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ANALYSIS OF NAVY FLIGHT SCHEDULING METHODS USING FLYAWAKE

by

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September 2009

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Sleep-related fatigue has negative effects on both human performance and decision making. Pilots are particularly vulnerable to these adverse effects due to the environment and operational requirements, which entails both long and irregular duty cycles.

The Air National Guard received funding from Office of the Secretary of Defense, Defense Safety Oversight Council to create FlyAwake, a software application that predicts aircrew fatigue based on circadian cycles. FlyAwake uses the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) Model and calculates predicted effectiveness. Recently, contract modifications have permitted integration with U.S. Navy's Sierra Hotel Aviation Readiness Program (SHARP) as an Operational Risk Management (ORM) tool. Naval Aviation does not currently use fatigue modeling as part of operational flight scheduling, and it is the intent of this thesis to provide a proof of concept analysis of FlyAwake for Commander, Navy Air Forces (CNAF).

In order to validate FlyAwake, flight schedules from February 2008 were collected from the Helicopter Antisubmarine Squadron Light Four Two (HSL-42) SHARP database. A statistical analysis compared fatigue levels of aircrew using conventional scheduling methods against those with fatigue modeling, and showed improved fatigue-based performance effectiveness with the utilization of FlyAwake.

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ANALYSIS OF NAVY FLIGHT SCHEDULING METHODS USING FLYAWAKE

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LIST OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS

AFB	Air Force Base
AFI	Air Force Instruction
AFRL	Air Force Research Laboratory
ANG	Air National Guard
AMC	Air Mobility Command
ATO	Air Tasking Order
BAC	Blood Alcohol Content
Capt	Captain, United States Air Force
CAPT	Captain, United States Navy
CFR	Code of Federal Regulations
CNAF	Commander, Naval Air Forces
CO	Commanding Officer
CRM	Crew Resource Management
CTC	Concurrent Technologies Corporation
DoD	Department of Defense
DSOC	Defense Safety Oversight Council
FAA	Federal Aviation Administration
FAM	Familiarization
FAST	Fatigue Avoidance Scheduling Tool
FCF	Functional Check Flight
FDP	Flight Duty Periods
GPO	Government Printing Office
GUI	Graphical User Interface

HCI	Human Computer Integration
HSI	Human Systems Integration
HSL	Helicopter Antisubmarine Squadron Light
JALIS	Joint Air Logistics Information System
JTF	Joint Task Force
LT	Lieutenant, United States Navy
LtCol	Lieutenant Colonel, United States Air Force
MAF	Maintenance Action Form
MAJCOM	Major Command
MGEN	Major General, United States Air Force
MOE	Measure of Effectiveness
MPH	Masters of Public Health
M-SHARP	Marine Sierra Hotel Aviation Readiness Program
NATOPS	Naval Air Training and Operating Procedures Standardization
NMCI	Navy Marine Corps Intranet
NPS	Naval Postgraduate School
NSC	Naval Safety Center
NUFEA	Navy Unique Fleet Essential Aircraft
OPNAVINST	Office of the Chief of Naval Operations Instruction
OPTEMPO	Operations Tempo
ORM	Operational Risk Management
OSAA	Operational Support Airlift Agency
OSD	Office of the Secretary of Defense
PEX	Patriot Excalibur
PIC	Pilot in Command

POC	Proof of Concept
SAFTE	Safety, Activity, Fatigue, and Task Effectiveness
SAIC	Scientific Applications International Corporation
SAM	Sleep and Activity Monitor
SBIR	Small Business Innovation Research
SCN	Suprachiasmatic Nucleus
SCUBA	Self Contained Underwater Breathing Apparatus
SDR	Sleep Dose-Response
SHARP	Sierra Hotel Aviation Readiness Program
SIC	Second in Command
SOP	Standard Operating Procedures
SPM	Sleep Performance Model
T/M/S	Type/Model/Series
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
USUHS	Uniformed Services University of the Health Sciences
VR	Fleet Logistics Support Squadron
WFC	Warfighter Fatigue Countermeasures
WRAIR	Walter Reed Army Institute of Research

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EXECUTIVE SUMMARY

Naval Aviation has established strict scheduling guidelines aimed at mitigating aircrew fatigue and enhancing performance effectiveness. These governing publications mandate maximum and minimum lengths for crew day and crew rest, respectively, but fatigue is still a primary cause in aviation mishaps. Currently, aircrew fatigue information is not provided to the squadron operations and safety departments based on personal circadian cycles. Aircrew fatigue levels, referred to as "predicted effectiveness" in fatigue modeling, can be calculated based upon 72 hours of sleep history and recent flight schedules and provided to the scheduling decision makers. This information can be utilized to create safer flight schedules by optimizing crew compositions based on predicted effectiveness.

Aviation specific fatigue modeling is currently available through FlyAwake, which is a software application designed to implement the Department of Defense (DoD) approved Safety, Activity, Fatigue, and Task Effectiveness (SAFTE) Model. The FlyAwake application was designed by MarcoSystems under guidance from the 201st Air National Guard (ANG) and funded from the Office of the Secretary of Defense (OSD) Defense Safety Oversight Council (DSOC). A contract modification was made in spring of 2009 to include the United States Navy's (USN) aviation database, Sierra Hotel Aviation Readiness Program (SHARP) created by Innova Systems, as a recipient for software integration. Currently, integration efforts are underway between the two software companies to make a seamless integration of SHARP and FlyAwake. Once this is accomplished, the USN's Commander, Navy Air Forces (CNAF) will select candidate fleet squadrons to provide usability feedback.

The original intent of this thesis was to explore the utility of combining SHARP with FlyAwake. However, the software release of FlyAwake v2.0 and subsequent integration with SHARP were delayed, making this impossible given time constraints. Instead, we conducted a proof of concept (POC) analysis. Using a retrospective analysis of actual U.S. Naval Aviation missions and flight schedules, this thesis determined if the

FlyAwake algorithm identified aircrew at high risk of fatigue. Helicopter Antisubmarine Squadron Light Four Two (HSL-42) flight scheduling data were obtained through the SHARP database. The month of February 2008 was selected for the period of analysis in order to capture a time period within the year with typical operations tempo (OPTEMPO). Special scheduling requests ("snivels"), ground events, qualifications reports, currency reports, logbooks, and completed flight schedules were extracted from SHARP and focused on two distinct detachments for this research.

The focus on detachments was deliberate and intended to spotlight unique characteristics of Naval Aviation. Once an aviation detachment embarks on a warship, they are limited to their embarked crew resources. This scenario is an accurate example of how naval squadrons and detachments conduct flight operations while deployed. Historically, HSL detachments deploy with one or two helicopters and are limited to five or six pilots. Knowing this, we designed the POC to reflect these realistic restrictions which bound this thesis analysis.

Historical flight schedules were submitted to FlyAwake to calculate predicted effectiveness of individual pilots. The FlyAwake algorithm was able to identify specific occurrences in which pilots' predicted effectiveness levels dropped below a critical threshold (77.5%) level. Only those occurrences below this threshold were considered candidates for potential flight schedule changes. Additionally, schedule changes were limited only to alterations in crew composition (i.e., switching pilots) rather than rescheduling mission times. This restriction from changing assigned flight times reflected the limited ability that detachment operations officers have when scheduling actual flight operations.

Those identified and feasible changes were made to historical flight schedules during instances in which FlyAwake identified a pilot dropping below the critical threshold during any portion of the flight profile (i.e., preflight, in-flight, post-flight). The altered flight schedules were re-submitted to FlyAwake and the results were collected and compared as measures of effectiveness (MOE). The MOEs of this retrospective analysis assessed whether predicted effectiveness improved after applying FlyAwake and modifying the flight schedules that were identified as high risk.

Maximum, minimum, and range of predicted effectiveness of each detachment were calculated and we found that these values remained fairly constant after executing schedule changes based on FlyAwake results. However, categorical data analysis revealed the added value of the FlyAwake fatigue modeling. One detachment experienced a 16.7% reduction of post-flight occurrences below the critical threshold, while the other showed a 25.0% reduction of in-flight occurrences coupled with a 12.5% reduction of post-flight occurrences below the critical threshold. Additionally, all occurrences observed in this study in the high-risk category occurred at night, which highlighted another current flight scheduling weakness regarding fatigue modeling (i.e., fatigue risk management).

In summary, this research provides a statistically valid proof of concept for the FlyAwake integration into SHARP by demonstrating the software's capability of identifying aircrew susceptible to fatigue during naval flight operations. This study does not recommend any Naval Aviation policy changes, but advocates the consideration of FlyAwake fatigue feedback when Operations Departments create flight schedules. Recommendations included assigning a permanent program manager to oversee and coordinate future developments for integration and usability study suggestions.

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I. INTRODUCTION

A. PURPOSE AND OVERVIEW

Fatigue was identified by the Naval Safety Center (NSC) as a cited cause of over 24% of mishaps in Naval Aviation from 1997–2002 (Davenport, 2005). Historical statistics such as these have been a driving factor for almost 30 years worth of research and development focused on fatigue management in the Department of Defense. These efforts have resulted in many advancements in the understanding of human fatigue and the development of fatigue management models and software. However, fatigue persists as a major contributor to mishaps in Naval Aviation.

Naval Aviation has published instructions that establish specific guidelines for crew day and crew rest requirements for Naval Aviators, Naval Flight Officers, and Naval Aircrewmen. These requirements have been implemented into the flight scheduling processes of all U.S. Navy squadron Operations and Safety Departments. Additionally, they are included as a guideline for flight schedule validation within the U.S. Navy's Sierra Hotel Aviation Readiness Program (SHARP) scheduling software. However, are these requirements sufficient to manage fatigue in the operational aviation environment? Can the implementation of fatigue assessment software within SHARP result in safer flight scheduling? The purpose of this thesis is to conduct a systematic assessment of the advantages of utilizing the newly developed fatigue management software, FlyAwake, in the Navy flight scheduling and ORM processes.

B. BACKGROUND

The United States Department of Defense (DoD) has been heavily involved in research and development of fatigue assessment and mitigation models, and software for over 30 years. It has funded research in both military and civilian sectors to conduct studies that led to enhanced fatigue awareness and mitigation. While much of this research has resulted in broader awareness and safety regulations, there continues to be a void in the incorporation of these advancements into user-friendly software that is capable of being easily integrated into current flight scheduling processes. However, recently, this void may have been filled by the development of a program called FlyAwake.

In 2007, the U.S. Air National Guard (ANG) was awarded funding through the Office of the Secretary of Defense (OSD) Defense Safety Oversight Counsel (DSOC) to contract with MacroSystems, a small business based in Seattle, to develop a new fatigue-assessment software application with a focus on usability: FlyAwake. This software package is web-based and has a graphical user interface (GUI) that was designed on principles of simplicity and efficiency. FlyAwake applies the already validated and DoD accepted Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) Model in a method that compliments current aviation databases and flight scheduling software (Capt Lynn Lee, personal communication, April 9, 2009).

FlyAwake was successfully incorporated into the flight scheduling process of ANG 201st Airlift Squadron stationed in Maryland. The ANG 201st used it as a safety validation method of proposed flight schedules, and saw direct effects of reduced aircrew fatigue levels and increased morale. As a result, DSOC funded a second revision of FlyAwake in 2008. In this current contract, funding is available for integrating the FlyAwake software into military aviation flight scheduling software. The U.S. Air Force Patriot Excalibur (PEX) is one the military software programs benefitting from this contract, and there is also an opportunity to integrate FlyAwake into the U.S. Navy's SHARP scheduling software.

C. OBJECTIVES

This thesis is a comparative analysis of Naval Aviation fatigue management tools involved in U.S. Navy squadron flight scheduling. The current methods of flight scheduling are compared against flight scheduling using FlyAwake, a newly available software application. DSOC funding covers contract support for MacroSystems to integrate FlyAwake into the U.S. Navy's aviation scheduling database, SHARP. The intent of this study is to determine the benefit of integrating this software into the Navy's flight scheduling process. The study analyzes whether the use of FlyAwake could potentially enhance safety in naval aviation by avoiding crew fatigue through more appropriate scheduling of the aircrew.

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

The military flight scheduling process is complicated and detailed, subject to many constraining factors. Schedules are generally drafted on multiple time scales, ranging from yearly to hourly intervals. This study focuses on the generation of daily and weekly flight schedules. A typical Navy squadron will draft a weekly flight schedule that is based on operations, training, and maintenance requirements and is subject to aircraft availability. The combination of these factors results in a dynamically changing schedule that is not usually finalized until just prior to execution. These dynamics are not captured in this study (i.e., logged flight times were not altered in the study). Instead, this study uses historical data from an actual squadron to analyze flight schedules over a time period representing an average operations tempo, comparing the two scheduling methods to determine if there are differences in the predicted effectiveness of aircrew using the two scheduling methods (i.e., with and without FlyAwake).

There is one other dynamic of the flight scheduling process this study does not consider. This study does not analyze the human computer integration (HCI) portion of software implementation with SHARP in a U.S. Navy squadron. This would require Command compliance and endorsement, and is beyond the scope of the current effort. However, FlyAwake usability tests have been conducted by the ANG in their flight scheduling process. These tests found the software to be user-friendly and the squadron experienced a decrease in fatigue related mishaps following its incorporation into their scheduling process. Due to the similarity in the flight scheduling processes, this study makes the assumption that the ANG HCI analysis is adequate for U.S. Navy purposes as well.

The final assumption in the comparative analysis pertains to the extent of deviation permitted after historical flight schedules are analyzed by FlyAwake. FlyAwake predicts when a crewmember will be below a certain threshold of predicted effectiveness. However, a squadron operations department always retains the ability to override any recommendations offered by the software. In this analysis, 77.5% predicted effectiveness was used as the indicator for considering alternative scheduling options. For the purposes of simulating the restrictive nature of scheduling flight operations while embarked on U.S. Navy warships, no alterations to takeoff or landing times were permitted. Realizing that these times are often rigid, the analysis only considers changes to crew assignments. The assumption that the scheduled flight times could not be altered focused the study on the aircrew vice the continuous nature of naval flight operations.

E. THESIS ORGANIZATION

Chapter I introduces the study by describing the background of fatigue assessment software, the objective, limitations, and assumptions of the study. Chapter II contains a review of literature that covers sleep, fatigue, aviation rest regulations, and aviation operational risk management for the different military services and a chronological history of fatigue assessment models and software developed through the Department of Defense (DoD). Chapter III explains the methods used in this thesis, while Chapter IV contains the results of this study. Chapter V concludes the study with a discussion of additional thesis efforts and Chapter VI provides conclusions and recommendations for future work.

II. LITERATURE REVIEW

The purpose of this literature review is to provide scientific background to illustrate the dynamics and driving factors present in fatigue modeling. This discussion begins by focusing on sleep and the factors that affect its quality, the distinct phases of sleep, and effects of sleep deprivation on human performance. The focus then transitions to the effects of fatigue on performance and current measures employed to counter its negative effects. Current regulations governing aviation work cycles and rest requirements are discussed in addition to the risk matrices developed to mitigate fatigue-related risk. The ultimate objective of this literature review is to introduce and explain the terms and concepts that researchers and developers have incorporated into the fatigue assessment models and software that are introduced in Chapter III.

A. SLEEP

Sleep is one of several factors that can contribute to fatigue and performance degradation in aviation. It is arguably one of the most important factors in safe and sustained operations, and generally one that can be managed through proper planning. Research studies have shown that sleep has direct effects on overall health (National Sleep Foundation, 2009). It is a basic physiological human need that is essential for maintaining a strong immune and endocrine system, along with stabilizing moods, increasing memory, and maintaining cognitive performance levels (National Sleep Foundation, 2009). While sleep requirements vary from 6 to 10 hours per day between different individuals, optimal performance and alertness is achieved with an average of 8 to 8.25 hours of daily sleep (Neri, Dinges, & Rosekind, 1997). Thus, a daily sleep cycle is formed that includes 8 hours of sleep and 16 hours of wakefulness.

A scientific understanding of different sleep factors such as sleep reservoir, circadian rhythm, and sleep stages can assist an operator or scheduler successfully manage daily schedules to reduce the risk of fatigue by providing conditions for quality sleep. The following sections will discuss these sleep factors and their affects of human performance.

1. Sleep Reservoir

Sleep reservoir is defined as a sleep-dependent process that governs the human capacity to perform cognitive work (Hursh et al., 2003). It is further described as either the replenishment (sleep accumulation) or depletion (sleep debt) of sleep that an individual obtains. Sleep accumulation is governed by both the quality and intensity of sleep while sleep debt refers to the current level of an individual's sleep reservoir. Anytime a person is awake, their sleep reservoir is considered to be in a state of depletion. Conversely, as an individual enters sleep, they begin to replenish the depleted sleep reservoir. The rate at which this cycle of accumulation and depletion occurs depends on various environmental, circadian, and operational factors.

Sleep debt can be further described as either acute sleep loss or chronic cumulative sleep loss. Both circumstances refer to the condition where an individual obtains less than their required amount of sleep within a given 24 hour time period. Acute sleep loss occurs when a person misses or gets an abbreviated period of sleep. This form of sleep debt can be alleviated by obtaining a greater amount of sleep or an increased quality of sleep during the following sleep period (Lambert, 2005). Acute sleep loss is generally associated with a decreased ability to perform tasks and feelings of fatigue. Cumulative sleep loss encompasses chronic sleep loss over a greater range of time. The period of cumulative sleep loss can range from days and weeks to years. During these longer periods, smaller amounts of sleep deprivation exist than usually seen in an acute sleep loss scenario. However, this does not necessarily translate into the negative effects also being smaller. The effects of cumulative sleep loss may take longer to present, but also takes longer for recovery (Hursh et al., 2003).

Research has shown that cumulative sleep loss may result in degraded human performance including decreased abilities in decision-making skills, attention spans, short-term memory retention, and problem-solving (Chapman, 2001). Another impact of sleep deprivation is an absence or reduction in the ability of an individual to assess their personal fatigue level. A study by Van Dongen et al. (2003) showed that individuals overestimated their personal level of alertness when subject to chronic sleep deprivation. This inability to assess one's state of restfulness can be especially dangerous to aviation operators. In addition to these examples of performance degrading effects, chronic sleep debt has also been linked to high blood pressure, obesity, and diabetes (Van Dongen, Rogers, & Dinges, 2003).

2. Circadian and Homeostasis Factors

The sleep/wake homeostasis and circadian biological clock are the two internally regulating factors in the human body (National Sleep Foundation, 2009). The sleep/wake homeostasis process, or restorative process, regulates the necessary sleep and wakefulness balance in the body. It is the driving force that identifies the need for sleep and then controls the quantity of sleep needed to properly account for time spent awake. If this process were the only governing factor of sleep, an individual would wake up fully rested and deplete energy at a steady rate until going to sleep in the evening. However, this is not the case. The circadian biological clock, more commonly referred to as circadian rhythm, governs the actual timing of feelings of sleepiness and wakefulness throughout the day. These feelings vary slightly between individuals, but the strongest sleep drives generally occur between 2:00am and 4:00am and again later with less intensity between 1:00pm and 3:00pm (National Sleep Foundation, 2009). The magnitude of these circadian sleep drives is dependent on whether a person is rested or experiencing sleep deprivation. A sleep-deprived individual will experience a more intense sleep drive during the periods noted than a rested person. The circadian rhythm has natural wakefulness peaks, generally occurring around 10 am and 8pm, to counter the sleep drives.

The circadian rhythm is controlled by cells in the brain called the suprachiasmatic nucleus (SCN) which responds to light and dark signals (National Sleep Foundation, 2009). When the human eye detects light, it sends signals to the SCN that indicate the start of a wakefulness period. The SCN then distributes signals to other portions of the brain initiating the release of hormones such as cortisol, a rise in body temperature, and other functions that control feelings of wakefulness. This signal from the SCN also results in the delay of the release of hormones such as melatonin, which is associated with sleepiness. Melatonin, a naturally occurring hormone produced by the pineal gland, is released when the optic nerve receives no light signals; it promotes sleep and reverses the alerting process.

Research shows that there is a biological drive for the human body to be awake during the day and asleep at night (National Sleep Foundation, 2009). The sleep debt concept further explains the importance of sleep regularity. Irregular sleep patterns are not only linked to increased fatigue and decreased performance effectiveness, but are also related to chronic illnesses. This poses serious challenges for aviation flight scheduling. Proper consideration of sleep debt and circadian processes when creating flight schedules is a necessary practice for reducing the unnecessary risk of scheduling fatigued aviators for missions. The current regulations regarding sleep with respect to aviation flight scheduling are discussed in Section C of this chapter.

B. NAVAL AVIATION OPERATIONAL RISK MANAGEMENT

Operational Risk Management (ORM) is defined in OPNAVINST 3710.7T as "a systematic, decision making process used to identify and manage hazards that endanger naval resources." It is a decision-making methodology that allows personnel to manage risk by employing this five-step process:

1.) Identify hazards

2.) Assess hazards

3.) Make risk decisions

4.) Implement controls

5.) Supervise

This process is further enhanced by providing four guiding principles that instruct decision makers to “accept risk when [the] benefits outweigh the costs, accept no unnecessary risk, anticipate and manage risk by planning, [and] make risk decisions at the right level.” These principles provide a clear cut framework in which to employ the five-step ORM process. The instruction recognizes that this process is dependent on time and asset availability, and provides three levels of implementation; time critical, deliberate, and in-depth. A time critical situation requires a quick mental review of the ORM steps when conducting time essential mission changes that do not permit a full discussion. A brief overview of the steps will allow the crew to recognize any risks involved and take mitigating action. The deliberate level is one that does provide time for brainstorming in groups to use collective experience in order to identify hazards and mitigate risk. Finally, an in-depth level is one that entails a high level of scrutiny that thoroughly studies hazards and risks in complex operations such as weapons detachments.

The ORM process is not unique to Naval Aviation, but is practiced by the entire U.S. Navy and has been designed for warfighter applicability across all naval communities. The general purpose of ORM is to allow warfighters to make informed risk decisions and increase operational readiness by using a combination of professional knowledge and experience to anticipate and mitigate risk. The resulting effect decreases the potential for loss in combat and ultimately gives naval forces an advantage. Type/Model/Series (T/M/S) NATOPS model managers are further directed by OPNAVINST 3710.7T to enhance this baseline ORM process to address specific risk management concepts that may be unique to each individual Naval Aviation community.

C. AVIATION CREW REST/CREW DAY REGULATIONS

Fatigue has been identified as a causal factor in countless mishap investigations; as a result, both military and civilian regulatory authorities have imposed strict guidelines defining requirements for aircrew rest and work cycles. These terms are known within the aviation community as crew rest and crew day, respectively. The guidelines in both sectors are similar and provide well defined timelines that specify the maximum number of flight hours that can be scheduled. Mandated rest periods both before and after flight completion are always specified. While these regulations have succeeded at standardizing rest requirements and duty cycles, they have failed to address many of the other contributing factors to fatigue such as circadian rhythms.

This section will first specifically review the civil regulations regarding crew day and crew rest requirements of the Federal Aviation Administration (FAA) and then proceed to military instructions of the U.S. Navy, U.S. Marine Corps and the U.S. Air Force.

1. United States Federal Aviation Administration

The Federal Aviation Administration is tasked with the responsibility for the advancement, safety, and regulation of civil aviation, developing new aviation technology, and other duties within the United States (FAA, 2006). They are the primary oversight authority for regulating and enforcing crew rest for commercial aviation. The FAA has accomplished this by creating a document entitled the Code of Federal Regulations (CFR). The CFR contains four different sections pertaining to flight time regulations and crew rest requirements.

CFR Part 91.1057 first establishes a baseline of definitions for the terms used within the document regarding duty and rest requirements. The FAA considers pilot crew assignments as comprised of one pilot, two pilots, or an augmented flight crew, which is defined as "at least three pilots" (Government Printing Office [GPO] Access, 2009). Two other significant definitions are the duty period and rest period. Duty period is defined as:

> The period of elapsed time between reporting for an assignment involving flight time and release from that assignment by the program manager. All time between these two points is part of the duty period, even if flight time

> is interrupted by non flight-related duties. The time is calculated using either Coordinated Universal Time or local time to reflect the total elapsed time (GPO Access, 2009).

Rest period is defined as:

> A period of time required pursuant to this subpart that is free of all responsibility for work or duty prior to the commencement of, or following completion of, a duty period, and during which the flight crewmember or flight attendant cannot be required to receive contact from the program manager. A rest period does not include any time during which the program manager imposes on a flight crewmember or flight attendant any duty or restraint, including any actual work or present responsibility for work should the occasion arise (GPO Access, 2009).

The CFR Part 91.1059 focuses on flight time limitation and rest requirements for one or two pilot crews and CFR Part 91.1061 discusses the same limitation and requirements as applicable to augmented flight crews of fractional ownership operations. In these sections, guidelines are set forth to minimize crew fatigue by establishing flight time regulations. For one or two pilot crews and augmented flight crews, no crewmember is permitted to exceed 500 flight hours in any calendar quarter, 800 hours in any two consecutive calendar quarters, or 1,400 hours in any calendar year. Additionally, in any 24-hour period, no flight crew is permitted to be assigned a flight that exceeds 8 hours for one pilot or 10 hours for two pilots. Any pilot assigned to an augmented flight crew is limited to no more than 8 hours of flight deck duty accrual in any 24 consecutive hour time period. The document also mandates sufficient pilot in command (PIC) and second in command (SIC) requirements to afford pilots in an augmented flight crew the ability to sleep (GPO Access, 2009).

CFR Part 121.471 governs flight time limitations and rest requirements of all flight crewmembers conducting domestic operations. This regulation is similar and applicable to military regulations and is the basis of comparison for this study. This regulation focuses on all flight crewmembers, which is also how the military handles flight scheduling. The FAA includes pilots and flight attendants under this categorical umbrella. The following sections reviewing USN, USMC, and USAF aviation regulations illustrate how the U.S. military includes pilots, flight officers, and aircrewmen under a similar category. This regulation restricts any flight crewmember from exceeding 1,000 hours in any calendar year, 100 hours in any calendar month, and 30 hours in any seven consecutive day time periods. It further mandates that crewmembers have eight hours between required rest periods (GPO Access, 2009).

The document goes into further detail by establishing different rest criteria within any 24 consecutive hour time period prior to the scheduling completion of a flight. If the scheduled flight is less than eight hours in duration, the flight crewmember must be provided nine consecutive hours of rest. For scheduled flights of eight or more hours, but less than nine hours, the crewmembers must be afforded ten consecutive hours of rest. Finally, any flight with a scheduled duration greater than nine hours requires eleven consecutive hours of rest. The regulation includes a caveat that excludes certain circumstances that are beyond the control of the flight crewmembers (such as adverse weather conditions, unforeseen air traffic delays, or emergencies) (GPO Access, 2009).

2. United States Navy and United States Marine Corps

All personnel in the U.S. Navy and U.S. Marine Corps designated as either a Naval Aviator, Naval Flight Officer, or Naval Aircrewman are subject to regulations promulgated by OPNAVINST 3710.7T (2004), the Naval Air Training and Operating Procedures (NATOPS) specific to their Type/Model/Series (T/M/S) aircraft, and the specific Squadron Operating Procedures (SOP). These documents are listed in order of increasing restriction; that is, each successive document is permitted to add regulations, but is never allowed to undermine regulations mandated in the parent document. This allows a commanding officer (CO) of a squadron the ability to add a regulation in the SOP that pertains to his/her specific operating environment. However, the CO cannot remove a regulation that has been directed by higher authority in either the aircraft NATOPS or OPNAVINST 3710.7T.

OPNAVINST 3710.7T Chapter 8.3.2.1 Rest and Sleep establishes basic guidelines to "attain and monitor personnel performance." The wording used in this document is very important in that it allows for deviation from the guidelines in cases where "operational necessity" dictates. Operational necessity is officially defined as "a mission associated with war and peacetime operations in which the consequences of an action justify accepting the risk of loss of aircraft and crew. The use of the word "shall" indicates mandatory compliance, the word "should" precedes a recommended procedure, "may" is used when a procedure is optional, while "will" indicates futurity and does not state any level of procedural requirement. Understanding these key terms is essential to implementation of USN and USMC guidelines.

Chapter 8.3.2.1 begins by stating guidelines for the work cycles of flight crew and flight support personnel. It states that eight hours of sleep "should" be provided for every 24 hour period with special consideration for collateral duties, watch standing, training, and off-duty activities. The instruction further extends to the flight crew specifically by stating that sufficient time "should" be provided to eat and allow eight hours of uninterrupted rest. The flight crew "should" not be scheduled to be on continuous alert status or flight duty over 18 hours. If this restriction is violated for any reason, OPNAVINST 3710.7T mandates 15 continuous hours of off-duty time "shall" be provided to the flight crew.

Flight time guidelines are provided to assist commanding officers with conducting flight operations. The instruction refers to the impractical nature of mandating strict requirements due to the varying constraints associated with different aircraft communities. It states that daily flight time "should" not normally exceed 6.5 hours or three flights for single-piloted aircraft and that individual flight time in other aircraft should not normally exceed 12 hours. These numbers are based on the assumption that the average time from brief to debrief totals four hours. Weekly maxima are recommended to not exceed 30 hours for single-piloted aircraft and 50 hours for others while neither "should" be assigned flight duties for more than six consecutive days. The remaining guidelines are provided in Table 1.

Period (Days)	Single Piloted Aircraft	Multi-Piloted (Pressurized) Ejection Seat Aircraft	Multi-Piloted Non-Pressurized Aircraft	Multi-Piloted Pressurized Aircraft
1	6.5	12	12	12
7	30	50	50	50
30	65	80	100	120
90	165	200	265	320
365	595	720	960	1120

Table 1. Maximum Recommended Flight Time (OPNAVINST3710.7T, 2004)

Each community within Naval Aviation must also comply with the NATOPS manual and SOP applicable to their specific T/M/S aircraft. For the scope of this research, it is not necessary to review the guidelines of each manual. However, a majority of communities observe a standard 12-hour crew day and 10 hour crew rest. A crew day begins when a crewmember enters the squadron spaces and terminates after completion of the last military obligation. Crew rest is considered the time after completion of the last military obligation until the next scheduled military obligation (e.g., duty, simulator, preflight briefing). Additionally, the workday following watch standing disqualifies crewmembers from participating in the following day's flight operations. These rules are subject to operational requirements and deviation from the guidelines requires authorization by the CO. The interpretation and implementation of these rules may vary between different commands, but remain similar in application.

3. United States Air Force

The U.S. Air Force crew rest and flight duty limitations are governed by the Air Force Instruction (AFI) 11-202, Volume 3, Chapter 9 (2006) which defines maximum flight duty periods (FDP) and crew rest requirements for all USAF aircrew. The document is structured similar to the OPNAVINST in which it sets forth maximum and minimum requirements and delegates MAJCOM commanders to implement further restrictions at their discretion. It allows commanders to account for specific fatiguing effects such as extreme weather, mission requirements, jet lag, impaired crew rest, mission delays, and type of aircraft flown. Chapter 9 also states that the T/M/S publications may have more restrictive requirements and therefore take precedence over the less restrictive standards.AFI 11-202 Volume 3 provides specific definitions for crew rest and flight duty limitation terminology. It defines a crew rest period as, “the non-duty period before the flight duty period begins. Its purpose is to allow the aircrew member the opportunity for adequate rest before performing in-flight duties. “Crew rest is free time, which includes time for meals, transportation, and rest.” (AFI 11-202V3.9.3.5, pg. 69) It further defines rest as “the condition which allows an individual the opportunity to sleep.” (AFI 11-202V3.9.3.5, pg. 69) Crew rest is normally 12 hours prior to the FDP and requires at least eight hours of uninterrupted rest within the specific time period. Any official business that results in crew rest interruptions (including telephone calls) results in eight additional hours of uninterrupted rest with additional time provided to dress, eat, travel, etc.

The AFI defines the Flight Duty Period as “a period that starts when an aircrew reports for a mission, briefing, or other official duty and ends when engines are shut down at the end of a mission, mission leg, or a series of missions.” (AFI 11-202V3.9.3.6.1, pg. 69) This definition is very similar to the Navy’s crew day and FAA’s duty period definitions and essential covers the same periods of duty. The Air Force also details the maximum FDP based on the aircraft type; a descriptive chart is provided below with the published guidelines.

Flight time regulations are established for all T/M/S aircraft on larger time scales. Total flight time is limited to 125 hours within any 30 consecutive day period and 330 hours within any 90-day period. The instruction has provided other scheduling restrictions that cover SCUBA diving, hypobaric chambers, blood donations, and alcohol consumption. The final portion of the instruction includes waiver authority, which permits MAJCOM/DO (or ANG/XO) to extend the maximum FDP up to two additional hours if the mission priority justifies the risk of fatigue. The pilot in command (PIC) is authorized this authority if circumstances arise that prohibit the ability to contact the regular approval authority. This is a necessary delegation of authority due to the nature of military operations in which aircrew often operate under electronic emissions restrictions or outside of communication reception ranges.

AFI 11-202 Volume 3 Chapter 9 Table 9.1

Type Aircraft	Basic Aircrew	Augmented Aircrew
Fighter, Attack, or Reconnaissance (Single Control)	12	
Fighter, Attack, or Reconnaissance (Dual Control)	12	16 (Note 1)
Bomber or Reconnaissance (Single Control)	12	
Bomber, Reconnaissance, or Battle Management (Dual Control)	16	24
Transport	16 (Note 2)	
Transport (Sleeping Provisions)	16	24
Tanker	16	
Tanker (Sleeping Provisions)	16	24
Trainer	12	16 (Note 1)
Rotary Wing (without Auto Flight Control System)	12	14 (Note 1)
Rotary Wing (with Auto Flight Control System)	14	18 (Note 1)
Utility	12	18 (Note 1)

NOTES:

1. Applies when basic aircrew requires only one pilot and a second qualified pilot (includes pilots enrolled in a formal AFCAT 36-2223 aircrew training course) is designated an aircrew member to augment pilot duties.

2. For the purpose of this paragraph, the T-43 and the T-39 may be considered transport.

Table 2. United States Air Force Flight Duty Period Time Regulations

In summary, there are strong similarities among the FAA, Navy, and Air Force regulations regarding aviation crew rest and length of crew day. While there are subtle differences in wording and structure that reflect the different nature of operations among the organizations, the underlying theme is a detailed framework of guidelines set forth to govern the flight scheduling process and enhance safety in operations. These instructions acknowledge the importance of mitigating fatigue and its physiological effects on human performance. While they do not directly instruct schedulers and aviators on how best to mitigate these risks in flight scheduling, they leave a design opportunity for aviators, schedulers, and researchers to develop their own scheduling methods to best balance the operational needs of the organization with the physiological needs of the operators.

D. DEPARTMENT OF DEFENSE AVIATION FATIGUE MANAGEMENT MODELS AND SOFTWARE

Over the past four decades, the U.S. Department of Defense (DoD) has been heavily involved in the research and development of fatigue management models. This section of the chapter reviews the chronological evolution of fatigue research and the major models developed in DoD. It also provides an overview of the capabilities and limitations of different software applications developed to manage and assess fatigue in flight scheduling.

1. Sleep Performance Model

In the early 1980s, the Department of Defense (DoD) funded joint research between Walter Reed Army Institute of Research (WRAIR) and Scientific Applications International Corporation (SAIC) to investigate the relationship between sleep levels and effectiveness with regard to artillery ordnance employment. WRAIR later augmented these studies by conducting a major study in the 1990s that used wrist-worn activity monitors or actigraphs. These wrist-worn actigraphs, originally called Sleep and Activity Monitors (SAM), allowed researchers to collect activity and estimation of sleep on 66 subjects over the course of one week. They provided the means to compare real-time assessment of cognitive performance based on sleep patterns. The subjects were permitted normal sleep, partial sleep deprivation, or total sleep deprivation and performed psychomotor vigilance tasks under these three conditions. This sleep dose-response (SDR) study provided data used to formulate numerical estimations of parameters, which became the foundation of the Sleep Performance Model (SPM). It also clarified several sleep-related performance measures that became baselines in further model and software development.

The SPM takes an individual's retrospective sleep data to produce an estimate of current predicted effectiveness. The estimation can be applied to a specific individual or unit of operation. The feedback provided by the SPM can be used to identify when an individual needs more sleep, or substituting crewmembers, to mitigate the risk of fatigue. It can even be applied on a macro level by providing a weighting function representing the effects of fatigue on larger scale operations.

2. Sleep, Activity, Fatigue, and Task Effectiveness Model

After the development of SPM, further research was conducted by the U.S. Air Force Research Laboratory (AFRL). The Warfighter Fatigue Countermeasures (WFC) Program of the AFRL supported Dr. Steven Hursh in efforts to develop the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) Model. This model is based on sleep and circadian rhythm research conducted over many years. It was designed to consider a wide range of schedule and sleep conditions over any time period and produce valid performance predictions. Additionally, the circadian data were on subjects ranging from ages ranging from twenty to the mid-fifties to accurately model the demographics of the majority of operators.

SAFTE models how the human circadian process affects both sleep regulation and performance. In the model, sleep regulation entails hours of sleep and awake, current sleep debt, sleep fragmentation, and the circadian process. All of these factors influence quality of sleep. Performance encompasses the current balance of sleep regulation, sleep inertia, and the circadian process. This homeostatic model takes data inputs of recent sleep history and creates predictions of future performance of an individual or group. SAFTE was also developed to easily be amended to incorporate fatigue effects that specific to different operator communities. This allowed widespread operational usage in the scheduling of operations ranging from the railroad industry to military aviation.

While this model was an advancement of the SPM, it also has shortcomings that had to be addressed before usage. The severity of the shortfalls depends of the specific application. The first limitation is that the model does not directly address individual parameters such as age, time of day, or sleep requirements for maximum performance effectiveness. Additionally, it does not provide any form of group variance estimations about the average performance prediction. Essentially, these limitations may not affect large group scheduling or generic schedules. However, they have potentially consequential effects when dealing with individual performances. The DoD acknowledged these shortcomings and funded research for further development.

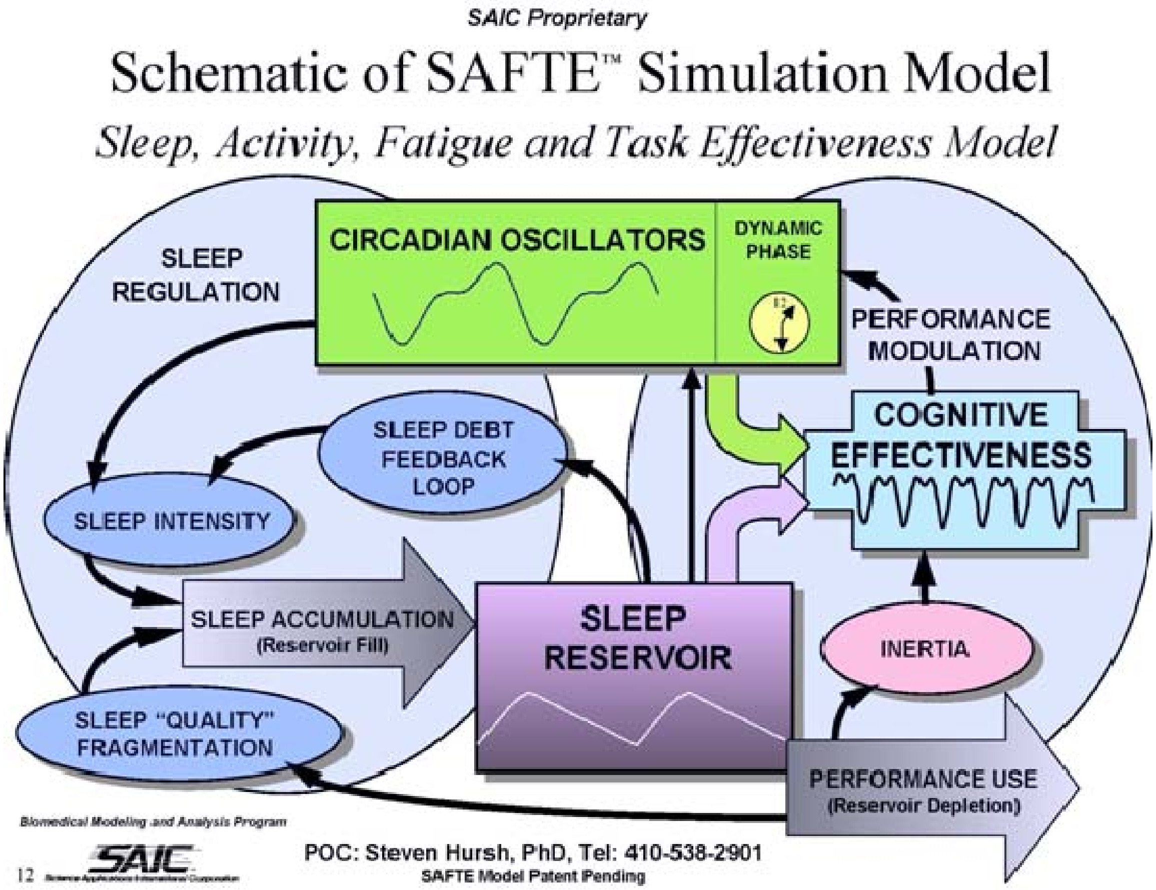

Figure 1. SAFTE Model Schematic (Hursh, 2003)

The Air Force awarded a contract to NTI, Inc. and Science Applications International Corporation (SAIC) to develop a software application of the fatigue modeling research under a Small Business Innovation Research (SBIR) grant. The end product was the Fatigue Avoidance Scheduling Tool (FAST).

3. Fatigue Avoidance Scheduling Tool

The objective of creating FAST was to apply the SAFTE Model in a computer-based tool for operational planning and scheduling. The user is afforded graphical output and quantitative estimates to evaluate and compare predicted effectiveness in alternative scheduling scenarios, a function of fatigue and circadian variation as calculated by the SAFTE Model.

FAST is an interactive tool that relies heavily on user inputs. It provides predicted effectiveness estimates based on user-defined sleep/wake schedules. The user can select a desired time period ranging from six hours to 30 days to view the fatigue effect on a proposed schedule. FAST generates a graphical display of performance effectiveness over the desired period of time. In addition to the graph curve, the software also includes interpretation tools to aid the user. The familiar Windows menu structure allows a dashboard feature to be enabled. The fatigue indicator dashboard is a movable window that corresponds to a single point in time along the curve of the graphical performance estimate. The dashboard was designed to provide the user a detailed snapshot of the predicted effectiveness at a given time. The dashboard provides detailed statistics to aid scheduling of critical events. The output is divided into two major categories of performance and fatigue factors. The performance category is further divided into sub-categories of effectiveness, mean cognitive, lapse index, reaction time, and reservoir. The fatigue factors category entails sub-categories of sleep (amount of sleep within last 24 hours), chronic sleep debt, hours awake, time of day, and circadian phase de-synchrony. Finally, the top display of the dashboard has these fatigue factors listed with red flags next to any sub-category that is negatively affecting the overall performance effectiveness. The driving force behind the implementation of this feature was to aid in the analysis of factors that cause decreased predicted performance.

Other features of FAST are the color-coded graphical background and vertical axis display options. The graphical output is colored to enhance the ability to visualize degradation. The upper portion (greater than 90% effectiveness) of the graph is shaded green to represent a safe zone. The middle portion (between <90% and 65%

effectiveness) is shaded yellow to represent a caution zone. Finally, the bottom portion (<65% effectiveness) is shaded red to depict a danger zone. This familiar color scheme aids the user in deciding which portions of the schedule need further analysis. The right-hand vertical axis display compliments this feature by allowing the user to select criteria such as blood alcohol content (BAC) equivalence, lapse index (likelihood of attention lapse due to microsleep), sleep reservoir, and acrophase (time at which the peak of the circadian rhythm occurs) as an overlay on the graph. This provides the user a quick and simple indication of the severity of degradation in predicted effectiveness.

There are assumptions and limitations incorporated into FAST. FAST requires the user to input past and future schedule times. It accounts for time as either on-duty, sleeping, or awake and off-duty. The program allows the user to rate the quality of sleep using four descriptive levels; excellent, good, fair, and poor, that directly correlate to performance effectiveness. This level of detail is essential in accurate fatigue modeling in harsh sleeping environments such as aboard naval vessels. Factors such as machinery noise and excess movement from heavy seas can have varying effects on sleep in individuals. However, FAST contains no method to factor the effects of fatigue countermeasures such as sleep aids and alerting drugs such as caffeine, which may play a significant role in sleep quality. The most significant limitation to this software is the time required to use it. FAST is very detailed and gives the user a high level of feedback, but is costly in terms of time resources. This factor was the leading cause for movement toward developing a software application that encompassed the key benefits of FAST but focused on ease of use seen in FlyAwake. The FlyAwake effort focused on the production of fatigue assessment software that is easy to use and immediately deployable to the military units at strategic, operational, and tactical levels.

4. FlyAwake

While FAST effectively applied the SAFTE algorithm in scheduling, it has been limited because of usable issues. It has been helpful in safety investigations and research, but its complex user interface has prevented it from being integrated into operational squadrons. However, after two significant fatigue related mishaps in 2007, the Air National Guard (ANG) 201st Airlift Squadron began using FAST to model aircrew fatigue in their flight schedules. After six months of FAST utilization, Lt. Col. Edward Vaughn, of the USAF Air National Guard Safety Center, obtained funding from the Defense Safety Oversight Council (DSOC) of the Office of the Secretary of Defense (OSD) in order to contract development of an improved software program. The objective was to develop a web-based software program based on the SAFTE algorithm with a graphical user interface (GUI) that reduced workload requirements for schedulers and was deployable at the squadron level.

The Air National Guard and MacroSystems, Inc. began developing FlyAwake in late 2007. Air National Guard pilots from 20 wings were recruited to assist in the software development by providing user feedback in order to tailor the product specifically to scheduler needs. A major burden identified by FAST critics was data entry into the software program. In order to alleviate this burden, FlyAwake was developed with pre-populated data specific to a squadron's Type/Model/Series (T/M/S) aircraft such as missions and duties. This improved graphical user interface (GUI) significantly decreases laborious typing of data by schedulers and aircrew. It also has default settings for mission brief, launch, recovery, and debrief times in order to further reduce the workload. However, the user has the ability to customize the schedule as necessary to input an accurate depiction of a work cycle or flight schedule. FlyAwake takes the user inputs and performs a fatigue algorithm that accounts for the duty cycle and sleep history of an aircrew, and provides an accurate assessment of overall fatigue levels.

FlyAwake steadily gained support in the aviation safety community as a result of its success in fatigue modeling and assessment. Specifically, the U.S. Air Force Patriot Excalibur (PEX) program and the Air Mobility Command (AMC) Tactical Airlift Control Center (TACC) were interested in incorporating FlyAwake into their scheduling processes. As a result, the DSOC again funded the ANG, which contracted with MacroSystems to create a second version with the ability to communicate with other software scheduling programs. FlyAwake v2.0 was released during the summer of 2009 and can now be integrated into existing flight scheduling. This capability provides the user with fatigue mitigation recommendations to provide flight-scheduling optimization for fatigue management.

The DSOC encouraged the software developers of FlyAwake to make it into a joint military application. In effort to support this requirement, the second contract with MacroSystems also included the incorporation of FlyAwake with the Joint Air Logistics Information System (JALIS). JALIS is multi-service coordinated air logistics scheduling program and decision support tool servicing Operational Support Airlift Agency (OSAA) and Navy Unique Fleet Essential Aircraft (NUFEA). However, due to compatibility issues and contract time constraints, the decision was made to replace the JALIS requirement with the U.S. Navy Sierra Hotel Aviation Readiness Program (SHARP). This modification allows the immediate incorporation of FlyAwake into a large aviation community of software users and may ultimately enhance safety in Naval Aviation.

Innova Systems, the software development company of SHARP, is currently working with MacroSystems under the guidance of Commander, Naval Air Forces (CNAF) to produce a version of SHARP with the built-in functionality of FlyAwake for the October 2009 version release. This version will be available for designated squadrons for usability testing in the fleet. Further dissemination of SHARP versions with FlyAwake integrated capabilities will depend on the CNAF evaluation of the feedback provided from test squadrons.

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III. METHODS

A. OVERVIEW

The objective of this thesis is to conduct a comparative analysis of U.S. Navy flight schedules using current baseline fatigue-related scheduling against flight scheduling that uses FlyAwake software. Retrospective flight schedules were analyzed for aircrew fatigue levels using FlyAwake and then compared against alternative scheduling options with the aid of FlyAwake. Section B describes the method for the aircrew data collection and the selection process. Section C covers the data input procedures and data output that processes the flight scheduling data through FlyAwake. Finally, Section D describes the analytical strategy employed during the flight schedule comparison.

B. AIRCREW DATA COLLECTION

The retrospective aircrew data were obtained from the SHARP database of Helicopter Antisubmarine Squadron Light Four Two (HSL-42). Permissions and administrative rights were granted by Innova Systems for full access to all functions of SHARP within the HSL-42 squadron. Previously completed and executed flight schedules, scheduled ground events, special scheduling requests (referred to by aircrew as "snivels"), aircrew qualifications, pilot logbooks, and currency reports were all exported from SHARP into Excel spreadsheets for analysis.

After the access to SHARP data was granted, the process of selecting an appropriate date range for the analysis of data was necessary. The process of transferring data between SHARP and FlyAwake required extensive manual user input at this stage of development of the analysis. This limitation led to the selection of one month as an appropriate time frame for the analysis. February 2008 was selected for several reasons. to. It had a standard operations tempo (OPTEMPO), was sufficiently past the holiday season to minimize the number of aircrew on vacation. In addition, it was mid-quarter so the operations department usually has a solid projection of flight hours remaining in the second quarter, and it was a month that is generally associated with detachment underway and deployment cycles.

The final challenge in the selection process was the isolation of a specific group of aircrew for analysis. February 2008 had two separate detachments with underway periods, which conducted workups for their upcoming deployments. These detachments were chosen in order to provide a glimpse into the benefits that FlyAwake affords while flight scheduling at homeguard with a large pool of pilots versus underway scheduling with a limited pool of only five (in the case of this analysis) which limits the options for a detachment operations officer. Additionally, the selection of detachment pilots conducting operations underway bounded the analysis by significantly reducing the flight scheduling variability that is present when analyzing schedules of an entire squadron. The detachments embarked on their respective ships and only had scheduling access to their five assigned pilots. This restriction assisted in the analysis by limiting certain aircrew dynamics that cannot be captured by a software database. Flight scheduling events and time frames are always approved and/or assigned by higher authority and disseminated through the Air Tasking Order (ATO), translating into reduced freedom and ability for detachments to build their own flight schedules. While the homeguard operations department also has some mandated time commitments to honor, overall they usually have much more freedom and flexibility in their flight schedules. In summary, February 2008 provided the ability to sufficient bound the analysis in order to provide a realistic and valid approach to conducting this comparison.

C. PROCEDURES

The first procedure following the completion of the collection and selection of the aircrew data set was filtering the data to extract only the desired aircrew members. The data set was contained in Excel spreadsheets and was filtered and organized chronologically for ease of processing through FlyAwake. An example of the data set is provided in Figure 2 with aircrew names removed.

	A	B	C	D	E	F	G	H	I	J	K
1	LAUNCH	light Tim	TFT	SIDE	CREW 1	CREW 2	CREW 3	CREW 4	CREW 5	MISSION 1	ICAO
2	2/29/2008 3:25 PM	15:25 - 18:20	2.9	426						Log/Sked	FF59/FF59
3	2/29/2008 2:00 PM	14:00 - 15:20	1.3	426						SSC	FF59/FF59
4	2/29/2008 9:15 AM	09:15 - 12:45	3.5	426						SSC	FF59/FF59
5	2/28/2008 7:30 PM	19:30 - 23:00	3.5	423						MIO TRNG	KNRB/KNRB
6	2/28/2008 4:00 PM	16:00 - 19:00	3	423						MIO TRNG	FF28/FF28
7	2/28/2008 3:30 PM	15:30 - 18:24	2.9	426						ASUW Trng	FF59/FF59
8	2/28/2008 12:30 PM	12:30 - 15:30	3	423						SSC	FF28/FF28
9	2/28/2008 12:00 PM	12:00 - 14:55	2.9	426						ASUW Trng	FF59/FF59
10	2/28/2008 8:30 AM	08:30 - 11:25	2.9	426						ASUW Trng	FF59/FF59
11	2/27/2008 5:00 PM	17:00 - 18:00	1	423						Det Fly	KNRB/KNRB
12	2/27/2008 4:30 PM	16:30 - 19:00	2.5	426						GunEx G16	FF59/FF59
13	2/26/2008 12:25 PM	12:25 - 15:00	2.6	426						SSC	FF59/FF59
14	2/26/2008 8:30 AM	08:30 - 11:30	3	423						Log/Sked	FF28/KNRB

Figure 2. Excel Spreadsheet Containing Detachment Executed Flights

Logged flights for each pilot were processed through FlyAwake in order to calculate the predicted effectiveness. Access to FlyAwake is via the internet and the initial screen prompts the user to select the aircraft specific to the analysis. For the purposes of this study, the F-15 was selected because there was not a functional helicopter option in FlyAwake at the time of analysis. The selection of the F-15 option was primarily for ease of data input. The aircraft selection does not affect the fatigue algorithm, but only changes the preset options that are specific to each aviation community such as standard flight scheduling time frames, mission types, and number of aircrew. This study focused only on the scheduling of pilots, which was a similar setup as the F-15 option. Additionally, the F-15 option contained both FAM (Familiarization) and FCF (Functional Check Flight) flight options, which were appropriately complex for the current analysis. The type or difficulty of the flight event selected in this procedure also had no effect on the algorithm. Sample screenshots of the user interface are provided in Figure 3, Figure 4, and Figure 5.

Figure 3. FlyAwake Aircraft Selection Screenshot

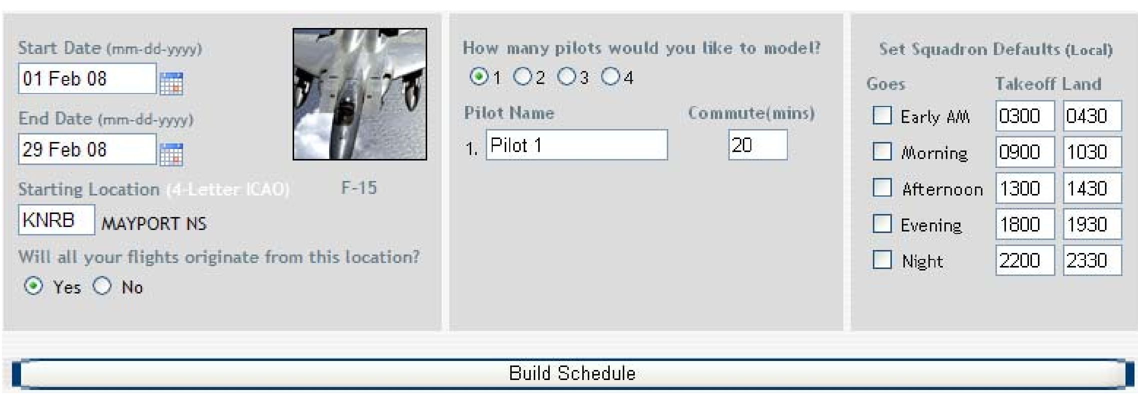

Figure 4. FlyAwake Schedule Builder Screenshot

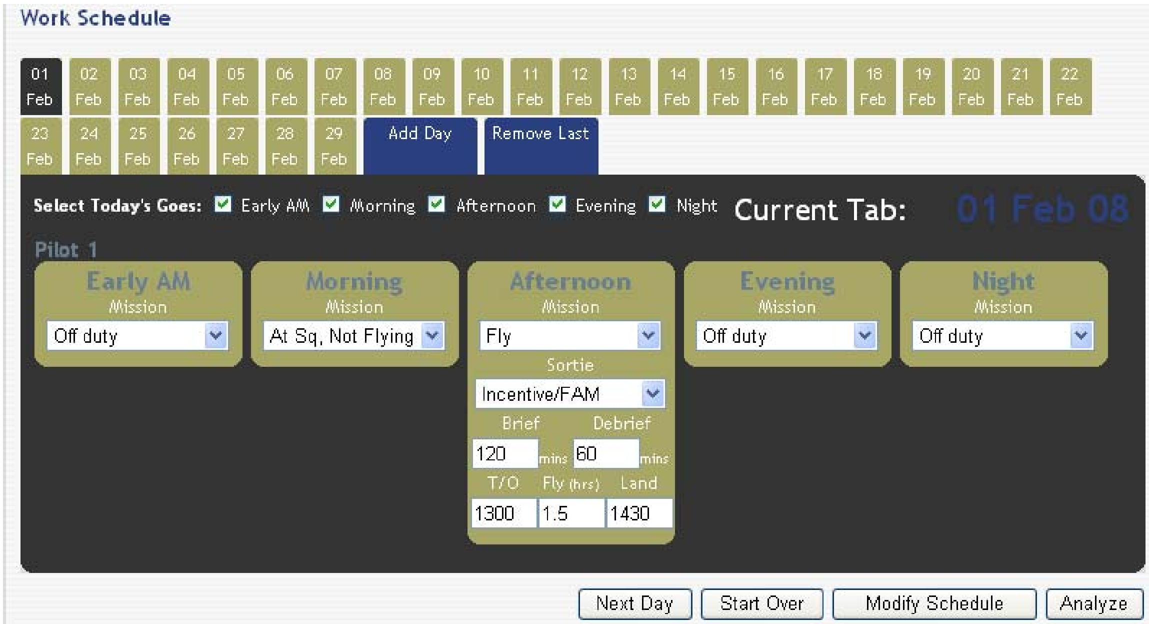

Figure 5. FlyAwake Work Schedule Builder Screenshot

After the aircrew data set was input, FlyAwake generated a graphical display of the predicted effectiveness over time for each pilot. An example of this output is provided in Figure 6.

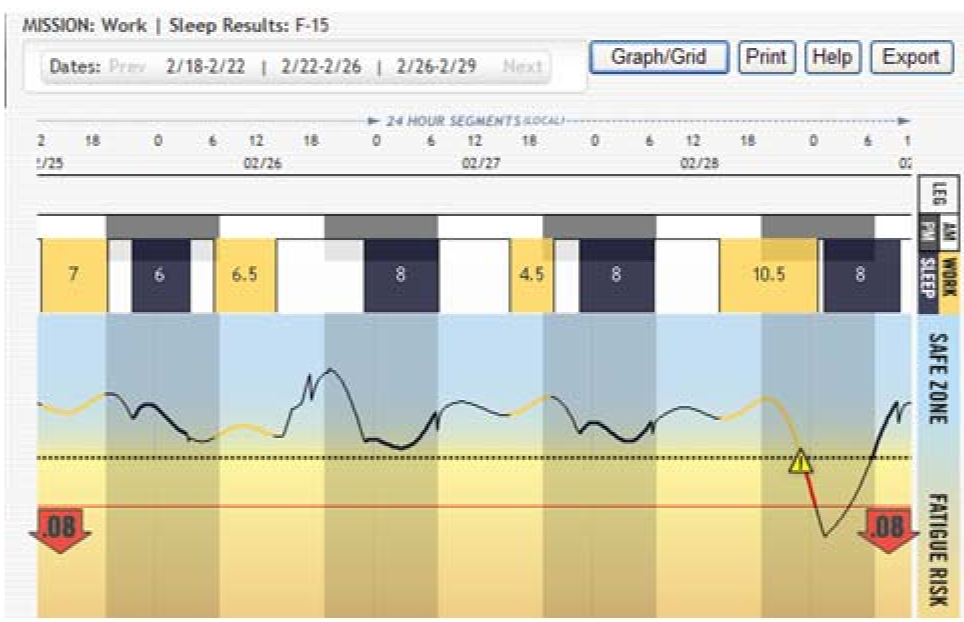

Figure 6. FlyAwake Graphical Output Screenshot

The graph in Figure 6 displays the predicted effectiveness on the y-axis with respect to time on the x-axis. It also provides overlays of day and night time, periods of work and sleep, and the safe zone versus the fatigue risk zone to visually aid the user. Every graphical display has a horizontal dashed line, which indicates the 77.5% predicted effectiveness threshold. This threshold is currently used by the Air National Guard (ANG) as the minimum level of acceptable in-flight predicted effectiveness when scheduling flight operations. This threshold also served as the baseline for scheduling recommendations or changes in the analytical strategy of this study.

FlyAwake also gives the user an option to export the row data from the graphical display shown previously in Figure 6. An example of the raw FlyAwake data export is provided in Figure 7. The data set is exported from FlyAwake in vertical columns representing zulu time, local time, schedule type (None, Sleep, or Work), and predicted effectiveness percentage. These data exports were saved as a .txt files and later imported into Excel spreadsheets for statistical analysis.

2/4/2008 8:10:00 PM	2/4/2008 3:10:00 PM	2/4/2008 3:10:00 PM	None	83.5697129766345
2/4/2008 8:11:00 PM	2/4/2008 3:11:00 PM	2/4/2008 3:11:00 PM	None	83.57259757679 (
2/4/2008 8:12:00 PM	2/4/2008 3:12:00 PM	2/4/2008 3:12:00 PM	None	83.5756312232575
2/4/2008 8:13:00 PM	2/4/2008 3:13:00 PM	2/4/2008 3:13:00 PM	None	83.5788140193625
2/4/2008 8:14:00 PM	2/4/2008 3:14:00 PM	2/4/2008 3:14:00 PM	None	83.5821460516447
2/4/2008 8:15:00 PM	2/4/2008 3:15:00 PM	2/4/2008 3:15:00 PM	Work	83.585627389815 (
2/4/2008 8:16:00 PM	2/4/2008 3:16:00 PM	2/4/2008 3:16:00 PM	Work	83.5892580867132
2/4/2008 8:17:00 PM	2/4/2008 3:17:00 PM	2/4/2008 3:17:00 PM	Work	83.5930381782676
2/4/2008 8:18:00 PM	2/4/2008 3:18:00 PM	2/4/2008 3:18:00 PM	Work	83.5969676834557
2/4/2008 8:19:00 PM	2/4/2008 3:19:00 PM	2/4/2008 3:19:00 PM	Work	83.6010466042665
2/4/2008 8:20:00 PM	2/4/2008 3:20:00 PM	2/4/2008 3:20:00 PM	Work	83.6052749256641
2/4/2008 8:21:00 PM	2/4/2008 3:21:00 PM	2/4/2008 3:21:00 PM	Work	83.6096526155531

Figure 7. FlyAwake Data Export Screenshot

After the data set was imported and saved as an Excel spreadsheet, it required filtering for analysis. This study focused only the predicted effectiveness percentages of the pilots when they were executing a scheduled flight. In this study, work was defined as a combination of the preflight, in-flight, and post-flight duties associated with flight operations. Each flight was assigned a value of 120 minutes for preflight duties to account for time in briefs, planning, weather analysis, aircraft inspection, and all aircraft ground preparations executed before takeoff. Post-flight was assigned a value of 60 minutes to capture duties such as engine waterwash, completion of Maintenance Action Forms (MAF), logging the flight details into SHARP, and debriefs. Any time that a pilot was either at the squadron or on the ship in a non-flying capacity was included in the analysis of predicted effectiveness in this study. However, it was considered as a contributing factor to overall fatigue levels and subsequently inputted into the FlyAwake schedule builder module. This required considerable attention to detail and a manual comparison of data to logbooks to ensure that only flights that were actually executed remained in the spreadsheets that were used for analysis.

The predicted effectiveness percentages were then color-coded into four categories, highlighted accordingly, and used in the later analysis. An example of this is depicted in Figure 8.

3375	2/29/2008	3:27:00	AM	2/28/2008	10:27:00	PM	Work	80.28877
3376	2/29/2008	3:28:00	AM	2/28/2008	10:28:00	PM	Work	80.22071
3377	2/29/2008	3:29:00	AM	2/28/2008	10:29:00	PM	Work	80.15238
3378	2/29/2008	3:30:00	AM	2/28/2008	10:30:00	PM	Work	80.08377
3379	2/29/2008	3:31:00	AM	2/28/2008	10:31:00	PM	Work	80.01488
3380	2/29/2008	3:32:00	AM	2/28/2008	10:32:00	PM	Work	79.94571
3381	2/29/2008	3:33:00	AM	2/28/2008	10:33:00	PM	Work	79.87627
3382	2/29/2008	3:34:00	AM	2/28/2008	10:34:00	PM	Work	79.80656
3383	2/29/2008	3:35:00	AM	2/28/2008	10:35:00	PM	Work	79.73659
3384	2/29/2008	3:36:00	AM	2/28/2008	10:36:00	PM	Work	79.66634
3385	2/29/2008	3:37:00	AM	2/28/2008	10:37:00	PM	Work	79.59583
3386	2/29/2008	3:38:00	AM	2/28/2008	10:38:00	PM	Work	79.52506

Figure 8. FlyAwake Data Imported into Excel Spreadsheet

The predicted effectiveness ranges were represented by the colors green, yellow, red, and black. Green represents predicted effectiveness above 82.5%, yellow represents predicted effectiveness calculations equal to or less than 82.5% but above 80.0%, red represents calculations equal or less than 80.0% but above 77.5%, and black represents calculations equal of less than 77.5%. Table 3, Categories of Predicted Effectiveness Ranges, displays these categorical ranges.

Category	Predicted Effectiveness Range
Green	PE > 82.5
Yellow	80.0 < PE ≤ 82.5
Red	77.5 < PE ≤ 80.0
Black	PE ≤ 77.5

Table 3. Categories of Predicted Effectiveness Ranges

The final procedure in this study was to statistically test whether the predicted effectiveness percentages calculated by FlyAwake aids a squadron operations department when constructing a flight schedule. A baseline condition was required in order to conduct a statistical comparison. The descriptive statistics tool available in Excel was utilized to calculate the mean, maximum, minimum, and range of predicted effectiveness percentages for each pilot and detachment. Additional data, including the number of occurrences and percentage of time in each category, were also collected for each pilot and detachment. These metrics served as a baseline measurement of effectiveness for this study. Identical procedures were followed when changes were incorporated to reflect the changes identified by FlyAwake. The analytical strategy employed in order to feasibly incorporate this knowledge is discussed in Section D.

D. ANALYTICAL STRATEGY

The analytical strategy of this study was intentionally conservative. The overall objective was to preserve the validity of the analysis by incorporating changes that minimized alterations to the previously executed flight schedules. Specifically, this prohibited altering any takeoff or landing times. This eliminated the option of shifting takeoff and landing times in order to minimize pilot exposure to reduced predicted effectiveness calculations. The basis of this analytical restriction is due to the often rigid nature of flight scheduling when conducting shipboard operations. This is a reality with which every squadron operations officer is familiar.

The threshold represented by the black category (i.e., less than or equal to 77.5% predicted effectiveness) served as the baseline for flight schedule change consideration. As mentioned in Section C, this is the current scheduling baseline for the 201st ANG.

Any occurrence in this category served as a highlighted event for analysis. Each occurrence in the black was either assigned a recommendation for action or an alternate crew composition. All considerations of an operations officer were simulated. These include pilot qualifications, currency requirements, crew day, crew rest, duty schedules, ground events, medical status, and snivels when implementing a crew change. A recommendation for action was issued whenever a crew change was deemed unfeasible. These recommendations included exercising extra vigilance, naps, and the substitution of rested pilots for engine waterwash and aircraft traversing during post-flight duties. Chapter IV contains a detailed discussion of the results of this analysis.

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IV. RESULTS

The purpose of this chapter is to present and summarize the results produced from the methods discussed in Chapter III. An overview is presented in Section A and the results for the helicopter air detachments embarked on USS BOONE (FFG-28) are covered in Section B, with results for USS KAUFFMAN (FFG-59) in Section C.

A. OVERVIEW

This section provides an overview of the historical flight profiles for both USN aviation detachments. This information illustrates the portion of the flight duty period (FDP) which was used in the current study. The total SHARP data set from February 2008 contained 192.2 flight hours, which translated into 498.2 cumulative hours of individual pilot FDP. These data were exported from SHARP into Excel, manually input into FlyAwake, and then exported from FlyAwake into Excel for analysis. This information was exported in one-minute increments (29,892 separate observations) by FlyAwake (Shown in Figure 8). Of these 29,892 rows of aircrew data, only a small portion was identified by FlyAwake as potentially high risk to the aircrew. This pays tribute to over four decades worth of safety research that focused on crew day and crew rest and the effectiveness of current USN aircrew scheduling practices. These regulations are discussed in Chapter II.

Figures 9, 10, and 11 display the actual percentages of preflight, in-flight, and post-flight times identified by FlyAwake for each fatigue category during February 2008. As displayed in Table 3 (located in Chapter III), the green category refers to predicted effectiveness ranges greater than 82.5%, the yellow category is the interval 80.0% to 82.5%, the red category is the interval 77.5% to 80.0%, and the black category is less than or equal to 77.5%. As seen in these figures, only a small percentage of time actually falls in the critical black category. During the preflight phase, 100% of the pilots fell into the green category (that is, FlyAwake did not identify any instances where pilots were vulnerable to fatigue). Less than one percent (0.93%) of the in-flight duty time fell in the black category. While this is a small percentage of the total flight profile, this equates to 1.79 hours of flight time, which is a considerable length of time for fatigued pilots who are controlling an aircraft. Nearly 20% (19.4%) of the post-flight phase falls into the black or "danger" category. These occurrences in the post-flight phase are the focus of the current analysis. Sections B and C contain detailed discussions of these results, but the significant increase of time in the black category during the post-flight phase can be attributed to night flights and multiple missions.

These figures illustrate that the current scheduling regulations are quite effective. However, FlyAwake is a decision support tool designed to highlight those aircrew at high risk of fatigue during their FDP. The OPTEMPO of the operations department is usually high and the availability of a decision support tool to automatically aid scheduler identification of fatigued aircrew is a tremendous asset.

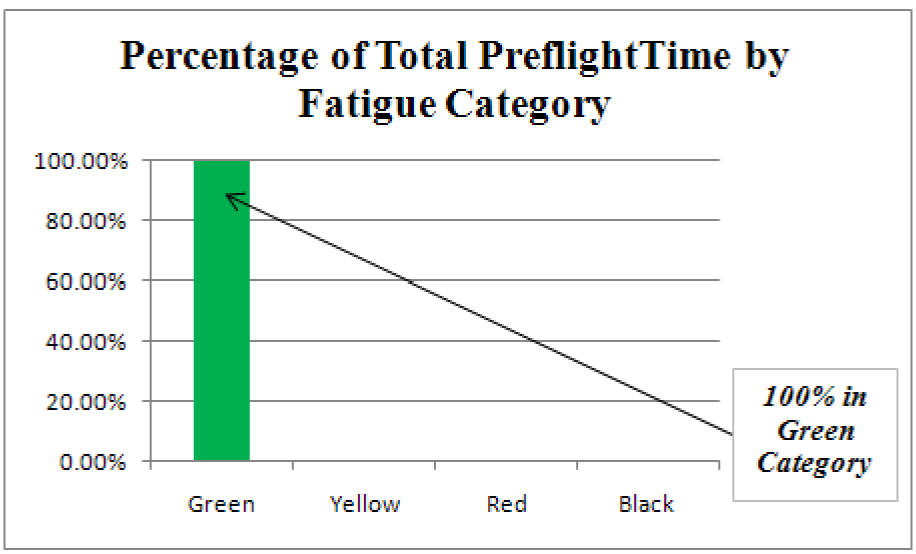

Figure 9. Percentage of Total Preflight Time by Fatigue Category

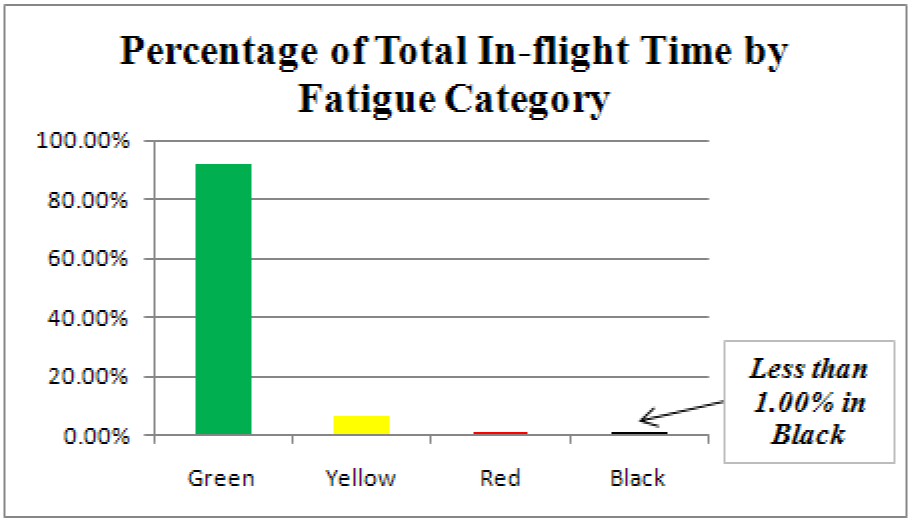

Figure 10. Percentage of Total In-flight Time by Fatigue Category

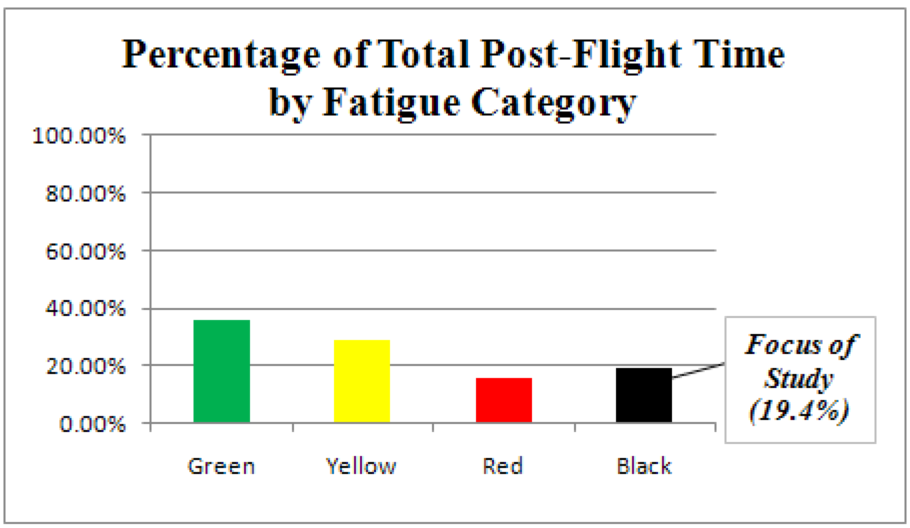

Figure 11. Percentage of Total Post-Flight Time by Fatigue Category

B. USS BOONE (FFG-28) AIR DETACHMENT

The first detachment analyzed was embarked on the frigate, USS BOONE, for the majority of flights logged in February 2008. The pilots logged 62.2 (70.4%) of their 88.3 February 2008 flight hours while embarked on BOONE. The detachment was assigned one SH-60B helicopter and five pilots to support air operations onboard the frigate during this pre-deployment workup cycle. There were also aircrewmen and aviation maintenance personnel attached to the detachment, but these individuals were omitted from the analysis. The following paragraphs discuss the results.

FlyAwake indentified five of the 33 flights logged by the detachment as having one or more pilots in the black category at some portion of their work period. Of the five flights, only two flights were considered feasible candidates for schedule changes. Both changes consisted of eliminating prolonged night flights by altering crew composition. Specifically, the pilots who were highlighted in the black category had been scheduled for two consecutive flights (referred to as a "double bag") in which at least one flight was completely at night. In this case, using alternative crew compositions for night flight operations reduced the exposure of the pilots in the black category (predicted effectiveness ≤ 77.5%). The results are displayed in Table 4 and are further analyzed in the following sections.

FFG-28 Detachment Summary	
Total Flight Hours Logged	88.3
Number of Flights with at Least One Detachment Pilot	33
Number of Flights Identified by FlyAwake as Potentially Hazardous	5
Number of Flights Changed due to FlyAwake	2

Table 4. Overview of FFG-28 Detachment Changes

The categorical data analysis measured the scheduling effectiveness after implementing FlyAwake by calculating the percentages of time exposure per category, the number of occurrences per category, and the distribution by phase of flight for occurrences in the black category. The percentages of time in each predicted effectiveness category are displayed in Table 5 and graphically in Figure 12. The results showed increased percentages of time in both green and yellow categories and corresponding decreases in red and black categories. Most significant were the 4.15% and 5.01% relative decreases of time spent in red and black categories.

Percentages of Time in Fatigue Categories (FFG-28)				
	Before FlyAwake	After FlyAwake	Difference	Percent Change
Green	89.97%	90.14%	0.18%	0.20%
Yellow	5.70%	5.72%	0.02%	0.36%
Red	2.01%	1.93%	-0.08%	-4.15%
Black	2.32%	2.21%	-0.12%	-5.01%

Table 5. FFG-28 Detachment Percentages of Flight Duty Period in Category

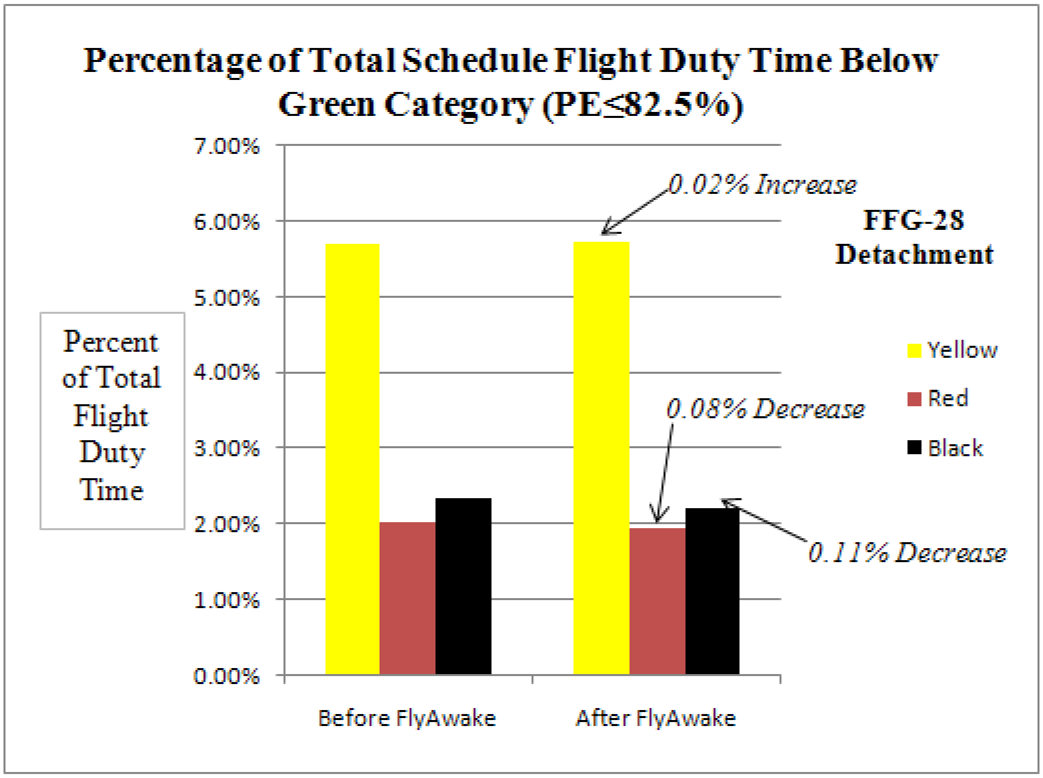

Figure 12. FFG-28 Detachment Percentage of Total Schedule Flight Duty Time Below Green Category

The next measure of effectiveness (MOE) was a tally of the total number of categorical occurrences per pilot. It was imperative to calculate this MOE with respect to each detachment pilot instead of each logged flight due to differences in flight scheduling at the homeguard squadron compared to shipboard operations. The detachment pilots are able to fly with any qualified pilot while at homeguard while they are restricted to only other detachment pilots while embarked. This explains the ambiguity between 33 total flights listed in Table 4 and 56 occurrences in the green category listed in Table 6 and Figure 13. The results showed no increase in occurrences in any category and a 12.50% decrease in the black category. The reduction of pilot occurrences in the black category resulted from a crew composition change.

Total Number of Occurrences by Fatigue Category (FFG-28)				
	Before	**After**	**Difference**	**Percent Change**
Green	56	56	0	*None*
Yellow	21	21	0	*None*
Red	10	10	0	*None*
Black	8	7	-1	-12.50%

Table 6. FFG-28 Total Number of Occurrences by Fatigue Category

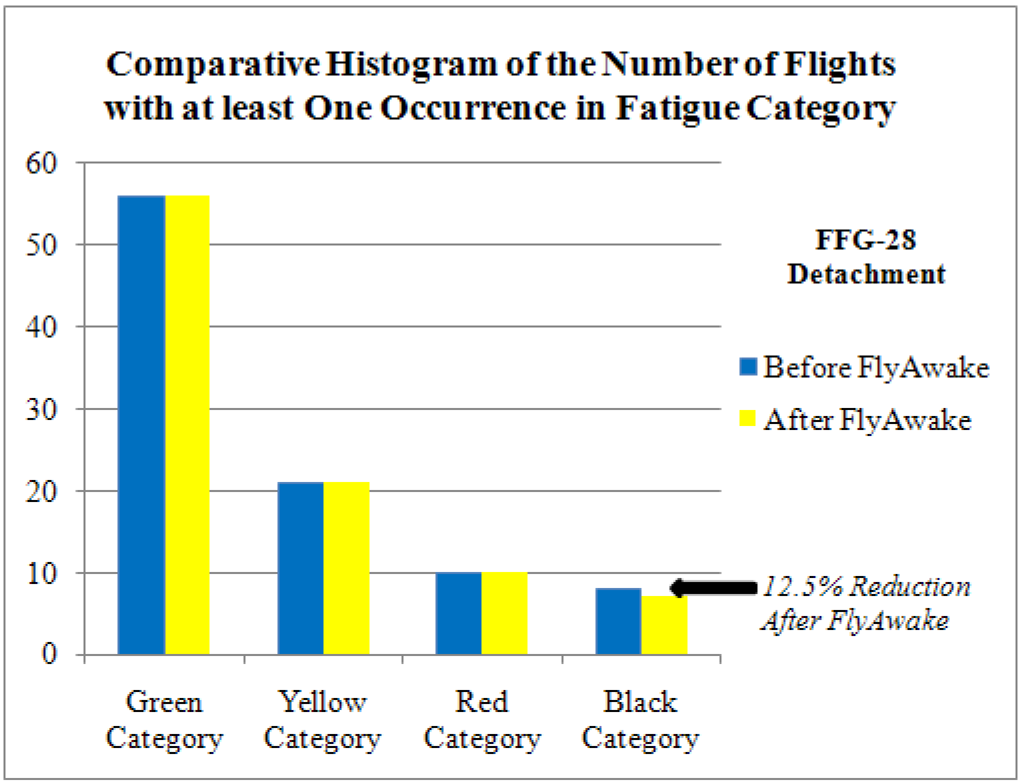

Figure 13. FFG-28 Detachment Comparative Histogram of the Number of Flights with at least One Occurrence in Fatigue Category

The study categorically divided each flight into preflight, in-flight, and post-flight phases in order to determine the specific timing of all eight occurrences in the black category before and after implementing scheduling changes. The results showed a 25.0% decrease of in-flight occurrences in the black fatigue category and a 12.5% decrease of post-flight occurrences in the black category. These results are displayed in Table 7 and in Figure 14.

Flight Phase Distribution of Occurrences in Black Category (FFG-28)			
	Preflight	**In-flight**	**Post-flight**
Number of Occurrences Before FlyAwake	0	4	8
Number of Occurrences After FlyAwake	0	3	7
Difference	0	-1	-1
Percent Change	0.0%	-25.0%	-12.5%

Table 7. FFG-28 Detachment Flight Phase Distribution of Occurrences in Black Category

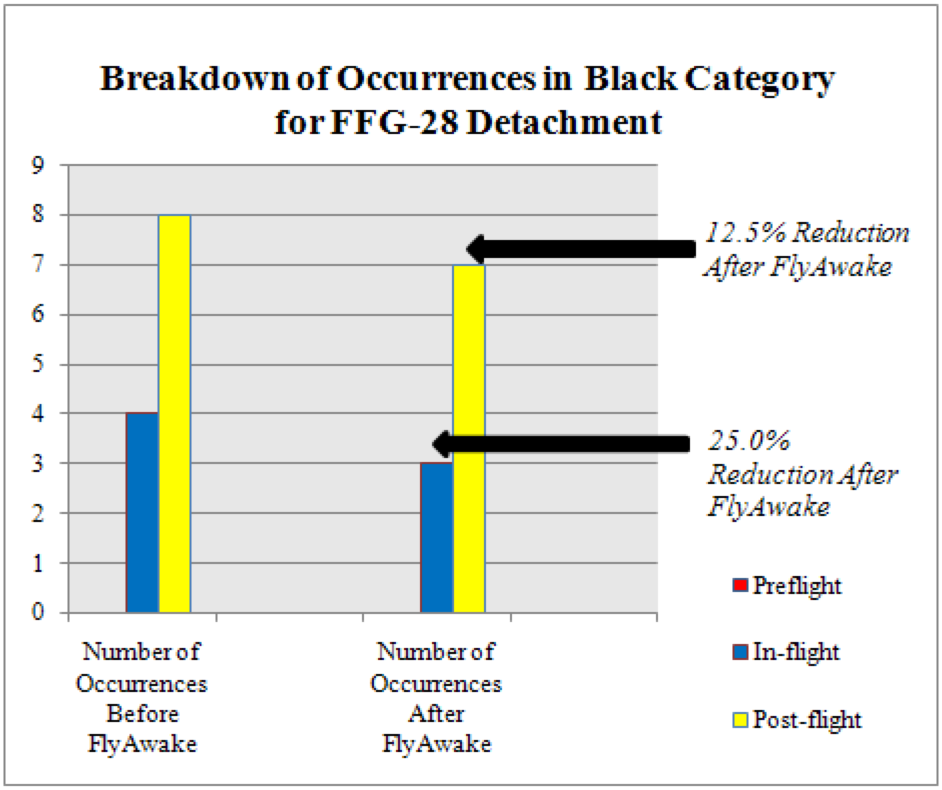

Figure 14. FFG-28 Detachment Breakdown of Flights with Occurrences in Black Category

C. USS KAUFFMAN (FFG-59) AIR DETACHMENT

The second detachment that was analyzed was embarked on the frigate, USS KAUFFMAN, for the majority of the flights it logged in February 2008. The pilots logged 76.4 (73.5%) of their 103.9 February 2008 flight hours while embarked on KAUFFMAN. The detachment was assigned one SH-60B helicopter and five pilots to support air operations onboard the frigate during this pre-deployment workup cycle. There were also aircrewmen and aviation maintenance personnel attached to the detachment, but these individuals were omitted from this analysis. The following paragraphs discuss the results.

FlyAwake indentified four of the 38 logged flights by the detachment as having one or more pilots highlighted in the black category at some portion of the FDP. Of the four flights highlighted, only two flights were considered reasonable candidates for schedule changes. Similar to the USS BOONE Air Detachment, both changes consisted of eliminating prolonged night flights by altering crew composition. The results are displayed in Table 8 and are further analyzed in the following sections.

FFG-59 Detachment Summary	
Total Flight Hours Logged	103.9
Number of Flights with at Least One Detachment Pilot	38
Number of Flights Identified by FlyAwake as Potentially Hazardous	4
Number of Flights Changed due to FlyAwake	2

Table 8. Overview of FFG-59 Detachment Changes

The categorical data analysis measured the scheduling effectiveness after implementing FlyAwake by calculating the percentages of time exposure per category, the number of occurrences per category, and the distribution by phase of flight for occurrences in the black category. The percentages of time in each predicted effectiveness category are displayed in Table 9 and graphically in Figure 15. The results showed slight increased percentages of time in the green category and corresponding decreases in the yellow, red, and black categories. Most significant were the 14.53% and 20.00% relative decrease in time spent in red and black categories.

Percentages of Time in Fatigue Categories (FFG-59)				
	Before FlyAwake	After FlyAwake	Difference	Percent Change
Green	94.35%	94.86%	0.51%	0.54%
Yellow	3.92%	3.70%	-0.22%	-5.61%
Red	1.17%	1.00%	-0.17%	-14.53%
Black	0.55%	0.44%	-0.11%	-20.00%

Table 9. FFG-59 Detachment Percentages of Flight Duty Period in Category

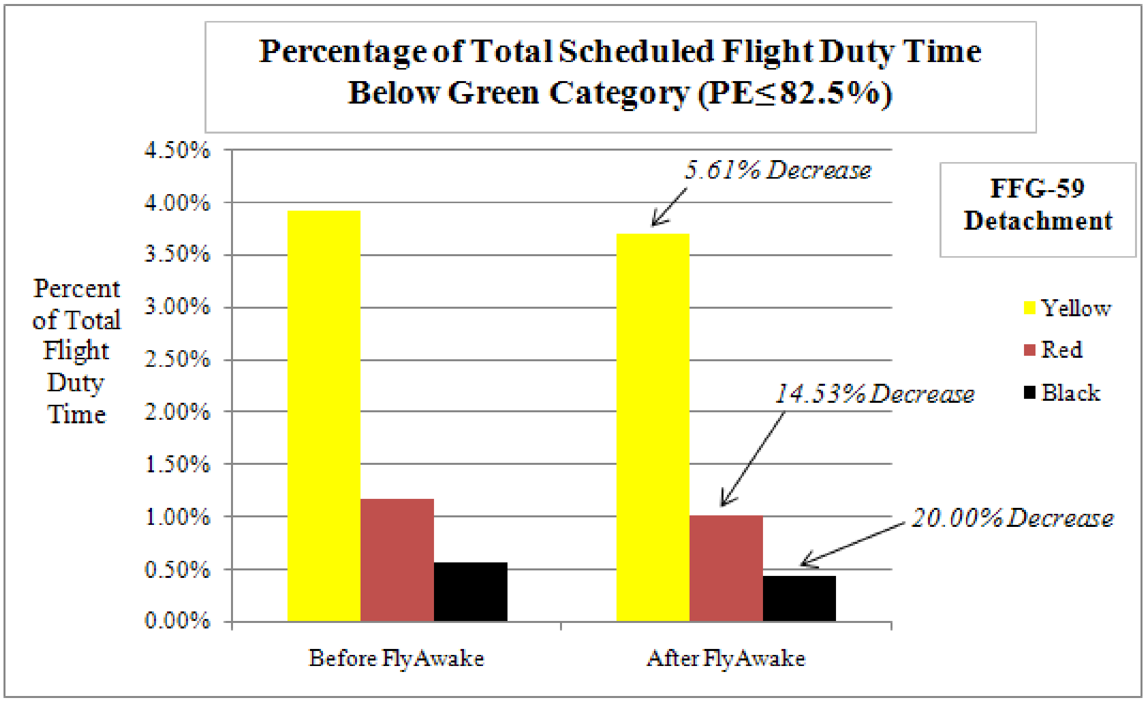

Figure 15. FFG-59 Detachment Percentage of Total Schedule Flight Duty Time Below Green Category

The next measure of effectiveness (MOE) was a tally of the total number of categorical occurrences per pilot. This MOE was calculated with respect to each detachment pilot, instead of with each logged flight, due to differences in flight scheduling at the homeguard squadron compared to shipboard operations. The detachment pilots are able to fly with any qualified pilot while at homeguard while they are restricted to only these detachment pilots while embarked. This explains the ambiguity between the difference of 38 total flights listed in Table 8 and 67 occurrences in the green category listed in Table 10 and Figure 16. The results showed no increase in occurrences in any category and a 16.67% decrease in the black category. The reduction of pilot occurrences in the black category resulted from a crew composition change.

Total Number of Occurrences by Fatigue Category (FFG-59)				
	Before	**After**	**Difference**	**Percent Change**
Green	67	67	None	*None*
Yellow	17	17	None	*None*
Red	8	8	None	*None*
Black	6	5	-1	-16.67%

Table 10. FFG-59 Total Number of Occurrences by Fatigue Category

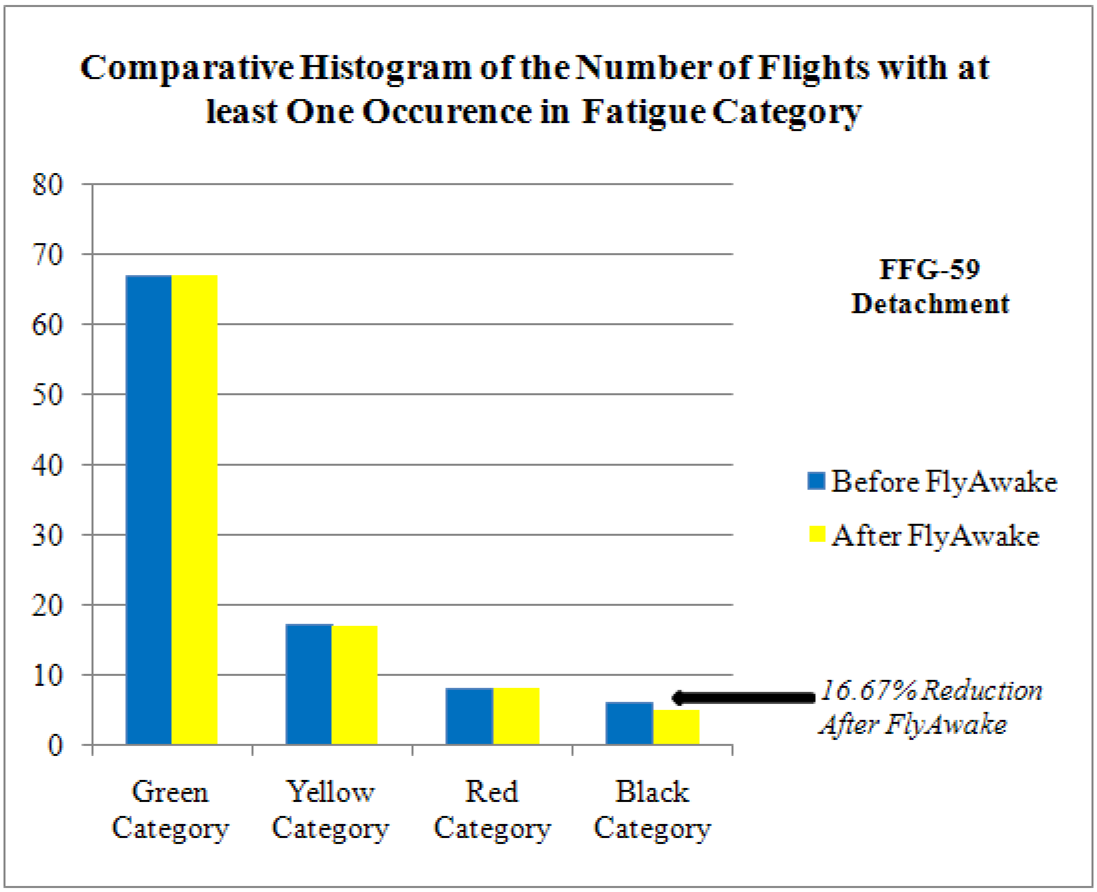

Figure 16. FFG-59 Detachment Comparative Histogram of the Number of Flights With At Least One Occurrence in Fatigue Category

Each flight was divided into preflight, in-flight, and post-flight segments in order to determine the specific timing of all eight occurrences in the black category both before and after implementing schedule changes. The results showed a 16.7% decrease of post-flight occurrences in the black category and are displayed in Table 11 and in Figure 17.

Flight Phase Distribution of Occurrences in Black Category (FFG-59)			
	Preflight	**Inflight**	**Postflight**
Number of Occurrences Before FlyAwake	0	0	6
Number of Occurrences After FlyAwake	0	0	5
Difference	0	0	-1
Percent Change	0.0%	0.0%	-16.7%

Table 11. FFG-59 Detachment Flight Phase Distribution of Occurrences in Black Category

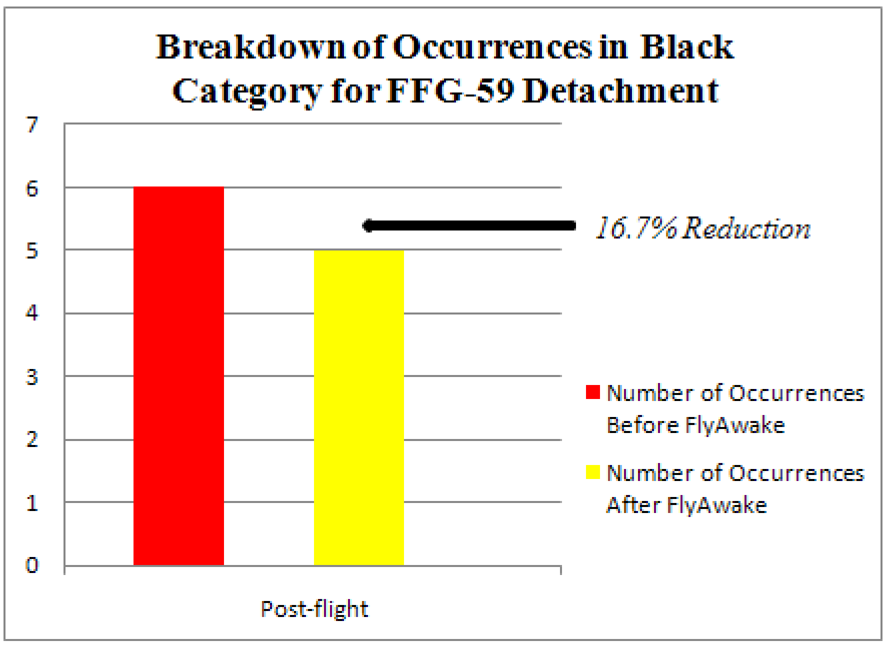

Figure 17. FFG-59 Detachment Breakdown of Occurrences in Black Category

V. ADDITIONAL THESIS EFFORTS

The objective of this chapter is to discuss the non-quantitative portion of this research. This original intent of this thesis was to program the SAFTE algorithm using Microsoft Visual Basic (VB) in order to process SHARP generated flight schedules for fatigue modeling assessments. The idea was that a scheduler could then analyze the algorithm's assessment and make changes where feasible. However, during the conceptual development planning of this model, it was discovered that achieving this method of assessment would result in a significant increase in workload for personnel in the Operations Department. This defied one of the original objectives of minimizing additional work for the flight schedulers in the Operations Departments. However, during the thesis research, we discovered that the ANG 201st had received funding for the development of a fatigue modeling software program, FlyAwake.

After learning that the ANG 201st was using FlyAwake, we contacted them to discuss the algorithm, software usability, and squadron scheduling procedures. Capt. Lynn Lee from the 201st ANG Wing offered the opportunity to merge FlyAwake, owned by MacroSystems, with the U.S. Navy's SHARP along with ongoing integrations with other DoD aviation scheduling software programs. Capt. Lee generated a contract modification and added SHARP, owned by Innova Systems, to the list of software available for integration.

This contract modification changed both the theme and scope of the thesis research. The thesis was no longer the development of a fatigue modeling scheduling tool, but instead involved conducting a proof of concept analysis for validation purposes of the integration of fatigue modeling into SHARP. This change of direction also translated into a change in roles and responsibilities for this thesis. In conjunction with formulating a method to conduct a proof of concept analysis, there were liaison responsibilities to coordinate the efforts between Innova Systems, MacroSystems, and CNAF. The coordination began with obtaining the necessary permissions to advance these efforts from CNAF and then engaging directly with the program managers and design teams of the two companies. After the Non-Disclosure Agreement (NDA) was obtained, teleconferences were routinely held in order to discuss the design specifications of this integration.

Currently, the FlyAwake technical lead is working to meet a September 2009 deadline set by Innova Systems in order to have a beta version of SHARP with the FlyAwake algorithm inside the Scheduler Module. CNAF is in the process of determining the specific squadrons designated for providing operational feedback from the Fleet. In conjunction with the Fleet squadron selections, four Fleet Logistics Support Squadrons (VR) squadrons have volunteered to assist in usability studies to provide this feedback. Pending the results of the squadron feedback, the FlyAwake fatigue-modeling algorithm may be a Fleet-wide application as early as the spring 2010 release of SHARP.

VI. DISCUSSION AND RECOMMENDATIONS

A. DISCUSSION

The objective of this study was to conduct a proof of concept to determine whether the integration of the FlyAwake fatigue-modeling algorithm within the SHARP scheduler module would benefit naval aviation. The results of the thesis determined that FlyAwake improved the predicted effectiveness of flight schedules and reduced the number of pilot occurrences below the fatigue threshold designed as critical.

The analysis illustrated the advantages of applying FlyAwake during critical phases of flight. The results showed enhanced predicted effectiveness with regard to all three MOEs. The USS BOONE (FFG-28) Detachment experienced a 4.15% improvement of the percentage of time spent in the red category and a 5.01% improvement in the black category. The detachment also reduced its total number of occurrences in the black category by 12.5%. Finally, they experienced a 25.0% reduction of in-flight occurrences and a 12.5% reduction of post-flight occurrences in the black category.

The USS KAUFFMAN (FFG-59) Detachment experienced a 5.61% improvement of the percentage of time spent in the yellow, a 14.53% improvement in the red category, and a 20.00% improvement in the black category. The detachment also reduced its total number of occurrences in the black category by 16.7% while experiencing 16.7% reduction of post-flight occurrences in the black category. Overall, the results consistently showed improved predicted effectiveness after the implementation of flight schedule changes highlighted by FlyAwake.

Both detachments showed an overall improvement in predicted effectiveness following the implementation of crew composition changes after fatigue related vulnerabilities were identified by FlyAwake. The descriptive statistics did not reflect added value of the information provided by FlyAwake due to the overall small exposure time (less than 1.00% of total flight duty period) in the black category. This was identified in Section A and resulted in the study focusing on the occurrences in the black category during in-flight and post-flight segments. The results showed that the mean remained fairly constant in both the FFG-28 and FFG-59 detachments with an increase of 0.77% and a decrease of 0.003%, respectively. This was attributed to the method of generating these calculations and the statistical ability of the mean to dampen small variability.

A relaxation of the procedural constraints would have generated drastically different results by increasing the minimum, decreasing the range, and improving the categorical analysis. If schedules could shift those "at risk" night flights identified by FlyAwake so that takeoff and landing times were 30 minutes earlier, there would have been an overall 35.7% reduction of occurrences below the critical threshold (<77.5% predicted effectiveness). Allowing schedule times to be adjusted up to 60 minutes would further reduce occurrences in the black category to 50.0% and completely eliminate any in-flight occurrences of the high risk category.

The United States Navy implements good flight scheduling regulations consistent with other military branches and civilian aviation. These policies, which were created from decades of expertise and research, drive current flight scheduling procedures. This thesis addressed the ability of the FlyAwake algorithm to identify pilots at high risk of fatigue using historical Navy flight schedules. From the small percentage of flights identified by FlyAwake as "high risk," the conservative approach of this analysis (i.e., considering only crew composition changes for pilots identified by FlyAwake as "high risk") inhibited the ability to display the benefits of FlyAwake through the descriptive statistics.

The categorical analysis highlighted both the strength and value of FlyAwake. It reinforced pilot vulnerability to fatigue while conducting night operations, but also showed that exposure to these levels of fatigue can often be avoided by eliminating prolonged flights or multiple consecutive flights at night. In this study, every flight that was highlighted in the black category occurred at night. There were a total of four flights changed, and they all minimized pilot exposure from the black category by altering the crew composition in order to eliminate consecutive flights at night. The ability to swap crewmembers will vary depending on T/M/S aircraft of a specific aviation community; however, there are other scheduling options that may achieve similar results. An example of this is the addition of an extra pilot in platforms such as P-3s, C-130s, or CH-53s, which can provide resting opportunities for the other pilots.

The results of this study suggests that Naval Aviation regulations promulgated in OPNAVINST 3710.7T, T/M/S NATOPS manuals, and SOPs regarding flight operations are very good minimizing aircrew exposure to fatigue while conducting flight operations, especially while conducting flight operations during daytime. This study found only four (3.25% of total study) in-flight occurrences of pilots below the 77.5% predicted effectiveness threshold in which all were at night. FlyAwake was able to eliminate one of these occurrences and reduced the total study percentage to 2.44%. While the pre-FlyAwake percentage of 3.25% was relatively small, one must keep in mind the SH-60B helicopter detachment standards reserve a 30% minimum of all allocated flight hours for nighttime flight operations. Using the standard as the minimum, the detachments in this study experienced an in-flight occurrence below the threshold on 10.8% of their night flights. Furthermore, they experienced 14 (11.4% of total study) post-flight occurrences of pilots below the threshold. This is calculated as 46.67% of all night flights when using the 30% detachment standard. It is evident that fatigue was present in both detachments while conducting night operations.

This analysis concludes that there is room for improvement in flight scheduling by using fatigue modeling. Current Naval Aviation regulations address much of the crew rest and crew day requirements, but the addition of aircrew fatigue modeling will further augment the existing procedures and regulations. This FlyAwake augmentation will result in safer flight operations, since it will reduce aircrew exposure below critical aviation fatigue thresholds. It is also important to note that the integration of the FlyAwake algorithm into SHARP does not add a significant workload to the flight scheduling process. FlyAwake can provide the operations department, safety department, and commanding officer an additional piece of data when constructing, reviewing, and approving a flight schedule while enhancing the ORM of the scheduled aircrew.

B. RECOMMENDATIONS FOR FUTURE WORK

This research provided a proof of concept to validate the integration of FlyAwake fatigue modeling into the SHARP Scheduler Module. While this analysis demonstrated that FlyAwake improved flight schedules with regard to predicted effectiveness, actual implementation of FlyAwake/SHARP will still require a usability study. This section provides recommendations for the usability study and references for similar studies conducted in the past.

1. Squadron Usability Study

This thesis provides a proof of concept validation to support the integration of FlyAwake fatigue modeling algorithm into the SHARP schedule module. However, the final validation of this effort will ultimately come directly from the Fleet. The plan has been for CNAF to select operational Fleet squadrons that will provide assessments of the operational effects of implementing FlyAwake into actual squadrons. To accomplish this goal, squadron Operations Departments should specifically focus on three main areas: aircrew usability, impacts on flight operations, and Operation Risk Management (ORM).

Aircrew usability feedback should focus on the time, accuracy, and mental workload of the aircrew personnel in the Operations Department responsible for writing the daily flight schedule. The integration efforts are focused on minimizing the impacts on the Operations Department with respect to time. Squadrons should also provide feedback addressing any increases in workload or delays in the release of the daily flight schedule.

Next, the squadrons should provide feedback on the impact of FlyAwake on flight operations. The integration of fatigue modeling is not associated with any adjustments to

Naval Aviation policies. However, it is important to determine whether potential policy changes deriving from the integration of FlyAwake and SHARP would significantly impact a squadron's operational effectiveness.

Finally, information regarding aircrew ORM is a key feedback consideration. In theory, fatigue modeling should not only provide safer flight schedules, but also create increased fatigue awareness among the assigned aircrews. Surveying pilots and aircrewmen in the participating squadrons for feedback regarding their personal fatigue awareness levels is an effective method of obtaining this data.

An example of an excellent usability study can be found in a NPS thesis entitled Applied Warfighter Ergonomics: A Research Method for Evaluating Military Individual Equipment. CPT Koichi Takagi, USMC completed this project in September 2005 and it can be obtained by submitting a request to the Dudley Knox Library at NPS. Chapter III of his thesis specifically addresses usability study approaches and Appendices E and F provide examples of surveys and usability test scenarios. Referring to CPT Takagi's thesis will provide a well-designed template for a FlyAwake usability study.

2. Aircrew Fatigue Survey

The recommendation for an aircrew fatigue survey will provide further validation for fatigue modeling. This survey can scientifically measure the efficacy of FlyAwake through aircrew fatigue measurements. LCDR Eric Deussing, a flight surgeon currently working on his Masters of Public Health (MPH) at the Uniformed Services University of the Health Sciences (USUHS), is interested in administering this type of study. Fleet Logistics Support Squadrons (VR) stationed at Andrews Air Force Base (AFB) have volunteered to participate in this study with LCDR Deussing. Using FlyAwake validation in this manner will require the approval of CNAF. However, the combination of operational Fleet squadron feedback, joined with aviation medical research, can provide an excellent assessment of the operational effects of fatigue modeling in naval flight operations.

3. FlyAwake Program Manager

The final recommendation is to assign a program manager to oversee FlyAwake into the U.S. Navy. There is a need for a single point of contact, preferably within CNAF, with the ability to coordinate future requirements, revisions, and contracting issues associated with FlyAwake. This research served as a coordinating liaison between the commands and private companies; however, upon the completion of this NPS thesis, there will no longer be a designated Navy point of contact to coordinate and oversee the final stages of integration and initial rollout for Fleet usability testing. It is my recommendation that a program manager be designated to ensure sufficient oversight for future efforts.

APPENDIX A. SUPPLEMENTAL STATISTICS

A. USS BOONE AIR DETACHMENT

The first step in the analysis was to conduct basic descriptive statistics. The mean, minimum, maximum, and range of the predicted effectiveness provided by FlyAwake were calculated in order to determine the adjusted values of FlyAwake following schedule changes. Table 4 provides a comparison of detachment statistics before and after implementing FlyAwake-based schedule changes. The results show that the minimum, maximum, and range of predicted effectiveness all remained fairly constant after implementing changes. This is not surprising considering that FlyAwake identified less than 1.0% of flights in the black category of the total FDP during February 2008. The detachment minimum remained unchanged and can be explained by the nature of its occurrence. The minimum occurred at the end of a night vision goggle (NVG) flight onboard the ship, which restricted the ability to implement a schedule change. Additionally, there were no alternative crew options available to alleviate the predicted fatigue. However, the minimum did occur during post-flight duties, which resulted in issuing an advisory to the crewmember and recommending an alternative pilot conduct post-flight duties, which require operating or traversing the aircraft.

There was 0.08% increase in mean predicted effectiveness after executing the two feasible schedule changes. This slight increase can be attributed to the fact that only 15.15% of the flights identified by FlyAwake (black category) were considered candidates for schedule change. Of this 15.15%, only 6.06% of the total logged flights were considered feasible for and experienced schedule modifications. This limited exposure to schedule changes directly resulted in limited opportunities to increase the mean. Not surprisingly, the statistics displayed in Table 12 showed that changes based on FlyAwake had little positive effect on the overall flight schedule in regard to predicted effectiveness.

Descriptive Statistics of USS BOONE (FFG-28) Detachment				
	Before	After	Difference	Percent Change
Mean	84.683	84.749	0.065	0.077%
Minimum	69.078	69.078	*None*	*None*
Maximum	94.381	94.381	*None*	*None*
Range	25.303	25.303	*None*	*None*

Table 12. FFG-28 Detachment Descriptive Statistics Comparison

B. USS KAUFFMAN AIR DETACHMENT

The first step of the analysis was to conduct basic descriptive statistics identical to those discussed above regarding the FFG-28 Detachment. The mean, minimum, maximum, and range of the predicted effectiveness provided by FlyAwake were calculated in order to determine the adjusted values of schedule changes following FlyAwake. Table 13 provides a comparison of detachment statistics before and after implementing FlyAwake-based schedule changes. The results show that the minimum, maximum, and range all remained fairly constant after implementing changes. This is not surprising considering that FlyAwake identified less than 1.00% of the total FDP in the black category during February 2008. Similar to the previously discussed detachment, the minimum remained unchanged and can be explained by the nature of its occurrence. The minimum occurred at the end of a night vision goggle (NVG) flight while conducting shipboard operations, which restricted the ability to implement a schedule change. Additionally, there were no alternative crew options available to alleviate the predicted fatigue. However, the minimum did not occur in-flight. The occurrence was during post-flight duties, which resulted issuing an advisory to the crewmember and recommending an alternative pilot to conduct post-flight duties which require operating or traversing the aircraft.

There was an overall 0.003% decrease of the mean predicted effectiveness after executing the two feasible schedule changes. This insignificant decrease can be attributed to rounding errors during calculations. Only 10.52% of the flights identified by FlyAwake (black category) were considered potential candidates for schedule changes and of those; only 5.26% were considered feasible and subject to schedule modifications. These statistics displayed in Table 13 showed the overall negligible effects of FlyAwake-based schedule changes with regard to predicted effectiveness.

Descriptive Statistics of USS KAUFFMAN (FFG-59) Detachment				
	Before	**After**	**Difference**	**Percent Change**
Mean	84.931	84.928	-0.003	-0.003%
Minimum	73.096	73.096	*None*	*None*
Maximum	89.477	89.477	*None*	*None*
Range	16.381	16.381	*None*	*None*

Table 13. FFG-59 Detachment Descriptive Statistics Comparison

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LIST OF REFERENCES

Air Force Instruction (AFI) 11-202V3. (2006). Flying operations: General flight rules, crew rest, and flight duty limitations. Headquarters, Air Force Flight Standards Agency, 68–71.

Caldwell, John A. (2005). Fatigue in aviation. *Travel Medicine and Infectious Disease* 2005, Volume 3, 85–96.

Chapman, S. (2001). Fatigue management amongst royal Australian navy submariners. Submarine Service Allowance review, Report 5/2001.

Federal Aviation Authority (FAA). (2008). Federal aviation administration: Mission and History. Retrieved March 1, 2009 from http://www.faa.gov/about/index.

Government Printing Office (GPO) Access. (2009). Electronic code of federal regulations. Retrieved March 15, 2009, from http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=4f9da871d28f02f12266391b6f7e0c1&rgn=div5&view=text&node=14:2.0.1.3.10&idno=14.

Hursh, Steven R. and Bell, Glenn B. (2001). Human Performance Cognitive Model for Air Force Information Operations. *Science Applications International Corporation*. December 2001. 1–26.

Hursh, Steven R., et al. (2003). The DoD Sleep, Activity, Fatigue, and Task Effectiveness Model. *Science Applications International Corporation and Johns Hopkins University School of Medicine*. 1–8.

Hursh, Steven R., et al. (2004). Fatigue Models for Applied Research in Warfighting. *Aviation, Space, and Environmental Medicine*, 75, 44–53.

Lambert, C. (2005). Deep into sleep. *Harvard Magazine, 107*(6).

National Sleep Foundation. (2009). Shift Work and Sleep. Retrieved June 1, 2009, from http://www.sleepfoundation.org.

National Sleep Foundation. (2009). Sleep Drive and Your Body Clock. Retrieved May 14, 2009, from http://www.sleepfoundation.org.

Neri, D., Dinges, D., & Rosekind, M.R. (1997). Sustained carrier operations: Sleep loss, performance, and fatigue countermeasures. NASA Ames Research Center: Moffet Field, CA.

OPNAVINST 3710.7T. (2004). Ch. 8: Aeromedical and Survival. NATOPS General Flight & Operating Instruction. 3710T.

Reeves, Michael D. (2007). Fatigue Avoidance Scheduling Tool™ (FAST ™). *Ergonomics in Design*. Spring 2007, 25–27.

Van Dogen, H., Rogers, N., & Dinges D. (2003). Sleep debt: Theoretical and empirical issues. *Sleep and Biological Rhythms*, 1, 5–13.

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