ESTIMATING THE NEED FOR MEDICAL INTERVENTION DUE TO SLEEP DISRUPTION ON THE INTERNATIONAL SPACE STATION

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SPACE LIFE SCIENCES SYMPOSIUM (A1.)

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Abstract

During ISS and shuttle missions, difficulties with sleep affect more than half of all US crews. Mitigation strategies to help astronauts cope with the challenges of disrupted sleep patterns can negatively impact both mission planning and vehicle design. The methods for addressing known detrimental impacts for some mission scenarios may have a substantial impact on vehicle specific consumable mass or volume or on the mission timeline. As part of the Integrated Medical Model (IMM) task, NASA Glenn Research Center is leading the development of a Monte Carlo based forecasting tool designed to determine the consumables required to address risks related to sleep disruption. The model currently focuses on the International Space Station and uses an algorithm that assembles representative mission schedules and feeds this into a well validated model that predicts relative levels of performance, and need for sleep (SAFTE Model, IBR Inc). Correlation of the resulting output to self-diagnosed needs for hypnotics, stimulants, and other pharmaceutical countermeasures, allows prediction of pharmaceutical use and the uncertainty of the specified prediction. This paper outlines a conceptual model for determining a rate of pharmaceutical utilization that can be used in the IMM model for comparison and optimization of mitigation methods with respect to all other significant medical needs and interventions.

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INTRODUCTION

Maintaining high alertness and performance levels during space operations is critical to both the safety and success of the mission. However, research has shown that performance decrements occur during spaceflight and it is not uncommon for these observed decrements to be associated with reductions in sleep quality and quantity [1-3]. Subjective and objective measures have shown that daily sleep duration during orbit is around 6 hours and can even be as few as 4 hours per day [3-8]. This quantity of sleep is significantly less than the average daily sleep need of ~ 8 hours considered necessary to maintain alertness and performance across waking hours. Sleep loss continues to be documented across in-flight days with total durations being even further reduced prior to mission critical tasks [9]. Figure 1 illustrates a typical sleep situation on board the US Space Shuttle in which it is clear that environmental factors including confined space and lack of a secure sleeping quarters (i.e., sharing sleeping space with others) can also contribute to reduction in the quality of sleep in space.

The challenge of crew members obtaining consolidated and efficient sleep, i.e. uninterrupted and restorative sleep, is further evidenced by the increasing reports of the use of sleep aids and hypnotics during flight. While less than 50% of astronauts requested or reported using sleep medication during a shuttle mission in the mid 1990's [10, 11], recent subjective data collected for 10 US Space Shuttle flights have shown that 81% of crew members reported using medication to help them sleep [9]. The data also revealed that astronauts reported using sleep aids during 50% of in-flight days and not just during the first few days in orbit, which is considered to be an adjustment period.

Although the majority of sleep/wake data and the prevalence of sleep aid and hypnotic use have been collected during shuttle operations, the same factors that challenge human physiology remain. These factors include, but are not limited to, insomnia, disrupted sleep schedules due to operations scheduled for off-nominal hours, noise levels within the spacecraft, physiological adaptation to microgravity, and the need to, and complications with, voiding.

Figure 1. Pam Melroy, George Zamka, bottom right,and European Space Agency's Paolo Nespoli, sleep in the of the Space Shuttle Discovery middeck while docked with the International Space Station, Thursday, Nov. 1, 2007. (http://www.daylife.com/photo/05m194q0hQcNl, original provided by NASA)

Given the risks associated with sleep loss during space flight, NASA continues to focus research on the development of countermeasure and intervention approaches that will optimize sleep/wake cycles during flight. Mitigation strategies have been implemented, including those that require pharmacological consumables, to avoid increased operational risks associated with chronic sleep loss. However, There is a need to predict, based on what already occurs during space flight, the level of sleep disruption and sleep loss expected for future missions so that related factions influencing mission planning and consumable usage can be better understood..

The Sleep Disruption-Medical Intervention Forecasting (SDMIF) tool is being developed to estimate the occurrence

and severity of sleep loss. This tool will assist International Space Station (ISS) planners in identifying the optimal amount of sleep promoting and alertness enhancing pharmaceuticals needed to ensure astronaut performance during all future space flight operations through its integration into the Integrated Medical Model (IMM).

IMM and SDMIF

As part of the NASA Exploration Medicine Capability Project, the IMM is being developed to help guide exploration planning, requirements development, and R&D investment activities. The IMM is a software-based system that will identify and quantify the medical needs and health risks of exploration crew members during space flight, as well as evaluate potential mitigation strategies. The IMM project employs an evidence-based approach to quantify probable consequences of all potential in-flight medical events for different space mission scenarios. The approach incorporates success probabilities of typical treatment strategies to respond to each medical event and those of pre-flight and in-flight efforts to address maintaining crew health in order to avoid the medical event occurrence.

The IMM uses Monte Carlo simulations and other stochastic techniques to simulate planned mission scenarios and quantify levels of medical risk by utilizing the best available evidence and understanding with regard to the occurrence and successful response to medical conditions in space. These quantified scenarios will ultimately inform decision makers of the relative impact of potential medical risks and enable objective assessment of crew health and optimization of mission success. For more information regarding the development of the IMM Project see Fitts et al.[12].

The goal of the NASA – Glenn Research Center Sleep Disruption-Medical Intervention Forecasting (SDMIF) tool is to assist planners using the IMM to optimize the medical supplies (i.e. consumable pharmaceuticals) required to treat sleep related challenges in order to ensure mission success and astronaut performance. Similar modeling processes have been developed at the NASA-Glenn Research Center to estimate the likelihood of bone fracture for planning and optimization of various space missions [13, 14]. The following paragraphs describe the SDMIF conceptual model structure and the planned implementation, illustrate preliminary results, and discuss remaining efforts, as well as model application and known limitations of the approach.

MODEL OUTLINE

The IMM model uses the SDMIF tool to obtain an estimate of the amount of stimulant, hypnotic medication, and other pharmaceutical countermeasures that are needed during space flight missions, based on the current state of knowledge of sleep conditions and operational planning. To accomplish this goal, the SDMIF tool addresses the disruption of normal sleep patterns associated with mission operations and environmental conditions by integrating an industry accepted sleep performance model and research data regarding the use of sleep aids.

Model Requirements

To address the needs of the IMM parent tool and to simplify the integration effort, the SDMIF is designed to meet several requirements. The primary requirement is that the SDMIF tool has the ability to predict the incidence rate and probability of a clinically significant occurrence of circadian rhythm disruption, insomnia, sleep deprivation or other

significant sleep disturbance. In this case, a clinically significant occurrence is defined as a condition that would be recognized by a physician medical operations officer (clinical diagnosis) or the impaired crew member (self diagnosis) resulting in some level of intervention. In most cases this would be modeled as a need to use a hypnotic to promote consolidated and efficient sleep during prescribed sleep periods or to use a stimulant during work periods to help maintain performance levels. To be used as a planning tool within the IMM, the rate of use is to be provided in the form of a probability density function, which describes the most likely rate of consumption per astronaut per mission time in addition to the uncertainty in the estimate.

Further requirements of the SDMIF tool focus on insuring that appropriate consideration is given to the underlying causes resulting in the need for medical intervention. Generally, this means that the predicted schedule, means of diagnosis, and forecasted rate of intervention is in agreement with the past experiences of mission crews and medical operations personnel. The desired outcome is that factors that affect sleep quantity and quality are adequately assessed such that simulated sleep/wake periods are indistinguishable from those observed in past missions given the same initial parameters and planned schedule. Similarly, the means of diagnosis, such as sleep drive, performance decrement, or operational standards, must be appropriate for the specified scenario in order to adequately forecast the rate of medical intervention.

Initial development of the model is to focus on the sleep/wake patterns for Shuttle and ISS crew due to the abundance of information available from experience on these vehicles. This will help future ISS increments more adequately plan their pharmaceutical stores. Further, successful implementation focused on ISS missions will provide a baseline, from which adjustments can be made for use in more complex mission scenarios, such as to the moon and Mars.

Conceptual Model

Figure 2 graphically outlines the conceptual framework for the SDMIF modeling tool, which includes four major components: a mission parameter module, a well validated sleep and performance model, a sleep drive metrics translation function, and a diagnostic decision making tool.
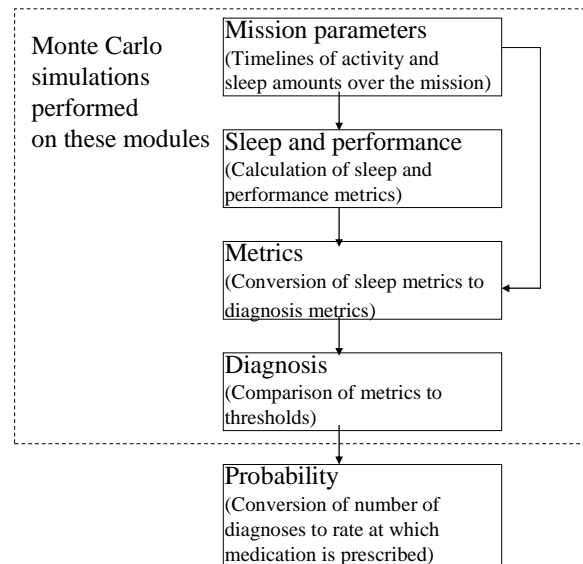

Figure 2. Conceptual Outline of Modeling Tool Structure

In concept, the model algorithm assembles representative mission sleep opportunities and actual sleep times and predicts human effectiveness levels based on these patterns. This information is transformed into metrics representative of measures for the need for sleep, compared to threshold values to diagnose the likelihood for treatment. The metrics are correlated to the likelihood that a consumable mitigation approach is used during a particular mission day. The components of the model are integrated within a Monte Carlo simulation

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to provide a predicted rate of consumables that corresponds to the wide variations in affecting parameters over the course of an entire mission.

Model Components

Overview

As described in the Conceptual Model section, a Monte Carlo approach is taken to address the wide variation within the parameters contributing to the occurrence of sleep disruption and for forecasting the need for medical intervention. Relative to the statistical variation of the input parameters, the Monte Carlo simulation randomly samples each parameter space as required by each module. Each trial of the model then consists of a random combination of the model parameters that represents a reasonable scenario based on the available data. The results are integrated over the random trials of the mission scenario to prescribe the rate at which medical intervention is required due to sleep disruption. Convergence of the simulation is said to be achieved when the standard deviation of the output PDF varies by less than 0.01 for each additional 100 sample trials. By encapsulating these modules in this manner, a statistically relevant representation of the rate of consumable use, an understanding of the uncertainty in the estimate and information of the chief contributors to that uncertainty are developed.

Mission parameter module

The mission parameter module generates realistic ISS mission schedules of sleep and wake times. The schedules include events that cause a shift in the sleep schedule, the best available data on the actual amount of sleep obtained by astronauts in space and the quality of that sleep. The program takes into account the uncertainty in these parameters by using distributions rather than single values for the parameters. During each trial[1] of the Monte Carlo simulation a new schedule is generated from the parameter distributions. The output of the mission parameter program is a matrix where each row represents a mission day and each column represents a one minute time increment throughout the day, from 00:00 to 23:59. The matrix is filled with ones and zeros. A one indicates the astronaut is awake during that time increment and a zero indicates the astronaut is asleep.

Astronauts are scheduled to be awake from 06:00 to 21:30 GMT during a normal International Space Station (ISS) mission day. ISS extra-vehicular activities (EVAs) and Shuttle, Soyuz and Progress dockings are critical events that require a shift in the work day. The mission parameter program incorporates a representative number of these events, based on historic data, and shifts the scheduled work day accordingly. The normal scheduled sleep opportunity for astronauts is 8.5 hours per night and studies have quantified the actual amount of sleep obtained during that sleep opportunity [3, 15]. A distribution for the actual amount of sleep obtained per night was developed for our model from these reported data [3, 15].

The quality of sleep depends upon the frequency and quantity of wakefulness, or interruptions, during a sleep period. Modeling occurrences and types of interruptions within the sleep periods was based on measured sleep pattern data from past US space missions [3, 16].

The mission parameter information is converted into input compatible with sleep and performance module. Transitions between work and sleep are determined by

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[1] A trial is defined as one pass through the SDMIF, representing a single mission simulation, with one set of randomly determined parameters

calculating the difference between adjacent matrix elements across all days of the simulated mission. Three possible cases exist: the difference equals negative one, representing a wake event (0-1), positive one for a sleep event (1-0), and zero for no change (0-0 and 1-1). After all transitions are located, the time and duration of work/sleep periods are calculated. This information, along with initial conditions and other variables related to the quality of sleep during sleep periods are converted into an XML file for input into the sleep and performance module.

Sleep and performance module: SAFTE

The effects of sleep timing and duration and the influence of time of day (circadian effects) on performance are estimated using the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) Model, (IBR Inc) model. This model was chosen for five reasons:

1. it predicts performance in non-arbitrary units of performance effectiveness that relate directly to performance on a psychomotor vigilance task.
2. it requires a minimum number of input variables.
3. it has a method for reflecting the degrading effects of sleep fragmentation or sleep interruptions.
4. it tracks changes in circadian phase based on changes in the work/rest schedule that commonly occur on ISS.
5. it has been validated as an accurate predictor of risk in the work environment[17].

At the center of the model is a sleep reservoir which, along with the circadian rhythm and sleep inertia, determines performance effectiveness. Each unit of the reservoir is equal to 1 unit of effectiveness that is accumulated during normal sleep at the average rate of 1 unit per minute and used during time awake at the rate of 0.5 units per minute. Hence, 8 hours of sleep provides enough units of effectiveness to sustain 16 hours of performance. The capacity of the reservoir is sufficient to sustain continuous performance for a maximum of 96 hours, or 2880 units. The reservoir percent fill is defined as the linear component of percent effectiveness function while awake. The reservoir component sums with a circadian oscillator (a two component cosine function) which is defined in +/- units of percent effectiveness, and with a sleep inertia function, defined in units of temporary deficit in percent effectiveness immediately following awakening. The SAFTE model will directly predict changes in percent effectiveness within the practical range of zero sleep deprivation (nominal 8 hours of sleep per day) to 96 hours of continuous sleep deprivation[2]. Actual data may be compared to the model by plotting the performance as percent of baseline; baseline being defined as the average performance of a person fully rested and fully trained on the task being tested.

During periods of scheduled sleep, the model replenishes the sleep reservoir. The rate of accumulation or sleep intensity is determined by the amount of deficit in the reservoir and the circadian drive to sleep based on time of day. Further, the SAFTE model incorporates simple logic to reflect the degradation of sleep benefits caused by interruptions in sleep in unfavorable sleeping environments or when a crew member is suffering some from of discomfort.

The SAFTE model has been validated against laboratory data on sleep restriction and a major study of railroad

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[2] Note: the maximum duration of sleep deprivation in the literature is less than 85 hours.

accidents has demonstrated that the model can predict increases in accident likelihood and severity (risk) based entirely on work schedule data [17].

For this project, each trial wake/sleep schedule generated from the Monte Carlo sampling is passed through the SAFTE model to determine both the predicted levels of performance effectiveness and predicted levels of sleep intensity while scheduled to be asleep over the mission duration. Difficulties sleeping will be inferred from the co-occurrence of a scheduled period of sleep and a low level of predicted sleep intensity.

Diagnosis module

The diagnostic module remains under construction, but the conceptual framework has been generated. In general the diagnosis module is a means of relating a prospective need for sleep to the likelihood that a sleep aid is utilized to achieve restorative sleep. The underlying premise of this approach is that below a certain threshold of estimated sleep intensity, a pharmaceutical intervention is likely to be utilized. The specification of this threshold level will likely be complex, with inter-individual differences contributing to a wide uncertainty in exact specification.

To account for the expected uncertainty and to forecast the use of a sleep aid during a sleep period within the mission, a two step process is followed:
1. Calculate the probability a sleep aid is needed and used. This is termed the Probability of intervention.
2. Execute a decision process to decide if a sleep aid is used for that sleep period.

The forecasted utilization for pharmaceutical sleep aids is summed over each trial mission and a rate per unit day per astronaut is determined. The probability density function (PDF) output of the Monte Carlo

simulation is then generated from the ensemble average of the forecasted rates of usage.

Estimating the probability of a pharmaceutical intervention based on assessments of sleep intensity and other sleep metrics could be accomplished with a sigmoid function as illustrated in Figure 3. The sigmoid formulation provides a feasible translation function that can be derived from estimates of the sleep metric (intensity) threshold (taken to be the point where an intervention is more likely than not, i.e. Pr > 50%). Uncertainty in the actual interventional threshold can be represented as a family of probability mapping functions, whose parameters can be specified as functions within the Monte Carlo Simulation. Efforts to specify this formulation are ongoing.
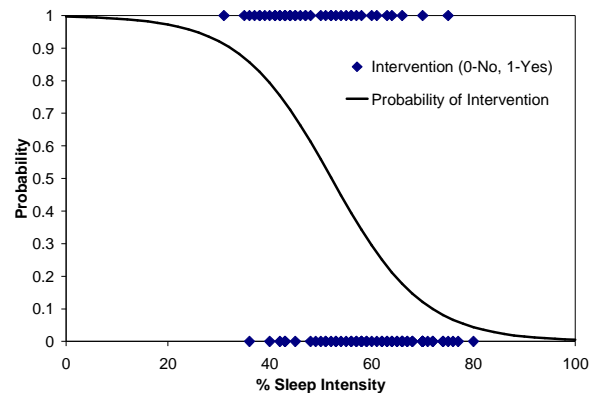
Figure 3. Illustration of type and form of the transfer function that will relate sleep intensity to probability of interventional medication. The data points at 0 and 1 illustrate how the non –use or use of a sleep aid will be combined with estimated % sleep intensity predicted by SAFTE to estimate the probability of intervention to promote sleep.

The decision process for determining the predicted use of a sleep aid during a sleep period utilizes probability of intervention and the fact the parent model is executing a Monte Carlo trial. To accomplish the decision making step, the probability of intervention is assumed to be

a YES-NO (special case binomial distribution), which can be sampled in the same manner as the parameter values within the overall Monte Carlo simulation. In effect this removes the necessity to simulate subjective perception of sleep difficulty from the decision making process of a particular instance and replaces it with a random sampling of the statistical likelihood of the sleep aid usage.

DISCUSSION

A numerical approach has been developed to generate quantitative estimates of the utilization of sleep aids on space missions. As part of the IMM project, the SDMIF tool concept outlines probabilistic and stochastic modeling techniques, in conjunction with validated models of sleep and performance, to forecast the need for medical intervention throughout a specified mission scenario. With this approach, the SDMIF will enable informed mission planning and allow for relative comparison of benefits and determents of adverse health mitigation strategies with respect to all medical events simulated in the IMM frame work. At present the model is designed to address only the forecast of the utilization of sleep aids, but will be extended to address interventional medications that address other sleep and fatigue issues related to performance.

The SDMIF framework is structured similar to an object oriented program, where encapsulated sections of data and model processes can be replaced as new data or more appropriate processes are developed. At the core of the SMDIF is the use of a well validated sleep and fatigue model. In the SDMIF developmental framework, SAFTE was chosen due to its comparative versatility to other models and will be used as a bench mark with the overall model structure. Compared to other fatigue models, the SAFTE model has many fewer

estimation parameters required to predict performance and minimal input requirements to represent the effects of a given schedule. SAFTE also includes components that permit the model to represent the performance and sleep disruptions associated with sudden shifts in schedule and the rate of adaptation to such disruptions. However, other models are in development that could provide additional insight into space mission sleep interventions[18]. Due to the versatile framework of the SDMIF structure, it will be possible to incorporate other sleep/performance models as needed in future versions.

Preliminary work with the SAFTE model to illustrate the expected changes in sleep intensity between generic terrestrial works days and generic ISS work days is shown in figure 4. Comparison of the daily output values illustrates that at a predicted sleep intensity of 0.55, initiation of sleep would likely be difficult.
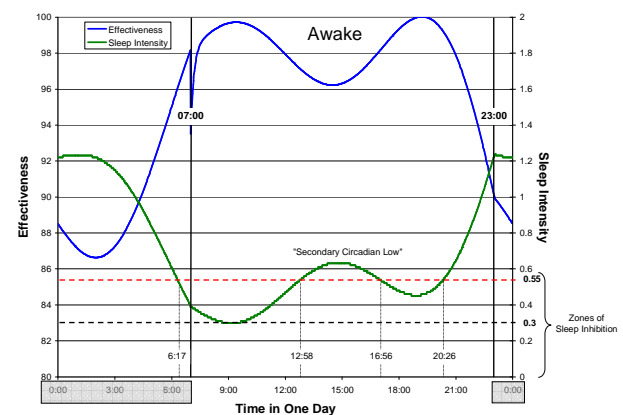
Figure 4. SAFTE output for a generic terrestrial work day. At times when sleep intensity is less than 0.55 units, it is proposed that SLEEP INITIATION would be difficult, a request for a sleep aid would be more likely (i.e. the probability is greater than 50%) and that the degree of risk would be inversely proportional to sleep intensity below 0.55.

Work continues to complete the SMDIF metric conversion and diagnosis modules

with expected completion and validation by the end of Calendar year 2009 at which point an internal review with subject matter experts from NASA and supporting organizations will be conducted. After a successful review the SDMIF output will be integrated into the IMM parent model.

Limitations

Probabilistic models are inherently difficult to validate, especially for space mission scenarios where much of the data normally used in validation must be included in the model. When possible, the predicted rate of use of sleep-decrement associated consumables will be compared to reference mission data from existing ISS increments for validation. However, this is expected to provide limited validation until further studies isolating the per astronaut utilization of medications are completed. In the mean time, an advisory board with members from the space life science community, specializing in Space flight and the impact of sleep disruption and inhibition will provide guidance and a "face-validation" to the model concept, data utilized, and model implementation.

As indicated in the text, the versatility of the SAFTE model provided sufficient cause for its use in the development stage of the SDMIF, it does not preclude the use of other modeling schemes developed to have more focused application to addressing to the rigors of space flight on sleep[18]. As the SDMIF frame work is straightforward, it should be straightforward to integrate these more specific models if deemed necessary.

Although the SDMIF tool is based on probabilistic risk analysis and stochastic modeling techniques, the primary goal is not to predict risk of a given performance decrement or how such a decrement could impact a mission outside the predicted rate of consumable use. The model is currently specific to IMM requirements and does not directly address NASA Human Research Program gaps associated with sleep and human performance. However it may be modified to address such gaps in the future, as well as, provide a foundation to address these gaps.

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Abstract

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ESTIMATING THE NEED FOR MEDICAL INTERVENTION DUE TO SLEEP DISRUPTION ON THE INTERNATIONAL SPACE STATION

Integrated Medical Model Task
Exploration Medicine Capabilities Project
Human Research Program

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Topics to cover
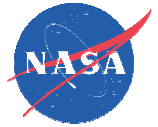
- Overview
  - Integrated medical model (IMM)
  - Need for determining the rate and total sleep intervention medication
- Sleep disruption-medical intervention forecasting (SDMIF) tool
  - Conceptual model structure
  - Model assumptions
  - Model output
- Model components and supporting data
  - Forecasting mission parameters
  - Estimating sleep and performance measures
  - Diagnosis the need for medications
- Sample calculations and model uncertainty
- Validations of the model
- Conclusions

Integrated Medical Model (IMM)

Potential Medical Condition

Evaluate with IMM

Crew Demographics and Medical history

Treatmetn Options

Training Effectiveness

Best Evidence Clinical Literature

Integrated Medical Model

Equipment and Supplies

Mission Profile

Medical Procedure Effectiveness

Impact to Crew Health

Likelihood of Mission Success

Likelihood of occurrence, probable severity of occurrence, and optimization of treatment and resources.

- Captures and uses organizational knowledge across the space medicine, systems engineering, logistics, and research domains.
- Uses this domain knowledge in the context of mission constraints and profiles, crew profiles, and in-flight medical capabilities to forecast impacts to the mission due to medical events.
- Identify medical resources necessary to optimize health and mission success.

Space Flight and Sleep
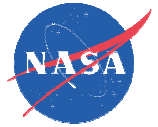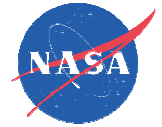
- Space flight induces reductions in sleep quality and quantity
  - Potential performance decrements
- Primary mitigation
  - Consolidated and efficient sleep
    - Power naps
    - Extended sleep opportunities
    - Impacted by scheduling and environmental factors
  - *Medications* or sleep aids
    - Medication usage rates not explicitly known
- Challenge in support of the IMM:
  - Develop a tool to estimate rates of medical intervention resulting from low sleep quality and duration

Sleep Disruption- Medical Intervention Forecasting (SDMIF) Tool

- ## Model requirements
  - Predict the incidence rate of **clinically significant** sleep disturbance
    - Circadian rhythm disruption, insomnia, environmental disruptions
  - Predicted schedule, means of diagnosis, and forecasted rate of intervention is in agreement with the past experiences

- ## Conceptual model structure

- ## Underlying assumptions
  - Utilize validated modeling of sleep and performance
  - Sufficient data exists to allow statistically representation of events

Monte Carlo Simulation

Mission Parameters

↓

Sleep & Performance

↓

Metrics Translation

↓

Diagnosis & Decision

↓

Probabilities & Rates
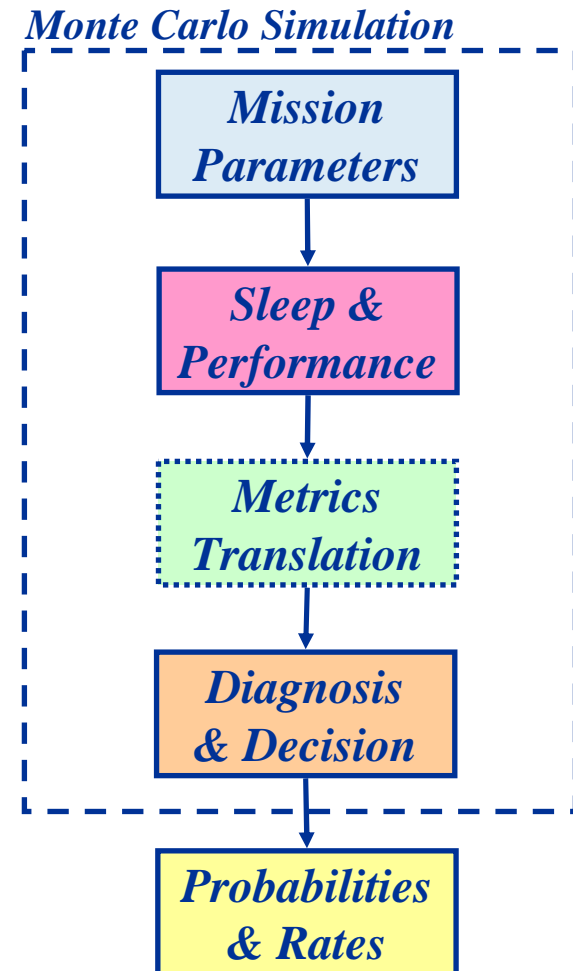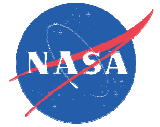
Mission Parameter Component

- The mission parameter component generates realistic ISS mission schedules of sleep and wake times.

- The key components of the mission parameter module are:
    - Sleep/wake schedule, including shifting
    - Actual sleep time within a scheduled sleep period
    - The sleep quality of the actual sleep

- The program takes into account the uncertainty in these parameters by using distributions rather than single values for the parameters.

Mission Parameter Component
Sleep/wake schedule
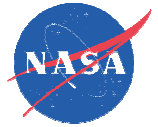
- During a normal day on ISS the astronaut is awake from 6:00 – 21:30 GMT, and their sleep opportunity is from 21:30 – 6:00 GMT.

- Critical operations include:
  - EVAs
  - Unmanned dockings (i.e. Progress)
  - Manned dockings at the end of an increment (Shuttle and Soyuz)

- Many of the critical operations include shifts to the sleep/wake schedule including:
  - Slam shifts and gradual shifts
  - Phase advance and phase delay shifts

Mission Parameter Component
Sleep/wake schedule
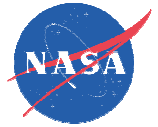
- The output of the mission parameter component is a matrix of 1's and 0's. A 1 indicates the astronaut is awake, a 0 indicates the astronaut is asleep. The matrix is graphically shown here with a * representing a 1.
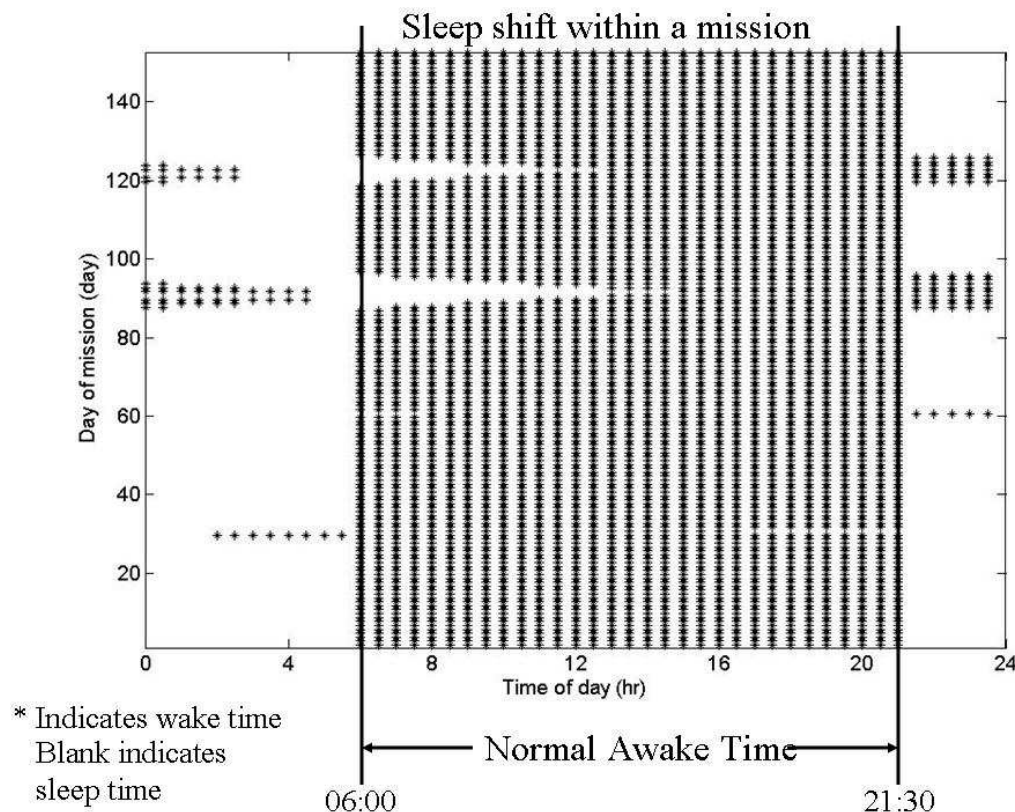
References:
1) Personal communication with Lauren Leveton 2008.

Mission Parameter Component
Actual sleep
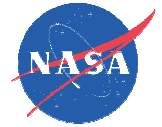
- A relationship exists between time in space and the number of hours of sleep per night obtained.

- Data from shuttle and Skylab missions were used to quantify the relationship.
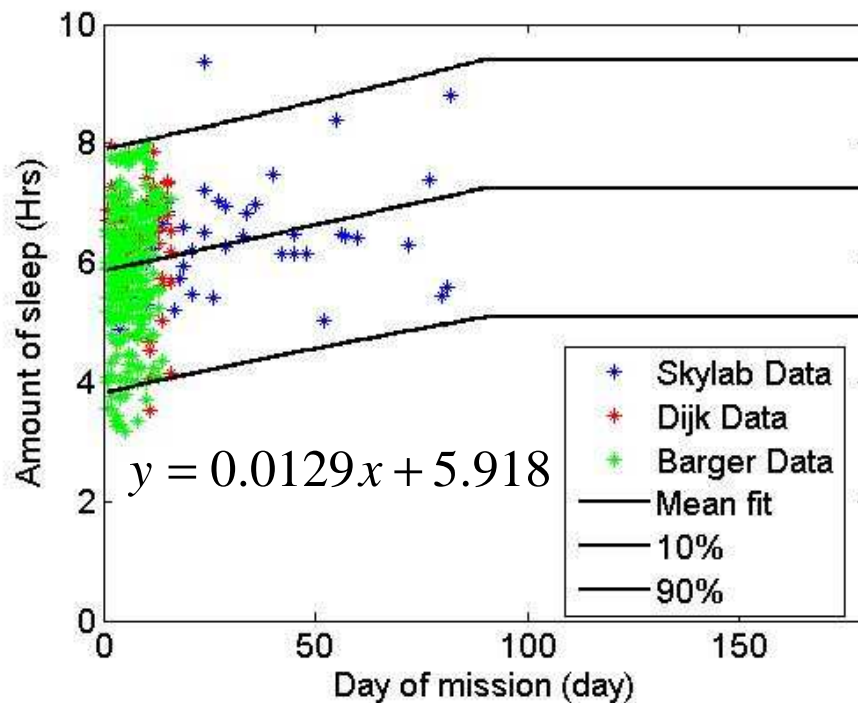
$$y = 0.0129x + 5.918$$

References:

1) Dijk DJ, Neri DF, Wyatt JK et al. Sleep, performance, circadian rhythms, and light-dark cycles during two space shuttle flights. Am J Physiol Regul Integr Comp Physiol 2001; 281(5):R1647-R1664.

2) Frost JD, Shumate WH, Salamy JG, Booher CR. Experiment M133. Sleep monitoring on Skylab. In: Johnston RS, Dietlein LF, editors. Biomedical Results from Skylab. Washington, DC: NASA; 1997.

3) Personal Communication with Laura Barger. 2008.

Mission Parameter Component
Sleep quality
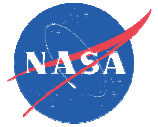
- The quality of sleep depends upon the frequency and quantity of wakefulness, or interruptions, during a sleep period

- A sleep factor correlated to sleep quality uniformly distributes sleep loss due to interruptions throughout the sleep period

References:
1) Dijk DJ, Neri DF, Wyatt JK et al. Sleep, performance, circadian rhythms, and light-dark cycles during two space shuttle flights. Am J Physiol Regul Integr Comp Physiol 2001; 281(5):R1647-R1664.
2) Personnal Communication with Laura Barger. 2008.
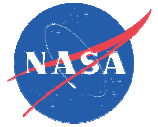
Sleep and Performance Component
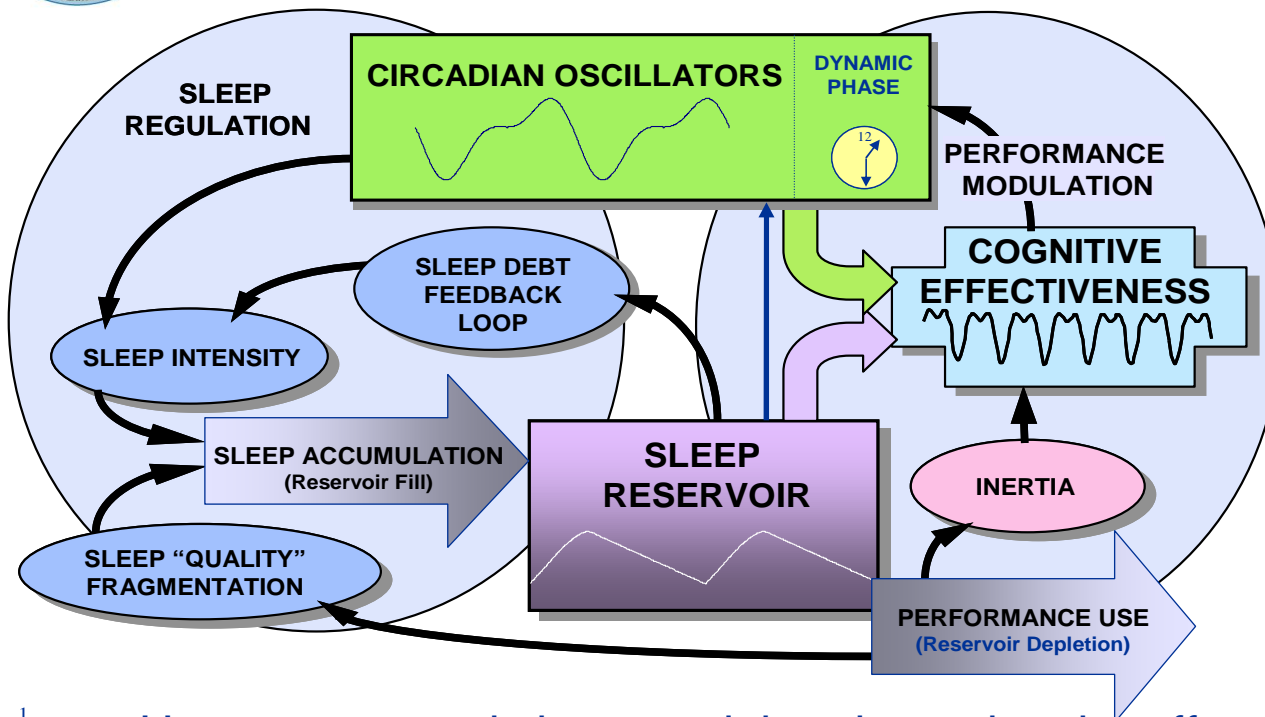
Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE™) Model
IBR, Inc.

- Use an accepted sleep model to determine the effects of sleep timing and duration and the influence of time of day (circadian effects)
- SAFTE proprietary process
  - Allows the tracking of changes in circadian phase based on changes in the work/rest schedule such as those that commonly occur on ISS
  - Accurately reflects the degrading effects of sleep fragmentation or sleep interruptions
- SAFTE input
  - Mission Schedule and Astronaut parameters

Sleep and Performance Component SAFTE Output
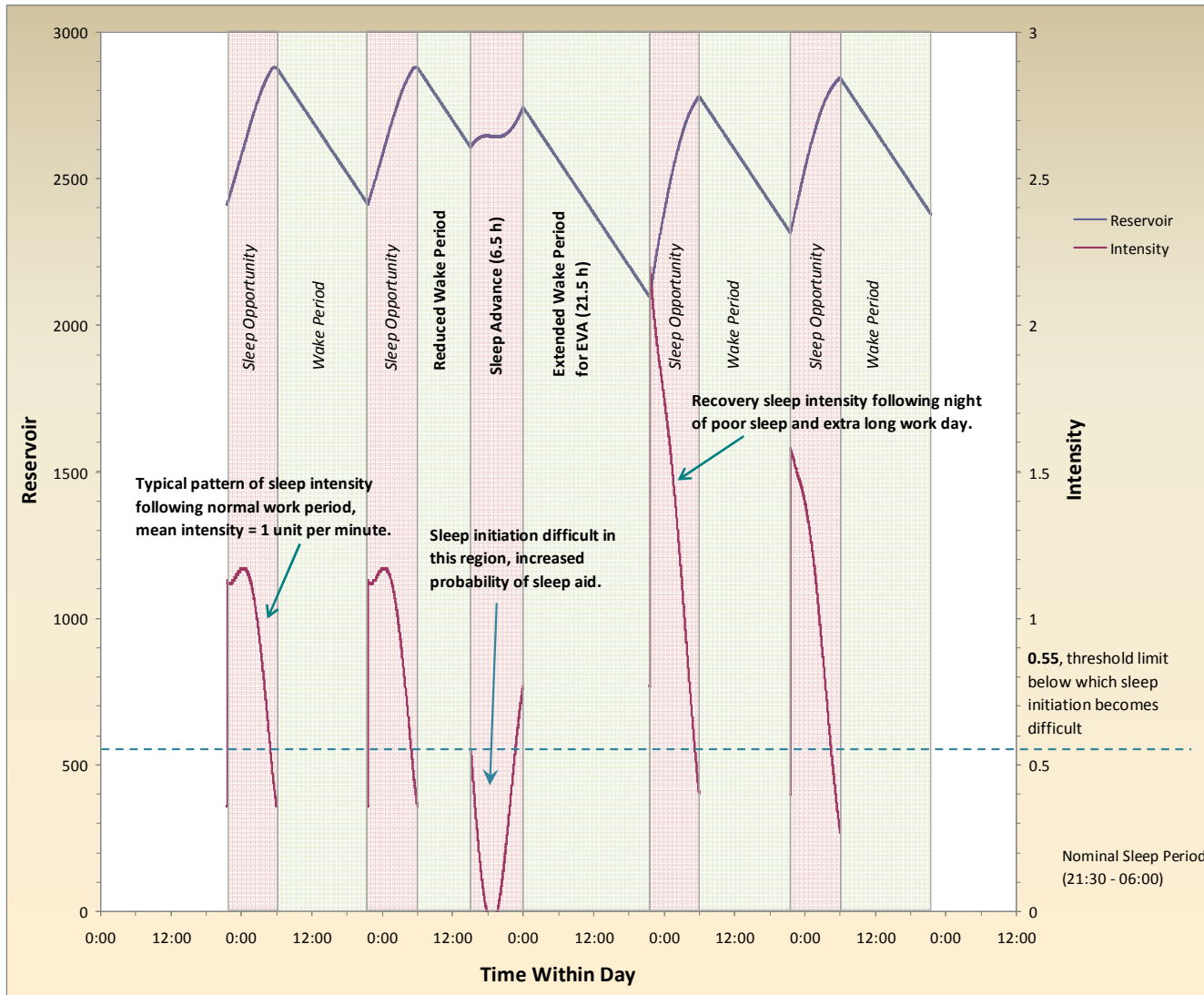
- Measures of
  - Effectiveness
  - Sleep Reservoir
  - Sleep intensity
- Diagnostic Metric
  - Sleep intensity is a measure of the relative circadian process and the level of sleep debt
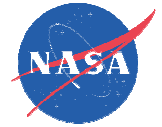
Diagnosis and Decision Component

- **Must answer**
  - At what "*threshold level*" of sleep intensity does intervention occur
- **Approach**
  - Associate sleep intensity with probability that medication is used
  - Logistic regression of ground and space based data
- **Output is a probability of using a sleep aid**
  - Relative to each scheduled sleep period
- **Decision of sleep aid use is based on binomial representation of this probability estimate**
- **Component still under development**
  - Currently integrating new data
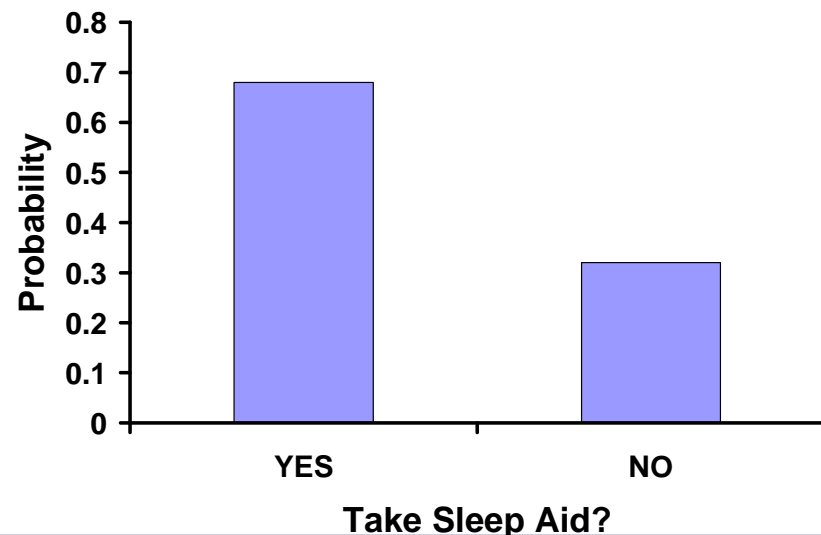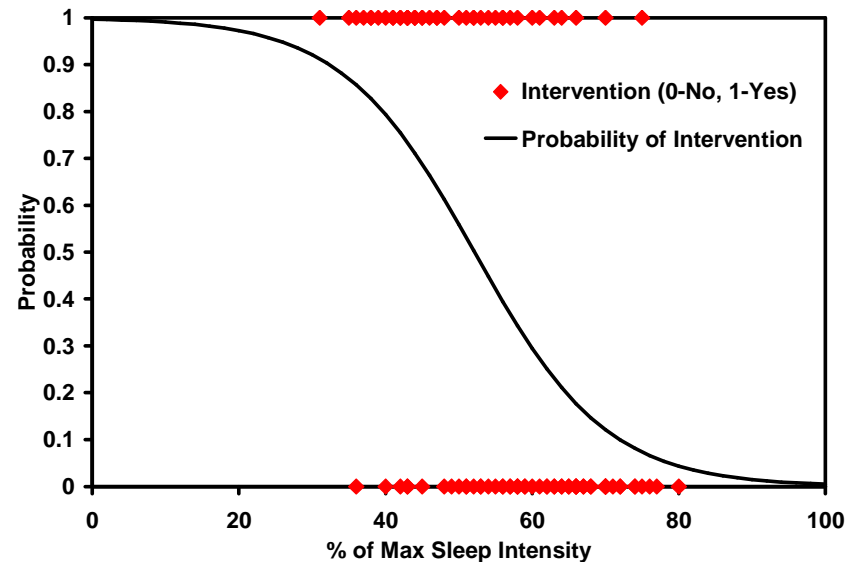
Illustration of How Model will Trigger Increased Probability of Sleep Aide Use

# Probability and Rates Component

- Calculations through an entire mission set is a *trial* within the Monte Carlo Simulation
  - Represents a possible mission based on the input parameters
  - Many simulations with random (but realistic) parameters produces
    - The most probable rate of medication uses
   - The associated uncertainty in the rate of usage estimate
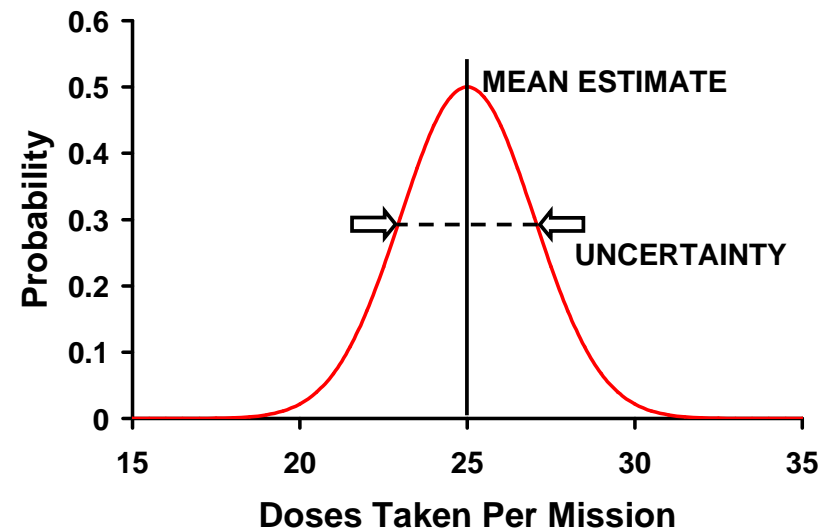
Validation
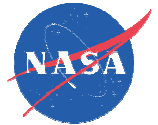
- Hard to validate probabilistic models
  - Typically Face validation with SME
- Validation individual components
  - Sample schedules generated from the mission parameter program will be given to mission schedulers for evaluation of how well they represent ISS mission schedules
- Validation of model conceptual structure
  - SME review and advisory panels
- Comparison and Refinement based on ongoing work
  - In flight sleep data
  - Ground based studies
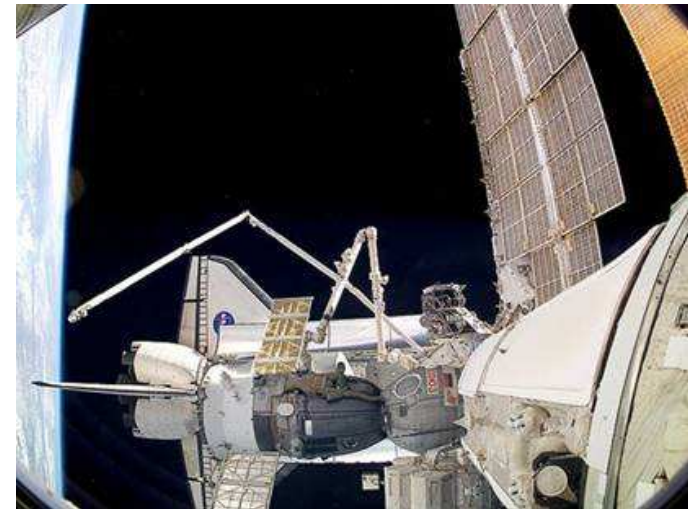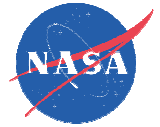
Ongoing Efforts and Limitations

- Completing V1.0 by 2009
- The diagnosis probability translation function is likely not a single curve
  - More likely a family of curves whose variation represents individual variation not accounted for in the model
  - Currently examining this issue
- SAFTE not originally designed for non-terrestrial usage
  - Modifications being made to address this issue
  - Modular nature of the modeling approach allows other sleep analysis simulations to be used if needed
- SDMIF tool is not currently designed to predict a given performance decrement
  - Specifically structured to implement in the IMM
  - Outlining how approach will be augmented to address sleep induced performance risk for the NASA HRP-BHP

Acknowledgements

- The SDMIF was funded by the NASA Human Research Program, which is managed at the Johnson Space Center.

- Special Thanks
  - Laura Leveton – BHP Lead NASA-JSC
  - Laura Barger - NSBRI
  - Mary Fitts – NASA IMM Project Manager
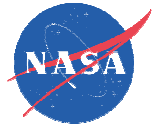 - ExMC and IMM development teams
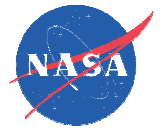
Extra Slides

SAFTE

- The Sleep, Activity, Fatigue, and Task Effectiveness (**SAFTE**) Model is based on 12 years of fatigue modeling experience and over $3M of US DOD investment.

- Validated against laboratory and simulator measures of fatigue.

- Validated and calibrated to predict accident risk by the Department of Transportation.

- Peer reviewed and found to have the least error of any available fatigue model.

- **Now accepted by the US DOD (Air Force, Army, Navy, Marines) as the common warfighter fatigue model.**

Sleep and Performance Component
SAFTE Output