



# **NAVAL POSTGRADUATE SCHOOL**

**MONTEREY, CALIFORNIA**

## **THESIS**

**CIRCADIAN RHYTHMS, FATIGUE, AND  
MANPOWER SCHEDULING**

by

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December 2004

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**CIRCADIAN RHYTHMS, FATIGUE, AND MANPOWER SCHEDULING**

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Submitted in partial fulfillment of the  
requirements for the degree of

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## ABSTRACT

The Benefield Anechoic Facility (BAF), Edwards Air Force Base, CA, is the largest anechoic military test facility in the world for testing developmental and operational electromagnetic equipment. Supervisors must often extend employees' work hours considerably in order to meet mission (i.e., test) timelines. Supervisors at the BAF currently have no accurate means of identifying when an employee's work performance is at risk of decreasing due to sleep deprivation, unbalanced circadian rhythms, and/or fatigue. Therefore, the focus of this research was to create a method for supervisors to effectively gauge the work performance levels of employees placed at risk for sleep deprivation. Thus, individual sleep data were collected for one week on eight volunteers at the BAF using assigned sleep monitoring devices known as Actigraphs. Extensive questionnaires were developed to determine volunteers' sleep pattern, demographics, and sleep history. For analysis purposes, the Fast Avoidance Scheduling Tool (FAST), based on the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model was used to determine how the performance level of each volunteer differed based on the amount of sleep acquired. The results demonstrated that as the week progressed and the volunteers' sleep decreased, the effectiveness of their work performance correspondingly decreased to a level where the safety of the test and the volunteers were both at risk.

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## EXECUTIVE SUMMARY

The Benefield Anechoic Facility (BAF) is a military test facility that conducts developmental and operational testing, usually by working a single eight-hour shift. If testing falls behind schedule, however, this eight hour shift is either extended or weekend work is required. Currently, the BAF has no way to identify when an employee's performance becomes at risk due to sleep deprivation, unbalanced circadian rhythms, and fatigue. Modeling circadian rhythms, fatigue, and employee performance is of significant interest to the management of the BAF. Since employees are not reliable judges of their own level of biological sleepiness, BAF management needs an objective means to assess their employees' ability to perform. Models that could be used include the Two-Process Model, Fatigue Audit InterDyne Model, Circadian Alertness Simulator Model, or the Three-Process Model. This research used the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) (Hursh and Bell, 2001) model which has an additional related tool, Fast Avoidance Scheduling Tool (FAST). FAST was developed by the Air Force and is already being used as an approved monitoring tool. SAFTE is a biomathematical model designed to predict individual performance under conditions of sleep deprivation. For this research, each volunteer wore a wrist actigraphy monitor for seven days. Actigraphy data were then downloaded into FAST; sleep-wake intervals were calculated, processed, and plotted; and graphical data were analyzed for performance effectiveness levels.

The results of this study indicate that as work hours are extended and the amount of sleep decreases, the predicted effectiveness of individual performance decreases. Participants with predicted effectiveness levels at or below 78% for their daily average are at higher risk of errors due to fatigue. When predicted levels fall below this point, the supervisor can then make a well-informed, knowledgeable decision to send the individual home for some needed rest. The supervisor also must take employees' commuting time and distance into account. A person with performance effectiveness level at or below 78% might fall asleep while driving resulting in a potentially serious automobile

accident; therefore, not only is employee safety during conduct of a test at risk, but also the employee's safety and that of other people on the road is jeopardized by fatigued workers.

FAST can also help managers identify borderline workers who may be at risk of fatigue-related safety violations. Volunteers whose daily average performance effectiveness falls in the 79%-85% range of performance effectiveness can be identified as possible at-risk workers and can be monitored closely by the supervisor to make sure they do not fall below the acceptable level (79%) of performance effectiveness.

A demonstration is given to show how employees enter sleep data into FAST and how the program then calculates each employee's predicted effectiveness level. A discussion follows (Chapter V) on how this information can be used as a management risk tool to identify employees with predicted effectiveness levels at or below 78% who are at risk for fatigue. A comparison between the reported sleep data and actigraphy data shows the reported data are not as accurate as using the actigraphy data; however, it still gives the supervisor the estimated daily effectiveness to make a better decision on whether to send a person home or keep them at work.

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# **I. INTRODUCTION**

## **A. OVERVIEW**

The Benefield Anechoic Facility (BAF) at Edwards Air Force Base (EAFB), CA, is a clean radio frequency (RF) military test facility for testing electromagnetic equipment. It is the largest RF test facility in the United States, originally built to test the B-1B bomber. At that time there was not another facility big enough to house the entire B-1B. Since then, the BAF has tested other programs such as the F-15, the F-16 Harm Targeting System (HTS), the Apache helicopter, and, most recently, the CV-22.

The BAF can operate 24 hours a day, seven days a week; however, doing so can cause serious scheduling problems. The BAF is no longer manned exclusively by the military, but rather by a mixture of military, civilian, and contract employees. The BAF does not staff sufficient personnel to work around-the-clock. The BAF is currently staffed to work only one shift: an eight-hour day shift starting at 0730 and ending at 1630. The BAF does allow for flexible start and end times, allowing people to come in between 0630 to 0800. When testing goes beyond the normal eight-hour day shift, employees must extend their work hours to accommodate the testing.

The BAF has 10 required positions that must be filled hour-by-hour with a given level of expertise and knowledge. This requirement presents a complicated personnel-scheduling problem because of long commute times, child care, school, and personal requirements. For example, employees drive anywhere from 30 to 60 minutes to work one-way and their commute time to and from work is not taken into consideration when scheduling people beyond their normal eight-hour shift.

When planned tests are delayed for any reason, the BAF might be forced into a situation requiring around-the-clock usage up to and including 24 hours a day, seven days a week. However, when employees extend their workweek to staff such a situation, sleep deprivation, unbalanced circadian rhythms, and fatigue can lead to poor decision-making and mistakes. Consequently, poor decisions or mistakes can result in damage to equipment and/or facilities, translating into wasted time for equipment repairs,

increased test time, and increased man-hours. More test time translates into increased test costs and program delays, ultimately jeopardizing entire programs.

Currently the BAF uses Gantt charts (Gantt, 1903) and Excel spreadsheets (Microsoft, 2000) to lay out test and personnel schedules. Each test task is put in a Gantt chart with a name assigned to it. During the actual test, an Excel spreadsheet is created, showing where each person is assigned, for what day(s) of the week, and for which hours of the day. Sleep deprivation, circadian rhythms, and fatigue are not generally taken into consideration when creating these schedules. This scheduling is a very tedious manual process, often requiring over a week to produce a plan. Once complete, there is no way to tell how employees' sleep, circadian rhythms, and fatigue will be affected when their schedules are extended. The initial Gantt chart planning method schedules personnel Monday through Friday for nine hours a day, to include a one-hour lunch break for each shift. Weekends and overtime are considered management overhead and are used to catch up when a test has fallen behind the planned schedule.

This thesis develops a scheduling method that takes human fatigue into account, thereby giving supervisors a way to manage fatigue and the associated risk that might be incurred. Sleep data were collected at the BAF using actigraphy. The data were entered into the Fatigue Avoidance Scheduling Tool (FAST). FAST is then used to calculate the predicted performance effectiveness of each employee. The predicted effectiveness indicates the level of mental effective capability as a percent of the optimal performance of a fully rested person (Science Applications International Corporation, 2000). Experience with the FAST schedule might improve the planned schedule, reducing the risk of delays, and thus the necessity to work beyond human limits of performance.

This research builds on an existing validated model of human circadian rhythms—the Sleep, Activity, and Fatigue Task Effectiveness (SAFTE, Hursh and Bell, 2001) model that encompasses sleep and fatigue effects on cognitive performance. FAST can be used as a management risk tool to predict the effectiveness of each employee and help managers mitigate risk. FAST uses the SAFTE model with scientifically derived criteria to produce individual scheduling requirements. This thesis culminates in a

demonstration of how management can use FAST as a management risk tool to intervene when test and personnel safety are at risk.

## **B. BACKGROUND**

The BAF is a government-owned Installed System Test Facility (ISTF) (see Figure 1). The facility consists of an anechoic chamber that is 264 feet long, 250 feet wide, and 70 feet high. A turntable, 80 feet in diameter, is located in the floor near the chamber center. Test aircraft support utilities include air, power, instrumentation interfaces, and hydraulics, which are routed through access panels in the turntable. An 80,000-pound capacity hoist is mounted above the turntable. Aircraft can be hoisted off the ground into the “quiet zone” or the center of the chamber, where the system under test (SUT) is at the greatest distance from the walls, floor, and ceiling.

The chamber’s interior is completely covered with radar absorbing material (RAM) and provides a radio frequency (RF) shielding effectiveness of over 100 dB from 500 MHz to 18 GHz. The BAF chamber provides a quiet or low-reflection RF environment throughout the entire volume of the chamber.



**Figure 1. Anechoic Chamber**

The BAF begins scheduling by use of Gantt charts (see Appendix A) to schedule each individual task that must be completed before the SUT arrives, and after arrival, during the test itself. The length of each task is estimated (in days), and the planned workdays before the SUT arrives are limited to an eight-hour shift. This determines how long it will take to prepare the chamber before the SUT arrives. If there are not enough days to prepare the chamber before the SUT arrives using an eight-hour workday, then the workdays are extended to 10-hour workdays. These extended workdays are usually no longer than 10 hours. The actual time a SUT is in the chamber depends on how many measurements need to be obtained, the amount of money available for testing in the program, and the manpower skill level that can be assigned to the test. To date, the longest test is the B-1B Defensive System Upgrade Program (DSUB) test that ran for three months, requiring 15-hour workdays. This test required two eight-hour shifts, overlapping by an hour for a smooth shift-to-shift transition. Because a program is charged for the days a SUT does not fly, the number of days the SUT is in the chamber needs to be minimized. A program must also meet certain milestones. To meet such deadlines, the BAF will either use an extended shift or two separate shifts to finish on time. The Gantt chart helps manage time and effort, but most importantly, it highlights when the BAF is behind schedule. It also helps to determine the manpower needed to prepare the facility before the SUT arrives.

As the time for the actual test draws near, an Excel spreadsheet is created that shows the planned manpower schedule (see Appendix B). This schedule has a list of each position that needs to be filled, the names and phone numbers of each person scheduled, and the hours and days that each person will work. It also lists who will be alternates if the primary person cannot be present.

Appendix C defines each position that is required for the test. *The planned manpower schedules do not schedule people for overtime or weekends.* This time is considered “management overhead.” Management overhead is used to mitigate risk to a test. Risk is categorized as SUT breakages, BAF system breakages, etc. Anything that could delay the planned test schedule, thus putting the test at risk for noncompletion, ends up using management overhead.

As the test progresses and management overhead is used to keep on the planned schedule, any such overhead does not take into account any fatigue or stress issues. For example, on some tests, people can end up working long days (10 to 14 hours) during the week, as well as working on the weekend, to get back on schedule.

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## **II. LITERATURE REVIEW**

### **A. CIRCADIAN RHYTHM**

“Circadian” is a term from the Latin roots *circa* and *dies*. *Circa* means “about” and *dies* means “day” (McCallum, Sanquist, Mitler, and Krueger, 2003). Rosa and Colligan (1997) say circadian rhythm or daily cycle follows a major body rhythm with regular up (i.e., alert or awake) and down (i.e., sleepy or tired) episodes in a 24-hour day. Levels for many physiological indicators most activities, such as elevated body temperature, alertness, external time cue, heart rate, and various hormone levels, are usually elevated in the late afternoon or early evening. Humans are less active in the middle of the night. This is one reason why people feel most active and alert around 1600 to 1800, and sleepiest at 0400 to 0600. In the normal day-work, night-sleep pattern, people work when their circadian rhythms peak and sleep when they are low.

Finkel (1996) writes, “Human bodies have a 24-hour rhythm. The human core body temperature usually rises and falls each day with the decrease in temperature associated with sleep. Humans function on an internal 24-hour clock, which regulates when we are active and when we are asleep. The circadian clock regulates cycles in body temperature, hormones, heart rate, and other body functions. It is difficult to reset the internal circadian clock because the clock is strongly linked to nature’s cycle of light and darkness. Sudden shifts in our sleeping patterns can confuse the internal clock and disrupt sleep patterns, which then lead to fatigue. If a person loses sleep, fatigue could combine with the circadian low point to amplify the effect on a person’s ability to perform.” Poor performance could affect productivity and safety (Rosa and Colligan, 1997).

#### **1. Melatonin**

Melatonin is a hormone produced by the pineal gland in the brain. It generally is released, increases during the evening and nighttime hours and is associated with sleepiness. Synthetic or natural melatonin can be used to help induce sleep and might help adjust the circadian rhythm to new schedules. Melatonin in small doses has rapid sleep-inducing effects and lowers alertness and body temperatures (McCallum et al., 2003).

## **2. Effects of Light**

An individual's circadian rhythm is sensitive to external time cues, such as the level of sunlight. Human evolutionary patterns result in sleeping at night and waking during the day. The biological clock can be reset when people travel to different time zones, because the rhythm will adjust to the light and dark cycles (McCallum et al., 2003). Lewy, Wehr, Goodwin, Newsome, and Markey (1980) discovered that sunlight or artificial light suppresses melatonin levels.

## **3. Temperature**

Core body temperature has been linked to the sleep-wake cycle. There is a general decrease in body temperature during sleep (Knauth, Rutenfranz, Herrmann, and Poepl, 1978). According to Dr. Moore-Ede and Dr. Levert (1998) the body's temperature fluctuates, reaching a low point (about 96°) between 0400 and 0600. Once it reaches its low point, the body's temperature begins to rise until the afternoon, and then reaches its peak (about 99°) around 1900 to 2000, at which point it begins to fall again.

# **B. SHIFT WORK**

## **1. Overview**

In today's society there is an ever-increasing need for shift work. Who is a shift worker? The Office of Technology Assessment (1991) states a shift worker is someone who does not regularly work a standard daytime schedule. A standard daytime schedule might start as early as 0600 and end as late as 1800; evening shifts might start at 1400 and run as late as 2400; and night shifts might start as early as 2200 and run as late as 0800. For the purpose of this thesis, day shift is defined as 0800 to 1600, evening shift is defined as 1600 to 2400, and night shift is defined as 2400 to 0800. Other topics to be covered in this review include permanent, rotating, and extended shifts, rotation direction and speed, reasons for shift work, how shift work affects health and social events, designing shift systems, and coping strategies.

## **2. Sleep Length**

Paley and Tepas (1994) performed a study on 21 firefighters working rotating shifts. The firefighters worked two weeks on night shift (2400 to 0800), two weeks on evening shift (1600 to 2400), and two weeks on day shift (0800 to 1600). The firefighters' sleep length was revealed to be significantly shorter on the night shift than on the other two shifts and inadequate sleep or sleep debt was incurred. When the firefighters rotated to the evening shift, the first few days their sleep length was longer than eight hours. Sleep length decreased over the course of the evening shift and progressed to a normal sleep length. The firefighters were attempting to recuperate from two weeks of reduced sleep length on the night shift.

## **3. Time of Shift**

Time of shift (the period in which your shift takes place) is important because people who work late night or early morning hours (0200 to 0600) often feel sleepy and fatigued during their shift. This happens because their body's circadian rhythm tells them to be asleep at those times. Night workers also must sleep during the day, when their circadian rhythm tells them to be awake (1400 to 1800). Because of this, day sleep is short and feels "light." Day workers sometimes must wake up very early (0500 to 0700) and this might cause them to cut off their sleep, which makes them feel tired during the day (Rosa and Colligan, 1997).

## **4. Permanent Versus Rotating Versus Extended Schedules**

### ***a. Permanent Schedules***

Permanent schedules are those in which each crew only works one shift, i.e., day, evening, **or** night (Knauth and Rutenfranz, 1982). Fatigue occurs to permanent night shift workers because they go back to a "day schedule" on their days off. This is because family and friends are active during the day. Also many errands and chores must be done during the daytime. Because night shift workers often return to a day schedule, they never completely allow their sleep and body rhythms to adapt to being awake at night. They also sleep less during the day, so they do not have a chance to recover from fatigue (Rosa and Colligan, 1997).

**b.      *Rotating Schedules***

Rotating schedules are those in which each crew rotates their work hours to include each shift type, i.e., day, evening, **and** night (Knauth and Rutenfranz, 1982). For example, each crew will work the day shift for one week, have two days off, work the evening shift for one week, have two days off, and then work the night shift for one week and have two days off. The cycle is then repeated. Rotating schedules are often used because they are considered the most fair to all workers. People on rotating schedules face similar situations as permanent night crews. The shift times are always changing, so they can never completely adapt to a set work schedule. This could be one explanation for why rotating shift workers have more complaints than other workers about physical health and psychological stress (Rosa and Colligan, 1997).

**c.      *Extended Schedules***

Duchon, Keran, and Smith (1994) conducted a study at an underground metal mine in western Canada. The study addressed the effects of fatigue on safety and work performance associated with a change from the traditional eight-hour schedule to an extended 12-hour schedule. Two groups of subjects were evaluated over a 10-day period. The experimental group consisted of three crews of seven workers each, each crew working a backward rotating eight-hour shift, seven days on, three off; seven nights on, two off; and seven afternoons on, two off. The control group consisted of a crew of workers working five days on, two off, on a straight day, eight-hour schedule. After two months the experimental group switched to a 12-hour shift, four days on, four off, four nights on, four off. The 12-hour shift workers had a three-hour round-trip commute and therefore remained on-site for the duration of their four-day workweek. Questionnaires, bicycle ergometers, and mood scales were administered at the start of the shift, four hours into the shift, eight hours into the shift, and at the end of the shift. The results of the study suggested that the extended 12-hour schedules should be retained. The basis for this conclusion was overwhelming support of the 12-hour schedule by the workforce. Survey response indicated positive effects of the new schedule on absenteeism, morale, health problems, stress, eating habits, family life, and sleep quantity and quality.

Lodging of the workers on the 12-hour shift also influenced the results. This conclusion was based on improved sleep quality and better sleeping conditions associated with the mine site.

Tucker, Smith, MacDonald, and Folkard (1998) conducted a study on eight- versus 12-hour shifts. This study included looking at changing shifts at 0600 versus changing shifts at 0700. The results of this study also supported the extended 12-hour shift. The night shift worker preferred the early time change (0600), reporting less sleep disruption when ending at 0600. The day shift worker preferred the later time change (0700), reporting less sleep disruption when starting the shift at 0700. Tucker et al. (1998) concluded that flexible scheduling, by tailoring shift schedules to subgroups, should be considered.

#### ***d. Rotation Direction***

Adapting to rotating shifts can be affected by the direction of rotation. Direction of rotation means the order of shift change: A forward rotation is from day to evening to night shift. A backward rotation is from day to night to evening shift. The direction of rotation can affect the body's ability to adapt to the change in work times. Some researchers suggest that a forward rotation is better for helping a worker adjust to new sleep times. This suggestion was made because it is easier to go to bed later and wake up later. A backward rotation works against the circadian body rhythm by forcing the worker to go to sleep earlier and earlier (Rosa and Colligan, 1997). For example, if working the day shift, a worker will get up at 0600 and start the shift. When switching to the night shift, the worker must now get up at 2200 to start the shift. The worker must get up eight hours earlier than before.

#### ***e. Rotation Speed***

Adapting to rotating shifts can also be affected by the speed of rotation. Speed of rotation means the number of consecutive day, evening, or night shifts before a shift change occurs. For example, a short rotation lasting two or three days gets the worker through the night shift faster. Long rotations (e.g., 3 to 4 weeks) are supposed to allow workers more time to get adjusted to night shifts. Problems occur when workers

return to a day shift schedule on their days off because they have family responsibilities or daytime errands to run. A fast rotation (e.g., every two days) allows no time to get used to night work. However, some researchers suggest that fast rotations because the worker quickly gets through the tough shifts and then has a couple of days off (Rosa and Colligan, 1997).

## **5. Reasons for Shift Work**

In a study conducted by Barton (1994), the two most important reasons people gave for working shifts were the convenience of the work hours for domestic responsibilities and the added financial incentive associated with working shifts. Some workers actually prefer nonday work, but most do not seek out shift work. Other reasons for employees choosing shift work include more available time during the day for child care, more daylight hours for recreation, and more time to attend school. Some workers prefer the night shift because it is quieter and there are fewer supervisors. Usually, however, workers say they do not prefer shift work. They do it either because it is a job requirement, or because no other job is available (Rosa and Colligan, 1997).

## **6. Social Events**

Shift times might determine when a worker can see family and friends. Social events take place in the evening, which means evening or night workers might miss them. Parents who work the evening shift might not see their children during the week because they are at work when their kids return from school. If this happens too often, it can be stressful (Rosa and Colligan, 1997). Barton (1994) conducted a study of 587 nurses and midwives in England. Nurses and midwives that preferred to work a permanent nighttime shift reported less social disruption. Most problems arose when individuals did not prefer to work a permanent night shift, but would have preferred to work a permanent day shift.

## **7. Long-Term Health Effects**

### **a. *Digestive and Cardiovascular Problems***

Some research has suggested that shift workers have more upset stomachs, constipation, and stomach ulcers than day workers. Digestive problems could be more common in shift workers because digestion follows a circadian rhythm. People eat at regular times, during the day. Shift work can interfere with regular eating and digestive patterns by frequently changing work and sleep times. Digestive problems also could be caused by a lack of nutritious food. For example, sometimes on the night shift only junk food from vending machines is available (Rosa and Colligan, 1997).

Heart problems have been noted more often among shift workers than day workers. However, the exact mechanism in which one's work schedule affects the heart is not at all clear (Rosa and Colligan, 1997).

### **b. *Extended and Permanent Shift Workers' Health***

Peacock, Glube, Miller, and Clune (1983) conducted a study at the police department in the city of Dartmouth. The study compared two shift cycles: an eight-hour, 12-day shift cycle and a 12-hour, eight-day shift cycle, for the effects on the officers' state of alertness and the quality of police service offered to the community. The results showed support for the 12-hour, eight-day cycle because the officers achieved higher workloads with less physiological strain and they were healthier under this cycle. These improvements were related to more regular sleep patterns, eating habits, and recreational activity. In her study, Barton (1994) concluded that fewer health problems occurred in workers who prefer to work on night shift.

## **8. Suggestions for Designing Shift Systems**

Rosa and Colligan (1997) have the following suggestions for designing shift systems:

- Keep consecutive night shifts to a minimum. Two to four nights in a row should be worked and then a couple of days off.
- Avoid quick shift changes. Avoid going from day to night shift on the same day, giving the worker a 7- to 10-hour break.
- Plan some free weekends. If a seven-days-per-week schedule is required, allow one or two weekends a month off. Weekends provide the best time for contact with friends and family.
- Avoid several days of work followed by four- to seven-day “mini vacations”. Some schedules require 10 to 14 days of work with five to seven days off. These “mini vacations” should be avoided because not everyone can recover from fatigue incurred by long work periods.
- Keep long shifts and overtime to a minimum. Extra work time adds to fatigue by allowing less rest time per day. If 12-hour shifts are used, then minimize the number of workdays to two or three days in a row.
- Consider different lengths for shifts. Intense physical, mental, or boring work at night may require shorter shift lengths. If possible, move heavy work to shorter shifts and lighter work to longer shifts.
- Examine start-end times. Consider flexible start-end times for people with different circadian rhythms. It can also be useful for people with child care needs or long commute times.
- Keep the schedule regular and predictable. A regular schedule helps the worker to plan rest time, child care, and contact with family and friends.
- Examine rest breaks. If job requires intensive labor or repetitive physical work, rest breaks every hour helps recovery from muscle fatigue.

Similarly, Knauth and Ruthenfranz (1982) have done studies on developing the criteria for the design of shift systems. Through their research they developed the following recommendations when designing shift systems.

- Shift systems should have few (i.e., one or two) night shifts in succession.
- Morning shift should not begin too early (start times should begin between the hours of 0700 and 0900).
- Shift change times should allow individuals some flexibility (workers can start their shifts anywhere between the hours of 0700 and 0900). Flexible start-end times can be useful for people with child care needs, long commutes, and different circadian rhythms.
- The length of the shift should depend on the physical and mental load of the task, and the night shift could be shorter than the morning and afternoon shifts. Heavy physical, mental, or boring workloads can add to the night shift fatigue. If heavy physical, mental, or boring workloads are required on the night shift, then shortening the shift will help improve productivity and safety.
- Short intervals (i.e., seven, eight, or 10 hours) of time between two shifts should be avoided.
- Continuous shift systems should include some free weekends with at least two successive full days off (i.e., seven days on, two days off).
- In continuous shift systems, forward rotation is preferred. It allows the worker to go to bed later and wake up later. This works with the body's circadian rhythms.
- The duration of the shift cycle should not be too long. A four-week rotating shift (rotating to a new shift every week) allows more contact with friends and family.
- Shift rotations should be regular. Regularly scheduled shift rotations allow the worker to plan for sleep and time spent with friends and family.

## **9. Coping Strategies**

Rosa and Colligan (1997) have suggested the following coping strategies for shift workers:

- Try sleeping at different times. Keep a record of the different times sleeping was tried and note which times worked best. Some workers like to sleep in one long period, while others need two shorter sleep times.
- Resting helps enhance body and muscle recovery, but the brain has to have sleep. Schedule at least seven hours in bed, even if you don't sleep the whole time.
- All workers need at least six hours of sleep, but most need 7.5 to 8.5 hours.
- When switching back to days after the night shift, it is best to sleep a couple of hours shortly after the night shift (i.e., 0800 to 1000), stay awake all day, and then go to sleep at the regular bedtime for daytime workers (i.e., 2200 to 2300).
- For jobs that allow napping during a break, such as nurses or doctors, a 20 to 30 minute nap will help fight off sleepiness; however, a nap of 15 minutes or less might actually make a person sleepier.
- Soundproof the bedroom with insulation and heavy curtains. Put up signs to let others know you are sleeping. Switch off the phone and disconnect the doorbell. Set strict times for noisy activity.
- Avoid heavy, greasy foods that will cause an upset stomach. Don't drink alcohol an hour or two before sleep. Alcohol may make you sleepy, but it will also wake a person up too quickly after falling asleep.

## **10. Sleep**

### ***a. Overview***

On average, each person needs approximately eight hours of sleep a day, although a few might need as little as six hours, while others might need 10 hours (McCallum, Sanquist, Mitler, and Krueger, 2003). According to Rosa and Colligan (1997), night workers (2400 to 0800) usually get the least amount of sleep (six hours or less), while evening shift workers (1600 to 2400) get the most sleep (7.5 to 8.5 hours), and day shift workers (0800 to 1600) get a medium amount (six to seven hours) of sleep.

This is because night workers are forced to sleep during the day when their circadian rhythms make them feel more awake, and day shift workers are forced to get up when their circadian rhythms are at a low point. Because people feel more awake during the day, night shift workers do not get the required amount of sleep to sustain themselves through their wakeful schedule, and day shift workers' sleep is cut short. This affects the workers' ability to perform safely and efficiently. Sleepiness affects our ability to concentrate or pay attention. If a worker has lost sleep, fatigue can combine with the circadian low-point to double the effect on the worker's ability to perform. Poor performance can affect both productivity and safety. Barton (1994) concluded that tolerance to night shift work appears to increase when a worker prefers to work the night shift. Barton also concluded that these same workers exhibited a greater tendency toward evening alertness and a greater flexibility of sleeping.

***b. Sleep Cycles***

There are two types or states of sleep: Non-Rapid Eye Movement (NREM) and Rapid Eye Movement (REM). There are four different stages in NREM. Stage 1 is classified as a person drifting off to sleep or by slow eye movement. A slowing of the heart rate follows this, and a relaxing of muscle tension occurs as Stage 2 is entered. In Stages 3 and 4, slow wave brain activity is associated with very deep and restorative levels of sleep. During Stages 3 and 4 it is very difficult to wake a person. REM sleep occurs throughout the sleep cycle. It is characterized by rapid, conjugate eye movement and shows a brain activity pattern similar to Stage 1. This sleep stage is also associated with dreaming ( McCallum et al., 2003).

***c. Sleep Preferences***

People differ in their sleep patterns. Some people prefer to get up early in the morning and get their best work done before lunch. This person is considered a "morning person" or a "Lark." Others prefer the afternoon or evenings and do their best work at night. This person is considered a "night person" or an "Owl." The intermediate person, the one who does not go to either extreme, but can cope with either early

mornings or late nights when the need arises is called the “Regular Robin” (Moore-Ede and Levert, 1998).

**d. *Sleep Debt***

In today’s society, with shift work, jet lag, stimulants, and sleeping restrictions, people push the envelope of what their bodies can endure. When inadequate sleep is obtained repeatedly on consecutive occasions, sleep debt is incurred and might be referred to as “chronic” (Van Dongen, Rogers, and Dinges, 2003). We are becoming a society with chronic sleep debt. For example, Kripke, Garfinkel, Wingard, Klauber, and Marler (2002), examined data from a health questionnaire given to 1.1 million Americans and the results indicated that the population sleeps an average of 6 to 7 hours each night. This means the average person, who needs eight hours of sleep per night, incurs a sleep debt of 7 to 14 hours every week.

**e. *Recuperative Sleep***

One way to reverse the effects of sleep debt is to extend sleep on the weekends or to take short naps during the day. When people take a nap for more than an hour, they are likely to fall into Stages 3 and 4. When they are awakening from these stages, they are likely to experience “sleep inertia.” Sleep inertia is grogginess that can last 15 to 20 minutes. In order to get the benefits of a nap, it is suggested that you nap for about 45 minutes or less (McCallum et al., 2003).

**C. MISHAPS CAUSED BY FATIGUE**

**1. Overview**

The following examples describe four serious disasters: The Exxon Valdez oil spill, British Airways BAC1-11, the Chernobyl Power Plant, and Three Mile Island. All of these disasters have one thing in common—they all happened during the evening shift hours from 2400 to 0600. This is the time when circadian rhythms are low and our bodies are not functioning at optimal levels. Mental fatigue, stress, and sleepiness all

play a part in the decision-making process. In these examples, fatigue—combined with the circadian low point—affected the ability of people to perform and caused safety and environmental hazards.

## **2. Exxon Valdez**

On the night of March 24, 1989, Captain Hazelwood was drunk. The crew of the Exxon Valdez had been working 12 to 14 hours a day due to forced personnel cuts. The Exxon Valdez was navigating the shipping Lanes in Prince William Sound, Alaska. In order to navigate an oil tanker in the Sound, a special license is required and Captain Hazelwood was the only one on board who had such a license. Just outside the port of Valdez, the Exxon Valdez encountered some chunks of ice that had separated from a glacier. Captain Hazelwood changed the vessel's course to miss the ice, put the tanker on autopilot, and increased the speed. Captain Hazelwood then instructed an exhausted third mate to turn the ship when it came abeam of Busby Island. The turn was only two minutes away, but Captain Hazelwood did not wait the two minutes to supervise the turn; he left the deck and went to his cabin. The exhausted third mate went to the chart room to chart the turn. Just before 0100, the hour approaching a low point in the circadian rhythm, the ship ran aground on Bligh Reef off the Alaskan coast, spilling thousands of barrels of oil into the ocean (Shelby, 2004).

## **3. British Airways BAC1-11**

On June 10, 1990, a British Airways BAC1-11 was scheduled to fly from Birmingham, England to Malaga, Spain. The aircraft was scheduled to have its 60-pound left front windshield replaced before its flight. The supervisor on the night shift began to replace the windshield at 0300 in order to make a wash deadline of 0630. The supervisor removed 90 7D bolts from the windshield. He could not reuse all 90 bolts due to damage, so he looked for replacement bolts. The supervisor used one of the 7D bolts he removed from the windshield to compare to the other bolts he found. He ended up using 84 8C bolts and six 8D bolts to install the windshield. The 8C bolts differ from the 7D bolts by one-fortieth of an inch in diameter. The 8D bolts were the correct bolts to use according to the instruction manual. When the supervisor tightened the 8C bolts

down he did not notice that the bolts were not offering the resistance they should have as they went into the fuselage. The BAC1-11 made its flight time of 0720. As the BAC1-11 was climbing to 17,000 feet, the 8C bolts gave way and the windshield separated from the fuselage. A force of 5,500 pounds pulled the captain out of the aircraft. Flight attendants took turns hanging onto the captain's feet, while the co-captain landed in Southampton 18 minutes later. The captain survived the frigid temperatures and sustained frostbite, a broken elbow, wrist, and thumb (Chiles, 2001).

#### **4. V. I. Lenin Chernobyl Nuclear Power Station Reactor 4**

V. I. Lenin Chernobyl Nuclear Power Station was located on the edge of the Pripyat River, 80 miles north of Kiev, in the former Soviet Union. On April 26, 1986, shortly after midnight, the crew of the station was attempting to carry out an experiment to squeeze enough electrical power out of a reactor-generator set during an emergency shutdown to allow time for diesel generators to come on line to pick up the power loads. Very quickly the reactor suffered two powerful explosions, which blew the walls in, and the roof fell. At least two poor decisions were made leading up to the reactor's failure. The first occurred when the operators turned off the automatic safety shutdown system, thus violating safety rules. Then, two panicked workers attempted to drive in all the control rods to shut the system down. This pushed out the reactor channels when the rods entered and boosted the reaction too far and too fast. The reactor warped, broke up, and released at least 50,000,000 curies of radioactivity into the environment (Chiles, 2001).

#### **5. Three Mile Island Unit 2**

In the early morning hours of March 28, 1979, at Three Mile Island Power Plant Unit 2 near Harrisburg, Pennsylvania, the reactor came within a half hour of total meltdown. The night (2300 to 0700) maintenance crew was cleaning one of the giant water filters in the steam-making loop. Undetected by the crew, a few ounces of water seeped into the compressed air lines. At approximately 0400, the leaking water reached the control lines to the big valves controlling all the giant water filters (called a "condensate polisher"). The automatic controls interpreted this water as a deviation from proper conditions and shut all the valves that let coolant through. This was the beginning

of the problem. The stoppage of 5,000 gallons of water tore a pipe loose, pulled out controls, and sprayed the room with scalding water; when the coolant water stopped flowing, the reactor shut down. Heat production was slowed down, but not stopped entirely. As the temperatures rose the water expanded and the pressure climbed. The pressurizer tank was the only place water could expand to. As the pressure rose in the pressurizer tank, the automatic controls commanded the pilot-operated relief valve (PORV) to open and vent off steam, which reduced the pressure in the tank. When the pressure in the tank was returned to normal, the PORV was supposed to close. On this particular day, however, the PORV stuck open and continued the meltdown of the reactor core. In the control room, the PORV red indication light came on and indicated the command to open the PORV was given. A short time later the PORV light went out, indicating the command to shut the valve had been given. The control room operators, not understanding how the light worked, interpreted the PORV light going off to mean that the PORV had closed, when in actuality, the command had been given, but the PORV had stuck open. For two hours the control room operators tried to find the reason why the reactor core was not cooling down. At 0600, a well-rested supervisor arrived. Within 15 minutes of arriving, he assessed the situation and had two theories in mind. One was that a circuit breaker had blown and knocked out the electric heaters in the pressurizer tank and the second was that there was a small leak somewhere in the reactor coolant system. While one man checked on the circuit breaker, the fresh supervisor investigated the possibility of a leak. After looking at the control room instrumentation displays, the supervisor closed an electrically operated valve that would isolate the pressurizer tank from the PORV valve. With the closing of this valve, the coolant pressure began to rise and a total meltdown was averted (Chiles, 2001).

## **D. MODELS OF HUMAN PERFORMANCE AND SLEEP DEPRIVATION**

### **1. Overview**

This section summarizes five human performance and sleep models. Each model was developed for a different target group such as the scientific community of sleep research, the railroad and trucking industry, the United States Department of Defense,

and other workplace settings. All but the Fatigue Audit InterDyne Model (FAID) has the same basic Two-Process Model design. The major differences between these models are what kind of data is inputted, how the input data is handled internally to the program, and what kind of output data is created. The model used in this thesis is the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) Model, developed by the Science Applications International Corporation (SAIC) under a government contract.

## **2. Two-Process Model**

Dr. Peter Achermann, Head of the Human Sleep Laboratory at the University of Zurich, developed the Two-Process Model for the scientific community of sleep researchers. There are two processes in this model: Homoestasis Process S and Circadian Process C. Process S is the sleep/wake cycle modeled by an exponential function that decreases while sleeping and increases while awake. The circadian rhythm modeled by a skewed sine wave, where the maximum is around 1400 and the minimum is at 0500, drives process C. The Two-Process Model is at the core of numerous models addressing the regulation of fatigue and performance (Achermann, 2004).

## **3. Fatigue Audit InterDyne (FAID) Model**

The FAID was developed by the University of South Australia's Center for Applied Behavioral Science. FAID was primarily developed for organizations in workplace settings. FAID has one simple input: start and end times of work periods. Schedules are modeled as a square wave function between work and nonwork. Work-related fatigue is associated with a linear work component: length of work period; nonwork-related recovery is associated with a sinusoidal component: circadian timing (time of day); and recency component: a weighted factor such that more recent work or nonwork periods make a greater relative contribution to the overall fatigue score. The nonwork component estimates the amount of sleep likely to be obtained during the nonwork hours. The overall fatigue score is an algebraic function of the work and nonwork component weighted with the recency component. FAID's output is a single generic variable representing fatigue (Roach, Fletcher, and Dawson, 2004).

#### **4. Circadian Alertness Simulator (CAS) Model**

The CAS was developed for assessing fatigue risk in the 24-hour, seven days a week, workplace setting (such as the railroad and trucking industries) and for reducing the rate of fatigue-related accidents, injuries, and deaths at work. It has the same basic processes as the Two-Process Model: the Homeostatic Process S and Circadian Process C. The Homeostatic Process S represents the sleep and wake duration. It is an exponential function that increases during sleep and decreases during wakefulness. The Circadian Process C represents the phase, period, and amplitude of the circadian rhythm. It is a sinusoidal function with a 24-hour period. Either actual or estimated hours of sleep and wakefulness are inputted into CAS. If estimated wakefulness hours are used, the software estimates the sleep-wake pattern based on the actual work pattern of the individual. A minute-by-minute continuous alertness curve is created for the entire time period. Sleep, work, and alertness statistics are also created and given in a statistical table or graphical form. A cumulative fatigue score is computed and displayed (Moore-Ede, Heitmann, Guttkuhn, Trutschel, Aguirre, and Croke, 2004).

#### **5. Three-Process Model**

Dr. Akerstedt, Professor of Behavioral Physiology at the Karolinska Institute and the National Institute for Psychosocial Medicine, developed the Three-Process Model with the purpose of looking at alertness, sleep wake patterns, and performance. This model was developed for primary users such as schedulers and planning staff that want to evaluate the fatigue and performance effects of particular work schedules. The secondary users of this model are occupational specialists and hygienists who need information on human physiology and performance in relation to irregular work hours. The Three-Process Model is very similar to the Two-Process Model, except that it has three processes: Process S, Process C, and Process W. The input required is the start and end time of each work period. Software can generate bedtime and sleep termination times or they can be entered. Times of sleep, changes in time zones, diurnal types, sleep length, and sleep problems can also be entered. The main output is the predicted alertness curve that can have the default form of the 1-21 point scale (Akerstedt, Folkard, and Portin, 2004).

**a.      *Process S***

Process S consists of two parts: S represents the time since awakening and S' represents the time to recover. S is highest on awakening and decreases exponentially over the time awake. S' is lowest at the start of sleep and increases exponentially over the time slept (Akerstedt, Folkard, and Portin, 2004).

**b.      *Process C***

Process C represents the sleepiness due to the circadian rhythm. Process C is a sinusoidal wave with an afternoon peak (Akerstedt, Folkard, and Portin, 2004).

**c.      *Process W***

Process W represents sleep inertia or the wake-up process. Process W decreases exponentially over time (Akerstedt, Folkard, and Portin, 2004).

**6.      **Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) Model****

Group of researchers from various DoD services, headed by Dr. Steven Hursh from SAIC, developed the SAFTE Model (see Appendix E), which builds on the sleep and performance model (SPM) (Hursh and Bell, 2001). Hursh refined the SPM to serve as an integral element of the Actigraph-based Sleep and Activity Monitor (SAM). The actigraphy provided real-time assessment data of cognitive-performance potential based on sleep and wakefulness patterns derived from activity records. Hursh further developed the model to give it the capability to predict performance based on a schedule of sleep and activity. The new feature also extends the predictions of the model to task effectiveness as well as to cognitive capability (SAIC, 2000).

**a.      *Sleep Regulation Process***

The core of this model is designed as a Sleep Reservoir, which represents sleep-dependent processes that govern the capacity to perform cognitive work. A fully rested person has a maximum capacity to perform. This is called the “sleep reservoir” or “sleep debt.” When a person is awake, the sleep reservoir is depleted. Likewise, when a person is asleep, the sleep reservoir is replenished. Replenishing the sleep reservoir is

determined by sleep quality and sleep intensity (Hursh, Redman, Johnson, Thorne, Benlenky, Balkin, Storm, Miller, and Eddy, 2003).

***b. Circadian Process***

The circadian process governs sleep intensity and sleep quality. Performance and alertness reach a major peak in the early evening, around 2000, and fall to a minimum around 0400. There is a secondary minimum in the early afternoon, around 1400, and a secondary morning peak at around 1000. Correlated with this pattern is a varying tendency to fall asleep that reaches a peak at about the same time performance and alertness reach their minima. The existence of both a major and a minor peak in performance, and two corresponding minima at other times, suggests that at least two oscillations are involved in the circadian process (Hursh et al., 2003).

***c. Sleep Inertia***

Sleep inertia is the delay, after awakening from sleep, before expected levels of alertness and performance resume. The SAFTE Model estimates the sleep inertia as an exponential discharge function that is invoked for two hours after awakening from sleep. Sleep inertia is subtracted from effectiveness and the final output is performance effectiveness. The circadian effects and the level of the sleep reservoir modulate the level of effectiveness (Hursh et al., 2003).

**E. FAST AVOIDANCE SCHEDULING TOOL (FAST)**

In the past, there has not been a system to allow military planners to consider sleep and performance when planning for operations. FAST uses the newly designed SAFTE Model of sleep and performance as the basis of a fatigue avoidance decision aid for operational planning (SAIC, 2000). FAST includes features to track changes in geographic location and calculated levels of sunlight. The model can detect a difference between transmeridian schedule shifts and shift-work changes at the same location (Hursh et al., 2003). This scheduling system permits the planner to evaluate the relative benefits of various schedules that accomplish a mission. With the computerized system, optimal performance can be arranged at critical times and degradations can be avoided

(SAIC, 2000). FAST can be used as a fatigue management risk tool to identify personnel at compromised performance effectiveness.

### **III. METHODS**

#### **A. PARTICIPANTS**

Major efforts were taken to attract participants that represented a test crew at the Benefield Anechoic Chamber. However, the sample was for volunteers only—no one was forced to participate. For this analysis, a total of eight participants were used, all of whom were men. They represented six of the required positions needed to operate the test facility, and had various military experience and educational backgrounds. All of them signed a participant consent form, a minimum risk consent statement, and a privacy act statement prior to the start of data collection. Blank forms can be found in Appendix E. Originally, eight participants from the Benefield Anechoic Chamber volunteered to take part in this study. However, one participant was omitted from the Actigraph analysis because it was discovered that he was allergic to the material in the Actigraph wristband and could not wear the Actigraph continuously.

#### **B. IMPLEMENTATION AND DATA COLLECTION OF SLEEP DATA**

##### **1. Internal Review Board (IRB)**

The Naval Postgraduate School conducted an internal review board (IRB) on this sleep study to investigate any potential safety risks that the subjects may be exposed to. It was concluded that minimal or no safety risks existed. A copy of the IRB request form can be found in Appendix F.

##### **2. Questionnaires**

###### ***a. Lark/Owl/Regular Robin***

Appendix G has a copy of the Morningness-Eveningness scale. This scale was given to each volunteer to determine if he was a Lark, Owl, or Regular Robin. In order to determine which category each of the volunteers fell into, each question was scored on a scale of 1 to 3. If a question was answered by circling the letter A, 1 point was received, if letter B was circled, 2 points were received, and if letter C was circled, 3 points were received. After scoring all the questions, the points were totaled and a

score of 6-18 was generated. This score was plotted on the Circadian Type/Flexibility Profile found in Appendix I. The lower the score, the more of a morning person you were (Moore-Ede and LeVert, 1998).

***b. Flexible-Rigid Scale***

Appendix G has a copy of the Flexible-Rigid scale. This scale was given to each volunteer to determine how easygoing he was. In order to determine which category each of the volunteers fell into, each question was scored on a scale of 1 to 3. If a question was answered by circling the letter A, 1 point was received, if letter B was circled, 2 points were received, and if letter C was circled, 3 points were received. After scoring all the questions, the points were totaled and a score of 6-18 was generated. This score was plotted on the Circadian Type/Flexibility Profile found in Appendix I. The lower the score, the more rigid or inflexible a person was. The higher the score, the more able a person was to adapt to outside demands on his time or energy (Moore-Ede and LeVert, 1998).

***c. Demographic Survey***

Appendix G has a copy of the demographic survey. This survey was designed to provide statistical information on the population. The survey included questions on information such as gender, age, tobacco usage, medication, drive time to work, sleeping disorders, and consumption of caffeinated beverages.

***d. Sleep History***

Appendix G has a copy of the Sleep History questionnaire. This questionnaire provided information on each volunteers' sleep patterns for the last month. It helped in understanding the difference in sleep patterns on workdays and weekends. Weekend sleep patterns can indicate the amount of sleep a person needs or how sleep deprived a person may be. This questionnaire provided information on self-reported typical weekend and workday sleep patterns.

### 3. Data Collection

Data were collected on eight subjects. Each volunteer was assigned a wrist activity monitor (WAM) and wore it continuously from April 8, 2004 through April 16, 2004. WAMs were assigned to each volunteer by the WAM serial number (see Table 1, first column). The second column describes of the type of Actigraph, the third column lists the date and time each Actigraph was initialized, and the fourth column lists the time and date that each Actigraph was issued to each volunteer. The Actigraph collects sleep data on each volunteer and each volunteer fills out a data log to record when he sleeps, when he gets up in the morning, when he takes a nap, when he takes off the Actigraph, and any other unusual activity. A blank copy of the data log can be found in Appendix H.

| Serial Number | Type          | Initialized Date/Time | Time Issued    |
|---------------|---------------|-----------------------|----------------|
| 1065          | Basic w/light | 4/8/2004 23:22        | 4/9/2004 10:20 |
| 1066          | Basic w/light | 4/8/2004 23:14        | 4/9/2004 9:28  |
| 1067          | Basic w/light | 4/8/2004 23:21        | 4/9/2004 8:56  |
| 1179          | Basic         | 4/8/2004 23:31        | 4/9/2004 9:14  |
| 1181          | Basic         | 4/8/2004 23:29        | 4/9/2004 9:22  |
| 1185          | Basic         | 4/8/2004 23:24        | 4/9/2004 9:28  |
| 1188          | Basic         | 4/8/2004 23:25        | 4/9/2004 8:55  |
| 1197          | Basic         | 4/8/2004 23:27        | 4/9/2004 10:01 |
| 1198          | Basic         | 4/8/2004 23:34        | 4/9/2004 10:12 |

**Table 1. Actigraph assignment**

The Actigraphs, sleep logs, and questionnaires were collected at the end of the shift on 16 April 2004. Actigraphy data were downloaded to a computer using ACT Millennium software. Once downloaded, the data were exported into another program called Action-W, where it was trimmed or cleaned for unwanted data and checked to make sure data was marked “sleep” when volunteers were sleeping and “wake” when volunteers were active. Once the data were cleaned or trimmed, they were exported into FAST to be analyzed for performance effectiveness.

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## IV. RESULTS FROM BENEFIELD ANECHOIC FACILITY (BAF) TEST

### A. CIRCADIAN CHRONOTYPE OR LARK-OWL PREFERENCE

Figure 2 is a graphical representation of the Circadian Type and Flex-Ability profiles of the participants. All eight volunteers' Circadian Type and Flex-Ability scores are shown on the graph. The graph indicates that three of the volunteers are definite Regular Robins; three others have flexible Lark tendencies; one has rigid Lark tendencies; and one has flexible Owl tendencies.

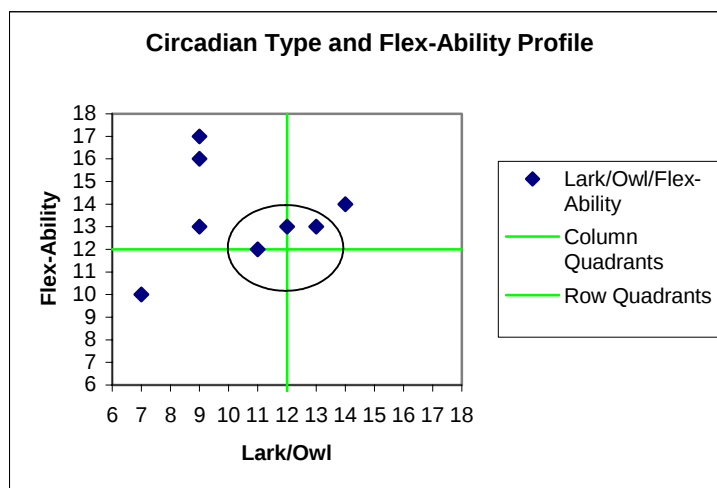
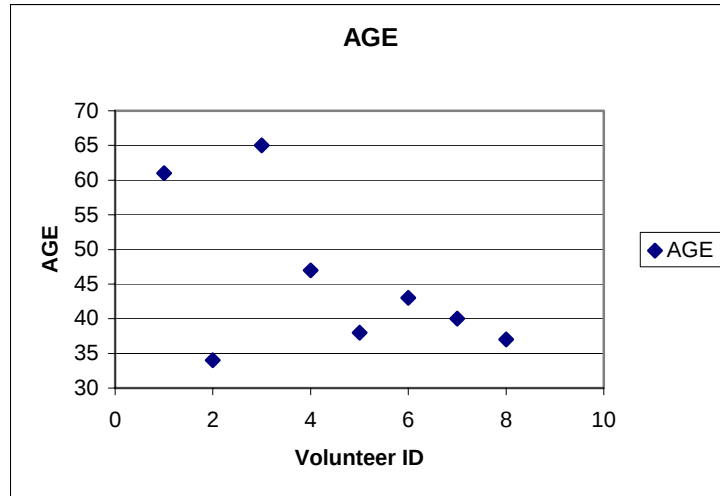


Figure 2. Circadian type and Flex-Ability Profile

### B. DEMOGRAPHICS

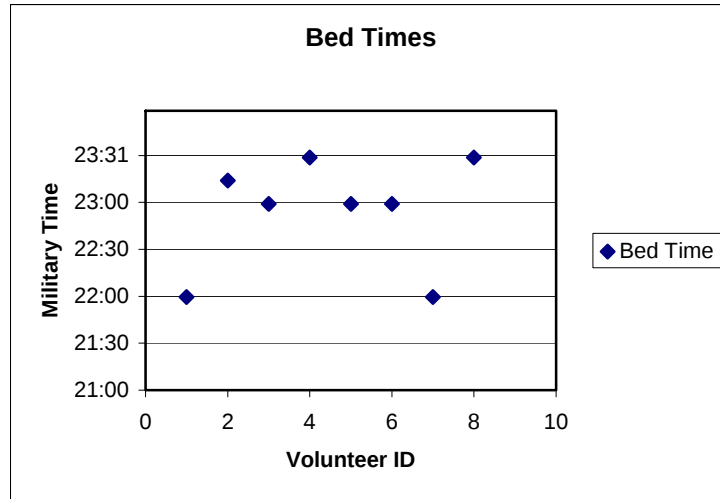
All eight volunteers are male, ranging in age from 34 to 65, with the average age being 46 (see Figure 3). The average number of caffeinated beverages consumed was four per person, with the minimum number consumed by one volunteer being 1 and the maximum number being 10. Two of the volunteers smoked tobacco products, while another volunteer used alcohol to help relax at night and go to sleep. A fourth volunteer had occasional insomnia and used over-the-counter medication to help him fall asleep. The average driving time to work was approximately 48 minutes, with the minimum driving time being 30 minutes and the maximum being 60 minutes.



**Figure 3. Age of volunteers**

### **C. SLEEP HISTORY**

The volunteers' bedtime on days off ranged from 2200 to 2330, with an average bedtime of 2254 (see Figure 4). The volunteers' rise time on days off ranged from 0500 to 0900, with an average rise time of 0737. The time it took for each volunteer to fall asleep at night ranged from 15 to 60 minutes, with an average time of 29 minutes. Volunteers' hours of sleep at night on their days off ranged from 5 to 9 hours of sleep, with an average time of 7 hours per night. The average number of times volunteers woke up during the night was 2 and ranged from 0 to 10 times per night. The reasons given for waking up at night include bathroom breaks, noise due to dogs and cats, children or other family members waking them, and dreams. The average time it took to return to sleep after being awake was 12 minutes, with a range of 1 to 30 minutes. One volunteer took naps during the day, while two others had problems getting to sleep at night. One of the two who had problems getting to sleep at night also had problems staying awake while driving, eating, or engaging in social activity. A fourth volunteer had problems staying awake while driving, eating, or engaging in social activities.



**Figure 4. Bed times**

One volunteer rated his sleep quality at night as fairly bad, while the others all rated their sleep quality as fairly good. The volunteers were asked to rate a variety of sleeping factors with scores from 1 to 5. A score of 1 represented “strong interference with sleep”; a score of 2 represented “slight interference with sleep”; a score of 3 represented “no effect on sleep”; a score of 4 represented “slight promotion of sleep”; and 5 represented “promotes sleep”. The factors were quality of sleep surface, heat, cold, thoughts running through your head, random noise events, constant background noise, background lighting, readiness for sleep, comfort of clothing, low humidity/dry air, high humidity, trips to the bathroom, bed partner, privacy, ventilation, sheets/blankets/pillow, and extreme smell in the room. The average scores for each of these are found in Table 2.

|                                           |   |
|-------------------------------------------|---|
| <b>Quality of sleep surface</b>           | 3 |
| <b>Heat</b>                               | 3 |
| <b>Cold</b>                               | 2 |
| <b>Thoughts running through your head</b> | 2 |
| <b>Random noise events</b>                | 2 |
| <b>Constant background noise</b>          | 3 |
| <b>Background lighting</b>                | 2 |
| <b>Readiness for sleep</b>                | 4 |
| <b>Comfort of clothing</b>                | 4 |
| <b>Low Humidity/Dry Air</b>               | 3 |
| <b>High Humidity</b>                      | 2 |
| <b>Trips to the bathroom</b>              | 2 |
| <b>Bed partner</b>                        | 3 |
| <b>Privacy</b>                            | 3 |
| <b>Ventilation</b>                        | 3 |
| <b>Sheets/Blankets/Pillow</b>             | 3 |
| <b>Extreme smell in the room</b>          | 2 |

**Table 2. Sleep factors**

Readiness for sleep and comfort of clothing scored the highest with a score of 4. Cold, thoughts running through your head, random noise events, background lighting, high humidity, trips to the bathroom and extreme smell in the room all scored the lowest with a score of 2. The other categories scored a 3, meaning no effect. One volunteer listed intestinal discomfort from high fat foods, beans, and garlic as interfering with sleep.

The volunteers' were also asked to rate how their sleep was interfered with by hunger, thirst, personal worries, and respiratory factors. The same response anchors (e.g., "strongly interferes with sleep" to "no effect") were user for the sequence of questions. The average scores were 3 for hunger, thirst, and respiratory factors and 2 for personal worries. One volunteer listed high fat foods and gas from beans, garlic, and spice as strongly interfering with his sleep.

#### **D. FAST RESULTS**

Seven of the eight volunteers' actigraphy data were entered into FAST. The eighth volunteer took off his WAM because he was allergic to the watchband material and was unable to complete the study. Two of the other volunteers removed their WAMs

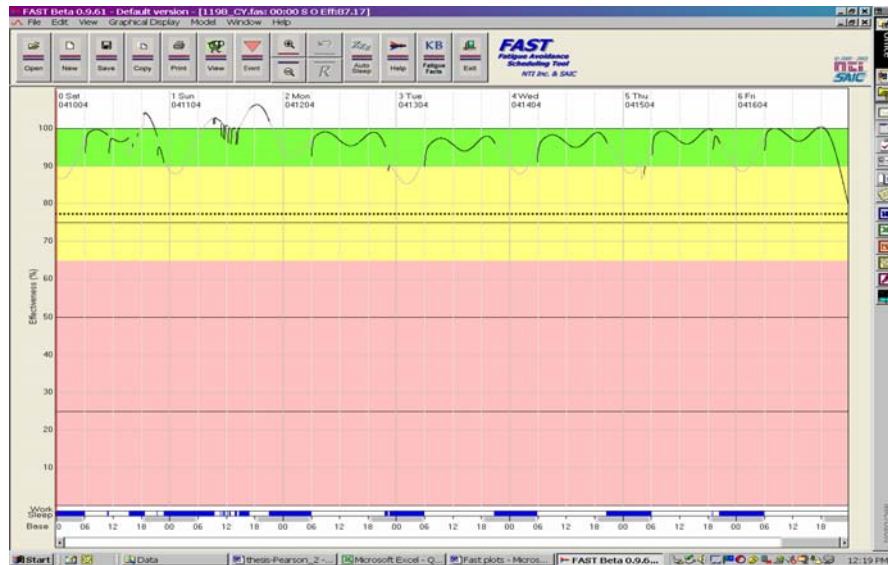
at night; they noted this in their activity logs, and the data were able to be inserted since FAST allows for editing of the actigraphy data. The data were edited to indicate that sleep was occurring during the time period that the WAMs were removed.

FAST graphical data for each volunteer can be found in Appendix J. Looking at the FAST data for Volunteer 1065 (see Figure 4), there is a downward trend for the predicted effectiveness each day. On day 1, FAST assumes that the volunteer has had good rest for the previous 3 nights and his predicted effectiveness is in the green zone. On day 2, Volunteer 1065's sleep is broken and results in his predicted effectiveness dropping into the yellow zone. Volunteer 1065's broken sleep continues, and on day 4, drops below the 79% predicted effectiveness line. As Volunteer 1065 continues to have short, broken sleep, he never recovers back to the green zone, but continues to fall into the red zone, representing a dangerous risk level.



**Figure 4. Actigraph 1065**

Looking at the FAST data for Volunteer 1198 (see Figure 5), the daily predicted effectiveness stays in the green zone. On days 1 and 2, FAST graphical data shows spikes during sleep. This represents brief awakening or moments of movement during sleep. On days 3 through 7, sleep is approximately 7 to 8 hours long and unbroken. This represents a good night's sleep.



**Figure 5. Actigraph 1198**

Appendix K, Table 3 displays the predicted effectiveness of each volunteer at 0700 each day. Volunteer 1065's data shows a daily decrease in his predicted effectiveness. On day 1, his effectiveness is 99.29%. His effectiveness decreases until it reaches a minimum of 66.8% on day 6. On night 6, the volunteer sleeps a solid 5.5 hours, which helps to increase his effectiveness to 69.48% on the following day.

Appendix K, Table 4 displays the daily average predicted effectiveness for each volunteer. Like Table 3, Volunteer 1065's data shows a daily decrease in his average predicted effectiveness. On day 1, his average effectiveness is 94.85%. His average effectiveness decreases until it reaches a minimum of 64.22% on day 6. Then it rises to 66.85% on day 7, due to 5.5 hours of solid sleep.

Appendix L displays a FAST summary data table for each volunteer. Overall average effectiveness for the entire seven days for each volunteer is displayed, as well as overall average effectiveness during the waking hours and overall average effectiveness during the sleeping hours. Volunteers 1067, 1179, and 1198 have the highest overall average effectiveness at 88.78%, 92.27%, and 95.59%, respectively. Volunteers 1067 and 1188 have average effectiveness ratings of 86.37% and 82.24%, respectively. Volunteers 1065 and 1197 have the lowest overall average effectiveness at 75.98% and 78.10%, respectively.

## **V. DEMONSTRATION OF MANAGEMENT TOOL**

### **A. OVERVIEW**

There are two methods of tracking fatigue and effectiveness levels. The first method is to wear a wrist activated monitor (WAM) throughout the entire test. The WAM is downloaded to FAST on a daily basis and a person's predicted effectiveness level is calculated. A supervisor then reviews the effectiveness levels and makes a knowledgeable decision on whether an employee should stay and work his shift or go home, get some sleep, and come back the next day, well rested and ready to work.

The second method is to give each employee access to FAST. At the end of each employee's shift, FAST is accessed and the last 24 hours' activities would be entered. Following the steps in Section B will allow sleep-wake data to be entered into FAST so management can monitor employee effectiveness.

Section C describes how to interpret the FAST data so risk management decisions can be made. Volunteer 1065's data log was used to create the FAST schedule used in this demonstration. Follow the steps listed in Section B to see how Volunteer 1065's data log was used to create the FAST schedules. Note: There are two ways to enter data into FAST. This demonstration shows how to enter data using the Edit Sleep and Work Intervals method.

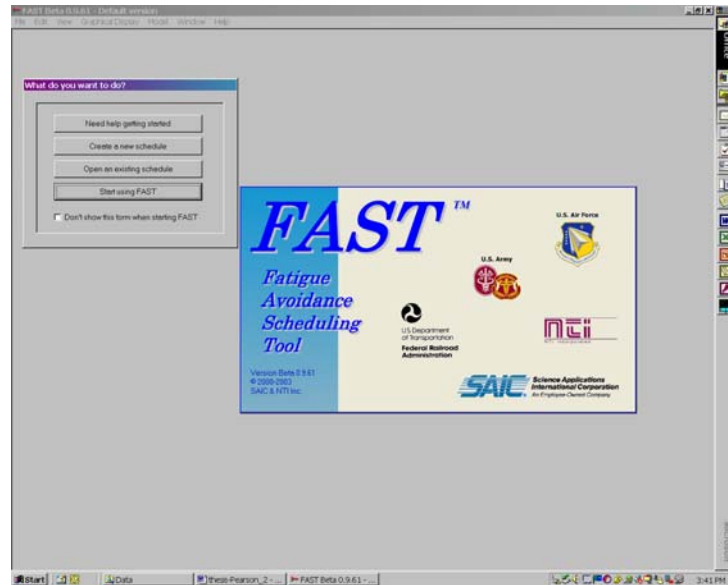
### **B. FAST AVOIDANCE SCHEDULING TOOL USED TO MONITOR EFFICIENCY LEVELS**

1. Double click on the FAST icon.

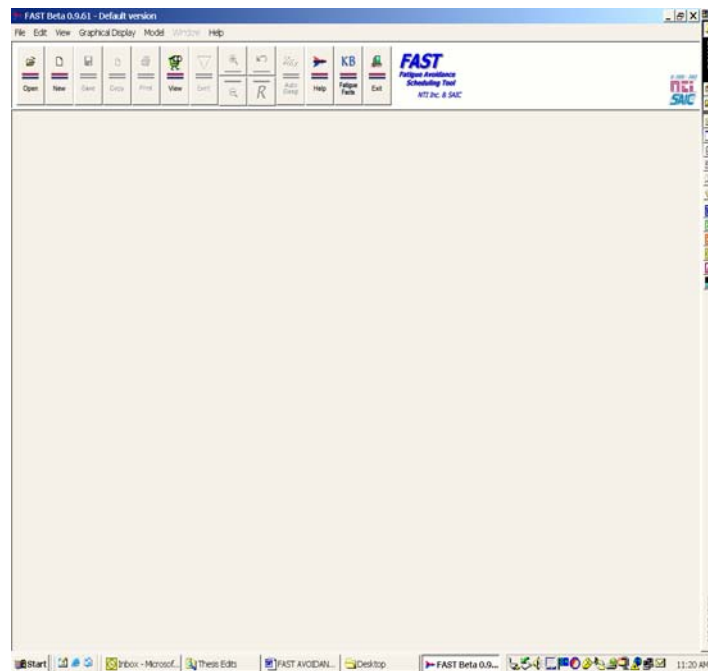


Fast-TR.Ink

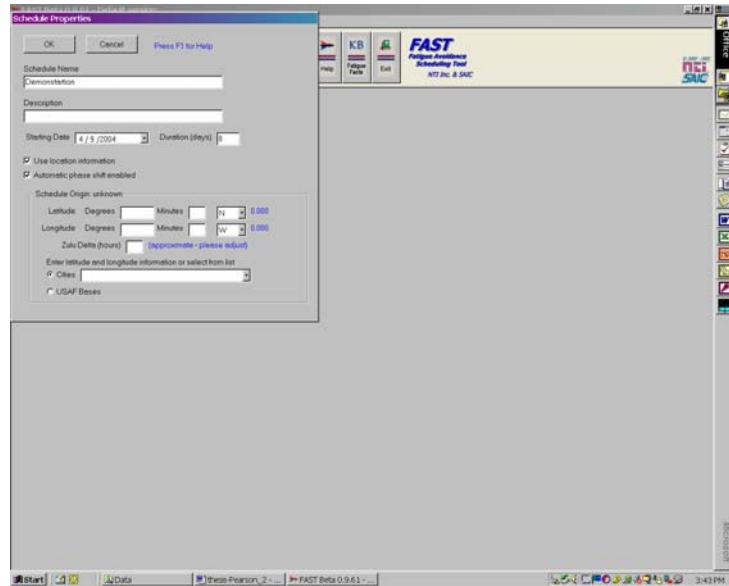
2. If entering for the first time, click on the Open a New Schedule button.



- a. Click New on the tool bar or select New from the Files Menu.



- b. Complete the file name screen and other descriptive information (start date, duration, location, time zone) for the new schedule.



c. Click OK.

3. Enter schedule information: After you open a new schedule you may enter the work intervals and sleep intervals on the blank schedule screen. Work intervals should include the entire on-duty period. Sleep intervals may be long normal sleep periods, naps, or a combination of both. All sleep between work intervals should be entered into the schedule. There are two ways to create work and sleep intervals:

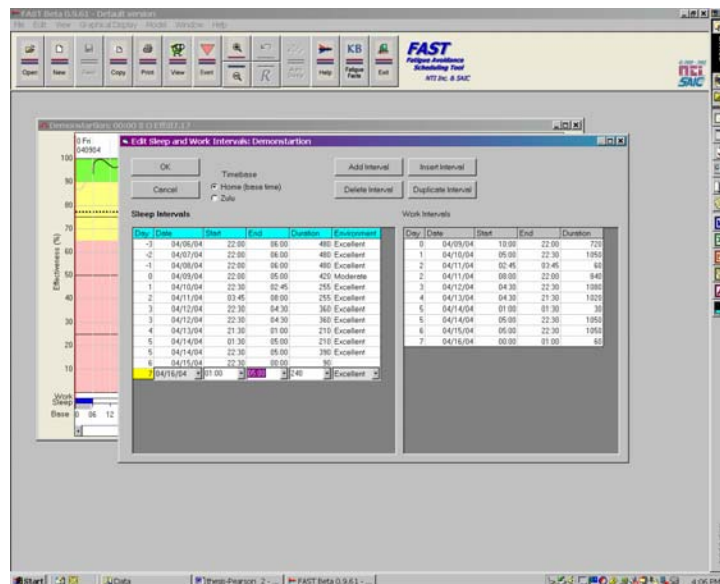
a. Graphic Screen entry method:

- On the graphic screen (select View Menu, Graphical Data): First, position the cursor on the day and time of the beginning of the work or sleep interval. Second, type “w” to start a work interval or “s” to start a sleep interval.
- Move the cursor to the time of the end of the interval and type “Shift w” or “Shift s” to end the interval. Repeat for each work and sleep interval. You may undo changes with the undo button on the tool bar.
- Work intervals show up as red and sleep intervals as blue on the bottom of the graphic screen. Gray blocks along the base axis indicate periods of darkness and will adjust with changes in location.

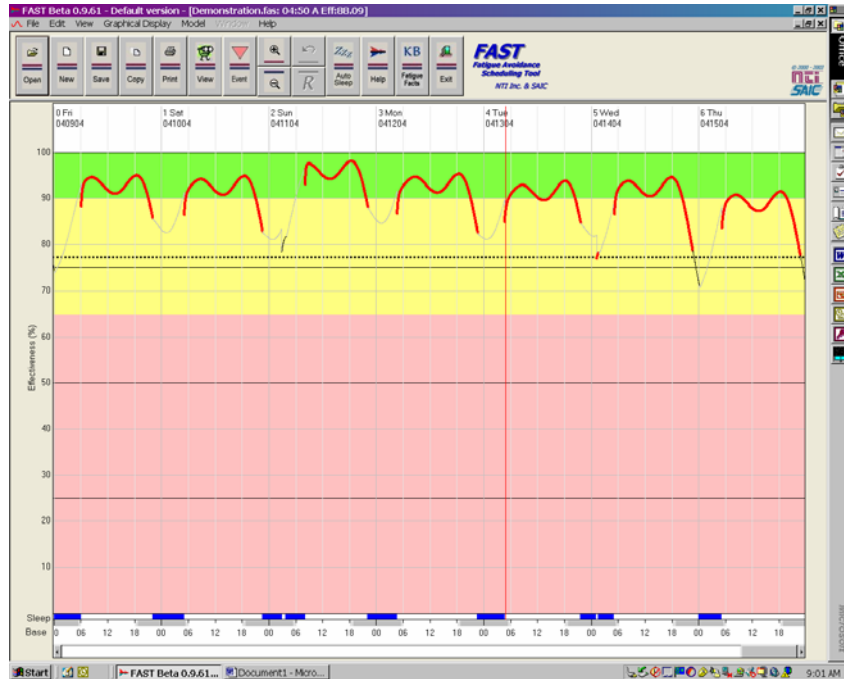
- After each sleep interval is entered, the Recalculate button will blink. When all intervals are entered, click Recalculate on the tool bar to update the predicted performance.

b. Edit Sleep and Work Intervals method:

- Select Edit Sleep and Work Intervals on the Edit menu. This method only allows entry of sleep and work intervals in Base time.



- Click the Sleep or Work Interval table to begin entering intervals.
- Click New Interval to create a new sleep or work interval.
- Enter the day and time of the beginning of the interval and the duration of the interval. Sequential numbers starting with 0 indicate days and the program will show the date for that day. For a sleep interval, enter the quality of the sleep environment. Click the "Copy these values to highlighted interval" button when done.
- When all the sleep and work intervals have been entered, click OK to enter these intervals into the schedule. The program will automatically recalculate.



When an employee is done entering his sleep and work data a supervisor then reviews the efficiency levels and makes a knowledgeable decision on whether an employee should stay and work his shift, or go home, get some sleep, and come back the next day, well rested and ready to work.

### C. DISPLAYING AND INTERPRETING PERFORMANCE EFFECTIVENESS

The Graphic Screen (select View, Graphical Data) displays a line graph of predicted performance effectiveness. The graph indicates the level of mental capability as a percent of the best normal performance of a fully rested person. The graph may be zoomed in or out using the +/- button on the tool bar. The same information may be displayed as a table (select View, Tabular Data). The level of effectiveness at the point of the cursor is indicated on the blue banner above the graph, along with the time and sleep-work status.



1. Green Zone: The green zone on the graph is the range of performance during a normal duty day following an 8-hour period of excellent sleep.
2. Yellow Zone: The yellow zone is the range of performance during the 24-hour period after missing one night of sleep. While difficult to avoid dropping into this zone during the early morning (2400 to 0400), naps and other countermeasures are recommended to keep performance in the top half of the yellow zone, above the heavy dashed line. Performance in the yellow zone below the dashed line represents performance equivalent to a person during the day following the loss of an entire night's sleep.
3. Red Zone: The red zone indicates performance that is below the level that is deemed acceptable for military operations. Reaction time in the red zone is more than double normal (e.g., if your normal reaction time is two seconds, then in the red zone your reaction time is doubled to four seconds—thus, your reaction time becomes slower or worse). The red zone represents the range of effectiveness equivalent to a person following sleep deprivation of two full days and one night.
4. Interval Statistics: A table of average performance effectiveness for each awake and work period may be overlaid on the graph by typing “CTRL T” or selecting View Menu, Interval Statistics from the menu.

FAST Beta 0.9.61 - Default version - [Statistics: 1197\_GL.fat]

File Edit View Window Help

The image shows the top toolbar of the FAST software. It contains icons for File, Edit, View, Window, and Help. Below these are icons for various functions: Open, New, Save, Close, Print, Load, Save As, Recent, Run, Help, KB, Sleep, Wake, and Exit. The FAST logo is also present, with the text "Fatigue Assessment Tool" and "NTI Inc. & SAC" below it.

Summary | Work | Wake | Sleep | Events

| Enter schedule        |          | Intervals |      |       |       |
|-----------------------|----------|-----------|------|-------|-------|
| Total Days            | 7        |           | Work | Wake  | Sleep |
| First                 | 04/09/04 | N         | 0    | 127   | 125   |
| Last                  | 04/15/04 | M         | 0.0  | 63.6  | 11.0  |
| Average Sleep per Day | 32       | Median    | 0.0  | 3.0   | 10.0  |
| Average Work per Day  | 0        | SD        | 0.0  | 158.7 | 16.4  |
| Average Effectiveness | 78.10    | Shortest  | 0    | 1     | 1     |
|                       |          | Longest   | 0    | 678   | 71    |
|                       |          | Avg. Eff. | 0.00 | 79.45 | 70.24 |

Start | Task - M... | FDL | Displaying... | FAST AVO... | Desktop | FAST Be...

1:23 PM

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## **VI. CONCLUSIONS AND RECOMMENDATIONS**

### **A. CONCLUSIONS**

The Benefield Anechoic Facility (BAF) is a military test facility that conducts developmental and operational testing by working one 8-hour shift. If testing falls behind schedule, however, the shift is either extended or weekend work is required. Currently, the BAF has no way to identify when an employee's performance becomes at risk for sleep deprivation, unbalanced circadian rhythms, and fatigue. Modeling circadian rhythms, fatigue, and employee performance is of significant interest to the management of the BAF. Employees' are not reliable judges of their own level of biological sleepiness; thus, BAF managers require an objective means to assess their employees' ability to perform. One method is the Fast Avoidance Scheduling Tool (FAST), the software based on the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model. SAFTE is a biomathematical model designed to predict individual performance under conditions of sleep deprivation. With FAST, several days' worth of sleep and wakefulness data must be collected before a meaningful assessment can be produced. For this research, each volunteer wore an Actigraph for seven days. Actigraph data was then downloaded into FAST, Actigraph sleep wake data was processed and plotted, and graphical data was analyzed for performance effectiveness levels.

The graph in Appendix I indicates three volunteers have flexible Lark tendencies (1065, 1067, 1188); one has rigid Lark tendencies (1179); another one has flexible Owl tendencies (1198); and three others are Regular Robins (1066, 1179, 1181). Of the three Regular Robins; one has more Lark tendencies (1066); and one other has more flexible Owl tendencies (1179). The five volunteers that have Lark tendencies received on average between 4 to 7 hours of sleep per night. Volunteers 1065 and 1197 had the lowest overall average effectiveness scores (75.98% and 78.10%, respectively) and also had the least amount of sleep (4 hours, 46 minutes and 5 hours, 23 minutes on average, per night, respectively). Factors that could contribute to loss of sleep might be excessive caffeinated beverages (six or more) for both volunteers and use of tobacco products for Volunteer 1197. In contrast, the two volunteers with Owl tendencies received, on

average, between 8 and 9 hours of sleep per night. Both volunteers (1179 and 1198) reported drinking less than four caffeinated beverages per day and neither used tobacco products.

If you look at the FAST data for Volunteer 1065 (Appendix J) you will see there is a downward trend for the percent effectiveness each day. Running along the bottom of the graph is a bar that shows the periods of wakefulness or sleep. The sleep periods on this graph are short and broken up, which leads to ineffective rest and increased sleep debt. As sleep debt is incurred, the percent effectiveness will decrease each day. The data starts off in the green zone, which indicates the range of performance during a normal duty day following an 8-hour period of excellent sleep. As the data progresses through time it reaches the yellow zone, which indicates range of performance during the 24-hour period after missing one night of sleep. Performance in this area below the heavy dashed line indicates performance equivalent to a person during the day following the loss of an entire night's sleep. The data during sleep reaches the red zone, which indicates performance below the level that is deemed acceptable for military operations. Reaction time in this zone is two times longer than the normal reaction time. The red zone represents the range of effectiveness equivalent to a person deprived of sleep for two full days and one night.

Appendix K, Table 3 displays the percent effectiveness of each volunteer at 0700 each day and Table 4 displays the daily average percent effectiveness for each volunteer each day. Volunteer 1065's data shows a decrease each day in his percent effectiveness. At 0700 on day 1, his effectiveness is equal to 99.29% and his daily average percent effectiveness is 94.85%. Volunteer 1065's effectiveness decreases until it reaches a minimum of 66.8% and 64.22%, respectively, on day 6. On night 6, the volunteer sleeps a solid 5.5 hours, which helps to increase his effectiveness to 69.48% and 66.85%, respectively, on the following day. If Volunteer 1065 continues to get more than 6 hours of undisturbed sleep each nights, his performance effectiveness will continue to increase into the green zone.

Appendix L displays a FAST summary data table for each volunteer. Overall average effectiveness for the entire seven days for each volunteer is displayed, as well as

overall average effectiveness during the waking hours and overall average effectiveness during the sleeping hours. Volunteers 1066, 1179, and 1198 have the highest overall average effectiveness at 88.78%, 92.27%, and 95.59%, respectively. Volunteers with an effectiveness rating this high are getting the required amounts of sleep at night and are at optimal working limits. Volunteers 1067 and 1188 have average effectiveness ratings of 86.37% and 82.24%, respectively. These scores are above the minimum criteria and are not at risk for fatigue. However, if these volunteers were to have any kind of sleep loss, they could fall below 79% and be at risk for fatigue. Volunteers 1065 and 1197 have the lowest overall average effectiveness at 75.98% and 78.10%, respectively. Management should consider daily average effectiveness of 78% or lower as possible fatigue risks.

The results of this study indicate that as work hours are extended and the amount of sleep decreases, the effectiveness of individual performance decreases. Two volunteers (1065 and 1197) have daily performance effectiveness averages below 79% for the last four days, which is equivalent to a person losing an entire night's sleep. Such loss of sleep can lead to poor performance and affect productivity and safety. Effectiveness below 79% is an indication to the supervisor that these individuals are at risk. The supervisor can make a well-informed, knowledgeable decision to send the individual home for some needed rest. The supervisor also needs to take into account drive time home. The average drive time one way for these individuals is 48 minutes. A person with loss of sleep and performance effectiveness below 79% might fall asleep at the wheel and cause a serious automobile accident. Therefore, not only is the safety of a test at risk, but also the employee's safety and that of other people on the road.

FAST can also help management identify borderline at-risk candidates. Volunteers 1067 and 1188 have daily performance effectiveness averages that are decreasing through time and are approaching the 79% performance effectiveness safety line. If either of these volunteers were to have any kind of sleep loss, they would fall below the 79% minimum performance effectiveness level. If a supervisor was using FAST as a risk management tool, the supervisor could determine which individuals could extend their hours and which individuals should be sent home because they are approaching—or are already below—79% performance effectiveness.

The demonstration showed how employee's can enter sleep data into FAST on a daily basis. However, this method does have inaccuracies. Volunteer 1065's sleep log was used to create a FAST schedule using this method. When the demonstration schedule is compared to the Actigraph schedule, the demonstration schedule shows Volunteer 1065 above the 79% effectiveness line a considerable amount of the time. The demonstration schedule does not capture all the activity of Volunteer 1065. These data are not as accurate as actigraphy, but can still give the supervisor the estimated daily predicted effectiveness, enabling him to make a better decision on whether to send a person home or to keep them at work. Therefore, for the most accurate sleep data, WAMs should be used to monitor employee's effectiveness.

## **B. RECOMENDATIONS**

It is recommended that another study be done using FAST to collect two weeks or more of extended shift or two shift data. This would give a clearer indication of the performance levels of BAF employees. The study should also include estimates of how effective individuals are according to their self-report (although this may be unreliable) and by trained observers who can make appraisal of employee performance. FAST should be implemented as a risk management tool to identify employees at risk for poor performance because of sleep deprivation. Purchasing actigraphs to keep accurate records on sleep data during test periods would help supervisors to better determine at-risk employees. When creating a test schedule, flexible scheduling to accommodate such issues as different sleeping preferences, child care needs, schooling, and other factors should be considered.

## APPENDIX A.      EXAMPLE OF BAF GANTT CHART

The Gantt chart consists of six columns, with the first column listing each row number. The second column of the first row contains the name of the major task to be completed. Rows 54-66 of the second column list each subtask to be completed for the major task. The third column lists the number of days required to accomplish the task. The fourth column has the start date, while the fifth column has the end date for each task. The sixth column lists the personnel assigned to accomplish each task and the percentage of time required for each person to complete the job.

|    |                             |        |             |             |                                                                                                                                                                             |
|----|-----------------------------|--------|-------------|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 53 | F-15 EW TEST                | 5 days | Mon 9/25/00 | Fri 9/29/00 |                                                                                                                                                                             |
| 54 | Test Conductor              | 5 days | Mon 9/25/00 | Fri 9/29/00 | BROWNLOW,Mosley,PEARSON[20%]                                                                                                                                                |
| 55 | Test Technical Consultant   | 4 days | Mon 9/25/00 | Thu 9/28/00 | RADEBAUGH[30%],BOOKHEIMER,CURRY                                                                                                                                             |
| 56 | Site Chief                  | 4 days | Mon 9/25/00 | Thu 9/28/00 | Young[50%],Conway                                                                                                                                                           |
| 57 | Data Collection             | 4 days | Mon 9/25/00 | Thu 9/28/00 | WAGNER                                                                                                                                                                      |
| 58 | CEESIM Operators            | 4 days | Mon 9/25/00 | Thu 9/28/00 | Threat Site<br>1,TOC,Chamber,BOOKHEIMER[80%],HUNT,AMNOTTE,Barti,LONG[80%],CURRY                                                                                             |
| 59 | Turntable Operator          | 1 day  | Mon 9/25/00 | Mon 9/25/00 | Sowa[50%],Larson[80%]                                                                                                                                                       |
| 60 | Free Space Monitor          | 4 days | Mon 9/25/00 | Thu 9/28/00 | 413TH                                                                                                                                                                       |
| 61 | Hoist                       | 4 days | Mon 9/25/00 | Thu 9/28/00 | Young[50%],Facilities                                                                                                                                                       |
| 62 | Test Equipment              | 4 days | Mon 9/25/00 | Thu 9/28/00 | BARTLEY[10%],CORNELL[50%],BOOKHEIMER[20%],LONG[20%],Sedesky,Sowa[50%],Macaluso,Snyder                                                                                       |
| 63 | ICOM / Video                | 4 days | Mon 9/25/00 | Thu 9/28/00 | Truong[20%],Larson[20%]                                                                                                                                                     |
| 64 | Roll out / Chamber Clean-Up | 1 day  | Fri 9/29/00 | Fri 9/29/00 | Chamber,CORNELL[50%],TAYLOR[50%],LONG[50%],RUTH[50%],HUNT[50%],Sedesky[50%],Sowa[50%],Young[50%],Larson[50%],Truong[50%],Lagos[50%],Macaluso[50%],Mizell[50%],Threat Site 1 |
| 65 | CEESIM History file         | 1 day  | Mon 4/3/00  | Mon 4/3/00  | WAGNER                                                                                                                                                                      |
| 66 | F-15 POST TEST DOC          | 5 days | Wed 9/27/00 | Tue 10/3/00 | BROWNLOW[50%],MADDOCK[50%],Corbett,WAGNER                                                                                                                                   |

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## APPENDIX B.      BAF MANPOWER SCHEDULE

The top row of the BAF Manpower Excel spreadsheet lists the different events that happen during the course of a test. Right below each event, the second row lists the dates that these events happen. The second row starts with the date of the first event, and each column after that has a date listed until the end of the test appears in the last column. On the third row, first column, in bold letters, the title of the required position is listed. On the fourth row, first column, the name of the person filling the position and their office phone number is listed. In the rest of this row, under the appropriate date, the hours of each shift the person is working is listed. Each required position appears, with the personnel filling this position separated by a black pair of lines. A list of shift definitions, lunch breaks, and any other required information is placed at the bottom of the schedule.

| EVENT                     |                          |                                                                                   |               | A/C Rollin    |               |               | Holiday    |               |               |               |
|---------------------------|--------------------------|-----------------------------------------------------------------------------------|---------------|---------------|---------------|---------------|------------|---------------|---------------|---------------|
| DATE                      |                          | 8 Jan Mon                                                                         | 9 Jan Tue     | 10 Jan Wed    | 11 Jan Thu    | 12 Jan Fri    | 15 Jan Mon | 16 Jan Tue    | 17 Jan Wed    | 18 Jan Thu    |
| Test Director             |                          |                                                                                   |               |               |               |               |            |               |               |               |
|                           | Customer                 | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
|                           | Customer                 | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |
| Crew Chief                |                          |                                                                                   |               |               |               |               |            |               |               |               |
|                           | Customer                 | Day on call                                                                       | Day on call   | Day on call   | Day on call   | Day on call   |            | Day on call   | Day on call   | Day on call   |
|                           | Customer                 | Night on call                                                                     | Night on call | Night on call | Night on call | Night on call |            | Night on call | Night on call | Night on call |
| Test Conductor            |                          |                                                                                   |               |               |               |               |            |               |               |               |
|                           | Ron Taylor (7-5725)      | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
|                           | Huy Pham (7-3948)        |                                                                                   |               |               |               |               |            | Alternate     | Alternate     | Alternate     |
|                           | Oai Phung (7-5717)       | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |
| Technical Lead            |                          |                                                                                   |               |               |               |               |            |               |               |               |
|                           | Barry Bookheimer(7-5720) | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
|                           | Jim Brownlow (7-5738)    | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |
| Chamber Operation         |                          |                                                                                   |               |               |               |               |            |               |               |               |
|                           | Colin Young(7-5696)      | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
|                           | Steve Conway(7-5729)     | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |
|                           | Jeff Cornell(7-5666)     | Alternate                                                                         | Alternate     | Alternate     | Alternate     | Alternate     |            | Alternate     | Alternate     |               |
| CEESIM Operators          |                          |                                                                                   |               |               |               |               |            |               |               |               |
|                           | Jim Leduc (7-5744)       | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
|                           | Regina Maddock(7-1655)   | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
|                           | Dan Hunt(7-1675)         | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            |               |               |               |
|                           | Chris Long(7-5684)       | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |
| CEESIM Maintenance        |                          |                                                                                   |               |               |               |               |            |               |               |               |
|                           | Joe Wagner(7-5713)       | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |
|                           | Chris Long (7-5684)      | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
| General Tech/Support      |                          |                                                                                   |               |               |               |               |            |               | Alternate     |               |
|                           | Jim Snyder(5-3277)       | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
|                           | Mike Macaluso(7-5587)    | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
|                           | Sergio Alfaro(7-5960)    | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |
|                           | Angel Cruz(7-5667)       | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |
| Data Support              |                          |                                                                                   |               |               |               |               |            |               |               |               |
|                           | Doug Corbett (75649)     | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
|                           | Rob Perez(7-5646)        | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
|                           | Bobby Truong(7-5690)     | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |
|                           | Jerry Phibbs(7-6988)     | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |
|                           | John Franzen (7-5675)    | Alternate                                                                         | Alternate     | Alternate     | Alternate     | Alternate     |            | Alternate     | Alternate     |               |
| Turn Table                |                          |                                                                                   |               |               |               |               |            |               |               |               |
| Operator/Facilities       |                          |                                                                                   |               |               |               |               |            |               |               |               |
|                           | Dave Mulvey(7-5731)      | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
|                           | Jerry Sowa(7-5652)       | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |
| Hoist Operator/Facilities |                          |                                                                                   |               |               |               |               |            |               |               |               |
|                           | 0630 - 1530              | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
|                           | Andy Campbell (7-5636)   | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |
| 413 FLTS Support          |                          |                                                                                   |               |               |               |               |            |               |               |               |
| ICOM Support              |                          |                                                                                   |               |               |               |               |            |               |               |               |
|                           | Glen Larson(7-5682)      | 0630 - 1530                                                                       | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |            | 0630 - 1530   | 0630 - 1530   | 0630 - 1530   |
|                           | Drew Alexander           | Alternate                                                                         | Alternate     | Alternate     | Alternate     | Alternate     |            | Alternate     | Alternate     |               |
|                           | Bobby Truong(7-5690)     | 1000 - 1900                                                                       | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |            | 1000 - 1900   | 1000 - 1900   | 1000 - 1900   |
|                           |                          | Both shifts will have a one hour lunch break at 1200 - 1300.                      |               |               |               |               |            |               |               |               |
|                           |                          | Weekend work is not planned, but could be used as get well time.                  |               |               |               |               |            |               |               |               |
|                           |                          | The Schedule could slip to the left if testing concludes early.                   |               |               |               |               |            |               |               |               |
|                           |                          | Day on Call = 0630 - 1530 (needed to help control the aircraft while hoisting)    |               |               |               |               |            |               |               |               |
|                           |                          | Night on Call = 10:00 - 1900 (needed to help control the aircraft while hoisting) |               |               |               |               |            |               |               |               |
|                           |                          | Normal = Normal work day (may be called for troubleshooting)                      |               |               |               |               |            |               |               |               |
|                           |                          | Alternate = Normal work day (may be called to substitute personal)                |               |               |               |               |            |               |               |               |

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## APPENDIX C.      BAF POSITION DESCRIPTIONS

This table lists the required positions in column 1. In column 2, there is a description of each required position. Column 3 lists the required number of personnel needed for each shift, and column 4 lists the required number of backup personnel needed for each shift should the primary personnel not be available for part or all of the shift.

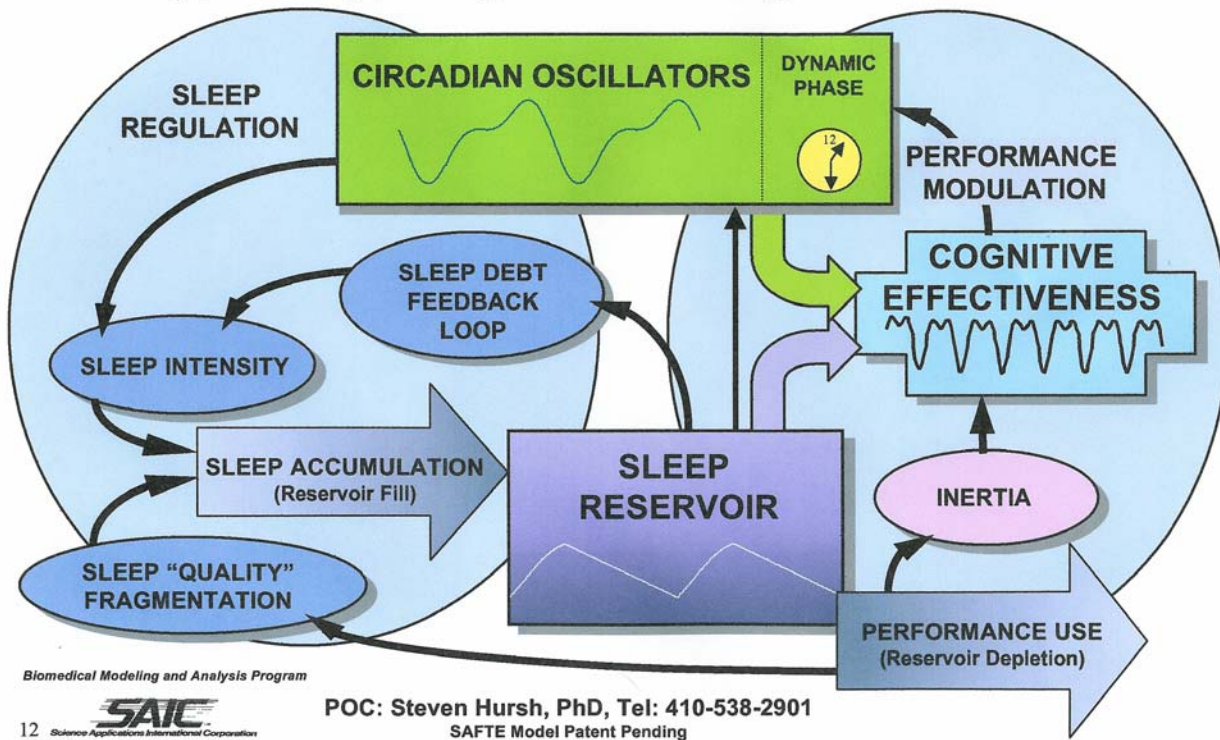
| <b>Required Positions</b> | <b>Position Description</b>                                                                                               | <b>Required Personnel per Shift</b> | <b>Required Backups to be Able to Cover Any Shift</b> |
|---------------------------|---------------------------------------------------------------------------------------------------------------------------|-------------------------------------|-------------------------------------------------------|
| Test Conductor            | Test leads, conducts all chamber operations, and controls test environment.                                               | 1                                   | 1                                                     |
| Technical Lead            | Expert on system under test and BAF operations.                                                                           | 1                                   | 1                                                     |
| Chamber Operations        | Lead on all operations going on in the chamber such as setup, hoist, etc.                                                 | 1                                   | 1                                                     |
| CEESIM Operator           | Operates and programs CEESIM, CEESIM generates RF threat environment.                                                     | 3                                   | 1                                                     |
| CEESIM Maintenance        | Fixes problems that occur with the CEESIM.                                                                                | 1                                   | 1                                                     |
| General Tech Support      | Miscellaneous duties during test such as operates o-scope, etc.                                                           | 3-4                                 | 1                                                     |
| Data Support              | Runs and hooks up all data recording systems such as recording 1553 data, or video data, etc.; real-time monitoring, etc. | 2                                   | 1                                                     |
| Turntable Operator        | Operates and controls the turntable and its movement.                                                                     | 1                                   | 1                                                     |
| Hoist Operator            | Operates and controls the hoist and its movement.                                                                         | 1                                   | 1                                                     |
| ICOM Support              | Sets up and maintains closed loop communications system within the anechoic facility.                                     | 1                                   | 1                                                     |

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APPENDIX D. SLEEP, ACTIVITY, FATIGUE, AND TASK  
EFFECTIVENESS (SAFTE) MODEL (HURSH, 2003)

SAIC Proprietary

Schematic of SAFTE™ Simulation Model  
*Sleep, Activity, Fatigue and Task Effectiveness Model*



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**APPENDIX E. PARTICIPANT CONSENT FORM, MINIMAL RISK CONSENT  
STATEMENT, PRIVACY ACT STATEMENT**

**PARTICIPANT CONSENT FORM**

1. **Introduction.** You are invited to participate in a sleep study for schedule optimization. With information gathered from you and other participants, we hope to discover insight on fatigue issues that might cause poor decision-making and extended test hours. We ask you to read and sign this form indicating that you agree to be in the study. Please ask any questions you might have before signing.
2. **Background Information.** The Naval Postgraduate School Operation Research Department is conducting this study.
3. **Procedures.** If you agree to participate in this study, the researcher will explain the tasks in detail. There will be one session no longer than an hour to introduce the task. At this session an Actigraph will be given to you as well as a sleep log handed out. How to fill out the sleep log will be explained. The Actigraph will be worn for 7 days and the log filled out.
4. **Risks and Benefits.** This research involves no risks or discomforts greater than those when wearing a regular watch. The benefits to the participants are gaining a better manpower-scheduling tool and being less fatigued during tests.
5. **Compensation.** No tangible reward will be given. A copy of the results will be available to you at the conclusion of the experiment.
6. **Confidentiality.** The records of this study will be kept confidential. No information will be publicly accessible which could identify you as a participant.
7. **Voluntary Nature of the Study.** If you agree to participate, you are free to withdraw from the study at any time without prejudice. You will be provided a copy of this form for your records.
8. **Points of Contact.** If you have any further questions or comments after the completion of the study, you might contact the research supervisor, Dr. Nita Miller (831) 656-2595 [nlmiller@nps.edu](mailto:nlmiller@nps.edu).
9. **Statement of Consent.** I have read the above information. I have asked all questions and have had my questions answered. I agree to participate in this study.

-----  
Participant's Signature

-----  
Date

-----  
Researcher's Signature

-----  
Date

**MINIMAL RISK CONSENT STATEMENT**  
NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943

Participant: VOLUNTARY CONSENT TO BE A RESEARCH PARTICIPANT  
IN: **Optimization of Personal Work Schedules and Fatigue Issues**

1. I have read, understand and been provided "Information for Participants" that provides the details of the below acknowledgments.
2. I understand that this project involves research. An explanation of the purposes of the research, a description of procedures to be used, identification of experimental procedures, and the extended duration of my participation have been provided to me.
3. I understand that this project does not involve more than minimal risk. I have been informed of any reasonably foreseeable risks or discomforts to me.
4. I have been informed of any benefits to me or to others that might reasonably be expected from the research.
5. I have signed a statement describing the extent to which confidentiality of records identifying me will be maintained.
6. I have been informed of any compensation and/or medical treatments available if injury occurs and is so, what they consist of, or where further information might be obtained.
7. I understand that my participation in this project is voluntary; refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled. I also understand that I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled.
8. I understand that the individual to contact should I need answers to pertinent questions about the research is Professor Nita L. Miller, Principal Investigator, and about my rights as a research participant or concerning a research related injury is Prof. Jim Eagle, Operations Research Dept. Chairman or CAPT Nick Davenport, MC, USN, the Naval Postgraduate School Flight Surgeon. A full and responsive discussion of the elements of this project and my consent has taken place. *NPS Medical Monitor:* CAPT Nick Davenport, MC, USN, Flight Surgeon, Naval Postgraduate School (831) 656-7876, nadavenp@nps.edu.

---

Signature of Principal Investigator

---

Date

---

Signature of Volunteer

---

Date

---

Signature of Witness

---

Date

## PRIVACY ACT STATMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943

### PRIVACY ACT STATEMENT

1. Purpose: Sleep data will be collected to enhance knowledge of fatigue issues, and to develop an automated scheduling tool that will help in producing optimized manpower schedules.
2. Use: Sleep data will be used for statistical analysis by the Departments of the Navy and Defense, and other U.S. Government agencies, provided this use is compatible with the purpose for which the information was collected. Use of the information may be granted to legitimate non-government agencies or individuals by the Naval Postgraduate School in accordance with the provisions of the Freedom of Information Act.
3. Disclosure/Confidentiality:
  - a. I have been assured that my privacy will be safeguarded. I will be assigned a control or code number which thereafter will be the only identifying entry on any of the research records. The Principal Investigator will maintain the cross-reference between name and control number. It will be decoded only when beneficial to me or if some circumstances, which is not apparent at this time, would make it clear that decoding would enhance the value of the research data. In all cases, the provisions of the Privacy Act Statement will be honored.
  - b. I understand that a record of the information contained in this Consent Statement or derived from the experiment described herein will be retained permanently at the Naval Postgraduate School or by higher authority. I voluntarily agree to its disclosure to agencies or individuals indicated in paragraph 3 and I have been informed that failure to agree to such disclosure may negate the purpose for which the experiment was conducted.
  - c. I also understand that disclosure of the requested information, including my Social Security Number, is voluntary.

---

Name, Grade/Rank (if applicable)

DOB

SSN

[Please print]

---

Signature of Volunteer

Date

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## APPENDIX F. REQUEST FOR IRB



Nita Lewis Miller, Ph.D.  
Operations Research Department  
Glasgow Hall  
Naval Postgraduate School  
Monterey, California 93943

831-656-2281  
DSN: 756-2281  
Fax: 831-656-2595  
nlmiller@nps.edu

To: Protection of Human Subjects Committee

Subject: **Application for Human Subjects Review for Optimization of Personal Work Schedules and Fatigue Issues for Kristen A. Pearson**

1. Attached is a set of documents outlining a proposed experiment to be conducted over the next few months in a collaborative effort by Benefield Anechoic Chamber (BAF) and Naval Postgraduate School (NPS).
2. We are requesting approval of the described experimental protocol. An experimental outline is included for your reference that describes the methods and measures we plan to use.
3. We include the consent forms, privacy act statements, and debriefing forms we will be using in the experiment.
4. We understand that any modifications to the protocol or instruments/measures will require submission of updated IRB paperwork and possible re-review. Similarly, we understand that any untoward event or injury that involves a research participant will be reported immediately to the IRB Chair and NPS Dean of Research.

Nita Lewis Miller

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |  |                                                            |  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|------------------------------------------------------------|--|
| APPLICATION FOR<br>HUMAN SUBJECTS REVIEW (HSR)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |  | HSR NUMBER <i>(to be assigned)</i>                         |  |
| PRINCIPAL INVESTIGATOR (S) <i>(Full Name, Code, Telephone)</i><br>Nita Miller, Ph.D., Research Assistant Professor, Naval Postgraduate School, Monterey, CA 93943-5001                                                                                                                                                                                                                                                                                                                                                                                           |  |                                                            |  |
| APPROVAL REQUESTED <input checked="" type="checkbox"/> New <input type="checkbox"/> Renewal                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |  |                                                            |  |
| LEVEL OF RISK <input type="checkbox"/> Exempt <input checked="" type="checkbox"/> Minimal <input type="checkbox"/> More than Minimal<br>Justification: There is no known risk to volunteers; they will be performing duties per usual method during data collection. They will be wearing Actigraphs on their wrist for a week's period of time and logging information on a data log.                                                                                                                                                                           |  |                                                            |  |
| WORK WILL BE DONE IN (Site/Bldg/Rm)<br>Edwards Air Force Base, Edwards, CA<br>Bldg 1030                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |  | ESTIMATED NUMBER OF DAYS TO<br>COMPLETE 7 days             |  |
| MAXIMUM NUMBER OF SUBJECTS<br>14 Actigraphs on 14 people                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |  | ESTIMATED LENGTH OF EACH<br>SUBJECT'S PARTICIPATION 7 days |  |
| SPECIAL POPULATIONS THAT WILL BE USED AS SUBJECTS<br><input type="checkbox"/> Subordinates <input type="checkbox"/> Minors <input type="checkbox"/> NPS Students <input type="checkbox"/> Special Needs<br>(e.g., Pregnant women)<br>N/A<br>Specify safeguards to avoid undue influence and protect subject's rights:<br>N/A                                                                                                                                                                                                                                     |  |                                                            |  |
| OUTSIDE COOPERATING INVESTIGATORS AND AGENCIES<br>Principal Investigator:<br>Nita Miller, Ph.D., Research Assistant Professor<br>Naval Postgraduate School, Monterey, CA 93943-5001<br><br>Co-Investigator:<br>Kristen Pearson, Student<br>Naval Postgraduate School, Monterey, CA 93943-5001<br><br><input type="checkbox"/> A copy of the cooperating institution's HSR decision is attached.                                                                                                                                                                  |  |                                                            |  |
| TITLE OF EXPERIMENT AND DESCRIPTION OF RESEARCH (attach additional sheet if needed). <b>Optimization of Personal Work Schedules and Fatigue Issues:</b> The experiment will require 14 subject to wear Actigraphs 24 hours a day for 7 days. They will also need to record on a data log when they go to sleep at night, when they get up in the morning, when they take a nap anytime during the day or night, and any reasons they may take the watch off such as shower, aircraft mechanical work, etc. Also each subject will complete a demographic survey. |  |                                                            |  |
| I have read and understand NPS Notice on the Protection of Human Subjects. If there are any changes in any of the above information or any changes to the attached Protocol, Consent Form, or Debriefing Statement, I will suspend the experiment until I obtain new Committee approval.                                                                                                                                                                                                                                                                         |  |                                                            |  |
| SIGNATURE _____                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |  | DATE _____                                                 |  |

## APPENDIX G. QUESTIONNAIRES

### Morningness – Eveningness Scale

**Instructions:** *This scale is designed to help you identify your chronotype, that is, your tendency toward a morning (lark), Mid-range or evening (owl) circadian rhythm pattern. To complete this Scale, read each question and consider all of the responses carefully. Then, answer the following questions by circling the most appropriate response as accurately as you can.*

1. What time would you get up if you were entirely free to plan your day?
  - A. Before 7 a.m.
  - B. 7 – 9 a.m.
  - C. After 9 a.m.
2. How easy is it for you to get up on workdays?
  - A. Fairly easy
  - B. Moderately difficult/depends on the day
  - C. Very difficult
3. How alert do you feel during the first 30 minutes after you get up in the morning?
  - A. Alert/fresh
  - B. Varies
  - C. Sleepy/tired
4. What time would you go to bed if it were completely up to you?
  - A. Before 10:30 p.m.
  - B. 10:30 p.m. – midnight
  - C. After midnight
5. How sleepy/tired are you 1½ hours before going to bed during the workweek?
  - A. Very tired/ready to fall asleep
  - B. Moderately tired/depends on the day
  - C. Not very tired
6. When you've stayed up later than usual (had a late evening), when do you wake up the next morning (assuming you didn't have any alcohol)?
  - A. At your usual time, with a desire to get out of bed
  - B. Varies
  - C. Later than usual, with a desire to fall back asleep

### Flexible – Rigid Scale

**Instructions:** *This scale is designed to help you identify your chronotype, that is, your tendency toward a Flexible), Regular or Rigid circadian sleep needs. To complete this Scale, read each question and consider all of the responses carefully. Then, answer the following questions by circling the most appropriate response as accurately as you can.*

1. When you're feeling drowsy, can you easily overcome it if there is something important you have to do?

- A. Rarely
- B. Sometimes
- C. Usually

2. When you have to do something important in the middle of the night, can you do it almost as easily as you could at a more normal time of the day?

- A. Rarely
- B. Sometimes
- C. Usually

3. Do you enjoy working at unusual times of the day or night?

- A. Rarely
- B. Sometimes
- C. Usually

4. If you have a lot to do, can you stay up late or get up very early to finish it without feeling too tired?

- A. Rarely
- B. Sometimes
- C. Usually

5. Do you find it as easy to work late at night as you do earlier in the day?

- A. Rarely
- B. Sometimes
- C. Usually

6. Do you find it fairly easy to sleep whenever you want to?

- A. Rarely
- B. Sometimes
- C. Usually

## Demographics Scale

***Instructions: This scale is designed to help you identify your demographics. To complete this Scale, read each question and fill in the appropriate response. Please, consider your answer carefully and answer with the most appropriate response as accurately as you can.***

1. Your gender is (circle one): Male or Female
2. During the past month, how many caffeinated beverages (coffee/tea/soda) did you consume in an average 24-hour period? \_\_\_\_\_
3. During the past month did you use any tobacco products (circle one):  
Yes or No If yes, how many per week? \_\_\_\_\_
4. During the past month, how often (per week) have you used alcohol to help you sleep? \_\_\_\_\_
5. Within the past week, have you taken, or are you currently taking any medication to help you sleep (circle one): Yes or No  
If yes, what are you taking? \_\_\_\_\_
6. What is your age? \_\_\_\_\_
7. How long does it take you to get to work (ex. 30 minutes, 1 hour)? \_\_\_\_\_
8. Please list any sleeping disorders you may have  
(Narcolepsy/Insomnia)? \_\_\_\_\_

## SLEEP HISTORY QUESTIONNAIRE

Instructions: The following instructions relate to your usual sleep patterns during the last month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

1. During the past month, what time have you usually gone to bed at night on your days off (Use 24-hour clock)? \_\_\_\_\_
2. During the past month, how long has it usually taken you to fall asleep each night on your days off (Use 24-hour clock)? \_\_\_\_\_
3. During the past month, what time have you usually gotten up in the morning on your days off (Use 24-hour clock)? \_\_\_\_\_
4. During the past month, how many hours of actual sleep did you get at night on your days off (This may be different than the number of hours you spent in bed) (Use 24-hour clock)? \_\_\_\_\_
5. During the past month, how many times on average do you wake up per night when you are sleeping at home (Use 24-hour clock)? \_\_\_\_\_
6. If you wake up during the night, what is it that usually causes you to awaken?  
\_\_\_\_\_
7. While sleeping at home, if you wake during the night on average how long does it take you to go back to sleep (Use 24-hour clock)? \_\_\_\_\_
8. How often per week do you take a daytime nap at home? \_\_\_\_\_
9. When sleeping at home, how many times per week do you have problems getting to sleep? \_\_\_\_\_
10. During the past month, how often have you had trouble staying awake while driving, eating, or engaging in social activity? \_\_\_\_\_
11. During the past month how would you rate your sleep quality overall?

|                          |                          |                          |                          |
|--------------------------|--------------------------|--------------------------|--------------------------|
| Very Good                | Fairly Good              | Fairly Bad               | Very Bad                 |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

12. Please rate the following factors and indicate how much they interfere with or promote your sleep at home.

|    |                                    | Interferes               | No effect                |                          |                          | Promotes                 |
|----|------------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
|    |                                    | 1                        | 2                        | 3                        | 4                        | 5                        |
| a. | Quality of sleep surface           | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| b. | Heat                               | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| c. | Cold                               | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| d. | Thoughts running through your head | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| e. | Random noise events                | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| f. | Constant background noise          | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| g. | Background lighting                | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| h. | Readiness for sleep                | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| i. | Comfort of clothing                | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| j. | Low humidity/dry air               | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| k. | High humidity                      | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| l. | Trips to the bathroom              | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| m. | Bed Partner                        | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| n. | Privacy                            | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| o. | Ventilation                        | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| p. | Sheets/blankets/pillows            | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| q. | Extreme smell in the room          | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| r. | Other (specify)_____               | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

13. Please rate the following on the extent to which they interfere with your sleep at home.

|    |                                         | Strongly Interferes      |                          |                          | No effect                |                          |
|----|-----------------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
|    |                                         | 1                        | 2                        | 3                        | 4                        | 5                        |
| s. | Hunger                                  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| t. | Thirst                                  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| u. | Personal worries                        | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| v. | Respiratory factors (asthma, allergies) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| w. | Other (specify)_____                    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

14. Please list any other factors that promote your sleep at home.

x. \_\_\_\_\_

y. \_\_\_\_\_

z. \_\_\_\_\_

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## APPENDIX H. SLEEP DATA LOG

Activity and Sleep Log

Name:

Example “Events:” Watch ON; Watch OFF; To Bed; Wake Up; Other

Example Date/Time Format: Date: 01/15/03 Time: 13:30

| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

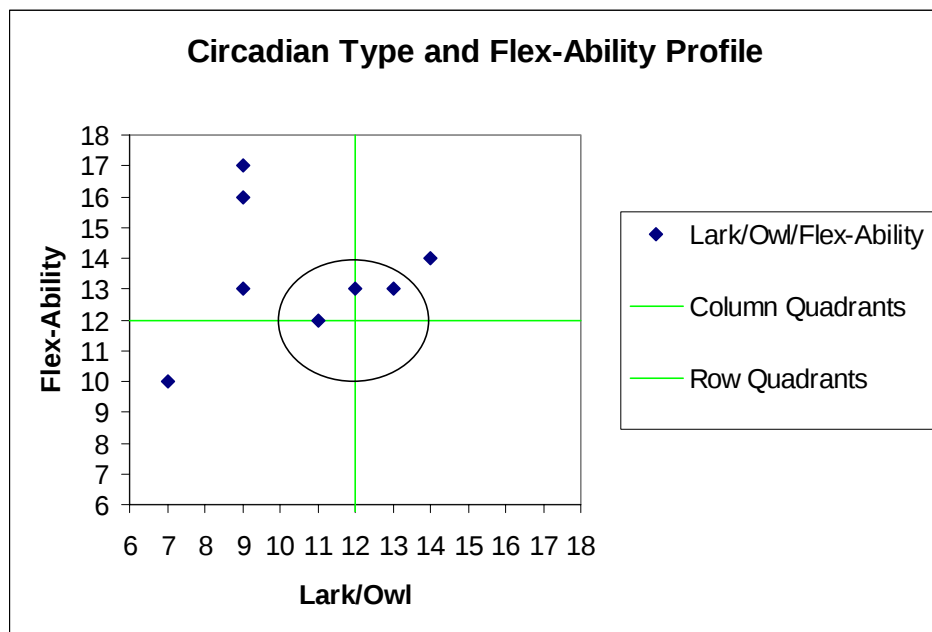
|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

|       |       |        |        |
|-------|-------|--------|--------|
| Date: | Time: | Event: | Notes: |
|-------|-------|--------|--------|

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## APPENDIX I. CIRCADIAN TYPE AND FLEX-ABILITY PROFILE

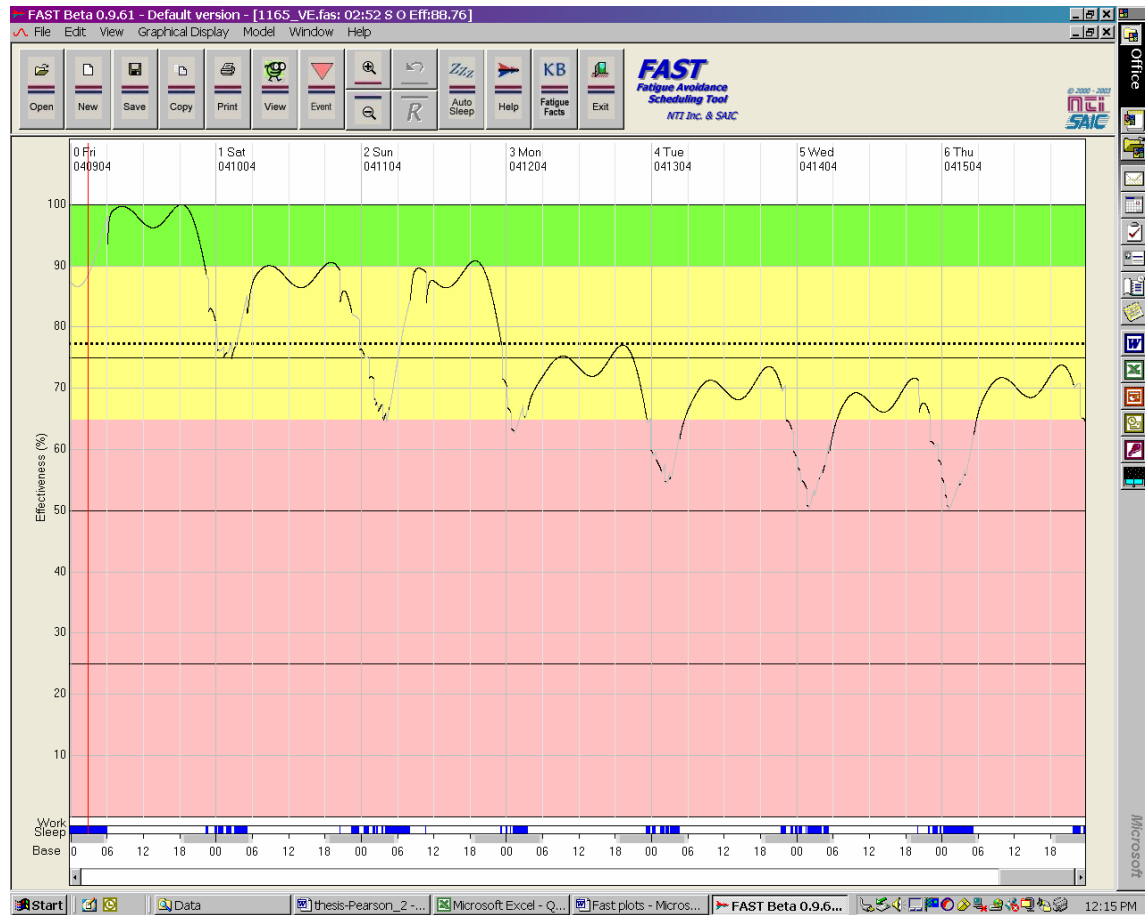
This graph (see Figure 6) shows the Lark-Owl score plotted against the Flex-Ability score for each volunteer. It is divided into four quadrants with a circle of radius 2 in the center of the graph. The closer to the middle of the chart the combination of scores, the more of a Regular Robin the volunteer tends to be. If a volunteer falls into the top half of the chart, the volunteer is fairly flexible in his sleep patterns. If the volunteer falls into the left side, the volunteer has more Lark tendencies, while scores placed on the right side indicate more Owl-like tendencies.



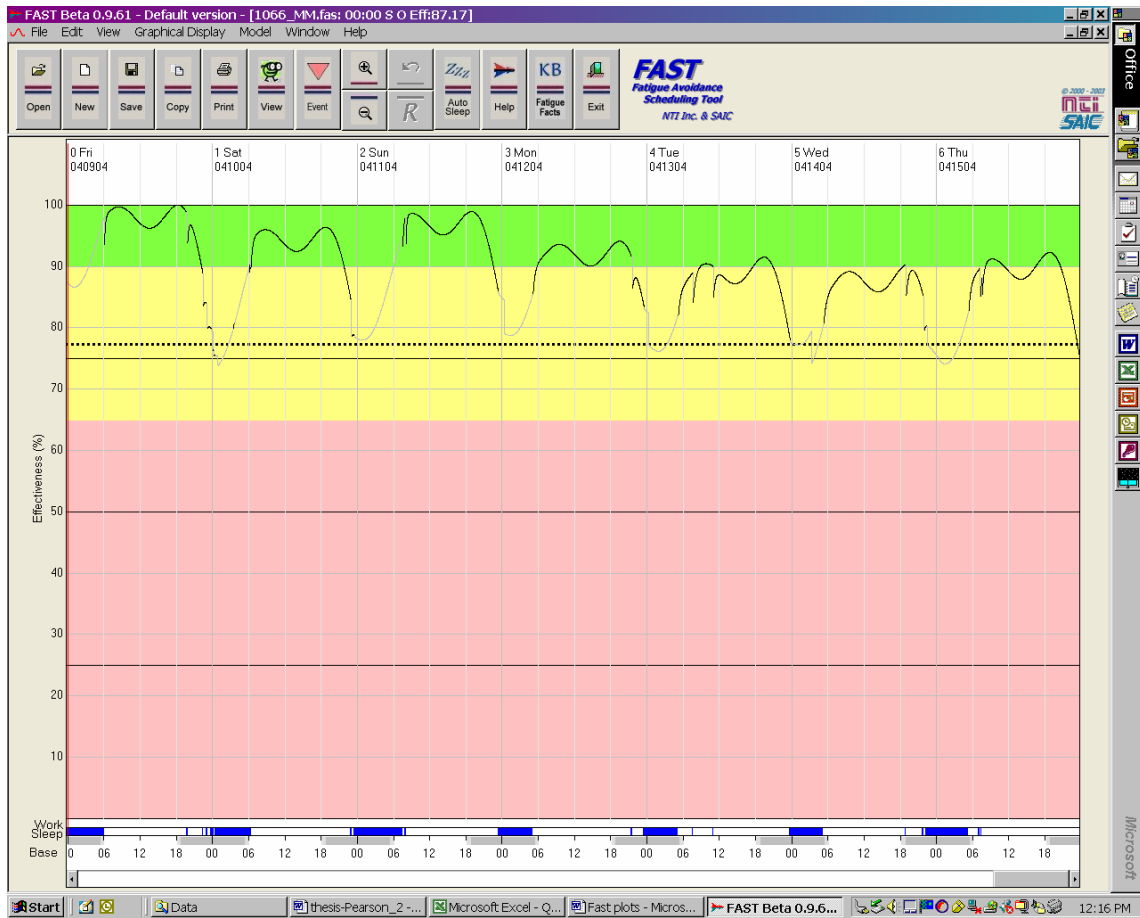
**Figure 6.** Circadian Type and Flex-Ability Profile Graph for BAF volunteers

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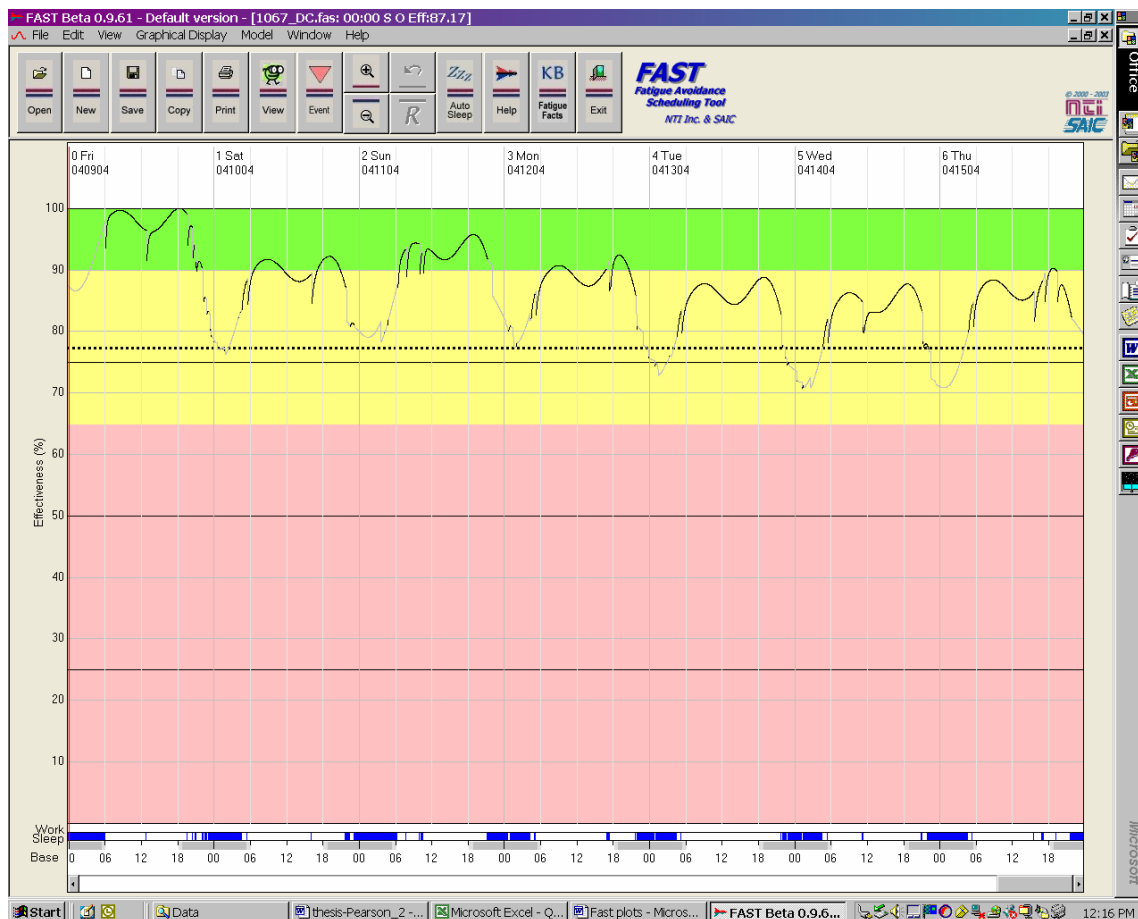
## APPENDIX J. FAST GRAPHICAL DATA



Actigraph 1065



Actigraph 1066



Actigraph 1067





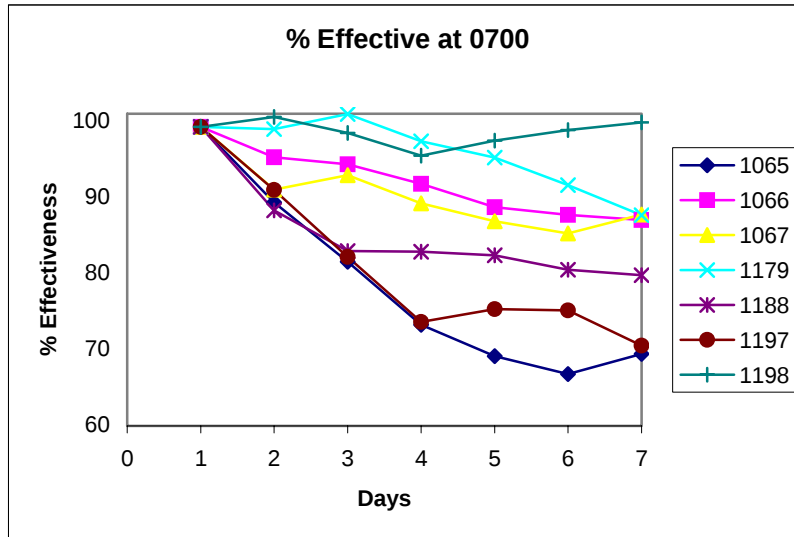




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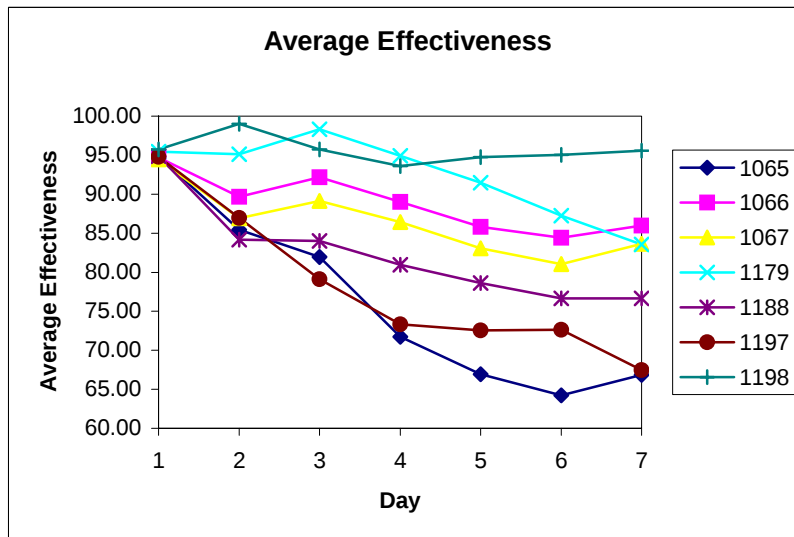
## APPENDIX K. PERFORMANCE EFFECTIVENESS PLOT

The percent performance effectiveness for each volunteer is plotted (see Figure 7). FAST calculated the effectiveness every 30 minutes. The effectiveness at 0700 each day is plotted for each volunteer.



**Figure 7.** Percent effectiveness at 0700 each day

The daily average percent performance effectiveness is plotted for each volunteer (see Figure 8). FAST calculated the effectiveness every 30 minutes. The daily average was calculated using the average function in Excel and then plotted for each volunteer.



**Figure 8.** Average percent performance effectiveness each day

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## APPENDIX L. FAST SUMMARY DATA

Tables 3 - 9 display a FAST summary data table for each volunteer. Overall average effectiveness for the entire seven days for each volunteer is displayed, as well as overall average effectiveness during the waking hours and overall average effectiveness during the sleeping hours.

| SUMMARY               |           |           |             |              |
|-----------------------|-----------|-----------|-------------|--------------|
| Entire Schedule       |           | Intervals |             |              |
| Total Days            | 7         |           | <b>Wake</b> | <b>Sleep</b> |
| First                 | 4/9/2004  | N         | 68          | 67           |
| Last                  | 4/15/2004 | Mean      | 118.4       | 24.3         |
| Average Sleep per Day | 286       | Median    | 15          | 6            |
| Average Work per Day  | 0         | SD        | 291         | 36.1         |
| Average Effectiveness | 75.98     | Shortest  | 1           | 1            |
|                       |           | Longest   | 1182        | 206          |
|                       |           | Avg. Eff. | 77.36       | 66.35        |

**Table 3.** 1065

| SUMMARY               |           |           |             |              |
|-----------------------|-----------|-----------|-------------|--------------|
| Entire Schedule       |           | Intervals |             |              |
| Total Days            | 7         |           | <b>Wake</b> | <b>Sleep</b> |
| First                 | 4/9/2004  | N         | 36          | 34           |
| Last                  | 4/15/2004 | Mean      | 205.5       | 67.9         |
| Average Sleep per Day | 383       | Median    | 25          | 8            |
| Average Work per Day  | 0         | SD        | 351.4       | 116.5        |
| Average Effectiveness | 88.78     | Shortest  | 1           | 1            |
|                       |           | Longest   | 995         | 481          |
|                       |           | Avg. Eff. | 91.46       | 80.03        |

**Table 4.** 1066

| SUMMARY               |           |           |       |       |
|-----------------------|-----------|-----------|-------|-------|
| Entire Schedule       |           | Intervals |       |       |
| Total Days            | 7         |           | Wake  | Sleep |
| First                 | 4/9/2004  | N         | 82    | 81    |
| Last                  | 4/15/2004 | Mean      | 87.9  | 31    |
| Average Sleep per Day | 410       | Median    | 8.5   | 12    |
| Average Work per Day  | 0         | SD        | 193.9 | 54.6  |
| Average Effectiveness | 86.37     | Shortest  | 1     | 1     |
|                       |           | Longest   | 987   | 327   |
|                       |           | Avg. Eff. | 88.88 | 78.63 |

**Table 5. 1067**

| SUMMARY               |           |           |       |       |
|-----------------------|-----------|-----------|-------|-------|
| Entire Schedule       |           | Intervals |       |       |
| Total Days            | 7         |           | Wake  | Sleep |
| First                 | 4/9/2004  | N         | 41    | 39    |
| Last                  | 4/15/2004 | Mean      | 163.8 | 61.7  |
| Average Sleep per Day | 481       | Median    | 2     | 6     |
| Average Work per Day  | 0         | SD        | 341.8 | 149   |
| Average Effectiveness | 92.27     | Shortest  | 1     | 1     |
|                       |           | Longest   | 1053  | 743   |
|                       |           | Avg. Eff. | 94.27 | 88.46 |

**Table 6. 1179**

| SUMMARY               |           |           |       |       |
|-----------------------|-----------|-----------|-------|-------|
| Entire Schedule       |           | Intervals |       |       |
| Total Days            | 7         |           | Wake  | Sleep |
| First                 | 4/9/2004  | N         | 106   | 104   |
| Last                  | 4/15/2004 | Mean      | 71.1  | 20    |
| Average Sleep per Day | 363       | Median    | 2     | 9     |
| Average Work per Day  | 0         | SD        | 242.1 | 24.5  |
| Average Effectiveness | 82.24     | Shortest  | 1     | 1     |
|                       |           | Longest   | 1085  | 108   |
|                       |           | Avg. Eff. | 84.29 | 73.95 |

**Table 7. 1188**

| SUMMARY               |           |           |       |       |
|-----------------------|-----------|-----------|-------|-------|
| Entire Schedule       |           | Intervals |       |       |
| Total Days            | 7         |           | Wake  | Sleep |
| First                 | 4/9/2004  | N         | 127   | 125   |
| Last                  | 4/15/2004 | Mean      | 61.6  | 15    |
| Average Sleep per Day | 323       | Median    | 3     | 10    |
| Average Work per Day  | 0         | SD        | 158.7 | 16.4  |
| Average Effectiveness | 78.1      | Shortest  | 1     | 1     |
|                       |           | Longest   | 978   | 73    |
|                       |           | Avg. Eff. | 79.45 | 70.24 |

**Table 8.** 1197

| SUMMARY               |           |           |       |       |
|-----------------------|-----------|-----------|-------|-------|
| Entire Schedule       |           | Intervals |       |       |
| Total Days            | 7         |           | Wake  | Sleep |
| First                 | 4/10/2004 | N         | 38    | 37    |
| Last                  | 4/16/2004 | Mean      | 131.1 | 98.4  |
| Average Sleep per Day | 573       | Median    | 14    | 7     |
| Average Work per Day  | 0         | SD        | 270   | 192.4 |
| Average Effectiveness | 95.59     | Shortest  | 1     | 1     |
|                       |           | Longest   | 942   | 623   |
|                       |           | Avg. Eff. | 97.82 | 92.87 |

**Table 9.** 1198

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