

Fatigue Avoidance Scheduling Tool

Phase I SBIR Final Report

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Fatigue Avoidance Scheduling Tool Phase I SBIR Final Report

SUMMARY:

The technological assets of the modern military provide the capability to conduct war operations 24 hours a day and under all but the worst of weather conditions. This capability unfortunately deprives the human component of weapon systems the opportunity for appropriate rest. This SBIR effort has developed a tool to assist commanders in scheduling activities and rest to optimize human performance.

1. Purpose of the Work

The purpose of the *FAST* Phase I effort has been to develop a highly researched and recognized model of human sleep and cognitive performance into an easily-used, computerized tool for military planners and schedulers. The Fatigue Avoidance Scheduling Tool (*FAST*) allows a user to predict cognitive performance efficiency for periods up to three weeks based on the timing and amount of sleep an individual or team receives prior to and during the period. *FAST* provides the military planner the ability to optimize performance under conditions of limited sleep and minimizes the need for pharmacological aids.

2. Brief Description of the Work Carried Out

The Phase I effort is built on a newly developed model of sleep and performance invented by Dr. Steven Hursh of SAIC called the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) Model. This model predicts human cognitive performance based on 20 years of sleep and circadian rhythm research. The model is homeostatic in that it adjusts its predictions based on the recent sleep history of the projected population. The SAFTE model incorporates the data from prior studies of pilots conducted at Brooks AFB. In the model a circadian process influences both performance and sleep regulation. Sleep regulation is dependent on hours of sleep, hours of wakefulness, current sleep debt, the circadian process and fragmentation (awakenings during a period of sleep). Performance is dependent on the current balance of the sleep regulation process, the circadian process, and sleep inertia. An additional benefit of SAFTE was that it could be easily enhanced by future studies to refine fatigue effects on specific subject populations, specific aspects of pilot performance, and the effects of interventions, such as stimulants, sedatives, and naps. However, as implemented in a spreadsheet, SAFTE was not user friendly in its operation.

Building on the plan put forth in the Phase I proposal, the contractor team and government representatives attended a kickoff meeting at Brooks AFB to plan the details of the Phase I effort. The team adopted the following objectives for the six-month effort.

- 1) Create a version of Dr. Steven R. Hursh's SAFTE Model that would serve to drive the first prototype of *FAST*.
- 2) Develop a prototype version of *FAST* based on the SAFTE model.
- 3) Develop an interface to permit the user to input a proposed schedule for analysis and to set other initial conditions (prior level of sleep per day, start hour, stop hour, etc.).

- 4) Develop an output interface to graph a comparison of predicted cognitive effectiveness for multiple proposed schedules.
- 5) Develop an output table of summary statistics describing the schedule and its impact on performance.
- 6) Conduct initial user testing of the prototype planning tool.

As work proceeded to accomplish the above objectives, a meeting was planned at approximately the mid point to review progress and make adjustments to the plan resulting from sharing early versions of *FAST* with potential users of the product. Further, a final meeting was used at the end of the project to present SAFTE and *FAST* to other researchers for criticism, suggestions and recommendations to enhance the Phase II work.

3. Findings and Results

Phase I of the *FAST* SBIR effort incorporated the SAFTE Model into a software tool for scheduling pilots and crews that permits mission planners to evaluate alternative schedules for their effects on performance capacity, as degraded by fatigue and circadian variation. The tool incorporates interpretive tools for visualizing performance changes over time and the capability to simultaneously compare multiple schedules on the basis of predicted changes in cognitive capacity.

The *FAST* program was developed in Visual Basic 5.0 that runs under Microsoft Windows 95, 98, or NT. The current Phase I product can be easily installed from a CD-ROM on any Windows-based computer. *FAST* allows the user to view the effects of pre-programmed and user-defined sleep/wake schedules on predicted performance effectiveness. The tool provides a simple, user interface enabling rapid visual and quantitative estimates of the effects of a variety of factors on the cognitive performance of aircrew members.

FAST employs a multiple document (MDI) user interface to allow simultaneous viewing of several program windows. Figure 1 shows an actual screen from the current *FAST* program comparing three schedules simultaneously. Each schedule is viewed in a window, and windows may be overlaid or tiled for comparison. They may be copied to another program or directly printed. The Phase I tool allows the user to load pre-programmed sleep schedules, edit them using keyboard and mouse commands, and save edited schedules.

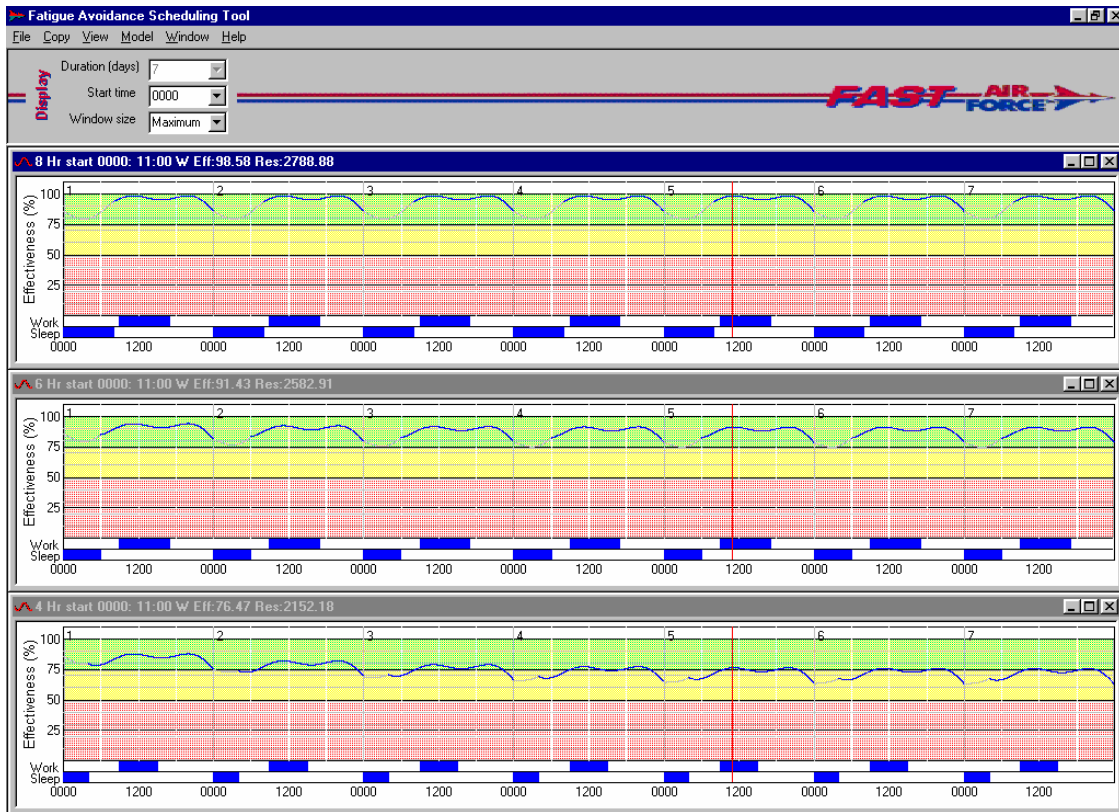


Figure 1: This is a screen image of the **FAST**, PHASE I main window and shows performance for sleep schedules of 8-, 6- and 4-hours a night for seven days. The performance line that is normally blue is gray during sleep. Sleep starts at midnight, 0000, and an 8-hour work-day is shown starting at 0900. The top of each graph also shows the performance effectiveness at the day and time indicated by the vertical cursor, 1100.

Effectiveness, as predicted by **FAST**'s model, is displayed for a user-selectable interval ranging from 6 hours to 21 days. For Phase I, the program allows simultaneous editing and comparison of any number of sleep schedules. A standard Windows menu structure has been implemented.

One valuable option to aid comparison of several schedules is the overlay of a table of interval statistics. This table shows the average "Performance Effectiveness" for successive hours while awake and while working. These tables, when selected, are displayed as an overlay on the graphic display and can be moved to any position that is convenient for simultaneous viewing of the graph and the table. These tables can be printed or copied to the clipboard for inclusion in a briefing or report.

During the Phase I effort, all six technical objectives listed in Section 2 were completed. Because of the absence of unanticipated problems in the Phase I effort, the **FAST** development team was able to create an algorithm for transmeridian relocation and test it within SAFTE. The only fundamental change in SAFTE was the logic to detect the change in work/sleep patterns and to readjust the phase of the circadian rhythm to the new work pattern indicative of the shift in time zone. The ensuing performance prediction

was a natural outgrowth of the shifting circadian phase. Dr. Hursh tested several triggering events to predict “Jet Lag” based on travel from east to west and west to east. This feature of the model will be incorporated into the scheduling tool during Phase II.

4. Potential Future Applications of the Effort

The *FAST* Phase II SBIR effort will build on the accomplishments of Phase I. The Phase II product will provide the AF with a crew scheduling tool to anticipate fatigue effects on performance, thus allowing the military planner to take action to reduce or mitigate the effects of fatigue or to alter the schedule to maintain performance without fatigue. The anticipated product will not only provide a graphic display of performance effects of multiple schedules, it will also provide a Mission Timeline to guide the crew during the performance of the mission.

During Phase II, the phase shifting component developed for SAFTE will be added to *FAST* and specific studies will be conducted on fatigue countermeasures: stimulants and sleep aids. These studies will provide significant parameters to the underlying SAFTE Model and provide planners with quantitative data to compare alternative courses of fatigue remediation. Lessons learned through exposure of *FAST* to potential users at Travis, Dyess and Langley AFBs during Phases I and II will be incorporated into the product. Specifically the product will allow input of information directly from the ATO (take off, waypoints, air refuelings, landing, etc.), include information on the light/dark cycle throughout the mission, and provide multiple time scales (home, Zulu, mission-elapsed, and destination) along with a plot of performance efficiency. Additionally, the tool will be enhanced to intelligently decide when sleep “typically” should occur during non-duty time.

Because the Phase I prototype was shown to be feasible and was enthusiastically accepted by the operations community (a letter written by Major General David MacGhee, Director of Aerospace Operations, HQ ACC/XO received in support of the Phase II effort), all of the new Phase II features and enhancements can be added without reconfiguring the basic product. Other organizations have also expressed an interest in using *FAST*. The Department of Transportation is using an early version of *FAST* to select shift schedules for light rail operators. NASA wishes to use a *FAST*-like tool on the space station and with ground crews to minimize the impact of fatigue on work and decision-making errors. The FAA has asked to be kept informed of progress in the Phase II effort.

Because of the cooperation and strengths of *FAST*'s development team, *FAST* has an excellent potential for future applications. The NTI contractor team has the expertise to extend the tool with new data and programming features that will make it an easy-to-use, accurate, human-performance, prediction tool. The AF sponsor has presented it to portions of the AF operational community that need its capabilities and they have responded positively. By the end of the Phase II effort, the *FAST* development team hopes to have the product validated and tested in an Air Expeditionary Force Battle Lab demonstration project. This should be sufficient for the AF to adopt *FAST* for use in fatigue management in other areas of air and ground operations throughout the Air Force.

Introduction

The technologies of modern air warfare have largely eliminated the constraints of night and day. Aircraft guidance systems and smart munitions permit us to exploit the cover of night. Mid-air refueling methods permit long duration flights that can take aircraft halfway around the world and back. It is tempting, then, for commanders to plan operations that exploit these systems for maximum surprise and intensity. Nevertheless, air operations still require the participation of human pilots, controllers, and ground support personnel. The human brain cannot function for long periods of time without severe degradation, nor is it immune to variations in attention produced by day and night conditions. Fatigue is well known to degrade performance; and while countermeasures can temporarily extend the performance of crews under unusual circumstances, in the long run there is no substitute for adequate sleep to refresh mental capacity.

A great deal of research has been done to study the limits of human performance under sleep deprivation. This research has allowed experts to advise on how to best utilize crew members to avoid the disruptions of day-night rhythms and fatigue (see Caldwell, 1997; Caldwell & Caldwell, 1998; Bonnet & Arand, 1994; Kreuger, 1989; Nicholson, 1987). At the time of writing the Phase I proposal, there was no system that permitted the military planner to automatically consider the lessons of sleep and performance research when planning flight operations.

In the Phase I proposal we described a variety of alternative approaches for managing fatigue in military operations (Caldwell, 1997; Lagarde & Batejat, 1995; Naitoh, Englund, & Ryman, 1982). These included:

- monitoring performance to detect fatigue,
- using pharmacological stimulants to temporarily overcome fatigue,
- using sedatives to improve sleep at odd hours or under stress,
- taking short naps, and
- using a fatigue prediction model as part of a scheduling decision aid to guide the design of schedules to avoid, as much as possible, dangerous levels of fatigue.

While each intervention may have an advantage under specific circumstances, a scheduling decision aid can help the planner avoid fatigue and, when mission demands create unavoidable conditions of fatigue, the tool can suggest alternative strategies and interventions to correct the situation and maximize crew safety. The Phase I proposal for this effort described a newly developed computer model of human sleep and performance, and a plan to develop an operator scheduling system that would use this model as the basis of a fatigue avoidance decision aid for operational planning. Such a scheduling system would permit a planner to evaluate the relative benefits of various schedules that accomplish a mission. With this computerized system, optimal performance could be arranged at critical times and human degradations could be avoided, scheduled at times of minimal workload, or scheduled at times with the least operational impact. We believe the development of a scheduling decision aid is the key to a comprehensive solution to the problem of fatigue.

Project Objectives

The technical objectives for the Phase I effort were refined to include the following:

- 1) Create a version of the SAFTE Model that will serve to drive the first prototype of **FAST**.
- 2) Develop a prototype version of **FAST** based on the SAFTE model.
- 3) Develop a user interface to permit a planner to input one or more schedules for analysis and to set other initial conditions (prior level of sleep per day, start hour, stop hour, etc.).
- 4) Develop an output interface to graph predictions of cognitive effectiveness for multiple schedules.
- 5) Develop an output table of summary statistics describing the schedule and its impact on performance.
- 6) Conduct initial user testing of the prototype planning tool, **FAST**.

Work Performed

For the Phase I effort, a work plan was established to meet all the technical objectives. All the objectives were completed as described below.

Task 1. Create a version of the SAFTE Model that will serve to drive the first prototype of the FAST. This task was performed by Dr. Steven R. Hursh and resulted in a version of the SAFTE Model updated to accommodate the latest Air Force performance data. Dr. Hursh validated the model against available performance data and provided to NTI a report describing the mathematics of the revised model.

Task 2. Develop a prototype version of FAST based on the SAFTE model. This task was completed by Dr. Timothy Elsmore, an NTI system analyst, with the consultation of Dr. Douglas Eddy, government representatives, and Dr. Hursh on the design of **FAST**. The organization of the tool's components that interacted with the model were designed with methods suggested to maximize their utility for the military planner. Drs. Eddy, Hursh and William Storm, AFRL/HEPM, reviewed each version of the software and provided comments and suggestions for improvements and corrections. Dr. Hursh tested the predictions of the finished scheduling tool against the stand alone SAFTE Model to insure accuracy of predictions.

Task 3. Develop a user interface to permit the planner to input a proposed schedule for analysis and to set other initial conditions of the model. This task created a graphical user interface (GUI) in Visual Basic that permits the military planner to set the characteristics of the proposed schedule. The planner sets initial conditions, the start and stop day, hour and minute of the operation, critical times for performance, and times for sleep periods.

Task 4. Develop an output display to graph a comparison of predicted cognitive effectiveness for multiple proposed schedules. This task created a system for graphic display of performance patterns. Because of efficiencies of work, a Phase II objective was completed as well, the simultaneous display of multiple proposed schedules. The

system displays changes in performance effectiveness and/or the reservoir of performance capability. It permits the display or printing of the graphic results for a user-selected portion of the schedule. The system permits the saving of an unlimited number of schedules along with customized parameter information used to create the schedule and predicted performance.

Task 5. *Develop an output table of summary statistics describing the schedule and its impact on performance.* This task created a table of summary statistics that describe the key features of performance under the comparison schedules at user selected periods during the schedule or combat mission. Another table can be displayed and printed that shows the model parameters used to predict the performance.

Task 6. *Conduct initial user testing of the prototype planning tool.* This task presented the prototype version of *FAST* to a variety of Air Force operational planners. Where possible, each user was trained in the use of the system, rated its utility and features, and made recommendations for future improvements.

Results Obtained

This section includes a brief description of the SAFTE model underlying *FAST*, its enhancement during Phase I (Task 1), a description of the *FAST* features at the end of Phase I (Tasks 2-5), and the results of preliminary user testing (Task 6).

The Model

The Phase I proposal included a detailed description of the historical background of the SAFTE model. An in-depth review of the design of the SAFTE model and its supporting research is included here for two reasons: to document the research foundation for the *FAST* model (see Hursh & McNally, 1993) and to describe the changes to the SAFTE model completed during Phase I.

The general architecture of the SAFTE model, as revised during Phase I, is shown in Figure 2. A circadian process influences both performance and sleep regulation. Sleep regulation is dependent on hours of sleep, hours of wakefulness, current sleep debt, the circadian process and fragmentation (awakenings during a period of sleep). Performance is dependent on the current balance of the sleep regulation process, the circadian process, and sleep inertia. Although developed independently, the resulting model has structural similarity to the scheme suggested by Achermann and Borbely (1991) and the mathematics are generally similar to the homeostatic model of Folkard and Akerstedt (1991).

Schematic of SAFTE Model

Sleep, Activity, Fatigue and Task Effectiveness Model

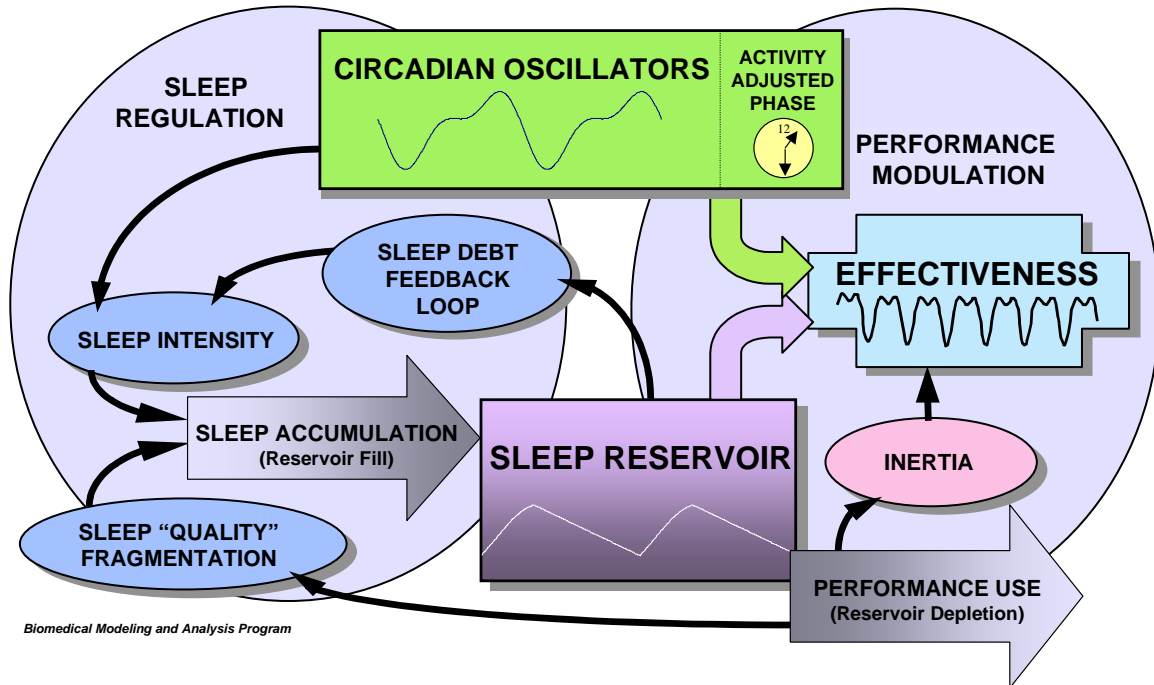


Figure 2: Block diagram of SAFTE model.

However, the new model has been optimized to predict changes in cognitive performance and incorporates features not included in any prior comprehensive model: a multi-oscillator circadian process, a circadian sleep propensity process, a sleep fragmentation process, and a circadian phase adjusting feature for time zone changes. Each component will be discussed in detail, with supporting data. The specific mathematical expressions that describe the model and the default values of all the variables are described in Appendix B.

Circadian Oscillators. Performance while awake and the drive to sleep are both controlled, in part, by a circadian process (Monk, 1991; Folkard and Akerstedt, 1991). Studies of performance (e.g. reaction time, Dinges & Powell, 1989), alertness ratings (Monk & Embry, 1981; Froberg, 1977), measures of the tendency to fall asleep (e.g. multiple sleep latency tests, Carskadon & Dement, 1977; Mitler, et. al., 1982; Richardson, et. al., 1978; see also Lavie, 1989), and body temperature (Froberg, 1977; Monk & Embry, 1981) indicate that the underlying circadian process is not a simple repeating sine wave. Performance and alertness reach a major peak in the early evening, about 2000 hours, and fall to a minimum at about 0400 hours. There is a secondary minimum in the early afternoon, about 1400 hours, and a secondary morning peak at about 1000 hours. Correlated with this pattern is a rising 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 suggest that at least two oscillators are involved in the circadian process.

The sleep and performance model incorporates a circadian process that is composed of the sum of two cosine waves, one with a period of 24 hours and one with a period of 12 hours. The two oscillators are out of phase, producing a predicted variation in arousal that closely parallels published patterns of body temperature. The circadian process within the model generates an arousal function that mirrors circadian changes in oral temperature such as that reported by Folkard (1975) based on 36 male and female subjects. This arousal oscillator drives both variations in predicted cognitive effectiveness and sleep propensity. These two translations of the oscillator have identical frequency and phase components and differ only in amplitude and sign; a rise in arousal produces an increase in performance and a decrease in propensity to sleep. The circadian process is indicated in the large rectangle shown in the diagram of the SAFTE model, Figure 2.

Activity Adjusted Circadian Phase. When subjects move to another time zone or alter work pattern so that sleep and work occur at different times of day, the internal circadian oscillator that controls body temperature and alertness shifts to this new schedule. During the period of adjustment, subjects experience performance degradation, disrupted mood and feelings of dysphoria, called circadian desynchronization or “jet lag” (Klein and Wegman, 1980; Graeber, 1980; Haus and Halberg, 1980). During Phase I, the model was refined to mimic this process and automatically adjust the phase of the circadian rhythm to coincide with the activity pattern of the subject. This feature of the model will be incorporated into the scheduling tool during Phase II. This feature is critical for the accurate prediction of the effects of moving to a new time zone or changing to a new and regular work pattern, such as changing from the day shift to the night shift. The model detects the average time of the awake period and maintains a running average “awake time.” The peak of the circadian rhythm has a reliable relationship to the timing of the period of wakefulness. When one moves to a new work schedule or a new time zone, the change in average awake time (relative to a reference time zone) is detected and a new “target phase” is computed. For example, when moving from the central US time zone to Germany, the awake time of the subject advances six hours. Instead of waking at, say, 0600 Central Time, the subject awakens at 0000 Central Time, which is 0600 German time. This causes a shift of 6 hours in the “target phase” of the subject. However, the human physiological system does not adapt immediately to such a shift. In general, a phase advance (eastward time change) takes about 1.5 days per hour of shift (Klein and Wegman, 1980; Graeber, 1980; Haus and Halberg, 1980). The model, therefore, adjusts to the new “target phase” gradually over the course of 9 days. During that time, the performance of the subject will show degradation due to the desynchronization of the internal circadian rhythm from the new rhythm of work and sleep. Likewise, westerly travel causes a phase delay in the circadian rhythm and research shows that phase delays take less time for adjustment, about one day per hour of shift, or six days for a six hour time change (Klein and Wegman, 1980; Haus and Halberg, 1980).

The Sleep Reservoir and Homeostatic Sleep Regulation. The control of sleep and its influence on cognitive capacity is a homeostatic process (see Akerstedt & Folkard, 1991; Folkard & Akerstedt, 1987). At the core of this process is a sleep reservoir, diagrammed as a rectangle at the center of the diagram in Figure 2. The model simulates the underlying processes that govern the capacity to perform. A fully rested person has a certain performance capacity indicated as the reservoir capacity, R_c . While awake, units of this reservoir are depleted each minute according to a linear performance use function, indicated by the arrow leaving the reservoir. While asleep, units of capacity are added to the reservoir each minute to replenish the reservoir and the capacity to perform and be alert. The rate of accumulation for each minute of sleep is called sleep intensity and is driven by two factors: 1) the circadian variation in sleep propensity, and 2) the current sleep deficit, which is the reservoir capacity R_c , minus the current level of the reservoir at time t , R_t . This deficit is constantly changing as one sleeps and replenishes the reservoir, or is awake and depleting the reservoir. The oscillation in the reservoir level is called the sleep-wake cycle and reflects the current reservoir deficit. Note that sleep accumulation does not start immediately upon retiring to sleep. There is a brief delay of about 5 min required to achieve a restful sleep state. This factor accounts for the penalty during recuperation that is caused by sleep in an environment that leads to frequent interruptions. These components of the sleep accumulation function are indicated as ellipses in the diagram (Figure 2) to the left of the sleep reservoir feeding into the sleep accumulation function. The level of the reservoir at time $t+1$ is the level at time t , R_t , plus sleep accumulation (S) while asleep and minus performance use (P) while awake. The units of the reservoir are minutes of effective sleep. Since the model is a simulation, it can easily accommodate a complex pattern of sleep and waking. While asleep, the simulation adds to the reservoir; while awake the simulation depletes the reservoir. A schedule can oscillate between these states as often as once a minute and the simulation will keep account of the net effects on performance capacity as the balance in the reservoir, like the balance in a check book.

The outcome of the reservoir process in the SAFTE model during continuous sleep converges to an exponential accumulation function, and, as such, is similar to the “S” process (Sleep process) of the Folkard and Akerstedt (1991) three process model of sleep and performance. But at the molecular level the SAFTE model is based on minute by minute additions to the reservoir during sleep with the size of these increments proportional to the reservoir deficit (the feedback process). Integrated over time, this iterative process is described by an approximate exponential function. But the model is not an exponential function. Rather, it is a moment by moment simulation of the effects of sleep on the reservoir balance. Hence, a momentary interruption in sleep (fragmentation) is simple to accommodate in the SAFTE model. The incremental process is interrupted for the duration of the awakening and the reservoir is depleted for that period of time by the performance function. The result of this process (in the absence of interruptions) parallels the Folkard and Akerstedt model, and is, therefore, confirmed by that convergence, but the SAFTE model is superior in the sense that it is directly tied to the real world events that drive the process, not to an a priori mathematical equation. The feedback process explicitly included in the SAFTE model and implied by the exponential form of the Folkard and Akerstedt “S” process is critical

in determining the effects of long schedules of less than optimal sleep. Such schedules deplete the reservoir and increase the intensity of sleep when sleep occurs. Eventually, the greater average intensity of sleep permits the person to adjust to such schedule and find a new equilibrium of sleep and stable performance, within limits. Performance will not be as effective as it might be with a full eight hours of sleep, but performance does not necessarily degrade indefinitely. This is what is meant by a homeostatic sleep and performance model. It is much like a person adjusting to a restricted diet; the person loses weight and conserves energy so that a new equilibrium stable weight is reached under the limited input of calories.

Cognitive Effectiveness. Consistent with the approach proposed by Monk (1991) and Achermann and Borbely (1991), the model stipulates that cognitive effectiveness and alertness are primarily dependent on variations in the two processes just described: the endogenous circadian rhythm (reflected in oral temperature) and the current sleep reservoir balance resulting from the sleep-wake cycle, as diagrammed in Figure 3. A third factor, not shown, is the temporary disturbance in performance that often occurs immediately following awakening, called sleep inertia (see Folkard and Akerstedt, 1991).

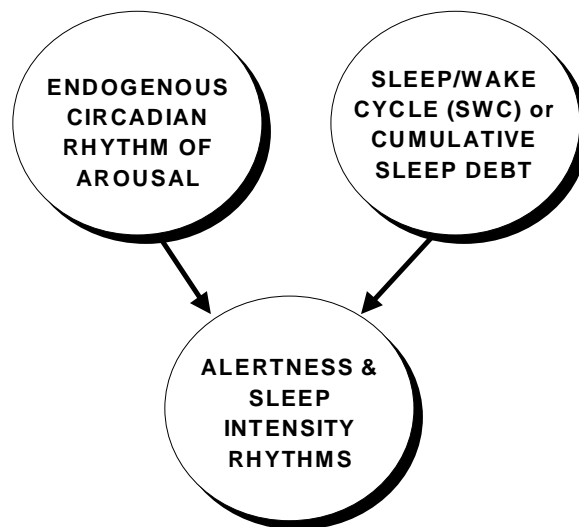


Figure 3: Major drivers of alertness and sleep regulation (after Monk, 1991).

Key Features and Advantages of the SAFTE Model of Air Crew Performance. The SAFTE Model has a number of key features that distinguish it from other attempts to model sleep and fatigue, summarized in Table 1. Together, these features of the model allow it to make very accurate predictions of performance under a variety of work schedules and levels of sleep deprivation.

Table 1. SAFTE Model of Air Crew Performance	
Key Features	Advantages
Model is homeostatic. Gradual decreases in sleep debt decrease sleep intensity. Progressive increases in sleep debt produced by extended periods of less than optimal levels of sleep lead to increased sleep intensity.	Predicts the normal decline in sleep intensity during the sleep period. Predicts the normal equilibrium of performance under less than optimal schedules of sleep.
Model delays sleep accumulation at the start of each sleep period.	Predicts the detrimental effects of sleep fragmentation and multiple interruptions in sleep.
Model incorporates a multi-oscillator circadian process.	Predicts the asymmetrical cycle of performance around the clock.
Circadian process and Sleep-Wake Cycle are additive to predict variations in performance.	Predicts the mid-afternoon dip in performance, as well as the more predominant nadir in performance that occurs in the early morning.
Model modulates the intensity of sleep according to the time of day.	Predicts circadian variations in sleep quality. Predicts limits on performance under schedules that arrange daytime sleep.
Model includes a factor to account for the initial lag in performance upon awakening.	Predicts sleep inertia that is proportional to sleep debt.
Model incorporates adjustment to new time zones or shift schedules.	Predicts temporary “jet lag” effects and adjustment to shift work.

Predictions of the Model

Performance and Alertness. The average person is assumed to require eight hours of sleep per day to be fully effective and to avoid accumulation of sleep debt. Based on the joint interaction of the endogenous circadian oscillator and the sleep-wake cycle, performance is predicted to have two peaks in percent effectiveness, one at approximately 1000 hours and another at 2000 hours. Performance also has a minor dip at about 1400 hours and a major trough in effectiveness during the early morning hours when a person is normally asleep. This pattern is shown in the upper graph of Figure 1. The nighttime pattern reveals a major trough in performance at about 0300 hours. The predicted pattern corresponds with the results of Monk and Embry (1981), which demonstrated the independence of the sleep reservoir and the circadian oscillator. The average alertness scores for a study group of shift workers reflected subjective alertness around the clock without accumulated sleep debt. The shift workers had a normal acrophase, but had slept prior to working their shift, hence no accumulated sleep debt. The pattern of alertness closely parallels the prediction of the model with two peaks in alertness, a mid-afternoon dip in alertness, and a major trough in alertness at 0600 hours.

A number of studies have confirmed the bimodal pattern of performance shown in the graphs of Figure 1. Lavie (1991) reported that traffic accidents in Israel between 1984 and 1989 reveal two peaks in sleep related accidents, a major peak at about 0300 hours, and a minor peak at about 1500 hours in the afternoon. These correspond to the dips in performance predicted by the model in Figure 1. Similarly, Voigt, et al., (1968) report acoustical reaction time as a function of time of day and, again, there are two peaks (slowing) of reaction time, a major one at about 0200 hours and a minor one at about 1400 hours. Finally, Folkard and Monk (1979) summarized results from industrial settings two dips in performance, one at about 0300 hours and a second at about 1400 hours.

Sleep Propensity and Sleep Intensity. The model assumes that the intensity of sleep is the sum of two processes (Lavie, 1991). As described earlier, the circadian process produces an oscillation in sleep propensity. This rhythm is the negative of the arousal rhythm and scaled in sleep units. Sleep propensity combines with the current sleep debt resulting from the sleep-wake cycle to generate a prediction of sleep intensity. For a person taking a normal 8-hour sleep from midnight to 0800 hours, sleep is most intense in the early morning at about 0300 hours. There is a mid-afternoon increase in sleep propensity at about 1600 hours that coincides with the mid-afternoon dip in alertness and consistent with the observation of increases in sleep related traffic accidents (Lavie, 1991).

Equilibrium States. A homeostatic representation of sleep regulation leads to an important implication seldom recognized, even by those proposing a homeostatic sleep process (Folkard & Akerstedt, 1987; Borbely et al., 1989). If a subject is scheduled to take less than an optimal amount of sleep each night, four hours for example, the reservoir initially loses more units during the awake period than are made up during the sleep period. This results in a sleep debt at the end of the sleep period that accumulates over days, see the lower graph in Figure 1. However, since the rate of sleep accumulation increases with sleep debt, eventually, the rate of sleep accumulation increases such that four hours of sleep makes up for twenty hours awake. At this point, the reservoir reaches an equilibrium state and no further debt is accumulated, although the initial deficit remains as long as the person remains on this schedule. By the sixth day of the restricted sleep schedule, cognitive performance oscillates about a stable level well below the baseline level achieved with 8 hours of sleep. Minimum effectiveness is about 64% on the seventh day, lower graph, Figure 1.

Progressive Sleep Debt under Extreme Schedules. The sleep homeostat is not infinitely elastic; there is a limit to the rate of sleep accumulation (sleep intensity). Any schedule that provides less than 4 hours of sleep per day (for the average person) will not reach an equilibrium state and performance capacity will gradually deplete to zero, although the rate of depletion slows over the first week of restriction as sleep intensity rises to its maximum level. Under a schedule of only 2 hours of sleep per day, minimum performance declines to about 19% on the seventh day.

Sleep Timing. The model is sensitive to the time of day of the sleep period. The performance of an individual given eight hours of sleep per day starting at 1200 hours

(noon) each day reaches a peak of 100% at the start of each work period (2000 hours) but rapidly declines during the late night and early morning hours to a strong dip at about 0500 hours. Minimum performance under this schedule is predicted to be as low as 66% compared to minimum performance of 86% under a normal sleep schedule. This alteration in pattern is the result of two factors. First, sleep intensity is initially less for sleep periods starting at noon. This creates a small, accumulated debt that is quickly offset by the homeostatic sleep mechanism. The second, more persistent effect is the circadian oscillator of performance that reaches its minimum in the early morning hours. This pattern has strong implications for performance under shift schedules that require daytime sleep. It is well documented that most mistakes on the night shift occur during the early morning hours (Bjerner, et. al., 1955; Harris, 1977; Hamelin, 1987; Ribak, 1983) and the model makes the same prediction.

Validation of Sleep and Performance Model (Task 1)

The current SAFTE model incorporates a number of improvements compared to the earlier model (SPM-96). In general, those changes discussed above were designed to improve the fidelity of the underlying principles that form the basis of performance predictions. As discussed above, the model now includes a more realistic representation of the underlying circadian processes, a more sophisticated routine governing the intensity of sleep as a function of time of day, and includes consideration of sleep inertia. To validate the new version of the model, the predictions of the model for the effects of total sleep deprivation were compared to an independent set of data reported by Angus and Heslegrave (1985). Their results were plotted against the predictions of the sleep model and are shown in Figure 4. All parameters within the model were set to the default values with the acrophase (peak of the 24-hr circadian rhythm) and start time as indicated in the legend. The SAFTE Model predictions for the actual data are exceptionally good and far superior to predictions based on the prior version of the model, SPM-96.

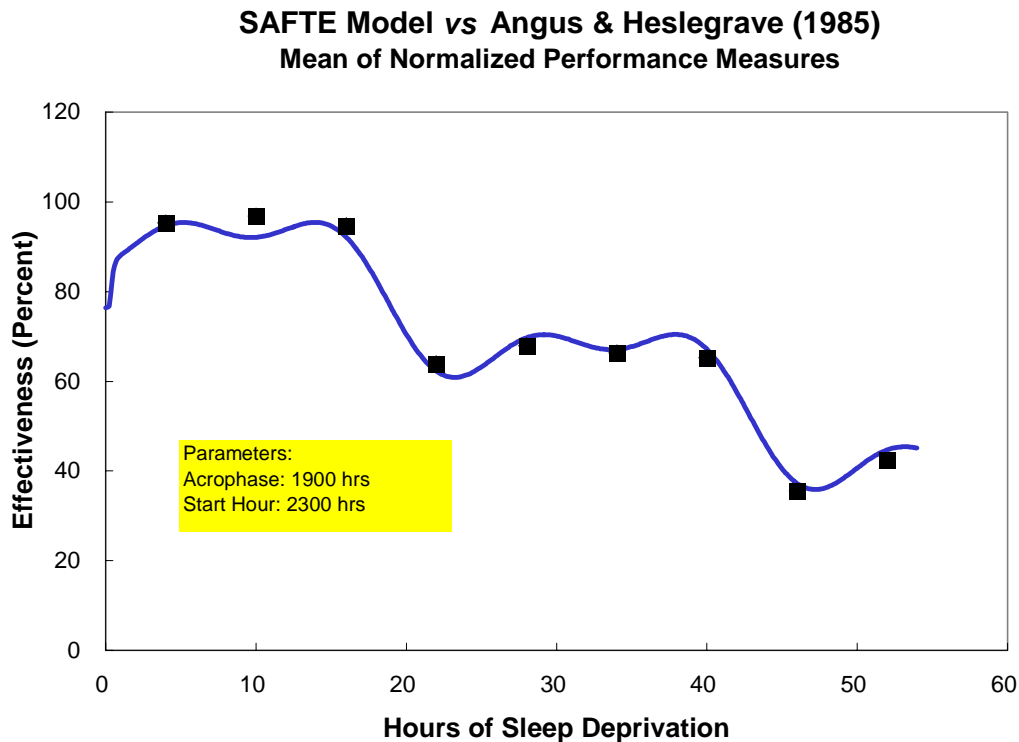


Figure 4: SAFTE Model predictions for cognitive performance under total sleep deprivation (solid line) compared to mean normalized cognitive performance (filled squares) reported by Angus & Heslegrave (1985).

Extrapolations to Performance of Military Tasks

The sleep and performance model has been optimized to predict changes in cognitive capacity as measured by standard laboratory tests of cognitive performance. It is assumed that these tests measure changes in the fundamental capacity to perform a variety of tasks that rely, more or less, on the cognitive skills of discrimination, reaction time, mental processing, reasoning, and language comprehension and production. However, specific military tasks vary in their reliance on these skills, and deficits in cognitive capacity may not produce identical reductions in the capacity to perform all military tasks. It is reasonable to assume, however, that the changes in military task performance would be correlated with changes in the underlying cognitive capacity. In other words, if one were to plot changes in military task performance as a function of measured changes in cognitive capacity, there would be a monotonic relationship between the two variables. Therefore, if these two sets of data were available from a test population subjected to sleep deprivation, linear (or non-linear) regression techniques could be applied to derive a transform function to translate predicted cognitive changes to changes in military task performance. Based on this reasoning, SAIC and NTI are currently collaborating with the Air Force in another contractual effort to obtain flight simulator performance measures in conjunction with standard cognitive tests under a schedule of progressive sleep loss up to 45 hours. The results of this study will provide a

basis for developing translation algorithms to extend the predictions of the sleep and performance model to a set of parameters of a military task, flying an aircraft.

Phase I Upgrade of the SAFTE Model (Unplanned)

Transmeridian Relocation Effects (“Jet Lag”). During the Phase I effort, a transmeridian relocation feature was developed for the SAFTE model. It will allow the scheduling tool, which will be enhanced during Phase II, to predict the adaptation of performance to changes in time zones that might accompany transmeridian flights or that might occur if the subject shifts to a regular schedule of night time work. Figure 5 displays the adjustment of performance to two flights, an east-bound flight across six time zones and a west-bound flight across six time zones.

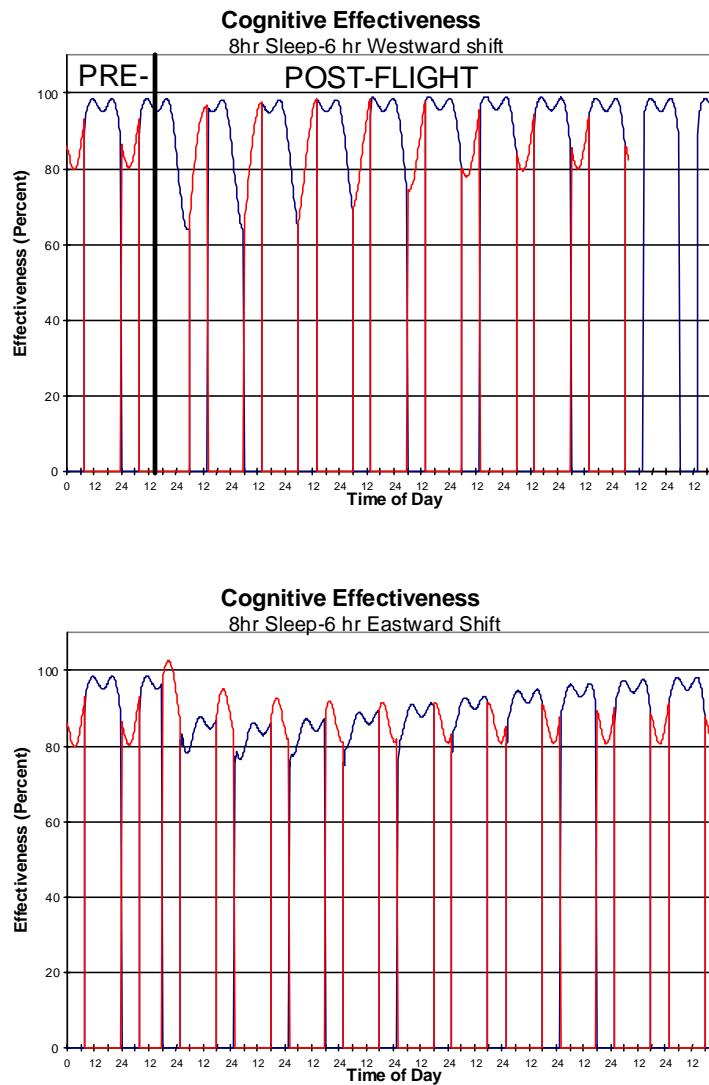


Figure 5: Performance effects of westward and eastward travel across 6 time zones.

Note that predicted performance while awake is more disrupted for a longer period of time by the east-bound flight compared to the west-bound flight. This is a commonly reported difference in “jet lag” for east and west plane travel (Klein and Wegman, 1980; Haus and Halberg, 1980). These effects on performance are a logical and inherent outcome of the interplay of the various processes in the model and did not require a special “jet lag” algorithm. The only fundamental change in SAFTE was the logic to detect the change in the sleep/work pattern and to readjust the phase of the circadian rhythm to the new work pattern indicative of the shift in time zone. The performance prediction was a natural outgrowth of the shifting circadian phase. This feature of the model will be incorporated into the scheduling tool during Phase II.

Features of the Fatigue Avoidance Scheduling Tool (FAST) Phase I Product (Tasks 2-5)

Predictive Model. Phase I of the SBIR effort incorporated the SAFTE Model into **FAST**. The **FAST** Phase I product allows mission planners to evaluate alternative schedules for their effects on performance capacity, as degraded by fatigue and circadian variation. The software incorporates interpretive tools for visualizing performance changes over time and the capability to compare schedules on the basis of predicted changes in cognitive capacity.

Software. The **FAST** program was developed in Visual Basic 6.0 and runs under Microsoft Windows 95, 98, or NT. The current Phase I product can be easily installed from a CD-ROM on any Windows-based computer. **FAST** allows the user to view the effects of pre-programmed and user-defined sleep/wake schedules on predicted performance effectiveness. The tool provides a simple user interface enabling rapid visual and quantitative estimates of the effects of a variety of factors on the cognitive performance of aircrew members.

Multiple Schedules. **FAST** employs a multiple document (MDI) user interface to allow simultaneous viewing of several program windows. Figure 1 shows an actual screen from the current **FAST** program showing a comparison of three schedules simultaneously. Each schedule is viewed in a window and windows may be overlaid or tiled for comparison. They may be copied to another program or directly printed. The Phase I tool allows the user to load pre-programmed sleep schedules, edit them using keyboard and mouse commands, and save edited schedules.

Menus and Options. Effectiveness, as predicted by the SAFTE model, is displayed for a user-selectable interval ranging from 6 hours to 7 days. For Phase I, the program allows simultaneous editing and comparison of any number of sleep schedules. A standard Windows menu structure has been implemented. Table 2 shows the menu commands. These commands are used to open and save sleep schedules, copy graphics and statistics to the Windows clipboard for use by other Windows applications (e.g., PowerPoint, Excel), modify the initial parameters of the SAFTE model, view graphs of effectiveness and/or sleep reservoir values, view a table of performance statistics, and obtain context-sensitive on-line program help and references to the sleep and circadian literature.

Table 2. FAST Phase I Menu Structure					
Main Menu	File	Copy	View	Model	Help
Sub Menu	New		Information Panel	Recalculate	FAST Program Help
	Open Schedule		Sleep Reservoir	Parameters	FAST Knowledge Base
	Save Schedule		Work Schedule		Using Help
	Save Schedule AS		Interval Statistics		About FAST
	Save Ascii File				
	Print				
	Exit				

Quantitative Schedule Comparison. One valuable option to aid comparison of several schedules is the overlay of a table of interval statistics. This table shows the average “Performance Effectiveness” for successive awake periods and work periods. Figure 6 shows two such tables that compare the same thirty-hour mission without and with two in-flight naps. These tables, when selected, are displayed as an overlay on the graphic display and can be moved to any position that is convenient for simultaneous viewing of the graph and the table. To compare the effectiveness at mission critical times under these schedules, three critical work periods were defined on the work line (see Figure 1 for the location of the work line), that defined the time of take-off, the time on target, and the time of landing. The tables in Figure 6 show the average effectiveness during those three work periods. Note the much higher level of effectiveness over target (88.33% vs. 70.36%) and at landing (79.07% vs. 43.60%) with the two-nap schedule. These tables can be printed or copied to the clipboard for inclusion in a briefing or report.

Thirty-Hour Mission – No Naps						Thirty-Hour Mission – Two In-flight Naps					
Awake			Work			Awake			Work		
Start	Duration	Mean Effec.	Start	Duration	Mean Effec.	Start	Duration	Mean Effec.	Start	Duration	Mean Effec.
1 08:00	839	97.00	3 04:00	180	62.27	1 08:00	839	97.00	3 04:00	180	68.69
2 06:00	3959	66.06	3 18:00	240	70.36	2 06:00	359	92.85	3 18:00	240	88.33
5 08:00	959	81.44	4 08:00	120	43.60	2 16:00	899	87.78	4 08:00	120	79.07
6 08:00	959	92.08				3 10:00	1079	81.95			
7 08:00	2400	79.81				4 07:00	1019	79.05			
						5 08:00	959	91.47			
						6 08:00	959	94.91			
						7 08:00	2400	80.61			

Figure 6: Two examples of the interval statistics table are shown comparing “Performance Effectiveness” for two thirty-hour missions. Note that the schedule with naps maintains work effectiveness at landing above 79%, compared to a low of about 44% without naps.

Initial User Testing (Task 6)

The prototype version of FAST was presented to a variety of Air Force operational planners and others. Where possible, each user was trained in the use of the system, rated its utility and features, and made recommendations for future improvements.

Captain Peter Garretson, 60 AMW Flight Safety Wing, Travis AFB, is a C-5 pilot and the Flight Safety Officer for his squadron. He is interested in a pre-mission scheduling tool that will predict the fatigue level associated with a variety of mission schedules. Drs. Storm and French took an early version of *FAST* with them on a trip to brief his squadron on fatigue countermeasures (August, 1999). He was very interested in the *FAST* product and would like to be a beta test site for *FAST* during Phase II. He made some thoughtful comments on the style of the graphics, military aviation performance measures, and ways of presenting the results of fatigue model predictions. His near verbatim comments are presented in Appendix A.

Col Peter Demitry, ACC/XRX, a pilot and medical doctor, is the chair of the AF committee tasked to develop an AF policy on fatigue management. Drs. Eddy, Hursh and Storm briefed him on concepts and demonstrated *FAST* to him at his office on Langley AFB. Based on his review of the Phase I version of *FAST*, he concluded that *FAST* can be a significant tool for managing fatigue and controlling the use of pharmacological interventions. He shared his findings along with the graphical output of *FAST* with his superior, the Director of Aerospace Operations, HQ ACC/XO.

Others outside the Air Force have also seen and endorsed *FAST*. John Pollard, US Department of Transportation, accepted an early version of *FAST* and is using it to schedule short-haul railroad engineers. Dr. Chris Flynn, Medical Operations Branch, NASA/JSC invited Drs. Eddy, Hursh and Storm to present *FAST* and its scientific basis to a meeting of sleep scientists, modelers, and interested parties. Dr. Flynn wants to develop a similar tool for use on the International Space Station.

Dr. Thomas Nesthus, CAMI, FAA, has expressed interest in the product and has volunteered to participate in an advisory group for the product during Phase II. General Aviation is in need of a similar tool for predicting cognitive degradation from sleep deprivation and circadian rhythm.

In general, potential users of the product found it useful and encouraged the *FAST* team to stay in contact with them because they were interested in testing and using the product as it matured. They also provided many ideas for new features, integration with existing data (e.g., air tasking order), presentation formats, etc.

Estimates of Technical Feasibility

Due to the success of the Phase I effort described in the previous section, NTI believes that the *FAST* product is technically feasible and has an enthusiastic customer base both within the Air Force, other government organizations, and in the commercial sector. NTI further believes that the Phase II product will satisfactorily meet the goal of the original proposal which was to develop a computerized, user-friendly decision-aid that can assist operational planners in scheduling work and rest to avoid or minimize the effects of fatigue on human performance.

The purpose of this section is to describe the work objectives planned for the Phase II effort, the anticipated results of the Phase II effort, the potential problem areas, and the

applications of *FAST*. The actual work plan for Phase II is described in detail in the Phase II proposal.

Work Planned for the Phase II Effort

There are three main goals for the Phase II effort:

- to enhance the underlying sleep/performance model with new features based on experimental findings (e.g., fatigue countermeasures, transmeridian shifts)
- to modify the graphical user interface (GUI) interface to make it more easily used by military and other planners
- to demonstrate the potential for a commercial product

These goals are defined by the following six primary objectives:

1. To add parameters to the underlying model based on the existing research literature and data collected at the Brooks laboratory both previously and in the proposed effort.
2. To update the software and GUI interface with Phase I lessons learned, user input, and from new information acquired during the proposed effort.
3. To conduct a countermeasure study to acquire data for developing model parameters for a stimulant(s).
4. To conduct a countermeasure study to acquire data for developing model parameters for a sleep aide.
5. To conduct research to discover the sleep and rest habits of pilots as they prepare for a mission during their normal sleep time.
6. To demonstrate *FAST* to potential Air Force users (customers), other government agencies (NASA, FAA, etc.), and the commercial sector (airlines, railroad, trucking, etc.) for feedback and guidance to maximize user acceptance and usability.

Elaboration of the Specific Objectives and Sub-Objectives

Objective 1: Extensions of the SAFTE Model

Task Performance and Pilot Population Based Predictions: During the Phase II effort, the SAFTE Model will be enhanced to predict changes in the effectiveness of piloting task performance based on studies conducted at the Cognitive Assessment and Sleep Laboratory (CASL) located at Brooks AFB, TX. Potential AF customers have requested that *FAST* predictions derive from tests conducted with samples from the pilot population and that *FAST* predictions be shown, as an option, in terms of changes in specific task measurements, such as “bombing error” or “reaction time.” After completing this objective, the effects of fatigue on several specific aircraft performance measures will be predicted by the model and plotted as a percentage of pilot baseline performance.

Transmeridian Adjustment: The scheduling tool must be able to evaluate schedules that transport the operator over time zones, with predictions of performance changes resulting from transmeridian desynchronization (“jet lag”) and an algorithm to readjust to the new time zone (“re-entrainment”). The modifications to SAFTE to account for transmeridian relocation effects will be validated against recent data collected by the Brooks Laboratory

describing the relationship of circadian rhythms and time zone changes to performance measures and alertness.

Countermeasures Effects on Performance: Predictions will also consider the effects of interventions, such as stimulants, sedatives, lighting, diet and naps on the prevention or reduction of fatigue effects on performance. The model will relate the effects of interventions to the underlying architecture of sleep and performance and will predict the magnitude of change in performance depending on the level of sleep deprivation and circadian modulation. Only well established findings will be incorporated into *FAST*.

Sleep Timing Algorithm: Based on user testing during Phase I, we found that many users will not know the sleep schedules of the crews, only their programmed time off-duty. However, the timing and duration of sleep is critical to performance predictions using the SAFTE Model. During Phase II, a separate model will be developed to generate a typical sleep pattern based on a given work schedule. This will require us to conduct user testing to develop an algorithm to automatically schedule expected sleep periods during discretionary (off-duty) intervals that is consistent with normal practices in the subject population. The parameters of this “sleep generation” algorithm will be available to the user to adjust for special populations, or sleep may be programmed directly as in the Phase I tool.

Objective 2: Refinements to *FAST*

Mission Timeline: User testing during Phase I also revealed a need to incorporate a method to permit tabular input of schedule information directly off the Air Tasking Order. During Phase II, a Mission Timeline feature will be added that permits the tabular input of on-duty time and mission related events (take-off, refueling, target time, landing, etc.). The table will also display user selected time zone information and periods of enroute darkness. Sleep periods and nap periods will also be shown on the timeline as a guide to the user. The concepts of transmeriden travel will be accommodated in this objective as well. A mock-up of a Mission Timeline that is currently generated manually is shown in Figure 7.

DYESS AFB TX B1 GLOBAL POWER MISSION # 2						
(GMT-6) (GMT)					BEST SLEEP	
HOME	ZULU	ELAPSED	GUAM	ENROUTE	MSN TIMED	SLEEP
TIME	TIME	TIME	TIME	DARKNESS	EVENT (z)	TIMES
<u>0630</u>	1230	0000	2230	■■■	TO 1242 Z	
<u>0700</u>	1300	0030	2300	■■■		
0730	1330	0100	2330	■■■		S
0800	1400	0130	2400	■■■		S
0830	1430	0200	0030	■■■		S
0900	1500	0230	0100	■■■		S
0930	1530	0300	0130	■■■		S
1000	1600	0330	0200	■■■		S
1030	1630	0400	0230	■■■		S
1100	1700	0430		■■■		S
1130	1730	0500		■■		S<<****International
1200	1800	0530		■		S Date Line
1230	1830	0600		■		
1300	1900	0630			AR#1 1900 Z	
1330	1930	0700				
1400	2000	0730				N
1430	2030	0800				N
1500	2100	0830				N
1530	2130	0900				N
1600	2200	0930				N
1630	2230	1000				N
1700	2300	1030				N
1730	2330	1100				
<u>1800</u>	2400	1130			AR#2 0010	
1830	0030	1200				
1900	0100	1230		■		S
1930	0130	1300		■■		S
2000	0200	1330		■■■		S
2030	0230	1400		■■■		S
2100	0300	1430		■■■		
<u>2130</u>	0330	1500		■■■	LD 0322 Z	

KEY: HOME TIMES THAT ARE UNDERLINED REPRESENT DARK AT HOME
 Enroute Darkness | = Twilight || = Dusk ||| = Dark
 Shaded times in Home column refer to Home darkness
 TO = TAKE-OFF AR = AERIEL REFUEL LL = low level LD = LANDING
 S = BEST AND N = NEXT BEST SLEEP TIMES; NAP AS NEEDED AND AS POSSIBLE

Figure 7: Mock-up of the Mission Timeline feature proposed for Phase II.

Alternative Populations and Performances: Users have asked that the **FAST** program provide options for tailoring the predictions to the expected performance of highly skilled pilots, rather than to the performance of an average person. It would also be helpful to provide options for the kind of performance metric that is predicted, in addition to the standard cognitive test battery currently used to guide predictions. **FAST** will be designed to offer selectable performance measures as the graphic output, based on revisions to the SAFTE model under Objective 1.

Use and Effect of Fatigue Interventions: User testing and discussions with the operational community indicated a strong interest in having the scheduling tool offer guidance to the user concerning the need for interventions, such as pharmacological aids or naps, and predictions of the enhancement in performance that could be expected. The SAFTE Model will be extended to include these modulator effects (Objective 1) and **FAST** will include options to provide user help and predictions concerning interventions to counter fatigue.

Sleep Schedule and Optimal Schedule Generation: **FAST** will include an option to generate a “typical sleep pattern” based on the work schedule, using the sleep generation algorithm described under Objective 1. In addition, **FAST** will contain an option to generate a “recommended sleep schedule” to optimize performance, given the constraints of on-duty time. The tool will also be enhanced to permit the user to enter “initialization

values” to represent varying histories of sleep deprivation prior to the schedule in question. This will allow the tool to predict the effects on a population that starts the schedule in a state of partial sleep deprivation.

User Testing of FAST: Studies will be conducted in field applications to provide information on operator acceptance and usability of the scheduling tool so that the product can be improved to better meet operational requirements.

Objective 3: Studies of the Effects of Stimulants on Pilot Performance: Under extreme battle conditions, fatigue may be unavoidable. Studies will be conducted with pilots undergoing experimentally-induced fatigue and operating laboratory flight simulators to test the amount and duration of improvements in task performance that can be expected with a newly developed stimulant compound called Modafinil. This unusual compound has been reported to restore alertness without the undesirable over-stimulation effects often reported with amphetamine like compounds. The results of these studies will be used to guide the extension of the scheduling tool to predict the effects of stimulants that may be needed when time to sleep is not an option.

Objective 4: Studies of the Effects of Sleep Aids on Pilot Performance: Occasionally during a long duration mission, periods of low activity may occur that would be opportunities for naps to restore performance. Unfortunately, these periods may be during the day when sleep is difficult or they may be accompanied by heightened arousal in anticipation of a combat mission. During such times, sleep may be aided by the ingestion of a mild sedative if it could be used without interference with cognitive ability after the administration of the drug. Zolpidim is a newly developed sedative that may have minimal performance side effects. Studies will be conducted with pilots undergoing experimentally induced fatigue and operating laboratory flight simulators. The pilots will be tested to measure the amount and duration of sleep that is induced by the use of the sedative and the improvements in task performance that can be expected following a sedative induced nap compared to a nap period of comparable duration without the sedative.

Objective 5: Studies of Sleep and Rest Habits in the Pilot Population and Comparison of Schedule Predictions: In order to develop a model to generate a typical sleep pattern based on a given work schedule, a study will be conducted with various pilot populations to assess their use of off-duty time and the self-selection of sleep times and durations. This will allow us to develop an algorithm to automatically schedule expected sleep periods during off-duty intervals that will be consistent with normal practices in the pilot population.

Objective 6: Demonstrate the *FAST* system to potential user populations both within and beyond the Air Force: The old adage of “build a better mouse trap and the customers will beat a path to your doorway” is no longer true. Throughout Phase II, as in Phase I, a list of potential customers in government agencies and commercial enterprise will be, and has been, developed for the purpose of marketing toward the end of the effort. This activity will provide a file of ready and enthusiastic potential customers for *FAST*.

Summary of Phase II Product Enhancements:

Table 3 summarizes the product features of *FAST* for both Phase I and Phase II.

Table 3. Summary of <i>FAST</i> program features			
Feature	Phase I	Phase II	Comments
SAFTE Model Based	X	X	Comprehensive model of fatigue & performance
Single time zone	X	X	Home base time zone
Multiple time zones, adjustment		X	“Jet Lag” Predictions
Cognitive Capacity	X	X	Generic Mental status
Pilot Task Effectiveness		X	Based on Brooks Study
Graphic User Interface	X	X	Input schedules, parameters, visualize results
Multiple Schedule Comparisons	X	X	Performance comparisons
Predefined Schedules	X	X	Library of predefined work and sleep schedules
User Defined Schedules	X	X	User-schedules database
Graphic Output of Predictions	X	X	Paste & Print capability
Quantitative Output of Predictions	X	X	Tabular output, key performance statistics
Sleep Quality Effects		X	Predictions consider sleep fragmentation
Automatic Sleep Schedule Generator		X	Based on work schedule, allocates sleep
Generation of Optimal Solutions		X	Reverse engineers “best” schedule
User define initial conditions		X	Consider sleep restricted populations
Mission Timeline Generator		X	Shows time zones, mission events, sleep
Countermeasure Effects		X	Sedatives, Stimulants, Napping, etc.
Performance Validation		X	Laboratory and Field Studies with Pilots
User Acceptance Testing		X	Field Studies in AF Units

Anticipated Phase II Results

⇒ Performance Predictions Based on the SAFTE Model

The *FAST* system will permit the user to enter any schedule of work and sleep on a timeline and visualize a graph of predicted performance capability that reflects the joint effects of fatigue and circadian rhythms. The architecture and parameters of the model are designed to be flexible so that the model can be updated based on new data or extended to make predictions for specific user populations or particular aspects of task performance.

⇒ Graphic User Interface

The *FAST* product uses a graphic user interface that displays the results of each schedule change. The display can be tailored to show single or multiple schedules and they may be tiled or stacked in the display. The user may select the information shown on the performance graph, including changes in the underlying sleep reservoir and summaries of performance for each time period defined on the timeline.

⇒ Schedule Save, Open and Edit

The product comes with a library of prearranged schedules that may be adapted to a specific situation and saved. In addition, new schedules that are programmed on the screen can be saved to a file. A library of specialized schedules can be created and accessed later for future use. All schedules are saved with information about the work

and sleep schedules and all parameters of the schedule that could be useful in a new context.

⇒ Printing of Graphic Displays and Tabular Data

FAST permits the user to print the current schedule, copy the graphic display to the clipboard for use in another graphics program. The user may also print the tabular display or copy the table to another Microsoft Windows application.

⇒ Predictions of Cognitive Capability

The *FAST* system is based on the SAFTE Model that is based on extensive studies of the effects of sleep deprivation and circadian rhythms on various aspects of cognitive performance, such as adding and subtracting, coding and decoding, logical reasoning, reaction time, decision making, and target tracking. The model predicts changes in performance on these “standard” cognitive tests and these changes can, in turn, be related to aspects of work performance.

⇒ Pilot Task Performance Predictions

The prototype version of the system will be based on the current SAFTE Model that predicts changes in cognitive capacity. Studies proposed for Phase II will test various pilot populations under a variety of schedules and using various countermeasures so that these factors can be incorporated into the predictions of *FAST*. The model will be revised to include transformations to predict changes in pilot task effectiveness for specific populations and operator tasks and *FAST* will predict these specific changes in task performance. The model will incorporate the effects of various countermeasures, such as stimulants and sedatives, as modulators of task performance.

⇒ Multiple Schedule Comparisons

The graphic display can show as many schedules as are available for analysis. The graphic display shows work and sleep schedules and predicted performance. The Phase II display will show multiple time zones and will permit both a work time line and a critical activity time line, such as refueling or landing at destination.

⇒ Transmeridian Adjustments (Jet Lag Effects)

Long duration flights often cross multiple time zones. The internal physiological rhythm is temporarily on the original time zone, so that when performance is required according to the new time zone, performance can be degraded by the desynchronization between the local time and the internal physiological rhythm. This temporary degradation is called “jet lag” and dissipates over a period of many days. The SAFTE Model predicted this temporary degradation due to time zone changes and *FAST* will reflect this period of readjustment as well.

⇒ Sleep Quality Effects

The SAFTE Model can adjust the benefits of sleep based on the occurrence of interruptions in the sleep period, called fragmentation. Studies of sleep apnea and simulated minor awakenings in normal subjects indicate that the quality of sleep can have major effects on its value in restoring performance. The Phase II scheduling tool will

permit the user to select from a menu of choices representing three levels of sleep quality, or sleep fragmentation. If the mission will not permit naps or periods of sleep in a quiet, undisturbed environment, the user may degrade those sleep periods by selecting a less than optimal sleep quality to be associated with those sleep episodes.

⇒ Countermeasure Effects

When adequate sleep is not possible because of mission demands, it may be possible to temporarily enhance performance with a countermeasure such as a stimulant drug or a short nap. Studies will be conducted with pilot populations under sleep deprivation conditions to measure the benefits of various interventions, such as stimulants, sedatives, and brief naps. The benefits of these interventions will be incorporated into the SAFTE Model and reflected in the predictions of *FAST*.

⇒ User Define Initial Conditions

The current scheduling tool assumes that the subject is fully rested at the start of the schedule. This assumption is not always true under realistic operational conditions. A user menu will be developed that permits the selection of three specific “initial conditions” that will modulate the predictions of the tool based on the recent history of sleep. These three parameters are: 1) the average daily sleep during the four prior days, 2) the normal time of sleep onset (bedtime) during the prior four days, the 3) the occurrence of any sleep immediately prior to the start of the schedule. The user may select initial values from lists of possible values, or the user may accept the default values of the tool.

⇒ Mission Timelines

A tabular data entry window will be created that will permit the user to input schedule information directly off the Mission Plan. The Mission Timeline feature will permit tabular input of on-duty time, mission related events, such as take-off, refueling, target time, landing. The table will display user selected time zone information and periods of enroute darkness. Sleep periods and nap periods will also be shown on the timeline as a guide to the user. The Mission Timeline can be printed and used by the crew as a guide during the mission.

⇒ Computer Generation of Sleep Schedules

The user may not know the pattern of sleep in the subject population, only periods of off-duty time when sleep would be possible. Based on studies of normal military pilot populations, the tool will be able to program periods of sleep during off-duty hours that reflect normal practice in the subject population. These “automatic” sleep schedules will make the tool easier to use and enhance its predictive value for the user community. The tool will also, upon request, generate an “ideal sleep schedule” that optimizes performance by arranging optimal sleep within the constraints of off-duty time provided by the user. This recommendation may be used as an educational tool to illustrate the value of good “sleep hygiene” during off-duty periods.

⇒ Computer Generated Optimal Schedules

Although *FAST* is primarily a tool for evaluating schedules proposed by the operations officer, it is possible to develop a version of the system that would propose a schedule that meets certain constraints and optimizes performance at critical times. Similar to the “ideal sleep schedule” feature described above, this version of the system would work the model “backwards”, testing alternatives iteratively until a maximum performance is observed. This feature will suggest alternative work timing as well as sleep timing to optimize performance. This computer-generated schedule can then be used or can serve as the basis of a compromise schedule that meets mission requirements. The system could also suggest countermeasures to further enhance performance.

⇒ Performance Validation

The scheduling tool makes specific predictions of changes in performance under a range of schedule conditions. Several studies will be conducted in actual AF populations to test and validate these predictions using portable cognitive test instruments and ratings of fatigue and alertness.

⇒ User Testing of the Scheduling Tool

As in Phase I, we will continue to provide the scheduling tool to various AF operational communities for user testing. In Phase II, a broader sample of users will be surveyed and a more detailed analysis of user requirements will be conducted. The information from these tests will guide the final design of the user interface and other features of the system, such as the Mission Timelines.

Potential Problem Areas

Some of the objectives defined for the Phase II effort have some risk associated with their completion. This section describes what the risks are associated with those objectives and the probability of failing to meet the objective.

1. Modeling of the effects of pharmacological fatigue interventions. Although early studies of the effects of stimulants on cognitive and flying performance have been conducted, there may be moderator variables associated with those interventions with insufficient databases. For example, Caldwell et al., 1994, 1995, and 1997 has found that stimulants can prevent the effects of sleep deprivation and circadian rhythm disruption in studies of fatigue using helicopter pilots. However, two potential moderators of that effect may be the time of administration and the duration of sleep deprivation prior to intervention.

If there are insufficient data in the literature to estimate the effects of these or other moderator variables, it may not be possible to construct model parameters that are reliable and fully useful. The design of the proposed studies under Objectives 3 and 4 will consider these issues thoroughly before research protocols are written or executed. It may be that model parameters can be developed that will be useful only with aviators or others that meet specific conditions related to the limitations of the current knowledge

of these moderator variables. Models of the effects of stimulants, sleep aides and other fatigue countermeasures are all susceptible to issues of this type.

Another example of a problem of this type is that an intervention may have such a weak effect on performance, that it is not useful to build it into the model. Another example would be that the useful effect is so limited that it would likely never be used. A specific example might be the use of a sleep aide with fully rested pilots prior to an early morning mission. An unaided nap may work as well as a pharmacological intervention. The probability that no useful parameter estimates will be possible for stimulants or sleep aides is rather low (less than 20%), that parameters will be possible but under a limited set of conditions is moderate (less than 50%), but that parameters for pharmacological countermeasures will be limited in some way is high (90%).

2. Sleep Schedule and Optimal Schedule Generation. In Task 5, we will be researching the “typical sleep patterns” of pilots as they prepare for various missions during their normal sleep time. The patterns uncovered may be so variable that no model can be constructed that will be helpful to a mission planner using *FAST*. Should this be the result of our research, we will include information in the help menus of *FAST* to provide guidance to crews and commanders on the best times to obtain rest for families of missions. If possible, *FAST* will contain an option to generate a “recommended sleep schedule” to optimize performance, given the constraints of on-duty time events. The probability of not developing a model to predict the “typical sleep patterns” of pilots is less than 30%.

3. Automated Entry of Mission Events into *FAST*. As we make *FAST* more user friendly, we will be attempting to integrate it with other user planning documents and tools. The AF is spear-heading the DOD effort to develop online, internet tools for the use of operational elements to acquire battle information for planning purposes. The AF uses the Air Tasking Order (ATO) to present the plan of action to each battle element. Although we have registered as a PFPS developer, we have not been able to acquire permission for our programmer to access the developer’s web site information. We anticipate that this problem can be resolved in a timely manner once the Phase II effort is funded and authenticated to the controlling authority. The probability of this authority not being granted or of failing to connect with the necessary information is less than 20%.

Applications of the *FAST* Product

Phase III Applications of *FAST* in the Transportation Industry: The problem of crew scheduling recognized by the AF and addressed by the *FAST* system is shared by many industrial and transportation enterprises. Dr. Hursh, developer of the SAFTE Model, presented as an invited speaker to the Center for Human Performance in Complex Systems. He described the application of the sleep and performance model for the management of fatigue in such diverse environments as nuclear power plants, offshore oil platforms, petroleum tanker ships, airlines, railroads, trucking, and weapons disposal operations. Perhaps the most direct application of the *FAST* system would be in the transportation industry. The problem these industries face are similar to those facing a

FAST paced military operation; equipment must be optimized, down time must be minimized, and crews must be available to operate the systems and must be able to complete the missions without dangerous fatigue. All of the transport industries operate under federal regulations that govern allowable hours of service. Unfortunately, most of the guidelines date back to the 1930's or before. It is generally accepted in the sleep and performance research community that these rules are outdated and the Department of Transportation occasionally reevaluates them. Nevertheless, currently no generally accepted alternative to hours of service rules has been developed.

NTI has already initiated a market survey of current crew scheduling systems for this project. This survey indicates all major modes of transportation have available some form of scheduling software for the management of personnel, see Table 4. Some of these systems relate crew schedules to applicable hours of service rules. The *FAST* system offers a modern solution to the problem of managing fatigue in the transportation industry. The features of *FAST* could be combined with the administrative systems for managing crews currently used by the various transportation modes summarized in Table 4. This hybrid product would simultaneously meet the administrative requirements of the respective industry and would evaluate proposed schedules against the predictions of fatigue and performance in *FAST*. The system could automatically adjust schedules to maintain performance within acceptable limits or offer suggestions to the scheduler for improved crew performance. The system would meet administrative and economic requirements and at the same time maintain performance of crews according to the guidance of the best available scientific model of fatigue and performance. Such a system would represent a "best practice" for fatigue management and would go beyond the outdated parameters of current hours of service rules.

A major Phase III effort will seek to obtain support from the Department of Transportation and the transportation industry to develop a demonstration system tailored to a specific transportation environment. The Department of Transportation has already expressed an interest in *FAST* and has obtained a Phase I version to assist AMTRAK in evaluating several proposed schedule changes for railroad engineers.

Table 4: Existing Transportation Scheduling Systems

AIRLINE	TRUCKING	RAILROAD	MULTIMODAL
<p>AIRCREWS SABRE Decision Technologies</p> <ul style="list-style-type: none"> - Forecasts Appropriate Number of Crew Members Needed for Future Flights - Generates All Possible Combinations for Staffing Flights and Determines the Most Cost-Effective Schedule - Ensures Scheduling is Fair to All Crew Members by Distributing Workload Evenly - Alerts User of Potential Problems such as Crew Member Illness and Offers Recommendations for Adjustments 	<p>LoadLogic Information Software, Inc.</p> <ul style="list-style-type: none"> - Enables Better Fleet-Resource Utilization - Automatically Optimizes Resources IAW Constraints and Regulations - Allows Dynamic Recalculation of Late-breaking Information - Generates Comprehensive Reports, including Bills of Lading, Etc. - Includes Mileage Database - Details Cost Definitions for Loadbuilding 	<p>Crew Requirements Model Muten Associates, Inc.</p> <ul style="list-style-type: none"> - Determines Minimum Number of Labor Crews Required to Operate All Trains for a Given Set of Circumstances - Traffic Database Provided by Client - Default Tables that Can be Modified to Accomodate Crew District Assignments, Work Rules, Crew Assignments - Model Can Simulate Outcomes of Changes to Tables - Can be Read by Other Software 	<p>Product Movement Planner (PMP) Federal Express TCSI</p> <ul style="list-style-type: none"> - Controls \$4 Billion Worldwide Fleet of Over 260 Aircraft and 31,000 Trucks - Allows Development of Rapidly-Defined, Cost-Effective Aircraft and Truck Schedules to Meet Forecasted Package and Cargo Volumes - Schedules Satisfy Complex Timing, Capacity, Operational and Cost Constraints - Allows "What-If" Analysis of What Could Happen in Advance and Prepare for It

Phase III Applications of FAST in the Nuclear Power Plant Industry: Fatigue is a potential problem in the highly complex and round-the-clock environment of the nuclear power plant industry. Both the Three Mile Island and Chernobyl accidents occurred in the early morning hours when fatigue could have been a contributing factor in the mismanagement of the plant failure. Unlike the transportation industry, no general hours of service rules govern work at nuclear power plants. A shift scheduling system based on *FAST* for the nuclear power plant industry could be used to schedule workers and schedule delicate maintenance operations to optimize performance and minimize risk. The utility industry currently uses Probabilistic Risk Assessment (PRA) to minimize the risk of equipment failure, but human error is seldom considered because, up to now, no model existed to guide the assessment of variation in human error probability resulting from fatigue and circadian rhythms. The *FAST* system could be enhanced to meet this requirement and reduce the risk of human error in the complex environment of the nuclear power plant industry.

Phase III Projects and Funding: In a letter of support for the SBIR effort, Dr. Chris Flynn, NASA/JSC, has indicated that NASA has an interest in “using *FAST* with ground-based personnel who work International Space Station console operations.” Many people at NASA operations have commented on the fatigue experienced during the ground-based monitoring of Shuttle Flights. The schedules used are very aggressive and often result in very fatigued console operators. In an extension to our Life and Microgravity Spacelab mission on STS 78, we had the opportunity to collect cognitive performance data on an Alternate Payload Specialist (APS) who worked the console at Huntsville, AL.

The ground crews work the same schedule as the shuttle crew, but start two hours earlier and end two hours later. Our data indicated that the APS was possibly the most fatigued of all the subjects we tested both on and off the shuttle.

Dr. Flynn is well aware of this situation. In his letter he indicated that “NASA/JSC would be interested in funding further studies of a fatigue/performance tool.” As we approach the end of Phase I, NTI and the *FAST* team will approach Dr. Flynn to develop specific objectives.

NTI is currently working with Wyle Laboratories to process data from NASA’s Space Cognitive Assessment Test (SCAT) that was used in a fatigue study at Brooks AFB. Pilots were kept up 52-hours, flew 3 simulated missions every three hours on FPASS and took the SCAT test battery. The soon to be published data showed that several of the SCAT tests, which were designed to be sensitive to neurological trauma, are also sensitive to fatigue. Because of this study, it would be logical to use the data from SCAT to develop a model for predicting cognitive performance.

Dr. Flynn has also expressed an interest in adding a capability to *FAST* for acquiring actigraph data. This would allow cognitive performance predictions to be based on actual sleep schedules rather than estimated. With this additional capability, *FAST* would be able to correct its predictions of cognitive efficiency based on actual sleep. We believe that the Medical Operations Branch at NASA/JSC is a likely candidate for Phase III funding of continued *FAST* development. All of the criteria for use of the product mentioned in Dr. Flynn’s letter of support (a fatigue model, a predictive performance model, and a front-end display of information) have already been met in the Phase I product. It would seem that we have developed exactly what he needs.

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Appendix A

1. It (*FAST*) seems very interesting, and likely very useful. To get operator buy in I think you will need to re-examine your terminology and decisions about where we draw the cut-off lines. From an ORM perspective, where you draw the caution and danger zones for performance should be based upon something more operational than time to complete an arbitrary mental task, or a better correlation needs to be shown to those operational tasks, including:
 - mean error rate performing procedural tasks (calculating TOLD, running checklists)
 - mean error rate performing hand-eye tasks (flying an ILS)
 - mean time to recognize and react to a stimulus (such as an engine fire light, GPWS warning, altitude alert)
 - mean time to analyze common problems (fix to fix, descent rates, inappropriate clearance)
 - number / time to conduct instrument cross checks
2. Certainly it is true that in major mishaps knowledge based mistakes are more likely to be causal than rule-based mistakes or slips, but since the majority of our operations occur in the later two realms (rarely encountering situation for which no pre-packaged rules or training exists), it is important to show where that red-line takes place.
3. Other "red-lines" may exist besides complex mental task, the most important of which in the aviation community is the number of cross-checks (the number of times the pilot purposefully scans and decodes information from his control and performance instruments). As these decline, opportunity to notice and correct a wrong input or malfunction diminish. In close proximity with the ground as in the final segment or initial takeoff this is extremely crucial. I would guess you reach a red-line long before you have your time to complete a circuit of cross checks has doubled-but since this is an over-learned recognition/motorskill, and one of the first learned (and so last to decay), it would be interesting to see where this red-line takes place relative to the decrease in mental task performance.
4. Yet another red-line I would be interested in seeing is where conservative judgment diminishes and the FIDO (forget it drive on) attitude of complacency takes over.
5. Basically, in airplane performance, we talk about three categories of performance:
Assuming a given set of circumstances:
CAT 1: Computed Performance exceeds what is required.
CAT 2: Computed Performance equals what is required.
CAT 3. Computed Performance is less that what is required.
6. For pilot performance on checkrides, we talk about three categories as well
Q-1: Pilot met all requirements in a satisfactory manner
Q-2: Pilot had minor discrepancies but was still considered safe
Q-3: Pilot did not meet all requirements in a satisfactory manner
7. The checkride is the standard of proficiency that we require from our pilots. A good measure of when a pilot "RED-LINES" or goes CAT 3 for fatigue would be when they are no longer able to complete all checkride requirements in a satisfactory manner. Most of this is very well defined in the Master Task List.

Appendix B. The specific mathematical expressions that describe the model and the default values of all the variables.

SAFTE Model Mathematical Expressions and Default Values of Variables

No.	FUNCTION NAME	EXPRESSION	WHERE:
Circadian Functions:			
1	Circadian Oscillators	$c = \cos(2 * P * (T - p) / 24) + \cos(4 * P * (T - p - p') / 24)$	T = time of day p = 24 hr phase in hours p' = 12 hr relative phase in hrs = rel. amplitude of 12 hr cycle
2	Sleep Propensity	$SP = m - (as * c)$	m = mesor as = sleep propensity amplitude
3	Performance Rhythm	$C = ap * c$	ap = perform. rhythm amplitude
Feedback Function:			
4	Sleep-Wake Cycle	$SWC = f * (Rc - Rt)$	Rc = Reservoir Capacity Rt = Current Reservoir Balance (Rc - Rt) = Current Reser. Deficit f = amplitude of feedback
Sleep Reservoir Functions:			
5	Sleep Intensity	$SI = SP + SWC$	in sleep units per minute
6	Sleep Inertia	$I = 100 * e^{(-1 * (ta * 1 / SI * i))}$ max=lmax	i = inertia time constant for two hr after awakening
7	Performance Use	$P = K * t$	K = performance use rate
8	Sleep Accumulation	$S = SI * t$	t = time interval
9	Reservoir Balance	$Rt = Rt - 1 + S - P$	total sleep units at time interval t
10	Effectiveness:	$E = 100 * (Rt / Rc) + C + I$	as percent of baseline
DEFAULT VALUES OF VARIABLES:			
	Pi		3.1415
	p = 24 hr phase in hours		1800 hrs
	p' = 12 hr relative phase in hrs		4 hrs
	= relative amplitude of 12 hr cycle		0.5
	m = sleep propensity mesor		0
	as = sleep propensity amplitude		0.5 sleep units
	Slmax = maximum limit on sleep accumulation per period		3.4 sleep units per minute
	ap = performance rhythm amplitude		10 percent
	Rc = Reservoir Capacity		2880 sleep units
	f = amplitude of feedback		0.002587
	i = inertia time constant for two hr after awakening		0.07
	lmax = maximum inertia following awakening		10 percent
	K = performance use rate		0.5 units per minute
	t = time interval		x minutes
	ta = time awake		minutes since awakening