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Crew Factors in Flight Operations X: Alertness Management in Flight Operations Education Module

Mark R. Rosekind, Philippa H. Gander, Linda J. Connell, and Elizabeth L. Co

November 2001

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Acknowledgments

We thank the many pilots, air carriers, and individuals who have participated in or otherwise supported the activities of the NASA Ames Fatigue Countermeasures Program. We wish to acknowledge particularly the hundreds of volunteer pilots who have made the program possible; the air carriers that have provided resources, support, and access to flight operations; and the pilot unions that have continually pushed to highlight and support this area for scientific research. Along with John Lauber and Charlie Billings, many of the original contributions and program activities were due to the efforts of R. Curtis Graeber (Boeing) and Clay Foushee (Northwest Airlines); James Jenkins at NASA Headquarters; Anthony Broderick, William White, and Ronald Simmons at the FAA; Donald Hudson (Aviation and Preventive Medicine Associates); and academic colleagues: David Dinges (Institute of Pennsylvania Hospital and University of Pennsylvania School of Medicine), William Dement (Stanford School of Medicine), Margaret Moline (Cornell School of Medicine), and Timothy Monk (University of Pittsburgh School of Medicine). Sharon Keenan (School of Sleep Medicine) provided helpful guidance in establishing the structure of workshops to implement this module. Activities have included the International collaboration of the following: Hans Wegmann, Alex Samel, and Alex Gundel (DLR Institute of Aerospace Medicine, Germany); Anthony Nicholson and Peta Pascoe (Royal Air Force Institute of Aviation Medicine, United Kingdom); Barbara Stone (Army Personnel Research Establishment, United Kingdom); Roderick Barnes and Geoffrey Bennett (Civil Aviation Authority, United Kingdom); and Mitsuo Sasaki (Japan Air Lines and the Jikei School of Medicine, Japan). The Fatigue Countermeasures Program has been fortunate to receive tremendous support from many individuals at NASA Ames Research Center, especially William Reynard. J. Victor Lebacqz, former Chief of the Flight Human Factors Branch at Ames, has recently made invaluable contributions to all aspects of the program. Finally, the NASA Ames Fatigue Countermeasures Program is an entity very much defined by the energetic, hardworking, and dedicated people actively involved in the program: Donna Miller, Kevin Gregory, Roy Smith, Lissa Webbon, Keri Weldon, Julie M. Johnson, Ray Oyung, Roxanne M. Johnson, Ron Anguilar, and Malachi Boyle.

This publication is dedicated to John K. Lauber, Ph.D., and Charles E. Billings, M.D., for their significant contributions to this subject and to aviation safety.

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FOREWORD

This report is another in a series of research reports from Ames Research Center on the subject of fatigue and jet lag in airline flight operations. However, the focus of this report is a bit different from that of the others—rather than being a scientific study of the causes and effects of fatigue and jet lag, it is a compendium of useful tips and personal management strategies for better coping with such causes and effects. The information provided here is intended to be used by airline flight crew members to help them develop effective countermeasures for the debilitating effects of flight schedules like the following one, which provided me with my first glimpse of such operations. The report's basic premise is that in the modern world, there will always be a requirement for 24-hour flight operations, and that it is possible for individual crew members to more effectively manage rest and sleep periods, diet, exercise, and other personal factors in such a way that adverse performance effects of such operations will be minimized. It is another tool that can be used by the professional pilot to further enhance both the quality of performance and the quality of life.

JOHN K. LAUBER, Ph.D.
Member
National Transportation Safety Board
December 1994

INTRODUCTION

In 1980, in response to a congressional request, NASA Ames Research Center created a Fatigue/Jet Lag Program to examine whether “there is a safety problem, of uncertain magnitude, due to transmeridian flying and a potential problem due to fatigue in association with various factors found in air transport operations.”[1] Since 1980, the Program has pursued the following three goals: (1) to determine the extent of fatigue, sleep loss, and circadian disruption in flight operations; (2) to determine the effect of these factors on flight crew performance; and (3) to develop and evaluate countermeasures to reduce the adverse effects of these factors and to maximize flight crew performance and alertness. It has been a priority since the Program’s inception to return the information acquired through its extensive research to the operators—the line pilots, air carriers, and others. In 1991, the Program underwent a name change, becoming the NASA Ames Fatigue Countermeasures Program, to highlight the increased focus on the development and evaluation of fatigue countermeasures. (For a more complete description of the Program, see footnote 2 below.) With this increased emphasis on countermeasures, it became important to organize and disseminate what had been learned about fatigue, sleep, and circadian rhythms in flight operations.

Although data continue to accumulate, there is now enough scientific and operational data to create this Education and Training Module on strategies for alertness management in flight operations. The overall purpose of this module is to promote aviation safety, performance, and productivity. It is intended to meet three specific objectives: (1) to explain the current state of knowledge about the physiological mechanisms underlying fatigue; (2) to demonstrate how this knowledge can be applied to improving flight crew sleep, performance, and alertness; and (3) to offer strategies for alertness management.

This module is presented in three distinct parts. The first part addresses fatigue factors in flight operations. It provides basic information on sleep, sleepiness, circadian rhythms, and how flight operations affect these physiological factors. The second part identifies some widely held misconceptions and shows why they are false. Finally, the third part provides recommendations for alertness management strategies in flight operations. This Education and Training Module is intended to be offered as a live presentation by a trained individual. Its interactive format will provide a forum for discussions of how this information and the recommended strategies can be applied in specific flight operations.

This NASA/FAA document was developed to complement the live presentation of the Module. It includes a foreword by Dr. John K. Lauber, one of the original investigators who started the NASA Ames Fatigue/Jet Lag Program and a former Member of the National Transportation Safety Board. The information contained in the presentation slides constitutes the main body of this publication.

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[1] *Pilot Fatigue and Circadian Desynchronosis.* (1980). Report of a workshop held in San Francisco, CA, on August 26–28,1980. NASA Technical Memorandum No. 81275. Moffett Field, CA: National Aeronautics and Space Administration.

[2] Rosekind, M.R., Gander, P.H., Miller, D.L., Gregory, K.B., McNally, K.L., Smith, R.M., and Lebacqz, J.V. (1993). NASA Ames Fatigue Countermeasures Program. *FAA Aviation Safety Journal*, *3*(1), 20–25.

Brief introductions to sleep disorders and to relaxation techniques are presented in appendixes A and B, respectively. Appendix C contains summaries of relevant NASA publications, including studies in short-haul, long-haul, and helicopter operations, and the NASA/FAA study on planned cockpit rest in long-haul flying. The last two appendixes provide a list of representative publications from the NASA Ames Fatigue Countermeasures Program (appendix D) and a list of general readings on sleep, sleep disorders, and circadian rhythms (appendix E).

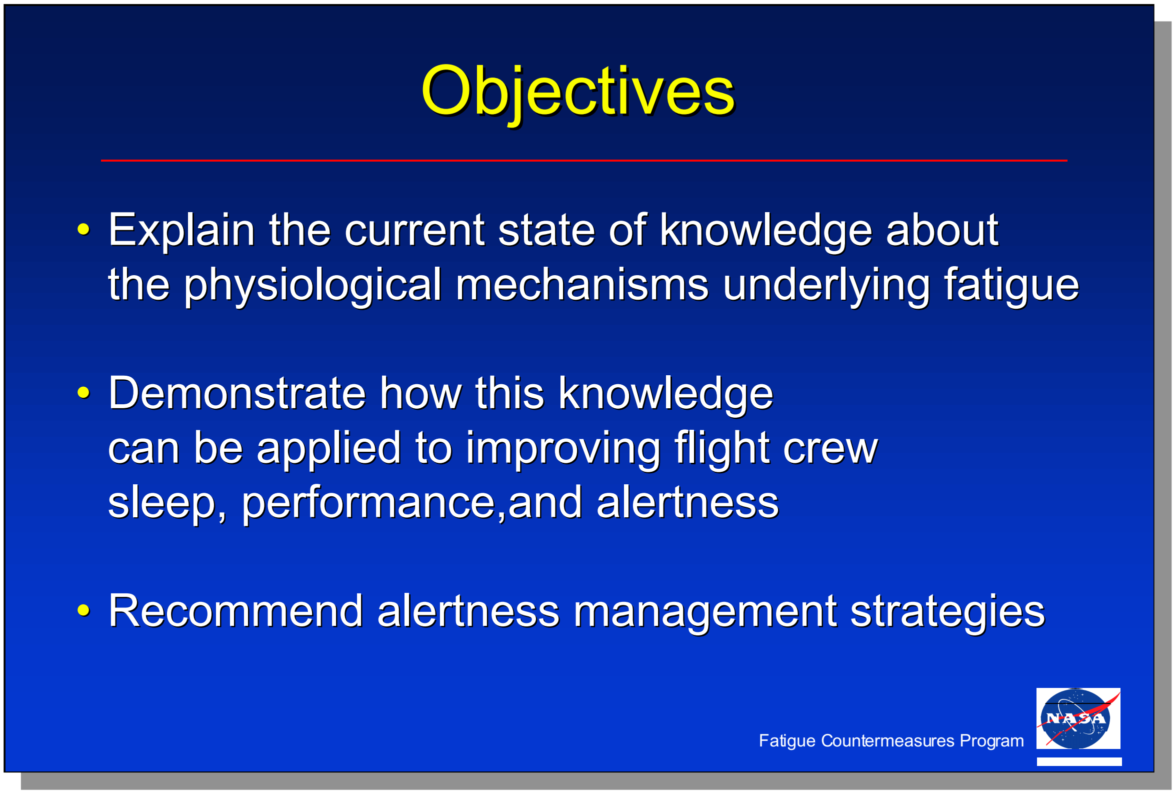
The format of this publication is designed for two purposes: (1) to facilitate training and (2) to provide a reference for those who use the information. For trainers, the slides provide presentation material, while the text provides some guidelines as to what information should be addressed when presenting the Module. For those applying the information, the text elaborates on the slides for later reference.

This is the first formal step taken by the NASA Ames Fatigue Countermeasures Program to provide education and training information on fatigue, sleep, and circadian rhythms in flight operations, and to recommend strategies for managing alertness on the flight deck. As future scientific and operational advances are made, this module will evolve to incorporate the latest findings, information, and recommendations. Therefore, any comments, questions, or requests regarding this module would be greatly appreciated. Please address them to: Fatigue Countermeasures Program, NASA Ames Research Center, MS 262-4, Moffett Field, California 94035-1000.

Alertness Management in Flight Operations

NASA Ames Research Center
Human Factors Research and Technology Division

Fatigue Countermeasures Program

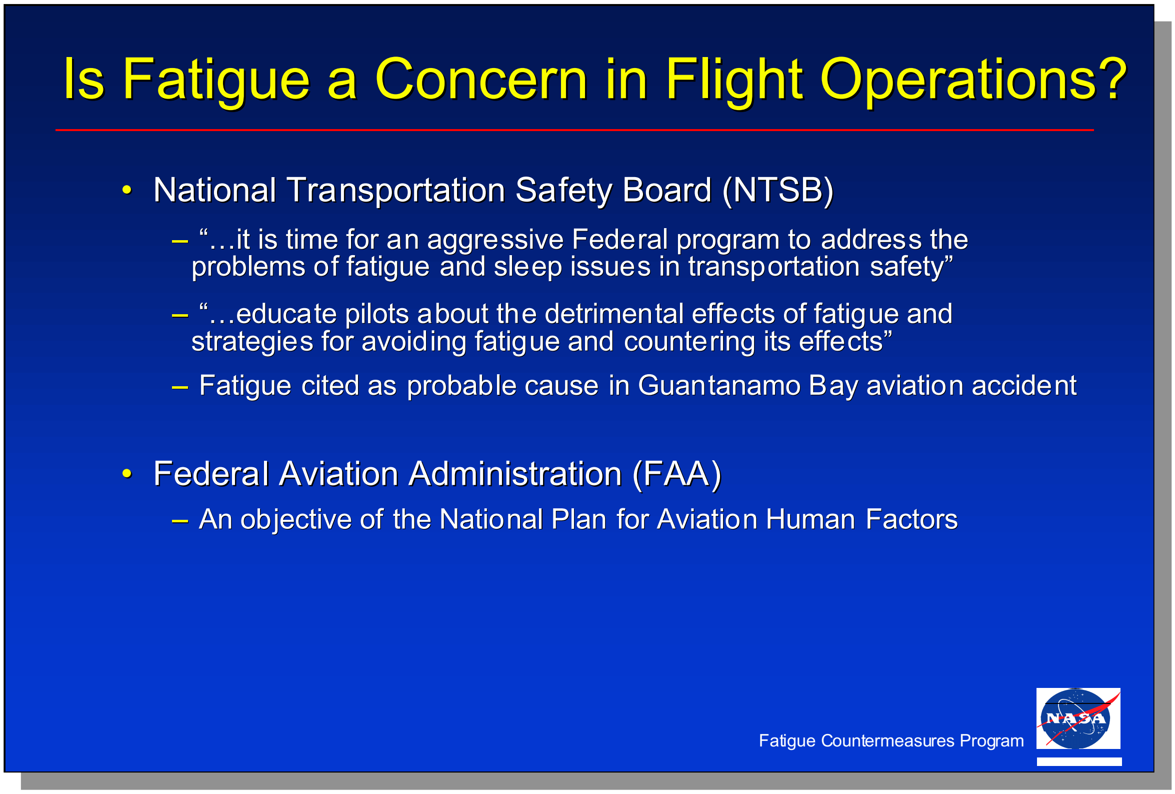


In response to a 1980 congressional request, NASA Ames Research Center initiated a Fatigue/Jet Lag Program to examine fatigue, sleep loss, and circadian disruption in aviation. Research has examined fatigue in a variety of flight environments using a range of measures (from self-report to performance to physiological). In 1991, the program evolved into the Fatigue Countermeasures Program, emphasizing the development and evaluation of strategies to maintain alertness and performance in operational settings. Over the years, the Federal Aviation Administration (FAA) has become a collaborative partner in support of fatigue research and other Program activities.

From the inception of the Program, a principal goal was to return the information learned from research and other Program activities to the operational community. The objectives of this Education and Training Module are to explain what has been learned about the physiological mechanisms that underlie fatigue, demonstrate the application of this information in flight operations, and offer some specific fatigue countermeasure recommendations. It is intended for all segments of the aeronautics industry, including pilots, flight attendants, managers, schedulers, safety and policy personnel, maintenance crews, and others involved in an operational environment that challenges human physiological capabilities because of fatigue, sleep loss, and circadian disruption.

The presentation is divided into three parts, followed by a discussion. First, there is a description of fatigue factors in flight operations, including a demonstration that fatigue is of national interest and a discussion of the principal causes of fatigue (i.e., sleep and sleep loss, circadian rhythms and their disruption, and the effects of flight operations on these physiological factors). Second, several examples of common misconceptions regarding fatigue in aviation are presented, and application of the information provided in the first part demonstrates why these notions are incorrect. Third, a variety of countermeasures are presented, including preventive approaches that can be used before going on duty or on layovers, as well as operational countermeasures to use during duty periods. Finally, a critical component of this module is the application of the information provided to the specific demands of the audience's or reader's flight activities. The discussion is intended to demonstrate and give specific examples of how this information can be applied to different types of flight schedules, individual physiological differences, and the varying operational requirements of a given audience. It is intended to be highly interactive with specific examples provided by participants.

The first two sections of this part will discuss the two main physiological factors that affect fatigue: 1) sleep and sleep loss, and 2) circadian rhythms. With the principles of these physiological factors as a background, a third section will then discuss the effects of flight operations on fatigue.



The following sources indicate that fatigue is a concern acknowledged at a national level.

The National Transportation Safety Board (NTSB) has stated the following in Safety Recommendations I-89-1, I-89-2, and I-89-3: "Based on its experience in accident investigation, the Safety Board believes it is time for an aggressive Federal program to address the problems of fatigue and sleep issues in transportation safety." On January 19, 1994, based on a Safety Study Review, the NTSB recommended that the FAA "Require U.S. carriers operating under 14 CFR Part 121 to include, as part of pilot training, a program to educate pilots about the detrimental effects of fatigue, and strategies for avoiding fatigue and countering its effects." A parallel recommendation was made regarding Part 135 carriers. For the first time, the NTSB cited fatigue as a probable cause in the Guantanamo Bay aviation accident. Through the research and other activities of the NASA Ames Fatigue Countermeasures Program, the FAA, and the NTSB, aviation is ahead of most other modes of transportation in examining the issue of fatigue and, especially, in developing potential countermeasures.

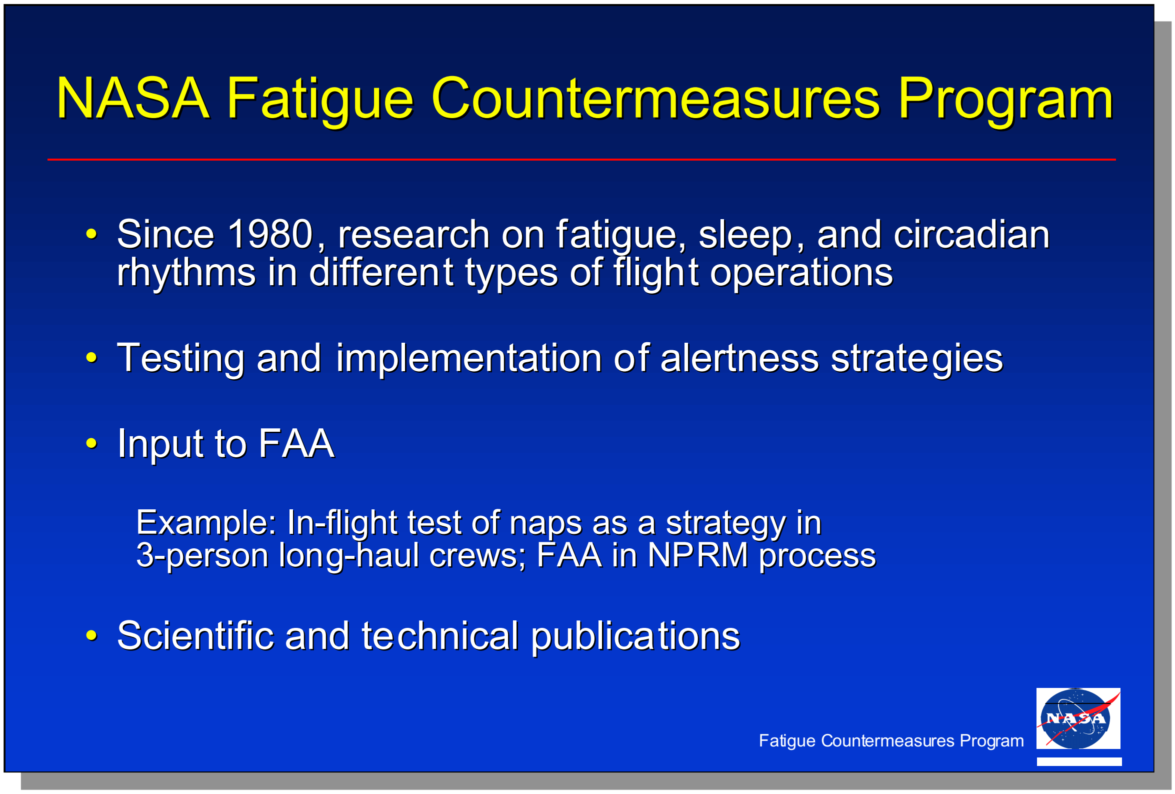
The FAA's National Plan for Aviation Human Factors identifies fatigue as an area for continued basic and applied research. These are only three examples of highly visible national agencies that acknowledge and call for continued activities addressing the issue of fatigue in aeronautical operations.

This presentation will clearly demonstrate that fatigue in flight operations is a complex issue with no one simple answer. Rather, every component of the aviation system that can be addressed to improve alertness and performance in flight operations should receive attention. Several examples are provided here.

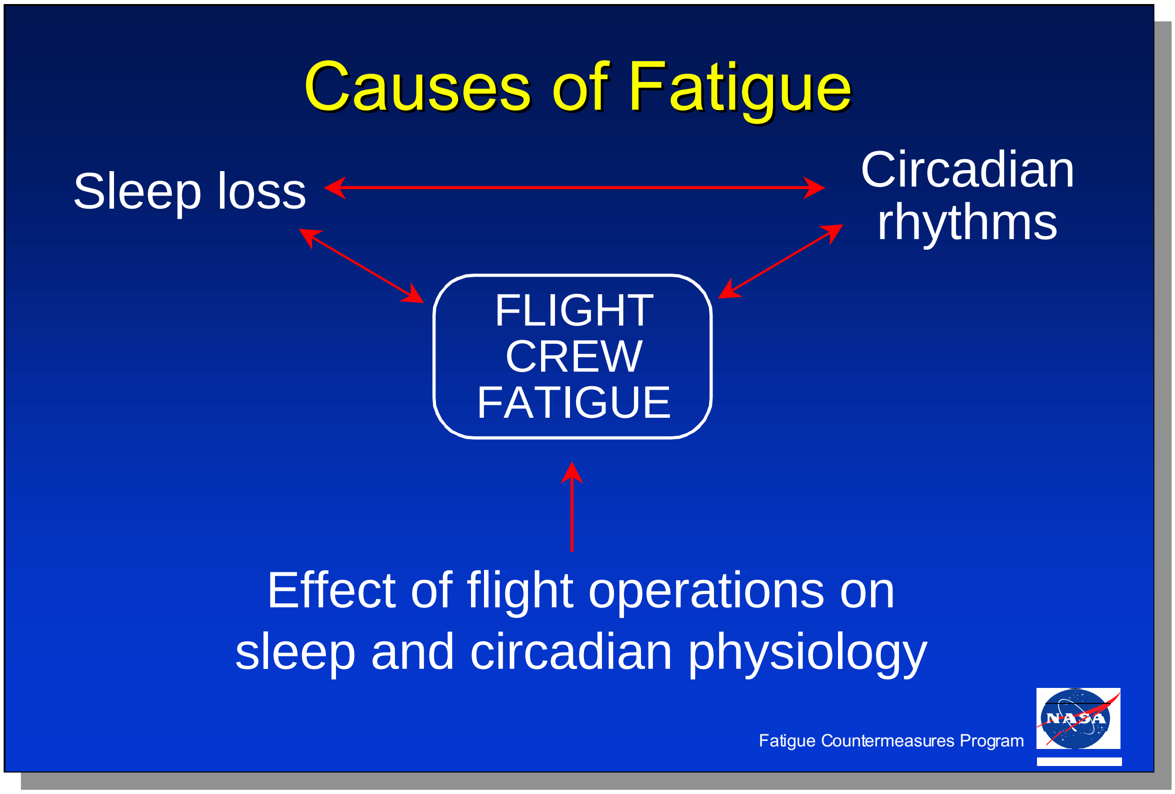
The Federal Aviation Regulations (FARs) could provide one means of incorporating what is now known about the physiological mechanisms that produce fatigue. This can be a long process and one that can be complex in its own right. The FAA recently established an Aviation Rulemaking Advisory Committee working group that examined current flight/duty/rest requirements. The working group evaluated current FAR requirements, and their interpretation and application within the aviation industry. Also, the FAA has established a rulemaking team to examine flight/duty/rest requirements.

Another approach is to conduct research that provides scientific data to be used by policymakers concerned with regulatory issues or interpretation of the FARs. The research can be the basis for a variety of actions, including the production of Advisory Circulars.

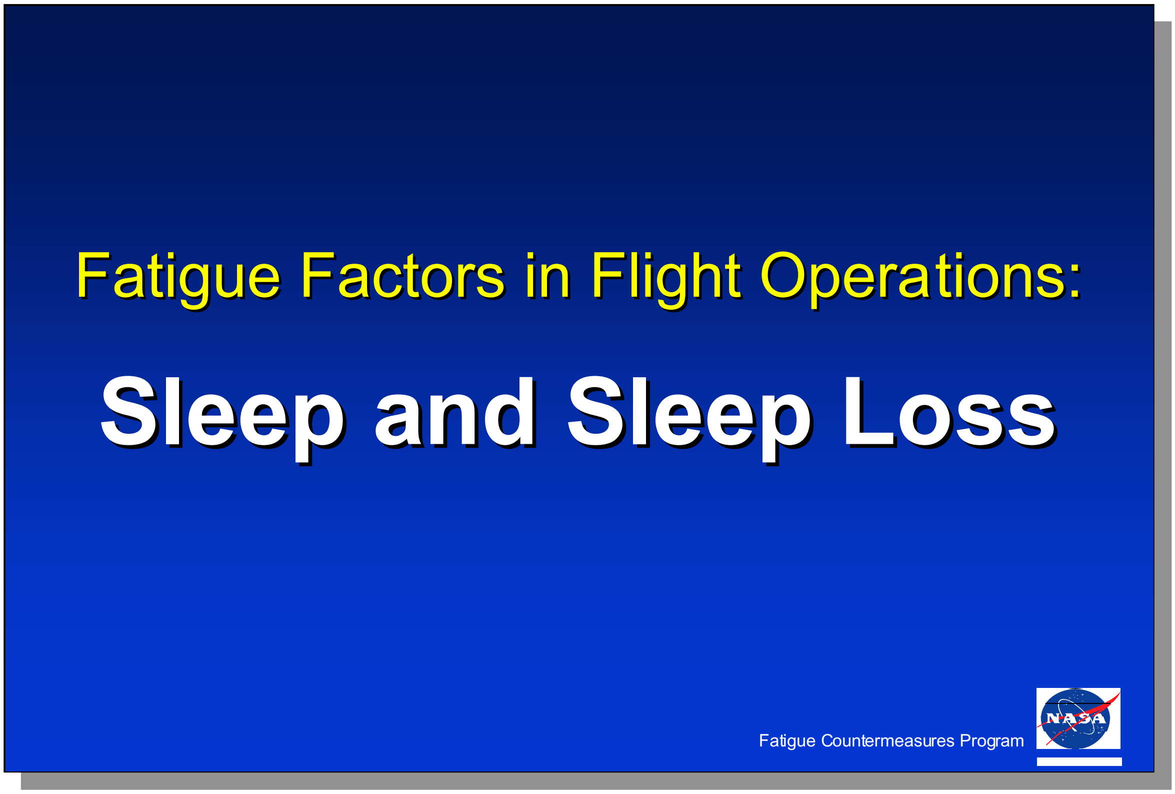
In another possible approach, the information provided in this presentation can be used right now by any individual challenged by the physiological demands of flight operations. The basic information and countermeasure recommendations can be used by all in the aviation industry who want to improve their ability to cope with the existing situation.



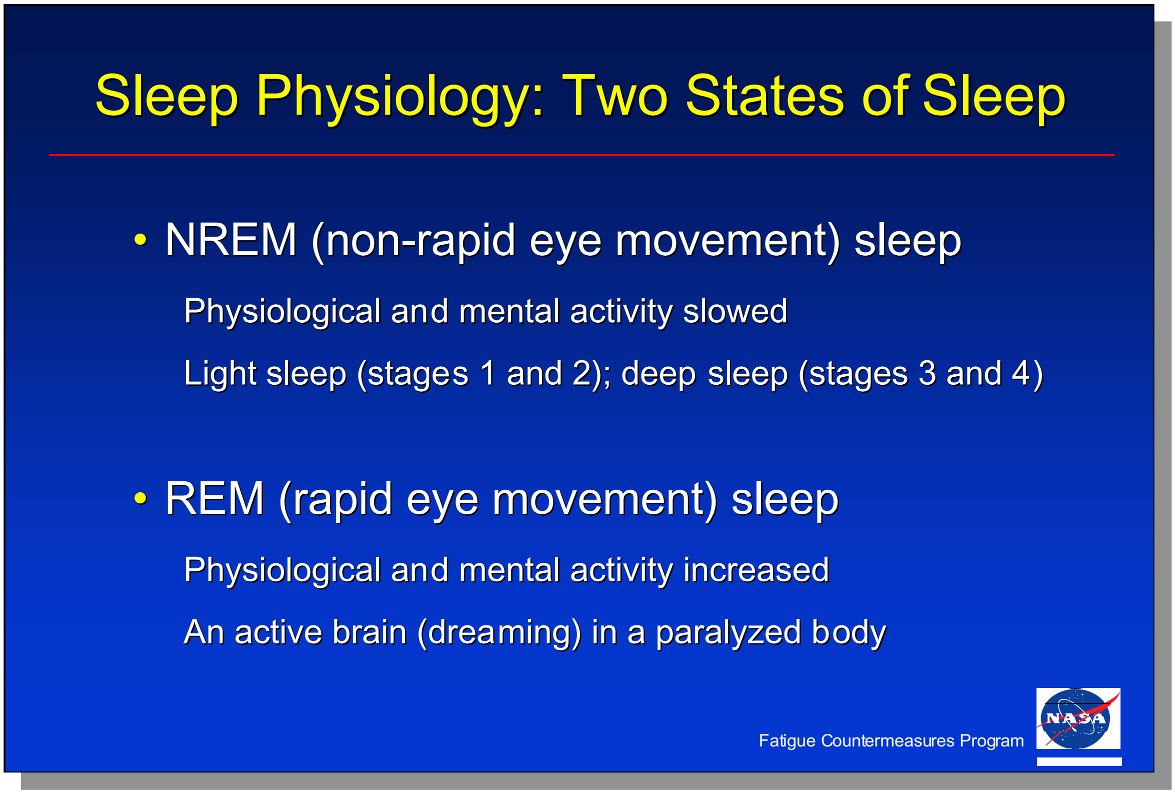
This information provides some insight into the research and activities that created the foundation for the development of this Education and Training Module. Since 1980, the NASA Ames Fatigue Countermeasures Program, in collaboration with the FAA, has conducted fatigue research; recently, it has emphasized the testing and implementation of countermeasures. An example of these activities is the recent NASA/FAA study of planned cockpit rest, which demonstrated the effectiveness of a controlled in-flight nap to improve subsequent alertness and performance during critical phases of flight. The FAA is currently in the Notice for Proposed Rulemaking (NPRM) process for “Controlled Rest on the Flight Deck.” Another important ongoing Program contribution is the production of scientific and technical publications, as well as industry articles, reporting study results and other information related to fatigue and potential countermeasures. Some representative Program publications suggested for further reading are provided in appendix D.



Fatigue is really a catchall term for a variety of different subjective experiences, for example, physical discomfort after overworking a particular group of muscles, concentration difficulties during a monotonous task, difficulty appreciating potentially important signals following long or irregular work hours, or simply difficulty staying awake. In the context of flight operations, crewmember fatigue becomes important if it reduces efficiency or otherwise impairs crew performance. Subjective fatigue can be affected by motivation or by the amount of stimulation coming from the environment. However, there are two systematic physiological causes of fatigue (and poorer performance)—sleep loss and circadian rhythms—both of which are affected by flight operations. It is also important to note that inadequate rest can result in sleep loss and circadian disruption, and can therefore be a source of fatigue in its own right. The NASA Fatigue Countermeasures Program focuses on these factors.



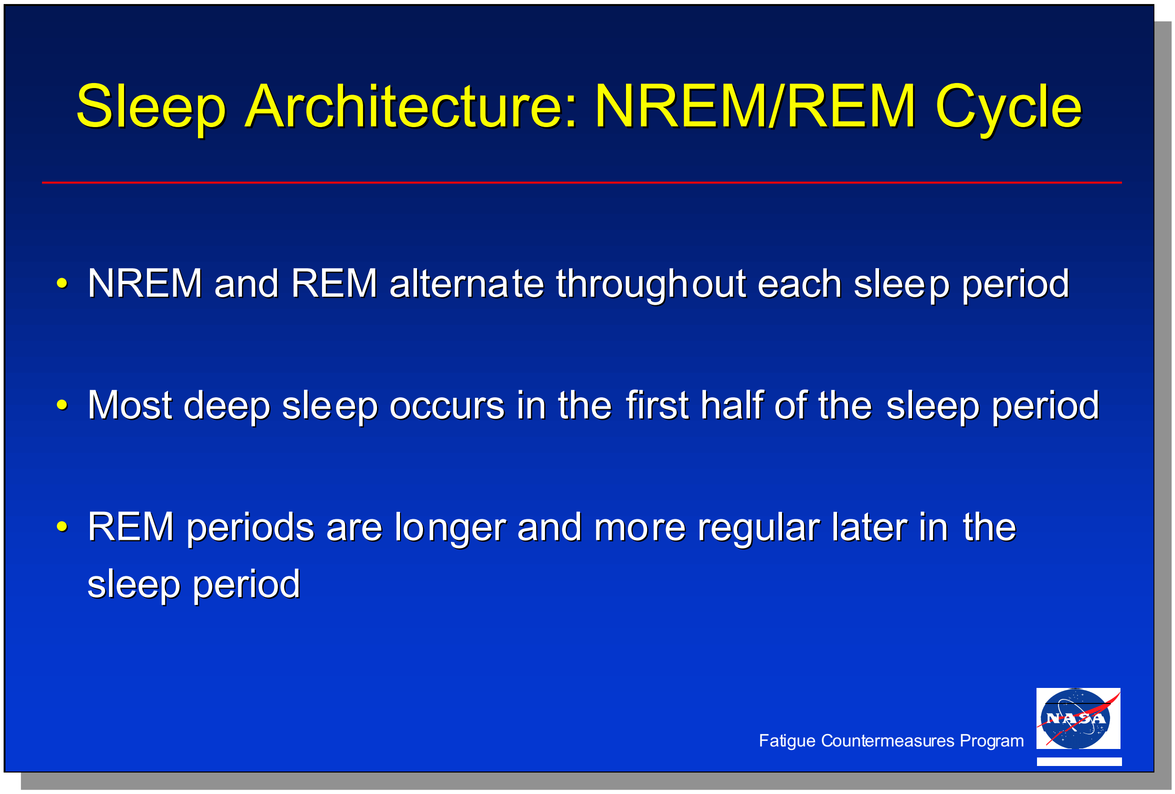
This section provides basic information about the complex physiological process of sleep and the effects of sleep loss and sleepiness.



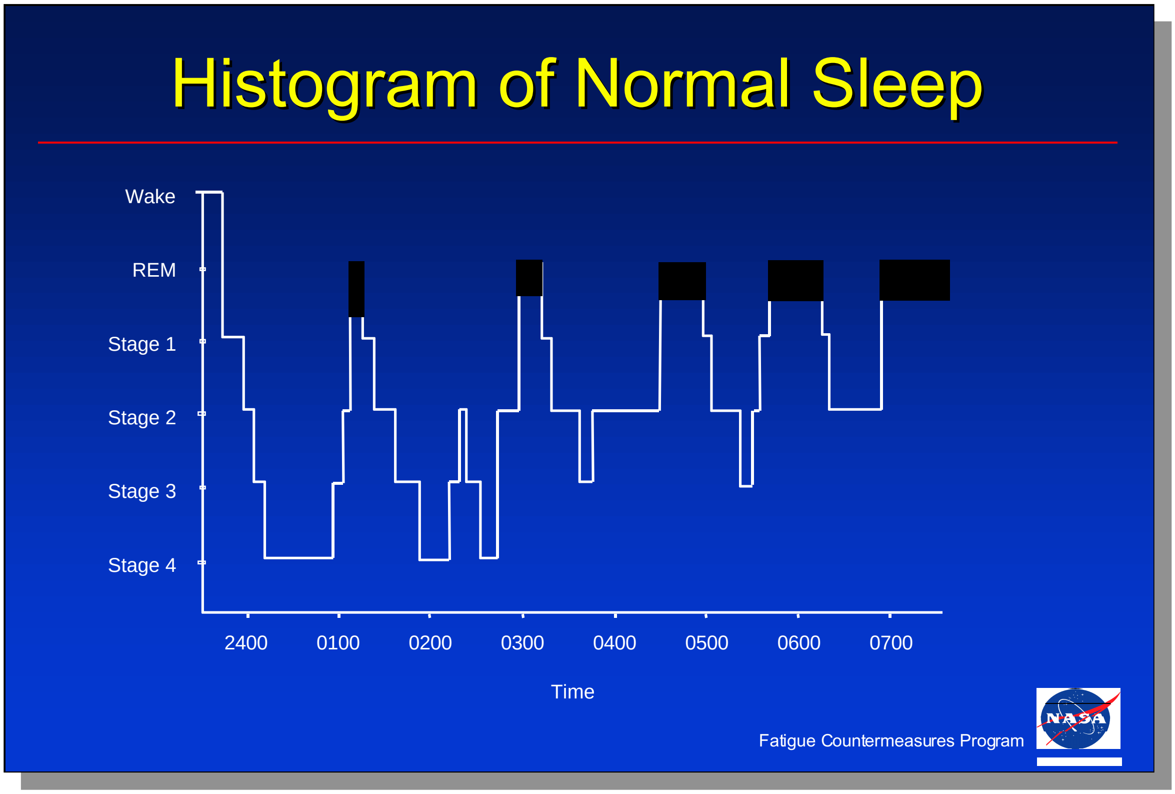
It is widely believed that sleep is a time when the brain and the body shut off and then re-engage upon awakening. Actually, sleep is a highly complex physiological process during which the brain and body alternate between periods of extreme activity and quiet, but are never “shut off.” Sleep is composed of two distinct states: NREM, or non-rapid eye movement, and REM, or rapid eye movement, sleep. These two sleep states are as different from each other as they are from wakefulness.

During NREM sleep, physiological and mental activities slow (e.g., heart rate and breathing rate slow and become regular). NREM sleep is divided into four stages, with the deepest sleep occurring during stages 3 and 4. There is usually very little mental activity during NREM stages 3 and 4. If awakened during this deep sleep, an individual may take sometime to wake up and then continue to feel groggy, sleepy, and perhaps disoriented for 10–15 minutes. This phenomenon is called sleep inertia.

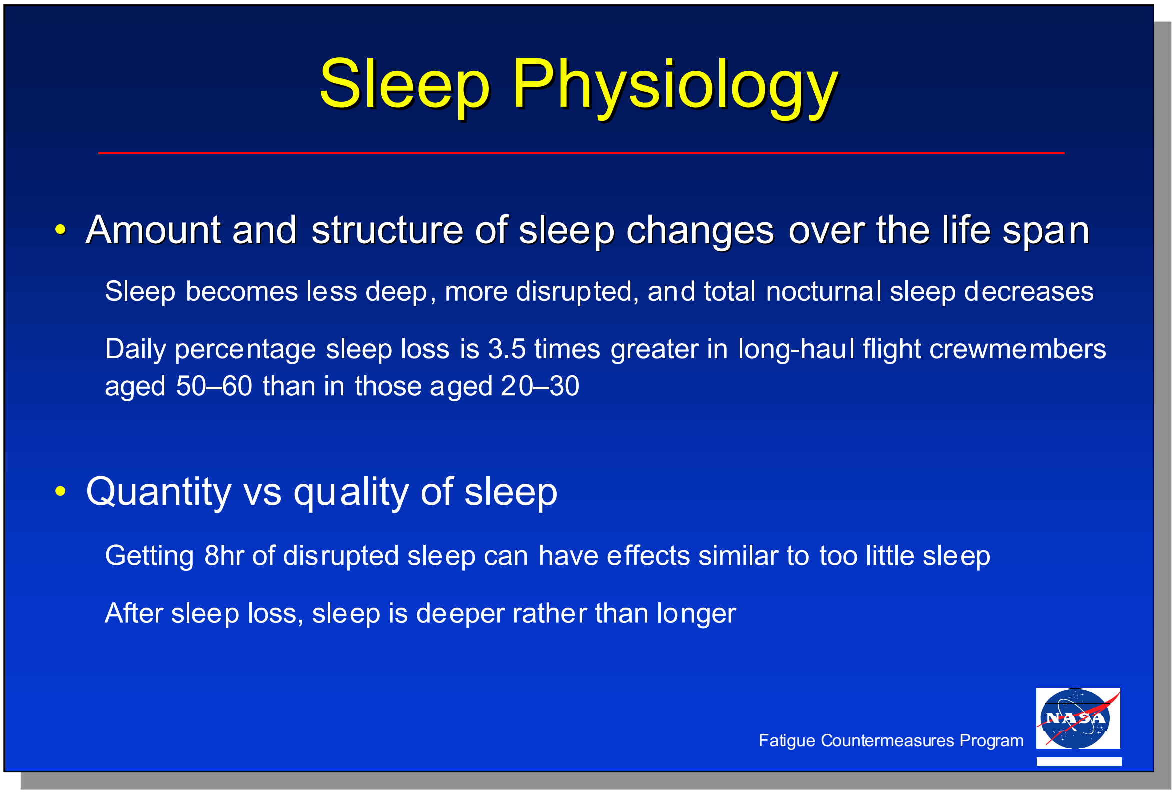
REM sleep is associated with an extremely active brain that is dreaming, and with bursts of rapid eye movements (probably following the activity of the dream); during REM sleep, the major motor muscles of the body are paralyzed. If awakened during REM sleep, individuals can often provide detailed reports of their dreams.



Over the course of a typical night, NREM and REM sleep occur in a cycle, with about 60 minutes of NREM sleep followed by about 30 minutes of REM sleep. This 90-minute cycle repeats itself throughout a typical sleep period. However, most deep sleep (i.e., NREM stages 3 and 4) occurs in the first third of the night, and REM periods are shorter early in the night and then become longer and occur more regularly later in the sleep period. Overall, about 25% of sleep time is spent in REM sleep and about 50% is spent in NREM stage 2.



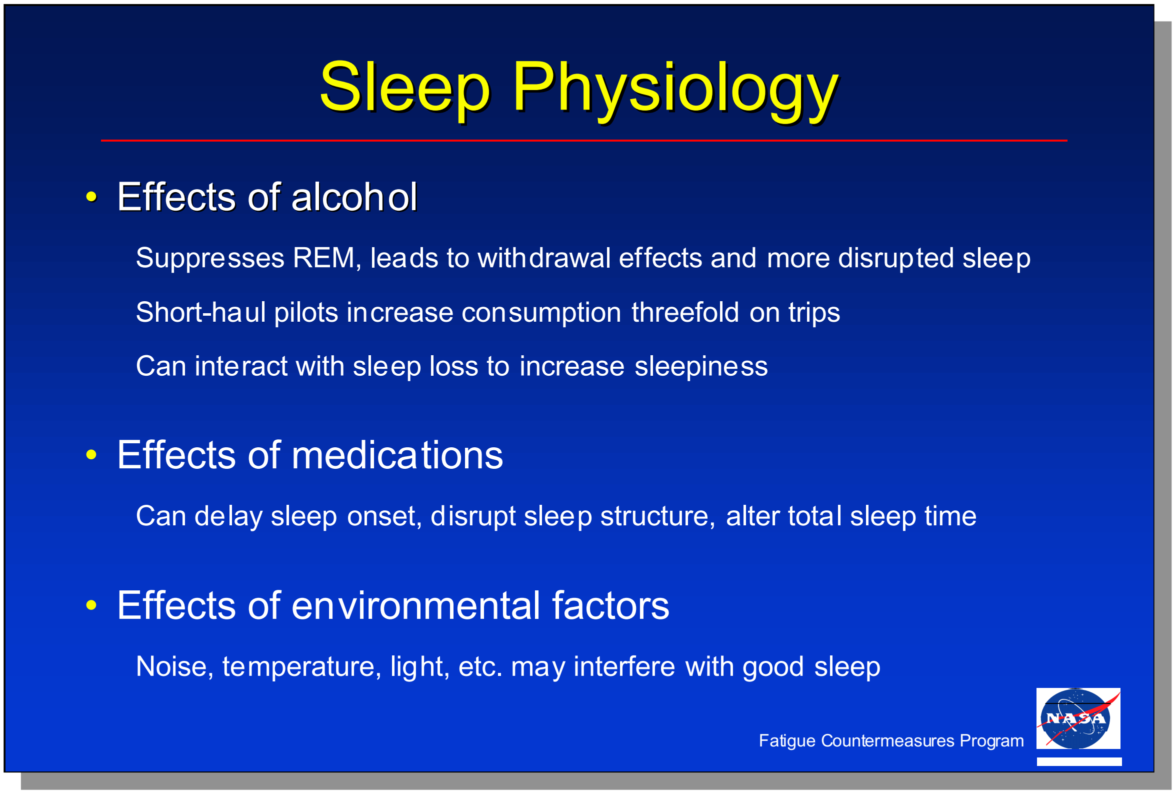
This graph portrays a typical night of sleep for a normal adult. It exemplifies the sleep architecture discussed on the previous slide: REM (indicated by darkened bars) and NREM alternating throughout the period; most deep sleep occurring in the first half of the sleep period; and REM periods becoming longer and more regular later in the sleep period.



The amount and structure of sleep change profoundly over the life span. With increased age, sleep becomes less deep (most NREM stages 3 and 4 disappears) and more disrupted (awakenings increase), and the total amount of nocturnal sleep decreases. It is not that older individuals need less sleep, but it appears that with age, our ability to obtain a consolidated and continuous period of nocturnal sleep decreases. These changes can be seen in individuals starting as early as 50 years of age. This normal part of the aging process is reflected in a recent finding from a NASA study. Long-haul flight crewmembers aged 50–60 had a daily percentage sleep loss 3.5 times greater during trip schedules than those aged 20–30 years.

The quality of sleep can be as critical as the quantity of sleep in restoring an individual. If an individual obtains 8 hours of sleep but the sleep is disrupted tens or hundreds of times, then upon awakening, the individual may feel as if only a few hours of sleep were obtained. There are many diverse reasons for disrupted sleep, from environmental causes (e.g., noise, light) to physical sleep disorders. For example, there is a sleep disorder called "periodic leg movements during sleep" that involves one or both legs twitching throughout sleep (see appendix A for further information). With each leg twitch, the sleeper is awakened briefly. Hundreds of these brief awakenings can occur during one sleep period. The sleeper can be completely unaware of the twitches or awakenings but feel sleepy and tired even after 8 hours of this fragmented sleep.

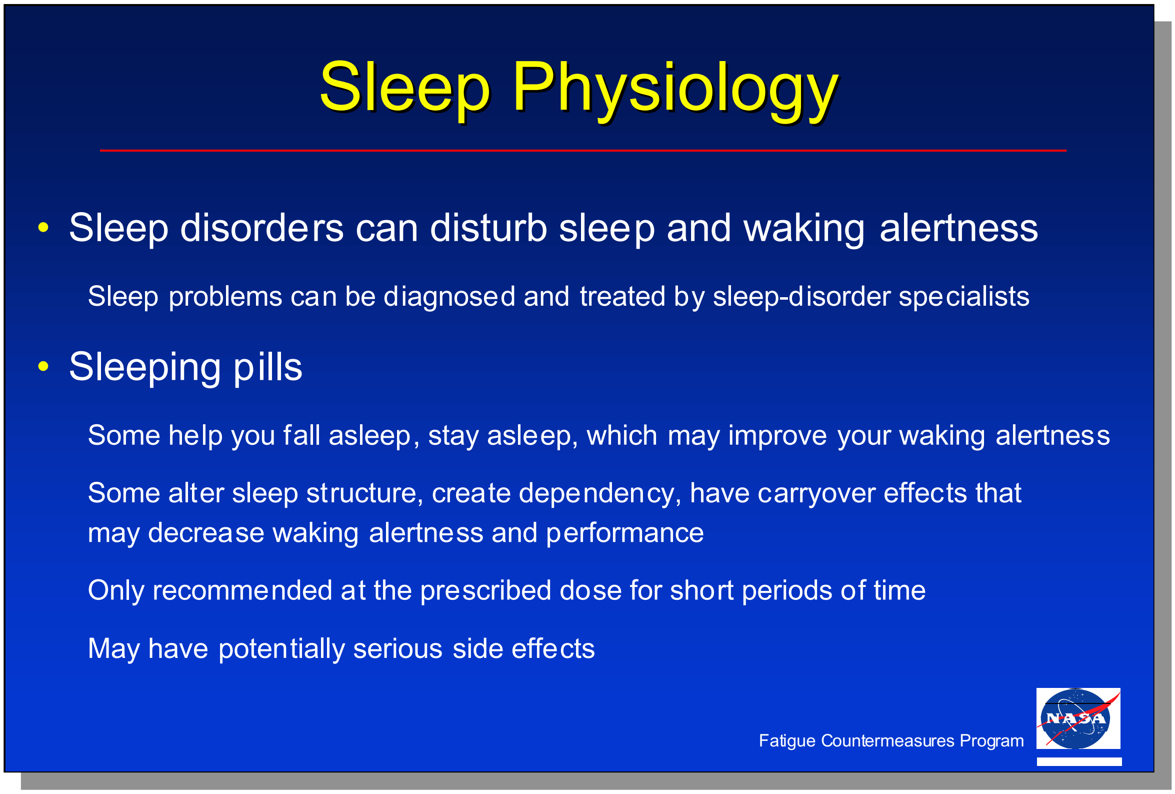
Another commonly held belief is that after sleep loss, an individual has to "make up" that sleep by sleeping a number of hours equal to those lost. Scientific laboratory studies have demonstrated that following sleep deprivation, recovery sleep is deeper (more NREM stages 3 and 4), rather than extended. During recovery sleep, an individual might sleep somewhat longer, but the most notable feature is the increase in deep sleep.



Alcohol has a profound effect on the usual sleep cycle. After more than a couple of glasses of wine or a couple of beers (with individual variations), alcohol can essentially eliminate all of the REM sleep in the first half of a sleep period. This can lead to subsequent alcohol withdrawal effects in the second half of the sleep period, including sleep fragmentation. Unfortunately, the most widely used sleep aid in the United States is alcohol. Ironically, although often used to promote relaxation and the ability to fall asleep, it will generally have major disruptive effects on the subsequent sleep. One NASA study found that short-haul pilots increased their alcohol consumption threefold during trips compared with home consumption. The pilots used alcohol within FAR guidelines to unwind after long duty days that included multiple flight segments and to promote sleep onset before an early wake-up for the subsequent duty day. Alcohol also interacts in a synergistic fashion with sleepiness. A sleep-deprived individual who is already sleepy will demonstrate more severe performance and alertness impairment following alcohol consumption.

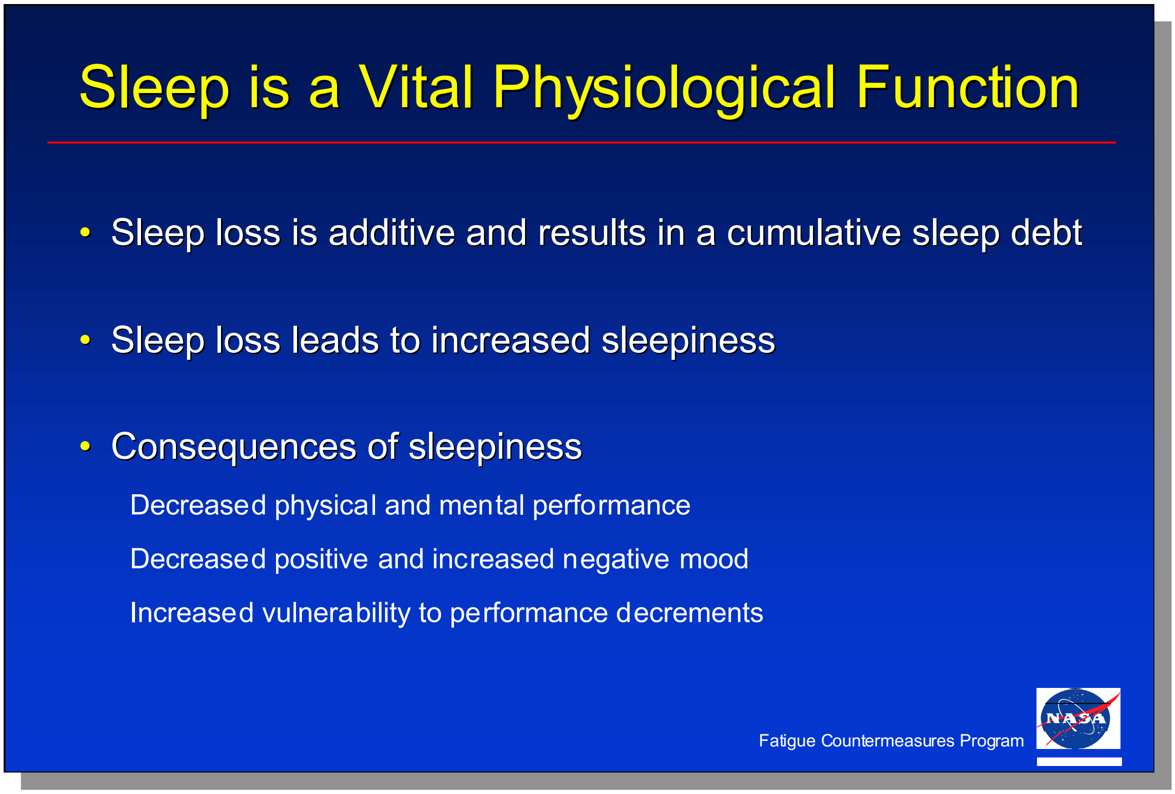
There are many medications (non-sleeping pill), both prescribed and over-the-counter, that can adversely affect sleep. Depending on the specific action of these medications, they may delay sleep onset, disrupt the sleep structure, or alter total sleep time.

Environmental factors may also interfere with good sleep. Noise, light, low or high temperatures, and a variety of other factors can decrease the quantity and quality of sleep. With FAA support, NASA has examined the effects of environmental factors on sleep in on-board crew rest facilities.



There are physical sleep disorders that can disturb sleep and impair waking alertness and performance. (See Appendix A for some examples, such as sleep apnea.) These sleep disorders can have profound effects on waking function, and yet occur with the sleeper essentially unaware of their existence. Sleep problems can be diagnosed and treated effectively by accredited sleep disorders specialists and clinics.

Appendix A also provides some general information about sleeping pills. Some prescription sleeping pills may facilitate falling asleep and staying asleep, with subsequent improvements in waking alertness and performance. However, many sleeping pills alter sleep structure dramatically, create drug dependence, and have carryover effects that decrease waking alertness and performance. Proper use of these medications typically means taking the lowest dose, and that for only a few days. Many sleeping pills can have potentially serious side-effects, and none should be taken except under the care and guidance of a physician.



Like food and water, sleep is a physiological need vital to human survival and critical to human existence. Sleep loss can be additive and can result in a cumulative sleep debt. Estimates suggest that in the United States, most people get 1–1.5 hours less sleep than they need. During a regular 5-day work week a typical individual might accumulate a 7.5-hour sleep debt, equal to a full night of sleep loss, going into a weekend. In today's society, many individuals actively attend to their nutrition and exercise to promote good health. Unfortunately, the first physiological need that suffers when individuals are faced with everyday pressures and demands is sleep. Losing sleep becomes a way of squeezing more hours and minutes into the day, which demonstrates a lack of concern for meeting this vital physiological need.

Sleep loss leads to increased waking sleepiness. Many people equate sleepiness with being lazy or acknowledge it only humorously. Sleepiness can have severe consequences for us as individuals and as a society. Sleepiness can degrade essentially every aspect of human performance. Sleep loss and sleepiness can decrease physical, psychomotor, and mental performance, and can increase negative mood and decrease positive mood. Therefore, a principal consequence of sleepiness is an increased vulnerability to performance decrements. It is important to consider this as a performance vulnerability because, like the effects of alcohol on performance and memory, sleepiness can lead to a reduced safety margin and an increased potential for operational incidents and accidents. Sleep loss and sleepiness resulting from extended duty or altered work/rest schedules have been suggested as contributory factors in many accidents and catastrophes. As individuals, many people put themselves at personal risk by driving when too sleepy, sometimes experiencing a near incident or an actual accident.

Sleep loss can result in a cumulative sleep debt and waking sleepiness. Sleepiness should be taken seriously. Its profound effects on waking performance, mood, and alertness can create a vulnerability to operational incidents and accidents. That vulnerability can be minimized, thus potentially avoiding an incident or accident.

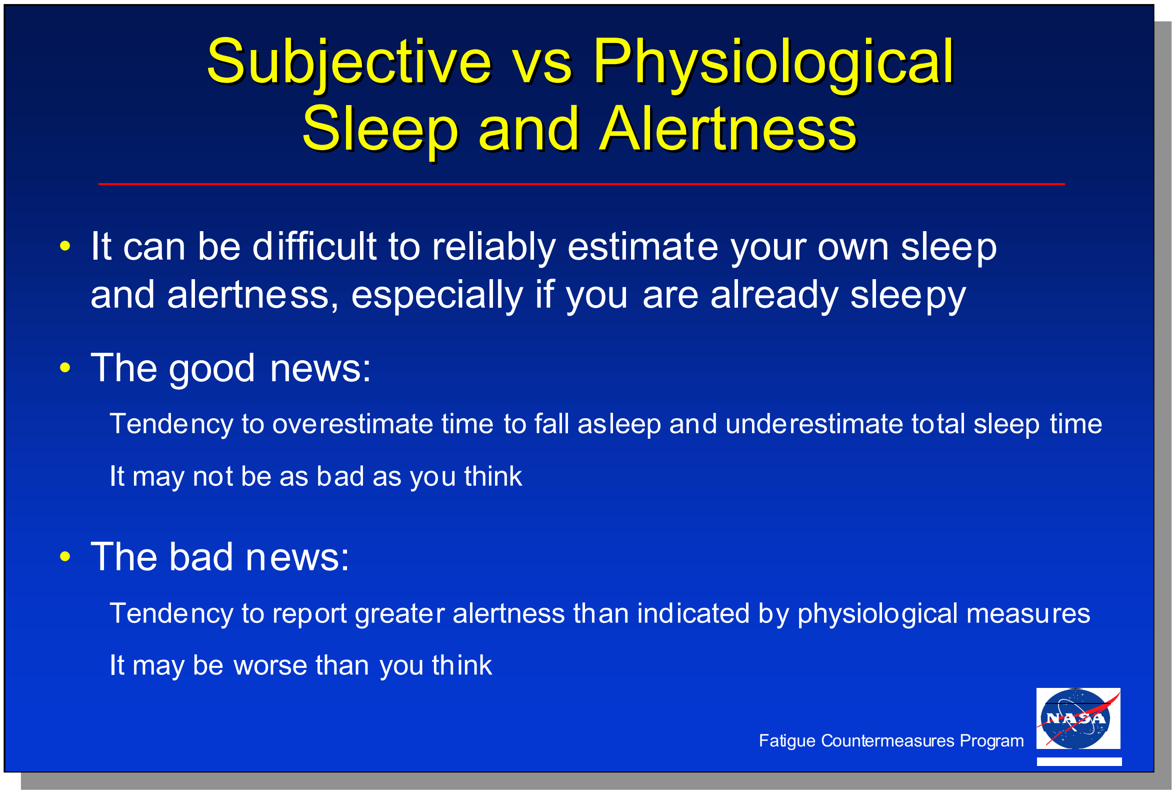
Sleepiness: Two Distinct Components

- Physiological sleepiness
  – Lose sleep, get sleepy
  – Underlying biological process
  – Only reversed by sleep
- Subjective sleepiness
  – How you feel; what you report
  – Can be concealed or altered by environmental stimulation, physical activity, caffeine, etc.

Fatigue Countermeasures Program

Two distinct components of sleepiness have been described. Physiological sleepiness parallels other vital physiological functions like hunger and thirst. Deprived of food or water, the brain signals that these vital physiological needs have not been met by developing feelings of hunger and thirst. When physiologically deprived of sleep, the brain's signal is sleepiness. Just as the only way to reduce or eliminate hunger or thirst is to eat or drink, when an individual is physiologically sleepy, only sleep will reverse this vital need.

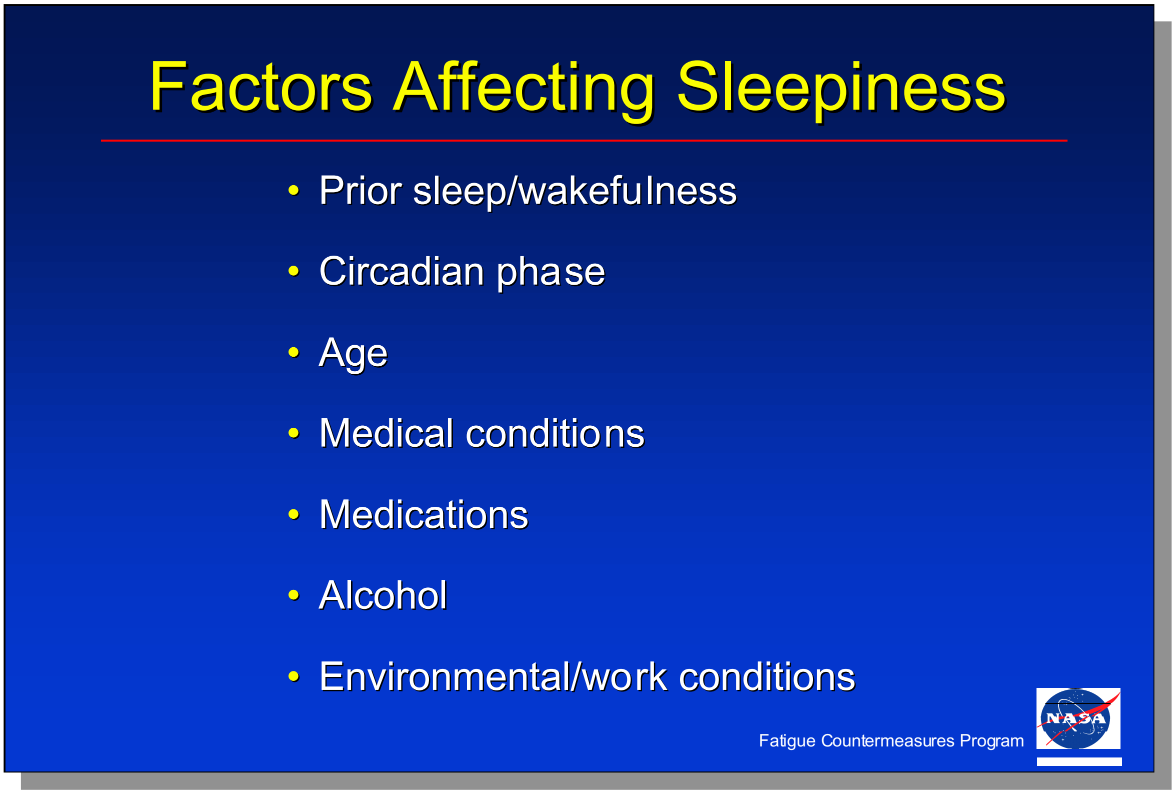
Subjective sleepiness is an individual's introspective assessment of the feeling and a self-report of that status. An individual can rate current sleepiness on a scale from "wide awake and alert" to "extremely sleepy, ready to nod off." However, this self-reported rating can be strongly affected by a variety of factors, such as environmental stimulation. The level of underlying physiological sleepiness can be concealed by an environment in which an individual is physically active, has consumed caffeine, or is engaged in a lively conversation. Whereas these factors may affect the self-reported rating of sleepiness (usually individuals will report greater alertness than is warranted), they do not affect the underlying sleep need expressed by the level of physiological sleepiness.



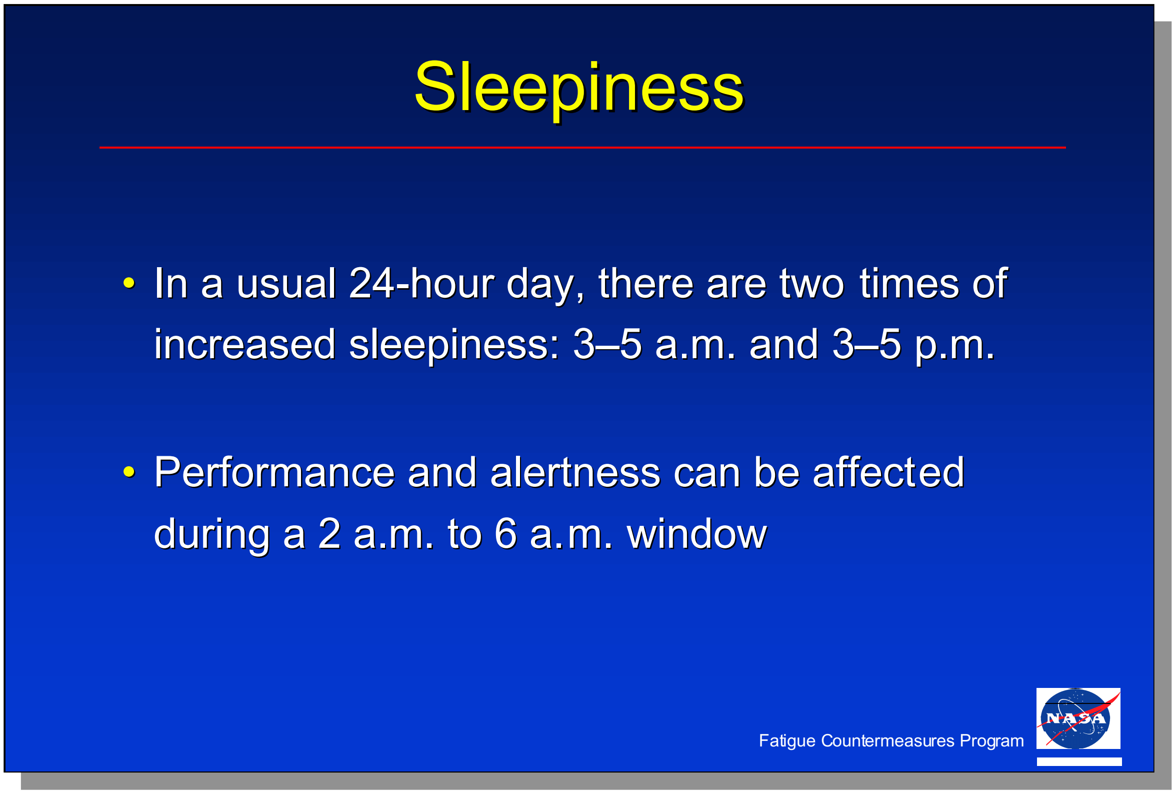
It is usually difficult for most individuals to reliably estimate their own sleep or their waking alertness, especially if they are already sleepy.

Overall, there is a tendency for individuals to subjectively overestimate how long it takes to fall asleep and underestimate total sleep time, relative to physiological measures. Generally, people fall asleep faster and sleep longer than they think. So when an individual experiences a bad night of sleep, it may not be as bad as it seemed.

However, the tendency is for individuals to subjectively rate themselves as more alert than is indicated by physiological measures. That is, most individuals are more likely to be sleepier than they report or experience.



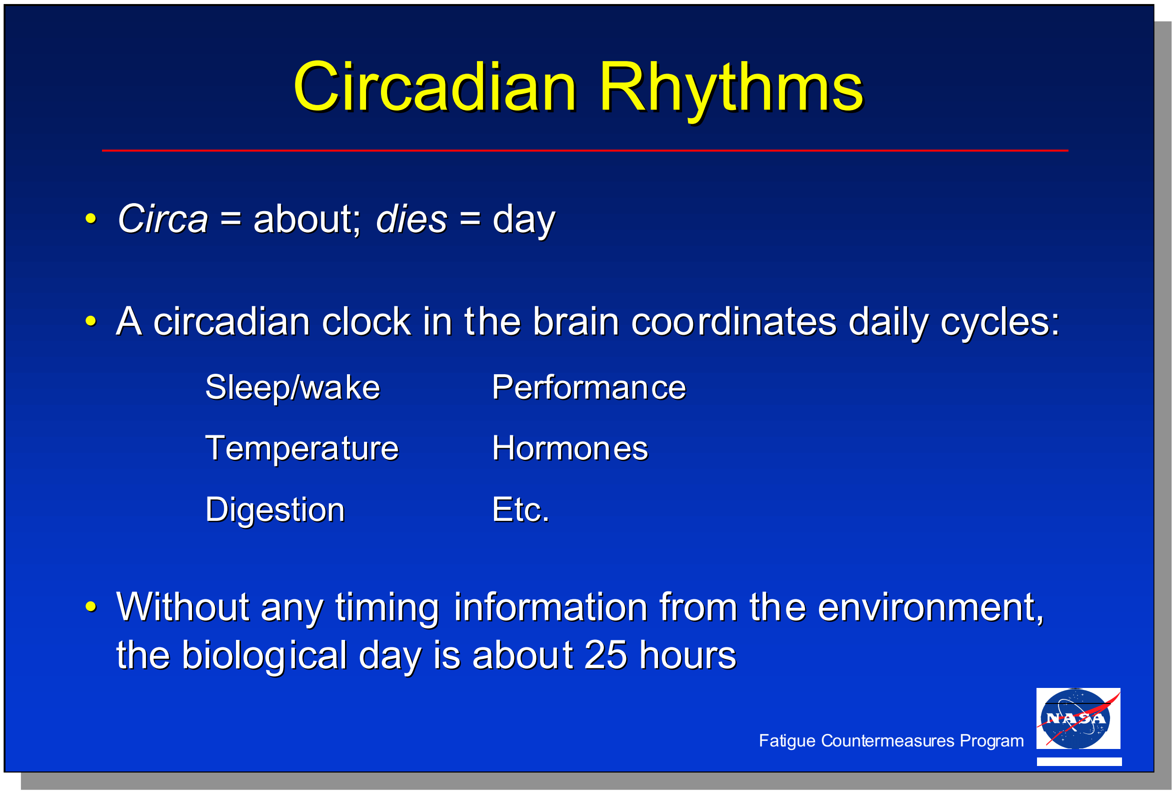
These factors have been demonstrated to affect waking sleepiness and therefore could be considerations in worsening or improving sleepiness.



We are physiologically programmed for two periods of maximal sleepiness in a usual 24-hour period. The period 3–5 A.M. is a circadian low point for temperature, performance, and alertness. During this time, the brain triggers sleep and sleepiness. The other period of increased sleepiness is roughly 3–5 P.M. Most individuals have experienced an afternoon wave of sleepiness. These windows can be used to schedule sleep periods or naps because the brain provides a period of maximal sleepiness and an increased opportunity for sleep.

Performance and alertness can be decreased during the nocturnal window, which is from 2 A.M. until 6 A.M. For some, the afternoon window of sleepiness may occur between 2 P.M. and 4 P.M. This highlights some of the differences among individuals.

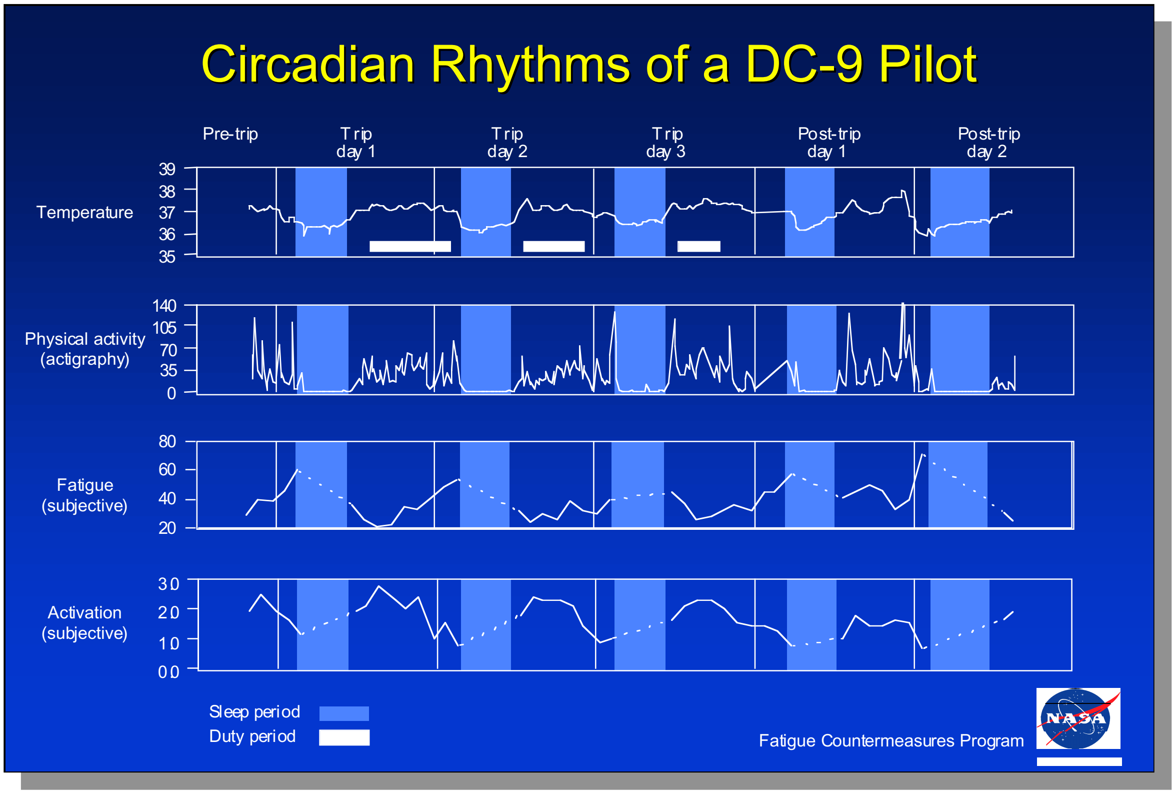
This second section provides basic information about circadian rhythms and how they apply to fatigue, jet lag, and shift work. Circadian rhythms are the second physiological factor that affects fatigue in flight operations.



Over evolutionary time, the daily cycles in the physical environment (produced by the Earth's rotation) have become hard-wired into our neuronal circuitry in the form of a biological clock in the suprachiasmatic nucleus of the hypothalamus. However, since the beginning of the industrial revolution, we have developed a cultural environment in which there is ever-increasing pressure for round-the-clock operations and services. The expedient (but incorrect) assumption that we can and do function equally at any time of the day or night underlies many activities in our society, from medical diagnosis and treatment to many hours-of-service regulations.

When people live alone in environments from which all possible time cues have been carefully excluded (deep caves, underground bunkers, or specially designed apartments), they begin to live "days" that are generally longer than 24 hours. Regardless of how long someone's subjective "day" becomes in a time-free environment, however, the circadian clock still enforces an approximately 25-hour cycle in many functions. Some people even develop "days" as long as 50 hours with, for example, 36 hours of wakefulness followed by 14 hours of sleep.

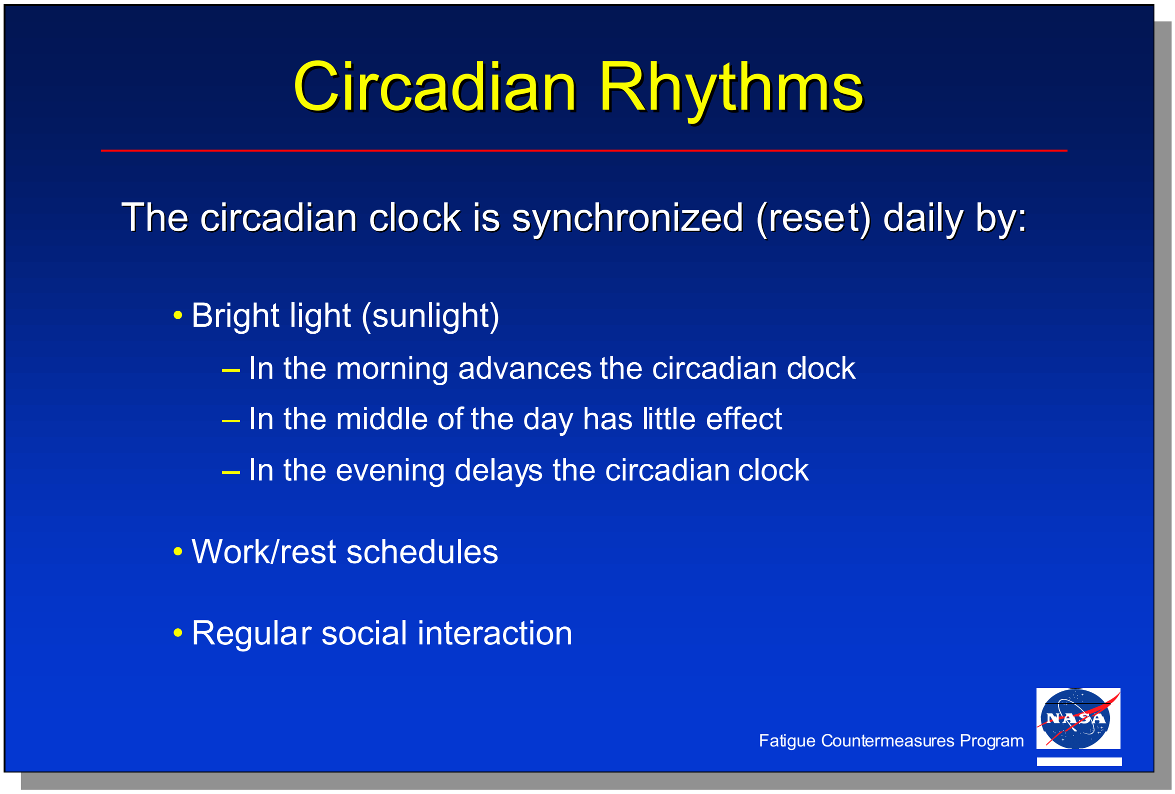
The circadian clock can be thought of as analogous to the conductor of a symphony orchestra. Many different systems in the body, down to the level of individual cells, are capable of generating circadian rhythms independently, just as the members of an orchestra must each be capable of playing their own part. However, if they are not all synchronized appropriately, the harmony rapidly degenerates into cacophony.



This figure shows a number of different circadian rhythms measured simultaneously in a 46-year-old DC-9 First Officer before, during, and after 3 days of scheduled commercial short-haul flying in the eastern United States. To obtain these data, the pilot wore a portable biomedical monitor which recorded his core body temperature, level of physical activity (measured using actigraphy), and average heart rate every 2 minutes. He also carried a logbook in which he rated his fatigue and mood, including subjective activation, every 2 hours, and kept detailed records of all his activities, including when and how well he slept.

Vertical shaded bars indicate times when the pilot reported being asleep. Since he was flying during the day and sleeping at night, his circadian rhythms during the trip maintained their normal relationships to one another and to the environment.

This figure illustrates an important feature of the circadian temperature rhythm. The pilot’s temperature reached a minimum during his daily sleep period, and began to rise well before he awakened. This spontaneous rise in temperature is not the result of increased physical activity. It reflects the action of the circadian clock, which is envisaged to drive a cyclic variation in the setpoint of the temperature-regulating system. In general, changes in heart rate closely paralleled the changes in the level of physical activity. As expected, by the end of the day the pilot felt more fatigued and reported less activation.



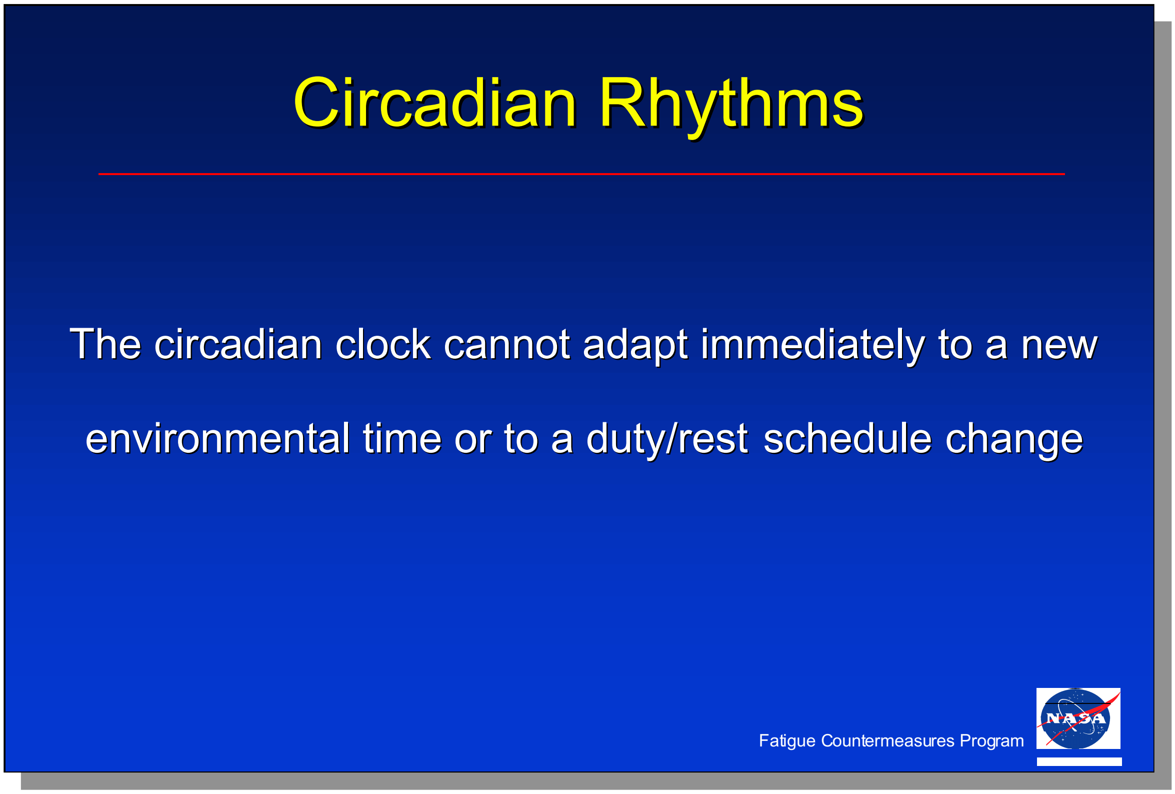
Unless timing information is received from the environment, the human circadian clock tends to run slow. The specific environmental time cues which synchronize it to a 24-hour day are known by the German term "zeitgebers," meaning "time-givers." Currently, two types of zeitgebers have been identified: exposure to bright light and social factors.

Bright light (more than about 2500 lux—normal indoor light is generally less than 500 lux) affects the circadian clock by means of a direct neural pathway from the eye. The principle behind synchronization of the circadian clock by light/dark cycles is reasonably well understood and can be summarized as follows.

1. Light exposure in the subjective morning advances subsequent circadian cycles.
2. Light exposure in the middle of the subjective day has minimal effect.
3. Light exposure in the subjective evening delays subsequent circadian cycles.

To synchronize a circadian clock with an innate period of 25 hours to a 24-hour day requires that the clock be advanced by 1 hour per day. An appropriate exposure to sunlight every morning would achieve the necessary resetting. Conversely, to synchronize a clock with an innate period of 23 hours would require a delay of 1 hour per day, in other words, an appropriate exposure to sunlight every evening. These examples are intended to illustrate the mechanism of synchronization (also known as "entrainment"). Clearly, however, they are highly simplistic. In everyday life, synchronization of an individual's circadian clock to a 24-hour day depends on a complex combination of different zeitgeber inputs.

There is some evidence that the human circadian clock may be synchronized by certain social factors, including the work/rest schedule. However, the specific aspects of the social environment that constitute time cues have not yet been identified, and the mechanisms by which they affect the clock remain unknown.

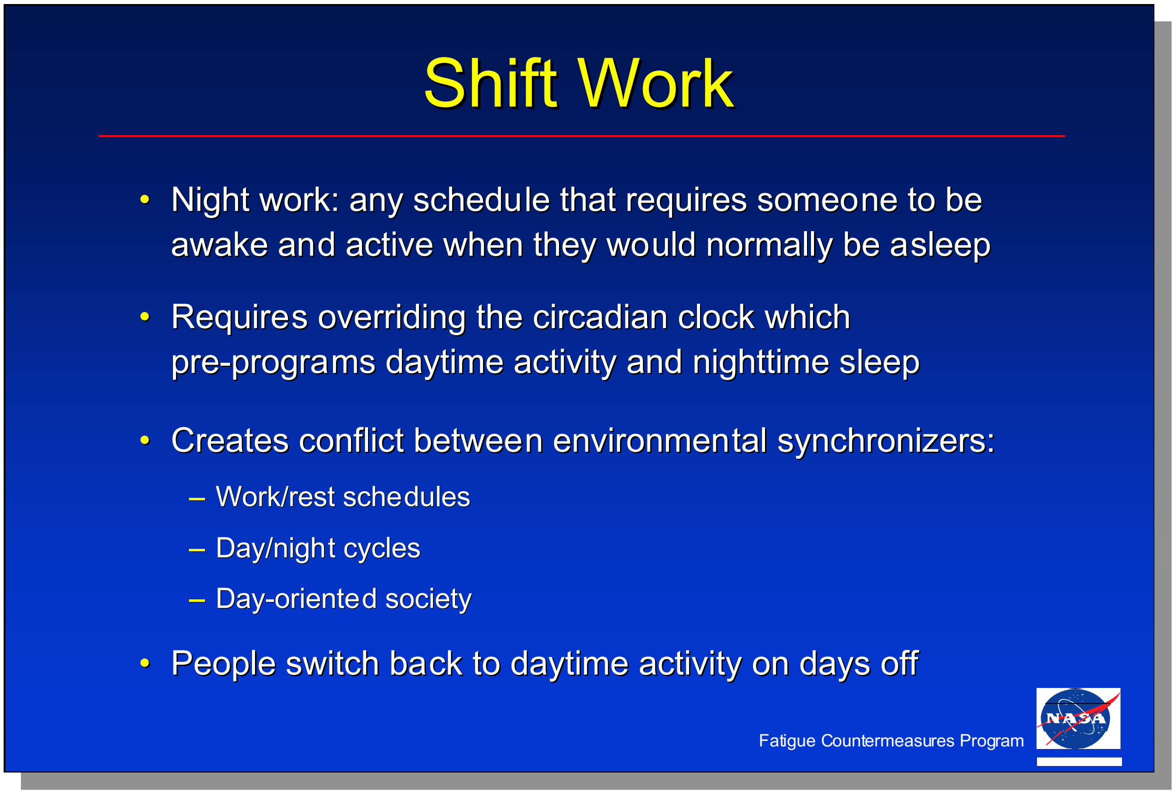


We cannot, as yet, reset our circadian rhythms at will, as we do our wrist watches. However, this is the aim of most circadian countermeasures.

It may take days to weeks for all rhythms to synchronize to a new time zone after one transmeridian flight. During commercial long-haul operations, flight crews usually have 1–2 days at each layover destination before they operate another transmeridian flight. Thus, they seldom become fully synchronized to local time during layovers.

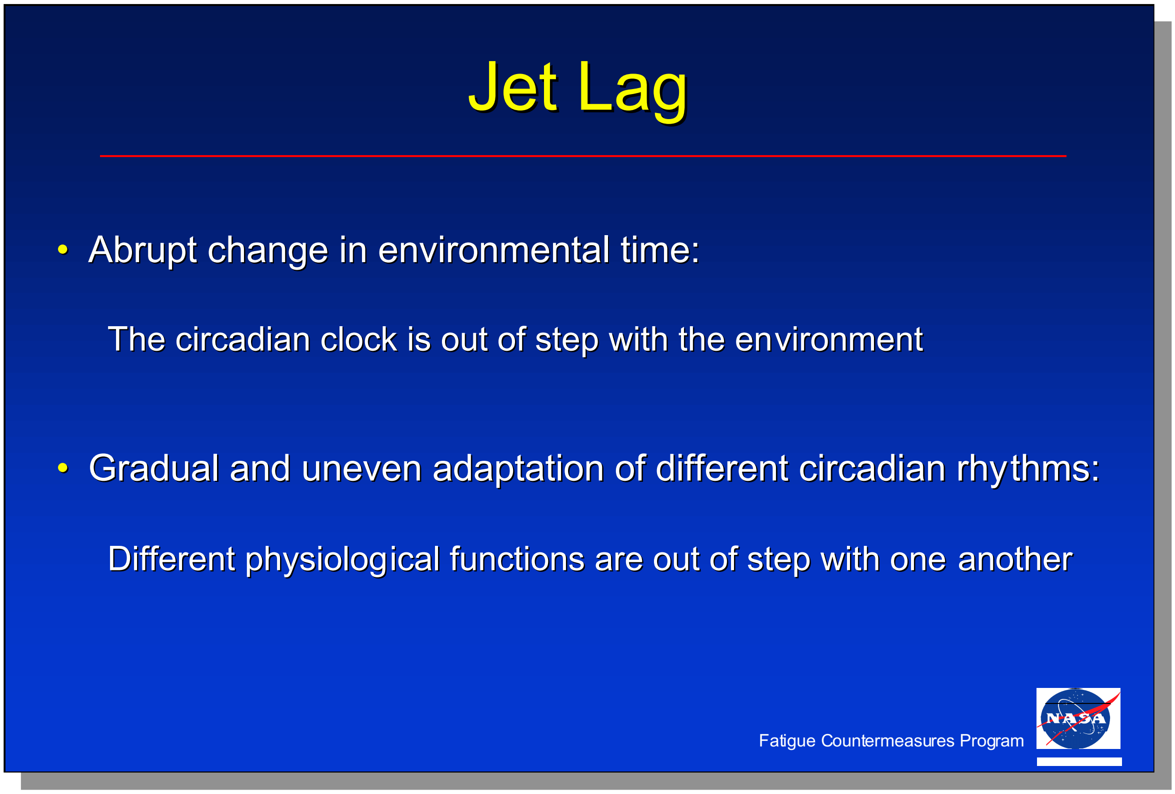
Similarly, shift workers are rarely, if ever, fully adapted to one work/rest schedule before they switch back to normal daytime activity and nighttime sleep on their next days off. In the case of rotating shift workers, going back to work then means trying to adapt to yet another work/rest schedule. Two different approaches have developed for scheduling rotating shift workers. With rapid rotations (changing hours of work every few days), circadian adaptation to any one work/rest pattern is minimal, and workers revert easily to being day-active on their days off. This approach is more common in Europe. With slower rotations (changing the hours of work every 1–2 weeks), the circadian clock has more time to synchronize to a given work/rest schedule. Sleep and performance are thus expected to improve progressively, at least until the next day off. This approach is generally preferred in the United States.

The problems engendered by the slow adaptation of circadian rhythms to new time zones and duty/rest schedule changes are examined in the following slides.



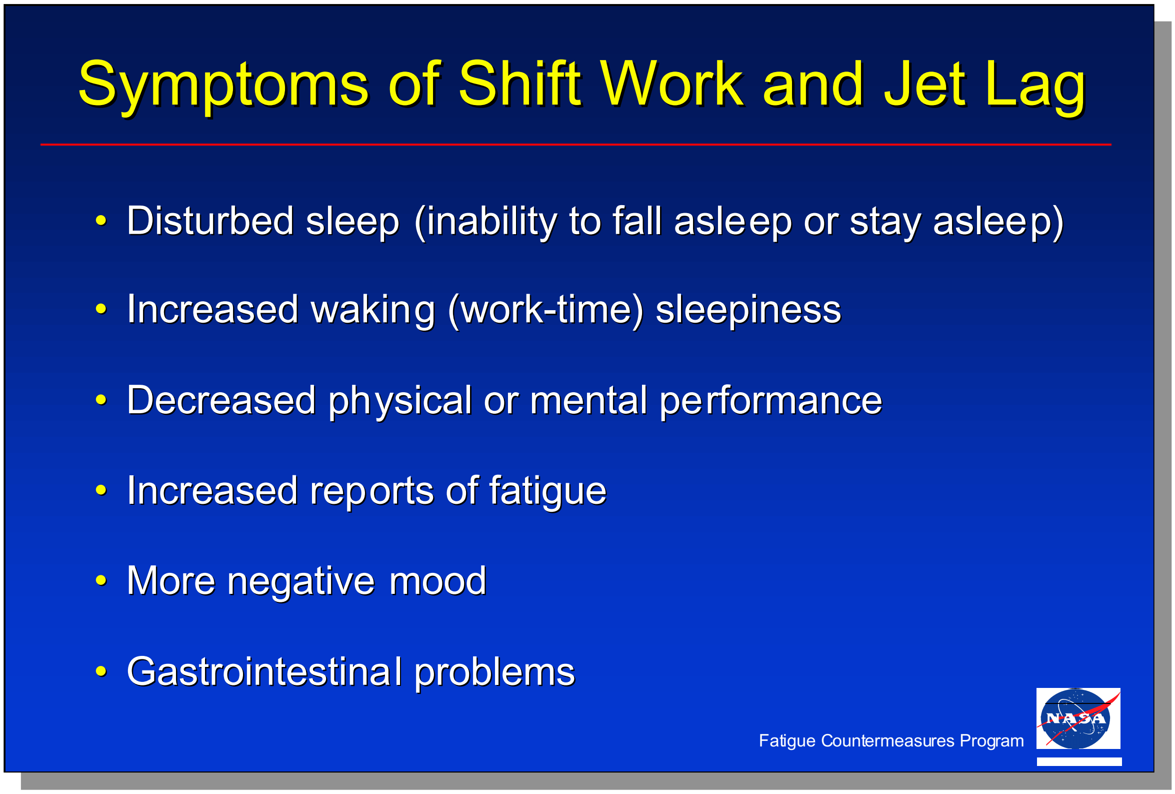
The basic problem with shift work is that it requires people to somehow override the circadian clock, which pre-programs us for daytime activity and nighttime sleep. The work/rest schedule itself may reset the clock of the shift worker to some extent. However, the competing zeitgeber inputs from the day/night cycle and our predominantly day-oriented society continually push it back toward its usual diurnal orientation. Thus, at best, the circadian rhythms of shift workers usually are only partially adapted to their current work/rest schedule. In addition, most shift workers revert to being day-active on their days off. This continuously changing orientation can result in chronic desynchronization of the circadian clock relative to the environment, and persistent internal desynchronization among different physiological systems.

The conflicting zeitgeber environment typical of shift work is further confounded in aviation operations by the day-to-day instability of the duty/rest cycles and by the element of unpredictability (associated with weather, mechanical problems, system delays, and other operational factors).



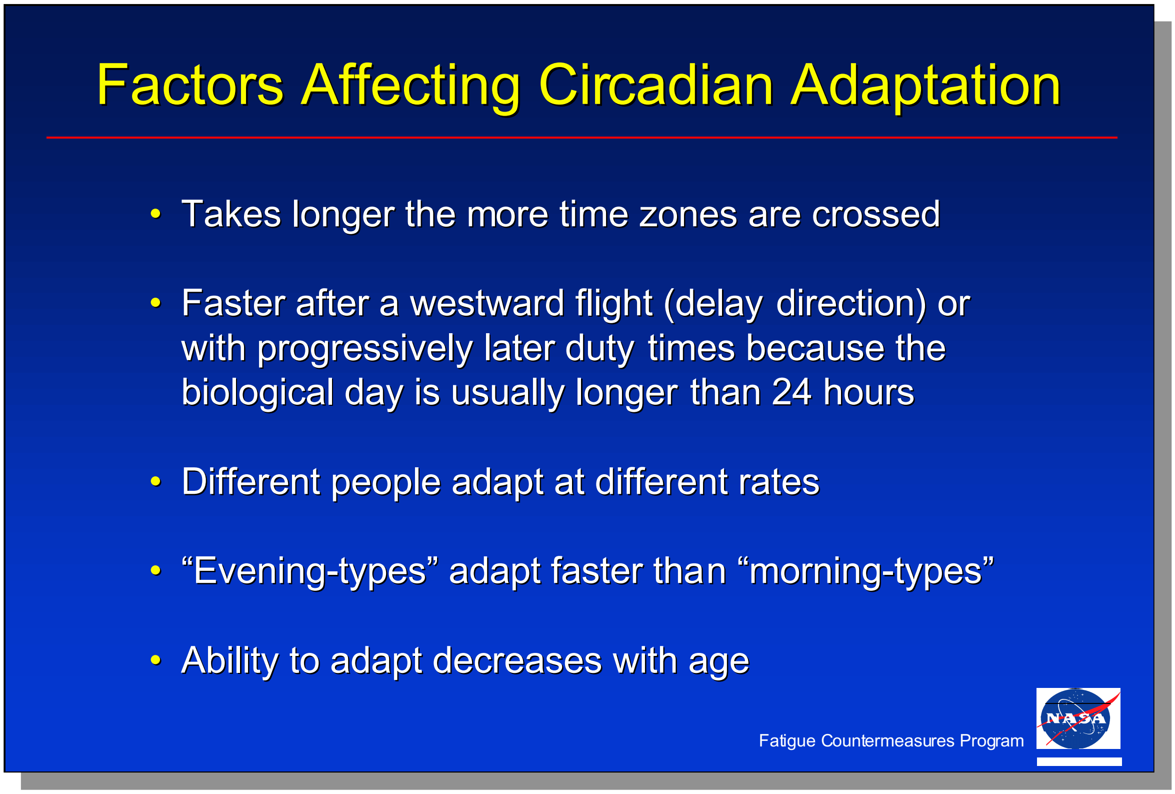
Crossing time zones produces an additional zeitgeber disruption regularly encountered by flight crews. The circadian clock resynchronizes only gradually to a new environmental time. Circadian rhythms in different functions adjust more or less quickly, depending on the tightness of their coupling to the clock and on their interactions with other physiological functions, each adapting at its own rate. Thus, after a transmeridian flight, not only is the circadian clock out of step with the local zeitgebers, but also different physiological functions are out of step with one another.

During commercial long-haul operations, crewmembers rarely stay long enough in one time zone for their circadian clocks to become synchronized to local time. Rapid sequences of transmeridian flights present continuously changing zeitgeber signals to the clock, which is buffeted back and forth and unable to stabilize.



Recent overviews of studies with shift workers indicate that 60% of them have sleep complaints, whereas only 20% of day workers have similar complaints; 75% of night workers experience sleepiness on every shift, and 20% report falling asleep.

Shift workers (particularly rotating shift workers) have a higher incidence of sick leave, more frequent visits to health care facilities at the work site, and more general health complaints than day workers. Night shift workers have higher incidences of gastrointestinal disorders, including general stomach discomfort and ulcers, than do day workers. These symptoms probably result from the interaction of several factors, including circadian desynchronosis and the increased domestic and social stresses that often accompany shift work.



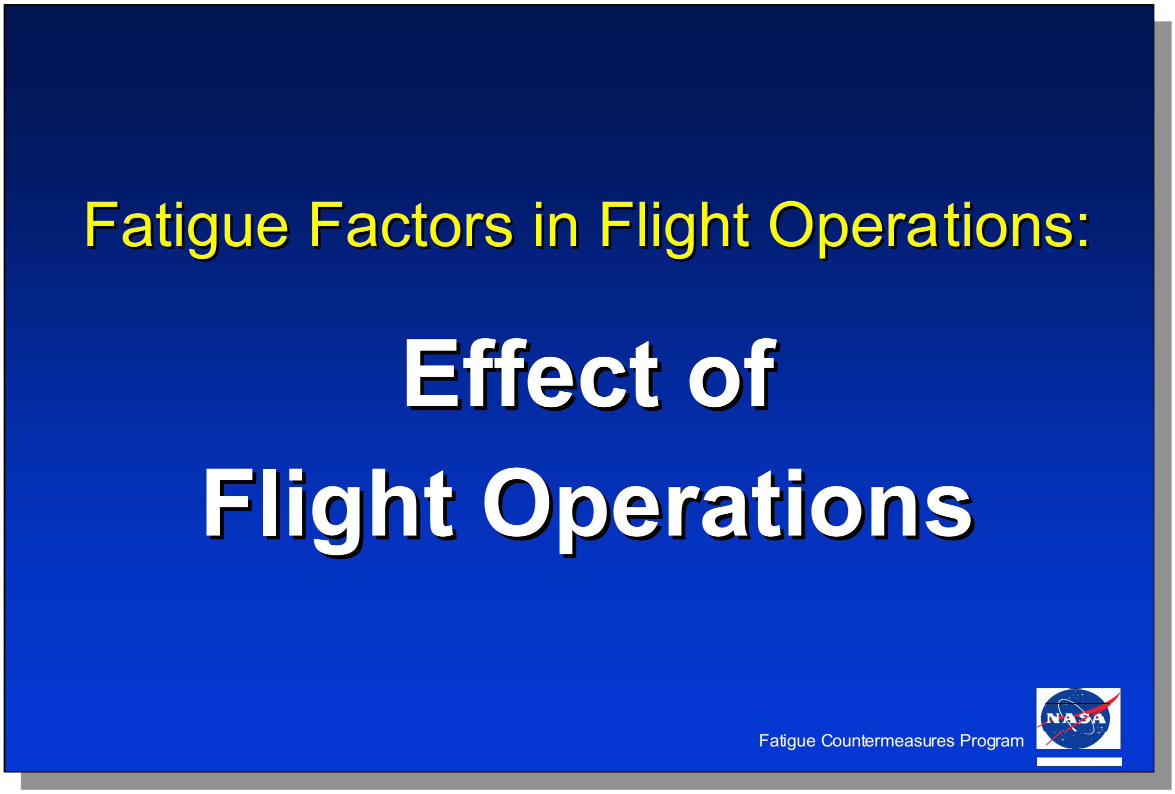
Circadian adaptation in flight crews after transmeridian flights has been examined in only a few studies.

Klein and colleagues at the DLR (the German Aerospace Establishment) found that flying skills of 12 German fighter pilots tested in an F-104 simulator were less impaired after a westward flight (as passengers) crossing eight time zones than after the return eastward flight.

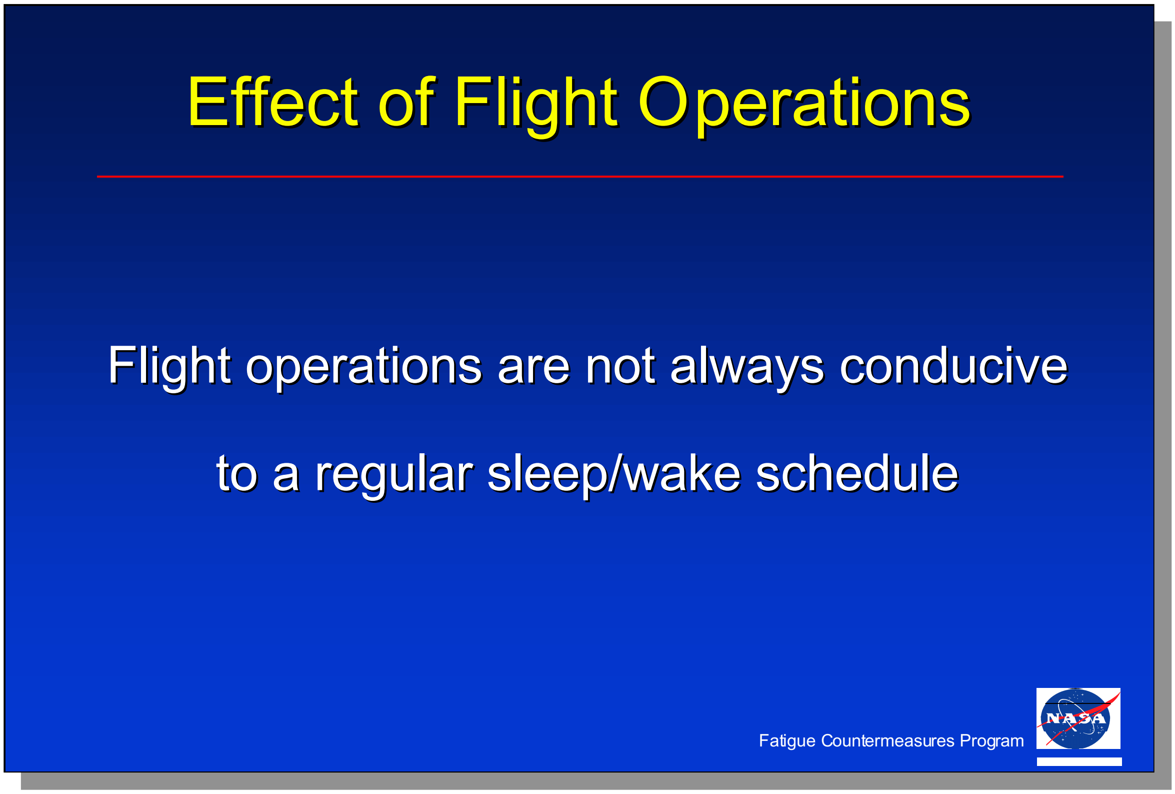
A joint study conducted by NASA and the Royal Norwegian Air Force Institution of Aviation Medicine examined adaptation of 9 crewmembers operating Orion P-3 aircraft during eastward and westward flights across nine time zones. Adaptation of sleep and the temperature rhythm to local time was faster after westward flights.

In an international study coordinated by NASA, sleep of long-haul flight crews during the first layover of scheduled international trips was less disturbed after westward flights crossing eight to nine time zones than after eastward flights crossing eight time zones. In the same study, crewmembers who scored as more evening-type showed lower levels of daytime sleepiness after an eastward flight crossing eight time zones (Tokyo-San Francisco) than did more morning-types.

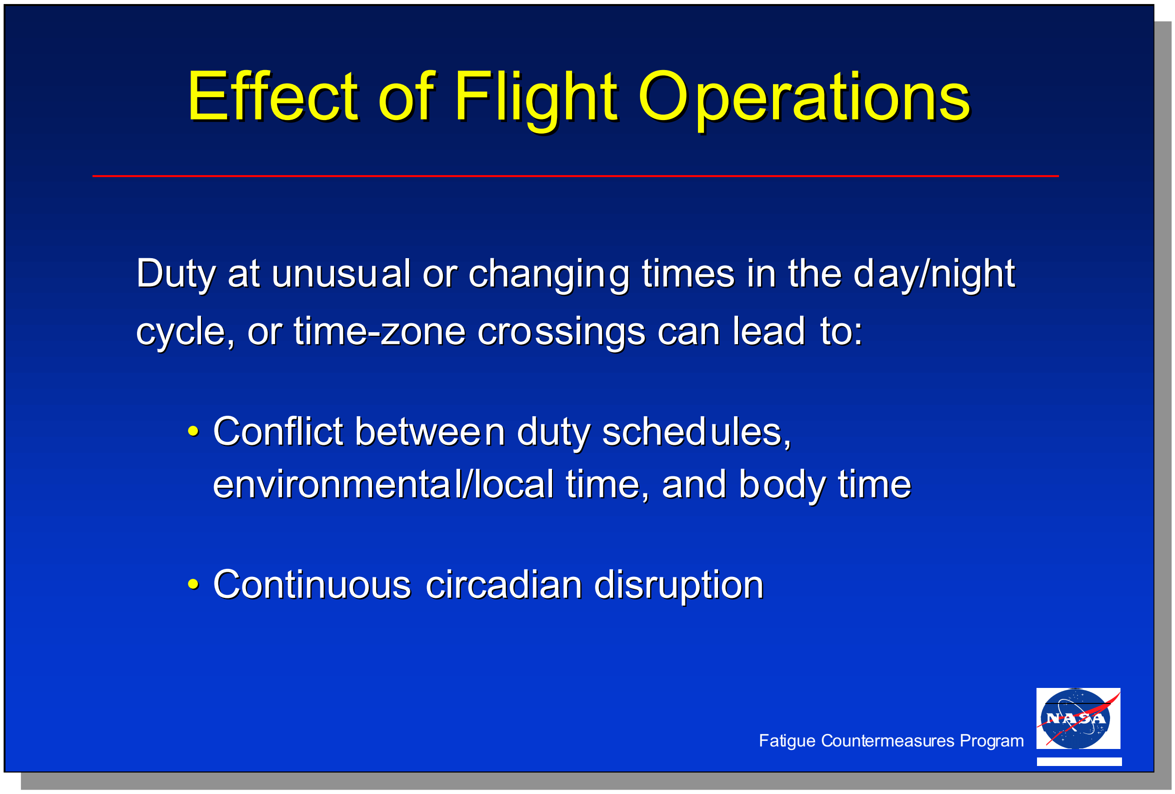
A NASA study of the effects of aging found that as flight crews get older, they become more morning-type and the amplitude of their circadian temperature rhythm declines. Daily percentage sleep loss during trips was 3.5 times greater among long-haul crews aged 50–60 than among long-haul crews aged 20–30.



The previous two sections dealt with the principal physiological factors that create fatigue. This section identifies how flight operations play a role in creating flight crew fatigue.



Certain kinds of flight operations occur during the day, involve minimal time-zone changes (and therefore minimal circadian disruption), and may have a minimal effect on usual sleep/wake schedules. However, it is very clear that many flight operations are not conducive to regular sleep/wake schedules.



Flight operations can affect sleep and circadian factors in two main ways: first, by occurring at unusual or changing times in the day/night cycle, and second, by requiring time-zone changes. Either of these, and especially the two combined, can have two basic effects: conflict between external time (environmental or local) and body time; and continuous circadian disruption.

The body's time can conflict with environmental time (in the case of unusual/changing schedules) or local time (in the case of changing time zones). The first case occurs because night flying is in direct opposition to the circadian clock's natural programming for sleep during nighttime, just as sleep during day hours is in opposition to the circadian clock's programming for wakefulness during daytime. The second case occurs due to the wide range of required time changes resulting from successive west-east/east-west flights.

When the body is required to adjust continuously, continuous circadian disruption can occur. Continual alternation between day and night schedules, for sleep or duty, can cause the circadian clock to be constantly resetting itself. Successive time-zone changes can also lead to symptoms of incomplete adaptation. There is currently no information on the specific effects of continuously resetting the circadian clock in flight operations.

Effect of Flight Operations

- Extended duty periods
  - Prolonged wakefulness
  - Fatigue from continuous operations
  - Boredom/complacency
- Restricted time available for sleep
  - Cumulative sleep debt

Fatigue Countermeasures Program

An obvious contributor to sleep loss is a prolonged period of continuous wakefulness. An extended duty period can create fatigue by extending wakefulness and decreasing sleep, and can involve circadian disruption. Other fatigue factors that can emerge in continuous operations are boredom and complacency. When a human is acting only as a passive monitor (e.g., of relatively rare events in highly automated aircraft), there is an opportunity for these factors to increase the likelihood for physiological sleepiness to emerge (i.e., the person may fall sleep).

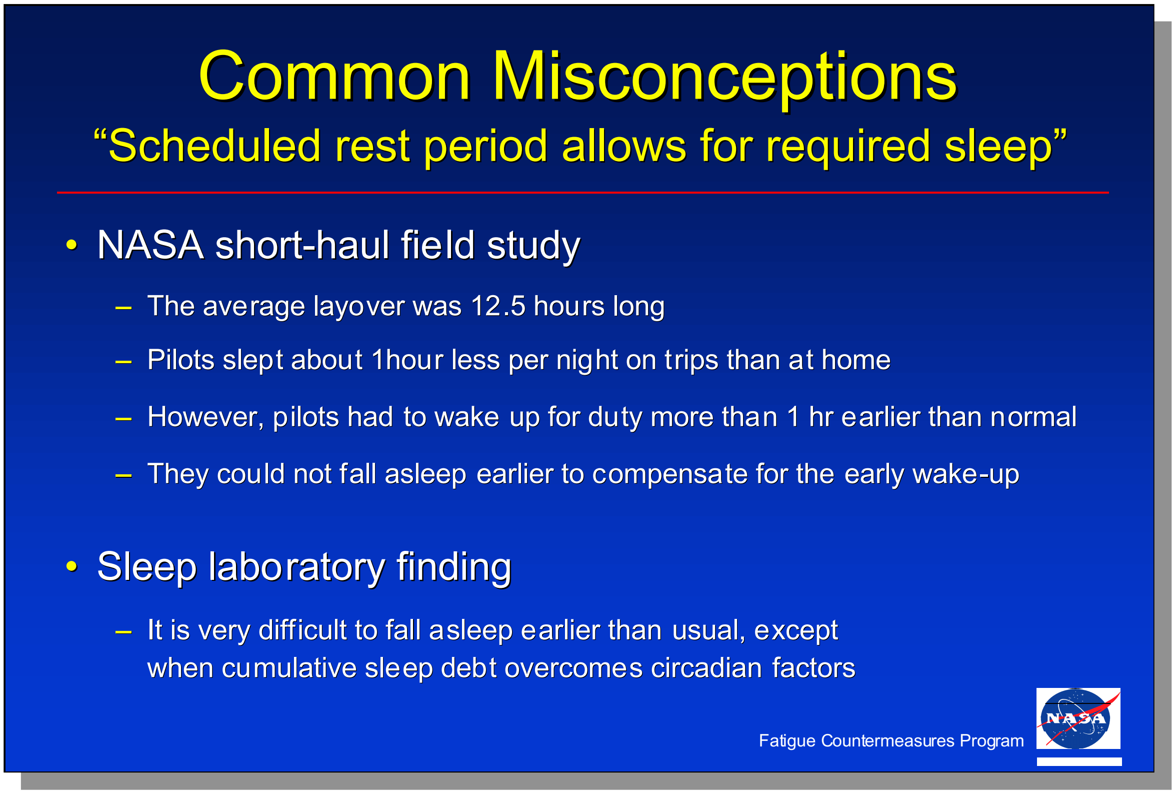
In many flight operations, the time available for sleep is restricted by a variety of constraints. If an individual's physiological timing for sleep does not coincide with the scheduled sleep opportunity, then a cumulative sleep debt can result.

Fatigue Signs and Symptoms

- Forgetful
- Poor decisions
- Slowed reaction time
- Reduced vigilance
- Poor communication
- Fixated
- Apathetic
- Lethargic
- Bad mood
- Nodding off

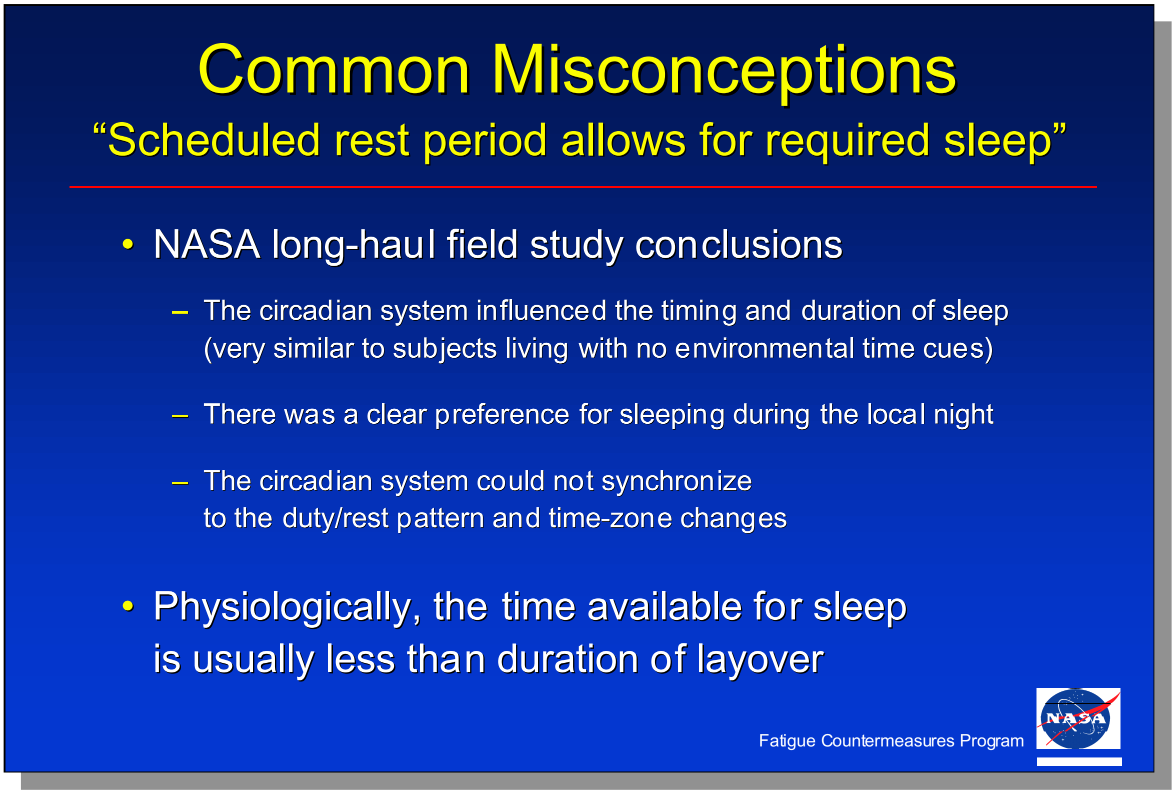
Fatigue Countermeasures Program

There are many misconceptions about fatigue in flight operations. Several commonly held misconceptions will be presented and then addressed using the information previously presented and additional scientific data.



The problem with having to get up earlier than usual is that it is very difficult, if not impossible, to fall asleep sufficiently early the night before to compensate (even when the duty schedule permits). It is not simply a question of discipline or motivation. The circadian clock effectively opposes falling asleep earlier than the habitual bedtime. Just as there are preferred times in the circadian cycle for falling asleep, there are also times when sleep onset is very unlikely. These times have been labeled "wake maintenance zones," and one of them occurs just before the habitual bedtime. In addition, because the "biological day" dictated by the circadian clock tends to be longer than 24 hours, it is easier to go to sleep later than to go to sleep earlier. Going to sleep later also means staying awake longer, which allows more time for the homeostatic "sleep pressure" to build up.

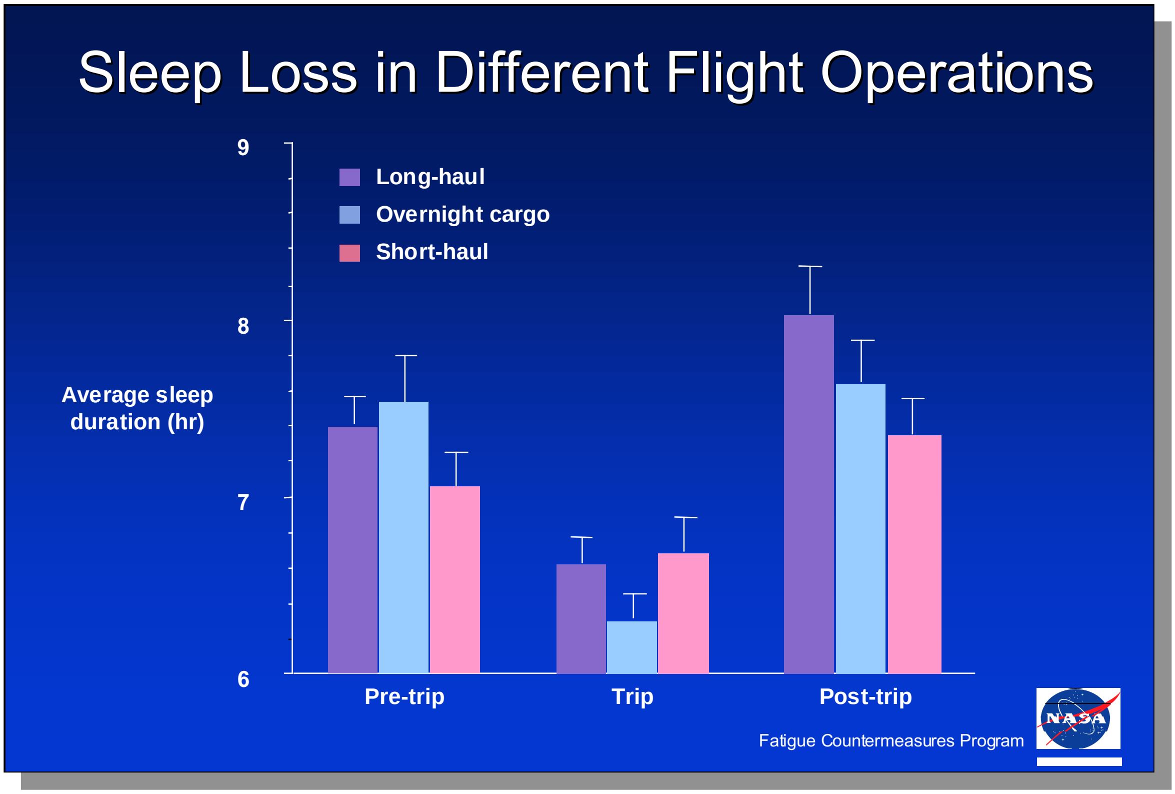
An example of the phenomena described above is from a NASA short-haul field study, which examined 44 pilots in the DC-9 and the B-737. The average layover was 12.5 hours. Yet, despite the fact that 12.5 hours seems an adequate amount of time for 8 or more hours of sleep, pilots slept about 1 hour less per night on trips than at home. The pilots had to wake up for duty more than 1 hour earlier than usual, and they could not fall asleep earlier to compensate for the early wake-up.



The information on this slide is based on a NASA long-haul study that also demonstrates the misconception that the entire rest period is available for sleep. The study examined 29 pilots in B-747s (each series except 400) during four trip patterns that lasted 5–9 days. The average duty period was 10.3 hours, followed by an average layover of 24.8 hours, resulting in an average rest/duty cycle of 35.1 hours. There were usually two sleep episodes (total 11.5 hr of sleep) per layover. A provocative finding here is that the average temperature rhythm for these long-haul pilots was extended to 25.7 hours. This is longer than the usual 24-hour circadian cycle and longer than the usual free-running rhythm of 24.9 hours. It suggests that after a period of time, the circadian clock could no longer follow the many time-zone changes and irregular hours of work and rest.

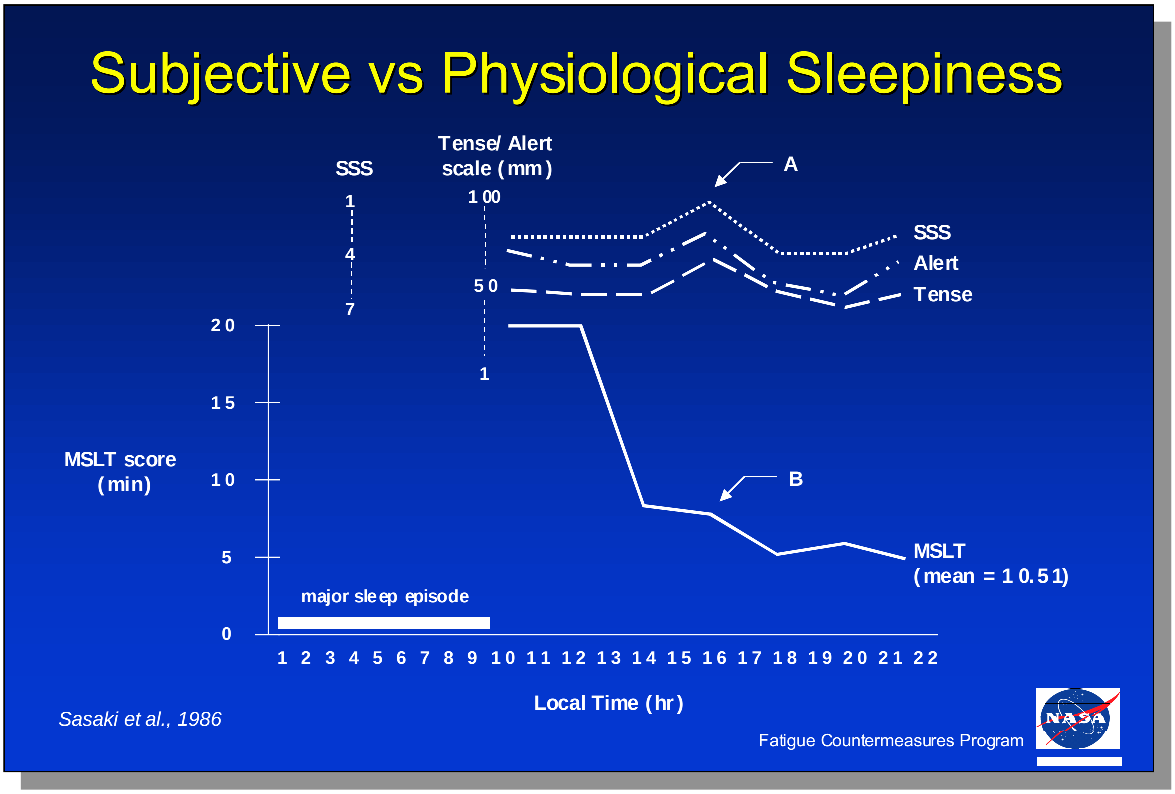
This NASA field study confirms that the circadian clock cannot keep up with the time-zone changes and non-24-hour duty/rest cycles experienced by long-haul flight crews. In addition, a 24-hour sleep/wake cycle is impossible with the average duty/rest pattern of 10 hours of duty followed by a 25-hour layover.

This forced internal desynchronization has a number of important consequences. First, the bi-circadian (twice per cycle) peaks in sleep tendency can occur in-flight, thus increasing the risk of inadvertent napping in the cockpit. Second, the part of the circadian cycle during which sleep normally occurs may or may not be contained within a layover, and may or may not coincide with local night. The interplay of these factors will have a major effect on how much sleep flight crewmembers are able to obtain en route and on layover. Third, the circadian rhythms in digestive function may or may not coincide with the patterns of meal availability in-flight and during layovers. Gastrointestinal problems can result from repeatedly eating at inappropriate times in the circadian cycle.



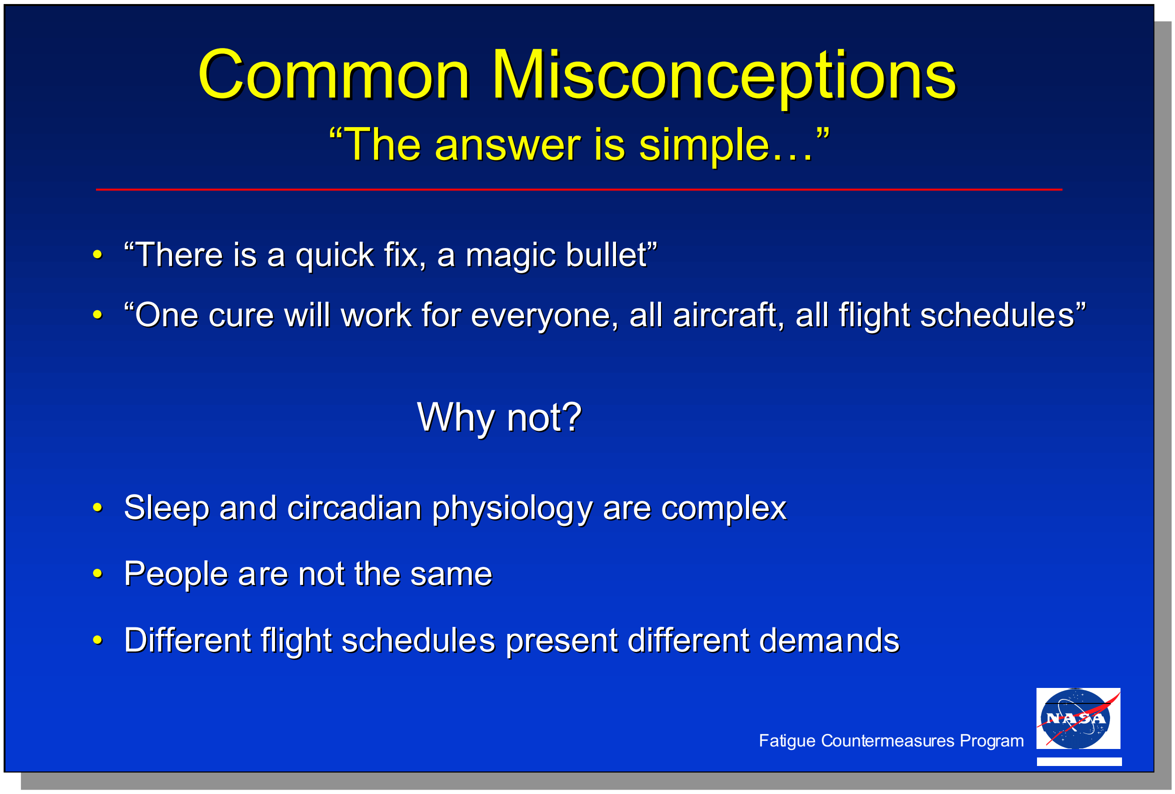
This graph demonstrates that in each flight operation studied, sleep loss occurred during trips. Three types of commercial flight operations are portrayed on this graph: short-haul, long-haul, and overnight cargo. The average hours of sleep obtained pre-trip are portrayed for each flight operation on the left. The middle three bars indicate the reduced sleep obtained, on average, in each type of operation during a trip schedule. The bars on the right display the average amount of sleep obtained posttrip. The principal finding is that in most cases any of these three types of flight operations will engender sleep loss during trip schedules.

One widely held belief is that individuals can accurately and reliably estimate their alertness and performance. Many people believe that being motivated, well-trained, and professional or having previous experience with sleep deprivation prepares them to combat the physiological consequences of sleep loss. As previously presented, individuals (especially sleepy individuals) do not reliably estimate their alertness and performance. The following data from a long-haul pilot illustrate the point.



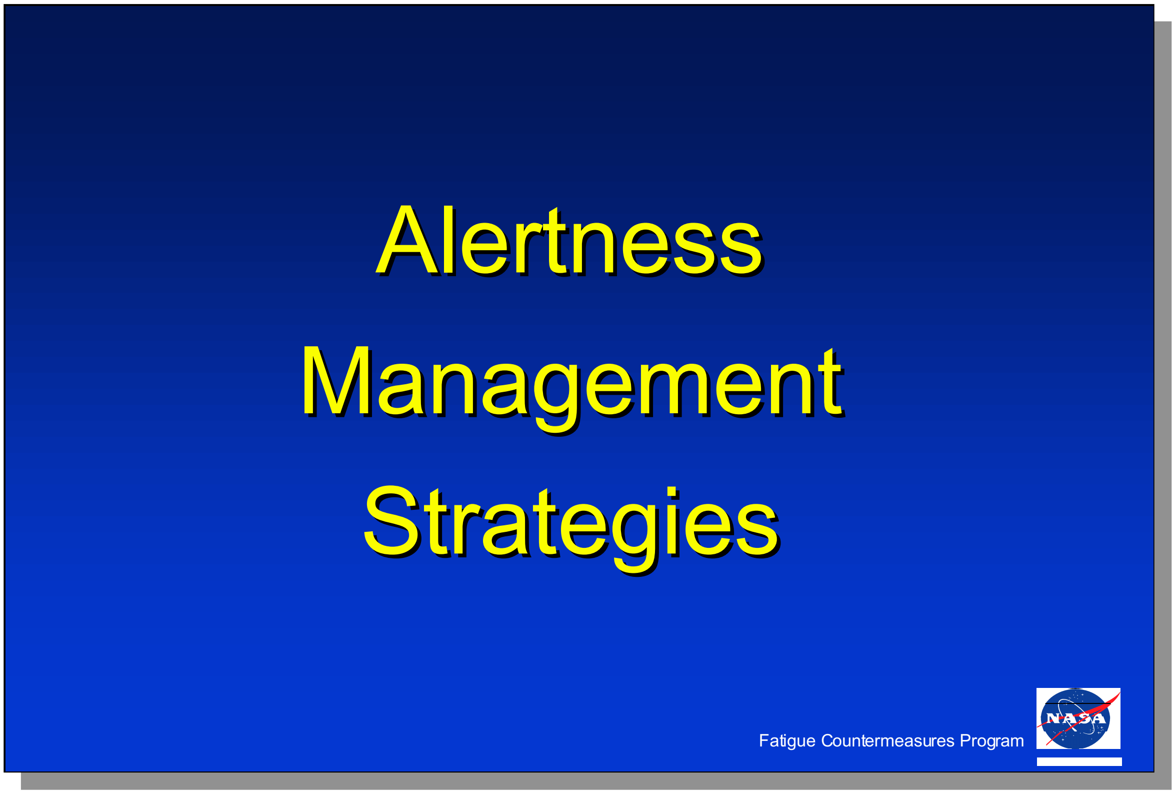
These data were obtained in a NASA collaborative study that examined layover sleep and waking sleepiness during layovers in international long-haul flight crews. This pilot was asked to rate his overall level of sleepiness throughout the day while simultaneously having it measured with an objective test of physiological sleepiness. The test of physiological sleepiness is called the Multiple Sleep Latency Test (MSLT) and is a laboratory standard for objective evaluation of physiological sleepiness. Essentially, the test defines sleepiness by the speed of falling asleep: the sleepier the individual, the sooner sleep onset will occur; the more alert the individual, the longer it will take for sleep onset to occur, if it does at all. Measurements of brain, eye, and muscle activity can quantify the speed of falling asleep to within half a second. Individuals have 20 minutes to fall asleep in a quiet, dark room. If they do not fall asleep, their score is 20 and they are considered very alert. If they fall asleep immediately, their score is 0 and they are considered very sleepy. This test has been used in thousands of studies involving sleep-disorder patients and sleep deprivation. Individuals who are sleep deprived experimentally or who have a sleep disorder that causes waking sleepiness will fall asleep on this test in 5 minutes on almost every opportunity. This MSLT score of 5 or less often is referred to as being in the “twilight zone”.

The pilot’s subjective sleepiness scores (SSS = Stanford Sleepiness Scale) are portrayed on the top half of the graph. The letter A indicates the point when the pilot reported his greatest level of alertness. The bottom half of the graph portrays his MSLT scores. The letter B indicates the point directly under A. At this time (when the pilot reported being most alert), his MSLT score is approaching the twilight zone, and on subsequent MSLT tests, it is clearly in the twilight zone. This demonstrates the discrepancy between the self-report of sleepiness and the level of physiological sleepiness. Although reporting peak levels of alertness, this pilot was approaching the twilight zone and a high level of physiological sleepiness.

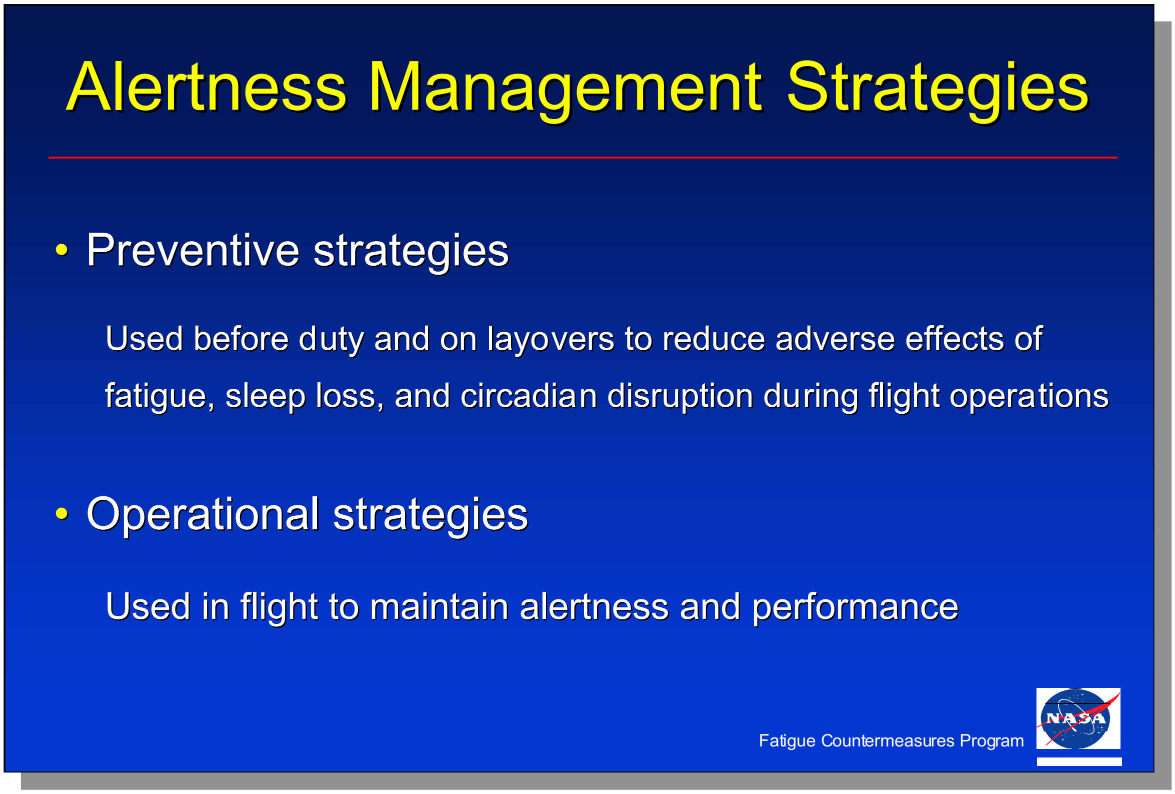


A misconception that must be dispelled is that there is a “magic bullet” that will cure the fatigue, jet lag, sleep loss, circadian disruption, and sleepiness engendered by flight operations. The previous sections have demonstrated clearly the complexities of the physiological systems and the diversity of effects created by the range of flight operations. Also, people are not the same, and the range of individual differences in response to these effects must also be considered.

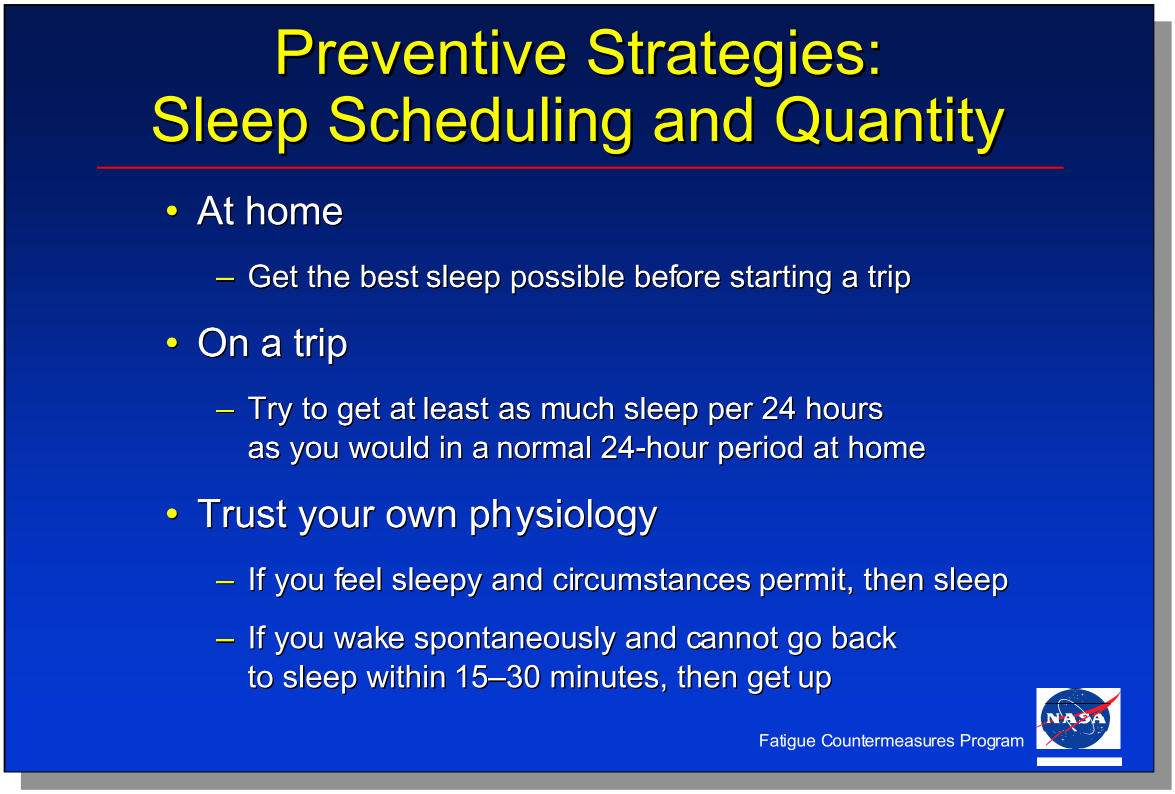
The idea that there is no magic bullet should be remembered whenever assessing the latest “cure” for jet lag. Be skeptical and weigh the claims in consideration of the physiological information previously presented.


Alertness
Management
Strategies
Fatigue Countermeasures Program

It will be continually emphasized that the following strategies are only recommendations and should be tailored to an individual's particular needs and activities. You should experiment with different strategies and evaluate their effectiveness in the context of your own physiology and specific flight operations. The best effects may result from combining strategies rather than relying on an individual strategy.



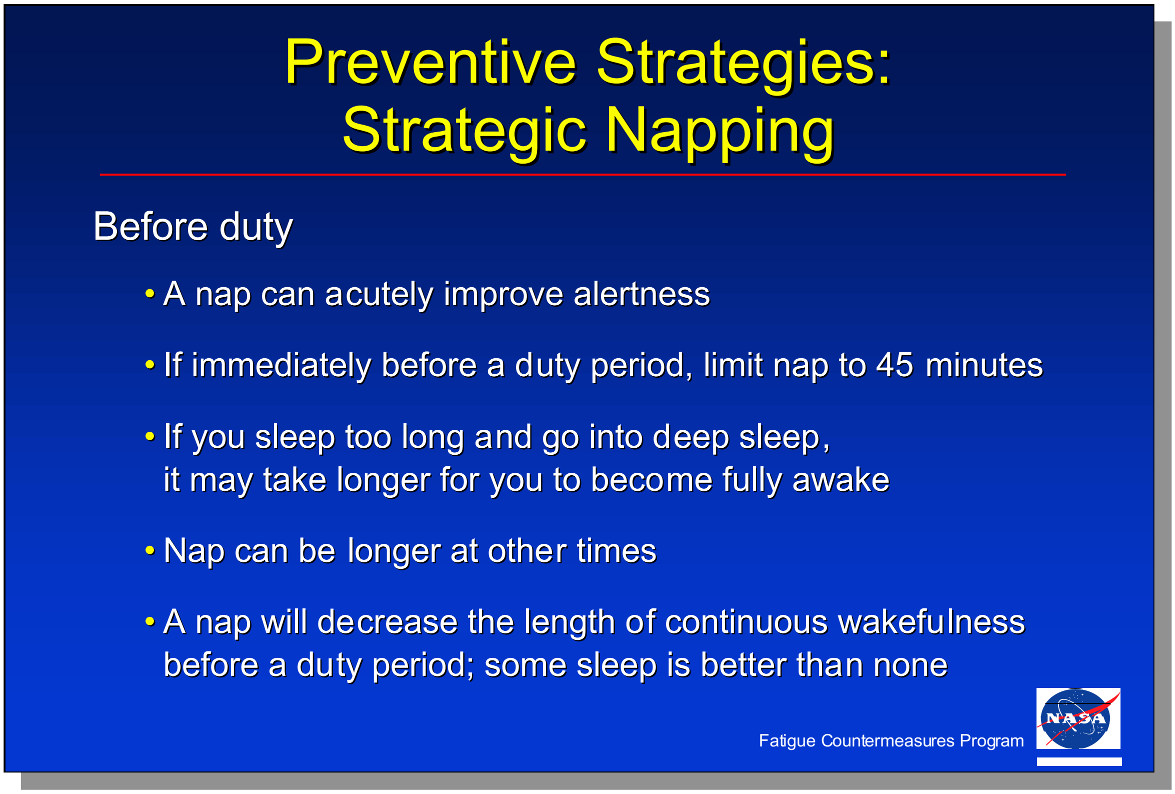
The following is an approach to differentiating alertness management strategies. Preventive strategies focus on the underlying physiology by attempting to manage and maximize sleep and promote circadian adaptation. These strategies are used at home before a trip or during a layover. Operational strategies are in-flight measures that help to maintain alertness and performance. These strategies do not necessarily affect the underlying physiological mechanisms, but focus more on managing fatigue during operations. Primarily, these short-term strategies help to conceal or attenuate underlying physiological sleepiness.



Prior sleep loss can be a significant factor in the severity of subsequent jet lag symptoms. That is, individuals who are sleep deprived before a trip can experience more difficulty than those who are well rested. Consider the previous information regarding sleep debt and the expected sleep loss associated with flight operations. An individual who begins a trip with a sleep debt, should expect that the it will only worsen during the trip schedule. The recommendation is to begin a trip schedule as sleep-satiated as possible. Maximize the amount of sleep at least 1 and preferably 2 days before departure.

As indicated previously, most flight operations are characterized by sleep loss during trip schedules. Individuals should attempt to obtain at least as much sleep during a layover as they would typically during a normal 24 hours at home. Knowing that circadian and other factors will diminish the physiologically available windows for sleep, attempts should be made to maximize these opportunities.

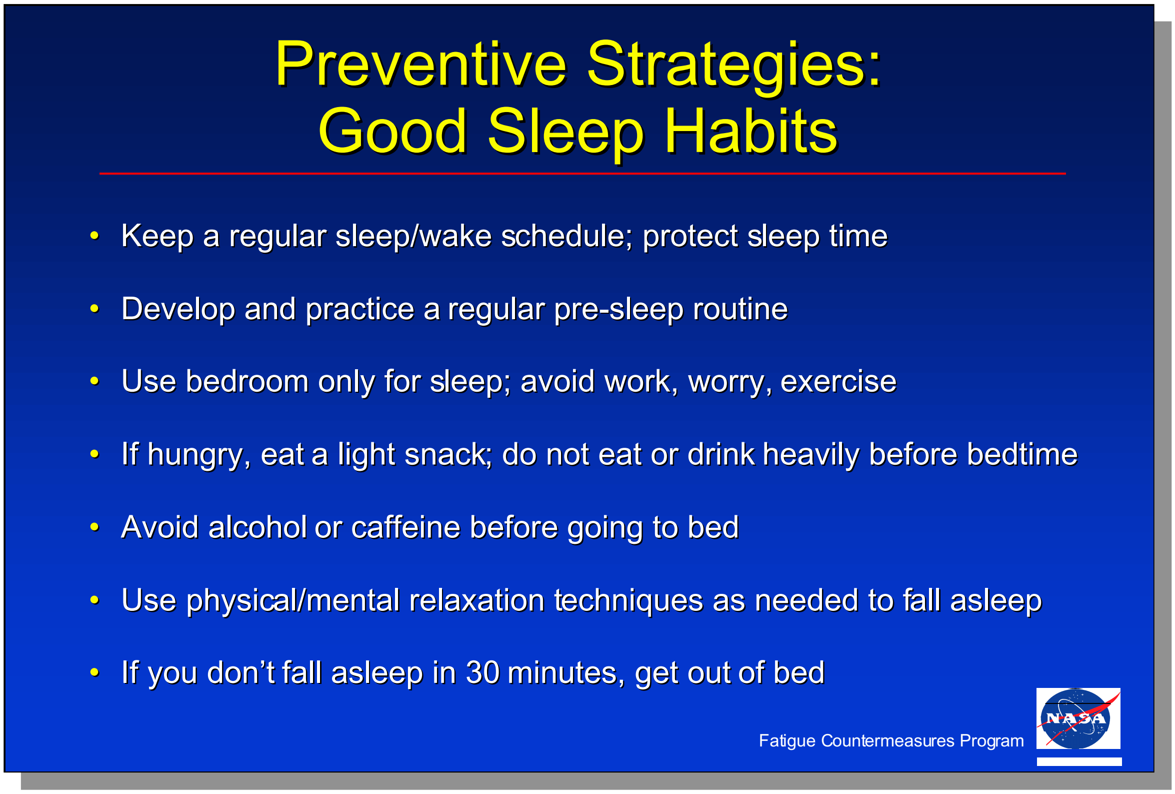
Learn to trust your own physiology. When struggling to stay awake, take the sleepiness as a clear sign to get some sleep. Instead of fighting the sleepiness, take a brief nap or a longer sleep time. The length of that sleep period will be discussed soon. Also, if after awakening spontaneously you are unable to return to sleep within 15–30 minutes, then get out of bed. The principal message is that if your brain is giving you clear signals that you are sleepy, then sleep. If you awaken and you are alert and unable to return to sleep, get up. You can force wakefulness, but you cannot force sleep.



An extensive scientific literature clearly demonstrates the effectiveness of naps in improving subsequent alertness and performance. One important consideration when napping close to a duty period is to minimize the chances of going into deep NREM sleep (stages 3 and 4). If awakened out of deep sleep, an individual may continue to feel groggy, sleepy, or disoriented for 10–15 minutes. This phenomenon is called sleep inertia. Therefore, if taking a nap before a duty period, limiting its duration to 45 minutes or less will decrease the chances of having significant amounts of deep sleep. A brief nap can be an important way to decrease the length of continuous wakefulness. It is usually much better to get some sleep than none at all.

When you nap at times other than immediately before a duty period, then the nap can be longer. In this case, a nap longer than 2 hours is likely to get an individual through at least one NREM/REM cycle.

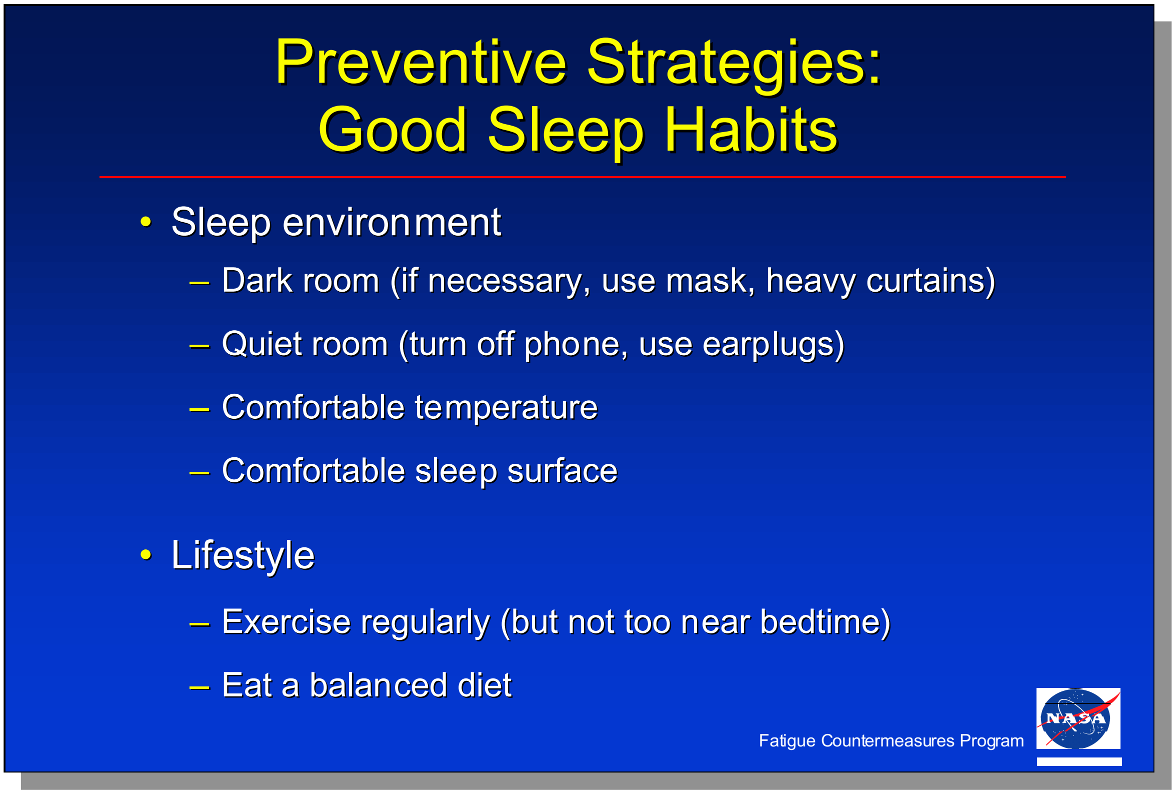
Strategic napping can be an extremely effective countermeasure in improving subsequent alertness and performance. Some individuals call these “power” naps. In flight operations, “NASA naps” have been demonstrated to be an effective acute fatigue countermeasure.



The following recommendations are generally considered important for maintaining good sleep habits. They apply to everyone. First, keep a regular sleep and wake schedule as much as possible. At home before trips, try to keep sleep time protected and minimize other responsibilities. A regularly practiced pre-sleep routine can be used to teach your mind and body that it is time to relax and fall asleep. A set of cues can be established to condition pre-sleep relaxation and can then be used anywhere and anytime before going to sleep. It is important to avoid work or worry in the bedroom and to prevent the association of the bed with activities contrary to relaxation and sleep.

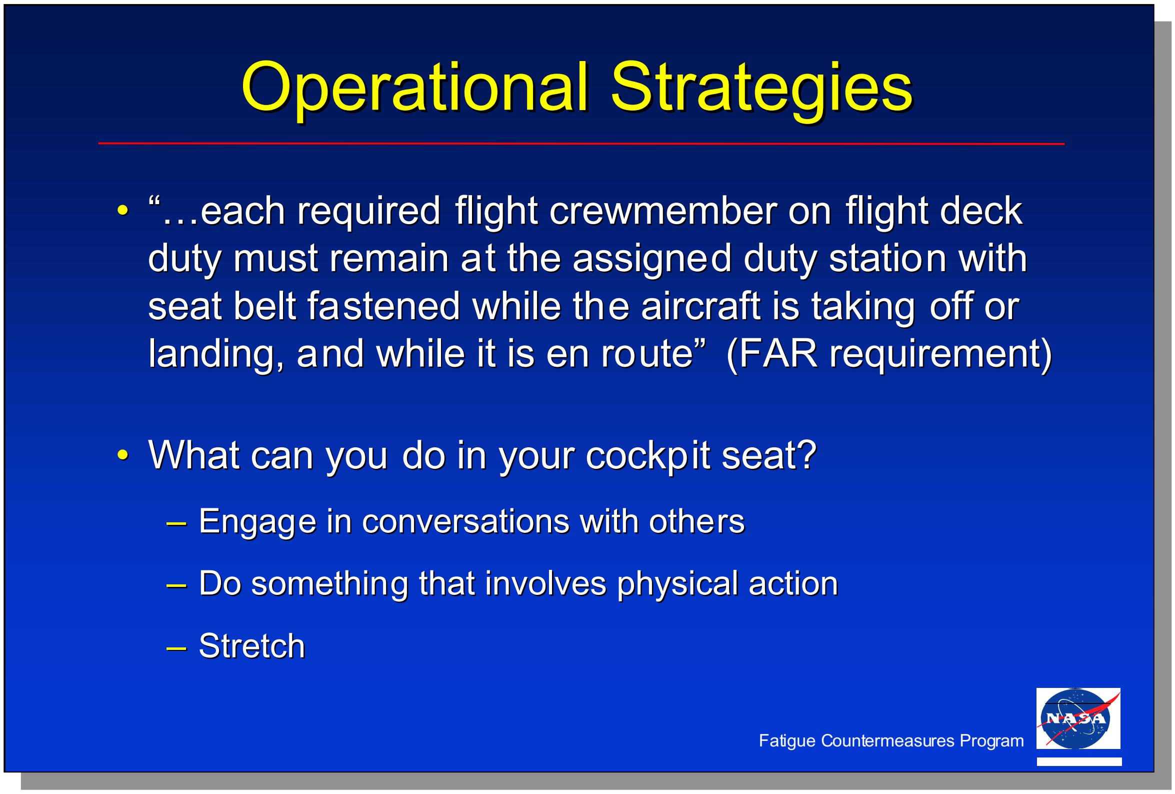
Going to bed hungry can delay falling asleep. Eating a heavy meal also can disrupt sleep, for the stomach is busy digesting food. If hungry or thirsty at bedtime, eat a light snack or have a small quantity of something to drink. As previously mentioned, alcohol should be avoided immediately before going to bed because of disruptive effects on sleep. Caffeine consumption should also be limited. Caffeine in coffee, tea, and colas can prevent sleep onset and disrupt subsequent sleep. Some individuals are sensitive to the caffeine in chocolate, and even a chocolate dessert after dinner is enough to interfere with their sleep. Many mild pain relievers also contain caffeine; read the label for ingredient information. Be sure to stop caffeine intake several hours before planned bedtime.

A variety of mental and physical relaxation techniques are proven to promote sleep onset and good sleep. Appendix B describes some of these techniques in more detail. Like any skills, these techniques can be practiced; then they can be used in a wide range of applications, essentially anywhere. If unable to fall asleep in 30 minutes, don’t lie in bed trying to fall asleep. Instead, get out of bed and engage in some activity conducive to relaxation and sleep.

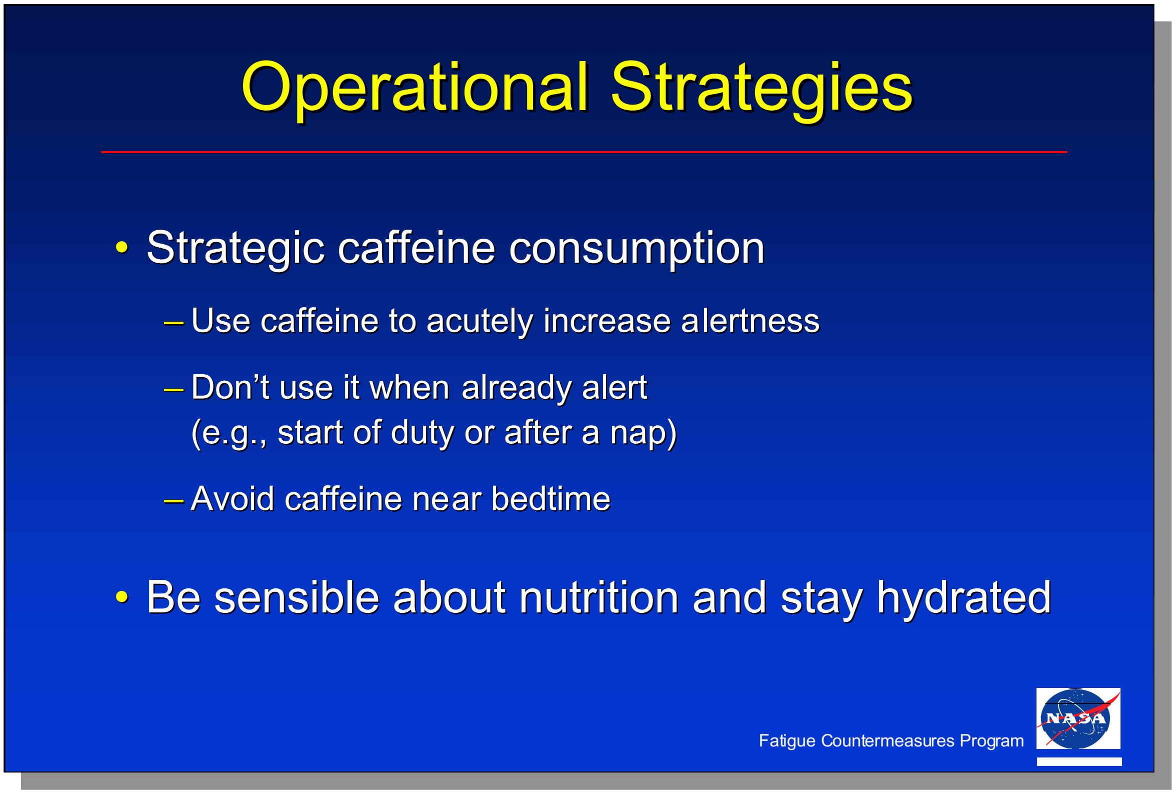


Disruptive environmental factors should be minimized. Sleep in a dark, quiet, temperature-controlled room, and on a comfortable sleep surface.

Laboratory studies suggest that regular exercisers may have increased amounts of NREM stages 3 and 4. However, exercising too close to bedtime can disrupt subsequent sleep. Although physically tiring, exercise elevates heart and breathing rates, and is generally activating physiologically. Usually, it is not possible to immediately wind down and fall asleep after exercise. A balanced diet and regular exercise are critical components for overall good health.

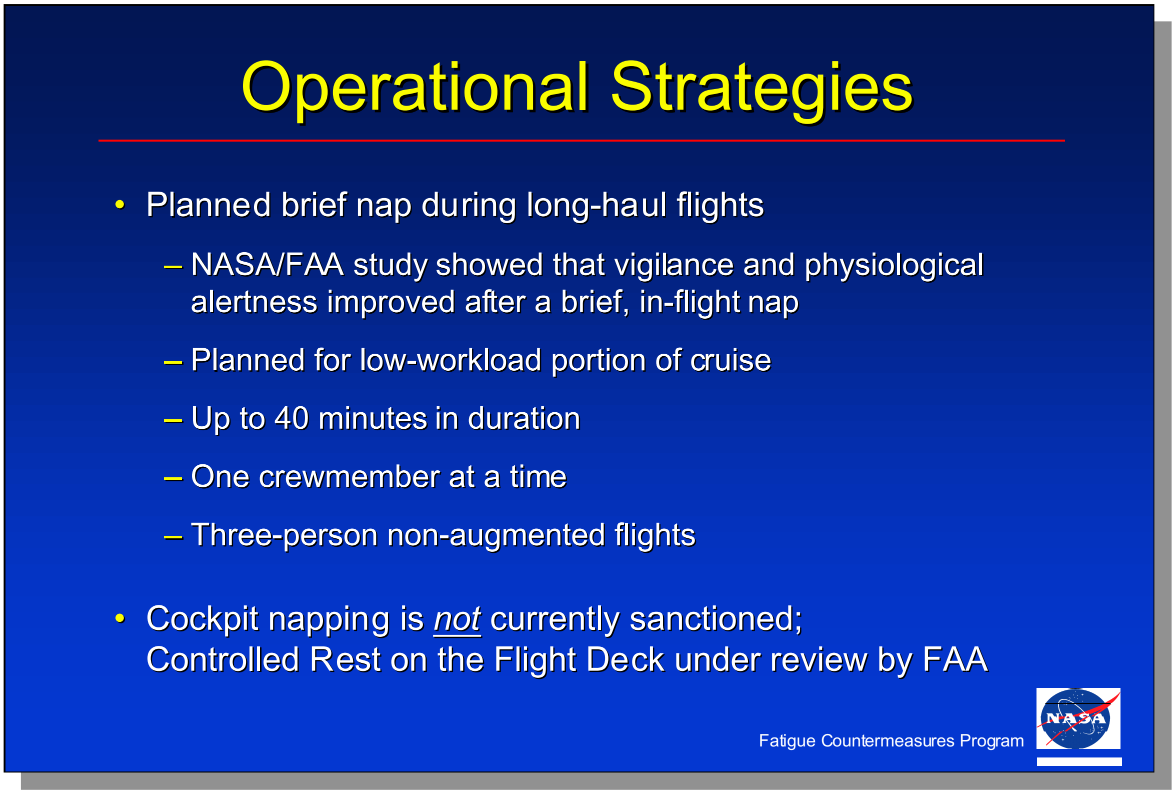


Operational countermeasures are challenged by FARs that require crewmembers to remain seated at their assigned duty stations with their seat belts fastened. This poses a challenge because one of the most successful technique for combating sleepiness, according to the earliest sleep-deprivation experiments, is physical activity. Whenever possible, engage in physical activity, even if it is only stretching. Take regular stretch breaks and while seated remain as active as possible—even writing helps. Engage in conversations with others and be sure to participate; don't just nod and listen.



Caffeine, a stimulant, can be consumed strategically to acutely increase alertness. It is best not to continually consume caffeine before, during, and after a trip. Instead, determine the potential periods when caffeine could be used to combat a specific period of sleepiness (e.g., 3–5 A.M. or 3–5 P.M.). Avoid using it when already alert, for example, when just beginning a daytime duty period or immediately after a nap. Though affected by several variables (e.g., body size, previous food intake), caffeine will usually take 15–30 minutes to take effect and then last for up to 3–4 hours. Therefore, continually consuming caffeine throughout a flight could interfere with subsequent sleep on layover. Stop caffeine consumption far enough in advance of a planned bedtime so that it will no longer be active.

Be sensible about nutrition. Whenever possible, maintain a balanced diet. Obviously, flight operations can interfere with regularly scheduled, balanced meals. Try to carry appropriate snacks as needed. Drink plenty of fluids and stay hydrated. Between reduced cockpit humidity and caffeine (a diuretic), it is easy to become dehydrated.



It must be emphasized that controlled rest on the flight deck is NOT currently sanctioned. A recent NASA/FAA study demonstrated the effectiveness of a brief in-flight nap in improving subsequent alertness and performance. As a result, the FAA is reviewing Controlled Rest on the Flight Deck. A planned brief in-flight nap would be an operational strategy that directly reduces the physiological sleepiness engendered by flight operations.

Future Considerations

- Bright light
  - Facilitates rapid circadian adaptation and promotes alertness
  - Provocative laboratory findings
  - Operational effectiveness still being demonstrated
- Pharmacologic agents
  - Continuing search for agents that safely and effectively promote sleep and maintain alertness and performance during wakefulness
  - Melatonin
    - Facilitates rapid circadian adaptation and promotes sleep
    - Studies to demonstrate operational effectiveness currently underway

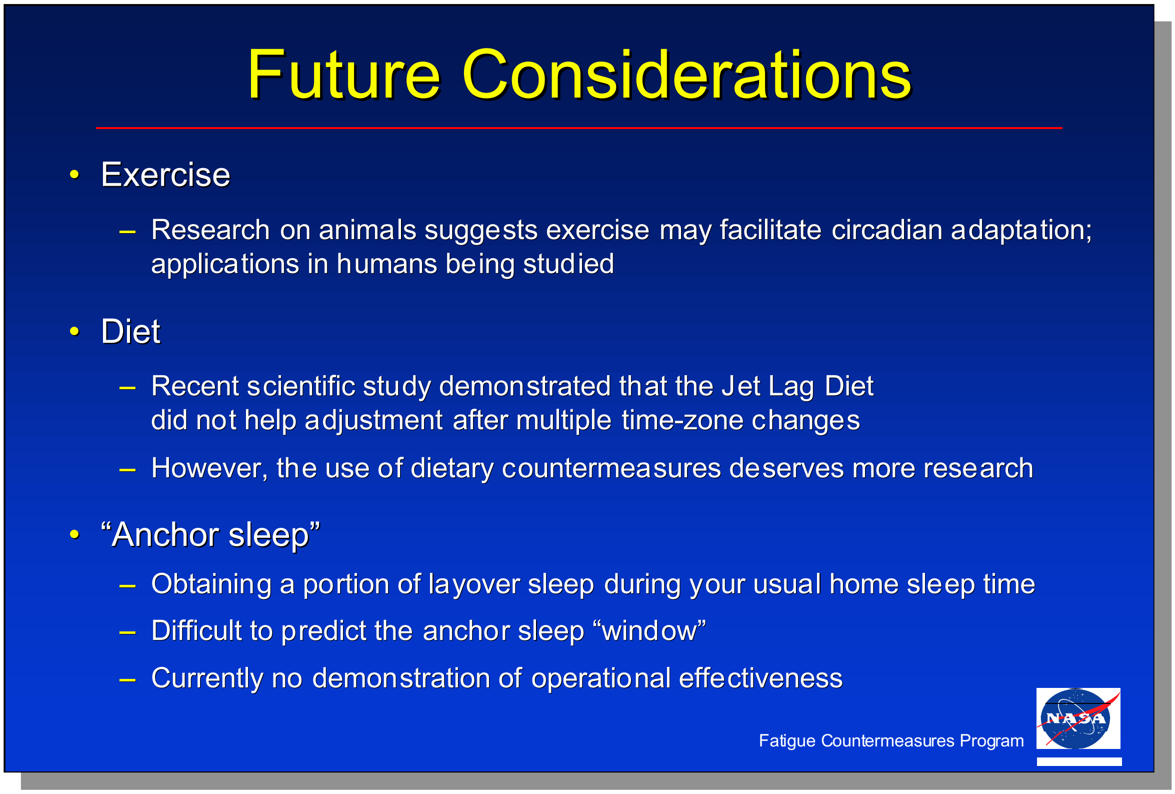
Fatigue Countermeasures Program

Several potential countermeasures are at various stages of development. Watch for their possible application to operational environments.

Bright light has been shown in laboratory studies to facilitate rapid circadian adaptation. Two to three hours of bright light (i.e., 2,500–10,000 lux) administered at the appropriate phase of the temperature cycle for three successive days may facilitate an 8- to 12-hour shift of the circadian clock. Separate from its effects on the circadian clock, bright light also can have an independent alerting effect.

There is a continuing search for pharmacologic agents that safely and effectively promote sleep and help to maintain alertness and performance during wakefulness. These agents include both sleeping pills to promote sleep and stimulants to promote wakefulness.

Recent studies suggest that the hormone melatonin may be useful for facilitating adaptation of the circadian clock and that it demonstrates sedative effects (i.e., may be a useful sleep aid). However, there are known cautions associated with melatonin. For example, it is not controlled by the Food and Drug Administration, and therefore there is no guarantee of content, dosage, or effectiveness.



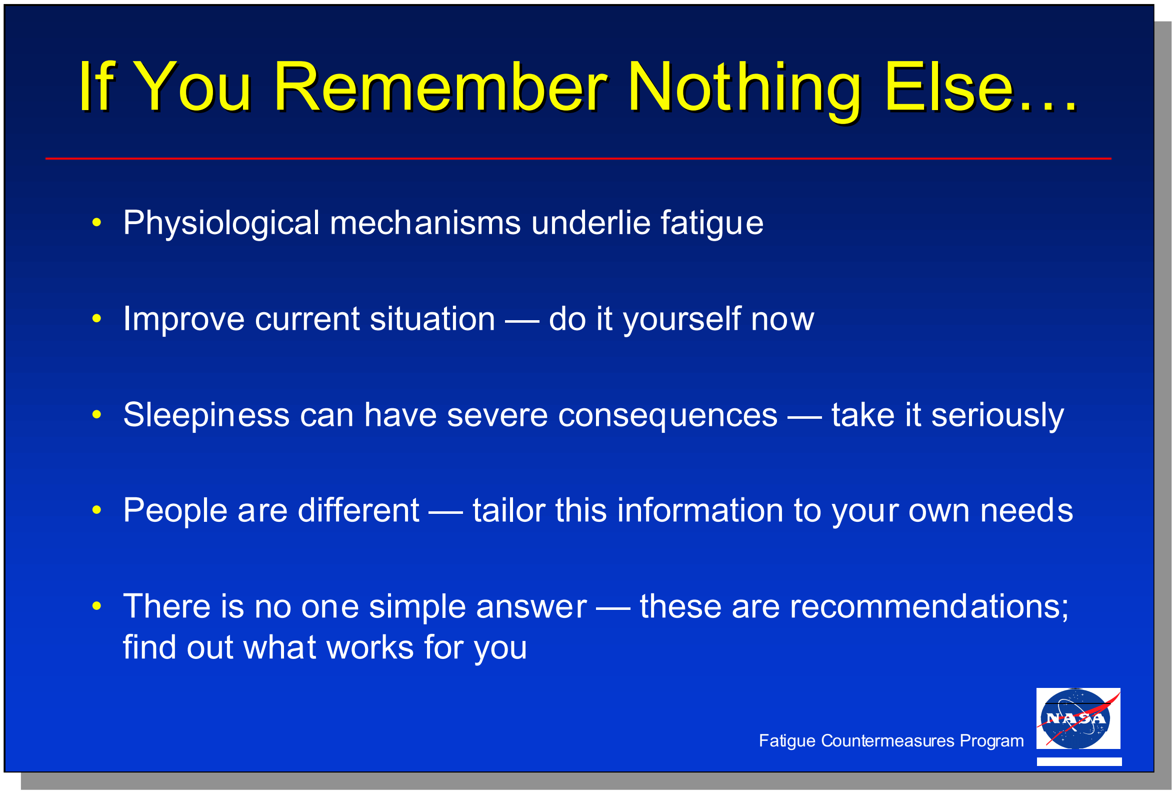
Exercise has been demonstrated to facilitate circadian adaptation in animals, and applications in humans are being studied currently.

Recent scientific studies have clearly demonstrated that the "Jet Lag Diet" is not effective in facilitating circadian adaptation.

Anchor sleep may be useful when the usual home sleep period can be determined reliably. However, it is difficult to predict the home sleep window for two reasons: 1) the individual differences in the circadian system, and 2) circadian resynchronization after multiple flight segments shifts the window.

There is no one "magic bullet" for eliminating the fatigue, sleep loss, and circadian disruption currently engendered by flight operations. It will be critical that potential countermeasures be developed and evaluated in operational environments to demonstrate their effectiveness. Individuals should be wary of unproved "cures." These "cures" may not only be ineffective, but may produce a false sense of security by causing individuals to think they are managing their fatigue when, in fact, they are not.

However, potential countermeasures are currently being evaluated, and in the future may provide additional strategies for overall alertness management in flight operations.



The critical messages to take home…

APPENDIX A
BRIEF INTRODUCTION TO SLEEP DISORDERS AND SLEEPING PILLS

Physical Sleep Disorders

There are several physical sleep disorders that can disturb sleep and cause excessive sleepiness during wakefulness. Two examples are described that illustrate why it is important to know about the existence of these medical disorders: sleep apnea and nocturnal myoclonus.

These are only two examples of sleep disorders, physiological conditions that can disrupt the quantity and quality of sleep and can have subsequent consequences during wakefulness. Sleep disorders often can exist without the knowledge of the individual sufferer and may produce waking difficulties that one would not typically relate to a sleep problem (e.g., high blood pressure, morning headaches, fighting sleep in many situations). It is imperative that health care professionals, especially accredited sleep-disorder specialists, be used to accurately determine the cause of sleep disturbances or the related waking difficulties, so that individuals receive appropriate and effective treatment.

Sleep Apnea

The sleep apnea syndrome (SAS) is a sleep disorder in which individuals cannot sleep and breathe at the same time. Apnea (a = not, pnea = breathing) is a pause in the regular pattern of breathing. Essentially, apneic individuals fall asleep and then periodically stop breathing. When this occurs, little or no oxygen is available to the brain or body. Usually, when the oxygen level in the blood drops below a certain level and carbon dioxide levels rise, the brain arouses the individual who then begins to breathe again. This awakening is often associated with a gasp for air or a snore as the individual resumes breathing. Depending on the severity of the disorder, this cycle of pauses in breathing and awakening to breathe can continue throughout the sleep period. Sleep apnea is a potentially lethal disorder—if the brain does not respond during an apnea, death can occur. There are two aspects of apneic episodes that affect the severity of the disorder: the duration of the apnea and the frequency (the number that occur during a given sleep period). Most apnea episodes usually last under 30 sec, though they can range from 15 sec up to 2 or 3 min in duration. Apneas may occur only a few times per hour of sleep or hundreds of times across a sleep period. In a very mild case, there may be only 5 or 10 apnea episodes per hour, whereas in a severe case there may be 50 to 80 per hour of sleep (i.e., 300 or 400 episodes during an average sleep period).

Many physical and behavioral problems can be caused by sleep apnea, for example, excessive sleepiness and cardiovascular difficulties such as hypertension. Currently, sleep-disorder specialists believe that a combination of frequent arousals from sleep (which also results in little or no deep sleep) and the oxygen deprivation lead to excessive sleepiness during wakefulness. Remember, the quality of sleep is an important factor in how refreshed and alert an individual feels after sleep. So, although someone with sleep apnea may sleep 8 hours, the sleep could be disturbed 300 or 400 times by apnea episodes, and therefore the quality of sleep can be very poor. Very often individuals with sleep apnea are completely unaware that they have the disorder. They may have high blood pressure during the day or problems staying awake because of excessive sleepiness, but they often do not relate this to a sleep problem. Thus, even persons who are awakened hundreds of times a night because of disturbed breathing may awaken the next morning and be unaware of what has happened. Frequently, a bed partner is the first to notice the repeated pauses in breathing during sleep and, depending on their duration, may become quite concerned.

Epidemiologic studies suggest that 3–4% of the general population and 10–15% of males had sleep apnea (depending on the definition used). The occurrence of the disorder and its severity appear to increase with age. The textbook sleep apnea case is an overweight, middle-aged male who snores, has high blood pressure, and has problems staying awake during the day (e.g., fighting sleep while in meetings, reading, driving a car, watching a movie or TV). There are a variety of reasons unrelated to sleep apnea that can cause people to snore, for example, colds, deviated septa (i.e., physical problems with the structure of the nose), and allergies. However, snoring is also a primary symptom associated with the occurrence of sleep apnea. Another caution is that alcohol, sleeping pills, and sleep loss can worsen the severity of sleep apnea (both the duration and frequency of apnea events).

A number of options are available to effectively treat the sleep apnea syndrome. The treatment usually depends on the severity of the disorder and can range from losing weight, to the continuous administration of oxygen during sleep, to surgery. It is critical that someone concerned about sleep apnea be evaluated by an appropriate health care professional. An individual should first consult a personal physician. Also, there are now sleep-disorder specialists who perform sleep-disorder evaluations, make diagnoses, and prescribe treatments. There are also specialized sleep-disorder clinics (accredited by the American Sleep Disorders Association) throughout the United States that provide full diagnostic and treatment services for the range of sleep disorders. These clinics are located in many university and community hospitals throughout the country.

Sleep apnea is an example of a medical disorder that can disturb sleep and cause excessive sleepiness, heart and blood pressure problems, and other difficulties during wakefulness. An individual can be completely unaware of the sleep disturbances and yet every night suffer from a disorder that can cause pathological sleepiness during the daytime. Like any medical problem, sleep apnea should be evaluated and treated by qualified medical specialists, using the approaches currently accepted for successful treatment of the disorder.

Nocturnal Myoclonus or Periodic Leg Movements

Another physical sleep disorder that can disturb the quality of sleep is nocturnal myoclonus, or periodic leg movements during sleep. This disorder is characterized by a twitching (or muscular contraction) of the lower leg muscles during sleep (though typically found in the lower legs, the arms could also twitch). The twitch can occur in one leg or both, typically last only about 0.5 sec, and appear in periodic episodes across the sleep period. There can be several hundred twitches during any given sleep period. Periodic leg movements constitute a sleep disorder because each muscular twitch is usually associated with either an awakening or a shift from deep to light sleep. Again, someone could be getting 8 hr of sleep but have that sleep interrupted 300 times with awakenings. This poor quality sleep can translate into complaints of non-restorative sleep, awakening unrefreshed, tired, sleepy, etc. This is another sleep disorder that can go unrecognized by the individual with the periodic leg movements and one that is often noticed first by a bed partner (often the recipient of multiple kicks during sleep!). Again, it is very important that the disorder be diagnosed and treated by a knowledgeable physician or accredited sleep-disorder specialist. Although not life-threatening like sleep apnea, periodic leg movements during sleep can result in excessive daytime sleepiness.

Medications

Alcohol

The most widely used self-treatment for disturbed sleep is alcohol. As noted in the presentation materials, alcohol is a very potent REM sleep suppressant. More than a couple of beers or glasses of wine can totally suppress REM sleep in the first half of a sleep period. During the second half of the sleep period, withdrawal effects can be seen, including awakenings, a REM rebound, and generally, very poor, disrupted sleep. Although alcohol is often used to unwind, relax, and promote the ability to get to sleep, its disruptive effects on the subsequent sleep will outweigh its usefulness in promoting the onset of sleep.

Sleeping Pills

CAUTION

> **The other widely used approach to treating sleep disturbances is prescription sleeping pills. The use of prescription sleeping pills close to and during duty periods is not medically allowed. However, it is acknowledged that many medications available only by prescription in the United States can be obtained over-the-counter, without prescriptions, in many overseas locations. Sleeping pills should only be used under the supervision of a knowledgeable physician. The information provided here is intended only to give a basic understanding about their effects.**

There are several important characteristics of sleeping pills that should be considered. The primary purpose of a sleep medication should be to promote sleep, either by facilitating sleep onset or by helping to maintain sleep (e.g., reducing frequent or long awakenings). It should maintain this positive therapeutic effect for the duration of its use (i.e., sleep should be as good on the fifth night of use as on the first). The improvement in sleep should be associated with waking benefits (e.g., increased alertness, better mood) and, at the very least, the sleeping medication should not impair waking function. So the optimal sleeping pill should promote sleep and improve subsequent waking function. A very important consensus statement (from physicians, sleep-disorder specialists, etc.) recommends that the safest and most beneficial use of sleeping pills is obtained when they are taken for short periods of time and at the lowest effective dose.

In the past, some of the most widely used prescription sleeping pills were in a class of drugs called barbiturates. These include medications such as pentobarbital and seconal. Scientific studies in sleep laboratories have shown that the barbiturates often lose their effectiveness to promote sleep within 7–10 days and can create tolerance to, and dependence on, the medication. It is important to keep in mind that barbiturates have been found to be factors in accidental or intentional drug overdose. The barbiturates are also potent REM sleep suppressants and, like alcohol, can disrupt the regular cycle of NREM and REM sleep, creating fragmented and poor quality sleep. Eventually, these medications can actually create an insomnia problem called drug-dependent insomnia. Only after careful tapering off and eventual withdrawal of the medication can sleep return to a more normal pattern. As prescribing physicians have learned more about these sleep laboratory findings regarding barbiturates, their use as a primary sleeping medication has rapidly declined, and they are rarely used today.

Today, the most widely prescribed sleeping pills (often called sedative/hypnotic medications) are in a class of drugs called the benzodiazepines. There are three that are commonly prescribed: Halcion (triazolam), Restoril (temazepam), and Dalmane (flurazepam). Sleep-laboratory tests of these three medications show that they promote sleep over many nights in sleep-disturbed patients. They are usually considered safer than the barbiturates because, generally, it is more difficult to accidentally or intentionally overdose with them and they can be more easily started and stopped with fewer negative effects.

The benzodiazepines, like all medications, are not without their adverse side-effects. Although the benzodiazepines do not suppress REM sleep, they can suppress NREM sleep stages 3 and 4 (the deep sleep that occurs in the first third to half of the sleep period). Reports suggest that the benzodiazepines can have side effects that affect short-term memory and, if withdrawn too rapidly, may cause a rebound anxiety or insomnia. In spite of these considerations, the benzodiazepines are widely used as safe and effective sleeping pills when prescribed by a knowledgeable physician.

There are properties of these three benzodiazepines that distinguish their effects from one another. The primary factor is their half-life, that is, the amount of time the drug continues to work in an individual's body. Halcion is a short-acting benzodiazepine (about 2–4 hr) that helps to promote sleep onset but is no longer active by the middle to end of a sleep period. In sleep laboratory studies, Halcion has been shown to effectively improve nocturnal sleep and to be associated with improved daytime alertness. There have been several scientific studies that showed Halcion to be effective for travelers using it as an aid to improve sleep on trips that involve multiple time-zone changes. Restoril is a medium-acting benzodiazepine (about 8 hr) that helps to maintain sleep throughout a night and is no longer active by the morning awakening. Dalmane is a long-acting benzodiazepine (about 100 hr) that effectively promotes sleep onset and maintains sleep throughout the night. However, if used over several nights, the long half-life results in an accumulation of the medication in the body that can have effects that carry over to wakefulness. Laboratory studies have shown that after several nights of administration, the build-up of Dalmane metabolites can be associated with increased sleepiness during wakefulness. It should be noted that the specific formulations of these medications can be different overseas. For example, Restoril obtained in the United Kingdom has a half-life of 5–6 hr.

Recently, a new prescription sleep medication, Ambien (a non-benzodiazepine), has been receiving attention as a safe and effective sleep aid.

The main message is that the benzodiazepines can be used effectively to help get to sleep and stay asleep. They have different properties that should dictate the appropriate use of the medications for different people in different circumstances. Finally, all of these are prescription medications that should only be used under the care and guidance of a qualified and knowledgeable physician.

Note

The information provided here is intended only to provide examples of sleep disorders and some of the medications used to promote sleep. You should not use this information to diagnose, medicate, or treat yourself. If you have any questions about your health, potential sleep disorders, or medication, see your physician. As indicated, accredited sleep clinics and sleep-disorder specialists are available for evaluation, diagnosis, and treatment for the range of sleep disorders. Seek them out by contacting a local university or community hospital for a referral. The general readings in appendix E suggest other sources of information about sleep, circadian rhythms, and sleep disorders.

APPENDIX B
BRIEF INTRODUCTION TO RELAXATION SKILLS

Flight operations can involve hectic schedules, significant responsibilities, and stressful events. Outside of flight operations, many people's lives also are affected by these factors. Scientific studies have demonstrated that these "life stresses" can affect an individual's physical and mental health. People respond to the perceived demands and challenges of situations differently: some individuals will become physically tense, others will worry, and so on. There are many situations in which pilots need to "unwind" and relax after coming off duty. This is especially important when they are preparing for a layover sleep period. As previously mentioned, alcohol is sometimes used to relax after duty, but it can significantly disrupt the subsequent sleep period (see appendix A). However, there are alternatives to alcohol. Many people use exercise, hobbies, and many other strategies to physically and mentally relax. This section is not intended to cover the full range of those options; entire books have been written on the subjects of stress management and relaxation skills. However, it is intended to briefly introduce some information about relaxation skills that may be useful in your efforts to relax and promote sleep.

Relaxation skills can be powerful techniques for promoting physical and mental relaxation in almost any situation or environment. Many relaxation skills have been scientifically tested and their effectiveness demonstrated in many different areas, from eliminating physical problems (e.g., tension headaches) to decreasing worry and anxiety to promoting good sleep.

There are a wide variety of relaxation skills that are practiced and effectively used by many individuals. Some relaxation techniques are primarily cognitive (i.e., involve focusing the mind, internally repeating phrases, etc.), others are primarily physical (e.g., tensing and relaxing the major muscle groups of the body), though most involve both cognitive and physical components (e.g., after tensing and relaxing a muscle, mentally focusing on the relaxation).

Examples of techniques that are primarily cognitive include meditation, positive imagery, and autogenic training. Meditation is one of the oldest relaxation methods and involves sitting quietly, repeating a phrase (individually chosen), and focusing on deep relaxation. Positive imagery often begins with guided imagery; an individual chooses a specific, relaxing scene and is guided through the pleasant images associated with the experience. Autogenic training involves repeating standard phrases as an individual cognitively focuses on each of the major muscle groups of the body (e.g., "my right hand is heavy and warm").

Examples of techniques that involve more physical action include yoga, deep breathing, and progressive muscle relaxation. Yoga is also a very old method for relaxing the body and mind; it involves a set of standardized movements and a cognitive component. Rather than short breaths primarily involving chest breathing, relaxation through deep breathing uses long, slow breaths that use both the abdomen and chest. During the deep breathing a word or phrase associated with relaxation is used to focus the mind and facilitate a deeper state of relaxation. Progressive muscle relaxation is a technique that has received much attention and is effectively used in a wide range of applications. It involves the systematic tensing and relaxing of the muscles, starting at the head and neck and moving all the way to the toes. The mind focuses on the difference between the tension and the relaxation associated with the release of the muscle.

It is important to think of these as relaxation skills. As skills, they can be taught, learned, and practiced. Practice is critical! Too often people try to quickly learn some technique and then use it in efforts to relax the next time they are in a highly stressful situation. Usually it does not work and the individual decides that the technique, and relaxation skills in general, are ineffective. Only after a skill has been mastered should it be applied, and even then it should be gradually tested for its effectiveness and usefulness in different situations. Eventually, relaxation skills are most effective when they are practiced on a regular basis and incorporated as a daily activity.

There are many different ways to learn relaxation skills and today many commercially produced resources are available. It is often useful to first read about a technique and a description of the specific skill. An external source (e.g., instructor, book, tape) that guides an individual through a particular technique can be useful in learning the skill and in focusing attention on the relaxation. Eventually, it is important to internalize and memorize the specifics of the skill. Once learned very well, an individual should be able to use his or her favorite, most effective relaxation skills in different situations and environments, without having to rely on an external source to help relax.

Relaxation skills can be a powerful tool to help individuals reduce physical tension, focus and relax the mind, and promote good sleep. If you decide to try some of these new skills, keep an open mind, practice, and enjoy learning to relax.

Note

> **There are many outrageous and unsubstantiated claims made regarding a wide range of techniques, devices, and approaches to relaxation. Please be wary! Today, many local health care facilities, hospitals, and licensed health care providers (e.g., physicians, psychologists, nurses, social workers) provide classes on relaxation skills or stress management techniques. Do some checking to be sure that reputable (e.g., accredited or licensed) practitioners are providing the services and instruction.**

The following references are recommended for further reading on relaxation skills and stress management. This is not an inclusive list of available resources but it does provide some guidance for a starting point. These books should be available at your local community library, college library, or bookstores.

Recommended Readings

Benson, H. (1976). *The relaxation response.* New York, NY: Avon Books.

Bernstein, D.A. and Borkovec, T.D. (1973). *Progressive relaxation training: A manual for helping professions.* Champaign, IL: Research Press.

Coates, T.J. and Thoresen, C.E. (1977). How to sleep better: A drug-free program for overcoming insomnia. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Farquhar, J.W. (1978). The American way of life need not be hazardous to your health. Stanford, CA: Stanford Alumni Association.

APPENDIX C
NASA AMES FATIGUE COUNTERMEASURES PROGRAM

Relevant NASA Technical Memoranda Operational Summaries from the "Crew Factors in Flight Operations" Series

This appendix comprises the operational summaries of five relevant NASA Technical Memoranda (TMs) from the Fatigue Countermeasures Program.

Crew Factors in Flight Operations II: Psychophysiological Responses to Short-Haul Air Transport Operations

Gander, P.H., Graeber, R.C., Foushee, H.C., Lauber, J.K., and Connell, L.J. (in press). *Crew factors in flight operations: II. Psychophysiological responses to short-haul air transport operations.* (NASA Technical Memorandum). Moffett Field, CA: National Aeronautics and Space Administration.

Operational Overview

This report is the second in a series on the physiological and psychological effects of flight operations on flight crews, and on the operational significance of these effects. This overview presents a comprehensive review and interpretation of the major findings. The supporting scientific analyses are described in detail in the rest of the text.

To document the psychophysiological effects of flying commercial short-haul air transport operations, 74 pilots from two airlines were monitored before, during, and after 3-day or 4-day trip patterns. All flights took place on the East Coast of the United States and data were collected throughout the year. Eighty-five percent of the pilots who had been awarded the trips selected for study agreed to participate. The population studied was experienced (average age 41.3 yr, average airline experience 14.6 yr) and averaged 68.6 hr of flying per month in all categories of aviation.

Subjects wore a portable biomedical monitor which recorded core-body temperature, heart rate, and wrist activity every 2 min. They also rated their fatigue and mood every 2 hr while awake, and recorded sleep episodes, naps, showers, exercise, duty times, food and fluid intake, voidings, cigarettes, medications, and medical symptoms in a daily logbook. A background questionnaire was administered which included basic demographic information, sleep and life-style habits, and four personality inventories. A cockpit observer accompanied the crews on the flight deck and kept a detailed log of operational events.

The trips studied were selected to provide information on the upper range of fatigue experienced by pilots in predominantly daytime and evening operations. Common features were early report times and long duty days with multiple flight segments (average 5.5 per day). Daily duty durations averaged 10.6 hr which included, on average, 4.5 hr of flight time. One third of all duty periods studied were longer than 12 hr. The mean rest-period duration, as defined by the pilots in their daily logs, was 12.5 hr. The mean rest-period duration calculated from the last wheels-on of one duty day to the first wheels-off of the next duty day was significantly longer (14.0 hr). Overnight layovers after successive duty days occurred progressively earlier across most trips.

On trip nights, subjects reported taking about 12 min longer to fall asleep, sleeping about 1.2 hr less, and waking about 1.4 hr earlier than on pretrip nights. They also rated their sleep on trips as lighter and poorer overall, and reported significantly more awakenings. In contrast, in the laboratory, sleep restriction results in more rapid sleep onset and more consolidated sleep. The longer sleep latencies and more frequent awakenings reported by pilots on trips may reflect the commonly reported need to “spin down” after coming off duty and the disruptive effects of sleeping in unfamiliar environments. The fact that sleep during trips was reported not only as shorter but also as more disturbed, suggests that the effects of this sleep restriction on subsequent daytime sleepiness, performance, and mood may be greater than those reported in laboratory studies with similar levels of sleep restriction.

The effects of duty demands on subjective fatigue and mood are most clearly seen in the comparisons of ratings made pretrip, during flight segments, during layovers, and posttrip. During layovers, fatigue and negative affect were rated as highest and positive affect and activation as lowest. Positive affect was rated as highest during flight segments, even though fatigue ratings were higher than for either pretrip or posttrip. Posttrip recovery was indicated by return of fatigue levels to baseline, the lowest negative affect ratings, and the highest levels of activation. Significant time-of-day variations were found in fatigue, negative affect, and activation. Fatigue and negative affect were low in the first three ratings after awakening, and rose thereafter to reach their highest daily values in the final rating before sleep. As expected, activation showed the opposite time-of-day variation. No significant relationships were found between the timing, duration, or flight hours in a duty period and the fatigue and mood during layovers. This may well have been because of the high levels of individual variability in these ratings.

The use of tobacco did not change on trip days relative to pretrip and posttrip days. However, significantly more caffeine and alcohol were consumed on trips. Additional caffeine consumption occurred primarily in the early morning, associated with the earlier wake-up times on trips, and also around the time of the mid-afternoon peak in physiological sleepiness. The urge to fall asleep at this peak time would increase progressively with the accumulating sleep debt across trip days. The additional alcohol consumption may be assumed to have occurred after coming off duty and before going to sleep. The common practice of using alcohol to relax before sleep is not recommended. Although alcohol may facilitate falling asleep, it has well-documented disruptive effects on sleep which can adversely affect subsequent waking alertness and performance. There were no significant changes in the use of medications, or in the number of reports of medical symptoms between trip days and pretrip or posttrip days. Similarly, the number of exercise sessions reported was no different on trip days than on pretrip or posttrip days.

The number and timing of meals on trip days was not significantly different from pretrip or posttrip days. However, more snacks were eaten, and they were eaten earlier, on trip days. This suggests that meals on trip days may have been smaller or less filling than meals on pretrip or posttrip days.

Heart rates during takeoff, descent, and landing were compared with values during mid-cruise for 72 pilots during 589 flight segments. Increases in heart rate were greater during descent and landing for the pilot flying. The difference between flying and not flying during descent was greater for first officers than for captains. Heart-rate increases were greater during takeoff and descent under instrument flight conditions than under visual flight conditions. On the basis of similar findings, the number of segments flown per day should be regulated.

A number of ways of reducing fatigue during short-haul air-transport operations are suggested by this study. First, since daily duty durations were more than twice as long as daily flight durations, and since about one third of all duty periods were longer than 12 hr, it would seem reasonable to limit duty hours in addition to, flight hours in short-haul operations. There may also be some advantage to defining the rest period more precisely, since significant variability is possible within the present system of definition by contract negotiation. Second, the practice of requiring early report times makes it more difficult for pilots to obtain adequate sleep, even during relatively long layovers. This is because circadian rhythms impede falling sleep earlier than usual, except after major sleep loss. Third, in the trips studied, duty began progressively earlier across the days of the trip. Because of the difficulty of falling asleep earlier, this has the effect of progressively shortening the time available for sleep across the days of the trip. In addition, because the innate "physiological day" determined by the circadian system is longer than 24 hr, it adapts more readily to schedule delays than to advances. Thus, where possible, successive duty days should begin progressively later. Fourth, the widespread use of alcohol as a means of relaxing before going to sleep has deleterious effects on subsequent sleep. It thus seems likely that the quality of sleep on trips could be improved in many cases by providing pilots with information on alternative relaxation techniques which have been well-tested in the treatment of sleep disorders.

International Cooperative Study of Air Crew Layover Sleep

Graeber, R.C. (Ed.) (1986). *Crew factors in flight operations: IV. Sleep and wakefulness in international aircrews.* (NASA Technical Memorandum No. 88231). Moffett Field, CA: National Aeronautics and Space Administration.

Operational Overview

The major goals of this research were to examine the changes in sleep associated with flights across multiple time zones and, if necessary, to suggest recommendations for improving such sleep. Flight crews were studied during the first layover after long flights crossing seven to nine time zones. The basic findings can be best described in terms of flight direction and discussed with respect to strategies used by crew members to obtain sufficient sleep before operating the return flight home.

Westward Flights

There was clear evidence that crew members experienced less sleep difficulties during layovers following westward flights (LHR-SFO, FRA-SFO, SFO-NRT) than after eastward flights. Following the westward flights almost all subjects went to bed soon after arrival. During the first night, sleep appeared to be of generally good quality and not unduly disturbed except for increased wakefulness during the second half of the night. In comparison with baseline, subjects generally fell asleep faster and slept essentially the same amount as at homebase. Some even reported better sleep quality.

During the next day, the increase in alertness usually seen during the late afternoon in local individuals was not observed. Instead, drowsiness continued to increase during the remainder of the wake span. By the second night, there was already some adaptation of sleep to the new time zone as indicated by even fewer awakenings occurring during the early morning hours.

Nevertheless, on the following day, the previous day’s pattern of increasing drowsiness was seen in crews who were available for testing. Most crew members successfully attempted to take a preflight nap in preparation for duty that afternoon. The same findings held for the one group of subjects whose layover lasted approximately 25 hr instead of the usual 48 hr. The only major difference was that their preflight nap occurred during the first afternoon after arrival.

The strategy of taking a nap before departure after a westward layover appears important in view of the coming night flight with its prolonged period of wakefulness. Recent research suggests that such a nap will help reduce in-flight drowsiness and avoid potential performance deficits. A second aspect of planning strategies to cope with this flight schedule emphasizes the potential importance of time of the latter part of flight in relation to the crew members’ circadian rhythms. Additional results obtained from some crews during the eastward return flight suggest that alertness improves as the circadian rhythms in body temperature and heart rate begin to rise. Therefore, certain schedules may be more desirable if they facilitate a nap before night and take advantage of the circadian rise in alertness during the latter part of the flight.

Eastward Flights

Sleep patterns were much more variable and fragmented after eastward night flights (NRT-SFO, SFO-LHR, SFO-FRA) than after westward flights across an equivalent number of time zones. There appears to have been a powerful influence which fractionated sleep, probably dependent on the difficulty which individuals experienced in shortening their day. Furthermore, the consequences of sleep pattern fragmentation were reflected in subsequent measures of daytime drowsiness.

Many crew members went to bed as soon as possible after arrival and fell asleep more quickly than observed during baseline but slept a relatively short amount of time even after a long overnight flight. Subjects tended to awake spontaneously at a time corresponding to the late morning of their home time. Overall, this strategy can be beneficial; however, the onset of the next major sleep varied considerably among individuals, with some crew members from each airline delaying sleep until it coincided with their usual bedtime at home. Similar wide-ranging differences were seen in the second night's sleep and intervening sleeps. In spite of a high degree of variability, sleep duration was usually shorter than baseline and subjectively worse.

Given the usual importance attributed by flight crews to obtaining "good" sleep immediately before a flight, these data suggest that their chance of doing so could be substantially improved by adhering to a more structured sleep schedule. In order to optimize sleep during an eastward layover of 24 hr or multiples thereof. It would be important to limit sleep immediately after arrival and prolong the subsequent wakeful period to end around the normal local time for sleep. This process would increase the likelihood that the sleep immediately preceding the next duty period would be of adequate duration for these operations. It appears that proper sleep scheduling during the first 24 hr is most critical and that crew members should develop the discipline to terminate sleep even though they could sleep longer.

Several subjects attempted the strategy of trying to maintain a sleep schedule based on home time. For the schedules under study, this practice would appear to be less desirable since it would produce a substantially shorter sleep span immediately before departure; however, this approach could not be adequately evaluated due to the relatively small number of subjects who used it.

Unless layover sleep is arranged in a satisfactory manner by an appropriate sleep-wake strategy, increased drowsiness is likely to occur during the subsequent long-haul flight. Other research suggests that under acceptable operational circumstances. Limited duration naps can be a helpful strategy to provide refreshment and improve alertness for a useful period of time. Although we do not have the appropriate data to address this issue directly, flight deck napping could be an important strategy if operationally feasible.

Individual Factors

While the subjects as a whole did not exhibit serious sleep problems, certain individual crew members did experience some difficulty. Further investigation of these data is required before any clarifying statement can be made regarding the factors responsible for this situation. Such work is currently under way.

Age is one individual factor which appears to have been important in this study. Older persons tend to experience more difficulties obtaining undisturbed sleep, and this was seen in the aircrew during baseline and layover recordings. Less restful sleep is a feature of growing older and begins to affect individuals in middle age. Surprisingly little is known about the nature and prevalence of less restful sleep over this important span of life, but the data obtained from these flight crews has highlighted the need for normative data in a similar age group of individuals who are usually involved in highly skilled and responsible occupations. These data are now being collected and may be helpful in understanding why some individuals in this age group have difficulty in adapting to unusual hours of work and rest. This issue may be relevant to the practice of occupational medicine.

Finally, in one group of pilots, preliminary analyses suggest that other individual factors may contribute to the crew member's response to layover sleep requirements. Although this evidence is currently limited to differences in daytime sleepiness in morning- versus evening-type individuals, it underscores the potential usefulness of factors related to personality and lifestyle as predictors of individual reactions to multiple time zone flights.

Study Limitations

Although these results have direct implications for air carrier operations, they must be viewed within the context of several limitations inherent in the study design. Most important is the fact that relatively uncomplicated trip patterns were studied. All but one of these trips involved an immediate return to the home time zone after the layover. The primary data were obtained from crew members during the first layover stay following an initial outbound flight. One group of subjects provided additional data upon return to homebase.

At present, such trips are not typical of most international flight crew duty schedules, which usually involve multiple flight segments and layovers in different time zones before return home; nevertheless, the trips under examination represent an important type of schedule which is becoming more prevalent.

Although the alterations in sleep were not considered to be of operational significance in the present schedules, it is nevertheless possible that the pattern of disturbed sleep would lead to cumulative sleep loss if the schedule were longer or if complete recovery of sleep were not attained before the next trip. The latter possibility is supported, at least in part, by the observation that baseline sleep was reduced in some subjects, though this may have also been due to other factors such as early rising. Furthermore, all flights occurred during late summer or early fall, which did not permit us to examine seasonal influences, particularly the length of daylight versus darkness, which may also be an important operational factor.

Secondly, the relatively limited sample sizes may not be representative of the flight crew population as a whole. In this regard, it is clear that the groups differed considerably in age and possibly may have differed along other dimensions related to the voluntary nature of their participation. Third, spending a layover at a sleep laboratory may not be equated with staying at a crew hotel. However, sleep log results from two participating groups of crew members suggest that sleep-wake patterns differ little under these two conditions.

Finally, a potentially more serious problem stems from the difficulty we experienced in obtaining baseline data immediately preceding the trip. Except for one airline, baseline data could only be obtained whenever the volunteers were available following at least three non-flying days. Consequently, these measurements often preceded or followed the trip by a week or more. Thus, any conclusions relating to baseline sleep must be tempered by the realization that the actual sleep obtained during the nights immediately prior to flight might have differed from that measured in the homebase laboratory and may have been confounded by the residual effect of the previous flight schedule, particularly if the preceding trip involved an eastward flight direction.

Regardless of these interpretative issues, the data revealed a high degree of similarity and consistency among the different flight crew samples despite significant differences in culture, age, and airline operational practices. Consequently, it is likely that the overall results apply to a wide spectrum of long-haul crew members and carriers.

Crew Factors in Flight Operations VI: Psychophysiological Responses to Helicopter Operations

Gander, P.H., Barnes, R., Gregory, K.B., Connell, L.J., Miller, D.L., and Graeber, R.C. (1994). *Crew factors in flight operations VI: Psychophysiological responses to helicopter operations.* (NASA Technical Memorandum No. 108838). Moffett Field, CA: National Aeronautics and Space Administration.

Operational Overview

This report is the sixth in a series on the physiological and psychological effects of flight operations on flight crews, and on the operational significance of these effects. This section presents a comprehensive review of the major findings and their significance. The rest of the volume contains the complete scientific description of the work.

Thirty-two helicopter pilots (average age 34 yr) were studied before, during, and after 4- to 5-day trips providing support services from Aberdeen, Scotland, to rigs in the North Sea oil fields. Duty days began and ended in Aberdeen. Half the trips studied took place in winter/spring, and the other half in summer/autumn. Heart rate, rectal temperature, and activity of the nondominant wrist were monitored continuously by means of portable biomedical monitors. Subjects kept daily logs of sleep timing and quality, food and fluid intake, medications taken, and medical symptoms. They also rated their fatigue and mood every 2 hr while awake. For every segment flown, they rated their workload (on a modified Bedford Scale) for each phase of flight, and rated five different environmental factors assumed to influence workload, that is, functioning of the aircraft systems (on a 5-point scale from perfect to useless); and weather conditions for landing, the landing site, letdown aids, and air-traffic control (each on a 5-point scale from very favorable to very unfavorable).

On trip mornings, subjects were required to wake up about 1.5 hr earlier than on pretrip mornings (average on-duty time 0725 local time). Although they came off duty relatively early (average 1437 local time), they averaged only 6.4 hr of sleep during layovers at home that averaged almost 17 hr. The inability to fall asleep earlier than the habitual bedtime is due to properties of the physiological mechanisms controlling sleep. Subjects were thus unable to compensate for the early wake-ups, and therefore averaged about 50 min less sleep per night on trips than on pretrip. In the laboratory, 1 hr per night of sleep restriction has been shown to accumulate and to progressively increase daytime sleepiness. Sleep was rated as better overall posttrip than on trip nights and deeper posttrip than pretrip, as is typical during recovery from sleep loss. Delaying the start of on-duty times (by 1.5–2 hr on average) would be expected to produce a significant improvement in the amount of sleep pilots are able to obtain, and should be given serious consideration.

Pilots reported more fatigue on posttrip days than on pretrip days, suggesting a cumulative effect of duty-related activities and sleep loss. Fatigue and negative affect were higher, and activation lower, by the end of trip days than by the end of pretrip days. The inability to maintain subjective activation by the end of trip days was exacerbated by early on-duty times.

Pilots drank 42% more caffeine on trip days than on pretrip and posttrip days. More caffeine was consumed in the early morning, in association with the early wake-ups, and also around the time of the mid-afternoon peak in physiological sleepiness. The urge to fall asleep at this time would increase as the sleep debt accumulated across trip days.

There were twice as many complaints of headaches on trips as at home. Reports of back pain increased twelvefold, and reports of burning eyes increased fourfold. Helicopter pilots were three times more likely to report headaches, and five times more likely to report back pain than were pilots of fixed-wing aircraft on short-haul commercial flights. The physical environment on the helicopter flight deck was probably an important factor. Studies of the same operations, conducted in parallel, demonstrated that pilots often had skin temperatures outside the range of thermal comfort, and that vibration levels in all of the helicopters studied exceeded the "reduced comfort" boundary defined by the International Standards Organization (I.S.O. 263). The longer pilots remained on duty, the more negative their mood became. This situation could be improved with better seat design, including better isolation of the seat from floor vibration, and better flight-deck ventilation.

The predominant environmental factors affecting subjective workload assessments were different for different phases of flight. The quality of the aircraft systems (rated on a 5-point scale from perfect to useless) had a significant effect during preflight, taxi, climb, and cruise. Paying particular attention to aircraft maintenance, thereby minimizing failures, might be one way of reducing workload during these phases of flight. Landing weather was the major factor influencing workload ratings during descent and approach. However, the effect of adverse weather on workload was reduced with better landing sites and better letdown aids. The quality of the landing site and air-traffic control had a significant effect on workload ratings during landing. These findings confirm that improvements in landing sites, letdown aids, and air-traffic control can reduce subjective workload during descent, approach, and landing.

Crew Factors in Flight Operations VIII: Factors Influencing Sleep Timing and Subjective Sleep Quality in Commercial Long-Haul Flight Crews

Gander, P.H., Graeber, R.C., Connell, L.J, and Gregory, K.B. (1991). *Crew factors in flight operations: VIII. Factors influencing sleep timing and subjective sleep quality in commercial long-haul flight crews.* (NASA Technical Memorandum No. 103852). Moffett Field, CA: National Aeronautics and Space Administration.

Operational Overview

This report is the eighth in a series on physiological and psychological effects of flight operations on flight crews, and the operational significance of these effects. The Operational Overview is a comprehensive review of the major findings and their significance. The rest of this volume contains the complete scientific description of the work. The aim of this study was to document how flight crews organize their sleep during a variety of international trip patterns, and to elucidate how duty requirements, local time, and the circadian system (measured by the rhythm of body temperature) influence the choice of sleep times, sleep duration, and subjectively rated sleep quality. Duty requirements and local time can be viewed as environmental constraints on the time available for sleep, while the circadian system is a major physiological modulator of sleep quality and duration.

Self-reports of sleep (and nap) timing and sleep quality, and continuous records of rectal temperature were collected from 29 male flight crew members (average age 52 yr) during scheduled B-747 commercial long-haul operations. Data from four different trip patterns were combined.

Sleep/wake patterns on these trips were complex. On average, duty periods lasted about 10.3 hr and were followed by layovers of about 24.8 hr during which there were typically two subject-defined sleep episodes. The average pattern of sleep and wakefulness (disregarding naps) was 19 hr wake/ 5.7 hr sleep/7.4 hr wake/5.8 hr sleep. The average durations of the first- and second-sleep episodes in a layover were not significantly longer episodes of wakefulness. However, first-sleeps were rated as being of better quality, with less difficulty falling asleep and deeper sleep. Sleep-quality ratings improved as sleep duration increased, reinforcing the importance of allowing adequate time for sleep.

The circadian system appeared to have a greater influence on the timing and duration of first-sleep episodes than on second-sleep episodes in the layover, except when that level of accumulated sleep debt was high, e.g., after eastward flights crossing five or more time zones. In such cases, crew members typically went to sleep sooner after arriving at the layover destination, during the local afternoon, and woke up either about 2 hr later (if they reported a nap) or 3 hr later (if they reported a sleep episode). Otherwise, crew members tended to delay going to sleep until the local night and/or until the hours preceding the temperature minimum.

The timing of second-sleep onsets seemed to be related primarily to the amount of sleep already obtained in the layover and generally coincided with local night. The duration of second-sleeps was strongly influenced by the amount of time remaining in the layover. For both first- and second-sleeps, the circadian time of sleep onset was also a significant predictor of sleep duration. Longer sleep episodes began earlier with respect to the minimum of the circadian temperature cycle.

In summary, the relative importance of duty requirements, local time, and the circadian system in determining sleep timing and quality was different for first- and second-sleep episodes in a layover and was related to specific flight schedules. Nevertheless, there were clearly preferred times for sleep within the layover, determined by the circadian modulation of sleep propensity and the factors driving the preference to sleep during the local night (noise, light, meal availability, etc.).

Flight and duty-time regulations can be interpreted as a means of ensuring that reasonable minimum rest periods are respected. There has been a tendency on the part of regulatory authorities to view the entire time off duty as being time available for sleep, despite anecdotal evidence that the ease of falling asleep and the ability to remain asleep were not constant throughout the layover. This study clearly documents that in scheduled commercial long-haul operations, there are physiologically and environmentally determined preferred sleep times within a layover, i.e., the time available for sleep is less than the time off duty.

Evidence from this and other studies suggests that the timing and duration of the second-sleep episode in a layover is strongly linked to the amount of sleep already obtained in the layover. Particularly when the first-sleep is short, as is typical after eastward flights crossing five or more time zones, it is essential that the layover be long enough to permit an adequate second-sleep episode appropriately timed with respect to the temperature cycle and local time. The duration of any specific layover should be determined with regard to the local arrival time, and the sequence of flights preceding it in the trip pattern, which influences both the cumulative sleep loss and the phase of the circadian system.

Based on polygraphic studies of flight crew sleep after a single eastward flight crossing eight or nine time zones, Graeber et al. recommended that crew members should limit sleep immediately after arrival and prolong the subsequent wake period to end around the normal local time for sleep. This is intended to improve the quality of the subsequent sleep episode, in keeping with the anecdotal report that flight crews consider it important to have a good sleep immediately before a flight. Their study looked only at sleep during the first (24 hr) layover of a trip sequence. The present study suggests that the recommended strategy may not be optimal after eastward flights later in the sequence, when crew members may have already accumulated an important sleep debt, and when the position of their circadian timing system would be much less predictable.

Naps were also reported, both during the layovers and on the flight deck. Naps that represented the first-sleep episode in a layover were significantly longer (average duration 2.0 hr) than subsequent naps in the layover or flight-deck naps, and followed significantly longer episodes of wakefulness (14.7 versus 5.9 and 9.3 hr, respectively). Such first naps were not very common and were associated with the acute sleep debt imposed by overnight eastward flights crossing five or more time zones (67%) or the prolonged wakefulness associated with westward flights crossing five or more time zones (25%). Naps later in the layover tended to occur just before the next duty period and, since they reduce the duration of continuous wakefulness before the next flight, may be useful as a strategy for reducing cumulative sleep loss.

On the flight deck, crew members were observed to be napping at least 11% of the available time. The average duration of these naps was 46 min (range 10–130 min). Recent work from our group suggests that a preplanned 40-min time interval for napping on the flight deck can reduce subsequent reaction times and the number of EEG/EOG microevents during long international flights. The optimal duration of such naps is an active research issue.

This study has significantly enhanced our understanding of how the circadian system functions in this complex operational environment. The flight schedules of the trips studied forced the sleep/wake cycle to adopt a period different from that of the underlying circadian pacemaker, although the influence of the circadian system was still seen in the selection of sleep times and in sleep durations, i.e., the two systems were not completely uncoupled. However, when the accumulated sleep debt was high, the circadian rhythm in sleep propensity could be overridden, and crew members could fall asleep at unusual times in their temperature cycles. The circadian system, in turn, effectively uncoupled from the very complex patterns of environmental synchronizing stimuli experienced by crews.

There are known to be differences between individuals in (1) the periods of their circadian pacemakers, (2) their sensitivity to environmental synchronizers, and (3) their self-selected patterns of exposure to social and sunlight cues in each time zone. At least some of these factors may be associated with certain personality profiles and probably all are age-dependent. An analysis of questionnaire data from 205 of the flight crew members in our data bases concurs with other studies suggesting that the period of the circadian pacemaker shortens with age. Age-related changes in sleep are also well documented, including shorter, less efficient nocturnal sleep and increased physiological sleepiness during the day.

The timing and quality of sleep obtained by flight crews is the product of a subtle and dynamic interplay between all of these factors and cannot be captured by any simple predictive algorithm. Based on the insights gained in this and other studies, we see two particularly promising approaches to improving en route sleep for flight crews during international commercial trip patterns. The first is education, providing crew members with basic information about sleep and the functioning of the circadian system, and how their behavior can modify both. Second, expert system technology should be used to combine our understanding of the underlying physiological systems with operational knowledge acquired from flight crew members and schedulers to develop a computerized intelligent scheduling assistant.

Crew Factors in Flight Operations IX: Effects of Planned Cockpit Rest on Crew Performance and Alertness in Long-Haul Operations

Rosekind, M.R., Graeber, R.C., Dinges, D.F., Connell, L.J., Rountree, M.S., Spinweber, C.L., and Gillen, K.A. (1994). *Crew factors in flight operations IX: Effects of planned cockpit rest on crew performance and alertness in long-haul operations*. (NASA Technical Memorandum No. 108839). Moffett Field, CA: National Aeronautics and Space Administration.

Operational Overview

This report is the ninth in a series on physiological and psychological effects of flight operations on flight crews, and on the operational significance of these effects.

Long-haul flight operations often involve rapid multiple time-zone changes, sleep disturbances, circadian disruptions, and long, irregular work schedules. These factors can result in fatigue, cumulative sleep loss, decreased alertness, and decreased performance in long-haul flight crews. Thus, operational effectiveness and safety may be compromised because of pilot fatigue. One natural compensatory response to the sleepiness and fatigue experienced in long-haul operations is unplanned, spontaneous napping and nonsanctioned rest periods. That these activities occur is supported by anecdotal, observational, and subjective report data from a variety of sources. In response to this information and to concerns for maintaining flight safety, it was suggested that a planned cockpit rest period could provide a “safety valve” for the fatigue and sleepiness experienced in long-haul flying. The cockpit rest period would allow a planned opportunity to sleep, with the primary goal being to improve subsequent levels of performance and alertness, especially during critical phases of operation such as descent and landing.

This study was co-sponsored and sanctioned by the FAA and involved the voluntary participation of two commercial airlines. The primary goal was to determine the effectiveness of a planned cockpit rest period to improve performance and alertness in nonaugmented, three-person long-haul flight operations. Twenty-one volunteer pilots participated and were randomly assigned to either a rest group (N = 12) or a no-rest group (N = 9) condition. The rest group (RG) was allowed a planned 40-min rest period during the low-workload, cruise portion of flight over water. Pilots rested one at a time, on a prearranged rotation, with two crew members maintaining the flight at all times. The no-rest group (NRG) had a 40-min planned control period identified during cruise but maintained their usual flight activities during this time. The four consecutive middle legs of a regularly scheduled transpacific trip, part of a 12-day trip pattern, were studied. Two legs were westbound day flights and two legs were eastbound night flights, with generally comparable flight and duty times.

Specific procedural and safety guidelines were successfully implemented in this initial study. However, not all of these would be necessary for a general implementation of planned cockpit rest periods in long-haul flight operations: (1) it was crucial that the rest period was planned, with first choice of rest period going to the landing pilot; (2) the rest periods were scheduled during a low-workload phase of flight and ended 1 hr before descent; (3) only one crew member was scheduled to rest at a time with a clear planned rotation established; (4) the rest opportunity was divided into an initial preparation period (3 min), followed by the 40-min rest period, followed by a recovery period (20 min) (these times might be altered to reduce the overall length of the period); (5) the rest was terminated at a preset time by a researcher, and the resting pilot was fully briefed before reentering the operational loop; and (6) it was established that the captain would be notified immediately at the first indication of any potential anomaly. The safe and normal operation of the aircraft was given the highest priority and, therefore, no cockpit rest procedure or activity was allowed to interfere with this.

Several measures were used to examine the physiological, behavioral, performance, and subjective effects of the planned cockpit nap. Continuous ambulatory recordings of brain wave and eye movement activity were conducted to determine physiologically how much sleep was obtained during the rest period, as well as the time taken to fall asleep and the stages of sleep. (These recordings allowed differentiation of non-rapid-eye-movement (NREM) sleep and its stages and rapid-eye-movement (REM) sleep). A reaction-time/sustained-attention task (psychomotor vigilance task) was used to assess performance capability. A wrist activity monitor was worn continuously before, during, and after the trip schedule. This activity monitor provided information regarding the pilots' 24-hr rest/activity pattern and was used to examine layover sleep episodes. Subjective measures collected in the study included in-flight fatigue and alertness ratings, a daily log for noting sleep periods, meals, exercise, flight and duty periods, etc., and the NASA Background Questionnaire.

The physiological data showed that on 93% of the rest period opportunities the RG pilots were able to sleep. Generally, they fell asleep quickly (average = 5.6 min) and slept for an average of 26 min. There were six factors related to sleep quantity and quality that were analyzed: total sleep time, sleep efficiency, sleep latency, percent NREM stage 1 sleep, percent NREM stage 2 sleep, and percent NREM slow wave sleep. Each of these factors was examined for effects related to trip leg, halves of the trip, day versus night, and flight position (captain, first officer, second officer). There were two significant effects that emerged from these analyses. The day flights had significantly more light sleep than night flights, and the night flights had significantly more deep sleep than day flights. An interesting finding emerged from analysis of the physiological data collected during the NRG 40-min control period. Although instructed to continue usual flight activities, four NRG pilots fell asleep (a total of five episodes) for periods lasting from several minutes to over 10 min.

There were generally consistent findings for the variety of analytical approaches used to examine the performance data. The median sustained attention/reaction time (a performance measure) for the NRG showed a greater range of average responses across flight legs and during in-flight trials than seen in the RG. After leg 1, the pilots in the NRG showed a steady increase in median reaction time across flight legs, with significant differences by the middle and end of flights. The RG pilots maintained a generally consistent level of performance both across and within flight legs, and did not show significant increases in reaction time. There were a total of 283 lapses (i.e., a response delay > 0.5 sec) for all 21 pilots (both groups combined). For in-flight trials, the NRG (with fewer subjects) had a total of 124 lapses, whereas the RG had a total of 81. There was an increase in lapses during in-flight trials 2 and 3 (after the test period) for the NRG, though this increase did not occur during in-flight trials following the nap in the RG. Both groups had more lapses before top of descent (TOD) on night-flight leg 4 than on night leg 2. However, the number of lapses in the NRG pilots increased twice as much as in the RG pilots. Vigilance decrement functions also revealed that on night flights the NRG pilots had a level of performance that was significantly decreased relative to the RG pilots. Generally, the performance task demonstrated decrements across flight legs and within flights for the NRG, whereas the RG maintained consistent levels of performance. These findings suggest that the planned nap prevented deterioration of vigilance performance.

Changes in brain wave and eye movement activity can reflect the subtle ways that physiological alertness/sleepiness changes. An intensive critical phase analysis was conducted to examine the effects of the cockpit nap on subsequent physiological alertness. The period from 1 hr before TOD through descent and landing was analyzed for the occurrence of brain and eye movement microevents indicative of reduced physiological alertness. During approximately the last 90 min of flight, each event greater than 5-sec duration was scored for both the NRG and RG. There was at least one such microevent identified in 78% of the NRG and 50% of the RG. Overall, there were a total of 120 microevents that occurred in the NRG (with fewer subjects) and a total of 34 microevents in the RG. The NRG averaged significantly more total microevents (6.37) than the average in the RG (2.90). This supports the conclusion that the sleep obtained during the rest period was followed by increased physiological alertness in the RG relative to the NRG.

The 24-hr rest/activity patterns, in combination with the subjective logs, demonstrated that 86% of the 21 subjects accumulated a sleep debt that ranged from 4 to 22 hr and averaged approximately 9 hr by the ninth day of the duty cycle. When the entire 36-hr duty period (layover and subsequent duty cycle) is considered, the percent of layover sleep time is 28%. This is less than the average 33% sleep time spent off-duty at home, hence the cumulative sleep debt. One subject gained sleep, and two others had no change. Further analysis demonstrated that the cockpit nap did not significantly alter the cumulative sleep debt observed in the RG. Also, 77% of the layovers involved more than one sleep episode. Generally, there were two sleep episodes, and if the first one was long, then the second one was short or did not occur. Conversely, if the first sleep episode was short, then there was almost always a second one that was long. This result demonstrated that there were multiple factors operating to control sleep timing and quantity (e.g., local time, home circadian time, prior sleep loss). This study was not designed to examine the issue of layover sleep periods, though recently, the timing of layover sleep periods, including naps, in long-haul flight operations, has been addressed.

Overall, the analysis of the subjective alertness ratings demonstrated that pilots reported lower alertness on night flights than on day flights and after the rest/control period than before it (except on leg 1). The results indicated that the nap did not affect the subjective ratings of alertness, though the objective measures clearly indicated better performance and greater alertness in the RG.

The level of physiological sleepiness experienced in long-haul flight operations was demonstrated in both subject groups. The speed of falling asleep has been used as a measure of physiological sleepiness (i.e., the more sleepy an individual, the faster he or she will fall asleep). The speed of falling asleep in the RG (5.6 min) is comparable to that seen in moderately sleep deprived individuals. A diagnostic guide for excessive sleepiness in sleep disorder patients is a sleep latency of 5 min or less. Also, there were five episodes of sleep that occurred during the control period in four NRG pilots who had been instructed to continue usual flight operations. This result reinforces previous findings that pilots are poor evaluators of their level of physiological sleepiness.

Overall, the study results provide support for differentiating fatigue countermeasures into two basic approaches. Conceptually and operationally, methods to minimize or mitigate the effects of sleep loss, circadian disruption, and fatigue in flight operations can be divided into (1) preventive strategies and (2) operational countermeasures. Preventive strategies involve those approaches that result in more long-term adjustments and effects on underlying physiological sleep and circadian processes (e.g., possibilities for further research include shifting the circadian phase before multiple time-zone changes, using bright lights or exercise to rapidly readjust the circadian clock, and maximizing the quantity and quality of sleep). These preventive strategies affect underlying physiological sleep need, sleepiness, and circadian phase in a long-term and chronic fashion. Operational countermeasures are focused strategies for reducing sleepiness and improving performance and alertness during actual operations (e.g., proved strategies include judicious use of caffeine, increased physical activity, and increased interaction). These short-acting countermeasures are not intended to reduce underlying physiological sleepiness or a sleep debt, but rather to increase performance and alertness during operational tasks. One acute, short-acting operational countermeasure that can temporarily reduce physiological sleepiness is napping. The planned cockpit nap in this study is considered to be an operational countermeasure that provided an acute, short-acting improvement in performance and alertness.

It must be acknowledged that every scientific study has specific limitations that restrict the generalizability of the results. This study involved only one trip pattern on a commercial airline carrier. The study was conducted on transpacific flights to utilize the opportunity of scheduling the planned rest periods during the low-workload portion of cruise over water. The intense physiological and performance data collection occurred during a specific and restricted middle segment (four consecutive flight legs) of the trip schedule. Therefore, the initial home-to-flight-schedule transition is quantified only with log book and activity data. Also, the highest levels of accumulated fatigue, which probably occurred during the final trip legs, were not studied except for log book and activity data. This study involved B-747 aircraft flown by three-person crews; the specific application of this countermeasure to the two-person cockpit was not addressed. There were two NASA researchers on the flight deck during the in-flight data collection periods. Although they were instructed to minimize their interactions and presence, there is no question that having two extra individuals on the flight deck may have potentially altered the regular flow of cockpit conversation and interaction. It is important to remain cognizant of these limitations when attempts are made to generalize the study results to questions that extend beyond the scope of the specific scientific issues addressed here.

In conclusion, the RG pilots were able to sleep during the planned cockpit rest period, generally falling asleep quickly and sleeping efficiently. This nap was associated with improved performance and physiological alertness in the RG compared to the NRG. The benefits of the nap were observed through the critical descent and landing phases of flight. The convergence of the behavioral performance data and the physiological data to demonstrate the effectiveness of the cockpit nap lends support to the robustness of the findings. The nap did not affect layover sleep or the overall cumulative sleep debt displayed by the most of the crew members. The nap procedures were implemented with minimal disruption to usual flight operations, and there were no reported or identified concerns regarding safety.

The planned nap appeared to provide an effective, acute relief for the fatigue and sleepiness experienced in nonaugmented three-person long-haul flight operations. The strength of the current results supports the implementation of planned cockpit sleep opportunities in nonaugmented long-haul flight operations involving three-person crews. If planned cockpit sleep opportunities were sanctioned, each airline could determine the appropriate incorporation of procedures into its specific mode of operation. If implemented, we recommend that a joint NASA/FAA follow-up study be conducted within

6–12 months to examine how planned cockpit sleep opportunities have been incorporated into airline procedures. That study would examine how the procedures were implemented and their effectiveness. This might take the form of a survey or include some field data collection. The results of that follow-up study might then lend support for further refinement of procedures and future implementation in other flight environments.

APPENDIX D
NASA AMES FATIGUE COUNTERMEASURES PROGRAM

Representative Publications

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APPENDIX E
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