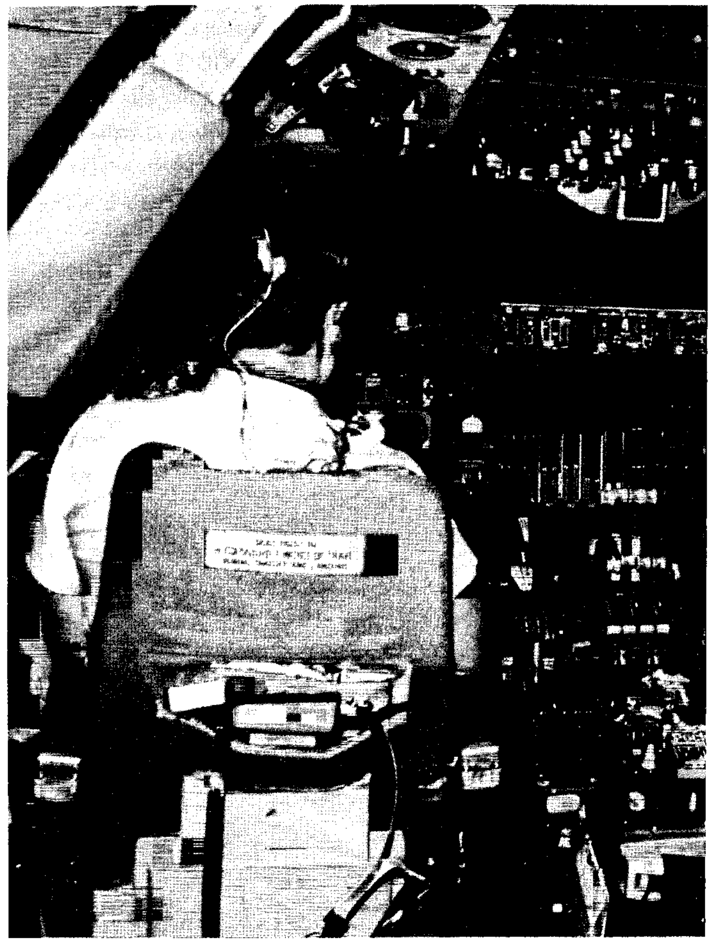
PILOT FATIGUE, SLEEP, AND CIRCADIAN RHYTHMS:

# NASA Fatigue Countermeasures Program



*This article summarizes some of the significant findings from the NASA Ames Fatigue Countermeasures Program. The research program was initiated following a NASA workshop requested by Congress in 1980 to examine a possible "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."*

The Fatigue Countermeasures program sought to collect systematic, scientific information on fatigue, sleep, circadian rhythms, and in-flight operations. NASA identified three program goals: 1) determine the extent of fatigue, sleep loss, and circadian disruption in flight operations; 2) determine how these factors affect flightcrew performance; and 3) develop and evaluate countermeasures to mitigate adverse effects and maximize flight crew performance and alertness. The research integrated data from field studies during regular flight opera-

# MEASURES

tions, full-mission high-fidelity simulations, and controlled laboratory experiments.

Research methods have varied over the past 10 years, depending on the specific question being addressed. Today's diverse measures range from self-report logbooks, to ambulatory recording of physiological variables, to vigilance performance measures (see Table 1 and Figure 2).

## Study findings

Over the last 12 years, studies have been conducted in many diverse settings and have provided important scientific and operational information that has been used in many different applications by air carriers, individual pilots, FAA, NTSB, and others. (see Table 2 and Figure 1) Some examples illustrate the results in different flight environments.

**The short-haul simulation study** was designed to examine the effects of fatigue on flight crew performance variables that could be measured in a simulator (5). Surprisingly, the major results did not address fatigue, but, instead, provided some of the original findings on the importance of crew familiarity, coordination, and communication in flight operations. The results of this study provided a foundation for what today is identified as crew resource management (CRM).

**The short-haul field study** examined fatigue, sleep loss, and circadian disruption in short-haul flight operations (2). The study examined 74 pilots before, during, and after 3 and 4 days of commercial short-haul trips. A variety of measures were taken, including physiological (core body temperature and heart rate), motor activity from the wrist, subjective ratings of fatigue and mood, and a log of sleep and other activities (e.g., eating, exercising). Trips averaged 10.6 hours of duty per day, involving an average of 4.5 hours of flight time and 5.5 flight legs. The average rest period occurred progressively earlier on successive trip days and was 12.5 hours long.

During the trip, pilots took longer to fall asleep, slept less, woke earlier, and reported lighter and poorer sleep (with more awakenings) compared to pre-trip sleep patterns. Subjective fatigue and mood were worse dur-

Survey/questionnaire data
Logbook subjective report
Observational/behavioral data
Physical performance and mental functioning tests
Long-term continuous recording of motor activity
Long-term continuous recording of physiological parameters (e.g., core body temperature, heart rate)
Continuous physiological recording of brain, eye, and muscle activity

**Table 1: Experimental Measures**

Short-haul field studies (military and commercial) (ref. 2)
Long-haul field studies (military and commercial) (ref. 3,4)
Short-haul simulation study (ref. 5)
Modeling the effects of long-haul schedules on the circadian system (ref. 6)
Circadian countermeasure and masking study (ref. 7)
Laboratory jet lag simulation: effects of scheduled naps (Cornell) (ref. 8)
International polar routes study (FRG, UK, JA) (ref. 9)
North Sea helicopter study (UK) (ref. 10)
International cooperative layover sleep study (UK, FRG, JA) (ref. 11)
Night cargo operations (ref. 12)
Bedrest bright light study to reset circadian phase (ref. 13)
Planned cockpit rest study (long-haul transpacs; FAA) (ref. 14)

**Table 2: Major Studies Completed**

*"My mind clicks on and off . . . I try letting one eyelid close at a time while I prop the other open with my will. But the effort's too much. Sleep is winning. My whole body argues dully that nothing, nothing life can attain, is quite so desirable as sleep. My mind is losing resolution and control."*

C. A. Lindbergh, *The Spirit of Saint Louis* (Scribners, New York, 1953).

ing layovers compared to pre-trip, in-flight, or post-trip levels. On trip days, pilots consumed more caffeine (presumably to maintain alertness during operations) and alcohol* (presumably to "spin down" after a duty day) and consumed more snacks earlier. Also, pilot heart rate increased during descent and landing (with greater increases for the flying pilot), and the increase was greater under IMC than under VMC. These results support the following conclusions:

- Regulation of duty hours should be considered, just as flight hours are controlled.
- Rest periods should occur at the same time on trip days or progressively later across days.
- Alternate techniques must be provided to relax after flights, particularly strategies other than the use of alcohol prior to sleep.

**The North Sea helicopter study** examined 32 helicopter pilots (average age 34 years) while they provided regular support service from Aberdeen, Scotland to oil rigs in the North Sea. Pilots were studied before, during, and after 4 to 5 days on duty. Continuous measurement of heart rate, core body temperature, and non-dominant wrist activity were collected with portable biomedical recorders. Pilots maintained daily logbooks to record information about the timing, quantity and quality of sleep, food and fluid intake, medications used, and medical and physical symptoms. Other information collected included fatigue and mood ratings every 2 hours while awake and the workload for each segment flown.

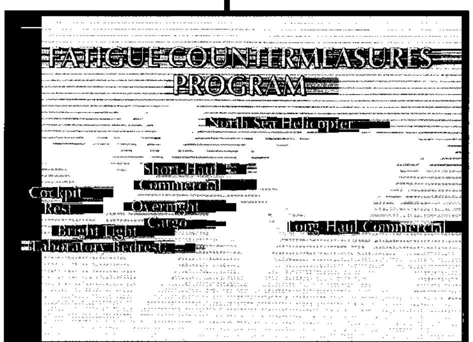



**Figure1: Over 500 pilots have been studied in many different types of flight operations in projects conducted all over the world.**

The results showed that pilots were required to wake up about 1.5 hours earlier on trip mornings, compared to pre-trip. Although average duty ended relatively early (1437 local time), pilots averaged only 6.4 hours of sleep on layovers that lasted about 17 hours. As indicated in the study of short-haul pilots, the physiological mechanisms controlling sleep make it difficult to fall asleep earlier than habitual bedtimes. Therefore, going to sleep earlier did not compensate for the earlier report time, and pilots averaged about 50 minutes less sleep on trip nights compared to pre-trip levels. Subjectively, pilots rated their post-trip sleep as better than that of trip nights and deeper on post-trip than on pre-trip nights. This would be the expected finding for pilots recovering from sleep loss accumulated during trip days.

Pilot fatigue and negative mood ratings were higher at the end of trip days compared to pre-trip end-of-day ratings. On trip days, pilots consumed 42 percent more caffeine than on pre- and post-trip days, and the number of physical complaints exceeded the level reported at home. Complaints of headaches doubled, back pain reports increased twelve-fold, and complaints of burning eyes increased four-fold. These helicopter pilots were three times more likely to report headaches and five times more likely to report back pain than were commercial short-haul fixed wing pilots. The physical environment of the helicopter flightdeck (vibration, noise, ventilation, and thermal comfort) is probably an important contributing factor to these reported symptoms.

**The international cooperative layover sleep study** involved the United Kingdom, Germany, Japan, and the United States. It examined changes in sleep quantity and quality associated with multiple timezone transitions in experienced international air crews (11) and how changes in sleep affected subsequent waking levels of sleepiness. Crewmembers were monitored in sleep laboratories after westward and eastward international flights, and a laboratory-based objective test of physiological sleepiness was conducted throughout the next day.

Results showed that, generally, the flight crews obtained adequate sleep during the layover by sleeping efficiently at selected times or sleeping less efficiently but staying in bed longer than their typical sleep period. The study also confirmed findings from laboratory studies on shifts of the internal circadian clock: the natural "biological day" determined by the physiological clock that regulates the sleep/wakefulness rhythm is usually longer than our 24 hour day—about 25 hours. Therefore, pilots should more easily adapt when flying westward, when the length of the day is extended (a phase delay going with the natural rhythm of the clock), than when flying eastward, when the day is shortened (a phase advance). Accordingly, the circadian effect should result in more disturbed sleep for eastward than for westward flights. Generally, crews slept slightly worse on layover, compared to home, but they had more disturbed sleep following eastward flights compared to westward flights. These disturbances were evident in the increased daytime sleepiness exhibited in the new time zone.

**Long-haul field studies.** Another NASA study documented how long-haul flight crews organize their sleep during a variety of international trip patterns and examined how duty requirements, local time, and the circadian system affect the timing,

* Alcohol use was in accordance with the FARs.

quantity, and quality of sleep (4).

Duty requirements and local time are external or environmental constraints, while the internal circadian system is a major physiological modulator of sleep. Data were obtained from 29 male flight crew members (average age 52) flying B-747 aircraft on one of four commercial international trip patterns. Self-reports of sleep timing, duration, and quality were collected prior to, during, and following the trip schedule. Core body temperature, heart rate, and activity (from the non-dominant wrist) were continuously monitored with an ambulatory physiological recorder. The core body temperature was used as a marker of the underlying circadian time-keeping system.

Sleep/wake patterns on these trips were complex, and, on average, duty periods lasted about 10.3 hours followed by 24.8-hour layovers. Crewmembers generally defined two sleep episodes during layovers. The circadian system had a greater influence on the timing and duration of the first sleep episode, with a preference for sleeping during the local night. The time of falling asleep for the second sleep episode was related to the amount of sleep already obtained, and the duration was related to the remaining time available before duty. The duration of both sleep episodes was longer when crewmembers fell asleep earlier in the circadian temperature cycle. Naps were reported during layovers and about 11 percent of the available time on the flight deck.

Flight schedules caused the sleep/wake cycle to differ from circadian rhythms, though the two systems were not completely uncoupled. The circadian system continued to influence the timing and duration of sleep episodes. However, the circadian system was unable to re-synchronize and quickly adapt to rapid, multiple time-zone shifts. Current flight and duty time regulations are intended to ensure that reasonable minimum rest periods are available for flight crews. This study demonstrates that commercial long-haul flight schedules include physiologically and environmentally determined preferred sleep times on layover. Therefore, off-duty time overstates the time available for sleep.

## Fatigue countermeasures program

In 1991, the Fatigue/Jet Lag Program evolved into the Fatigue Countermeasures Program to accelerate efforts to determine the consequences of sleep loss and circadian disruption on flight crew performance. The new program especially increased emphasis on the development and evaluation of operational fatigue countermeasures in specifically identified target areas. The recently completed NASA/FAA study of planned cockpit rest in non-augmented three-person long-haul flight operations is a highly visible and important example of this renewed emphasis on the development and scientific evaluation of fatigue countermeasures (14).


**Figure 2: These are some of the different scientific measures used to collect information during regular flight operations. They can provide continuous physiological measurements of brain, eye, and muscle activity to determine sleep/wakefulness; continuous body temperature to reveal the timing of the biological clock; performance tests of vigilance and sustained attention; and a wrist monitor that provides a 24-hour portrait of a pilot's rest/activity pattern.**

**Planned cockpit rest study.** Sleep loss and circadian disruption from long-haul flight operations can result in fatigue, increased sleepiness, and reduced performance. Anecdotal, observational, and self-report sources indicate that, to physiologically compensate for the sleep loss and circadian disruption, unplanned sleep can occur. The purpose of this study was to determine the effectiveness of a planned cockpit rest opportunity to maintain and/or improve subsequent performance and alertness.

The study examined the middle four legs of a regularly scheduled trans-Pacific trip. The B-747 volunteer crewmembers were randomly assigned to either a Rest Group or No-Rest Group. Each of the 12 Rest Group crewmembers had a 40-minute rest opportunity in the low workload cruise portion of flights over water. Crewmembers rested one at a time on a prearranged rotation. The nine No-Rest Group crewmembers had a 40-minute control period identified during which they were instructed to continue their regular flight activities.

Measures during the study flight legs included continuous physiological monitoring of brain and eye movement activity, a 10-minute test of vigilance/sustained attention, and self-report ratings of alertness and mood (see Figures 3 and 4). Before, during, and after the 12-day trip schedule, crewmembers wore activity monitors on their wrists and completed daily logbooks documenting sleep and other activities. Rest Group crewmembers slept on 93 percent of rest opportunities, falling asleep in 5.6 minutes and sleeping for 26 minutes. These naps were associated with the subsequent maintenance of initial performance levels compared to decrements observed in the No-Rest Group. Also, in the last 90 minutes of flight, the No-Rest Group had twice as many events indicating physiological sleepiness than did the Rest Group. This brief "NASA nap" appeared to act as an acute in-flight safety valve but did not affect the cumulative sleep debt observed in 85 percent of the crewmembers.

**Advisory Circular.** Based partly on the results of this NASA/FAA study, an industry-government working group has drafted an Advisory Circular

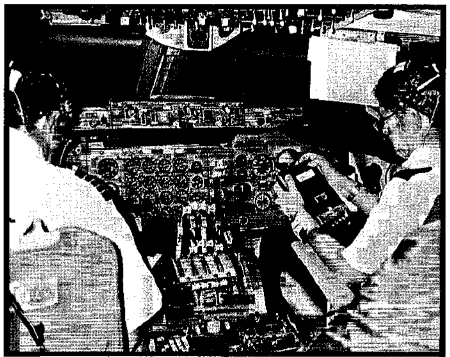


Figure 3: This pilot is completing a short performance test (held in his hands) that evaluates vigilance and sustained attention while his brain and eye movement activity is continuously monitored (sensors on his head and face).

(AC) currently under review by the FAA. The AC outlines specific guidelines for developing and implementing a program of controlled rest on the flight deck. Controlled rest, however, is just one acute in-flight countermeasure and is not the answer for all of the sleep loss and circadian disruption engendered by long-haul flight operations.

These examples systematically document the extent to which sleep loss, circadian disruption, and fatigue are concerns in all short- and long-haul flight operations, whether they involve fixed wing aircraft or helicopters. The research also provides a scientific basis for developing and evaluating countermeasures to reduce the adverse effects of these factors. Potential countermeasures can be objectively tested in operational settings to determine their effectiveness in maximizing crew performance and alertness.

## Current activities

The NASA Ames Fatigue Countermeasures Program is now involved in studies of on board crew rest facilities on long-haul aircraft, continued examination of the cockpit rest data (e.g., layover sleep strategies, relationship between performance and physiological activity), the continued development, application, and evaluation of other countermeasure strategies (e.g., bright light, exercise), and the implementation of an education and training module on Alertness Management in Flight Operations.

Figure 4: The information is brought back to our laboratory, where the intricate brain and eye movement recordings are analyzed by highly trained staff using specialized computers.

NASA's research has begun to identify preventive and operational countermeasures to reduce fatigue (16). Examples of preventive strategies, used prior to flight operations or on layovers, include scheduling sleep during layovers, organizing trip schedules, and napping. Operational countermeasures are used in flight and are typically acute, short-acting methods to maintain performance and alertness during actual flight operations. Examples include the use of caffeine, physical activity, and, perhaps in the near future, controlled rest on the flight deck.

**Alertness Management in Flight Operations education and training module.** Based on 12 years of extensive research, the NASA's Fatigue Countermeasures Program is preparing an education and training module on fatigue, sleep, and circadian rhythms in flight operations (15). The module provides basic information about these factors, such as how they are affected by flight operations, some common misconceptions, and some recommendations for alertness management on the flight deck. Generally, the information will involve live presentations, complemented by a NASA Technical Memorandum to provide all presentation material and other reference information. The module will be available to anyone interested, with the hope that air carriers, pilots, schedulers, pilot unions, government agencies, flight attendants, and others will use this resource. Write to the address below to request the module.

## Conclusions

More than a decade of research at NASA Ames on pilot fatigue, sleep, and circadian rhythms has identified new insights into crew fatigue. Some basic findings include:

- Sleep loss and circadian disruption from long-haul flight operations can result in fatigue, increased sleepiness, and reduced performance.
- While on short-haul trips for 3 to 4 days, pilots take longer to fall asleep, sleep less, awake earlier, and report lighter and poorer sleep compared to pre-trip sleep patterns.
- Pilots generally report feeling less well during extended duty periods, but helicopter pilots on short-haul flights for 4 or 5 days are far more likely to report headaches and back pain than are commercial short-haul fixed wing pilots, probably due to the physical environment of the helicopter flightdeck.
- Off-duty time overstates the time available for sleep.
- Regulation of duty hours should be considered, much like flight hours.
- Rest periods should occur at the same time on trip days or progressively later across days.
- On layovers, experienced international flight crews sleep efficiently at selected times or sleep less efficiently but longer than normal, with a preference for sleeping during local night.
- However, despite efficient or longer sleep during layover, the circadian system is unable to resynchronize and quickly adapt to rapid, multiple time-zone shifts.
- A brief in-flight nap is an acute in-flight safety valve to improve performance and alertness on long-haul flights, but naps do not affect the cumulative sleep debt in most crewmembers.

As aircraft become increasingly more automated and able to fly greater distances with smaller crews, maintaining the safety margin will continue to be an important consideration in all flight operations. In the future, the human factor (i.e., pilots, ground maintenance personnel, controllers, flight attendants, and others) will remain critical components of the aviation system. Therefore, the physiological capabilities of humans regarding sleep and circadian rhythms, and the importance of maximizing performance and alertness in flight operations, will continue to be important factors in flight safety, performance, and productivity. ✈

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# SAFETY CORNER


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