators should have multimodal data displays to compensate for sensory isolation, and augmented displays (e.g., SmartCam3D System) should be incorporated to assist with interpreting data from the UAV. UAS operations generally require hand-over procedures between systems and crew members, and hand-over procedures increase operator workload and chances of error. Air Traffic Controllers also have to handle delays in communication between the UAV and the UAS operator, which can cost important seconds of decision-making time. Additional considerations have to be made about whether UAS operators require certificates to operate UASs.

Man, Y., Lundh, M., Porathe, T., & MacKinnon, S. (2015). From desk to field-human factor issues in remote monitoring and controlling of autonomous unmanned vessels. *Procedia Manufacturing*, *3*, 2674-2681. https://doi.org/10.1016/j.promfg.2015.07.635

Automation has expanded to many modes of transport, and there are HF issues in shipping vessel automation that must be considered before wide use. Automated shipping vessels do not have a human onboard to receive external data from the environment, such as the pitching and rolling of the ship, and operators at the shore control center have to rely on data feed from the vessel instead. Data collected from mock scenarios and post interviews revealed a discrepancy between the data output from the vessel and operator understanding/decision making. Because there is no human onboard the vessel, the technology tasked with collecting environmental data needs to be able to collect relevant information and efficiently communicate it back to the shore control station. Operators have difficulty interpreting environmental outputs and have to refer to sources spread across multiple computer screens rather than incorporating their own physiological assessments (e.g., pitch and roll of the vessel), thus increasing cognitive demand. Operators also have to rely on the data from the vessel about extreme and sudden environment changes, which increases the risk of miscommunication between the operator and system. Navigation is also affected because the operators do not use the same navigation methods at the shore control station compared to being onboard the vessel. The paper recommends developing a new organizational hierarchy for decision making; the upward transmission of information from the operator to supervisor to captain used in the study is ineffective because the captain can be left out of the loop for important decisions, particularly if the on-shore operator or supervisor believes the incoming information from the vessel is not critical and does not need to be passed along. Clear roles and responsibilities should be defined among all crewmembers and the captain to avoid miscommunication and ineffective decision making.

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

A review of human error and contributing factors was conducted to identify HF concerns relevant to U.S. Navy UAS operations, and to select a method best suited to classify UAS human error. Sixty-eight reports from the U.S. Navy's Accident Classification System were analyzed using the Human Factors Analysis and Classification System framework, and 287 contributing factors were identified. Skill based procedural errors, complacency and overconfidence, equipment communication failures and instrument and sensory feedback, miscommunication, supervision, and organization procedures were major HF involved in UAS errors and accidents.

Phillips, A., Sherwood, D., Greenberg, N., & Jones, N. (2019). Occupational stress in Remotely Piloted Aircraft System operators. *Occupational Medicine*, *69*(4), 244-250. https://doi.org/10.1093/occmed/kqz054

Traumatic stress and the role that shift work may contribute to overall mental health is a major issue with UAS operators. The particular concern for UAS operators is that the combination of mission-related stress is uniquely coupled with the immediate return to a home environment after a mission, where there may be fewer opportunities to talk. A sample of United Kingdom (UK) (i.e., non-American) UAS operators were administered the following questionnaire measures: the Work and Social Adjustment Scale, Alcohol Use Disorders Identification Test, Patient Health Questionnaire, Generalized Anxiety Disorder, and PTSD Checklist–Civilian Version. Results indicated that 70% of participants reported significant impairment on the Work and Social Adjustment Scale; 41% of participants reported drinking at potentially "hazardous" or "harmful" levels; 10% of participants met criteria for probable moderate or severe anxiety; and 20% met criteria for moderate or severe depression. None of the participants scored above threshold for PTSD. Statistical analysis found no significant associations between work and shift factors and mental health outcomes. The results of this UK study suggest the same issues as American studies: the main occupational stress factors are related to workplace and shift patterns and less to potentially traumatic stress.

Porathe, T., Prison, J., & Man, Y. (2014, February). Situation awareness in remote control centres for unmanned ships. In *Human Factors in Ship Design & Operation*. London, UK: The Royal Institution of Naval Architects.

Many of the same implications of improvements for unmanned merchant vessels at sea can also have application to UAS commercial carrier operations. For example, staffing reductions of a flight crew could save money, and automation might increase safety by reducing human error elements plagued by the onset of stress and fatigue. The same issues arise in maritime unmanned operations – how to effectively replace situational awareness of a human on board the vessel with sensors transmitting data to a remote operators, rather than the operator physically sensing the movement of ownship. The paper emphasizes the high importance of transmitting quick and dynamic information to the remote operator. Conversely, this emphasis does not address the issue that the remote operator must now be vigilant through a different channel (i.e., maintaining situation awareness through visual input of data rather than combining input from other senses such as proprioception). One suggestion provided by the paper is to train remote operators with a new mental model of situation awareness. The new mental model should prioritize specific information required for the action needed for the current situation.

Wahlström, M., Hakulinen, J., Karvonen, H., & Lindborg, I. (2015). Human factors challenges in unmanned ship operations–insights from other domains. *Procedia Manufacturing, 3*, 1038-1045. https://doi.org/10.1016/j.promfg.2015.07.167

A literature review of unmanned operations in various fields, including aviation, automobile, subway transportation, and military, was conducted to identify potential HF issues that may be relevant to unmanned shipping vessel operations. Lack of environment/spatial feedback, boredom, reorientation to new tasks, efficient maneuverability of the system, visual lag between the command and action, and general adaptation to the system were identified as potential HF concerns. Additionally, unmanned shipping vessels will have to be able to differentiate between objects they encounter on the sea, which depends largely on video and audio output from the vessel.

Human Factors/Ergonomics

Alicia, T. (2015). *The bridging technique: Crossing over the modality shifting effect* (Unpublished doctoral dissertation). The University of Central Florida, Orlando, Florida, USA.

An important design consideration for an effective UAS interface is how to map alarm/alert display systems to an appropriate sensory modality (e.g., visual or auditory) to ensure fast and safe operator responses. Problems may occur during times when the operator is heavily taxed in one sensory domain, and the alert is presented in the same domain (e.g., visually demanding task coupled with a visually presented alert). This study examines a phenomenon referred to as bridging, which allows the transitioning of a cautionary alarm presented in one sensory modality to another modality to counteract the modality shifting effect. Results from an experiment employing an alarm responsiveness task indicate that response time performance was not influenced by switching modalities (e.g., abrupt change from an auditory alert to a visual alert) though further research is needed to develop generalizable design guidelines.

Coppin, G., Legras, F., & Saget, S. (2009, July). Supervision of autonomous vehicles: Mutual modeling and interaction management. In *International Conference on Engineering Psychology and Cognitive Ergonomics* (pp. 489-497). San Diego, CA: Springer. https://doi.org/10.1007/978-3-642-02728-4_52

A new model is proposed for human-system interaction with unmanned vehicle systems (UVS). The operator must be able to use the Operator Support System (OSS) to command the UVS, the OSS must be able to interpret operator commands, and the OSS must be able to convert the commands to a deliverable UVS action. The system has to be able to convert its data into an understandable format for the operator. Not only should the operator and OSS be able to communicate efficiently and understand the other's output, but the OSS should also provide a decision support system to assist the operator with decision-making processes. In this model, a bidirectional interaction must exist between the human and system, where both work to create and maintain mutual understanding between both parties. Dialogue between the human and system does not need to be complex- a simple yes/no or okay response is enough to develop mutual understanding between human and system. This supports the operator's goal of mission accomplishment and interaction with the OSS, and splits the amount of effort required by the operator in achieving this goal. In short, a tradeoff with effort should take place between the human and system when non-understandings occur to create a cooperative attitude between them that can be adjusted depending on the situation. For example, the OSS should propose, request, or ask the operator to recast their command, and the operator should respond with a simple response (yes/no) or rephrase their command. The OSS could potentially highlight a location on a map display and request the operator to confirm it. The model also allows the operator and system to predict and direct the other towards a desired outcome, thus constructing a model of the other and creating trust between human and system.

De La Torre, G., Ramallo, M. A., & Cervantes, E. (2016). Workload perception in drone flight training simulators. *Computers in Human Behavior*, *64*, 449-454. https://doi.org/10.1016/j.chb.2016.07.040

The relationship between workload perception and simulator training tasks is examined; workload refers to the combination of demands upon the worker, and the responses the worker makes. Eleven non-pilot participants were tasked to complete a set of 24 flight tests in AeroSIM RC simulator software, which took approximately one hour. After the flight task, participants completed the Axon Workload Test (i.e., a modified version of the National Aeronautics and Space Administration [NASA] Task Load Index) as a subjective measure of mental workload. Results show that mental workload was correlated with the landing task, and workload was also correlated with total errors. The results suggest that self-reported workload, as collected through the Axon Workload Test, may be useful in understanding human errors made in UAS operations.

Hobbs, A., & Lyall, B. (2016). Human factors guidelines for unmanned aircraft systems. *Ergonomics in Design*, *24*(3), 23-28. https://doi.org/10.1177%2F1064804616640632

The UAS control station design guidelines for large UAS operations is reviewed. Most countries have not developed regulations to address the unique challenges of larger UAS: reduced sensory cues, control and communication via radio link, physical characteristics of the control station, transfer of control during ongoing operations, unconventional characteristics of unmanned aircraft, flight termination, reliance on automation, and widespread use of interfaces based on consumer products. A major problem is that the current UAS control stations were developed without consideration of HF design principles. The article proposed five aspects of the HMI that may be improved by applying HF guidelines: task descriptions, display requirements, control requirements, properties of the interface, and general HF principles. Further, the system performance requirements expected of the overall human-machine system form a foundation under these five interface aspects. The FAA (2013) UAS roadmap identifies conditions that must be met before a UAS can operate routinely and without special accommodation in all classes of civil airspace. With FAA guidance, a systematic approach to develop HF guidelines for UAS control station design can be completed for UAS pilots. The FAA can use these HF principles to set guidelines for industry design.

Howse, W. R. (2011). *Knowledge, skills, abilities, and other characteristics for remotely piloted aircraft pilots and operators* (Report No. AFCAPS-FR-2011-0006). Air Force Personnel Center.

Few studies have investigated the required knowledge, skills, abilities and other (KSAOs) for UAS operators. A review of past studies from 1979 to 2011 identified the most relevant and current KSAOs for UAS operators (including both pilots and sensor operators). Knowledge includes possessing a fundamental understanding of aviation principles, including navigation, sensors, weapon systems, aeronautical/aviation terminology, and flight rules and regulations for airspace classification requirements. Skills include reading maps and sectional charts, rotating mental objects in 3-dimensional space, and interpreting photos. Abilities include oral and written comprehension, oral and written expression, memorization, problem sensitivity, mathematical reasoning, and visual perception/spatial processing. Other attributes identified in the review include the affinity for planning and logic, the affinity for uncertainty, and teamwork.

Narayan, P. P., Wu, P. P., Campbell, D. A., & Walker, R. A. (2007, March). An intelligent control architecture for unmanned aerial systems (UAS) in the national airspace system (NAS). In *2nd International Unmanned Air Vehicle Systems Conference*. Melbourne, Australia.

The development of an intelligent control architecture can reduce risks associated with UAS sense and avoid factors and mid-air collisions without direct input from the operator. A new multi-layer architecture is proposed that uses incoming data collected from sensors to guide the UAS on its own, reducing workload on the operator. The first layer consists of a deliberative "virtual operator" that assists in interpreting incoming sensory data to make and guide decisions. The next sublayer uses the data to guide the UAS flight path and issue maneuvering commands to avoid hazardous situations or objects. The bottom layer is an adaptive controller that maintains UAS stability throughout its flight. With this architecture, the operator would issue commands to the virtual operator, and the virtual operator would filter the command down through its layer to perform various functions related to the issued command to complete the task. The operator does not have to communicate with the sublevels or worry about adjusting the UAS stability, for example, as those functions would be filtered by the virtual operator to the appropriate layer.

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*(26), 1903-1907. https://doi.org/10.1177%2F154193120905302604

There has been little to no application of science to UAS training, even though knowing how to train new operators has been a concern in the UAS community. A literature review was conducted to survey UAS concepts in the military to create a taxonomy of information that is needed to learn to control UAS and improve training. KSAs were identified as important concepts for UAS training, and specific training methods were identified. Knowledge is any information needed to complete a task, whether coming from the environment or memory. It was broken into two branches: human-focused and equipment-focused knowledge. Human-focused knowledge is concerned with how an individual and the team operates, in addition to factors that influence productivity. Equipment-focused knowledge is related to the function and operation of a UAS, ranging from the system itself to its data outputs. Skills are the capabilities of an operator to perform the task or mission, such as flight and monitoring skills. These currently receive the most focus during UAS training. Attitudes are personal and team affective (emotional) states and characteristics. Varying complexity in UAS operations means that flexible training methods are required to teach the KSAs to new operators. Cross-training and multicultural training methods should be used for knowledge based information. Skill information should focus on team coordination, stress exposure and inoculation, and behavioral model training methods. Trust training, informed by attitude information, is necessary so that the operator learns to trust and depend on the UAS.

Singh, G., Roy, R. N., & Chanel, C. P. C. (2019, February). Towards multi-UAV and human interaction driving system exploiting human mental state estimation. In *10th International*

Conference on Bioinformatics Models, Methods and Algorithms (BIOINFORMATICS 2019). Prague, Czech Republic. https://hal.archives-ouvertes.fr/hal-02042960

Currently, UAS crews are staffed with at least one crewmember per aircraft, but increasing automation may allow for decreases in staffing so that each human operator is involved in the control of multiple UAVs. While this is expected to reduce HF errors, a UAS operation still requires a human pilot to control the aircraft in hazardous situations. This study examines mixed-initiative for HMI, where either the computer or the human can take control from the other, and the introduction of multi-UAV, where one human pilot controls multiple UAVs. In considering such an interactive system between computer and human control faced with multiple UAVs at a time, the current work explores measuring mental and physiological states as predictors for performance in such environments. Certain electroencephalogram features such as certain event related potentials (time-locked cerebral responses to specific events) have been linked to insufficient cognitive resources to process given events. Furthermore, power spectral density of different electroencephalogram frequency bands have been used to measure task allocation. Heart rate and heart rate variability (beat-to-beat time differences) have been shown to be sensitive to workload and engagement. Blink frequency (blink rate), fixation duration (time focused on one spot), and blink latency (time between blinks) may also vary with engagement. It is suggested that these measures allow for an automated system to determine human mental states and help allow successful control handovers between human and computer.

Stern, J. A., Boyer, D., & Schroeder, D. J. (1994). *Blink rate as a measure of fatigue: A review* (Report No. DOT/FAA/AM-94/17). Federal Aviation Administration, Office of Aviation Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/1990s/media/AM94-17.pdf

Research has suggested blinking might serve other functions beyond lubricating and cleansing the eye; specifically, blink rate has been identified as a way to measure fatigue. Studies recording blinks during a task of reading have provided support to using blink rate as a metric of fatigue. Specifically, rate of blinking increases with reading duration. Further, blink rates increase during the last minutes during an hour of reading, with smaller print, increased conditions of glare, and when wearing glasses with the wrong refraction. Although research suggests that blink rates may be linked to the effects of cognitive fatigue, one study showed blink rates for co-pilots and pilots differed in an unpredicted manner whereby the person in control of the aircraft had a lower blink rate. This result suggested that higher workload affects blink rates during certain flight conditions and phases of flight.

Szabolcsi, R. (2016). UAV operator training–Beyond minimum standards. *Scientific Research and Education in the Air Force – AFASES, 1*, 193-198.

A literature review was conducted to identify the proper standards for training requirements for a UAS operator to fly in the NAS. Each country within North Atlantic Treaty Organization (NATO) defines their own requirements for training to operate a UAS. Pilots flying UAS in Class A or B airspace, for example, must contact ATC in the air before entering the airspace. NATO recommends a range of general knowledge for high altitude UAS operators: airspace structure and operating requirements; ATC procedures and rules of the air; aerodynamics; aircraft systems; performance; navigation; meteorology; communication procedures (Aeronautical English, International Civil Aviation Organization [ICAO] Level 4); and mission preparation.

Tvaryanas, A. P. (2006). Human systems integration in remotely piloted aircraft operations. *Aviation, Space, and Environmental Medicine, 77*(12), 1278-1282.

The human systems integration (HSI) model is used by the USAF to focus on seven areas of HF challenges; HSI can be used to classify and identify HF challenges in UAS operations. UAS operators are impacted by higher levels of reported fatigue than traditional manned aircraft pilots, and an increase in fatigue may lead to more accidents and errors. UAS operators are also impacted by other HF challenges assessed by HSI processes. The design of ground control stations, operating multiple controls, selection of UAS operators, and operator training are some challenges identified with the HSI model. While aerospace medicine practitioners study and investigate UAS-related HF issues (and HF-related accidents), it should be kept in mind that increasing time-on-task will generally result in a decrease in performance from baseline measurements, and that stress present in crewmembers' environments may increase the likelihood of worsening underlying physical and mental conditions.

Waraich, Q. R., Mazzuchi, T. A., Sarkani, S., & Rico, D. F. (2013). Minimizing human factors mishaps in unmanned aircraft systems. *Ergonomics in Design, 21*(1), 25-32. https://doi.org/10.1177%2F1064804612463215

The use of UAS by the DoD has rapidly increased. Further, UAS mishap rates are considered high, with an average of 50 mishaps for every 100,000 flight hours. This mishap rate is attributed to lack of attention to HF and design to account for human capabilities/limitations in UAS ground control stations. This work describes the growth of UAS in DoD, HF/ergonomics mishap rates, the need for HF standards to minimize mishaps, and proposes a computer work station standard to mitigate HF issues in UAS ground control stations. This work followed the American National Standards Institute (ANSI) approved standard for HF/ergonomics engineering of computer stations (ANSI/HFES 100-2007) to verify its applicability to UAS ground control stations and further examine the link between commercial standards and DoD UAS ground control station design. Results found that most input-output devices (display, keyboard, mouse, trackballs, joystick, touch panels) used in the UAS ground control stations were in compliance with the ANSI/HFES 100-2007 standards. Gamepads (joypads and control pads) were the only input-output beyond the scope of the ANSI/HFES [Human Factors and Ergonomics Society] 100-2007 standards. Results suggest that ANSI/HFES 100-2007 standards could be applied to the design, development, and evaluation of UAS ground control stations in order to help minimize mishap rates.

Wohleber, R. W., Matthews, G., Lin, J., Szalma, J. L., Calhoun, G. L., Funke, G. J., Chiu, C.-Y. P., & Ruff, H. A. (2019). Vigilance and automation dependence in operation of multiple unmanned aerial systems (UAS): A simulation study. *Human Factors*, *61*(3), 488-505. https://doi.org/10.1177%2F0018720818799468

Recent concerns have been raised regarding the lack of knowledge of how automation affects human pilots when flying multiple UAS concurrently. In particular, the study was designed to examine vigilance when attention is spread across different tasks, as human pilots would do when operating multiple UAS. In the study, non-pilot participants completed 2 hours of surveillance tasks (e.g., signal discrimination and symbol counting) within Adaptive Levels of Autonomy, a UAS simulation testbed, set to require low cognitive demand to encourage passive fatigue. Depending on participant condition, automated tasks in the UAS simulation additionally were set at high or low reliability. Measured vigilance was lower when surveillance tasks were demanding, and dependence on automation decreased in this task over time. Coupled with the low-cognitive-demand design, the findings suggest that cognitive resources depleted slowly over time, which resulted in poor surveillance task performance observed in the second hour of the experiment. It is also found that participants' lessening dependence on automation is consistent with the concept of "task shedding"—participants appear to ignore automation information in an effort to reduce demand on cognitive resources under increasing fatigue.

UAS Airworthiness Certification Categories and Regulations

Clothier, R. A., Palmer, J. L., Walker, R. A., & Fulton, N. L. (2011). Definition of an airworthiness certification framework for civil unmanned aircraft systems. *Safety Science*, *49*(6), 871-885. https://doi.org/10.1016/j.ssci.2011.02.004

There is no consensus on the definition of UAS types and categories. The current conventionally piloted aircraft (CPA) airworthiness certification categories are applied to civil UAS airworthiness certification categories in order to achieve an equivalent level of safety (ELOS). However, UAS airworthiness should be determined by the potential harm caused to people and property on the ground, which is a function of system reliability and operating area. Meanwhile, CPA levels of airworthiness are principally defined by the risk to those onboard and are largely independent of the region over-flown. A number of risks would be associated with mapping CPA levels of airworthiness onto all UAS operations: unequal risk management across UAS types and operations, overregulation of different UAS operations that results in unjustified costs to the

UAS industry, and an airworthiness regulatory framework that does not satisfy an ELOS objective. The research here was to develop a framework of airworthiness categories to which regulations and standards can be adopted for civil UAS. It is hypothesized that a risk matrix (loss and uncertainty) could provide a framework to structure airworthiness certification for civil UAS through systematic assessment, comparison, and ranking of risks associated with UAS type and operations. The airworthiness certification matrix (ACM) is presented and includes type of category, category of operational environment, operational scenarios, and airworthiness certification categories. The ACM can also be used to consider various risk mitigation strategies. Thus, the ACM is proposed as suitable for structuring an airworthiness certification framework for UAS operations.

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). Reston, VA: AIAA.

Introducing UAS into the NAS presents a challenge as this increases the demand that is shared across all users and stakeholders. When physically removing the pilot from the aircraft in favor of remote operation, the pilot loses the use of their natural senses to see and avoid other traffic. Thus, it is important to implement a detect-and-avoid system with an equal level of safety as manned aircraft see-and-avoid outlined in 14 CFR Part 91.113. A challenge UAS regulators have is to validate a system that is reliable and applicable to all UAS missions to insure consistent maneuver directives. While developing a detect-and-avoid system, engineers should evaluate the system based on the implemented procedures, define a target level of safety (equally or more safe than see-and-avoid), evaluate relative risk to all involved, and compare against a reference system (e.g., Traffic Alert and Collision Avoidance System). Trade-offs between various system functionalities will more than likely be required when evaluating the appropriate system to implement in UAS operations, but some functionality should be included such as detect various hazards, track the motion of detected objects, evaluate tracked objects, prioritize safety concern for tracked objects, predict ownship path and tracked objects to evaluate for avoidance time, and determine avoidance maneuver. The system and display must provide the pilot with enough information to safely operate the aircraft but also not provide information overload to the pilot.

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

Three major issues are faced by the international UAS industry: (1) lack of regulations for civilian UAS operations, (2) lack of adequate insurance, and (3) general lack of awareness in public and in industry for potential UAS uses. Recurring themes include the development of standards such as American Society for Testing Materials qualification standards for crew, maintainers, and operators. Among the topics discussed were accidents and failures (addressed through continuous training of crew and updating of HMI); issues with situational awareness, and operational airworthiness (including risk management). Of note, many of these concerns from 2007 have been address by Part 107 and section 208 in the UAS operator regulations guide for UAS pilots of FAA.

Dalamagkidis, K., Valavanis, K., & Piegl, L. (2008, June). A survey of unmanned aircraft systems regulation: Status and future perspectives. In *2008 16th Mediterranean Conference on Control and Automation* (pp. 717-723). Ajaccio, France: IEEE. https://doi.org/10.1109/MED.2008.4602250

The ICAO began to place regulation on early UAS operations, such as, the prevention of flying UAS over other countries without their explicit permission, the presence of registered markings, and certificates of airworthiness for UAS pilots. The lack of UAS oversight and regulation has led to a great deal of interpretation of regulation; leaving UAS operators on the wrong side of regulatory processes. The United States began recommended regulation change in 1991, however, these changes mostly focused on design, maintenance, pilot qualification, and equipment requirements. In 2005, the FAA issued 50 COAs and 55 more in the first half of 2006 for UAS operations. Considerations for regulatory differences between UAS and manned aircraft include: Application – manned aircraft are usually in a point-to-point transportation, while UASs may be used in situations that would require the system to run localized operations centered on a point for hours or days; Sacrificability – a crash involving a manned aircraft is considered a catastrophic event, but it might be acceptable to crash a UAS in an attempt to reduce damage to property or persons; Awareness – pilots of manned aircraft are immersed in the environment of their aircraft. UAS operators are limited by the instruments they are flying with provided by the UAS. Thus, instrument failure can lead to failed operations of the UAS; and Authority – in manned systems the pilot is in control of the aircraft while UAS pilots are remote and sometime reacting to the UAS as though being controlled by the aircraft. A leading priority for UAS regulation is to provide at least the minimum level of safety as manned aircraft operations.

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

There are various regulation challenges that must be addressed prior to UAS being allowed to operate commercially. Some of the hazards associated with UAS include the design of the UAS, operator skill and related HF, workload, the airspace UAS will operate in, and how future regulations will have to address them. UAS must meet the same ELOS as manned aircraft, and future UAS regulations must keep this requirement in mind when addressing the identified hazards. Regulation 14 CFR Part 1 can serve as the foundation for the creation of UAS regulations while tailoring future regulations to the unique challenges presented by UAS.

International Civil Aviation Organization. (2019). *Unmanned aircraft system traffic management (UTM) request for information.* ICAO.

The ICAO is requesting information to address a set of problems in UAS: (1) developing a UAS traffic management (UTM) risk assessment model, (2) developing contingency operations in anticipation of system failures or emergencies, (3) developing UAV separation standards, and (4) defining roles and developing standards for UTM service suppliers. In developing a UTM risk assessment model, ICAO requests information on types of risks and other elements that should be addressed in such a model, and whether current risk assessment models can inform UTM models. In developing policies and procedures for contingency operations, ICAO requests a definition of contingency or emergency and information on how to address such events in terms of safety and how it would impact UTM system-wide, UAS specific, and airspace users whether manned or unmanned. For developing standards in separation management, ICAO requests information on how current standards for manned aircraft might be applied to the UTM, and what modifications may be necessary. ICAO also requests standards for air traffic management (ATM) communications, navigation, and surveillance equipment, as well as information on whether manned aircraft should meet the same standards when using UTM airspace. Additionally, ICAO requests information on both deconfliction at the strategic level and tactical separation management; the request includes information on models to validate proposed polices. For policies on UTM service providers, ICAO requests information on whether UTM Service Providers (USS) should be considered air navigation services providers, and whether existing rules for air navigation services providers should be applied to USSs. Similarly, ICAO requests information on whether standards for USS are currently being developed, and whether those standards should be interoperable. Information requested will be considered by ICAO for presentation at DRONE ENABLE/3, ICAO’s UAS industry symposium held November 2019.

Maddalon, J. M., Hayhurst, K. J., Morris, A., & Verstynen, H. (2013, August). Considerations of unmanned aircraft classification for civil airworthiness standards. In *Guidance, Navigation, and Control and Co-located Conferences* (pp. 1-10). Boston, MA: AIAA.

Aircraft and operational classification factors involving the appropriateness of the classification framework for manned aircraft could be applied to the grouping of UAS airworthiness. This research qualitatively analyzed the risks and hazards of each classification factor by likelihood, severity, duration, and expectation. These results found that many UAS specific classification factors include risks and hazards that are different from 14 CFR factors and operational limitations to a UAS certification may be necessary until these factor issues are resolved.

Rango, A., & Laliberte, A. (2010). Impact of flight regulations on effective use of unmanned aircraft systems for natural resources applications. *Journal of Applied Remote Sensing, 4*(1), 1-13. https://doi.org/10.1117/1.3474649

There is an increasing civil necessity of small UAS for rangeland management of natural resources. The step-by-step process for civilians to become certified to fly sUAS in the NAS under FAA regulations in 2010 are described as: 1) Qualifications, exams, training, 2) Application for COA, 3) Flying the UAS/Flight Missions, and 4) Documentation.

SKYbrary (2020, May). *UAS rules and guidance – EU.* https://www.skybrary.aero/index.php/UAS_Rules_and_Guidance_-_EU

This article describes the current view of the European Union Aviation Safety Agency (EASA) on the future legislation related to the operation of UAS in the European Union (EU) airspace. The EU envisions that UAS operations will be categorized based on risks, as opposed to quantifiable metrics such as weight or size of aircraft. This operation-centric concept would consist of ‘open’ and ‘specific’ categories, with relevant subcategories.

SKYbrary. (2019, July). *UAS rules and guidance – USA.* https://www.skybrary.aero/index.php/UAS_Rules_and_Guidance_-_USA

This article describes the current legislation and provides reference to the guidance materials and best practices related to the operation of UAS in the US. Details such as pilot certification, UAS certification, and operating requirements are discussed.

Washington, A., Clothier, R. A., & Silva, J. (2017). A review of unmanned aircraft system ground risk models. *Progress in Aerospace Sciences*, *95*, 24-44. https://doi.org/10.1016/j.paerosci.2017.10.001

Early in the regulatory process of UAS, policy makers have tried the one size fits all UAS and generalizing manned piloted regulations to UAS. Conversely, this approach has not been applicable across systems and mission types. A risk analysis on two major concerns regarding UAS was conducted: collision or near collision between a UAS and another aircraft and the impact of UAS with people or structures situated on the ground. The failure risk assessment models associated with human performance will provide insight for regulations concerning duty requirements for crews. The impact assessment models will provide insight on the size of the area that might be affected by a UAS crash.

Wolf, H. G. (2013, March). Unmanned aircraft systems integration into the national airspace. In *IEEE Aerospace Conference* (pp. 1-16). New York City, NY: IEEE. https://doi.org/10.1109/AERO.2013.6496918

The government holds a unique position when new technologies are introduced for use in public airspace, especially with UAS because of its effects on the private market, DoD operations, and civil rescue missions. The general public has met this new technology with apprehension because of the opportunity for ill-use of UAS technology. Thus, the government must play advocate for the technology while also insuring safe and seamless integration. Public concern regarding privacy issues and other issues has made policy oversight and progression in the subject slow moving. While many believe existing policies for Constitutional Rights violation concerning aerial privacy infringement are sufficient, privacy advocates believe they are insufficient. UASs are a new technology in the civil airspace, but these systems are not new to military operations Thus, strategies used for military integration might be transferable to civil airspace. Further, consideration must be made to the effects on the local economy and other aspects not directly related to UAS flight operations.

Manned Operations

Shift Work, Fatigue, and Fatigue Risk Management

Brown, L., Schoutens, A. M. C., Whitehurst, G., Booker, T. J., Davis, T., Losinski, S., & Diehl, R. (2014). *The effect of blue light on pilot and flight attendant behavioural alertness.* Western Michigan University. http:/works.bepress.com/lori_brown/3

There are various operational strategies used during flights to increase alertness and performance and reduce jet lag. High intensity (10,000 lux) blue lights have shown positive results for mitigating fatigue and jet lag in various population samples. Bright light exposures at various frequencies and times to the retina reactivate neurons that release vasopressin, allowing the individual to regain a normal sleep cycle. Results of this study found that 14 international flight and cabin crewmembers (pilots and flight attendants) had significant decreases in ratings of sleepiness and increases in physiology and performance as a result of using the operations strategies listed in the study.

Bryant, M. R., Nesthus, T. E., & Rowley, C. (2016). *Evaluation of fatigue and responsibilities of cargo supervisors and flight mechanic cargo supervisors* (Report No. DOT/FAA/AM-16/6). Federal Aviation Administration, Office of Aerospace Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2010s/media/201606.pdf

Fatigue and training are issues concerning loading supervisors, evident by accidents caused by the shifting of cargo and resulting in the total loss of the aircraft. The required 24/7 operations of cargo demands creates fatigue management issues as the load supervisors acquire a sleep debt. The current study sought to identify current rest/duty schedules, fatigue risks, and current duties and responsibilities. Fatigue was evaluated through a general fatigue survey, a field study, and a structured interview. The 14-day field study consisted of a daily activities journal with entries filled out within 40 minutes of waking up and at least 30 minutes before lying down to sleep. Entries include items on sleep, wake times, mood, foods or beverages ingested, and medications taken. Participants completed the psychomotor vigilance task (PVT; a commonly used measure of alertness) twice a day, once after waking and once before bed. Participants wore a watch-like wrist actigraphy device to collect movement and sleep data during the 14-day field study. Structured interviews of subject matter experts questioned common work duties related to load supervisor positions. Results of the study lent evidence to nightshift workers getting a lessened amount and quality of sleep than daytime load supervisors, evident by the actigraphy data and the daily activities journal responses. PVT results found lower performance at waking among nightshift workers than among dayshift, despite both groups reporting being more alert at waking. Results further indicated the night shift workers had a higher sleep debt than daytime load supervisors and never adequately acquired the necessary sleep to overcome their sleep debt, leading to higher levels of sleep debt by nightshift supervisors. The researchers recommended five steps to reduce the effects of fatigue on load supervisors. (1) Institute a training program for all cargo loading personnel to educate them on the effects and counter measures of fatigue. (2) Organizations should implement a tracking system to account for duty time and rest time, including overtime. (3) Organizations should implement a fatigue risk management system (FRMS), appropriate to the roles and responsibilities associated with load supervisors. (4) Organizations should use the feedback from their supervisors to take actions to prevent fatigue related accidents. (5) Organizations should emphasize the responsibilities and duties of the load supervisor.

Caldwell, J. A., Mallis, M. M., Caldwell, J. L., Paul, M. A., Miller, J. C., & Neri, D. F. (2009). Fatigue countermeasures in aviation. *Aviation, Space, and Environmental Medicine, 80*(1), 29-59. https://doi.org/10.3357/ASEM.2435.2009

There are currently various in-flight fatigue countermeasures including cockpit napping, activity breaks, bunk sleeping, in-flight rostering, and cockpit lighting. Pre-/post flight fatigue countermeasures include hypnotics, positive sleep hygiene, and non-Food and Drug Administration-regulated substances. The discussion includes new technologies for detecting fatigue such as real-time assessment, off-line biomathematical models of fatigue prediction, military regulation on fatigue management, and the use of stimulants, sleep aids, and non-pharmacological countermeasures.

Federal Aviation Administration. (2013). *Fatigue risk management for aviation safety* (Advisory Circular No. 120-103A). U.S. Department of Transportation, Federal Aviation Administration. https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentid/1021088

This advisory circular: (1) Describes the basic concepts of FRMS, as prescribed in 14 CFR Part 117, § 117.7, and how they relate to aviation industry employees safely performing their duties. (2) Provides information on the components of an FRMS as applied to aviation, and on how to implement an FRMS within an aviation operation. (3) Defines an FRMS as an operator-specific process; therefore, while all FRMSs will have common elements, the specifics will be tailored to a certificate holder's particular conditions. (4) Provides (in Appendix 2, Fatigue Risk Management System Development) the certificate holder with the necessary detailed guidance to prepare for the FRMS approval process, develop the required documentation, develop and apply fatigue risk management and safety assurance processes, collect and analyze data, develop flightcrew FRMS operations procedures and a step-by-step process required for FAA evaluation and validation of the proposed FRMS application.

Federal Aviation Administration. (2013). Chapter 58 management of aviation fatigue: Section 1 review and acceptance of fatigue risk management plans (FRMP). In *Flight standards information management system (Vol. 3)*. U.S. Department of Transportation, Federal Aviation Administration.

This document provides for an air carrier's management plan outlining policies and procedures for reducing the potential effects of day-to-day flightcrew member fatigue and improving flightcrew member alertness. The fatigue risk management plans should be tailored to the air carrier's specific kind and type of operations. This discussion includes the kind of operations (e.g., domestic, flag, and supplemental) and the type of operations (e.g., multiple segments, continuous duty overnights, night vs. day operations, cargo vs. passenger operations, short-haul vs. long-haul, etc.).

Freund, D. M., Knipling, R. R., Landsburg, A. C., Simmons, R. R., & Thomas, G. R. (1995). *A holistic approach to operator alertness research* (Report No. 950636). U.S. Department of Transportation.

Loss of alertness (LOA) is a major safety concern within transport operations because it affects the operator, the system, and the environment. LOA is also of particular concern because it can be caused by a variety of factors. A holistic approach is used to review LOA preventative and assessment measures. A review showed that most organizations address each component of the holistic model through fitness-for-duty assessments, vehicle operator monitoring, education initiatives, and updates to the working environment. Factors contributing to LOAs are also reviewed.

Gislason, S. H., Bogdane, R., & Vasiļevska-Nesbita, I. (2017). Fatigue monitoring tool for airline operators (FMT). *Transport and Aerospace Engineering, 5*(1), 67-74. https://doi.org/10.1515/tae-2017-0020

Airlines are required to implement a FRMS to monitor and mitigate fatigue accumulation in their crews. FRMS programs aid airlines in scheduling flight crews by identifying and predicting risks to control excess fatigue. FRMS allows airlines to mitigate risk of fatigue in the form of schedule changes or distributing crew duties for additional rest. However, FRMS makes the ability to maximize rest and rest opportunities individual crewmember's responsibility. This study examined the relationship between a fatigue monitoring tool (FMT) (constructed through a focus group of pilots, cabin crewmembers, and station managers to weight fatigue causal factors on fatigue severity) and scores on a self-report fatigue scale (Samn-Perrelli scale – designed for monitoring crew fatigue) from 155 participants. The FMT is a predictive and reactive model capable of automatically calculating daily fatigue and predicting overall fatigue load of a schedule. Results found a positive correlation ($r = 0.651$) between FMT model and self-reported fatigue; as FMT score increased, so did self-reported fatigue. The advantages of FMT can provide confidence within airlines to assess and predict the fatigue level of crewmembers based on accumulated FMT scores. An automated system to assess and predict fatigue that also includes individual differences and social factors will be essential to every airline and aviation safety.

Hobbs, A., Avers, K. B., & Hiles, J. J. (2011). *Fatigue risk management in aviation maintenance: Current best practices and potential future countermeasures* (Report No. DOT/FAA/AM-11/10). Federal Aviation Administration, Office of Aerospace Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2010s/media/201110.pdf

Fatigue affects communication, memory, and visual attention, and FRMS in aviation maintenance presents a unique challenge. A comprehensive FRMS is essential to managing human error in aviation maintenance. Three objectives of FRMS interventions included: reduce fatigue, reduce or capture fatigue-related errors, and minimize the harm of errors. Fatigue countermeasures already used in other industries are reviewed and may be considered for aviation maintenance. The majority of fatigue countermeasures already used are able to address the three objectives of FRMS interventions in aviation maintenance, but additional attention is required for reducing fatigue-related errors and resulting harm because they were not originally designed for those purposes.

International Civil Aviation Organization. (2016). *Manual for the oversite of fatigue management approaches* (Doc Series No. 9966) (2nd ed.). ICAO.

The guide for oversight of fatigue management in commercial airline operators, general aviation pilots, and air traffic service (ATS) providers is divided into three broad areas: general fatigue management, prescriptive approach, limits to fatigue management, and the FRMS approach. The first area describes an introduction to fatigue management, the science of fatigue management, and required operational knowledge and experience. The second area describes the prescriptive limits to manage fatigue in flight/cabin crewmembers. The third area describes the operational components, organizational components, and implementation steps of FRMS.

Jay, S. M., Aisbett, B., Sprajcer, M., & Ferguson, S. A. (2015). Sleeping at work: Not all about location, location, location. *Sleep Medicine Reviews, 19*, 59-66. https://doi.org/10.1016/j.smrv.2014.04.003

It is generally accepted that sleep at home is qualitatively better than sleep at work. However, the confound of work limiting sleep when away from home makes a direct comparison difficult This review of sleep research examines outcomes in work situations and the various factors that impact the quality of sleep including timing and duration of breaks, commute length, sleeping environment, circadian phase, demographic factors, and familiarity with the sleep location. This review further argues that employees can sleep well at work, despite the conventional view that sleep at home is better than sleep away.

Rudin-Brown, C. M., Harris, S., & Rosberg, A. (2018). How shift scheduling practices contribute to fatigue amongst freight rail operating employees: Findings from Canadian accident investigations. *Accident Analysis and Prevention, 126*, 64-69. https://doi.org/10.1016/j.aap.2018.01.027

The freight rail system in Canada transports more than two-thirds of the country's goods transported by ground and half of the country's exports. A survey of Canadian rail operators revealed many do not get the required amount of sleep due to rigorous schedules. Fatigue undoubtedly affects their performance on the job as railroad operators by reducing reaction time to safety concerns, lapses in attention, and impairment of decision-making abilities. Accident investigation between 1995 and 2015 attributed operator fatigue to about 20% of freight railway accidents during the period. Around the clock operations of the railroad industry make shift work a primary issue as shift work disrupts the natural circadian rhythm. Current shift schedules and fatigue countermeasures are not sufficient to keep the railways safe. Canada's Railway Safety Management System has adopted some of the US's regulation for inner-city railroad operators and scheduling software to combat fatigue issues. Reevaluation of the Canadian freight railway system is scheduled for 2021 providing further information about the effectiveness of the implemented fatigue counter measures in place.

Wilson, N. D., Tavakolian, K., & Fazel-Rezai, R. (2016). *Systems and methods to provide feedback to pilot/operator by utilizing integration of navigation and physiological monitoring* (U.S. Patent Application No. 15/153,198). Washington, DC: U.S. Patent and Trademark Office.

The patent describes a system and method to improve the situational awareness and fatigue management of vehicle operators. The patent describes various examples of scenarios in which any combination of tactile, visual, audible, thermal feedbacks are used to provide information to vehicle operators and/or third parties based on physiological and navigational data. It is possible these systems and methods could be adapted to UAS operations where operator fatigue and harm to people and property are at risk.

Air Traffic Control

Cruz, C., Detwiler, C., Nesthus, T., & Boquet, A. (2002). *A laboratory comparison of clockwise and counter-clockwise rapidly rotating shift schedules, part I: Sleep* (Report No. DOT/FAA/AM-02/8). Federal Aviation Administration, Office of Aerospace Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/0208.pdf

There is concern that counter-clockwise shifts result in less sleep duration compared to clockwise shifts, thus increasing fatigue. However, neither shift has been directly compared. The current study compared counter and clockwise shifts on ATC work shifts and the resulting effects on sleep quality, sleep-wake time, and sleep duration. When considering naps taken prior to a shift, there is no difference in sleep duration between counter- and clock-wise shifts, contrary to prior concerns. Naps in counter-clockwise shifts balance out with the longer wake times in the clockwise shifts. Morning shifts resulted in shorter sleep duration, higher reports of sleepiness, and less sleep quality compared to afternoon shifts, regardless of the rotating shift. However, the end of midnight shifts had higher reports of sleepiness than the morning and afternoon shifts. Results from the midnight counter-clockwise shifts suggest ATCs begin to implement copying strategies after 2 weeks to adjust to circadian disruptions and disrupted sleep duration.

Della Rocco, P. S. (1999). *The role of shift work and fatigue in air traffic control operational errors and incidents* (Report No. DOT/FAA/AM-99/2). Federal Aviation Administration, Office of Aerospace Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/1990s/media/AM99-02.pdf

National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) data from 1988-1996 and FAA operational error and deviations (OED) data from 1988-1994 are reviewed to investigate the relationship between fatigue and shift work on errors and incidents among ATC operations. The ASRS data indicated operator fatigue was listed most frequently when looking at fatigue categories, followed by workload and scheduling. The majority of reports occurred between 12 p.m. and 6 p.m., indicating fatigue is just as, if not more likely, during day operations. The most commonly reported incidents and errors were ground transgression, altitude and heading deviations, and "less than legal separation". The OED data indicated the majority of errors occur between 8 a.m. - 7 p.m., typically after returning from breaks. Shift work variables (hour in shift, day of week, time at position) did not predict the severity of errors. Data entry errors were more common at midnight and night shifts, suggesting ATCs had decreased alertness and vigilance due to circadian disruption.

Della Rocco, P. S. & Nesthus, T. E. (2005). Shiftwork and air traffic control: Transitioning research results to the workforce. In Barry Kirwan, Mark D. Rodgers and Dirk Schaefer (Eds.), *Human factors impacts in air traffic managemen*t (pp. 243-281). Ashgate.

Personnel in safety-related occupations, like ATC specialists, must staff facilities 24 hours per day, 7 days per week. Shiftwork presents an interesting HF challenge. Researchers have reported the disruptive effects of shiftwork on sleep, performance, circadian rhythms, social and family relations, and longer-term health status. With advances in our understanding of the circadian clock and the importance of sleep, researchers and practitioners have begun to focus on the challenge to mitigate the undesirable effects and to minimize conditions that are conducive to error. Over the past decade, a number of empirically developed coping strategies and fatigue countermeasures have been deployed in various operational environments. It was in this context that in 1990, CAMI revived a program of research on shiftwork in the FAA's ATC facilities. The program built upon several CAMI studies from the 1970s that had focused on shiftwork and stress. Research in the 1990s replicated and extended the early findings to understand how the shiftwork issues manifested in the ATC environment and target fatigue countermeasures to transition from the laboratory to the workforce. This chapter describes research of the CAMI Shiftwork and Fatigue Research Program and the activities undertook to transition findings to the ATC workforce.

Gawron, V. J., Kaminski, M. A., Serber, M. L., Payton, G. M., Hadjimichael, M., Jarrott, W. M., Estes, S. L. & Neal II, T. A. (2011). *Human performance and fatigue research for controllers—Revised* (Report No. MTR100316). The MITRE Corporation.

Identifying missing areas of knowledge, highlighting predictive models, and identifying countermeasures against fatigue in ATC and aircrews are a major concern in aviation fatigue research. Work-related factors identified by the review include shift work (in part due to time between shifts, changing schedules, and sleep amounts before shift), task complexity, workload, and performance (errors made); non-work factors include individual differences (personality characteristics), age, family responsibilities, and sleep disorders (and sleep disorder treatment). The review also identified several methods to counter fatigue: scheduling (where care must be taken to consider circadian rhythms, time for sleep opportunity, and scheduling shifts based on psychological principles) as well as personal and at-work measures such as appropriate workplace lighting, use of melatonin, use of caffeine, mitigation of boredom, exercise, social interaction during breaks, and napping. Countermeasures include FRMS that, in some countries and in various industries, are used to measure and mitigate the risk of fatigue. The review notes that existing models of controller performance account for numerous factors, but omit fatigue itself. The review recommends five priority research areas to cover gaps in knowledge. (1) Quantify air traffic controller fatigue across various positions within Center, Terminal Radar Approach Control, and Ground/Tower facilities. (2) Validate measures of the effects of fatigue on controller performance; [various tools and methods have been suggested for countering fatigue (e.g., avoiding alcohol, caffeine, and nicotine several hours before bed and limiting general consumption; napping during early morning or mid-afternoon; sleeping in a conducive sleep environment and using blackout curtains or eye masks when sleeping during the day), but none are well-tested for effectiveness]. (3) Validate individual shift schedules; shiftwork has not been examined with consideration of personality, demographics, cognitive performance, situational awareness, and long-term effects. (4) Collect data to support sleep disorder policy. (5) Validate human performance models to predict ATC fatigue.

International Civil Aviation Organization. (2016). *Fatigue management guide for air traffic service providers* (1st ed.). ICAO.

A focus for fatigue research in aviation has been concerned with shiftwork and fatigue in ATC. Chapter 2 discusses pertinent scientific principles, including a practical background in sleep architecture, sleep loss, circadian rhythms, and workload effects. Chapter 3 discusses operational knowledge, where factors such as work conditions (e.g., facilities, automation levels, responsibilities, supervision), geography (e.g., location remoteness and weather conditions), workload (traffic density and task intensity), irregular scheduling, interactions with others, experience, and staffing arrangements (e.g., sufficient staffing for tasks, career stability, and other employment concerns) are included. Also discussed are organizational knowledge, where factors such as career stability, fatigue management, safety concerns, and staffing levels are included. These concerns are discussed in terms of responsibilities - whether each concern falls in the purview of the Air Traffic Service provider or of the individual ATC, or whether the concerns are shared. Chapter 4 describes methods of mitigating fatigue, including roles of the air traffic services provider and of the individual ATC. For example, ATS operators are provided a set of five principles: (1) ATS must comply with prescribed duty cycle limits, closely managing the use of duty extensions or shortened rest reductions; periodic review of practices is recommended. (2) Air Traffic Services should use principles from fatigue science (c.f. Chapter 2) to construct ATC schedules; this allows fatigue hazards to be predicted and mitigated. (3) Unscheduled duties i.e., on-call periods must be designed to protect sleep opportunities before and after, which can be achieved through limiting on-call duty periods, providing earlier notice of an on-call period, scheduled to avoid conflicting with planned work periods, and limit the number of days subject to on-call periods. Also suggested are various methods for individual fatigue management. Chapter 5 recommends predictive, proactive, and retroactive methods of identifying fatigue hazards. This can include the use of experience to guide future scheduling (e.g., evidence-based scheduling), the use of bio-mathematical models of fatigue, self-reported fatigue, regular surveying for past and present fatigue, performance data, and incorporation of existing scientific data. Chapters 6 and 7 provide recommendations and guidance for developing and implementing a FRMS.

International Civil Aviation Organization. (2015). *Fatigue management guide for airline operators* (2nd ed.). ICAO.

A focus for fatigue research in aviation has been concerned with shiftwork and fatigue management in airline operators. Chapter 1 outlines the benefits of using prescriptive and FRMS approaches to fatigue management in terms of regulator and service provider responsibilities. Chapter 2 discusses scientific principles pertinent to understanding fatigue, including a practical background in sleep architecture, sleep loss, circadian rhythms, and workload effects. Chapter 3 discusses operational knowledge, divided into two contexts. (1) The flight operations context, where factors such as fleet attributes (e.g., onboard rest facilities), routes and destinations (e.g., airport traffic conditions, layover meals and accommodations, local customs), experience managing operational demands, staffing levels, and irregular operations (work scheduling) are discussed. (2) The organizational context, where factors such as career stability, crew autonomy, fatigue management, effective reporting practices, and workforce factors (i.e., crew cultures, procedural differences, and experience) are discussed. These concerns are discussed in terms of stakeholder responsibilities – i.e., whether each concern falls in the purview of the operator or of the individual crew members, or whether the concern is shared. Of particular note is the discussion of operator duties in encouraging crew members to report fatigue hazards. Chapter 4 describes the prescribed approach to risk management, where the goal is to ensure crew members are alert enough to perform under all circumstances. However, it is noted that prescriptive methods are not enough on their own to prevent fatigue-related problems (c.f. Chapter 5). Fatigue Management Training (including examples of common fatigue hazards and personal mitigation strategies), fatigue hazards (reactive hazard identification and reporting), designing crew rosters based on fatigue science, and unexpected operational circumstances and risks, are discussed. Chapter 5 discusses FMRS based on Safety Management System principles to manage crewmember fatigue. In Chapter 4, the prescriptive approach depends on crewmembers reporting potential fatigue issues and operators reacting to them; in Chapter 5, operators are tasked with predicting potential fatigue risks before and monitoring for them during operations. Key processes include understanding sources of data for fatigue monitoring, hazard identification (predictive, proactive, and reactive), risk assessment and mitigation, assurance processes (including continuous monitoring of the assurance processes themselves), and safety performance indicators (including bio-mathematical modeling). Chapter 6 provides example parts of an FRMS (including sample documents). Chapter 7 discusses FRMS implementation.

International Civil Aviation Organization. (2016). *Fatigue management guide for general aviation operators of large and turbojet aeroplanes* (1st ed.). ICAO.

A focus for fatigue research in aviation has been concerned with shiftwork and fatigue management in airline operators and general aviation operators. Chapter 2 discusses scientific principles pertinent to understanding fatigue, including a practical background in sleep architecture, sleep loss, circadian rhythms, and workload effects. Chapter 3 discusses operational knowledge, divided into two contexts. (1) The operational context, where factors such as fleet attributes (e.g., onboard rest facilities), routes and destinations (e.g., airport traffic conditions, layover meals and accommodations, local customs), experience managing operational demands, staffing levels, irregular operations (work scheduling), and aircraft aspects are discussed. (2) The organizational context, where factors such as career stability, crew autonomy, fatigue management, and effective reporting practices are discussed. These concerns are discussed in terms of stakeholder responsibilities – i.e., whether each concern falls in the purview of the general aviation operator or of the individual crew members, or whether the concern is shared. Of particular note is the discussion of operator duties in encouraging crew members to report fatigue hazards. Chapter 4 describes implementing a fatigue management program where the general aviation operator's objective is to manage fatigue hazards to an acceptable level. This includes establishing flight and duty time limits (including minimum rest requirements and considerations for planning unscheduled duties) and using Safety Management Systems to further manage fatigue risks.

Krishnan, V. K., Dasari, D., & Ding, L. (2014). *EEG correlates of fluctuation in cognitive performance in an air traffic control task* (Report No. DOT/FAA/AM-14/12). Federal Aviation Administration, Office of Aerospace Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2010s/media/201412.pdf

There has been little investigation on whether fatigue is associated with different brainwave activity among ATCs. Participants completed four sessions, ranging from 30 minutes to 2 hours, with the Minicog Rapid Assessment Battery (MRAB) and C-Team low-fidelity air traffic control simulator task. Response time and routing times increased with the longer the session in the C-Team, but no differences were observed in MRAB scores. Electroencephalogram data showed differential brain wave activity, suggesting changes in mental states were occurring over time between the MRAB and the C-Team tasks. General performance began to decline around 70 minutes, indicating mental fatigue was taking place during both tasks.

McCauley, D., & Nesthus, T. (2017). Status of FAA air traffic control fatigue interventions 2013-2016. In *19th International Symposium on Aviation Psychology* (pp. 160-166). Dayton, OH: Wright State University. https://corescholar.libraries.wright.edu/isap_2017/39

FRMS bases fatigue on three principles: physiological fatigue has individual effects; fatigue is common in shift work environments; and fatigue can become risky to health and safety. FRMS programs must/should: be scientifically data-driven; continuously monitor and manage fatigue risk and hazards; provide a method for measuring, mitigating, and reassessing fatigue risk; include schedule assessment, data collection, and system analysis; and provide fatigue mitigations that are scientifically guided. Recommendations and mitigations were offered and included: FRMS, scheduling, recuperative breaks, management of sleep disorders, personal fatigue management, and fatigue education and awareness training.

Nealley, M. A., & Gawron, V. J. (2015). Effects of fatigue on air traffic controllers. *The International Journal of Aviation Psychology*, *25*(1), 14-47. https://doi.org/10.1080/10508414.2015.981488

Many studies evaluate factors that influence fatigue, effects of fatigue and workload on ATC performance, and fatigue countermeasures. Work-Related factors (i.e., shift work, task complexity and workload, and performance) and Non-Work-Related factors (i.e., individual factors, age, family responsibilities, and sleep disorders) are described in detail. The results of these key articles has led to the FAA's implementation of scheduling changes in ATC that requires an additional hour off prior to a day shift. However, the FAA has no metrics in place to assess the effects of this policy change on ATC fatigue and performance (OIG, 2013). There is justification for a full implementation and evaluation of an FRMS program with the development and validation of a biomathematical model.

Orasanu, J., Parke, B., Kraft, N., Tada, Y., Hobbs, A., Anderson, B., McDonnell, L., & Dulchinos, V. (2012). *Evaluating the effectiveness of schedule changes for air traffic service (ATS) providers: Controller alertness and fatigue monitoring study* (Report No. DOT/FAA/HFD-13/001). Federal Aviation Administration, Human Factors Division.

A survey and field study on the effect of shift work scheduling on air traffic controller's attention, performance, and fatigue was conducted by NASA to establish a quantitative baseline for evaluating the impact of the FAA's FRMS program. The results replicated findings of a previous survey study (Della Rocco et al., 2000a) and other field studies (Della Rocco & Cruz, 1995; Cruz & Della Rocco, 1995b; Della Rocco & Cruz, 1996; Della Rocco et al., 2000b; Cruz et al., 2002; Della Rocco & Nesthus, 2005; Broach & Schroeder, 2005; Nesthus, Cruz, Boquet, & Dobbins, 2003; Nesthus, Dattell, & Holcomb, 2005; Schroeder, Rosa, & Witt, Banks, 1995) conducted by CAMI.

Schroeder, D. J., Rosa, R. R., Witt, L. A., & Banks, B. (1995). Some effects of 8-vs 10-hour work schedules on the test performance/alertness of air traffic control specialists (Report No. DOT/FAA/AM-95/32). Federal Aviation Administration, Office of Aviation Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/1990s/media/AM95-32.pdf

The effects of 8- versus 10-hour work shifts on performance of the National Institute of Occupational Safety and Health Fatigue Test Battery in 56 air traffic controllers were analyzed. Results found no significant between-group differences in performance for 8-h shift compared to 10-h shift schedules. However, there were significant differences in response time, response errors, digit addition, and grammatical reasoning in day and session variables for between-shift and within-shift measures. The effectiveness and limitations of rapidly rotating shift schedules are discussed.

Schroeder, D. J., Touchstone, R. M., Stern, J. A., Stoliarov, N., & Thackray, R. I. (1994). *Maintaining vigilance on a simulated ATC monitoring task across repeated sessions* (Report No. DOT/FAA/AM-94/6). Federal Aviation Administration, Office of Aviation Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/1990s/media/AM94-06.pdf

The effect of time on task on operational errors and vigilance across sessions in air traffic controllers was analyzed. Results found that controller's performance on detecting conflicts decreased with time on task across periods but performance did improve from the first to last session, performance of identifying altitude malfunctions remained relatively stable to time on task effects and across sessions, and detection of aircraft intruders found both improvements in performance and evidence of time on task effects. These results are consistent with a previous Thackray and Touchstone (1991) report. Those results suggested that decreases in performance were associated with lapses in attention associated with time-on-task. And that moreover, this study's results support the suggestion that vigilance and performance are a function of task complexity.

Flight/Cabin Crewmembers and Air Medical Operations

Avers, K. B., King, S. J., Nesthus, T. E., Thomas, S., & Banks, J. (2009). *Flight attendant fatigue, part 1: National Duty, Rest, and Fatigue Survey* (Report No. DOT/FAA/AM-09/24). Federal Aviation Administration, Office of Aerospace Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/200924.pdf

Flight operations that may contribute to flight attendant fatigue were investigated using a self-report survey that collected general demographic, work background, duty time and workload, work environment, health, sleep, and fatigue information. Results indicate that the majority of flight attendants reported having good or very good physical and mental health, and a little over half reported having a medical diagnosis that may lead to fatigue. Fatigue was reported as a major issue by nearly all attendants, and most reported experiencing fatigue on the job. A small portion reported receiving fatigue education and training, and most did not report it as very helpful. Work shift and workload factors such as consecutive work days, few breaks, length of shift, long layovers, and skipped meals were reported as major contributing factors to fatigue. Scheduling was also one of the most prominent fatigue factors. Updates to work and break schedules to allow more rest time between shifts and to mitigate the effects of fatigue are reviewed.

Avers, K. B., Nei, D., King, S. J., Thomas, S., Roberts, C., Banks, J. O., & Nesthus, T. E. (2011). *Flight attendant fatigue: A quantitative review of flight attendant* comments (Report No. DOT/FAA/AM-11/16). Federal Aviation Administration, Office of Aerospace Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2010s/media/201116.pdf

In 2008, the US Congress directed CAMI to conduct follow up studies on recommendations outlined in Nesthus et al. (2007). Avers et al. performed a quantitative analysis on comments provided by flight attendants on a survey. Results were consistent with previous findings on the national survey of flight attendant fatigue (Avers et al., 2009b). Results found that the most frequent factors related to fatigue include length of duty day, missed meals, lack of breaks, short layovers, and number of consecutive duty days. Further, findings suggested that regional airline flight attendants might experience different fatigue factors not found in low-cost and network operations.

Caldwell, J. A. (2005). Fatigue in aviation. *Travel Medicine and Infectious Disease, 3*(2), 85-96. https://doi.org/10.1016/j.tmaid.2004.07.008

There are known prevention strategies for fatigue in aviation operations. Pilots self-report fatigue as a major barrier and concern when flying and list task demands, sleep disturbances, and circadian rhythm disruptions as causes. Decreased cognitive function and micro-sleep have been observed in short and long-haul operations and night operations interfere with the body's natural circadian rhythm. Some methods for preventing and lessening the effects of fatigue include fatigue education, additional sleep options during flight operations, and better break and schedule management. Aircraft design (e.g., addition of bright light) and medical sleeping aids are other options to combat circadian rhythm disruption.

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

The FAA's 2010 proposal for duty and rest requirements for flight crewmembers and the notice of proposed rule-making (NPRM) specifically addresses pilot fatigue. Primary changes to regulation with the NPRM include longer rest hours that account for commuting to rest time and duty period. The final NPRM presents new challenges for air carriers to account for pilot's commuting time and makes fitness for duty both the pilot's and carriers responsibility. The NPRM's change to new rest requirements will include a financial burden and responsibility to carriers to provide adequate rest time including commuting. In addition, the NPRM will allow domestic flight augmentation for the first time in crew scheduling but this change may come with increased pilot fatigue. Cargo carriers will benefit the least from the NPRM resulting in greater labor and operational costs. The NPRM increases pilots rest time and extends daily flight times while limiting the pilots time on duty. These changes are believed to reduce pilot fatigue and are, therefore, necessary. However, it is unclear how augmentation in domestic flights will affect pilot's fatigue and efficiency. Further, the NPRM does not address several things that should be included: requiring carriers to provide additional and improved rest facilities, setting limits on pilots' commute distance, and including a no-fault pilot fatigue call-in policy. The NPRM is based on the sleep science and reflects an understanding of how circadian rhythms affect pilot fatigue and performance. For UAS operator fatigue, this NPRM can inform the UAS industry what rest and duty requirements are necessary to mitigate and prevent UAS operator fatigue.

European Union Aviation Safety Agency. (2019). *Effectiveness of flight time limitation (FTL).* EASA.

There have been efforts conducted by the EASA to evaluate pilot alertness as a function of current on-duty duration restrictions. Phase one of the study evaluated the alertness of manned pilots in two conditions: duties lasting more than 13 hours during favorable time of day (daytime), and duties more than 10 hours in less favorable times (nighttime shifts). Phase one used an online survey with over 15,000 aircrew respondents, flight rosters representing 260,000 flight duty periods, and a field study conducted with 381 crewmembers from 24 different airlines. Two elements emerged as contributing factors to fatigue: duties of more than 10 hours during less favorable time of day and disruptive schedules. Data on fatigue, sleepiness, mental effort during on-duty operations, and sleep log data from 14 consecutive days was gathered through an online application. Results indicated pilots had the most fatigue issues during top of descent and late night finish flights. The findings support the argument that decreasing effects of fatigue from sleep before a night duty and naps on flight deck may reduce the effects of fatigue on later flight stages. ESAS produced five recommendations. (1) Operationally define "night" to reflect subgroups (i.e. short/long duration, early/late night). (2) Develop regulations for pilots to practice fatigue risk management techniques for late-finish flights. (3) Place regulation for pilots to practice fatigue risk management techniques during over night flights. (4) Apply specific regulation to pilots who begin flight at 1:59 a.m. and finish at 6:00 a.m. or later, as these flights are the most effected by fatigue at top of decent. (5) Apply stipulations for pilots to attain adequate sleep before a night flight, especially for duties over 10 hours. (6) Pilots should optimize all opportunities to obtain sufficient sleep before all night flights.

Federal Aviation Administration. (2019). *Part 135 pilot rest and duty rules ARC charter*. U.S. Department of Transportation, Federal Aviation Administration.

The Aviation Rulemaking Committee was chartered to review and develop findings and recommendations regarding pilot rest and duty rules under 14 CFR part 135. Tasks include: (a) reviewing current FAA part 135 pilot rest and duty rules; (b) reviewing other commercial pilot duty rest and duty rules, including ICAO rules; (c) evaluate the effectiveness and deficiencies of current FAA part 135 rules; (d) evaluate current safety regulations and provide assistance in future rulemaking; (e) consider prior part 135 rulemaking committees, small businesses, scientific data from fatigue and sleep research, aviation safety reporting data, the diversity of operations under part 135, plus other appropriate considerations; and (f) the submission of a recommendation report.

Federal Register. (January 4, 2012). 14 CFR Parts 117, 119, and 121: Flightcrew Member Duty and Rest Requirements, Final Rule (Docket No. FAA-2009-1093, Amdt. Nos. 117-1, 119-16, 121-357). https://www.federalregister.gov/documents/2012/01/04/2011-33078/flightcrew-member-duty-and-rest-requirements

This rule amends the FAA's existing flight, duty and rest regulations applicable to certificate holders and their flightcrew members operating under the domestic, flag, and supplemental operations rules. The rule recognizes the universality of factors that lead to fatigue in most individuals and regulates these factors to ensure that flightcrew members in passenger operations do not accumulate dangerous amounts of fatigue. Fatigue threatens aviation safety because it increases the risk of pilot error that could lead to an accident. This risk is heightened in passenger operations because of the additional number of potentially impacted individuals. The new requirements eliminate the current distinctions between domestic, flag and supplemental passenger operations. The rule provides different requirements based on the time of day, whether an individual is acclimated to a new time zone, and the likelihood of being able to sleep under different circumstances.

Gawron, V. J. (2016). Summary of fatigue research for civilian and military pilots. *IIE Transactions on Occupational Ergonomics and Human Factors, 4*(1), 1-18. https://doi.org/10.1080/21577323.2015.1046093

The fatigue literature in civil and military pilots were reviewed. Findings indicated longer-haul flight and night flight produce higher levels of fatigue. Fatigue rates were recorded as the highest during 8:00 p.m. and 4:00 a.m. Pilots with less than five hours of sleep in a 24-hour period show higher levels of confusion and stress. Pilots with less than 12 hours of sleep in a 48-hour period displayed higher levels of unease and frustration. In a simulator study, 40.3% more errors occurred when the pilots had less than 5 hours of sleep. One possible solution is to add additional pilots to the crew for long flights to increase the amount of sleep each pilot can get while in-flight on long-haul flights. Current FAA duty-time limits for civilian pilots require 16 hours on with 8 hours of required rest between shifts and that rest time begins when the aircraft arrives at the gate. Military pilots operate under different guidelines. This summary study marked significant impairments due to fatigue after 19-hours awake, in general. From the outlined literature, eight factors were associated with increased fatigue: reduced sleep; length of duty day and time of task; long haul versus short haul; number of sectors flown during the duty day; reduced crew; time of day with early morning being associated with the most fatigue; overnight versus a daytime trip; and return rather than outbound flights.

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

Few analyses have been done to investigate the relationship between pilot fatigue and aviation accidents. This paper presents a comparison between pilot work schedules and the occurrence of accidents. Pilots working 13 or more hours in a shift had a higher proportion of overall accidents compared to pilots working less than 10 or 12 hours. Pilots with shifts over 10 hours also had a higher proportion of accidents compared to pilots with shifts less than 10 hours. The results show that the probability of accidents occurring increase as a pilot's hourly work shift increases. Few pilots work 10 or more hours, yet these work shifts account for the most accidents. The paper suggests current regulations on pilot schedules should be reviewed to lower the number of acceptable flight hours in a 7-day period to decrease the probability of accidents occurring.

However, the paper notes that increased work shifts cannot be exclusively blamed for the occurrence of accidents and that other contributing HF must be considered.

Gregory, K. B., Winn, W., Johnson, K., & Rosekind, M. R. (2010). Pilot fatigue survey: Exploring fatigue factors in air medical operations. *Air Medical Journal, 29*(6), 309-319. https://doi.org/10.1016/j.amj.2010.07.002

Understanding how humans confront physiological challenges from the lack of sleep while working a 24 hour/7 days a week operation is important in aviation. This study examines a sample of air medical pilots to better understand fatigue and sleep management issues. The data consists of a 34-item online survey of 697 participating emergency medical service (EMS) pilots. Results show that about 98% indicated they work a fixed schedule with about half reporting they work a 3/3/7 schedule (three 12-hour day shifts followed by a day off followed by three 12-hour night shifts followed by a week off). Forty-one percent reported a 7/7 schedule (seven day-shifts followed by a week off followed by seven night-shifts followed by a week off). More than 84% of the respondents had reported fatigue was a contributing effect on their flight performance. Forty-six percent reported degraded alertness and overall performance, and 68% reported never nodding off while in flight. Fifty-four percent of the pilots reported 3-5 hours of sleep during a typical night shift, and 51% reported they could get 6 hours or more of sleep on night-shifts when they did not have to fly. A little over 40% of EMS pilots reported the area of flight most affected by fatigue was the en route lag of the flight followed by preflight planning with a 20% report rate. These results are compared against previous research, which suggests the average human adult requires 7-9 hours of sleep per night, which is genetically determined and cannot be relearned or overcome by willpower. Previous research also suggests that accumulated sleep debt of two hours can result in degraded performance similar to drinking 2-3 12-ounce servings of beer. Age, alcohol, and sleep disorders are further discussed.

Nesthus, T. E., Schroeder, D. J., Connors, M. M., Rentmeister-Bryant, H. K., & DeRoshia, C. A. (2007). *Flight attendant fatigue* (Report No. DOT/FAA/AM-07/21). Federal Aviation Administration, Office of Aerospace Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/200721.pdf

Current Code of Federal Regulations (CFRs) on flight attendant schedules, fatigue incident and accident reports, and flight attendant fatigue studies were reviewed. Length of duty, workload, circadian disruptions, and sleep loss were identified as contributing factors to flight attendant fatigue. In general, flight attendant schedules comply with CFR but a portion of time worked exceeded CFR restrictions, especially when unexpected events occur (e.g., weather, delays). The review of accident/incident reports identified 17 fatigue related reports suggesting fatigue was an important factor in the event. Several fatigue models were identified that could assist with predicting crew member fatigue. The research suggests future work should include flight attendant surveys, fatigue-related incident report analyses, validation of fatigue models, reviews of international fatigue regulations, and fatigue education and training.

Nix, S., Gossett, K., & Shepherd, A. D. (2013). An investigation of pilot fatigue in helicopter emergency medical services. *Air Medical Journal, 32*(5), 275-279. https://doi.org/10.1016/j.amj.2013.04.001

Human errors have consistently caused most helicopter emergency medical services (HEMS) accidents in the US. Considering the demands of HEMS pilots, fatigue may be a contributing factor in pilot error and safety risk. Four variables in the literature stand out as predictors of HEMS pilot fatigue: 1) day shift workers experience fatigue because they limit their own sleep to increase available work schedule, 2) work schedules that overlap with the need for sleep can disrupt circadian rhythms and increase fatigue, 3) workers ability to manage fatigue may improve as exposure to the shift work environment is acquired, 4) general fatigue in daily life may increase with aging. This study quantitatively examined the relationship of fatigue reported by on-duty HEMS pilots on consecutive day shifts, night shifts, and HEMS pilot experience. Results of this study found that night shift HEMS pilots reported significantly higher Brief Fatigue Inventory (BFI) scores than day shift HEMS pilots. However, no significant relationship was found between BFI scores and consecutive 12-hour HEMS day and night shift pilots and age. In addition, a significant positive relationship was found between BFI scores and experience level in HEM high shift pilots, suggesting that fatigue increases on night shift as HEMS pilot experience increases. In other words, HEMS pilots may become more sensitive to fatigue as they become accustomed to the work environment and desensitized to the occupational demands. Recommendations include conducting additional studies to confirm the results of the current study, investigating the relationship between HEMS pilot fatigue and other variables not assessed in the current study, using qualitative methods to document and identify fatigue management strategies used by HEMS pilots, and establishing fatigue management systems.

Roma, P., Mallis, M., Hursh, S., Mead, A. M., & Nesthus, T. (2010). *Flight attendant fatigue recommendation 2: Flight attendant work/rest patterns, alertness, and performance assessment* (Report No. DOT/FAA/AM-10/22). Federal Aviation Administration, Office of Aerospace Medicine. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2010s/media/201022.pdf

In 2005 and 2008, Congress directed CAMI to conduct an investigation into policy and common practices to evaluate their effect on flight attendant fatigue. The current article outlines the findings from the field study of flight attendants from May 2009 to June 2010. Data was collected from healthy, currently-working flight attendants who provided adequate information in an online study. Sleep-wake data were collected via wrist actigraphy for a period of 3-4 weeks. Participants also wore a personal digital assistant to record movement (steps taken). The findings indicate flight attendants behaved in the same manner as others working a shift work schedule. The study did not find a significant difference in PVT scores between international routed and national routed flight attendants. The international flight attendants did show faster reaction time and less mistakes on the PVT before starting their shifts. The research suggests a holistic approach to managing the risks associated with fatigue in flight attendants.

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

Two different long-haul flight operations were examined to see their effects on flight crew fatigue. Fatigue was not reported as an issue in day flights over 12 hours, but night flight operations over 12 hours lowered vigilance and alertness of the pilots. Night flight operations suffer from changes in circadian rhythms, and ergonomic changes in the aircraft design are not appropriate methods to eliminate or lessen these effects. Instead, regulations governing ongoing tasks and task demands during flight should be adjusted to decrease the effects of fatigue in night flight operations. Although 12 or more hour day flight operations were not an identified problem in this study, fatigue alertness is known to become a significant problem after 12 hours and should be avoided. The authors recommend keeping day flight operations at 12 or less hours for two-pilot crews and 10 or less hours for night flight operations.

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

Reduced crew operations is common practice in military and general aviation. Conversely, it is not common practice in commercial piloted aircraft due to the safety concerns that reduced flight crews present. Reducing the flight deck crew size will place higher levels of workload on the pilots who will remain on the flight deck. In current commercial flight decks, at least two pilots are required to fly a commercial jet. During many legs of the flight, one pilot will handle controls while the other pilot(s) manage the system and provide oversight. The role of the flight deck crew is rapidly shifting from the role of actively aviating to the role of system manager as automation takes over various systems on the flight deck. Human error is inevitable, but a greater degree of automation in aviation systems may provide more safety measures. Many systems constructed under the NextGen vision have begun automating tasks, helping to streamline pilot duties.

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

Factors contributing to fatigue are reviewed. Fatigue occurs from circadian rhythm disruptions and sleep deprivation, which may result in unwanted behaviors such as micro sleeps, slowed cognitive responses, and error-making. Current regulations are designed to prevent overworking, but they do not promote adequate sleep or sleep recovery. It is recommended that current regulations be reviewed to include criteria for maintaining adequate sleep and to include better fatigue training for pilots so they can identify early signs of fatigue.

Military and Maritime

Caldwell, J. A., & Caldwell, J. L., (2005). Fatigue in military aviation: An overview of US military-approved pharmacological countermeasures. *Aviation, Space, and Environmental Medicine, 76*(7), C39-C51.

Fatigue accounts for about 8% of the USAF Class A accidents (defined as total loss of aircraft, fatality, permanent disability or damage > $2 million) from 1972 to 2000. The military has tried some counter measures for fatigue such as limiting time on task, ensuring high levels of fitness, and providing brief periods of exercise, however, with little avail from any of these measures. Some pharmaceutical solutions might be a solution for military pilots. These medications could be used during times when sleep is acceptable but initiation is difficult, and may be used for sleep maintenance. Zolpidem may be used for sleep initiation, but it is not recommended for pilots who may be on-call as 4 to 6 hours of sleep is required. Zaleplon may be used for sleep initiation involving short sleep times, but it is also not recommended for on-call pilots due to potential drowsiness following consumption. Flight crews should be aware these drugs should not be used during times when they may have to wake and become active-duty at a moment’s notice. Caffeine and medications may also be used for improving alertness. Caffeine produces short-term maintenance of alertness but tolerance may occur; Modafinil produces an intermediate-term of maintenance of alertness but is a relatively new Schedule IV controlled substance with comparatively little research, requires medical oversight; and Dextroamphetamine produces long-term maintenance but is easily abused and requires medical oversight and should not be used by individuals with high blood pressure or cardiac problems and only as short extreme case solutions.

Chennaoui, M., Van Beers, P., Caid, S., Guillard, M., Boissin, J., & Sauvet, F. (2017). Microsleep and alertness monitoring in French Air Force long haul pilots. *Journal of Science and Medicine in Sport, 20,* S134. https://doi.org/10.1016/j.jsams.2017.09.499

Microsleeps (i.e., sleep of 1-30 seconds in duration) and other involuntary sleep are a known risk factor in long-duration tasks. In this study, 11 pilots were continuously monitored via electroencephalogram and electrooculogram and asked to complete a sleepiness scale and a vigilance task every two hours. Results demonstrate increased microsleeps and decreased attention was related to lower amounts of sleep before flight, sleep debt, time of day, and duty time. A correlation between microsleeps and decreased sustained attention was also found. The research suggests value in continuous electroencephalogram and electrooculogram monitoring during flight to identify periods of low vigilance.

Grech, M. (2016). Fatigue risk management: A maritime framework. *International Journal of Environmental Research and Public Health, 13*(2), 175. https://doi.org/10.3390/ijerph13020175

New regulations are proposed for maritime fatigue management based on the "defense in depth model". The proposed model uses a risk-based approach to identify fatigue hazards while providing appropriate mitigation strategies for seafarers and organizations. The model includes work shift and break policy updates and resources on safety assurance tools for seafarers to manage their own risks. The first two layers begins with the organization's support for and policies to ensure adequate sleep opportunities. This includes tools for assessing fatigue risk and scheduler software. The next layer focuses on ensuring seafarers get adequate sleep through self-report assessment and personal responsibility tools (e.g., wearing fitness trackers for sleep). This is followed by whether adequate sleep schedules and alertness is maintained by seafarers through self and peer-assessment tools. The final layer is a reporting system for seafarers to report fatigue and near misses so they may be analyzed to develop improved regulations.

Miller, J. C., & Melfi, M. L. (2006). *Causes and effects of fatigue in experienced military aircrew* (Report No. AFRL-HE-BR-TR2006-0071). Air Force Research Laboratory.

Aircrew members have the perception that fatigue reduces their ability to fly their best. One hundred and sixty-two USAF pilots and navigators responded to a 17-question survey investigating pilot and navigator perception of the effects of fatigue on their flight performance. The aircrew members reported reduced situational awareness (73%), slowed reaction times (67%), increased distractibility (43%), and forgetfulness (41%) due to fatigue. Many of the crewmembers (74%) reported disruption of circadian rhythm as a leading cause for fatigue. Other contributing factors included lack of sleep, the pace of operational requirements, and poor scheduling as leading contributions to fatigue.

Thomas, T., Ulring, S., & Armstrong, J. (2019). *Human systems integration assessment of fatigue within RQ-4 pilot operations at Grand Forks AFB.* Air Force Research Lab.

Recent concerns regarding fatigue have focused on missing knowledge of the impact of work schedules, sleep hygiene, and other related factors. Previous analysis has recommended that fatigue be examined at Grand Forks Air Force Base. The study design developed to assess fatigue consists of wrist actigraphy and activity diary-keeping for a period of 3 weeks coupled with focused interviews. In the interviews, pilots answered questions covering a range of topics, including work schedules, typical shifts, and how they recognize and mitigate fatigue. Pilots expressed several work area concerns, but focused on working night shifts: few available pilots for relief staffing; and lack of available nighttime on-base services (e.g., getting meals). Pilots also expressed concern that they followed suboptimal schedules in order to fly certain types of missions so as to maintain certification. When Fatigue Avoidance Scheduling Tool (FAST) was used to analyze actigraphy data, a quarter of day shifts worked included pilots behaving as though they were missing a full-night's sleep. FAST identified poor effectiveness in night shift pilots as well. The best night shift worker received >8 hours sleep before the night shift in an environment that provided the best sleep quality; the worst night shift worker had poor sleeping conditions and habits. FAST did not account for reported alcohol and caffeine use. The research makes two areas of recommendations. (1) Sleep hygiene: the study noted alcohol and caffeine use, which is not well-studied in UAS contexts. Also recommended are readiness checks to ensure pilots are not already fatigued before shifts begin. (2) Night shift: the study recommends the regular use of actigraphy to help identify better working schedules.

Thompson, W. T., & Tvaryanas, A. P. (2006). *A survey of fatigue in selected United States Air Force shift worker populations* (Report No. HSW-RE-BR-TR-2006-0003). Air Force Research Lab.

A cross-sectional study quantitatively assessed self-reports of fatigue in 172 USAF shift workers. Mean fatigue scores were statistically higher in UAS but not manned aircraft shift workers. No significant differences in fatigue scores were found for crewmember versus maintenance personnel nor for home versus deployed environments. Interestingly, results found the validated fatigue measures to be a unidimensional construct rather than multidimensional.

U.S. Military Pilot Duty Time Regulations

Air Force

Department of the Air Force. (2018, October 2). Air Force guidance memorandum to AFI 11-202V3, General Flight Rules. https://www.e-publishing.af.mil/

USAF General Flight Rules dictate that single pilot manned operations are not to exceed 12 hours, and multiple pilot manned operations do not exceed 16 hours for a basic aircrew or 24 hours for augmented aircrew, depending on aircraft type. Similarly, unmanned single control aircraft operations are not to exceed 12 hours, and dual control unmanned aircraft are not to exceed 16 hours. The flight duty period (FDP) starts when the manned aircraft aircrew member reports for a mission or other official duty, and ends with final engine shutdown. For unmanned aircraft aircrew, FDP's begin when reporting for a mission or it might begin during an in-flight mission. FDP's end at final engine shutdown, final in-flight handover briefing, final crew swap, or whichever occurs last. Maximum flying time is limited to 56 flight hours per 7 consecutive days, 125 flight hours per 30 consecutive days, and 330 flight hours per 90 consecutive days. Distinctions are not made between manned and unmanned operations.

Similarly, the pilot rest requirements are the same for both manned and unmanned aircraft. Crew rest is compulsory for aircrew members prior to performing any duties involving aircraft operations and is a minimum of 12 non-duty hours before the FDP begins. Crew rest is free time for transportation, meals, and rest, and must provide an opportunity for at least 8 hours of uninterrupted sleep. Further, the crew rest period cannot begin until official duties are completed. If the crew rest period is interrupted, the pilot is responsible for informing leadership, and may either begin a new crew rest period or not perform flight duties. Exceptions are made for the pilot-in-command to initiate mission-related communication, or when necessary to maintain a 24-hour work/rest cycle (e.g., a pilot with a 14 hour FDP would require a 10 hour rest period to maintain a 24-hour schedule). The USAF stipulates that the latter exception cannot be used for scheduling convenience, and that transportation, meals, and sleeping quarters are pre-arranged to provide for 8 hours of uninterrupted sleep.

Army

The U.S. Army dictates guidelines for pilot duty and rest in AR 95-1, AR 40-8, DA Pam 385–90, and in Comperatore, Caldwell, and Caldwell (1997; see also Department of the Army, 2010, 2018, 2019). In general, the U.S. Army does not provide specific values for duty and rest time, but rather provides resources and guidance to commanders on developing guidelines tailored to the unit mission while considering the importance of adequate rest and sleep:

- Commanders will design a crew endurance program tailored to their unit mission and include it in their standard operating procedures.
- Crew endurance is an integral part of the overall risk management program. It is used to control risks due to sleep deprivation or fatigue and to prescribe thresholds to trigger command decisions whether to accept those risks.
- Commanders should consider the advice of the flight surgeon and aviation safety officer in designing their programs.

Navy and Marine Corps

Department of the Navy. (2016, May 5). *NATOPS general flight and operating instructions manual: CNAF M-710.7*. https://www.public.navy.mil/airfor/vaw120/Documents/CNAF%20M-3710.7_WEB.PDF

The U.S. Navy outlines flight duty and rest requirements in the Naval Air Training and Operating Procedures Standardization (NATOPS) General Flight and Operating Instruments manual. UAS flight crews are required to comply with all guidelines dictated in the "Human

Performance and Aeromedical Qualifications for Flight and Flight Support" section (p. 8-13), which covers duty and rest requirements. Crew rest is the non-duty time before a flight duty period begins. Crew rest includes free time for meals, transportation, and shall include an opportunity for 8 hours of uninterrupted sleep time for every 24-hour period. Crew rest does not begin until after termination of official duties and is required prior to reporting for preflight preparations. Flight crew shall not be scheduled for continuous alert and/or flight duty (required awake) in excess of 18 hours. However, if it becomes operationally necessary to exceed the 18-hour rule, 15 hours of continuous off-duty time shall be provided prior to scheduling the member for any flight duties. Daily flight time should not normally exceed three flights or 6.5 total hours for single-piloted aircraft, and 12 hours for other aircraft. Weekly maximum flight time for single-piloted aircraft should not exceed 30 hours, and 50 hours for multi-pilot aircraft. Additionally, when practical, flight personnel should not be scheduled for flight duties on more than six consecutive days. Flight and ground support personnel schedules shall be made with due consideration for watch standing, collateral duties, training, and off-duty activities. Crew rest can be reduced to less than 12 hours in order to maintain a 24-hour work/rest schedule, but a shortened crew rest period (e.g., to maintain circadian rhythm) shall always include an opportunity for 8-hours of uninterrupted sleep.

Coast Guard

United States Coast Guard. (2018, October 26). *Air operations Manual: COMDTINST M3710.1H*. https://media.defense.gov/2018/Nov/01/2002058346/-1/-1/0/CIM_3710_1H.PDF

The U.S. Coast Guard Air Operations Manual provides guidance and air crew flight duty and rest regulations. The manual states that aviation policies pertaining to manned aircraft also apply to unmanned aircraft, including flight scheduling standards and crew rest requirements. Further, it is noted that if the pilot conducts both manned and unmanned aircraft operations during the same 24-hour period, they both count toward the individual's flight hours and crew mission hours. However, UAS crew members should not normally be scheduled to operate manned and unmanned aircraft within the same 24-hour period. Land-based UAS aircrew should not exceed 10 individual flight hours or 14 crewed mission hours in a 24-hour period. Shipboard UAS aircrew should not exceed 8 individual flight hours or 12 crewed mission hours in a 24-hour period. UAS crewmembers may not fly more than four consecutive hours without a minimum 30-minute rest break, but it is also highly recommended that crewmembers are relieved every two hours to minimize fatigue. Post-mission rest requirements differ by individual flight hours, crew mission hours, and whether these hours were land-based or shipboard operations. Further, the hours differ depending on whether the aircrew flew on two or more consecutive days. The required hours off duty ranges from 10 to 24 hours. UAS crewmembers deployed aboard ship may remain in duty status indefinitely, but may not exceed an average of eight flight hours per day for the previous seven days, and may not exceed individual flight hours per day as dictated by type of flight operation. If the average flight hours in a day exceed eight hours (in the 7-day period), the crewmember is to receive 24 hours of rest. UAS crewmembers cannot fly more than 80 total hours in 14 consecutive days. It is recommended that contractors also follow these guidelines.

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