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Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) sleep, fatigue, and aviator performance study

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MARINE AVIATION WEAPONS AND TACTICS SQUADRON ONE (MAWTS-1): SLEEP, FATIGUE, AND AVIATOR PERFORMANCE STUDY

by

Pamelyn L. Maynard

December 2008

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The Weapons and Tactics Instructor (WTI) course conducted at the Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) command in Yuma, Arizona is considered the capstone of Marine aviation training. Concerned about its high aviation incident rate, MAWTS-1 leadership asked the Naval Postgraduate School (NPS) to assess whether student sleep is a contributing factor.

In a baseline study at MAWTS-1, the students were found to be chronically sleep deprived. Six months later, this thesis effort gathered sleep data on 20 WTI 1-06 student pilots using wrist activity monitors and activity logs. Results showed the mean nightly sleep to be significantly higher than the baseline study, possibly caused by the implementation of a Tactical Risk Management course. Unlike their predecessors, the students in WTI 1-06 were not sleep deprived. As a result, no significant correlations were seen between sleep quantity and quality and student performance, as measured by exam and flight scores, or between predicted effectiveness and performance, as generated with the Fatigue Avoidance Scheduling Tool (FAST) program. While other variables were found to be slightly correlated with performance, several issues were identified that may have affected these results, along with recommendations for improving future studies.

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MARINE AVIATION WEAPONS AND TACTICS SQUADRON ONE (MAWTS-1): SLEEP, FATIGUE, AND AVIATOR PERFORMANCE STUDY

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LIST OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS

AAW	Anti-air Warfare
AD	Aerial Deliver
AFI	Air Force Instruction
AGARD	Advisory Group for Aerospace Research and Development
AR	Army Regulation
AST	Assault Support Tactics
ATF	Aviation Training Form
BAC	Blood Alcohol Content
BAS	Battlefield Air Support
BSCS	Biological Sciences Curriculum Study
CAA	Civil Aviation Authority (United Kingdom)
CAO	Civil Aviation Orders
CAP	Civil Aviation Publication
CAR	Canadian Aviation Regulation
CAS	Close Air Support
CFR	Code of Federal Regulations
COMDTINST	Commandant, United States Coast Guard Instruction
COPE	Center for Operational Performance Enhancement
DACM	Defensive Air Combat Maneuvering
DAS	Deep Air Support
DEFTAC	Defensive Tactics
DM	Defensive Maneuvers
DND	Did Not Do
FAA	Federal Aviation Administration
FAC	Forward Air Controller
FAST	Fatigue Avoidance Scheduling Tool
FDA	Food and Drug Administration
FDP	Flight Duty Period
FINEX	Final Exercise
GPO	Government Printing Office
GTR	Ground Threat Reaction
Helo	Helicopter
HSD	Honestly Significant Difference
HSI	Human Systems Integration
IEC	International Electrotechnical Commission
LATI	Low Altitude Tactics Instructor
LRR	Long Range Raids
MAWTS-1	Marine Aviation Weapons and Tactics Squadron One
MRI	Magnetic Resonance Imaging
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NATOPS	Naval Air Training and Operating Procedures Standards

NAVFLIR	Naval Aviation Flight Records
NHLI	National Heart and Lung Institute
NHTSA	National Highway Traffic Safety Administration
NPS	Naval Postgraduate School
OAAW	Offensive Anti-air Warfare
OAS	Offensive Air Support
OPNAVINST	Office of the Chief of Naval Operations Instruction
ORM	Operational Risk Management
PWTI	Prospective Weapons Tactical Instructor
REM	Rapid Eye Movement
SAFTE	Sleep, Activity, Fatigue, and Task Effectiveness
SAIC	Science Applications International Corporations
SAS	School of Aviation Safety
SCAR	Strike Coordination and Reconnaissance
SWS	Slow Wave Sleep
TCT	Time Critical Target
TRM	Tactical Risk Management
UNSAT	Unsatisfactory
USAARL	United States Army Aeromedical Research Laboratory
USAF	United States Air Force
USAFSAM	United States Air Force School of Aerospace Medicine
WAM	Wrist Activity Monitor
WTI	Weapons and Tactics Instructor

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EXECUTIVE SUMMARY

Every spring and fall, the Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) command at Yuma, Arizona conducts the Weapons and Tactics Instructor (WTI) course. The course is considered the capstone of Marine aviation training, and its purpose is to increase aircrew knowledge about weapons systems and their delivery, and platform integration tactics, among Marine and joint aviation platforms. Upon graduation, students return to their commands as weapons and tactics instructors to serve as warfare instructors and to manage their unit's flight training programs. A WTI course requires six weeks of training, which is divided into two segments. The first segment is 2.5 weeks of formal classroom training, while the second segment involves 3.5 weeks of flight training. Because the environment for students attending WTI is constantly changing, stressful, and competitive, a higher than average incident rate occurs during flight training. MAWTS-1 leadership asked researchers from NPS to assess whether sleep is also a contributing factor to this incident rate.

A baseline study was conducted during the spring WTI 2-05 course. Ten students and ten instructor/staff members wore wrist activity monitors (WAMs) and filled out sleep logs from March 10, 2005 to April 21, 2005, to gather data on the quality and quantity of their sleep during this period. The sleep data were also input into the Fatigue Avoidance Scheduling Tool (FAST), version 1.0.23, to generate a predicted effectiveness for each participant during critical flight times. Due to missing information, the data from only six students and seven instructors/staff members were used in the study. The baseline study concluded that (1) students are not adequately rested at the beginning of the workday; (2) staff members had lower predicted effectiveness levels during critical times; and (3) the variance between actual and reported sleep data indicated an overestimation of how much rest is received per night. On average, students received 5.62 hours of sleep per night with an overestimation of 1.5 hours of sleep, while staff members received 6.10 hours of daily sleep with an overestimation of 45 minutes.

Failure to obtain the required hours of sleep each night results in a cumulated sleep debt. Studies have shown that cumulative sleep debt has detrimental effects on

human performance, perception, and decision making (Dinges, et al., 1997; Van Dongen, Roger, & Dinges, 2003). Pilots are particularly at risk for cumulative sleep debt due to the changing nature of flight operations and long duty cycles. Characteristics of the flight deck environment (i.e., restricted movement, variable airflow, noise, vibration, and low barometric pressure) also make pilots susceptible to the symptoms of sleep loss and fatigue (Strauss, n.d.).

This thesis research follows up on the baseline study by conducting a pilot observational study focusing on the sleep and fatigue levels of WTI 1-06 student pilots undergoing training to determine how sleep patterns affect their performance. WTI 1-06 was the first class to adopt a generic inventory exam and Aviation Training Forms for standardizing the measurement of student performance. The inventory exam tests fundamental tactical and tactical risk management knowledge and is based upon preliminary reading assignments completed before WTI training began. The Aviation Training Forms were used by instructors to assign flight scores to platform-specific graded criteria during flight scenarios.

Twenty WTI 1-06 student pilots, representing several air platforms, volunteered to wear WAMs and fill out activity logs from September 16, 2005 to October 29, 2005. The sleep data gathered from the WAMs were correlated with their individual inventory exam and flight scores to determine if performance was correlated with sleep quantity and quality. The sleep data were also used in the FAST program to generate predicted performance during critical training times (i.e., exam and flight times). The predicted performance was also compared to actual performance to determine if these two sets of data are correlated.

Results showed that WTI 1-06 participants received a significantly higher average nightly sleep than student participants from the baseline study (7.05 hours versus 5.62 hours, respectively) and were not considered chronically sleep deprived. The dramatic improvement in sleep from the baseline study may have occurred from the implementation of a Tactical Risk Management (TRM) course in March, 2005. The course focused on all aspects of TRM, including lectures on Human Factors and the effects of fatigue and sleep deprivation on flight performance.

As a result, sleep quantity and quality were not correlated with either exam or flight scores, although other significant variables, such as student age, accumulated flight hours, and flight scenario, were slightly correlated with performance. Also, the FAST-predicted effectiveness was insignificant in predicting actual performance. Several issues were identified in the study that may have affected these results, along with recommendations for improving future studies. The issues identified as possibly affecting the results included the size of the study sample, the failure of several students to return their activity logs, and the inconsistency between instructors in assigning flight scores with the flight training forms.

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I. INTRODUCTION

Fatigue is a big concern for military aviators. The acquisition of increasingly complex military equipment requires highly trained professionals who are alert and well rested for safe and effective operation and maintenance. In recent years, military operations have resulted in longer work periods, shorter transition times, and fewer opportunities for sleep and recovery. In today's combat environment, there is a combination of unpredictable challenges and the typical stresses of military operations, creating a level of increased fatigue that can impair situational alertness and job performance. The result is a negative impact on individual levels of fatigue, with concomitant changes in decision making, reaction time, judgment, and alertness, all of which impact job performance and mission success rates.

While fatigue factors into operational success, does it also affect aviator training? The purpose of this paper is to evaluate if fatigue is a factor in the performance of student pilots at the Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) during the U.S. Marine Corps' Weapons and Tactics Instructors (WTI) course during the fall of 2005.

A. BACKGROUND

MAWTS-1, at Yuma, Arizona, conducts the WTI course each spring and fall for pilots, weapons systems operators, and ground combat and combat service support officers from the Marine Corps and other U.S. and foreign services. The purpose of the course is to increase aircrew knowledge about weapons systems and their delivery; platform tactics, and integration among Marine and joint aviation platforms; and command and control systems. After completing WTI training, students are designated as weapons and tactics instructors and return to their commands to serve as warfare instructors and to manage their respective unit's training programs (Carlson, 2002).

A WTI course generally has 175 students per class and requires six weeks of training, which is divided into two segments. The first segment is 2.5 weeks of formal classroom instruction that teaches the "big picture" of Marine Corps aviation weapons and tactics. Students train first with their own communities and, later in the course, begin working with other communities. The second segment of WTI involves 3.5 weeks of flight training designed to hone aviation planning and execution skills during high-intensity, integrated tactical exercises. The Final Exercise (FINEX) of the flight phase is a culmination of the training in which the students plan and carry out a fully integrated, combined arms operation. All training flights include a MAWTS-1 instructor and use both inert and live ordnance (Carlson, 2002).

The importance of the WTI training received at MAWTS-1 can be seen on several levels. First, the training accurately simulates the realities of joint operations by maintaining close contact with aviation and tactics schools of all sister services and several allied nations. This is important because the United States military is increasingly engaging in joint operations with allied militaries. Secondly, the curriculum is continually updated to integrate new systems and methodologies. For example, the lessons learned from Operation Enduring Freedom were incorporated into the WTI curriculum soon after the event began. The training can also be used as a test bed for developing procedures and methods for new hardware and equipment (Carlson, 2002). Therefore, MAWTS-1 students are learning the most up-to-date material in both the classroom and in the field. Lastly, students take the knowledge learned at MAWTS-1 and teach it to other pilots, operators, and support officers at their respective commands. To do this successfully, MAWTS-1 graduates must have a firm understanding of the lessons learned during WTI.

Due to its continually changing environment, the WTI course tests the limits of its student pilots in a competitive and stressful environment. MAWTS-1 leadership, concerned with the command's high mishap rate during flight training, asked the Naval Postgraduate School (NPS) to assess whether sleep deprivation may be a contributing factor. They wanted to know if students were receiving adequate amounts and quality of sleep and what the potential impact of chronic sleep deprivation would have on student performance.

B. OBJECTIVE

During the spring WTI 2-05 course, researchers from NPS and the MAWTS-1 flight surgeon conducted a baseline study to assess sleep and fatigue levels at MAWTS-1.

Sleep data were collected on ten students and ten instructor/staff members from March 10, 2005 to April 21, 2005. The participants wore wrist activity monitors (WAMs) for a period of six weeks to record individual sleep duration and quality. The participants also maintained a written log of self-reported sleep, work, and flight times. Sleep data were extracted using ActiWare 3.41 software and input into the Fatigue Avoidance Scheduling Tool (FAST), version 1.0.23. The FAST program generated a predicted effectiveness for each participant during critical times. Due to missing information, the data from only six students and seven instructors/staff members were used in the study. On average, students received 5.62 hours of sleep per night with an overestimation of 1.5 hours of sleep, while staff members received 6.10 hours of daily sleep with an overestimation of 45 minutes.

The baseline study contained the following conclusions:

- Students are not adequately rested at the beginning of the workday.
- Staff members had lower predicted effectiveness levels during critical times of their waking hours, e.g., during flight.
- Variance between actual and reported sleep data indicates an overestimation of how much rest is received per night.

Since there were no standard measures of actual performance to evaluate with predicted performance, the baseline study recommended a further MAWTS-1 sleep and fatigue analysis that included staff and student academic and flight performance measures with predicted effectiveness. After the completion of the baseline study, a standardized inventory test and aviation training forms were adopted by MAWTS-1 to allow for a comparison between student performance and predicted effectiveness.

This thesis research is a pilot study that follows up on the baseline study by focusing on the sleep and fatigue levels of the students undergoing training at MAWTS-1 to determine how sleep patterns may affect actual performance. The standardized test and flight scores for 20 MAWTS-1 students were correlated with their individual sleep data. Data collection on the students of class WTI 1-06 began on September 16, 2005 and concluded on October 29, 2005.

This thesis sought to determine whether sleep and fatigue patterns have an effect on student performance, both in the classroom and during in-flight training. The command could use information from this study to educate students on the importance and effects of sleep and/or modify its own program to optimize students' sleep, thereby increasing safety and facilitating learning. Any sleep hygiene training received by students during WTI has the added benefit of extending beyond the training environment into their daily lives.

C. LIMITATIONS AND ASSUMPTIONS

Due to the limited availability of sleep monitoring equipment, only officer pilots who volunteered were chosen to participate in the study. These students were assumed to be well-trained in their flight platform, physically fit, and suffering from no sleep disorders. Conservative estimates of sleep were used during data analysis when no sleep data were available. For example, because no sleep data were gathered before the thesis research began, all participants were assumed to have received the conservative FAST default of eight hours of excellent sleep during the three days prior to September 16. Throughout the remainder of the study, the calculated average sleep duration and average sleep quality of the individual participants were used to fill in any other missing data.

D. HUMAN SYSTEMS INTEGRATION (HSI)

HSI is a multidisciplinary field of study that emphasizes the human as a priority in systems design and acquisition, focusing on reducing life-cycle costs and improving total system performance. HSI, as defined at NPS, is composed of eight domains: Human Factors Engineering, Manpower, Personnel, Training, Human Survivability, Health Hazards, System Safety, and Habitability. Although these domains seem to encompass independent and unrelated areas of interest, recent experience within the military shows that interactions exist between them. A change in the priority of one domain can have a positive or adverse effect in another.

The scope of this thesis, which encompasses fatigue and aviator performance at MAWTS-1, covers four of the eight HSI domains:

- **Training:** The instruction, education, and training required to provide personnel with the knowledge, skills, and abilities needed to operate and maintain systems (Naval Postgraduate School [NPS], 2005). Training all personnel on maintaining proper sleep hygiene and the negative consequences of accumulating sleep debt, to include its effects on the body and cognitive abilities, can potentially improve classroom learning and flight performance. In the event that a pilot must perform in a fatigued state, specific training could be provided on how to mitigate or counteract the effects of fatigue.
- **Human Survivability:** The ability of a system and its personnel to avoid or withstand hostile environments without jeopardizing mission accomplishment (NPS, 2005). Accumulated sleep debt and fatigue can prevent personnel from effectively functioning in a hostile operational environment. The practice of maintaining minimal sleep debt increases the ability of personnel to avoid fatal mistakes.
- **System Safety:** The ability to effectively operate and maintain a system without harm to the system or personnel involved with the system's operation (NPS, 2005). Flight personnel need to consistently receive proper sleep to effectively and safely operate their air platform. Failure to meet sleep requirements could cause a fatigued pilot to make poor decisions and commit operational errors that could injure personnel and passengers, as well as harm the system.
- **Habitability:** The qualities of the physical living environment and support services that lead to mission effectiveness (NPS, 2005). The students attending MAWTS-1 live in the barracks during the six weeks of WTI. Maintaining a proper sleep environment in the barracks during training could positively affect training performance.

E. THESIS ORGANIZATION

Chapter I described the WTI training at MAWTS-1, the objective and limitations of the study, and how this study pertains to HSI. Chapter II contains a review of the literature on sleep and fatigue, existing aviator regulations to minimize fatigue effects, and fatigue countermeasures for pilots. Chapter III explains the methods and analytical strategy used in this study, while Chapter IV contains the statistical analysis and results of the study. Chapter V ends with the conclusions and a discussion of the study's results. It also gives recommendations for future research.

II. LITERATURE REVIEW

Much research has been conducted on sleep and fatigue, and an extensive review of these topics is beyond the scope of this thesis. However, an overview of the field is crucial for understanding how pilots, especially those in training, can be influenced by the effects of sleep and fatigue. This thesis gives an overview of sleep, including the factors that affect its quality, the stages of sleep, sleep and memory, and the effects of sleep deprivation on performance. The literature review then focuses on fatigue and its effect on pilot performance, current civil and military regulations to reduce pilot fatigue, and available fatigue countermeasures for pilots.

A. SLEEP

Like food, water, and shelter, sleep is a basic physiological need that is necessary for life, promoting health and bodily function. Sleep is crucial for maintaining mood, memory, and cognitive performance and is essential for the normal function of the endocrine and immune systems. Research shows a link between sleep duration and obesity, diabetes, hypertension, and depression (National Sleep Foundation, 2006).

Individual sleep requirements vary, but the recommended amount by sleep experts is "the amount of sleep necessary to achieve full alertness and an effortless level of functioning during the waking hours" (Rosekind et al., 1996). Typically, adult sleep patterns range from 6 to 10 hours daily, with optimal performance and alertness obtained with an average 8 to 8.25 hours of daily sleep (Neri, Dinges, & Rosekind, 1997). This period of sleep, combined with approximately 16 hours of wakefulness, forms the sleep-wake cycle.

1. Sleep Debt and Its Effects

Obtaining less than the physiologically required amount of sleep during a 24-hour period results in sleep loss, which can be acute or cumulative. Acute sleep loss occurs by a shortened or missed night of sleep. An inability to function normally following this period of sleep loss may be alleviated by sleeping more and/or more deeply the following night (Lambert, 2005). Cumulative, or chronic, sleep debt occurs when some sleep is lost over a period of weeks, months, or even years. Many adults in the United States are estimated to lose approximately 1.5 hours of sleep per night during workdays, with an accumulated sleep debt of 5 to 7.5 hours by the start of the weekend (LeClair, 2001). Restricted sleep over a long period of time impairs performance as much as losing a night of sleep. While the impact of cumulative sleep debt takes longer to build up, it also may take longer from which to recover. For example, recovery from sleep debt cannot be accomplished through hour-for-hour restitution in sleep. Studies suggest that at least two nights of recovery sleep, in which there is an increase in deep sleep, are needed to return an individual to a normal baseline of waking performance and alertness (Rosekind, Neri, & Dinges, 1997).

Cumulative sleep loss, or “sleep debt” (LeClair, 2001), significantly degrades individual performance, alertness, and mood, which become more pronounced as sleep debt increases. Degraded performance may include slow reaction times, short attention spans, problems with short-term memory, and decreased problem-solving and decision-making abilities (Chapman, 2001). The practice of continually acquiring inadequate sleep results in chronic sleep debt. In healthy individuals, chronic sleep debt occurs after extensive hours of voluntary wakefulness, usually in an effort to accomplish more tasks. In addition to performance degradation, chronic sleep debt contributes to obesity, diabetes, and high blood pressure (Van Dongen, Rogers, & Dinges, 2003).

Many scientific studies provide evidence on how human performance, perception, and decision making is negatively affected by cumulative sleep loss. Dinges et al. (1997) found that restricting sleep by 33% for seven days caused participants to experience continual performance decrements, even after their self-reported subjective sleepiness leveled off after the first two days (Dinges et al., 1997). A 14-day study by Van Dongen, Maislin, Mullington, and Dinges (2003) showed that participants restricted to 4 to 6 hours of sleep produced performance deficiencies comparable to those suffering from 1 to 2 days of total sleep deprivation. The study also showed that people cannot adapt to chronic sleep restriction in a few days or reliably self-assess sleepiness if consistently receiving at least four hours of sleep. The intense feelings of sleepiness felt with total sleep deprivation are absent with restricted sleep, causing people to think they adapted to less sleep and making them more likely to practice chronic sleep restriction

(Van Dongen, et al., 2003). An individual's inaccuracy in assessing true levels of sleepiness can be affected by various factors. For example, physical activity or a stimulating environment, such as interesting conversation, can mask physiological sleepiness, resulting in overestimated levels of alertness (Rosekind et al., 1996).

The above studies were conducted in occupations associated with chronic sleep restriction (e.g., shift workers, military personnel, medical and surgical residents) or parents of young children. During the baseline study at MAWTS-1, staff and students were found to consistently receive between 5 and 7 hours of sleep a night throughout the six weeks of training, which is an indication they could be suffering from the effects of chronic sleep restriction.

2. Homeostasis and Circadian Rhythms

The sleep-wake cycle is controlled by the combination of two internal processes, sleep homeostasis and circadian rhythms (National Sleep Foundation, 2006). Homeostasis is the process by which the body maintains a "steady state" of internal conditions, such as blood pressure, body temperature, and the amount of sleep obtained each night. The homeostatic drive for sleep increases while awake, reaching a maximum level in the evening when most individuals fall asleep. The homeostatic process is thought to be controlled by adenosine levels, a sleep-inducing chemical. Adenosine levels rise while awake (increasing the need for sleep) and decrease while asleep (thereby reducing the need for sleep). Some drugs, like caffeine, can block adenosine receptors and disrupt this process (National Sleep Foundation, 2006).

Circadian rhythms refer to the "biological clock" that controls the body's cyclical changes throughout the day. Also known as the circadian cycle or circadian clock, circadian rhythms govern sleep patterns, motor activity, hormonal processes, body temperature, performance, and other factors (LeClair, 2001; National Sleep Foundation, 2006). Many internal functions operate in a 25-hour circadian cycle (LeClair, 2001), but specific external cues, such as environmental, social, and work schedules, synchronize the cycle to a 24-hour day (LeClair, 2001; National Sleep Foundation, 2006). Light is the strongest synchronizing agent in humans (National Sleep Foundation, 2006). Based on circadian factors, there are two periods of maximal wakefulness and sleepiness during a normal 24-hour day. The primary and secondary peaks of wakefulness occur at 12 p.m. and 9 p.m., while the first dip in alertness, or trough, occurs between 3 a.m. and 5 a.m., with the secondary dip in alertness occurring between 3 p.m. and 5 p.m. The afternoon increase in sleepiness occurs whether a meal has been eaten or not (Rosekind et al., 1996). Figure 1 depicts the cyclical changes in alertness due to circadian rhythms.

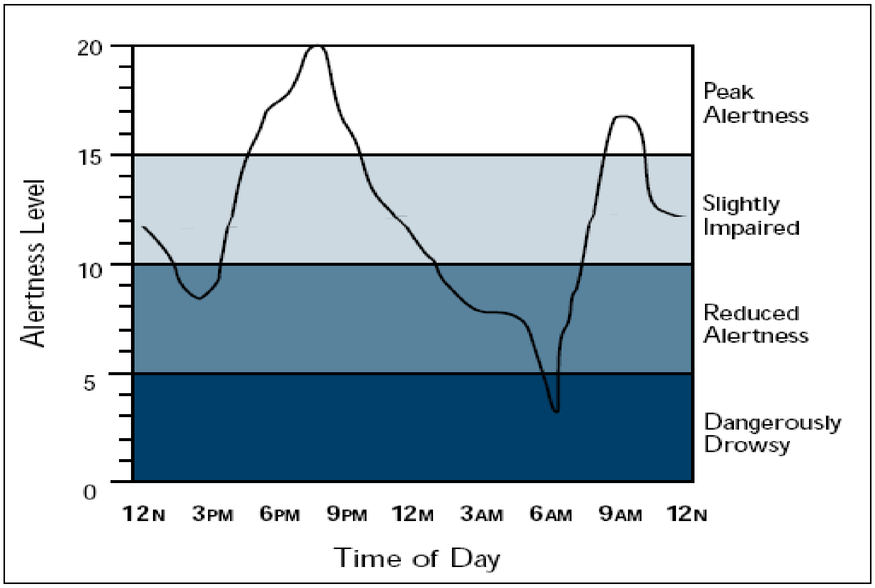

Figure 1. Daily Circadian Rhythm (From: National Highway Transportation Safety Administration [NHTSA], 2007)

Quality of sleep is as important as the quantity of sleep, and the lack of either can decrease or impair performance and alertness (Neri et al., 1997) The complex interaction between homeostasis and circadian rhythms directly influences both the quality and quantity of sleep. In general, the homeostatic system causes one to get progressively sleepier throughout the waking period, regardless of time of day, while the circadian cycle prompts wakefulness during the day and sleepiness during the evening. The best sleep quality and restfulness occurs when sleep schedules are regularly synchronized to internal circadian rhythms and external light-dark cycles (National Sleep Foundation, 2006). Sleeping at irregular times (i.e., other than night) conflicts with circadian rhythms and results in a shorter, disrupted sleep period, an altered sleep structure, and an increase in the time it takes to fall asleep. This is why the quality of daytime sleep is often lower than nighttime sleep. Sleep duration also depends on the time of day. Longer periods of rest occur at night, while shorter periods occur during the day, regardless of sleepiness or sleep deprivation (Rhodes & Gil, 2002).

The natural inclination to perform during the day and sleep during the night may run counter to the schedules faced by MAWTS-1 students. During the flight phase of WTI, students train under the various conditions faced by Marine pilots in the field, including both day and night exercises. MAWTS-1 leadership is aware of the circadian disruption imposed by this schedule. Schedules should be attuned to the time of day relative to the body's internal clock and time since awake when scheduling flight exercises. Preventing sleepiness should be considered when scheduling flight times during the circadian troughs, or conversely, ways to facilitate the onset of sleep when scheduling rest periods during circadian peaks. These concerns will be addressed when discussing fatigue countermeasures in Section D of this chapter.

3. Stages of Sleep

Sleep is an active physiological process that consists of two distinct states of sleep: Rapid Eye Movement (REM) sleep and non-REM sleep (McCallum, Sanquist, Mitler, & Krueger, 2003; National Sleep Foundation, 2006). Some researchers suggest that REM sleep serves as a restorative function for the brain and non-REM sleep serves as a restorative function for the body (Reite, Ruddy, & Nagel, 2002).

During non-REM sleep, there are changes in physiological and mental activities, such as slowed heart and breathing rates, and drops in blood pressure. Non-REM sleep is composed of four distinct stages and accounts for 75% to 80% of a typical sleep cycle. Stage 1 is characterized by drowsiness and a transition from wakefulness to sleep (Folkard & Barton, 1993; National Sleep Foundation, 2006). While awake, one may lapse into brief 20 to 30 second periods of Stage 1 sleep without knowing it. These lapses, called micro-sleeps, are often not remembered and may allow someone to fall asleep without knowing it (Rhodes & Gil, 2002). An individual then typically transitions into Stage 2 sleep, which is a light sleep characterized by a slowing heart rate, decrease in body temperature, and relaxing of muscle tension (Folkard & Barton, 1993; National Sleep Foundation, 2006). Stages 3 and 4 together are called slow wave sleep (SWS), resulting in the deepest and most restorative levels of sleep. Blood pressure falls, breathing slows, and body temperature decreases further. The body is immobile and there is very little mental activity during these stages. If awakened during these stages of deep sleep, an individual is likely to experience “sleep inertia,” a feeling of grogginess and disorientation, for as long as 10 to 15 minutes after waking (LeClair, 2001; National Sleep Foundation, 2006).

REM sleep is associated with an extremely active, dreaming brain with bursts of rapid-eye movement. Breathing is more rapid and shallow; heart rate and blood pressure increase; and the major motor muscles of the body are temporarily paralyzed during REM sleep. If awakened during this state, individuals can often provide detailed reports of their dreams (LeClair, 2001; National Sleep Foundation, 2006). In a normal 8-hour sleep period, REM sleep makes up about 20% to 25% of the sleep cycle (Folkard & Barton, 1993; National Sleep Foundation, 2006).

The right balance of REM and non-REM sleep is important for obtaining restful, restorative sleep and for promoting processes like learning, memory, mood, and the ability to concentrate (National Sleep Foundation, 2006). A complete sleep cycle consists of a combination of REM and non-REM sleep, with approximately 60 minutes of non-REM sleep followed by 30 minutes of REM sleep (LeClair, 2001). This repetitive 90- to 110-minute cycle is repeated 4 to 6 times a night (LeClair, 2001; National Heart and Lung Institute [NHLI], 2003). Within a sleep cycle, a person progresses from Stage 1 through Stage 4 non-REM sleep to REM sleep. The sleep cycle is then reversed, and the individual regresses from REM sleep backward through the stages of non-REM sleep (Folkard & Barton, 1993).

The time spent in each stage of sleep varies throughout the night. The first sleep cycles contain longer periods of slow wave sleep with short periods of REM. REM periods increase in length throughout the night, while the amount of slow wave sleep decreases. By morning, nearly all sleep is in Stage 1, 2, and REM (National Sleep Foundation, 2006). The entire 8-hour cyclic process of sleep must be completed to gain its full benefits. Insufficient sleep duration, alcohol, drugs, medication, and noise can interfere with the physiological structure of the sleep cycles, which, in turn, impairs performance and alertness (McCallum et al., 2003).

4. Sleep and Memory

The consolidation of human memories is complex in nature. New memories are formed in the brain when a person engages with information to be learned, but they are initially vulnerable and must be solidified and improved to be retained (Walker, Stickgold, Alsop, Gaab, & Schlaug, 2005). Memory consolidation occurs when the connections between brain cells and different brain regions are strengthened. Historically, these strengthened connections were thought to develop as a passage of time, but recent studies show that sleep plays a key role in preserving memory (Stickgold, Hobson, Fosse, & Fosse, 2001; Walker et al., 2005; Ellenbogen, Hu, Payne, Titone, & Walker, 2007).

Recent evidence strengthens the hypothesis that sleep affects learning and memory processing at several levels, but exactly how this occurs is still being debated. In a study by Walker et al. (2005), Magnetic Resonance Imaging (MRI) scans showed a dramatic shift in brain regions during sleep after a new task was learned. Participants who learned a procedural skill and were retested after a full night of sleep not only showed improved motor skills in the task, but also had MRI scans that indicated that some areas of the brain were more active, while other areas were less active. The cerebellum, which was more active, controls speed and accuracy, while the limbic system, a less active area, controls emotions such as stress and anxiety. These results suggest that, following the introduction of a new skill, memory tasks were performed more quickly and accurately with less stress and anxiety after obtaining a full night of sleep. Results also suggest that procedural skills (skills that use and interpret sensory and perceptual information from the surroundings) become more automatic after a sleep period.

The role of sleep and memory consolidation is also demonstrated in other ways. Sleep processes are thought to be necessary for memory consolidation and that memory is fragile until the first sleep period after exposure is obtained (Maquat, 2001). Stickgold, James, and Hobson (2000) found that performance on particular tasks did not improve later that same day, but did improve after a night of sleep (Stickgold et al., 2000; Maquat, 2001; Stickgold et al., 2001). Results from their study of a visual discrimination task suggest both early-night SWS and late-night REM sleep are required for performance improvement, with a linear relationship existing between improved performance and the amount of SWS and REM obtained. The results also showed that sleep deprivation on the first night after training eliminated the benefits of that training, even when measured after two full nights of recovery sleep. Another theory suggests that tasks are impaired by sleep deprivation, especially of REM sleep, when the task entails a new behavioral strategy (Maquat, 2001). A study by Ellenbogen et al. (2007) also shows that relational learning (the ability to extract relationships between learned complex patterns) occurs during offline sleep periods.

Studies of sleep physiology and experimental observations provide evidence that both REM and non-REM play important roles in memory consolidation (Maquat, 2001; Stickgold et al., 2001). Given the substantial differences between SWS and REM sleep, it is likely that each sleep stage contributes to memory trace processing in different ways. It is debatable whether the sleep stages act in parallel (Dual Process) or in series (Double-Step Process) (Maquat, 2001), outlined below.

- Dual Process:
    - SWS is favorable to explicit memory traces
    - REM sleep is favorable to implicit memory consolidation
- Double-Step Process:
    - Memory consolidation requires SWS, followed by REM sleep

Explicit memories, or declarative memory, include facts, images, and episodic memory, while implicit memory is expressed primarily through performance and not consciously recalled. In support of the Dual Process theory, REM sleep is shown to be critical in the consolidation of procedural, not declarative, memory and processing emotional memories. REM effects have also been seen with learning complex logic games and foreign languages, after intensive studying, and impaired retention of procedural learning after training (Stickgold et al., 2001). The Double-Step Process may be evidenced in the study by Stickgold et al. (2000), as discussed in Section A.4 of this chapter.

The bottom line is that research has shown that sleep is critical for consolidating memories. Since both SWS and REM sleep are necessary for processing different types of memory, obtaining a full night of rest is crucial for learning effectively. Worst of all, missing a night of sleep after learning a new task results in a performance similar to amnesia, i.e., never learning the task in the first place.

B. FATIGUE

Fatigue is defined as the "non-pathologic state resulting in a decreased ability to maintain function or workload due to mental or physical stress" (Strauss, n.d.). It has been used to describe many different experiences, such as sleepiness, physical tiredness, and the inability to focus mentally. These indications may manifest themselves as the need to nap during the day because of sleepiness, repeatedly pressing the snooze button when the alarm clock sounds; looking forward to catching up on sleep during the weekends; and the inability to stay awake during sedentary activities, such as sitting in meetings, watching television, or reading (Caldwell, 1999).

It is difficult to reliably estimate one's own sleep or alertness, especially when sleepy. Individuals tend to overrate themselves as being more alert than is indicated by physiological measures (LeClair, 2001). Unfortunately, the impact of fatigue on performance is also underrated by individuals. Fatigue imposes biological limitations that impair the performance of even highly motivated and skilled individuals that cannot be overcome by training, experience, money, or other incentives (Caldwell, 1997). Obtaining less than six hours of daily sleep can noticeably decrease performance, while long periods of wakefulness can cause simple tasks to become more difficult to perform. Studies have shown that 17 hours of continuous wakefulness degrades aspects of performance as much as a blood alcohol content (BAC) of 0.05%. Being awake for 24 hours can reduce performance to that of a BAC of 0.10% (Caldwell, 1999).

Fatigue is common in military conflicts, with reports from Desert Shield, Desert Storm, and subsequent conflicts showing evidence of this problem. The fatigue effects that concern the operational community stem mainly from sleep loss, circadian rhythm disruption, and time on task (Co et al., 1994; Williams, Streeter, & Kelly, 1998). The culmination of intense operations or required long-range flights leads to cockpit fatigue because of the difficulty in properly controlling sleep periods (Caldwell, 2003). These factors can affect aviator crewmember alertness and performance.

1. Fatigue Effects on Aviator Performance

Flying fatigue is defined as “a decrease in skilled performance related to duration or repetitive use of that skill, aggravated by physical, physiological and psychic stress” (United States Air Force [USAF], 2000). Fatigue is a normal response to the conditions of flight operations because of sleep loss, shift work, and long duty cycles. In particular, tactical aviators may experience circadian rhythm disruption as their schedules may shift daily or when late-night missions are followed by early morning briefings (Williams et al., 1998). The physiological and performance consequences of fatigue make it essential that flight crew members remain alert and contribute to flight safety through their actions, observations, and communications (Caldwell, 1997). Fatigue fluctuates throughout the day and these fluctuations affect different aviator capabilities at different rates. From most to least sensitive, the capabilities affected are: (1) subjective sense of well-being; (2) vigilance and attention; (3) judgment and decision making; (4) complex intellectual or physical tasks; and (5) well-learned/simple intellectual or physical tasks. While basic psychomotor skills of flight are retained when flying fatigued, novel tasks and scenarios are impaired (Center for Operational Performance Enhancement [COPE], n.d.).

The flight deck environment has characteristics that make pilots susceptible to fatigue, such as restricted movement, variable airflow, low barometric pressure and humidity, noise, and vibration. Pilots may be exposed to stimuli that mask sleepiness and other fatigue symptoms and sleepiness, particularly during preflight and departure operations. These stimuli include noise, physical activity, caffeine, nicotine, thirst, hunger, excitement, and interesting conversation. However, once underway and established in flight controls, the symptoms may manifest in a sleep-deprived pilot (Strauss, n.d.).

Some of the common signs and symptoms of fatigue are forgetfulness, fixation, slowed reaction time, apathy, lethargy, nodding off, poor communication, increased irritability, and reduced vigilance (Rosekind et al., 1996; COPE, n.d.). Pilots are more likely to fail to appropriately respond to cockpit demands; are at risk for missing task-related details; show degradation in problem solving, reasoning, and control accuracy; are more likely to take risks; and are impaired in the ability to pay attention to flight instruments and manage radio communications, crew coordination, and navigational tasks (Caldwell, 1999). Fatigue produced by sleep deprivation also makes aviators more vulnerable to the effects of motion sickness (Williams et al., 1998). Extreme fatigue can result in microsleeps, an involuntary and uncontrolled lapse of attention that can last for a few seconds to a few minutes, and can occur regardless of motivation, professionalism, and training (Strauss, n.d.). If critical information is presented during these lapses, the pilot will miss this information. For a tactical aviator, lapses of attention could be fatal, depending on the timing and environment of the diminished awareness (Williams et al., 1998). All of these symptoms can significantly decrease the performance and safety of aircrews.

Aircrew fatigue has been recognized by governing agencies as a contributory factor in aircraft accidents since the 1950s, when the United Kingdom commissioned the Bader Report to regulate the hours worked by aircrews (Civil Aviation Authority, 2004). International and domestic agencies, such as the National Aeronautics and Space Administration (NASA) and North Atlantic Treaty Organization (NATO), routinely conduct research to determine the effects of fatigue on aviator performance and how to combat these effects. For example, NATO distributed a report under the Advisory Group for Aerospace Research and Development (AGARD) that researched the characteristics of circadian cycles, examined the consequences of disturbing circadian rhythmicity and sleep-wake cycles in air and space operations, and offered formulas and models for rest duty regulations (Klein & Wegmann, 1980). Still, even with the volumes of information available, fatigue continues to be a contributing factor in aviation mishaps. Fatigued pilots are thought to be responsible for 4% to 7% of U.S. aviation incidents or accidents every year. Within the U.S. military, fatigue has been identified as a contributing factor in 4% of U.S. Army aviation mishaps from 1990 to 1999 (Caldwell, 2003), 25% of U.S. Air Force night fighter Class A accidents from 1974 to 1992, and 12.2% of the U.S. Navy's total Class A mishaps from 1977 to 1990 (Ramsey & McGlohn, 1997).

C. AVIATOR SLEEP REQUIREMENTS

This section addresses the military and civilian regulations that exist for crew rest and work cycles as an effort to combat aircrew fatigue. These regulations typically constrain the number of hours worked and specify the amount of rest required before and after flight duty. They may also limit the amount of duty, based on the time of day and whether the crew is operating near its own time zone. Unfortunately, while the regulations represent safety limits, they do not address personal factors contributing to fatigue, such as matching duty hours to the crew member's circadian rhythms (Chittick, 1998).

The crew rest standards of the United States military are described first, followed by the domestic policies of the Federal Aviation Administration (FAA), followed by the flight regulations of foreign countries such as the United Kingdom, Canada, and Australia.

1. United States Military

a. United States Navy and United States Marine Corps

All U.S Navy and U.S. Marine Corps pilots, including those at MAWTS-1, are directed to follow Naval Air Training and Operating Procedures Standards (NATOPS) regulations for sleep. The current instruction, OPNAVINST 3710.7T (2004), requires that flight crews and flight support personnel have eight hours available for sleep during every 24-hour period. Ground time between flight operations should allow the crew to eat and obtain at least eight hours of uninterrupted rest. Flight crews should not be scheduled for duties that require them to be awake, such as continuous alert or flight duty, in excess of 18 hours. If it is necessary to exceed the 18-hour rule, then 15 hours of continuous off-duty time should be provided.

OPNAVINST 3710.7T (2004) provides guidelines to assist commanding officers in scheduling crew flight times, because imposing strict limitations on flight times is often impractical due to the varied conditions encountered in flight operations. Daily flight time for aircrews of single piloted aircraft should not exceed 6.5 hours (12 hours for all other aircraft). In addition, aircrew members should log no more than

30 hours of flight over seven days, 65 flight hours over 30 days, 165 flight hours every 90 days, and 595 flight hours per 365 days. When practical, flight personnel should not be assigned flight duties on more than six consecutive days.

An update to the Navy and Marine Corps flight regulations, OPNAVINST 3710.7U, was drafted in 2005, but has not yet been released. OPNAVINST 3710.7U (2005) imposes the same restrictions and standards as the older version, but it expands definitions and incorporates more sleep/fatigue information. For example, crew rest is defined as the nonduty time before a flight duty period begins and includes free time for meals, transportation, and rest, along with an opportunity for eight hours of uninterrupted sleep time for every 24-hour period. The instruction specifies that crew rest does not begin until after termination of official duties and is required prior to reporting for preflight preparations. Flight crew schedules in OPNAVINST 3710.7U mirror those for the older instruction, with the following exception: crew rest can also be reduced to less than 12 hours in order to maintain a 24-hour work/rest schedule, but a shortened crew rest period (e.g., to maintain circadian rhythm) must always include an opportunity for eight hours of uninterrupted sleep (OPNAVINST 3710.7U, 2005).

b. United States Air Force

Air Force Instruction (AFI) 11-202, Volume 3 (2006), prescribes crew rest and maximum flight duty periods (FDP) for aircrew members flying United States Air Force aircraft. It also provides basic guidance for alertness management strategies and addresses waiver authority procedures. A sleeping provision for allowing crew bunks or suitable substitute rest facilities aboard appropriate aircraft is also discussed. The rest facilities should allow adequate privacy and acceptable or decreased noise levels needed to obtain suitable rest.

Rest, as defined by AFI 11-202V3 (2006), is a condition that allows an individual the opportunity to sleep. Crew rest is normally a minimum 12-hour, nonduty period before the FDP begins and includes such activities as free time, time for meals, transportation, and rest. The purpose for a 12-hour crew rest is to ensure that the aircrew member is adequately rested before performing flight or flight-related duties. If crew rest is interrupted so that an individual cannot get an opportunity for at least eight hours of uninterrupted sleep, the individual must be afforded the opportunity for at least eight more hours of uninterrupted sleep, plus reasonable time to dress, eat, travel, etc.

As opposed to just flight time, FDPs begin when the crew reports for a mission, briefing, or other official duty and ends when the engines are shut down at the end of the mission. Maximum flight duty periods vary based on the type of aircraft and type of aircrew. A fighter with a basic aircrew has a maximum FDP of 12 hours, while a transport is limited to 16 hours with a basic aircrew and 24 hours with an augmented aircrew. See AFI 11-202V3 (2006) for additional maximum FDP. In addition to maximum flight duty periods, crew members should log no more than 56 hours flight time per seven consecutive days, 125 flight hours per 30 consecutive days, and 330 flight hours per 90 consecutive days. Also, if official postflight duties are anticipated to exceed two hours, consideration should be given to reducing the FDP to ensure that fatigue does not affect the safe completion of those duties (AFI 11-202V3, 2006). When continuous operations cause FDPs greater than 12 hours, but less than 14 hours, crew rest can be reduced to a minimum of ten hours to maintain a 24-hour work/rest schedule(AFI 11-202V3, 2006).

c. United States Army

Army Regulation (AR) 95-1 (*Aviation Flight Regulations*) (1997) provided a guide to commanders on scheduling aircrew members for unit missions. The instruction accounted for maximum duty periods and maximum flight times within a specific time frame with environmental factors to adjust flight times under certain conditions. Within a 24-hour time period, aircrew members had a maximum duty period of 16 hours, with eight hours maximum flight time. Flight time was limited to 37 hours over seven days and 90 hours over 30 days (140 hours if mobilized). The regulation also called for a minimum of eight hours of rest within each 24-hour duty period.

In 2006, a modification to AR 95-1 deleted hourly limits for crew endurance and incorporated AR 385-95 (*Army Aviation Accident Prevention*) for guidance (AR 95-1, 2006). AR 385-95 provides the following guidance to commanders on how to consider fatigue when scheduling aircrew personnel for missions:

> Commanders will—
>
> (1) Ensure fatigue is controlled or eliminated as a risk factor in all operations.
>
> (2) Implement programs to ensure that personnel operating/servicing military equipment, planning operations, and making critical decisions, are alert and not degraded by fatigue. Endurance management programs will, as a minimum—
>
> > (a) Provide a plan to ensure personnel performing the above duties receive sufficient recuperative sleep time in each 24-hour period.
> >
> > (b) Provide the best possible environment for recuperative sleep that protects the individual from noise, light, and temperature extremes for the entire sleep period.
> >
> > (c) Provide for adjustment of the individual body clock for those personnel changing time zones and those changing day/night work cycles.
> >
> > (d) Provide for periodic command assessment and risk-control decisionmaking on soldier endurance status and its effect on the current operation or course of action.
> >
> > (e) Be developed based upon human physiological sleep requirements as opposed to individual attitudes. Flight surgeons will assist the commander in program development to meet this requirement.
>
> (AR 385-95, 1999)

d. United States Coast Guard

The United States Coast Guard *Air Operations Manual* (COMDTINST 3710.1E, 2002) provides the aircrew utilizations standards needed to help reduce fatigue as a contributing factor in aircraft mishaps. As in the other military services, operational commanders can make exceptions to the following guidance when urgent operations are required.

The maximum flight time in a consecutive 24-hour period for a single-pilot, fixed-wing aircraft ranges from 8 to 12 hours, depending on aircraft pressurization (six hours for rotary wing). Flight crewmembers are limited to 50 hours in any seven consecutive days, 125 flight hours for 30 days, and 1,100 flight hours for 365 days. Flight times should not be extended when scheduled for maximum times except for urgent mission requirements. The instruction also provides guidance for length of off-duty hours. For example, if an individual has an accumulated flight time of

8, 10, or 12 hours, hours off duty should be 10, 12, or 15 hours, respectively. All off-duty time must allow for a minimum of eight hours of bed rest. Chapter 3, Section C of the *Air Operations Manual* provides more flight and off-duty restrictions (COMDTINST 3710.1E, 2002).

2. Civil Authorities

a. United States

The Federal Aviation Administration (FAA) was created in 1958 and is primarily responsible for the advancement, safety, and regulation of civil aviation, developing new aviation technology, and other duties within the United States (FAA, 2006). The FAA flight time limitations and rest requirements appear in three separate Codes of Federal Regulations (CFR). CFR Part 91.1057 defines the terms used within the codes including duty and rest period, while CFR Part 91.1059 specifies flight, duty, and rest time requirements for crewmembers of fractional ownership operations. Part 121.471 addresses flight time limitations on domestic, flag, and supplemental operations, with subpart Q addressing all flight crewmembers requirements and subpart R focusing on one or two pilot crews. The last regulation, Part 135.263, contains general limitations comparable to those found in the other sections (Government Printing Office [GPO] Access, 2007). For the purpose of this research, CFR Part 121.471 for all crewmembers will be the focus for reporting standards.

Under the regulation for domestic operations for all crewmembers, scheduled rest periods must include nine consecutive hours for less than eight hours of scheduled flight time. If flight time increases to nine hours, scheduled rest must increase to ten hours. Any flight time over nine hours must allow for 11 hours of consecutive rest. A provision does allow for a reduced rest period of eight hours, if the crewmember is scheduled for a rest period of at least 10 to 12 hours to begin within 24 hours of the reduced rest period (GPO Access, 2007).

Total flight time is also limited under CFR Part 121.471. It cannot exceed eight hours between rest periods, 30 hours within seven consecutive days, 100 hours per calendar month, and 1,000 hours per calendar year. Exceeding these limitations does not include circumstances beyond the control of the scheduler (i.e., adverse weather conditions) (GPO Access, 2007).

b. United Kingdom

The Civil Aviation Authority (CAA) is the agency responsible for safety, economic regulation, and consumer protection in the aviation industry in the United Kingdom. Under the CAA, Civil Aviation Publication (CAP) 371 was written to define a basic framework for the duty hours of flight crews and cabin crews. The regulations contained in the publication establish a work pattern for these crews that are designed to prevent the onset of fatigue, while minimizing the economic impact on the aviation industry. Instead of total flight time, CAP 371 places a maximum on the FDP, which is based on the number of aircrew, local start time, and number of sectors flown. Though many exceptions exist to change these numbers, minimum crew rest time is no less than 12 hours and the maximum FDP for a single pilot is ten hours per 24 hours and 55 hours for seven days. CAP 371 also limits flight times for 30 days to 100 hours (90 hours for a helo) and 900 flight hours for 365 days (800 hours for a helo) (Civil Aviation Authority, 2004). CAP 371 provides more specific guidance on duty period and rest times.

c. Canada

Transport Canada is Canada’s aviation regulator, and its Canadian Aviation Regulation (CAR) 720.15 describes the country’s flight duty limitations and rest periods for its pilots and crewmembers (Transport Canada, 2006). Maximum flight times are limited to eight hours in a 24-hour period, 60 hours every seven days, 150 hours every 30 days, 450 hours every 90 days, and 1,200 hours every 365 days. The accumulated 30- and 90-consecutive day flight times can be reset to zero when the crewmember is allowed at least five consecutive days free from duty. Crewmembers are also required to receive at least ten hours per day for rest.

An article posted in the *Toronto Star* (Cribb, Vallance-Jones, & McMahon, 2006) identified Canada as being one of the worst countries in battling pilot fatigue. Pilot on-duty hours, set by Transport Canada, exceed the rules set in the

United States and many other Western nations. For example, pilots are allowed to work a 14-hour shift that can be extended to 17 hours for unforeseen circumstances and, by adding another pilot, may be increased to 20 hours. Please refer to CAR 720 for more exceptions to the flight limitations (Transport Canada, 2006).

d. Australia

Australia's Civil Aviation Safety Authority issued Civil Aviation Orders (CAO) Part 48 for pilot flight-time limitations and rest requirements. CAO Part 48 requires a rest period of nine consecutive hours between the hours of 10 p.m. and 6 a.m. local time or ten consecutive hours for all other time periods. A pilot is limited to eight hours of flight time in a 24-hour period, but can be extended to nine hours when necessary. Extended flight times require an additional one hour of rest for each 15 minutes the flight time was extended. Pilots are also limited in flight time to 30 hours every seven consecutive days, 100 hours every 30 days, and 900 every 365 days (CAO 48, 2004).

Table 1 lists the maximum flight times and rest limitations for many military and civilian agencies.

United States Military							
		Flight Limitations					**Rest**
	Citation	**24 hours**	**7 days**	**30 days**	**90 days**	**365 days**	**24 hours**
Navy and Marine Corps	OPNAVINST 3710.7U, 2005	6.5 (single-pilot)/ 12 (other aircraft)	30	65	165	595	8
Air Force*	AFI 11-202V3, 2006	12 (fighter)/ 16 (transport)	56	125	330	---	12
Army	AR 385-95, 1999	---	---	---	---	---	---
Coast Guard	COMDTINST 3710.1E, 2002	8-12 (pressurized)/ 6 (rotary)	50	125	---	1,100	10
Civil Authorities							
	Citation	**Flight Limitations**					**Rest**
United States	GPO Access, 2007	8	30	100	---	1,000	9
United Kingdom	Civil Aviation Authority, 2004	13-Oct (2+ aircrew)*	55*	100 (90 helo)	---	1,000	9
Canada	Transport Canada, 2006	8	60	150	450	1,200	10
Australia	CAO 48, 2004	8	30	100	---	1,000	9 to 11
Note: All times are given in hours. The absence of a regulation is represented by dashed lines (---).							
*Time for Flight Duty Periods, not Flight Time							

Table 1. Comparison of Flight Time Limitations and Rest Requirements

D. FATIGUE COUNTERMEASURES

The only effective treatment for fatigue is getting adequate daily sleep and possessing good sleep habits (Caldwell, 1997; COPE, n.d.). A normal sleep period is generally accepted as 7 to 8 hours of uninterrupted rest. Good sleep hygiene improves sleep quality and includes going to bed and getting up at the same time every day. An appropriate environment, such as sleeping in a darkened room and avoiding exposure to sunlight, is also fundamental for getting proper sleep. Background noise should be reduced to a minimum, and a white-noise generator, such as a fan, should be used when possible. Snoozing outside of normal sleep periods, such as during the day, can reduce the quantity and quality of sleep. This can be counteracted by allotting more time for sleep and going through a normal sleep routine to prepare for rest (COPE, n.d.).

Unfortunately, the operational tempo for sustained U.S. military operations frequently requires 24-hour activities and may not allow for proper sleep to be obtained. The continuous hours of operation gives the United States an advantage by causing the enemy to suffer from sleepiness, thus producing procedural errors, poor planning, and a decrease in judgment and the ability to act properly in response to rapidly changing events (Caldwell, 2003). However, continual operations may also cause warfighters to suffer the same effects. Mission planners need to be aware of this fatigue and provide aircrews with regular opportunities to recover during periods of high operational tempo. In operational settings, effective rest should be promoted and the duration of wakefulness minimized by extending crew rest periods, prepositioning aircraft and crew, and supplying sleep quarantine areas (AFI 11-202V3, 2006). If these approaches are not possible, then several strategies can be used to sustain crew alertness and performance during periods when fatigue is more likely to occur. These strategies are broken into two broad categories: nonpharmaceutical and pharmaceutical. Nonpharmacological countermeasures, such as controlled cockpit rest and bright light or physical activity breaks, work to increase alertness and performance. Pharmacological agents can be used to increase the rest and alertness of pilots and aircrew.

1. Nonpharmaceutical Strategies

Nonpharmaceutical, or "natural," fatigue management strategies minimize fatigue by controlling sleep periods with proper sleep management and duration of duty periods. Unfortunately, this approach is not always possible. A U.S. Army survey of pilots showed sleep in the field or while on travel, even during peacetime, to be poorer than sleep at home (Caldwell & Gilreath, 2002). Other than sleep difficulties, working during times when circadian factors increase the prevalence of attention lapses and involuntary sleep episodes is difficult to avoid (Caldwell, 2003).

Employing good sleep hygiene helps to improve the quality of sleep. A proper sleep environment—one that is quiet, dark, and ergonomic—should also be provided to improve sleep quality. Other approaches to remedy fatigue include exercise (LeDuc, Caldwell, & Ruyak, 1998), work breaks, high levels of physical fitness, and strategic naps (Angus, Pigeau, & Heslegrave, 1992). Exercise has been shown to have temporary alerting effects, but should be avoided before bedtime (four hours for heavy exercise and one hour for mild) so as to not interfere with sleep (COPE, n.d.). The use of bright light (above 2,500 lux) has an alerting effect with exposure or, when administered at appropriate times of the circadian cycle, has been shown in laboratories to resynchronize the body's biological clock when suffering from jet lag (LeClair, 2001; COPE, n.d.). Exposure to sunlight or appropriate artificial light of this intensity suppresses the secretion of melatonin, a hormone produced in the pineal gland that causes drowsiness, and acts to increase alertness. Recommendations for adjusting to new time zones are beyond the scope of this thesis. Those interested in using light exposure to facilitate adaptation should refer to the United States Air Force School of Aerospace Medicine's publication, *Warfighter Endurance Management During Continuous Flight and Ground Operations* (COPE, n.d.), for guidance.

Naps, in particular, seem to compensate for the loss of quality nighttime sleep (Battelle Memorial Institute, 1998; COPE, n.d.; Strauss, n.d.). The most restorative naps are short naps of 30 minutes or long naps that are 2 to 4 hours in length. These lengths are designed to miss the SWS epoch of the sleep stages and avoid sleep inertia, the 15 to 20 minutes of grogginess that can be felt after waking. Short naps are commonly called "combat naps" or "power naps," and are short enough to have minimal impact on a mission, but also provide a benefit to the crew. These naps should be limited to less than 40 minutes from attempt to sleeping to awakening and may restore alertness for up to 3 to 4 hours. Longer naps of 3 to 4 hours are best for when the crew has time for rest during the mission, but not enough time for a full night of sleep. Long naps are designed to progress through and avoid SWS epochs and are most efficient during circadian rhythm troughs. These naps can restore alertness for up to 12 to 15 hours. However, whether long or short, naps are but a temporary solution to fatigue. Short naps can be used for 2 to 3 days and long naps for 4 to 5 days before the cumulative effects of sleep debt become overwhelming.

Unfortunately, exercise and work breaks offer only temporary relief from fatigue. Physical fitness may improve physical work capacity, but has almost no impact on maintaining mental performance for sleep-deprived people. Lastly, strategic naps are great for improving alertness, but are often not feasible in a high op-tempo setting. Because of these reasons, the military has continued to employ a variety of pharmacological fatigue countermeasures.

2. Pharmaceutical Strategies

Pharmaceutical strategies for fatigue countermeasures include stimulants and hypnotics, referred to as "go and no-go" pills, respectively, that help aviators maintain alertness and performance or acquire restorative sleep. Stimulants used in the aviation community are amphetamines, caffeine, and modafinil. Hypnotics may include temazepam, zolpidem, and possibly melatonin. Both stimulants and hypnotics may be available through prescriptions or over-the-counter, but the flight surgeon must always approve any medication or supplement that is taken by an aviator.

If medication, especially a stimulant, is elected to be used operationally the pilot will first be educated on the medication and its effects. After signing a consent form, a test dose is administered on the ground for familiarization and to determine if any adverse side effects will be experienced by the pilot. This procedure helps the aviator make an informed choice about whether and when to use the medication (Caldwell, 2003).

a. Amphetamines

Amphetamines are an anorexic/stimulant that have been used in the United States since 1937 to treat narcolepsy and hyperactivity/attention-deficit disorder (Caldwell, 2003; Bonnet et al., 2005). The most commonly administered form of amphetamines is dextroamphetamine. Studies were conducted in the 1940s and 1950s to determine if dextroamphetamine could be used by the military to restore or maintain the performance of sleep-deprived subjects to well-rested levels (Caldwell, 2003). In the laboratory, single 20 mg doses of dextroamphetamine were shown to return alertness and cognitive performance of nonaviators to near baseline levels and maintain performance for 7 to 12 hours, even after 48 hours of total sleep deprivation. Multiple 10 mg doses of dextroamphetamine were also shown to sustain pilot performance throughout 40 hours of sleep deprivation when administered prior to onset of fatigue degradations. Both dextroamphetamine and modafinil (discussed in Subsection c) were more effective in improving performance on the first night of sleep deprivation than a 2-hour nap. The nap, however, taken at the circadian nadir, was more effective on the second night without sleep (Bonnet et al., 2005). Overall, use of dextroamphetamine has shown to increase alertness and positive mood and reduce fatigue, confusion, and depression, while increasing feelings of vigor.

The military used amphetamines during World War II, and the United States Air Force has used dextroamphetamine to sustain performance since 1961. While a typical dose is 5 to 20 mg (Bonnet et al., 2005), the Air Force approved the use of 10 mg doses of dextroamphetamine for sustaining pilot performance in single- and dual-seat aircraft. The flight surgeon determines how many doses to prescribe based on mission duration (Caldwell, 2003).

Amphetamine's benefits for psychomotor performance in sleep-deprived adults need to be weighed against its unwanted side effects (Caldwell, 2003; Bonnet et al., 2005). It is listed in Schedule II of the Controlled Substances Act of the Drug Enforcement Agency, which means that it possesses a high potential for abuse and risk of dependence. Side effects may include increased blood pressure and pulse rate, nausea, headaches, anxiety, stomach cramps, dry mouth, pounding heart, excitation, or jitteriness. Tolerance and physical dependence may also develop rapidly with withdrawal symptoms appearing during abstinence. Dexedrine's long half-life of 16 to 30 hours also has a negative impact on sleep (Bonnet et al., 2005). Studies have shown that ingesting dextroamphetamine up to 15 hours before bedtime was associated with decreased sleep efficiency, increased sleep latency, increased duration of wakefulness during sleep, and increased movements. The drug may also impair sleep on the night following administration.

b. Caffeine

Caffeine is a readily available, short-acting stimulant shown to reduce some of the deficits associated with sleep loss. Sleep restriction studies have shown significant beneficial effects of caffeine compared to a placebo in performance or vigilance, memory, and reasoning tasks (Bonnet et al., 2005). It is also known to sustain overnight performance and improve performance during the day and has been used in air operations. Caffeine works by stimulating the central nervous system 15 to 45 minutes after ingestion and remains active for 3 to 5 hours, although individuals sensitive to caffeine can experience effects for up to ten hours (LeClair, 2001).

Caffeine is available in many forms and is found in a variety of daily consumables in varying amounts (e.g., coffee [100 to 175 mg per cup], soft drinks [31 to 55 mg], tea [40 mg], caffeine tablets [200 mg per pill], chocolate bars [10 mg]) (Caldwell, 2003; Bonnet et al., 2005). Caffeinated beverages can be used without explicit flight surgeon and command authorization, though caffeinated tablets can be used only after flight surgeon clearance. The minimum amount of caffeine recommended to improve alertness and performance is 75 to 150 mg after acute sleep loss and 200 to 600 mg after one or more nights of total sleep loss (Bonnet et al., 2005).

Long-term efficacy for caffeine has not yet established, especially for habitual users (Caldwell, 2003). Since the body adjusts quickly to the effects of daily caffeine consumption, habitual users may need more caffeine to achieve the same benefit as nonusers. Habituating is thought to occur at ten mg/kilograms per day, or approximately 6 to 10 cups of coffee (LeClair, 2001; Caldwell, 2003). Frequent use can also lead to tolerance and withdrawal symptons, such as headaches, daytime sleepiness, and fatigue (Caldwell, 2003; Bonnet et al., 2005).

Possible side effects of caffeine include muscle tremors (or “the shakes”), dehydration, frequent urination, feelings of nervousness and tension, and may sensitize the heart to the development of irregular heartbeats. Doses should not exceed 600 mg per day to avoid negative side effects (Caldwell, 2003; Bonnet et al., 2005). Caffeine before sleep also leads to lighter sleep with more awakenings and reduced total sleep time. Conservative recommendations for caffeine consumption are to not take it six hours before bedtime (LeClair, 2001).

Based on the decreased severity of potential side effects, caffeine is the stimulant of choice by many. It is available in multiple forms, and most people have previous experience with caffeine and are familiar with its side effects. It is not a restricted substance, has limited abuse potential, and has relatively little impact on sleep periods that follow administration after several hours (Bonnet et al., 2005).

c. Modafinil

Modafinil is a relatively new drug and has been approved for use in the United States since December 1998. Using the brand name Provigil[R], modafinil is a prescription medication used to sustain performance during prolonged periods of total sleep loss (Caldwell, 2003). Research shows modafinil maintains the alertness of people with sleep disorders, such as narcolepsy, and improves the functioning of those missing sleep from night work or long duty periods. Laboratory studies have also shown that modafinil sustained alertness and performance of pilots during 40 hours of sleep deprivation, with no reported side effects related to dizziness and vertigo (Caldwell, 2003). Modafinil has shown to improve psychomotor performance, objective and subjective alertness, and mood during sleep-loss periods up to 85 hours. A typical dose is 200 mg (Bonnet et al., 2005).

A possible alternative to dextroamphetamine, modafinil may have the positive benefits of amphetamines without the side effects of increased heart rate and blood pressure. It is a Food and Drug Administration (FDA) Schedule IV medication with a low potential for abuse and low tolerance development (Bonnet et al., 2005). Modafinil has a half-life of 12 to 14 hours and may have some adverse effects on sleep periods that follow administration by 14 hours (Caldwell, 2003; Bonnet et al., 2005). Possible side effects of modafinil include headache, nausea, depression, and anxiety (Bonnet et al., 2005). More research is needed before the military will adopt modafinil for use on a widespread basis.

d. Temazepam (Restoril)

Until recently, temazepam was the only hypnotic approved by the United States Air Force for crew use. Due to its long elimination half-life of 8.4 +/– 0.6 hours, it requires a 12-hour grounding period after administration. Temazepam may also worsen fatigue toward the end of a mission if used for premission or in-flight napping (LeClair, 2001). Temazepam has been shown to alter sleep architecture by increasing Stage 2 sleep and reducing both SWS and REM sleep. It can cause persistent drowsiness upon waking through drug accumulation after three doses and can cause acute withdrawal effects similar to alcohol. A typical dose of Temazepam is 15 mg (Ramsey & McGlohn, 1997).

e. Zolpidem (Ambien)

Zolpidem is a sedative that can aid in providing restorative sleep to acute and chronically fatigued individuals. It can provide restorative sleep in situations not conducive to sleeping, such as troop transport, napping during extended missions, premission or preshift napping, and rest during circadian peaks. Zolpidem may be preferred for use in aviators because it is relatively free from debilitating side effects and does not cause tolerance or promote drug dependence (LeClair, 2001). It preserves normal sleep architecture, is not associated with persistent waking drowsiness, and does not have acute withdrawal effects. A typical dose of Zolpiderm is 10 mg (Ramsey & McGlohn, 1997).

f. Melatonin

Melatonin is a hormone produced in the pineal gland that may be useful for treating disturbed sleep because it has sleep-promoting and circadian phase-shifting effects. Darkness and circadian rhythms prompt the pineal gland to release melatonin, causing drowsiness, while bright light suppresses secretion of melatonin and facilitates alertness. Proper use of melatonin may help resolve sleeping problems by boosting the body's natural melatonin levels, thereby increasing drowsiness, and may help speed up the resynchronization of the circadian clock when jet lag is present (LeClair, 2001). In a study by Sharkey, Fogg, and Eastman (2001), melatonin was shown to prevent the decrease in sleep time common during daytime sleep. Also, no hangover effects were found from administering melatonin (Sharkey et al., 2001).

Melatonin tablets may be found over-the-counter and are currently not certified by the Food and Drug Administration. Suggested dosages range from 100 to 200 mg, though it is best to start with small dosages and increase until the desired effect is reached (Ratzburg, n.d.). More research is needed on melatonin before it can be adopted for use by the military.

III. METHODOLOGY

A. OVERVIEW

The objective of this thesis is to determine if sleep is related to student performance during classroom instruction and flight evaluations at MAWTS-1. Along with academic and flight performance, sleep logs and actigraphy data were continuously gathered during WTI 1-06 from September 16, 2005 to October 29, 2005. This chapter discusses how the data were gathered to answer the study's objective. Section B describes the participants who volunteered for the study. Section C explains the equipment and software used to gather and process the data. Lastly, Section D describes the data collection procedure, while Section E explains how the sleep data were analyzed.

B. PARTICIPANTS

The students attending WTI 1-06 at MAWTS-1 checked into the school on September 11, 2005 and started classroom training the next day. Classes were held Monday through Saturday. Their day typically began at 7 a.m. and ended between 4 p.m. and 7 p.m.. In-flight training began on October 3, 2005 and ended on October 29, 2005. The in-flight training hours varied between 5 a.m. and 10 p.m., depending on the type of exercise to be executed. WTI 1-06 graduation was held on October 30, 2005.

The student body of WTI 1-06 was briefed on September 15, 2005 about the thesis research and its importance in determining if fatigue effects are present during training. All students signed a form indicating whether or not they wanted to participate in the study. Only officer pilots were recruited for the study due to the limited availability of actigraphy watches. From those pilots who volunteered, individuals were stratified by flight platform and randomly selected from each of those groups to participate in the study. Altogether, 21 students were chosen to wear a WAM and fill out a daily activity log. The daily log was used to help analyze data and kept track of five critical times: time to bed, wake-up time, naps, time in class, and flight times. An example of the log can be found in Appendix A. Participants signed a consent form and privacy act statement prior to the start of data collection on September 16. One participant left the study after disenrolling from MAWTS-1 for personal reasons. The ages of the remaining 20 participants ranged from 26 to 32 years, with an average age of 29.75 years. One participant did not give his age.

The participants were all male United States Marine Corps officer pilots, with varying degrees of military and flight experience at the time of data collection. Several air platforms were represented in the study. Table 2 summarizes the demographic data for the participants. No data was gathered on Participant 16 after he disenrolled from MAWTS-1 for personal reasons.

Participant #	Rank	Age (years)	Air Platform	Flight Hours
1	Capt	28	AH-1W	1,098.6
2	Capt	28	UH-1N	1,082.2
3	Capt	26	AH-1W	763.9
4	Capt	31	UH-1N	1,545.1
5	Capt	28	AH-1W	1,174.7
6	Capt	27	AH-1W	783.0
7	Capt	32	CH-53E	1,021.6
8	Capt	29	CH-46E	793.7
9	Capt	28	CH-46E	938.7
10	Capt	31	AV-8B	857.7
11	Capt	30	F-18C	1,274.0
12	Capt	30	F-18D	1,238.3
13	Capt	30	AH-1W	1,262.1
14	Maj	32	F-18D	1,535.8
15	Maj	N/A	KC-130	2,309.4
17	Maj	32	F-18D	1,785.1
18	Capt	30	AV-8B	727.2
19	Capt	32	CH-53D	1,059.1
20	Capt	31	CH-46E	856.4
21	Capt	28	AH-1W	1,104.3
Average:		29.75		1,160.5
Note: N/A = Information Not Available				

Table 2. Participant Demographics

C. APPARATUS

1. Performance Measurements

The instruments used to measure student pilot performance were the generic inventory exam and Prospective Weapons Tactical Instructor (PWTI) Aviation Training Forms (ATFs).

The inventory exam was the generic exam given to all WTI students on September 19, 2005, four days after WTI academics began. All WTI students were required to complete preliminary reading assignments and training modules before they arrived for training. The intent of the assignments was to ensure that the WTI students had a solid foundation of tactical and tactical risk management knowledge on which to build the WTI course of instruction. The generic inventory exam tests this baseline knowledge and was generated from questions located at the end of each chapter of the study materials.

The PWTI ATF was used in obtaining flight scores for student pilots during flight training. The ATFs were developed to standardize what and how the exercises were scored by instructors. The five areas graded for students during flight exercises were: (1) Plan and Prep; (2) Brief; (3) General Execution; (4) Specific Close Air Support (CAS); and (5) Debrief. These main areas of focus are broken into more specific tasks on the ATF, some of which are platform specific, and assigned one of six scores (i.e., Did Not Do [DND], Unsatisfactory [UNSAT], or numbers 1 through 4) based on the students' level of proficiency:

- DND: Not applicable or not observed.
- UNSAT: Unsafe or complete lack of ability and/or knowledge. Requires substantial input from instructor for safe execution and/or mission accomplishment.
- 1: Safe, but limited proficiency. Requires frequent input from the instructor.
- 2: Correct. Recognizes and corrects errors. Requires occasional input from the instructor.
- 3: Correct, efficient, skillful, and without hesitation. Requires minimal input from the instructor.
- 4: Unusually high degree of ability. Requires no input from the instructor.

Only the numbered scores from each task were averaged to determine a final grade for the exercise. The averaged scores were then correlated with the amount of sleep obtained to determine if flight performance was correlated with fatigue factors.

2. Actigraphy

Actigraphy, a method for objectively quantifying activity and sleep, is recorded on humans by a participant wearing a WAM for a specified period of time. The WAM contains a small accelerometer that produces a signal when motion is detected. This signal is used to digitally record the number of movements in a specified time period. The data are stored in the WAM's memory for download and analysis (Peacock, 2006). Because it continually records the movements of a user during sleep and wake cycles, actigraphy can be used to help assess daytime sleepiness, where a laboratory sleep latency test is inappropriate. Actigraphy is also used to clinically evaluate insomnia, circadian rhythm sleep disorders, and sleep-related movement disorders, e.g., restless leg syndrome and periodic limb movement disorder (Respironics, 2008). Digitally recording wrist activity has been found to be a reliable indicator of sleep/wake states.

The WAMs used in this study were the Actiwatch-64 and Actiwatch-L from Mini Mitter, a Respironics Company, located in Bend, Oregon. Both models contain a highly sensitive accelerometer that records a digitally integrated measure of gross motor activity (Mini Mitter, n.d.). While most sensitive to motion changes in certain orientations, the accelerometer is omnidirectional and is sensitive to motion changes in all directions. The integration of movement, including directional aspects, is stored as activity "counts" in each WAM (Actiwatch Instruction Manual, 2005).

Both Actiwatch-64 and Actiwatch-L are worn on the wrist and are the size of a standard wristwatch. The Actiwatch-64 is the standard actigraphy model used most often for diagnosing insomnia and documenting circadian rhythm (Mini Mitter, n.d.). The model has 64 KB of memory and, when recording in 1-minute epoch times, has 45 days of continuous life. The model has an integrated event marker that can be used to indicate events, such as bed times and get up times. The marker feature was not used in this study. Actiwatch-64 specifications are shown in Figure 2.

Actiwatch-64 Specifications

- Weight: 16 grams
- Size: 28 x 27 x 10 mm*
- Non-Volatile Memory: 64 kbytes
- Recording Time at one minute sample interval: 45 days
- Battery Life: 180 days
- Waterproof to IEC Standard 60529 IPX7 (watertight to a depth of one meter for 30 minutes)

Figure 2. Actiwatch-64 (From: Mini Mitter, n.d.)

Prior to data collection, each WAM was initialized by clearing the memory, calibrating it with the correct local date and time, and programming it to begin data collection in 1-minute time intervals, or epochs. This epoch length records sufficient motor activity, while also extending the WAM battery.

Actigraphy data were collected and downloaded using Mini Mitter's Actiware Program Version 5.02. The software uses raw actigraphy data to calculate quantitative measures, such as sleep start and end times, sleep duration, and sleep efficiency. The actigram is a visual representation of a participant's activity level. Vertical bars show activity with the height representing the level of motion sensed by the watch. See Figure 3 for an example of ten days' worth of output. Each line represents 24 hours; the areas shaded in light blue indicate sleep, while the black marks indicate activity during one-minute intervals.

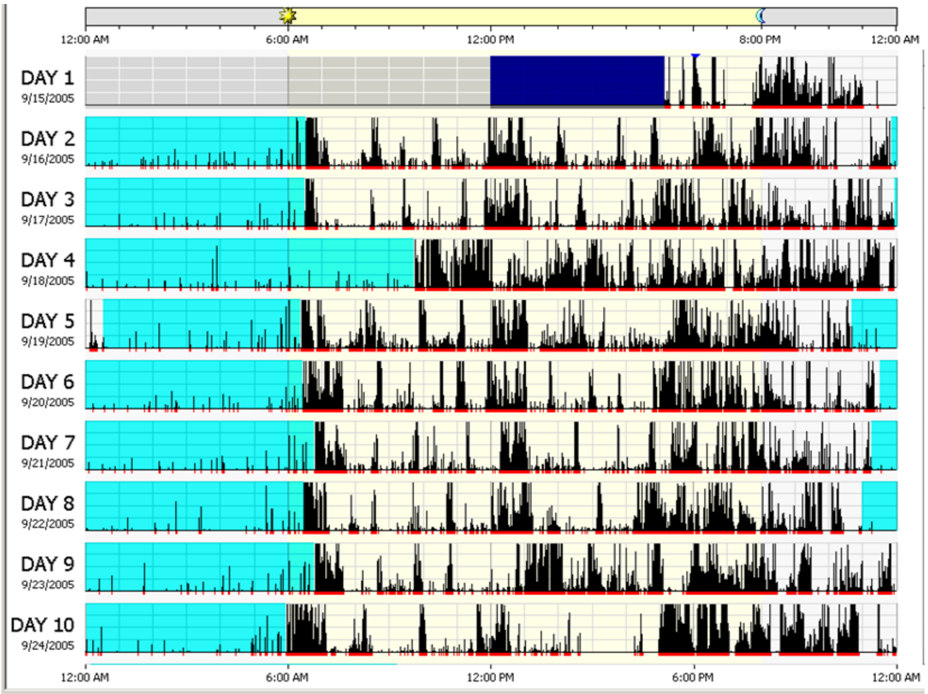

Figure 3. Example of Actigram Output

3. Fatigue Avoidance Scheduling Tool (FAST) Version 1.5.08

FAST is a software program that allows users to predict the effects of various work and sleep schedules on human performance. FAST calculates composite human performance effectiveness, based on time of day, circadian rhythms, time spent awake, and amount of sleep. FAST is based on the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model developed by Dr. Steven Hursh of Science Applications International Corporation (SAIC) for the Air Force Research Laboratory (COPE, n.d.). The SAFTE model is a cognitive fatigue model accepted by the Department of Defense as the most complete, accurate, and operationally practical model currently available to aid operator scheduling. The model combines the concept of a sleep reservoir with the concepts of circadian rhythms and sleep inertia to predict performance. However, the SAFTE model's algorithms do not take into account the effects of environmental factors, stressors, or medications (such as stimulants) when predicting performance (Eddy & Hursh, 2001).

FAST allows users to enter proposed schedules and generates graphical predictions of performance and tables of estimated effectiveness scores for an objective comparison of schedules. Optimal schedules can then be selected, based on average effectiveness for proposed work periods or mission-critical events. FAST may also be used for a retrospective analysis of fatigue-related factors that may have contributed to an accident or safety-related incident. To do this, the work and sleep schedules of operators prior to the event are entered into the program to determine the predicted performance effectiveness at the time of the event (Eddy & Hursh, 2001). This study on MAWTS-1 pilots used the retrospective method for predicting human performance at critical times.

Figure 4 shows an example of a graphical performance prediction generated by FAST. The green band at the top of the chart indicates the ideal performance level for aviators and ranges from 90% to 100% effectiveness. The yellow band below the green band indicates a cautionary zone ranging from 65% to 90% effectiveness. The red zone, in the bottom portion of Figure 4, represents performance effectiveness below 65%—the predicted effectiveness after two full days of sleep deprivation. The USAF requires its aviators to operate above the dotted line in the yellow band, or 78% predicted effectives, at all times. While away on mission-critical activities (e.g., take-off, bombing, and landing), USAF aviators must be in the green zone, or operating at a minimum 90% effectiveness.

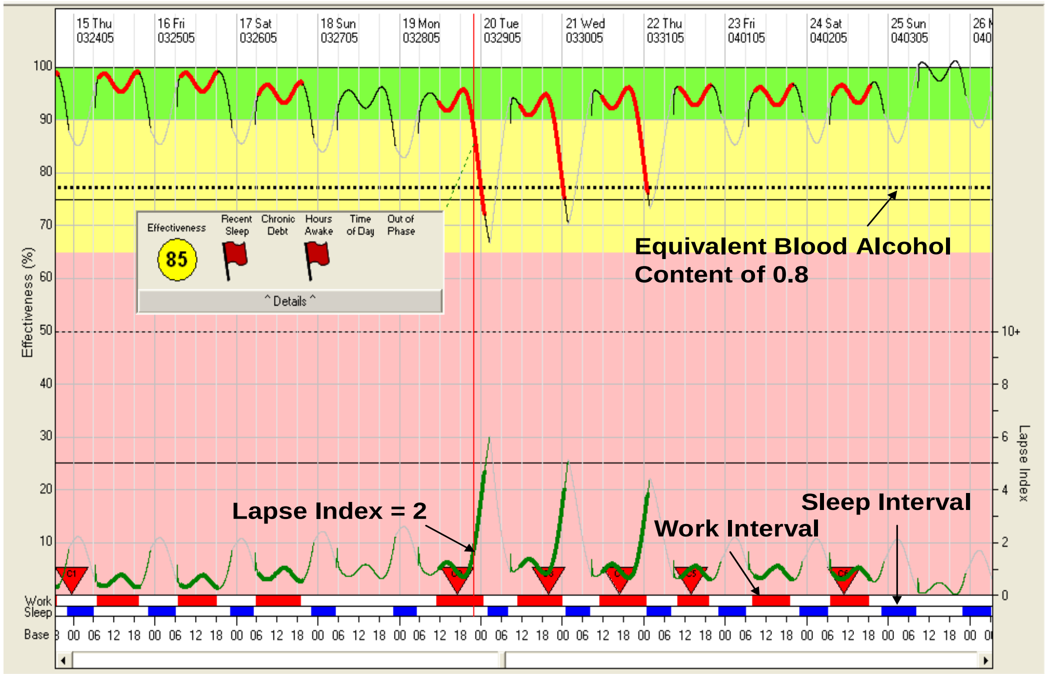

Figure 4. Example of FAST Output

D. PROCEDURES

To select the participants for the study, the MAWTS-1 flight surgeon first stratified volunteers by flight platform and randomly chose each participant from within each platform group. The selected participants were then issued WAMs and daily activity logs on September 16, 2005; data collection began that same day. They were instructed to wear the WAM at all times, especially during training periods, and to take the WAM off only when necessary (e.g., when taking a shower). Data were collected for 43 days and ended on October 29, when the WAMs were turned in. Data were also downloaded approximately every two weeks by the MAWTS-1 flight surgeon to ensure no data were lost due to the WAM's memory becoming full.

E. ANALYTICAL STRATEGY

At the end of the study, the data were sent from MAWTS-1 to NPS to be analyzed. The actigraphy files for each participant were first joined into a single file using ActiWare 3.41. Once joined, the files were "cleaned" in ActiWare 5.02 by manually marking the start and end of each sleep period in the actigraphy data. Participants maintained daily activity logs that included start and end times for nightly sleep, naps, classroom instruction, flights, and flight planning/debriefing. The daily log was used to make sure participant's sleep and activity was coded accurately. For example, if a participant reported a nap in the middle of the day, that period was assigned as "sleep." ActiWare 5.02 output included the start and end date, start and end time, duration, efficiency, and number of sleep bouts for each sleep period. These data were copied and pasted into Microsoft Excel for use in building FAST predicted performance, calculating sleep quality, and importing into other statistical analysis software.

Next, each participant's sleep and work schedules were directly imported from ActiWare 5.02 into FAST 1.5.08 to calculate predicted performance during times of interest. The FAST program automatically assumes excellent sleep quality for imported sleep periods, but this assumption may not accurately reflect a participant's actual sleep quality. The Excel worksheets were used to calculate and manually set the sleep quality for each sleep interval and to verify that the start and end of each sleep period in FAST matched the output from ActiWare. Because FAST 1.5.08 assumes sleep quality based upon interruptions, or sleep bouts, per hour, this value was calculated from ActiWare 5.02's quantitative output of number of sleep bouts. Table 3 shows FAST sleep quality based upon hourly sleep bouts. Fair and poor sleep quality can be used to simulate a person with mild or moderate sleep apnea experiencing this many sleep apnea episodes per hour. Sleep quality can be used in conjunction with the length of sleep to create a more accurate portrayal of predicted performance within the FAST program.

Sleep Quality	**Bouts/Hour**
Excellent	Less than 2
Good	2 to 4
Fair	4 to 6
Poor	More than 6

Table 3. FAST Sleep Quality Based on Bouts/Hour

Naps were noted in the sleep logs or, when logs were missing, assumed when inactive periods of greater than 30 minutes, outside of known work periods, were displayed on the actigram. ActiWare 5.02 does not allow for a nap analysis and was not factored into daily sleep quantity or efficiency. Naps, however, were included in the FAST analysis and had a positive impact on predicted performance.

Three forms of missing data were encountered during this thesis study. First, several participants failed to return their daily activity logs at the completion of the study, making the logs unavailable for cleaning a participant's actigraphy data. In these instances, the beginning and end of sleep periods were estimated by the observation of consistently low activity levels in the actigraphy data. These estimated sleep periods were set conservatively so that the amount of sleep attained was not underestimated, which would negatively affect results. Secondly, participants would sometimes take off the WAM and neglect to put it back on, resulting in no actigraphy data being recorded during that time. ActiWare 5.02 allows these intervals of missing data to be "excluded" and would not be factored into its data analysis. FAST, however, requires a continuous interval for input and substitutes excellent sleep throughout an interval with missing actigraphy data. To avoid potentially skewing the data in FAST, the start and end times of sleep indicated from a participant's activity log were substituted for any missing data. The sleep quality for the missing interval was determined by averaging the sleep quality before and after the missing data. The third form of missing data occurred when a participant failed to return the activity log and had intervals of missing actigraphy data. When this happened, the participant's mean nightly sleep and sleep quality calculated from ActiWare was substituted for the missing data in FAST. This process of substituting the mean for missing data is a common and conservative method for handling missing data; although the FAST results may be very sensitive to these substitution if the subjects' sleep patterns vary widely from day to day, it does not change the participant's mean nightly sleep. Periods of missing data are highlighted by gray triangles on the FAST graphical output, which are located in Appendix C. Table 4 summarizes the missing data for those participants who failed to return the activity log and/or had incidents of missing actigraphy data during classroom and flight training. Participants 1, 4, 7, 11, and 12 did not have any missing data.

	Missing Data		
Participant	**Activity Logs**	**Actigraphy Data** (# of incidents)	
		Classroom	Flight
2	X	1	0
3		1	0
5		0	2
6	X	0	0
8	X	6	6
9	X	2	1
10	X	0	1
13	X	0	0
14		0	1
15	X	0	0
17		1	0
18		9	0
19		1	0
20		1	0
21		1	0

Table 4. Summary of Participant Missing Data

It is unclear if the failure to turn in activity logs or have incidents of missing actigraphy data is a random condition or a potential for self-selection within the participants. However, it may be interesting to note that both Participants 6 and 8, who had the least mean nightly sleep of 5.31 hours, failed to turn in their activity logs, and due to the conservative method of estimating nightly sleep, may have had less sleep than calculated. Participant 11, however, had the highest mean nightly sleep of 8.17 hours and did not have any missing data.

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IV. RESULTS

This thesis research follows up on the baseline study of WTI 2-05 that found its student sample population to be chronically sleep deprived with an average nightly sleep of only 5.62 hours throughout training. The data collected from WTI 1-06 for this thesis assumed similar sleep deficiencies would be seen in its student population, but this was not the case. Instead, dramatic improvements in sleep quantities were seen from the baseline study. The mean nightly sleep for the 20 participants was 7.05 hours (7 hours, 3 minutes), with standard deviation of 0.74 hours (44 minutes). Figure 5 below graphically shows the significant difference in mean nightly sleep between WTI 2-05 and WTI 1-06. A student's t-test also concludes there is a statistically significant difference between the means with p = 0.0016.

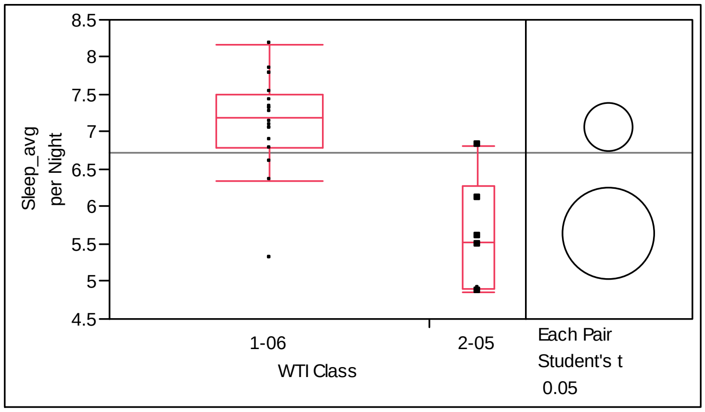

Figure 5. Box Plot of Mean Nightly Sleep by WTI Class

The student sample from WTI 1-06 received on average 1.43 hours more sleep than WTI 2-05 students. This significant improvement in mean nightly sleep shows that the students obtained enough sleep throughout training and were adequately rested. Therefore, no correlations were anticipated between student sleep patterns and student performance, the original objective of this thesis research. However, a statistical analysis was completed to determine if any other correlations arise in the data. The following analysis is also an approach one could follow in correlating sleep data with performance if chronic sleep deficiencies had occurred.

A. STATISTICAL ANALYSIS

This analysis is based upon a pilot observational study of the actigraphy data, exam scores, and flight scores for 20 MAWTS-1 student pilots. Because the students were found to be getting adequate sleep throughout training, the data set was small, and unexpected problems were encountered with missing information (i.e., activity logs, actigraphy data, or both), the analysis is exploratory in nature, determining if correlations exist that could be explored in more detail in future studies. Basic summary statistics and bar charts were used for initial familiarization of data points and to identify possible problems with the data set. Statistical significance was explored using the Tukey-Kramer “Honestly Significant Difference” (HSD) Test and students’ t-test with α = 0.05 for comparing multiple variables, or by using regression analysis (bivariate or multivariate fits) when looking at continuous data.

1. Descriptive Statistitics

a. Age

Figure 6 shows the age distribution of the 20 participants.

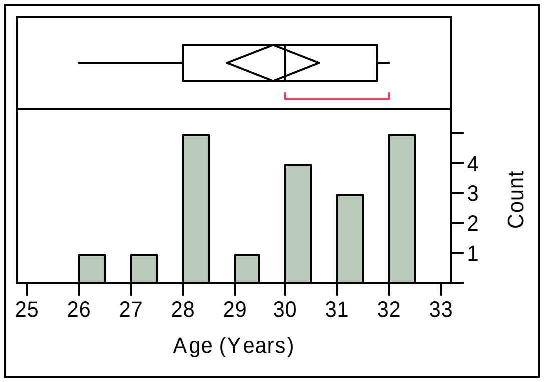

Figure 6. Age Distribution

The ages ranged from a minimum of 26 years to a maximum of 32 years. The median was 30 years, while the mean age of the participants was 29.75 years.

b. Sleep

The objective of this thesis was to determine if sleep is predictive of classroom and flight performance, as measured by scores from classroom inventory exam and flight training forms, of MAWTS-1 students. In order to do this, sleep was broken into four distinct periods during training: average sleep obtained 72 hours prior to the classroom exam for all participants (Sleep_avg Exam), sleep obtained 72 hours prior to individual scored flights (Sleep_avg 72 hrs before flight), average sleep obtained 72 hours prior to all scored flights (Sleep_avg before scored flights) and average sleep obtained across all six weeks of WTI 1-06 (Sleep_avg per Night).

"Sleep_avg per Night", or the mean nightly sleep across all WTI 1-06 training, was used to see which participants received the minimum and maximum sleep during training. This variable was also substituted for missing data when appropriate. A distribution of the study sample, using quarter-hour increments, is shown in Figure 7.

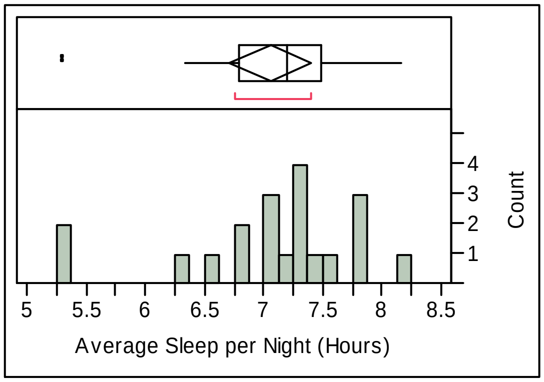

Figure 7. Mean Nightly Sleep Histogram

The distribution was unimodal, except for the two participants who received 5.25 to 5.50 hours of sleep. The students received an average of 7.05 hours (7 hours, 3 minutes) of nightly sleep, with a standard deviation of 0.74 hours (44 minutes).

The variable "Sleep_avg Exam" was used in correlating sleep with inventory exam scores and FAST predicted performances during the exam. The inventory exam was taken by all students on September 19, 2005, three days after data collection began. As mentioned in the Literature Review in Chapter II, acute sleep restriction immediately after learning new material causes memory impairment of the new material. Since the material tested by the inventory exam was studied by students prior to attending WTI, gathering student sleep data while the material was being learned could not be accomplished. However, those participants practicing sleep restriction may have a sleep debt at the time the test was taken, potentially affecting their memory and concentration skills. Therefore, the average sleep obtained 72 hours prior to the exam was deemed sufficient in determining if sleep quantity prior to the exam influenced exam performance. Figure 8 displays the distribution of sleep obtained prior to the exam, shown in quarter-hour increments.

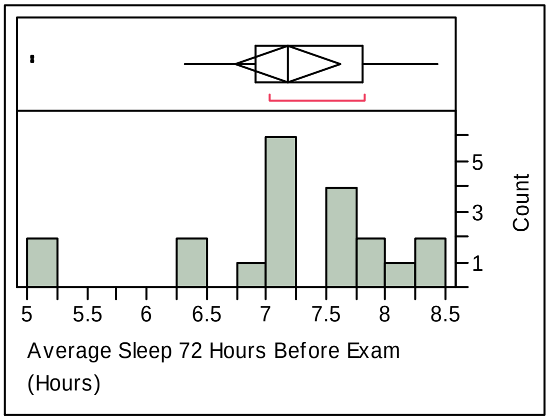

Figure 8. Histogram of Average Sleep 72 Hours before Exam (Hours)

The distribution was unimodal, with the exception of two students who received 5.00 to 5.25 hours of sleep. These students were the same participants identified as exceptions in the distribution of mean nightly sleep in Figure 6. The results showed that the students received an average of approximately 7.18 hours (7 hours, 10 minutes) of sleep 72 hours before the exam, with a standard deviation of 0.93 hours (56 minutes).

Because MAWTS-1 follows the NATOPS requirements for sleep, students were required to have a minimum of ten hours between flight exercises to allow for appropriate rest to be obtained between flights. “Sleep_avg 72 hrs before flight” averaged the sleep obtained 72 hours before every flight that was scored with an aviation training form for the 20 participants during the flight portion of training. This variable was also correlated with flight score data in Section A.3 of this chapter. While averaging the sleep before each flight event, missing sleep data were encountered when participants had missing actigraphy data from removing the WAM and failed to turn in an activity log. When this occurred, the participants' mean nightly sleep was substituted for a period of missing sleep. A flight score was excluded from analysis if two or more periods of sleep were missing during the 72 hours prior to the flight event. Table 5 shows the descriptive statistics for the average sleep obtained 72 hours before scored flights for each participant.

Participant	Mean	Standard Deviation	Median	Minimum	Maximum	No. of Flights
1	7.32	0.67	7.16	6.33	8.49	15
2	7.88	1.01	7.60	6.36	9.78	15
3	7.33	0.62	7.38	6.06	8.52	13
4	6.95	0.86	7.03	5.46	8.07	13
5	7.43	0.46	7.41	6.68	8.23	13
6	6.67	0.79	6.74	5.02	8.14	14
7	6.75	0.55	6.91	5.96	7.55	9
8	7.18	0.77	7.06	6.01	9.02	10
9	7.43	0.93	7.56	5.08	8.82	15
10	7.02	0.94	6.67	5.16	8.89	17
11	7.56	0.86	7.78	6.40	8.64	9
12	8.25	0.68	8.41	7.14	8.91	8
13	8.01	0.67	8.00	7.09	9.24	15
14	8.35	1.21	8.76	5.70	9.44	8
15	7.92	---	7.92	7.92	7.92	1
17	8.40	0.59	8.35	7.67	9.03	6
18	8.13	0.82	8.22	6.68	9.30	15
19	8.02	0.79	7.88	6.85	9.28	11
20	7.42	0.78	7.42	5.56	8.39	13
21	7.34	0.66	7.24	6.49	8.50	14

Note: All times are given in hours. The absence of a value is represented by dashed lines (---).

Table 5. Descriptive Statistics for Average Sleep Obtained 72 Hours Before Each Flight By Participant

Averaging the sleep obtained 72 hours prior to scored flights for each participant (Sleep_avg before scored flights) yielded the following distribution, shown in Figure 9, in half-hour increments.

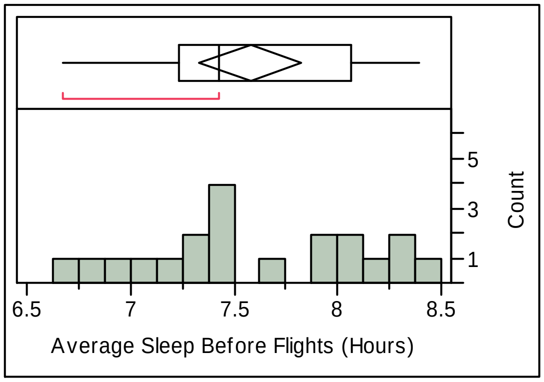

Figure 9. Histogram of Average Sleep Obtained Before Flights

The distribution above showed that the 20 students received an average of approximately 7.58 hours (7 hours, 35 minutes) of sleep 72 hours before a flight event, with a standard deviation of 0.53 hours (32 minutes). The minimum average sleep before a flight was 6.67 hours (6 hours, 40 minutes), while the maximum average sleep was 8.40 hours (8 hours, 24 minutes), a difference of 1.73 hours (1 hour, 44 minutes). Overall, students were well-rested before their flights.

The sleep data used in correlation with FAST predicted performance during flight training was also an average of the sleep obtained 72 hours prior to a scored flight. However, only those flights with flight times indicated in participant activity logs could be used for analysis. Seven participants failed to return their activity logs, reducing the number of participants available for FAST analysis to thirteen. Five of the remaining thirteen participants failed to indicate the flight times for several scored flights on their activity logs, reducing the number of flights available for analysis. Table 6 below shows the descriptive statistics for the average sleep obtained 72 hours before scored flights for the 13 participants used in correlating FAST predicted performance with actual flight scores.

Participant	Mean	Standard Deviation	Median	Minimum	Maximum	No. of Flights
1	7.29	0.65	7.16	6.33	8.49	13
3	7.38	0.60	7.58	6.06	8.00	11
4	6.66	0.99	6.43	5.46	8.07	13
5	7.44	0.44	7.44	6.68	8.23	14
7	6.75	0.55	6.91	5.96	7.55	9
11	7.84	0.77	7.83	6.89	8.64	5
12	8.33	0.68	8.59	7.14	8.91	9
14	8.33	1.10	8.76	5.70	9.44	10
17	8.34	0.58	8.35	7.67	9.03	8
18	8.13	0.82	8.22	6.68	9.30	15
19	8.02	0.79	7.88	6.85	9.28	11
20	7.42	0.78	7.42	5.56	8.39	13
21	7.26	0.20	7.14	7.14	7.49	3
Note: All times are given in hours.						

Table 6. Descriptive Statistics for Average Sleep Obtained 72 Hours Before Each Flight By Participant for FAST Analysis

Averaging the 13 participant's sleep obtained prior to scored flights yielded the following distribution, shown in Figure 10, in half-hour increments.

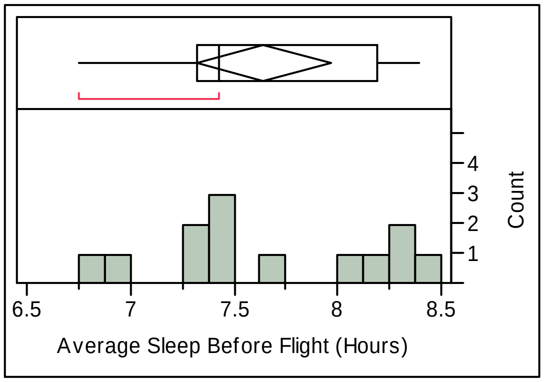

Figure 10. Histogram of Average Sleep Obtained Before Flights for FAST Analysis

The distribution above showed that the 13 students received an average of approximately 7.64 hours (7 hours, 38 minutes) of sleep 72 hours before a flight event, with a standard deviation of 0.54 hours (32 minutes). Again, students were getting adequate sleep before their flights.

c. *Flight Data*

The 20 participants selected in this study represented all the flight platforms present during WTI 1-06 training at MAWTS-1. Table 7 shows the number of students in each platform and the type of each platform. Sixty-five percent of the participants were helicopter pilots. While the actual number of students and airframes attending WTI at MAWTS-1 are determined by operational needs, a comparable ratio between helicopter and fixed-wing pilots was seen in subsequent classes.

Flight Platform	Number of Students	Platform Type
AH-1	6	Helicopter
CH-46/53	5	
UH-1	2	
KC-130	1	Fixed Wing
AV-8	2	
F-18	4	

Table 7. Flight Platform Breakdown

An exploratory analysis was conducted to determine if mean nightly sleep was correlated with individual flight platforms (i.e., AH-1) or type of flight platform (i.e., fixed wing versus helicopter); No significant correlation was found between these variables and mean nightly sleep. These results can be found in Appendix B.

Figure 11 below shows the distribution of scored flights for the 20 participants. A total of 234 scored flights were flown with a mean of 11.65 flights per participant and standard deviation of 3.90 flights.

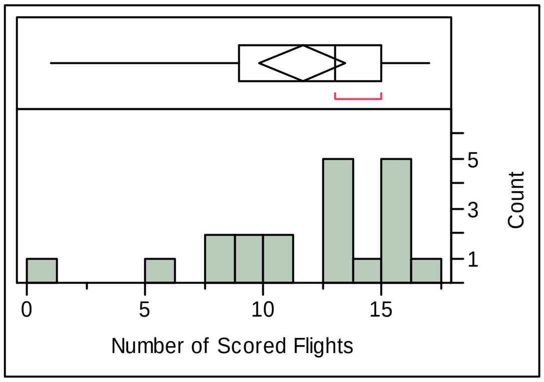

Figure 11. Histogram of Scored Flights for All Participants

The distribution of the number of scored flights for the 13 participants used in the FAST analysis of predicted flight scores are shown below in Figure 12. A total of 134 scored flights were recorded in the activity logs with a mean of 9.54 flights per participant and a standard deviation of 3.55 flights.

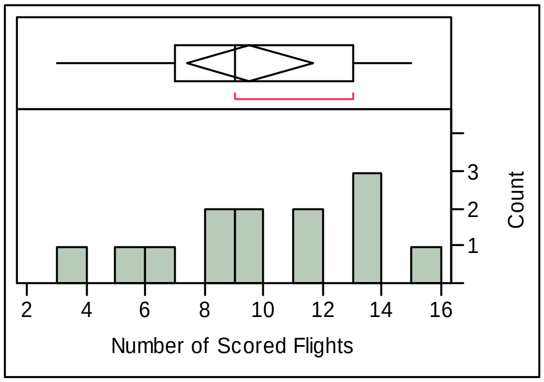

Figure 12. Histogram of Scored Flight for Participants in FAST Analysis

2. Exam Score Analysis

In examining if sleep was correlated with exam score, the data were first explored in JMP 7.0 by partitioning the data based upon relevant contributors. The Partition Platform, an analytical feature within JMP 7.0, allows users to analyze data sets to discover unknown or unsuspected relationships by recursively partitioning data according to a relationship between X and Y variables, creating a “tree” of partitions. The feature finds a set of cuts or groupings of X values that best predict a Y value and visually represents the results in a tree of decision rules once the desired fit is reached.

Five variables, Rank, Age, Flight Platform, Flight Hours, and Average Sleep Obtained 72 hours Before Exam, were input into the Partition Platform as X variables with the inventory exam score as the Y variable. The data were then “split” until all groupings significant to inventory exam score were found. Using the Partition Platform, the variables Age and Flight Hours were found to be the most significant contributors to exam score with $R^2 = 0.41$. Age was split at 31 years, where those participants 31 years or older scored an average of 2.09 points higher on the inventory exam than those younger than 31 years. For the participants under the age of 31, those with fewer flight hours (less than 1104.3 hours) scored an average of 1.40 points higher on the exam than those with 1104.3 or more flight hours. The partitioned data can be found in Figure B7 of Appendix B.

A regression analysis was conducted for the inventory exam score using the variables Age, Flight Hours (accumulated prior to attending MAWTS-1 training), and Average Sleep Obtained 72 hours Before Exam. Using $\alpha = 0.10$, the results showed that Age and the interaction of Age and Flight Hours are the only significant predictors of Exam Score. With $R^2 = 0.34$, the following model was found for best predicting Exam Score with the study sample.

$$\textit{Exam Score} = 77.64 + 0.68(\textit{Age}) - 0.0022(\textit{Flight Hours}) + 0.0015(\textit{Age}-29.75)(\textit{Flight Hours}-1160.55)$$

No significant correlations were found between Exam Score and Flight Platform and Type of Flight Platform (fixed wing or helicopter). These results can be found in Appendix B.

3. Flight Score Analysis

Due to the multiple flight platforms and varying number of scored flights for each participant, an exploratory analysis with participant flight scores and sleep (specifically "Sleep_avg 72 hrs before flight" and "Sleep_avg before scored flights") was conducted to determine correlations with flight scores.

Table 8 below shows the descriptive statistics of each participant's flight scores. There were a total of 234 scored flights with a mean of 2.50 and standard deviation of 0.41.

Participant	**Mean**	**Standard Deviation**	**Median**	**Minimum**	**Maximum**	**No. of Flights**
1	2.48	0.49	2.19	1.88	3.14	15
2	2.36	0.38	2.19	1.95	3.05	15
3	2.76	0.34	2.19	1.95	3.05	13
4	2.63	0.35	2.78	1.94	3.06	13
5	2.40	0.30	2.44	1.88	2.84	13
6	2.31	0.33	2.18	2.00	2.93	14
7	2.85	0.25	2.90	2.44	3.21	9
8	2.50	0.38	2.47	1.83	3.04	10
9	2.39	0.40	2.47	1.71	2.96	15
10	2.16	0.25	2.10	1.89	2.80	17
11	2.75	0.42	3.00	2.12	3.13	9
12	2.48	0.43	2.45	2.00	3.04	8
13	2.59	0.44	2.86	1.97	3.08	15
14	2.50	0.47	2.45	2.00	3.22	8
15	2.67	---	2.67	2.67	2.67	1
17	2.51	0.62	2.79	1.50	3.00	6
18	2.37	0.47	2.24	1.69	3.28	15
19	2.60	0.43	2.86	1.89	3.12	11
20	2.67	0.24	2.71	2.26	3.06	13
21	2.54	0.39	2.70	1.95	3.00	14

Note: The absence of a value is represented by dashed lines (---).

Table 8. Descriptive Statistics of Flight Scores By Participant

A bivariate fit, shown in Figure 13, was used to determine if a correlation exists between flight scores and the average sleep obtained 72 hours before each flight (Sleep_avg 72 hrs before flight).

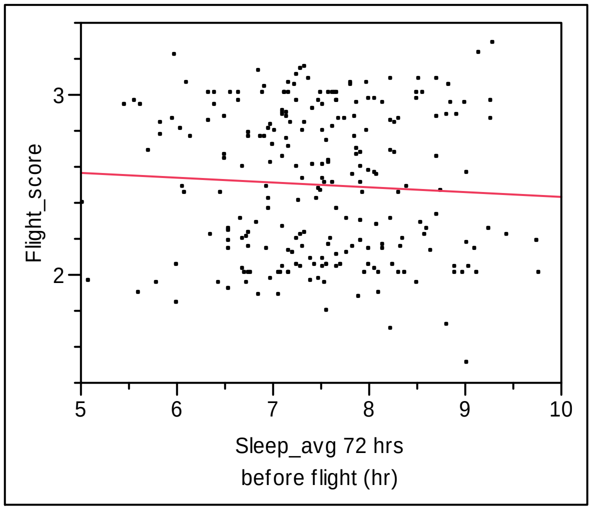

Figure 13. Bivariate Fit of Flight Scores with Average Sleep Before Each Flight

No correlation was found between Flight Score and the average sleep obtained 72 hours before each flight (R^2 = 0.0031 with p = .3960). Similarly, a bivariate fit for average flight scores and average sleep before all flights (Sleep_avg before scored flights) also yielded no correlation between the factors (R^2 = 0.00068 with p = 0.9132).

The exploratory analysis also correlated other variables with flight score data, including type of flight platform, flight name, time the flight began, age, flight hours, exam score, and number of sleep bouts. No correlation with flight scores was found with type of flight platform. The other variables and their results are described in the following paragraphs.

Flight Name refers to grouping the names of flight exercises into generic categories to simplify the analysis. The names of flight exercises were designated by event scenarios, which were either platform-specific or group exercises, and often included multiple flights. The result was a compiled database of over 40 separate flight names for the represented platforms. To simplify the process of analyzing the type of flight's effect on flight score, the names were grouped into eight generic headings, based upon type of scenario/exercise. This table of flight names can be found in Appendix D. As can be seen in Table B7 of Appendix B, the mean flight scores of Warm-up exercises were significantly different than the mean flight scores for Offensive Air Support (primarily for fixed wings), Assault Support, Anti-air Warfare, and the Final Exercise.

The start time of each flight was not correlated with flight scores, as shown in Appendix B. Flights were grouped by the following time intervals: day flights began between 7 a.m. and 3 p.m., afternoon flights went from 3 p.m. to 11 p.m., and night flights were flown between 11 p.m. and 7 a.m.

The impact of the average number of sleep bouts on flight scores was examined using bivariate fit. As explained in Section A of this chapter, the number of sleep bouts affects the quality of sleep and could potentially have an effect on flight performance. Results indicate that sleep bouts were not statistically correlated to flight scores, as shown in Appendix B.

A regression analysis was conducted for flight score using the variables of Age, Flight Hours, inventory Exam Score, and Average Sleep obtained before scored flights. The results show that none of these factors were significantly correlated with flight score.

4. FAST-Predicted Effectiveness

The objective of this thesis was to determine if the amount of sleep obtained during training is a predictor of classroom and flight performance for WTI students. To do this, the student inventory exam and training flight scores were compared with their predicted performance, as generated by the FAST program.

a. Predicted Exam Scores

All students took the generic inventory exam from 7 a.m. to 8 a.m. on September 19, 2005. Because of the known date and time of the test, predicted effectiveness for all 20 students based upon their actigraphy data—both sleep quantity and quality—was generated. Predicted effectiveness is denoted by the red triangle on the graphical output of each FAST schedule, located in Appendix C.

A bivariate fit with linear regression was used to determine if any correlations existed between predicted effectiveness on FAST and inventory exam scores.

The results indicate that the predicted effectiveness on FAST was not a statistically significant factor in predicting inventory exam scores ($R^2 = 8.578e\text{-}5$ with $p = 0.9691$).

b. Predicted Flight Scores

In-flight training for WTI 1-06 was conducted from October 3-26, 2005, for the final 3.5 weeks of training. Due to missing activity logs, the start and end times of scored flights could not be obtained for Participants 2, 6, 8, 9, 10, 13, and 15 during this phase of training. Therefore, the predicted effectiveness of these seven participants cannot be determined during flight evolutions and are not included in the analysis. Because the length of the flight evolutions changed depending upon the flight scenario/exercise, the average FAST scores across each flight evolution is used in the analysis.

A bivariate fit with linear regression, shown in Figure 14, was utilized to determine if FAST-predicted effectiveness was correlated with the flight scores of the remaining 13 participants. Results indicate that FAST-predicted effectiveness was not statistically correlated with the average flight score of each participant ($R^2 = 0.1484$ with $p = 0.1936$). Similarly, no correlation was found between the participants' average flight scores and average FAST predicted effectiveness ($R^2 = 0.005728$ $p = 0.3848$). An important item to note is that all average FAST predicted effectiveness values are above 78%, the minimum predicted effectiveness the USAF requires its aviators to operate above at all times.

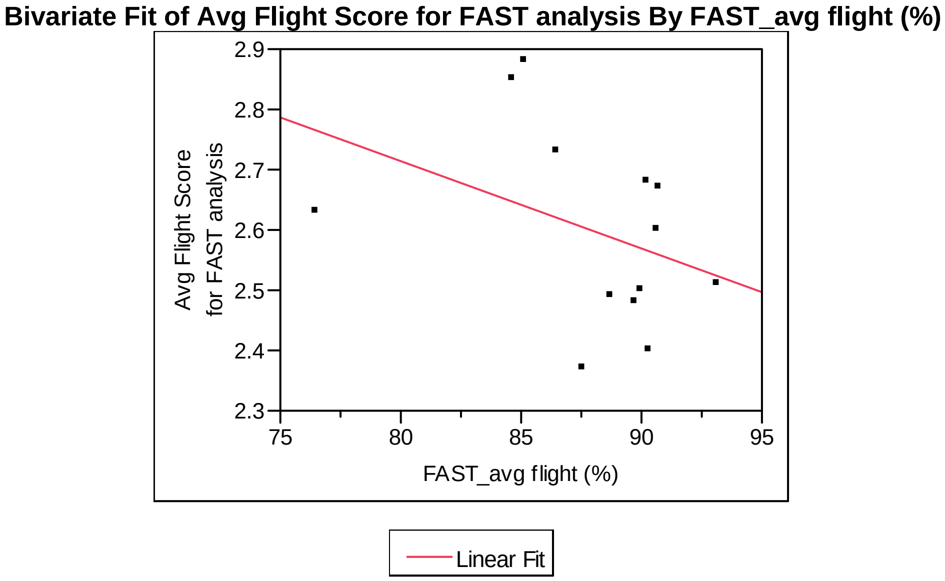

Figure 14. Bivariate Fit of Average Flight Scores by FAST Predicted Effectiveness

C. SUMMARY OF STATISTICAL RESULTS

As was expected, the results consistently showed no statistically significant relationship between sleep and actual or predictive scores for this study sample because the student population was not found to be chronically sleep deprived. Further statistical analysis found some other correlations in the data, which are described below.

Age and the interaction between age and flight platform were the only variables slightly correlated with exam score. Those participants 31 years or older, who account for 40% of the study sample, scored an average of 2.09 points higher on the exam than those less than 31 years of age. Also, for the participants whose age is less than 31 years, those with less than 1104.3 hours of accumulated flight hours prior to attending WTI 1-06 scored an average of 1.40 points higher on the inventory exam than those with fewer flight hours.

The only significant correlation for flight scores occurred with the grouped names of flight exercises. When looking at the significance of grouped flight names on flight scores, the Warm-up exercises were shown to be significantly different from four other flight scenarios: Offensive Air Support (primarily for fixed wings), Assault Support, Anti-air Warfare, and the Final Exercise. Also, correlating the predicted FAST effectiveness with the inventory exam scores or flight scores showed similar results—there were no significant correlations between predicted and actual performance.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The objective of this research was to determine if sleep patterns were predictive of student performance, as measured by scored exams and flight training forms, during both classroom and in-flight training during WTI 1-06. Because the students in this study obtained significantly more sleep than the baseline study, they were not considered chronically sleep deprived during this training. Not surprisingly, the results of the thesis determined that sleep was not a significant factor in determining or predicting exam and flight scores, but this finding is significant in other ways.

In response to an increase in Marine aviation mishap rates in fiscal year 2004, MAWTS-1 and the School of Aviation Safety (SAS) teamed up to implement an intensive three-day Tactical Risk Management (TRM) course during WTI training. The course focuses on all aspects of TRM, including lectures on Human Factors and the effects of fatigue and sleep deprivation on performance. The first course was given by SAS instructors during WTI 2-05 and again during WTI 1-06 from September 12-14, 2005. The TRM course has since been taught biannually during all WTI classes. Since its implementation in 2005, the Marine aviation mishap rate has declined.

Even though no major changes occurred in the TRM course between WTI 2-05 and WTI 1-06, significant improvements in average student sleep were seen between the two classes. The increased sleep may have occurred because this additional training increased student and staff awareness of the importance of obtaining adequate sleep to maintain performance. Not only did WTI 1-06 students receive an average of 1.43 more hours of nightly sleep throughout training than WTI 2-05 students, they also received 1.56 more hours of sleep before the generic inventory exam and 1.96 more hours of sleep before the scored flights. MAWTS-1 instructors may have learned from WTI 2-05 instructions on sleep management that, once implemented in WTI 1-06, resulted in positive influences on student behavior. The command climate concerning the importance of maintaining adequate sleep and minimizing fatigue may have positively changed between the two classes, causing staff to properly assimilate the TRM information into their own lives and to stress this importance to incoming students. Given the small data set and possible self-selection problems of the volunteers, there might be other reasons for the differences in sleep patterns. However, the statistically significant difference in the average sleep of WTI 2-05 and WTI 1-06 shows that the School's emphasis on safety and risk management may have been effective in teaching students to recognize the signs and symptoms of fatigue and to counteract these fatigue effects during their training. Similar interventions could be successful at improving sleep in other units.

During the statistical analysis, other variables were found to be slightly correlated with student performance during the statistical analysis. The inventory exam scores were correlated slightly with age ($R^2 = 0.34$). Those participants who were 31 years or older, 40% of the study sample, scored higher on this exam than those who were less than 31 years old. A small but statistically significant difference of 2.09 points on the inventory exam was seen between these two age groups. However, since there is very little variance in participant age (26 to 32 years), these results may not have much practical application to MAWTS-1.

These results may also have occurred because of what the test measures and how it is created. All WTI students were required to complete preliminary reading assignments and training modules before arriving for training. A large portion of the testable reading material is from *Six Functions of Marine Aviation,* which pilot students are expected to be familiar with from their past flight training and experiences. Studying the preliminary reading assignment could serve to reinforce their knowledge of Marine Aviation before taking the inventory exam.

This finding may suggest that older students begin training with a higher baseline knowledge than younger students, perhaps by studying the preliminary reading assignments more thoroughly or through their past training and experiences. As mentioned in the Literature Review (Section II.B.1), well-learned/simple intellectual or physical tasks are the least sensitive to the effects of fatigue (COPE, n.d.). Therefore, knowledge ingrained through years of training, such as the baseline knowledge reviewed during the preliminary reading assignments, would not be significantly affected by sleep debt, as was found in the analysis of exam score.

The only variable correlated with flight score was the generic grouping of flight names. The Warm-up Exercises were shown to be significantly different from four other flight scenarios: Offensive Air Support (primarily for fixed wings), Assault Support, Anti-air Warfare, and the Final Exercise. This difference between exercises was not unexpected. Warm-up Exercises are conducted at the beginning of flight training before the other scenarios began. This finding suggests that the warm-up exercises are easiest while the other exercises are more difficult.

Using the predicted effectiveness scores from FAST to predict exam scores or flight scores produced similar results: no significant relationship exists between predicted and actual performance. This relationship confirms the correlations found when analyzing exam scores and flight scores—sleep was not a predictor of performance for this well-rested study sample. Since FAST predicted effectiveness depends upon how much sleep was attained and the quality of that sleep, these results were not unexpected.

It is important to note that the interpretation and generalizability of these results should not be applied across all students or classes of WTI at MAWTS-1. A number of issues were encountered with the study that potentially influenced the results. First, unlike like the students from the baseline study, WTI 1-06 students were not chronically sleep deprived. Second, the study sample was small (N = 20) due to limited WAM availability. Third, the failure of seven participants, including those with the lowest mean nightly sleep, to turn in their activity logs only decreased the validity of the results when analyzing the correlation between actual and predicted performance scores. Finally, WTI 1-06 was the first class to use the PWTI Aviation Training Forms to score flight performance. While trained on how to use the forms, these forms were open for interpretation, and instructors may not consistently score flight performance based upon the definitions of the numbered scale (1 through 4). For example, a score of either 2 or 3 was considered “average,” depending on the instructor. After WTI 1-06 ended, instructor training has been modified to ensure that instructors consistently interpret and score student performance on the ATF to give the scores more validity and reliability.

B. RECOMMENDATIONS FOR FUTURE WORK

This research was an observational study, following a baseline study, to determine if student sleep patterns were significantly correlated with student exam and flight performance. No significant correlations were found between sleep data and student performance in this study because the students were not chronically sleep deprived during training. The baseline student participants averaged 5.62 hours of daily sleep throughout training while WTI 1-06 participants averaged 7.05 hours of daily sleep, a difference of 1.43 hours. This difference in nightly sleep between the two study samples may be seen because of the implementation of a TRM course during WTI training. However, another sleep and fatigue study may be desirable to determine if the sleep data gathered from WTI 1-06 in this observational study is now typical of student sleep patterns at MAWTS-1. Also, a sleep study directed at MAWTS-1 instructors may be desirable since staff received an average of 6.10 hours of nightly sleep, with an average maximum of 6.93 hours and an average minimum of 5.42 hours, during the baseline study and may be chronically sleep deprived. Since the implementation of the TRM course, would staff members also see an improvement in their nightly sleep? If another study is warranted, this section provides several recommendations on how to improve future sleep and fatigue studies at MAWTS-1.

First, the activity logs provided to participants were found to be open to interpretation and needed more detailed instructions on how to accurately fill out sleep and flight times. When logging the start and end of daily sleep periods, the instructions were not clear on how to log a sleep period that crossed into the following day. For example, if two students went to bed at 11 p.m. on September 16 and woke up at 7 a.m. on September 17, one student would show a start and end time for that sleep period of 11 p.m. and 7 a.m. on September 16, while the other student may log a start and end time of 11 p.m. and 7 a.m. on September 17. Only by comparing the logged sleep times with actigraphy data could the students' interpretations be known. To fix this problem, the instructions should be modified by either specifically stating how to interpret this scenario or by using a 24-hour time log in which student activities are input hourly throughout the day. Also, flight times were intended to encompass only those times that students were physically in their platform and flying, but some students interpreted flight time as the entire workday during in-flight training. These logged periods of “flight” were abnormally long and potentially affected the FAST-predicted performance of flight scores by causing more variability in predicted flight performance. Again, more specific instructions must be included for students to correctly log flight times.

A second way to improve the research would be to include a survey to collect more information on the participants. A survey was not included in this study, helping to maintain anonymity, but obtaining more participant information may identify why sleep quantity and quality was not significantly correlated with student performance. Obtaining data on individual use of tobacco/caffeine/alcohol, sleep preferences, or medications used during training could be useful when analyzing and interpreting results.

Finally, any future research correlating flight scores with sleep data gathered with WAMs may need to be limited to one or two flight platforms. This thesis research included and compared data across all available platforms and resulted in a small representative sample from each. However, each platform—even those that are similar such as the CH-46 and CH-53—has a distinct mission set and is graded on different criteria during flight events. This difference in grading criteria could affect the overall scores in each platform, making a comparison of scores within platforms instead of between platforms may be more statistically relevant.

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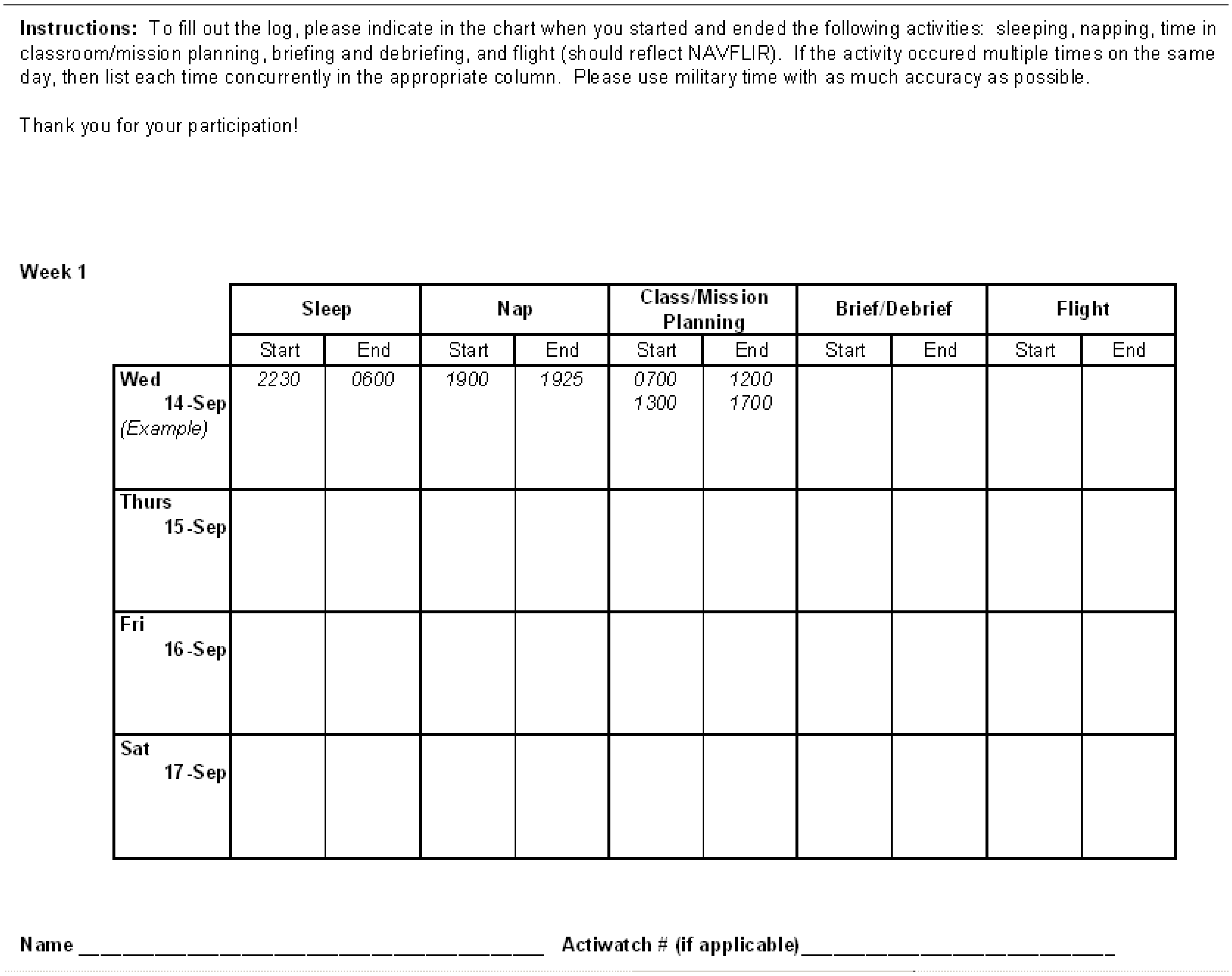
APPENDIX A. ACTIVITY LOG

Figure A1 shows the first page of the activity log that students filled out during WTI 1-06 training. The instructions can be seen at the top of the figure, along with an example on how to fill out the log. Each week of training had its own page (not shown here).



Instructions: To fill out the log, please indicate in the chart when you started and ended the following activities: sleeping, napping, time in classroom/mission planning, briefing and debriefing, and flight (should reflect NAVFLIR). If the activity occured multiple times on the same day, then list each time concurrently in the appropriate column. Please use military time with as much accuracy as possible.

Thank you for your participation!

Week 1

	Sleep		**Nap**		**Class/Mission Planning**		**Brief/Debrief**		**Flight**	
	Start	End	Start	End	Start	End	Start	End	Start	End
Wed **14-Sep** *(Example)*	*2230*	*0600*	*1900*	*1925*	*0700* *1300*	*1200* *1700*				
Thurs **15-Sep**										
Fri **16-Sep**										
Sat **17-Sep**										

Name ____________________________________ **Actiwatch # (if applicable)**__________________________

Figure A1. First Page of the Student Activity Log

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APPENDIX B. STATISTICAL RESULTS

Figure B1 shows the average hours slept by each participant during the classroom and flight phases of training. While most students fall above the 7-hour line during training (especially during flight training), it is interesting to see how Participant #6's sleep decreased during the flight portion of training.

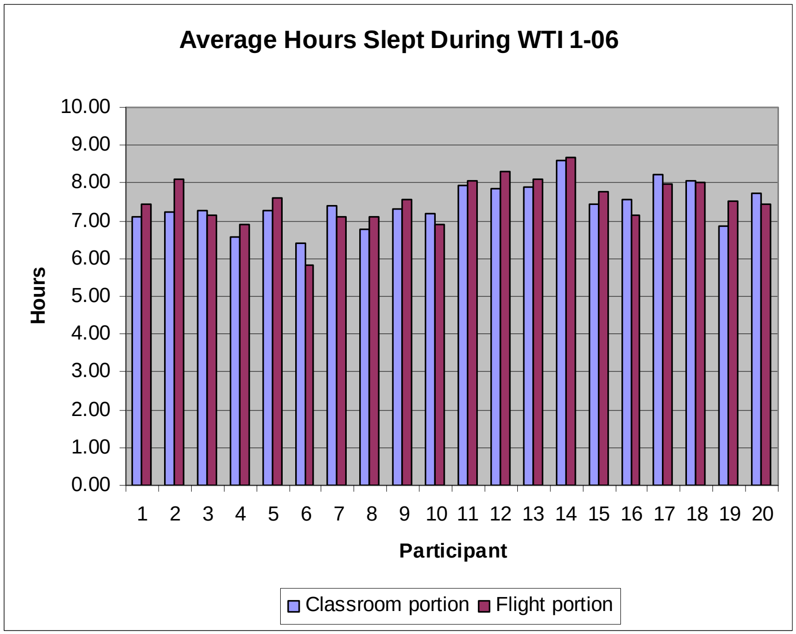


Figure B1. Participant's Average Nightly Sleep During Training Phases

Figure B2 is self-explanatory. Its purpose is to visually determine if any particular platform stood out from the rest in terms of how much sleep was obtained overall.

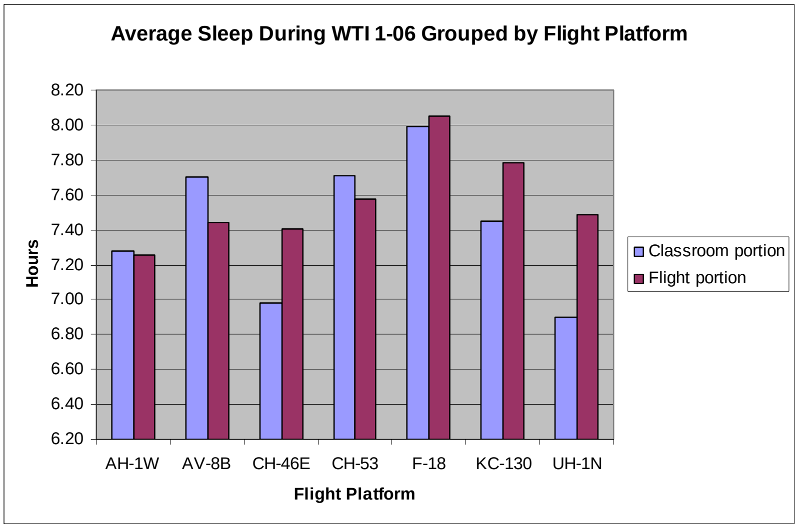


Figure B2. Flight Platform Average Nightly Sleep During Training Phases

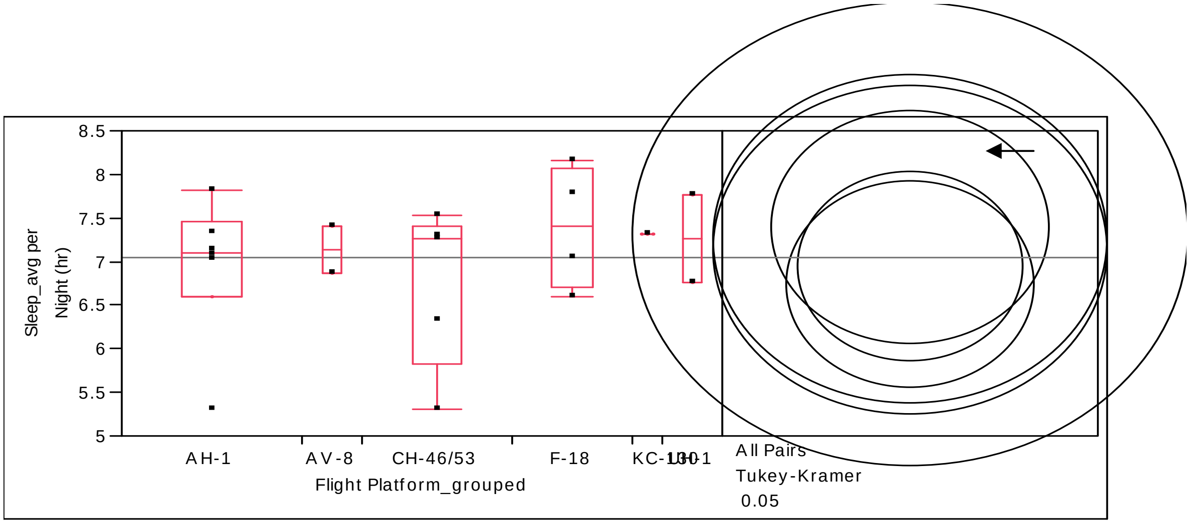


Figure B3. Boxplot of Mean Nightly Sleep by Flight Platform

Means Comparisons
Comparisons for All Pairs Using Tukey-Kramer HSD

q*	Alpha
3.27993	0.05

Abs(Dif)-LSD	F-18	KC-130	UH-1	AV-8	AH-1	CH-46/53
F-18	–1.8804	–2.8869	–2.1683	–2.0455	–1.2694	–1.1320
KC-130	–2.8869	–3.7608	–3.2085	–3.0858	–2.5115	–2.3475
UH-1	–2.1683	–3.2085	–2.6593	–2.5365	–1.8588	–1.7078
AV-8	–2.0455	–3.0858	–2.5365	–2.6593	–1.9816	–1.8305
AH-1	–1.2694	–2.5115	–1.8588	–1.9816	–1.5353	–1.4056
CH-46/53	–1.1320	–2.3475	–1.7078	–1.8305	–1.4056	–1.6819

Positive values show pairs of means that are significantly different.

Level		Mean
F-18	A	7.3956250
KC-130	A	7.3093333
UH-1	A	7.2609167
AV-8	A	7.1381667
AH-1	A	6.9484444
CH-46/53	A	6.7437667

Levels not connected by same letter are significantly different.

Table B1. Tukey-Kramer HSD of Mean Nightly Sleep by Flight Platform

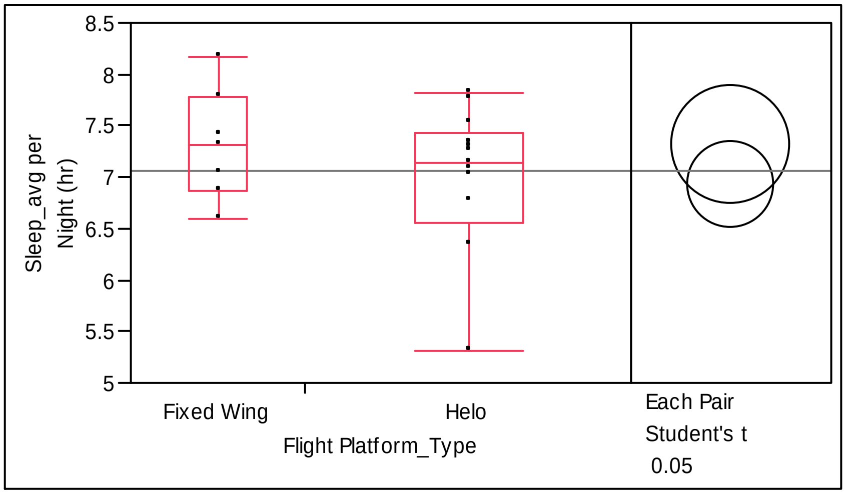


Figure B4. Box Plot of Mean Nightly Sleep by Type of Flight Platform

Means Comparisons
Comparisons for Each Pair Using Student's t

t	Alpha
2.10092	0.05

Abs(Dif)-LSD	Fixed Wing	Helo
Fixed Wing	–0.82369	–0.33048
Helo	–0.33048	–0.60442

Positive values show pairs of means that are significantly different.

Table B2. Student’s t Means Comparison for Mean Nightly Sleep by Type of Flight Platform

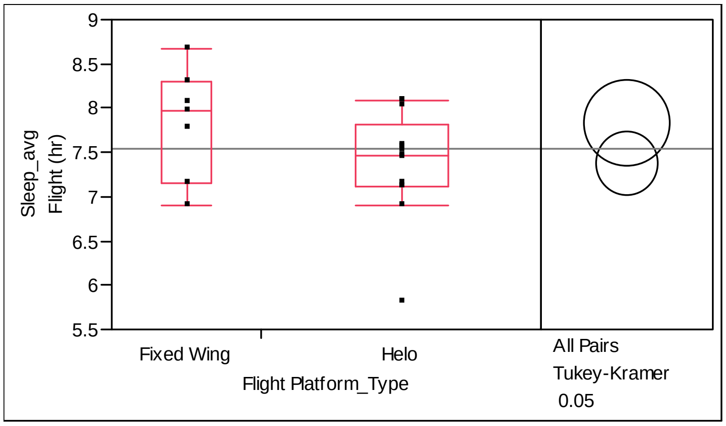


Figure B5. Boxplot of Average Sleep during Flight Training by Type of Flight Platform

Means Comparisons
Comparisons for All Pairs Using Tukey-Kramer HSD

q*	Alpha
2.10092	0.05

Abs(Dif)-LSD	Fixed Wing	Helo
Fixed Wing	–0.68510	–0.13727
Helo	–0.13727	–0.50273

Positive values show pairs of means that are significantly different.

Table B3. Tukey-Kramer HSD of Average Sleep During Flight Training by Type of Flight Platform

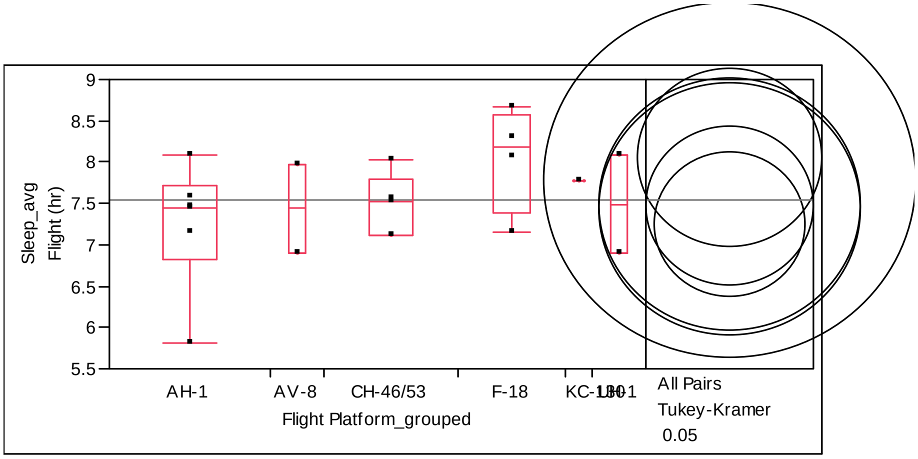


Figure B6. Boxplot of Average Sleep During Flight Training by Flight Platform

Means Comparisons
Comparisons for All Pairs Using Tukey-Kramer HSD

q*	Alpha
3.27993	0.05

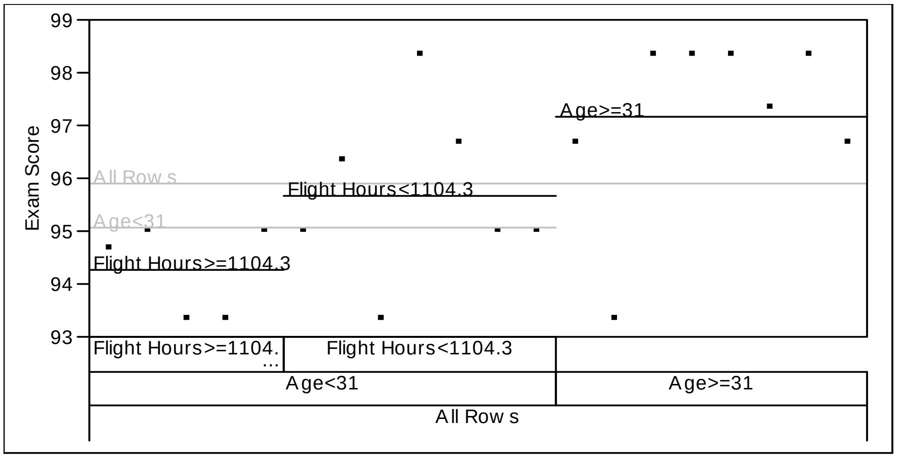
Abs(Dif)-LSD	F-18	KC-130	UH-1	CH-46/53	AV-8	AH-1
F-18	–1.5238	–2.1420	–1.3056	–0.8669	–1.2578	–0.5964
KC-130	–2.1420	–3.0477	–2.3461	–2.0494	–2.2983	–1.8004
UH-1	–1.3056	–2.3461	–2.1550	–1.7850	–2.1073	–1.5256
CH-46/53	–0.8669	–2.0494	–1.7850	–1.3630	–1.7733	–1.0890
AV-8	–1.2578	–2.2983	–2.1073	–1.7733	–2.1550	–1.5733
AH-1	–0.5964	–1.8004	–1.5256	–1.0890	–1.5733	–1.2442

Positive values show pairs of means that are significantly different.

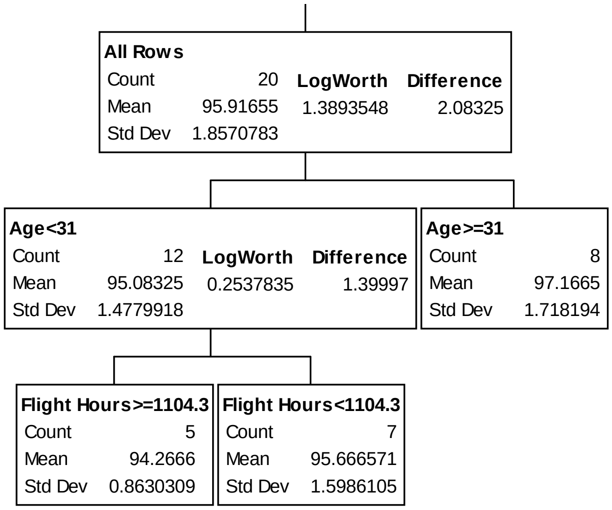
Level		Mean
F-18	A	8.0494842
KC-130	A	7.7820517
UH-1	A	7.4887825
CH-46/53	A	7.4707139
AV-8	A	7.4410258
AH-1	A	7.2547799

Levels not connected by same letter are significantly different.

Table B4. Tukey-Kramer HSD of Average Sleep During Flight Training by Flight Platform



RSquare	N	Number of Splits
0.405	20	2



Leaf Report

Leaf Label	Mean	Count
Age<31&Flight Hours>=1104.3	94.2666	5
Age<31&Flight Hours<1104.3	95.6665714	7
Age>=31	97.1665	8

Figure B7. Partition Data for Exam Score

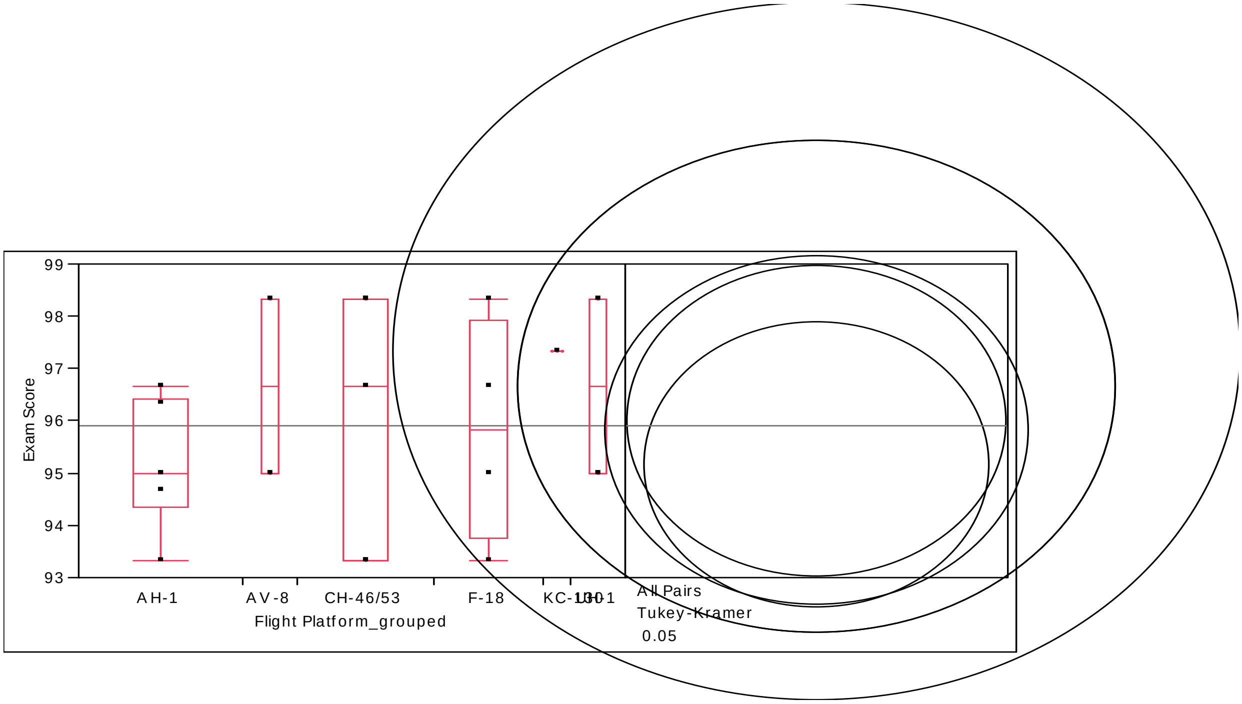


Figure B8. Boxplot of Exam Score by Flight Platform

Means Comparisons
Comparisons for All Pairs Using Tukey-Kramer HSD

q*	Alpha
3.27993	0.05

Abs(Dif)-LSD	KC-130	UH-1	AV-8	CH-46/53	F-18	AH-1
KC-130	–9.4277	–7.4981	–7.4981	–5.9695	–5.9535	–5.0342
UH-1	–7.4981	–6.6664	–6.6664	–4.9108	–4.9400	–3.9433
AV-8	–7.4981	–6.6664	–6.6664	–4.9108	–4.9400	–3.9433
CH-46/53	–5.9695	–4.9108	–4.9108	–4.2162	–4.3054	–3.2036
F-18	–5.9535	–4.9400	–4.9400	–4.3054	–4.7139	–3.6366
AH-1	–5.0342	–3.9433	–3.9433	–3.2036	–3.6366	–3.8488

Positive values show pairs of means that are significantly different.

Level		Mean
KC-130	A	97.333000
UH-1	A	96.666500
AV-8	A	96.666500
CH-46/53	A	95.999800
F-18	A	95.833250
AH-1	A	95.166667

Levels not connected by same letter are significantly different.

Table B5. Tukey-Kramer HSD of Exam Score by Flight Platform

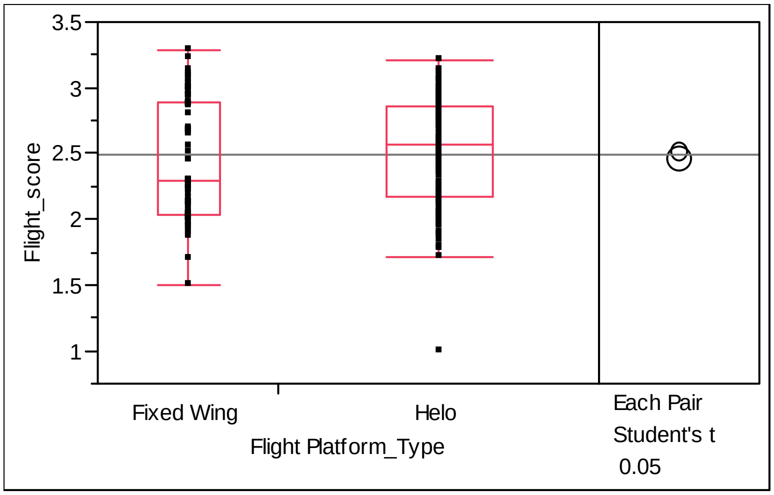


Figure B9. Boxplot of Flight Score by Type of Flight Platform

Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
Fixed Wing	1.5	1.965	2.04	2.3	2.8875	3.035	3.28
Helo	1	2	2.17	2.57	2.86	3	3.21

Means Comparisons
Comparisons for Each Pair Using Student's t

t	Alpha
1.97038	0.05

Abs(Dif)-LSD	Helo	Fixed Wing
Helo	–0.09641	–0.06253
Fixed Wing	–0.06253	–0.12754

Positive values show pairs of means that are significantly different.

Table B6. Student’s t Means Comparison of Flight Score by Type of Flight Platform

One-Way Analysis of Flight_Score by Flight_Name Grouped

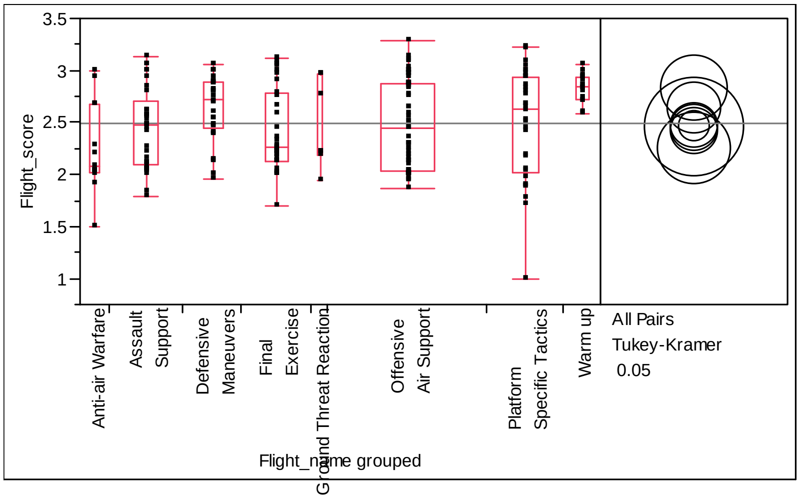


Figure B10. Box Plot of Flight Score by Grouped Flight Names

Means Comparisons
Comparisons for All Pairs Using Tukey-Kramer HSD

q*	Alpha
3.05995	0.05

Abs(Dif)-LSD	Warm up	Defensive Maneuvers	Platform Specific Tactics	Offensive Air Support	Ground Threat Reaction	Assault Support	Final Exercise	Anti-Air Warfare
Warm up	–0.44104	–0.20680	–0.03013	0.01751	–0.19628	0.00156	0.02272	0.10609
Defensive Maneuvers	–0.20680	–0.34598	–0.16650	–0.11280	–0.35173	–0.13511	–0.11459	–0.04143
Platform Specific Tactics	–0.03013	–0.16650	–0.30255	–0.24549	–0.49679	–0.27131	–0.25112	–0.18295
Offensive Air Support	0.01751	–0.11280	–0.24549	–0.20937	–0.48789	–0.24396	–0.22455	–0.16717
Ground Threat Reaction	–0.19628	–0.35173	–0.49679	–0.48789	–0.66678	–0.50654	–0.48432	–0.38195
Assault Support	0.00156	–0.13511	–0.27131	–0.24396	–0.50654	–0.30710	–0.28687	–0.21818
Final Exercise	0.02272	–0.11459	–0.25112	–0.22455	–0.48432	–0.28687	–0.31685	–0.24702
Anti-air Warfare	0.10609	–0.04143	–0.18295	–0.16717	–0.38195	–0.21818	–0.24702	–0.48929

Positive values show pairs of means that are significantly different.

Level			Mean
Warm up	A		2.8318750
Defensive Maneuvers	A	B	2.6423077
Platform Specific Tactics	A	B	2.4838235
Offensive Air Support		B	2.4691549
Ground Threat Reaction	A	B	2.4628571
Assault Support		B	2.4503030
Final Exercise		B	2.4251613
Anti-air Warfare		B	2.2600000

Levels not connected by same letter are significantly different.

Table B7. Tukey-Kramer HSD of Flight Score by Grouped Flight Names

One-Way Analysis of Flight_Score by Flight_Start Grouped

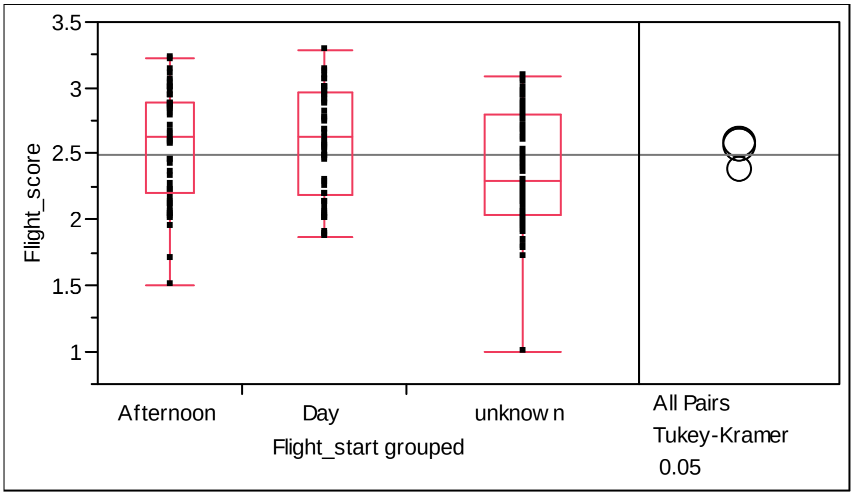


Figure B11. Box Plot of Flight Score by Flight Start Time of Day

Means Comparisons
Comparisons for All Pairs Using Tukey-Kramer HSD

q*	Alpha
2.35918	0.05

Abs(Dif)-LSD	Day	Afternoon	unknown
Day	–0.16350	–0.15201	0.04931
Afternoon	–0.15201	–0.17373	0.02702
unknown	0.04931	0.02702	–0.13748

Positive values show pairs of means that are significantly different.

Level			Mean
Day	A		2.5857143
Afternoon	A		2.5690323
unknown		B	2.3853535

Levels not connected by same letter are significantly different.

Table B8. Tukey-Kramer HSD of Flight Score by Flight Start Time of Day

Bivariate Fit of Flight_Score by Sleep Bouts_Average per Night

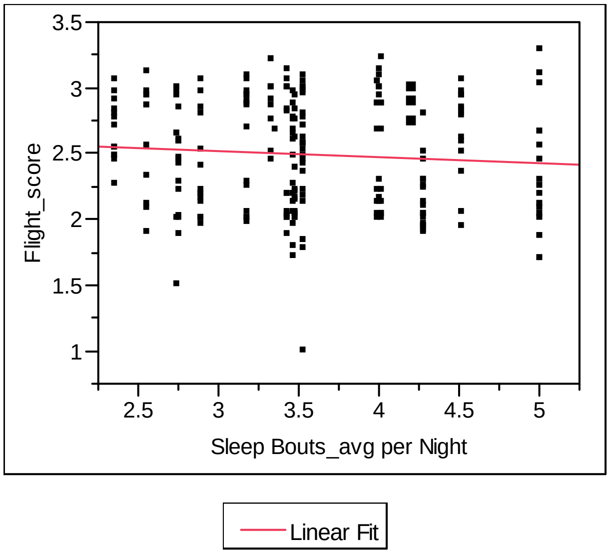


Figure B12. Bivariate Fit of Flight Score by Average Sleep Bouts

Summary of Fit

RSquare	0.005823
RSquare Adj	0.001482
Root Mean Square Error	0.418978
Mean of Response	2.495368
Observations (or Sum Wgts)	231

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.235450	0.235450	1.3413
Error	229	40.199293	0.175543	Prob > F
C. Total	230	40.434744		0.2480
Observations (or Sum Wgts)			231	

Table B9. Statistical Summary for Flight Score by Average Sleep Bouts per Night

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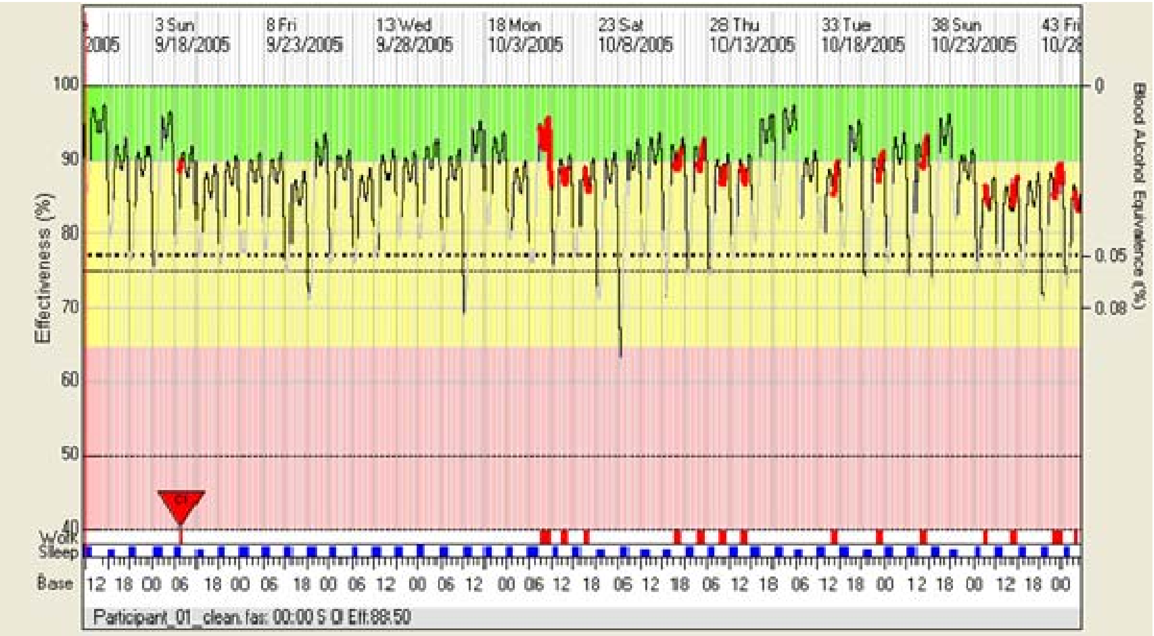
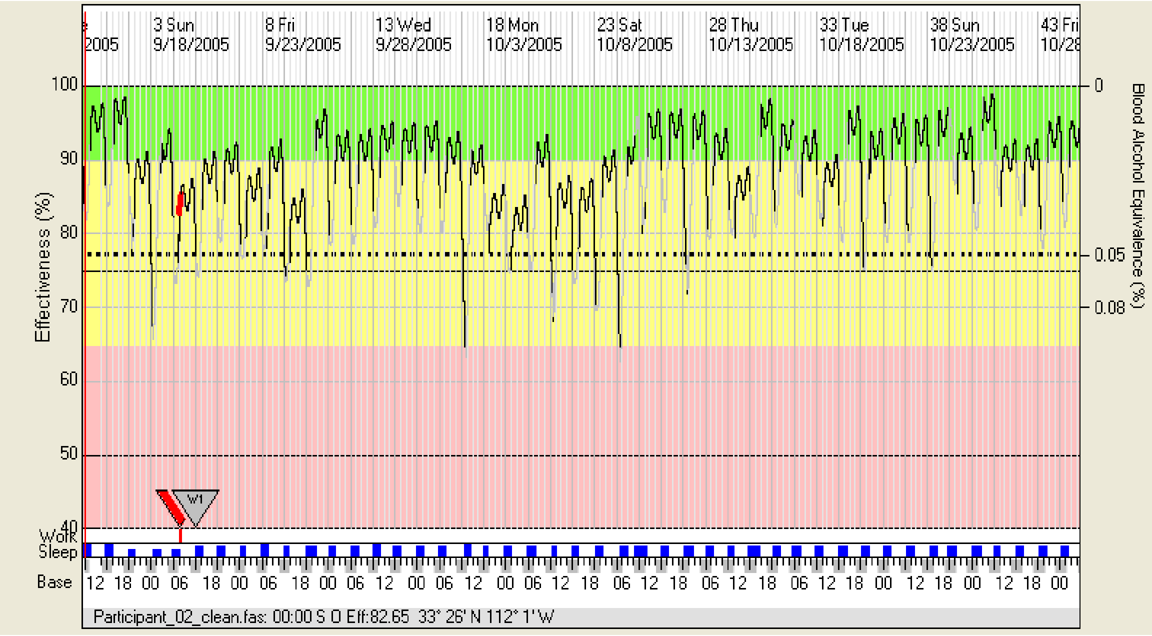
APPENDIX C. FAST GRAPHICAL OUTPUT

The FAST graphical output visually shows the predicted performance for the participant's based upon their daily sleep quantity and quality. Because Participant 16 disenrolled from MAWTS-1, due to personal reasons, early in the data collection effort, his data is not included in this appendix. Red triangles denote when the inventory exam was taken, while grey triangles indicate periods of missing actigraphy data due to WAM removal. The shaded red lines on the graph of predicted performance show the length and time of known flight periods, as indicated in participant activity logs.

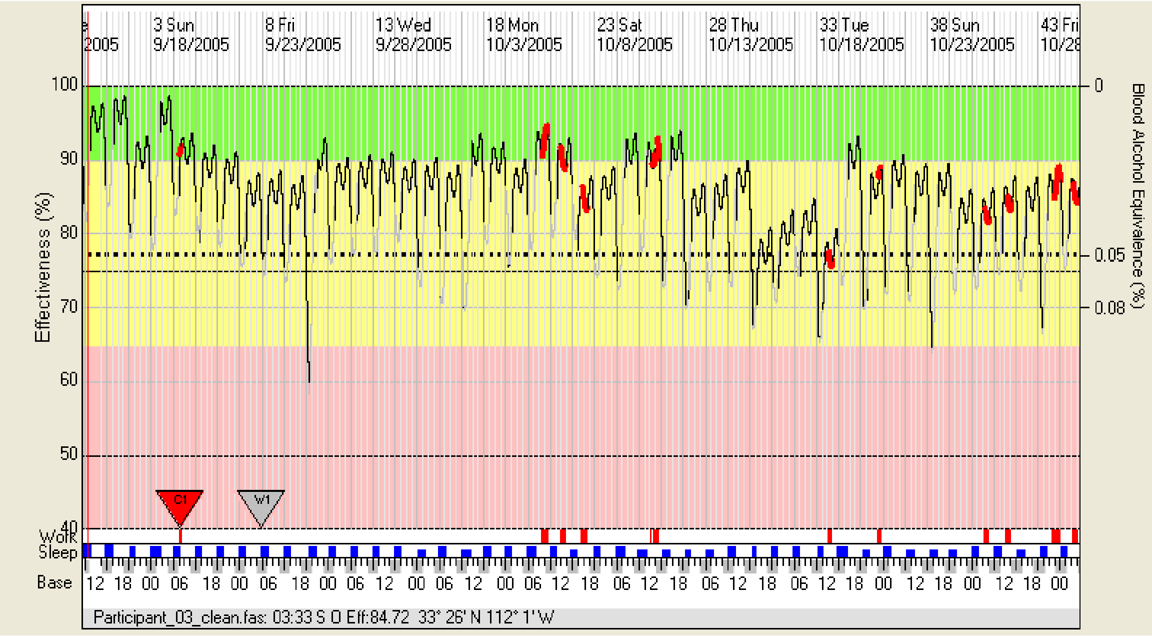
Participant 1



Participant 2



Participant 3



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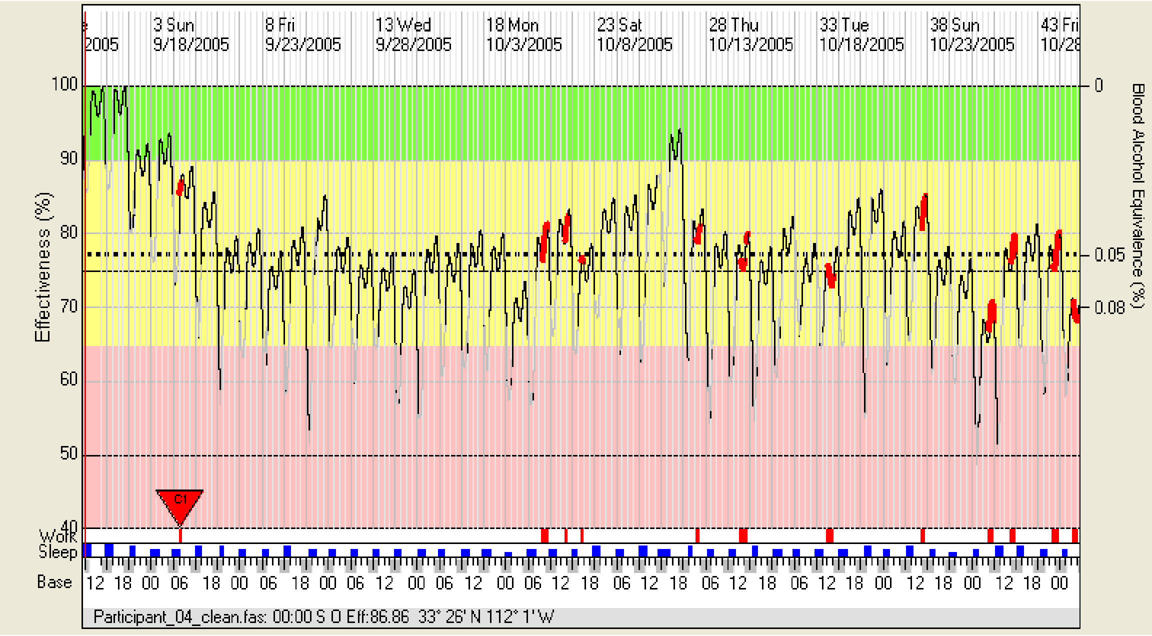

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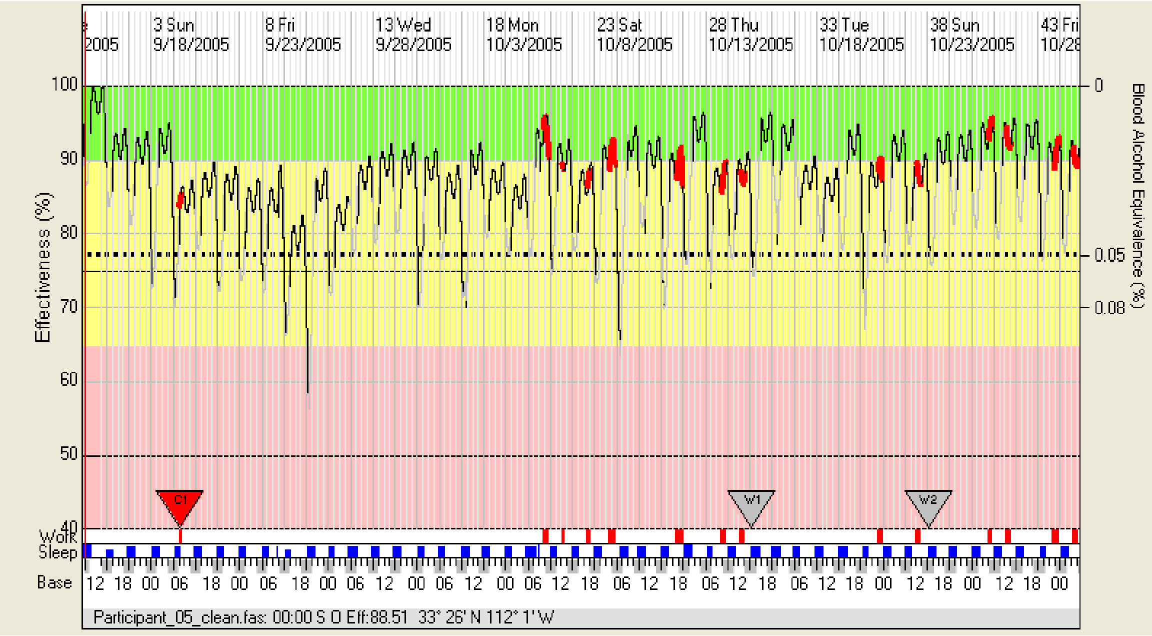
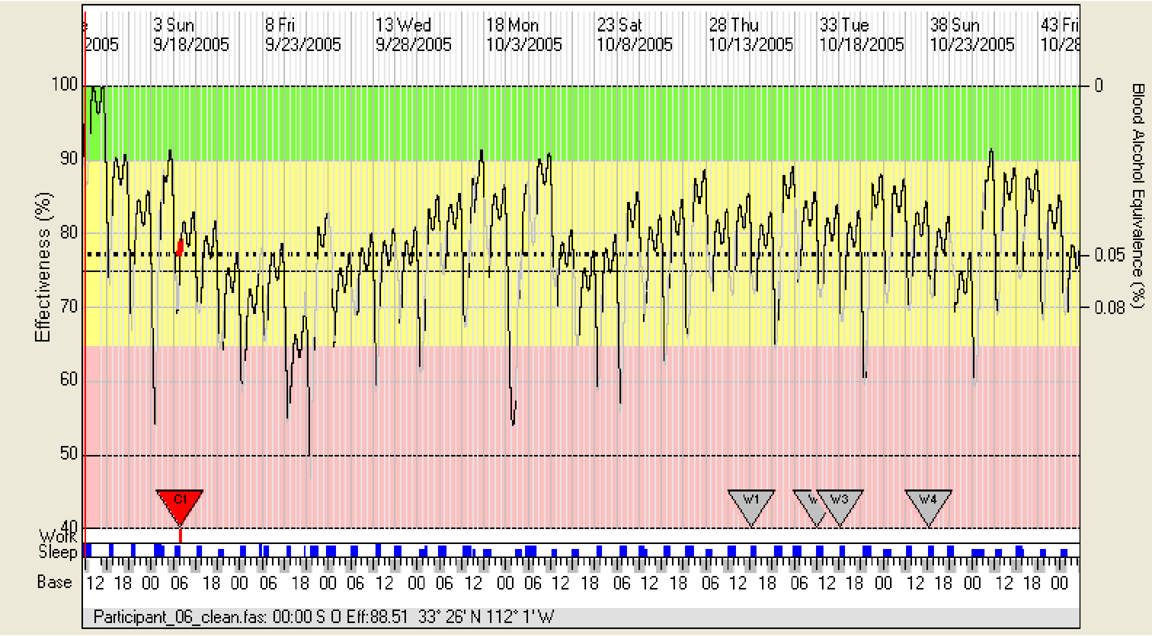


Participant 6



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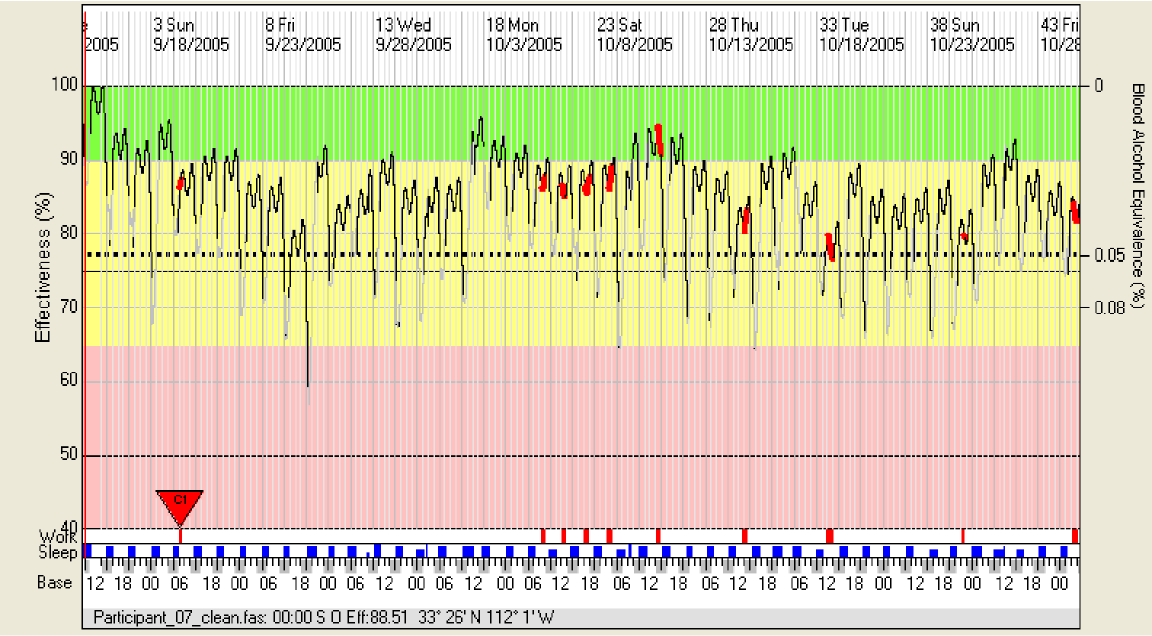

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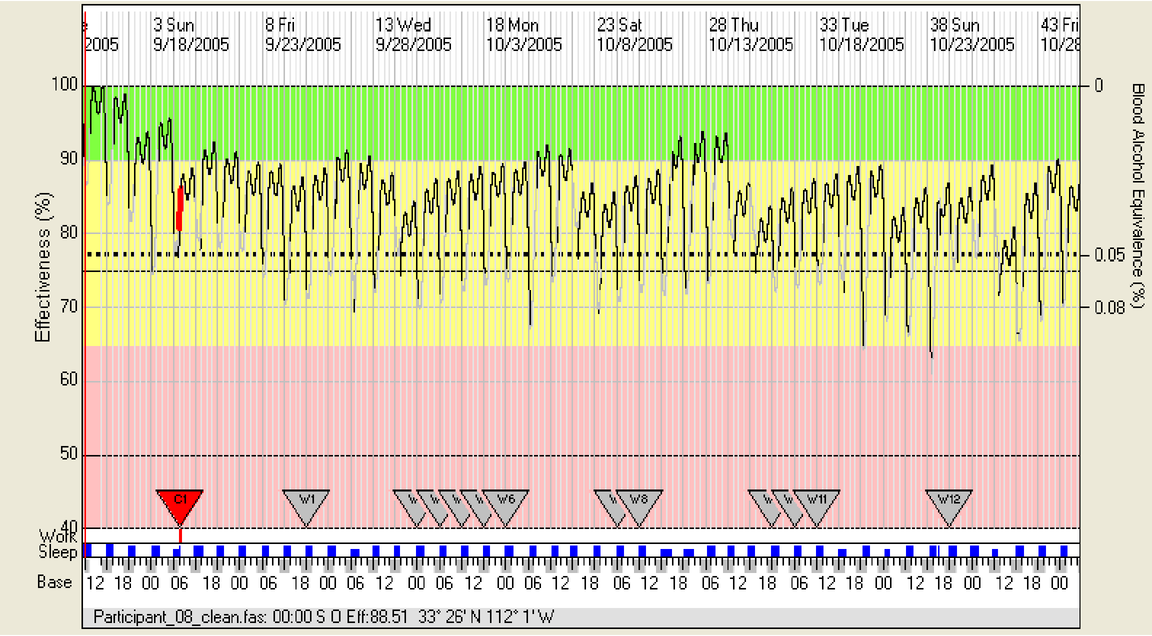

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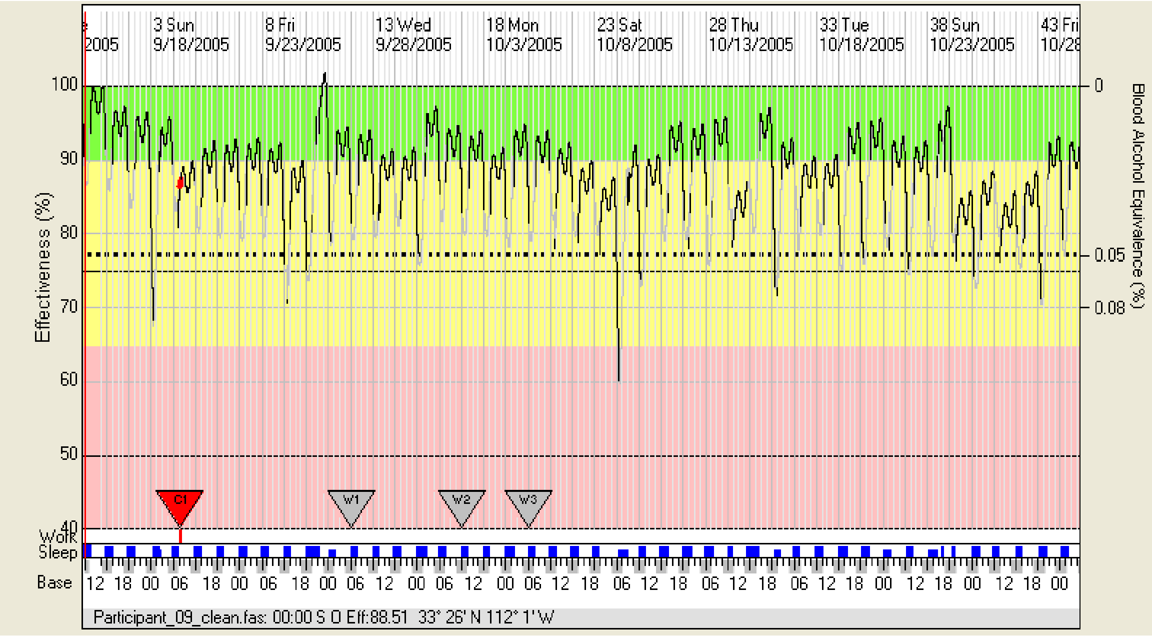

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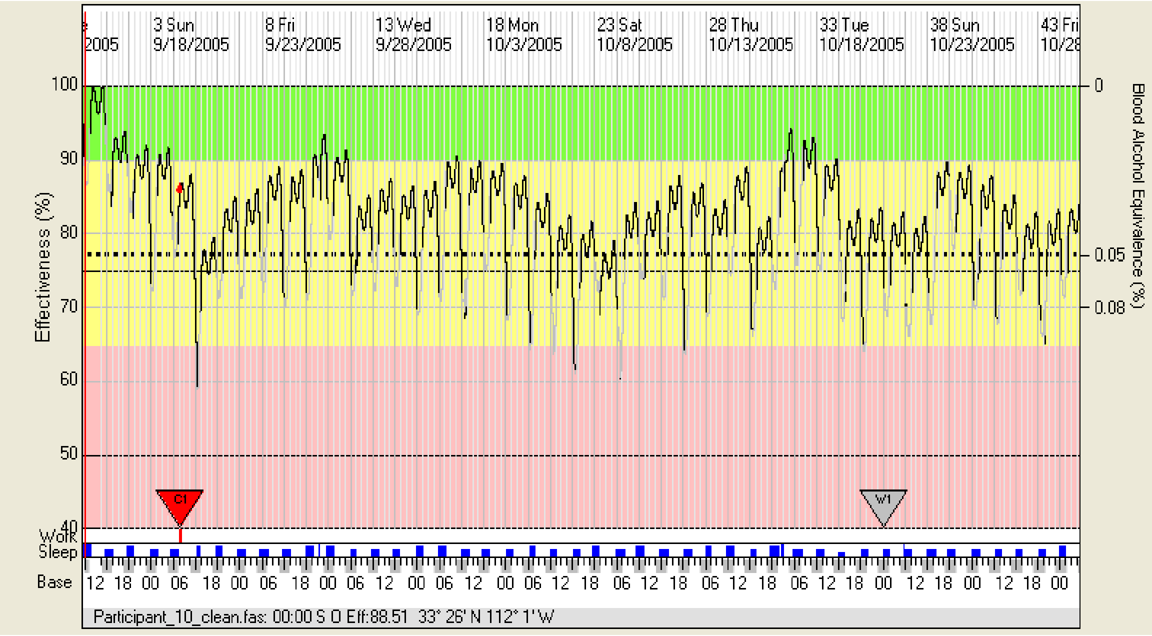

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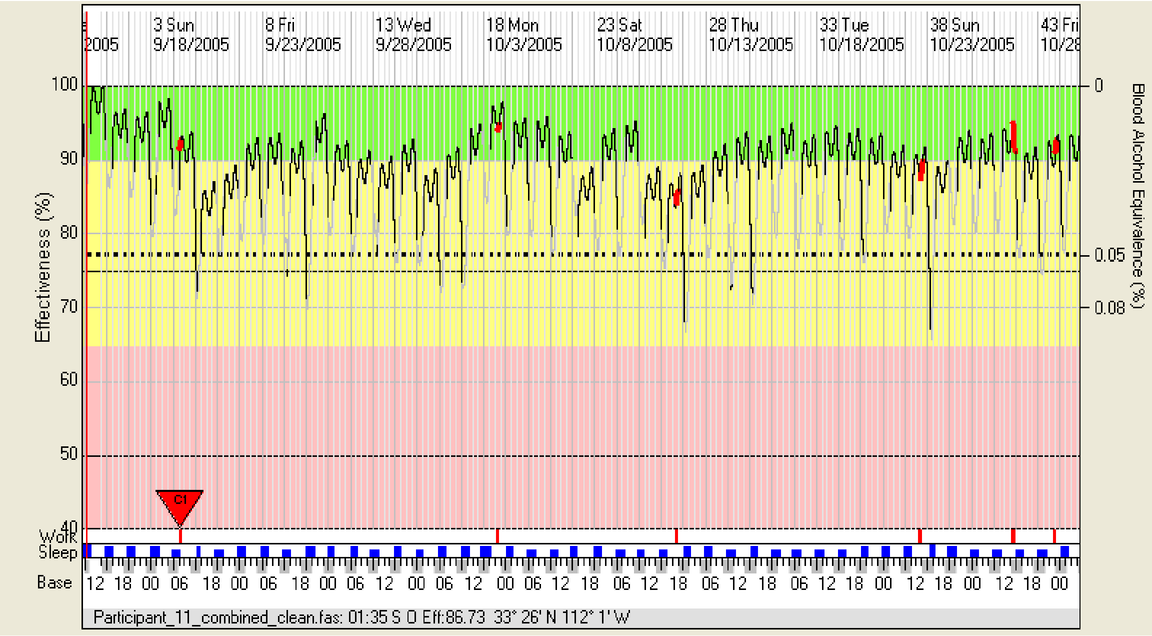

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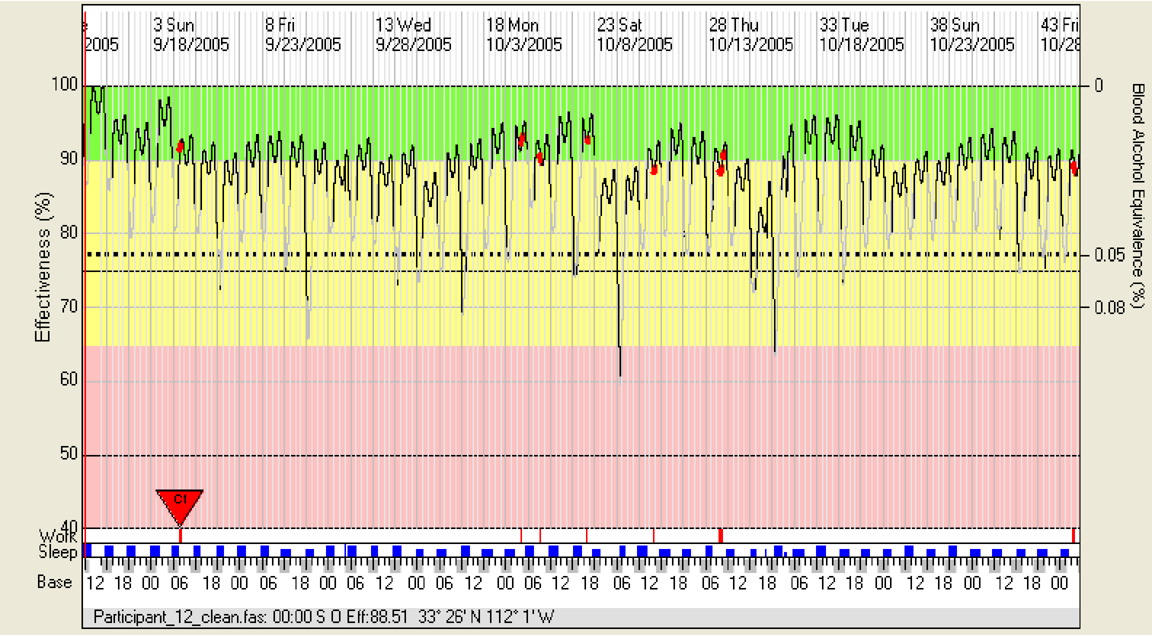

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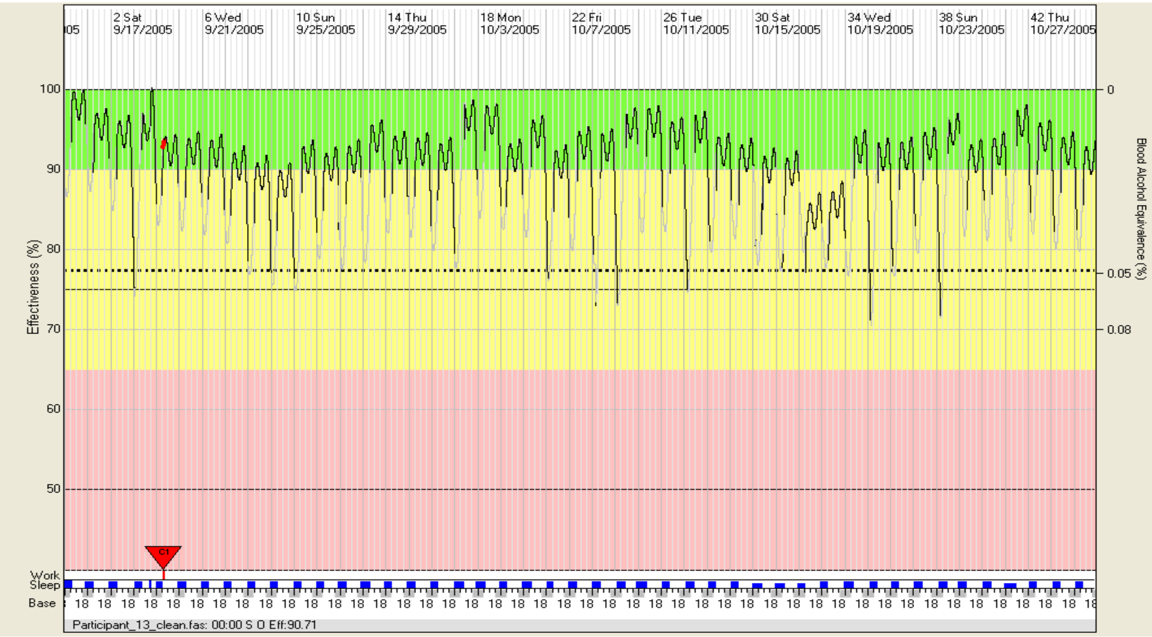

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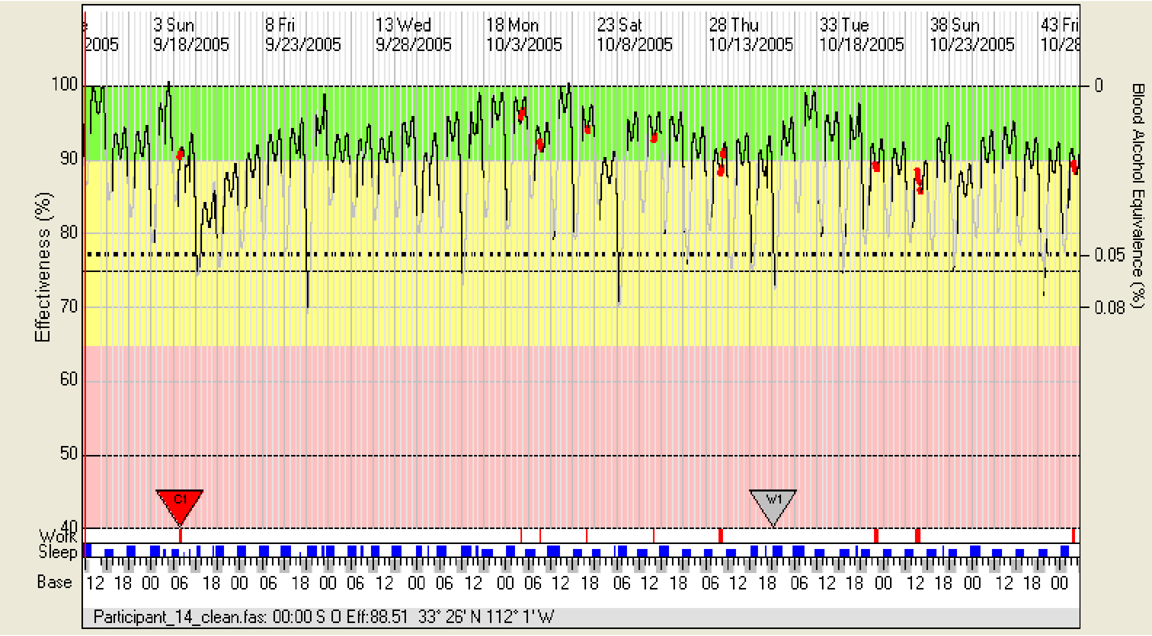

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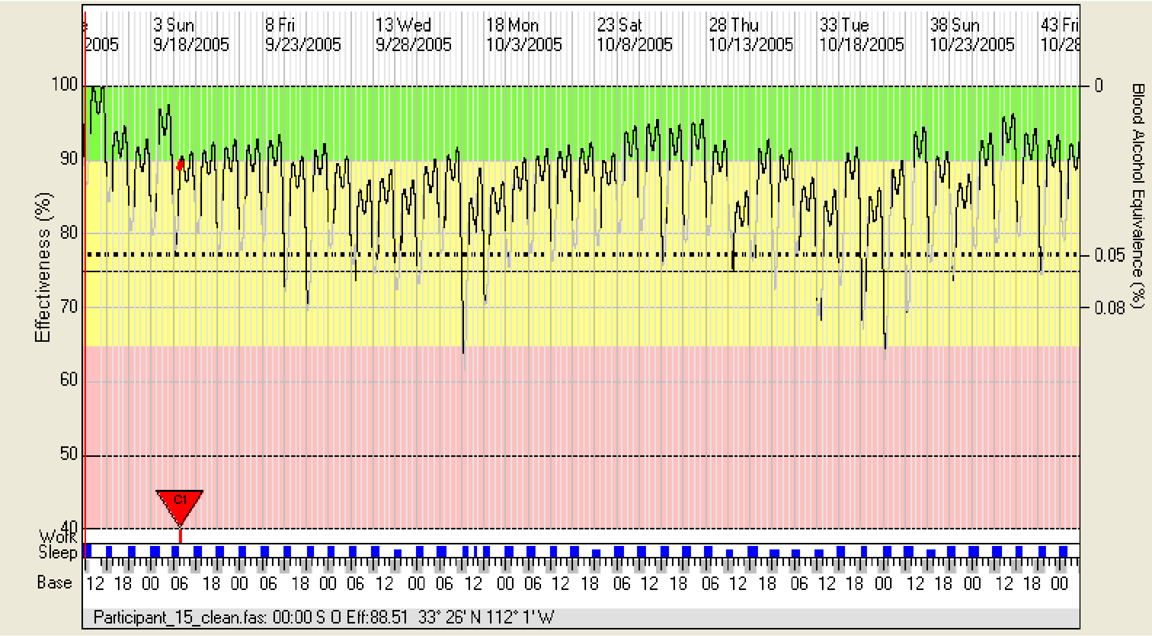
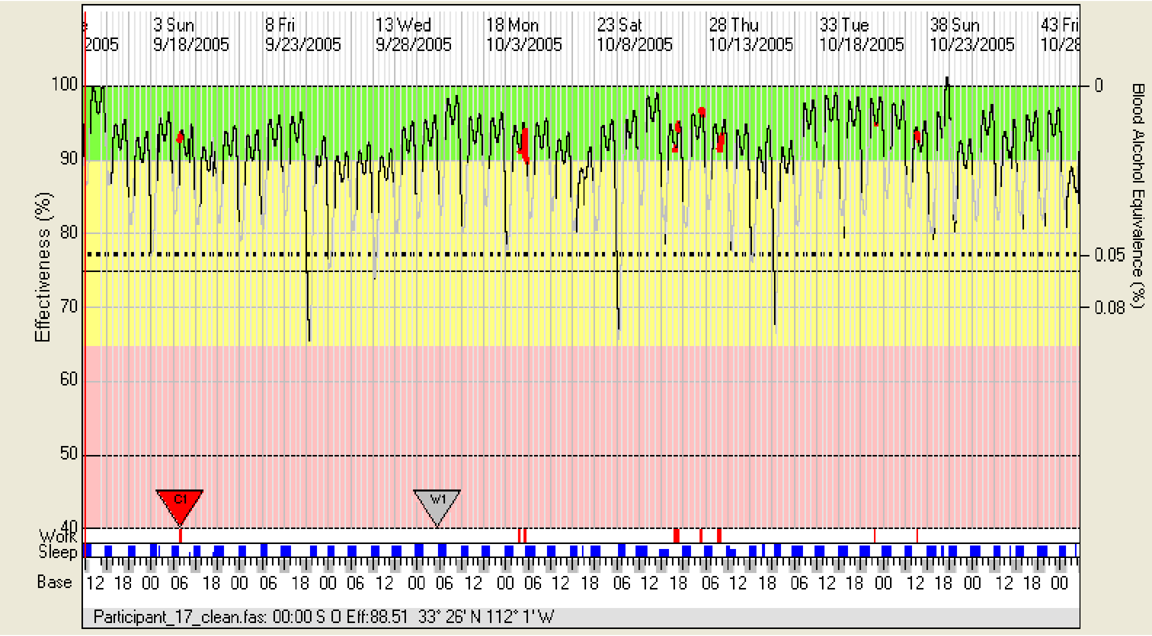


Participant 17



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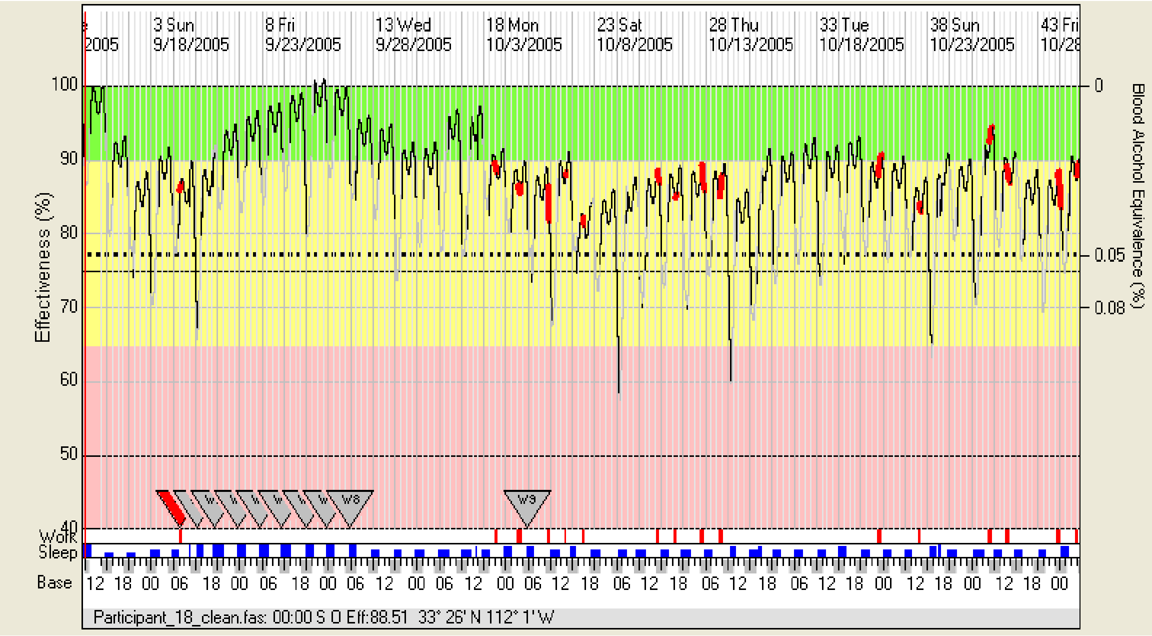

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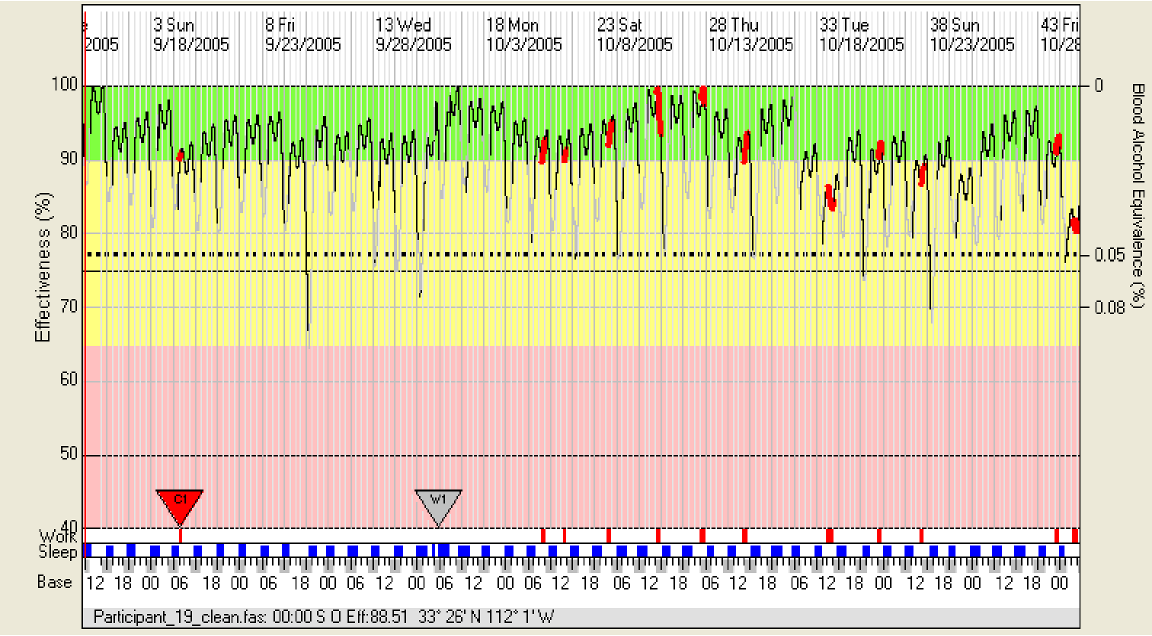

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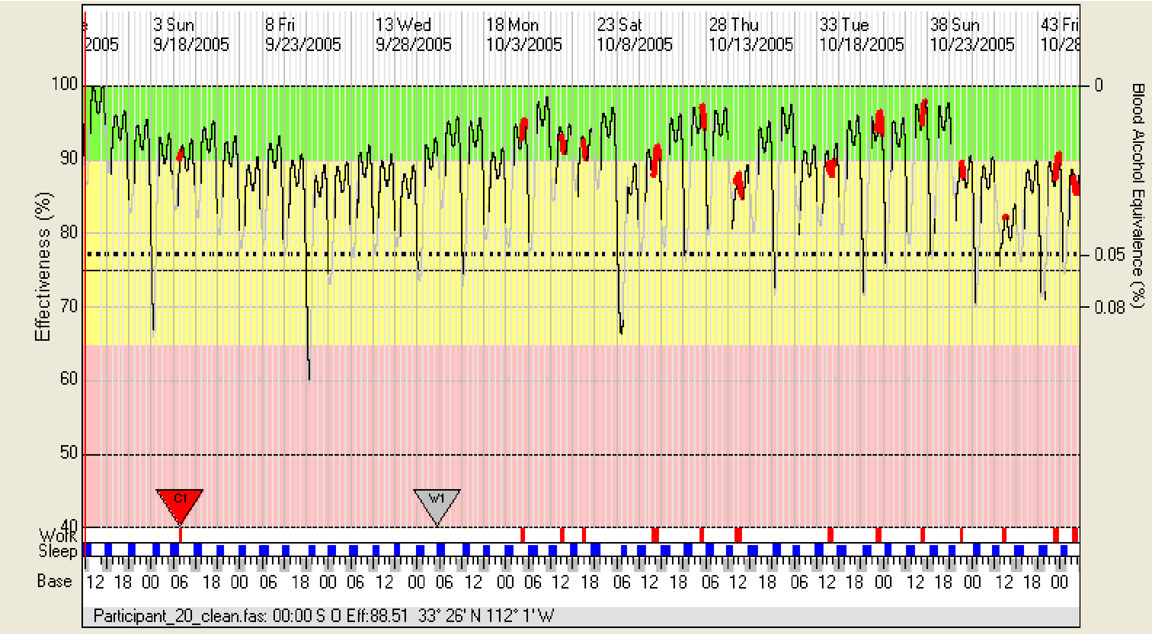
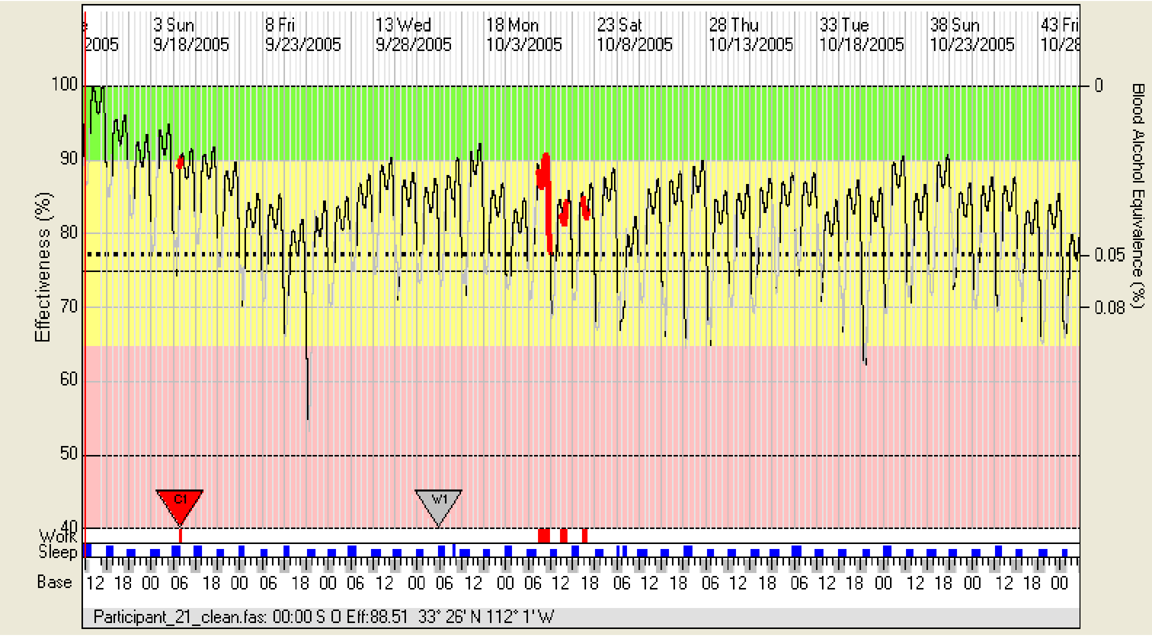


Participant 21



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APPENDIX D. TABLE OF GROUPED FLIGHT NAMES

Table C1 shows the number of individual flight names for all the platforms and how they were grouped into similar categories.

Flight Names	Grouping
CAS (AH, Urban, 1 & 2)	Offensive Air Support
DAS (6, 7)	
OAS (1 – 7)	
BAS (1 & 2)	
FAC (A)	
Strike Coordination and Recon (SCAR)	
AST (1,2,3)	Assault Support
Assault Supt/Recce	
LATI Stan Check (AV-8B and F/A-18)	Platform Specific Tactics
Ninja's Box (AH-1W)	
Stallion Flex (CH-53)	
Tactics (Sect, 1, 2, 3, 4)	
AD (1, 2)	
DEFTAC	
Long Range Raids (LRR)	
Battle Drill (Day & Night)	
Shadow Guns	
DACM	Defensive Maneuvers
DM (PWTI, Day 1, Day 2, Day 3)	
Offensive AAW (OAAW)	Anti-air warfare
AAW	
FINEX (1&2)	Final Exercise
Day/Night Warm-up	Warm-up for the Prospective Weapons and Tactics Instructor
Prospective WTI (PWTI)	
TCT	Ground Threat Reaction
GTR	
Shadow gun: platform-specific training for aerial gunnery crews	
LRR: conducted by CH-53s, CH-46s, MV-22s, and KC-130s	
SCAR: part of Offensive Air Support	

Table C1. Grouped Flight Names

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