Aviation Rulemaking Advisory Committee
Reserve Rest Working Group

Proposal of 77,955 Airline Pilots
January 8, 1999

Airline	*Pilots*	*Airline*	*Pilots*
Air Wisconsin	240	Mesa	1095
Alaska	1153	Mesaba	804
Allegheny	354	Midway	174
Aloha	192	Midwest Express	262
Aloha Island Air	64	Northwest	6103
America West	1532	Piedmont	368
American	9508	Polar Air Cargo	186
American Eagle	2055	PSA	254
Atlantic Coast	694	Reeve	33
Atlantic Southeast	763	Reno	302
Business Express	372	Ross	19
Carnival	219	Ryan International	257
CCAir	172	Skyway	132
Comair	1000	Southwest	2735
Continental	4769	Spirit	154
Continental Express	1010	Sun Country	213
Delta	9188	Tower Air	206
DHL	395	Trans States	806
Emery Worldwide	451	TWA	2516
Express	329	United	9621
Federal Express	3611	UPS	2100
Hawaiian	285	USAirways	5092
IBT	6000	USAirways Shuttle	167

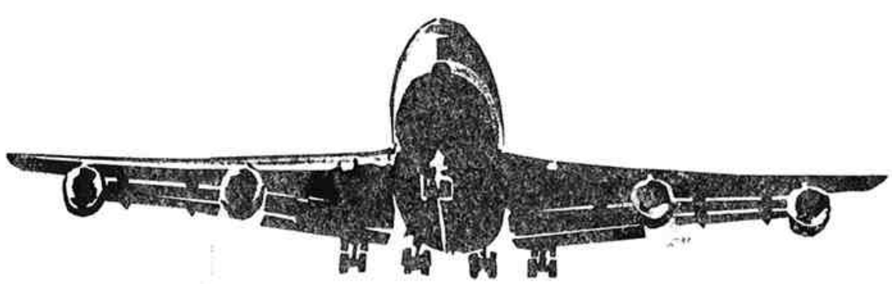


TABLE OF CONTENTS

AVIATION RULEMAKING ADVISORY COMMITTEE
RESERVE REST WORKING GROUP

PROPOSAL OF 77,955 AIRLINE PILOTS
January 8, 1999

PREAMBLE

This document is submitted on behalf of approximately 78,000 commercial airline pilots. The proposal that follows contains our recommendations for Federal Aviation Regulations concerning rest requirements and duty limitations for reserve pilots. It is applicable to all Domestic and International Part 121 operations under FAR Subparts Q, R, and S. Part 135 regulations should be revised to provide a level of safety equivalent to this proposal.

Our proposal is presented in two parts. Part I is the proposed regulatory language. Part II provides our intent, examples, and rationale. The scientific support for our proposal is included in the endnotes.

We are pleased that both pilots and air carriers were able to agree on the following elements of a proposed reserve rest rule:

1. A pilot should be scheduled by the operator to receive a protected time period as an opportunity to sleep for every day of reserve duty. The operator may not contact the pilot during this period.
2. An operator should limit the movement of a pilot's protected time period during consecutive days of reserve duty to ensure circadian stability.
3. A reserve pilot's availability for duty should be limited to prevent pilot fatigue as a result of lengthy periods of time-since-awake.

4. Sufficient advance notice of a flight assignment can provide a reserve pilot with a sleep opportunity.

We believe that it is incumbent upon the Federal Aviation Administration (FAA) to include time-of-day as a factor in designing duty and rest limitations. A substantial body of research and pilot reports shows that a decrease in performance frequently occurs during "back-side-of-the-clock" operations due to circadian factors. To address this issue, our proposal provides for a reduction in the reserve availability period when scheduled duty touches the 0200 – 0600 time period, or what the scientists refer to as the "window of circadian low."

Our submission refers to several documents that have provided us with a foundation of scientific support. Prominent among them is NASA Technical Memorandum 110404, *Principles and Guidelines for Duty and Rest Scheduling in Commercial Aviation*, (May 1996). This document, herein referred to as NASA TM, offers NASA's specific recommendations on duty and rest limitations based on more than 20 years of extensive research into the cause and prevention of pilot fatigue. It is attached hereto as Appendix A.

Another reference is *An Overview of the Scientific Literature Concerning Fatigue, Sleep, and the Circadian Cycle*, Battelle Memorial Institute Study (January 1998). This study, herein referred to as the Battelle Study, commissioned by the FAA's Office of the Chief Scientific and Technical Advisor for Human Factors, provides an in-depth review of scientific research concerning sleep and fatigue. Drawing upon 165 scientific references, the Battelle Report identifies major trends in the scientific literature, and has provided valuable information and conclusions. This study is attached as Appendix B.

Another reference is *A Scientific Review of Proposed Regulations Regarding Flight Crewmember Duty Period Limitations*, Docket #28081, The Flight Duty Regulation scientific Study Group. This study was sponsored by the Independent Pilots Association to provide a scientific review of NPRM 95-18. It is referred to as the Scientific Study Group and is attached as Appendix C.

The pilots met with sleep expert, Dr. William Dement, Director of Sleep Research and Clinical Programs at Stanford University. The transcript of that meeting appears in Appendix D.

We have attached an article titled *Fatigue, Alcohol, and Performance Impairment* that summarizes a study conducted by The Centre for Sleep Research at the Queen Elizabeth Hospital in South Australia in Appendix E. This study quantifies the performance impairment associated with sustained wakefulness in terms of equivalent percent blood alcohol impairment. A subsequent study, titled *Quantifying the Performance Impairment associated with Sustained Wakefulness*, by Lamond and Dawson replicates this study and extends the initial findings. It is attached as Appendix F.

The NTSB requested that the FAA conduct an expedited review of the FARs after pilot fatigue and continuous hours of wakefulness were found to be key findings in the crash of a DC-8 at Guantanamo Bay, Cuba in 1993. A NASA/NTSB report titled *Crew fatigue factors in the Guantanamo Bay aviation accident* is attached as Appendix G.

Several airlines have switched to reserve pilot schemes very similar to the one we propose. These carriers include Continental Airlines, UPS, America West, Alaska Airlines, and British Airways. The reserve pilots at these airlines have protected time periods of 8 to 12 hours with reserve availability periods of 14 to 18 hours.

We owe a debt of gratitude to the many pilots who provided us with reports of their encounters with pilot fatigue. These reports reveal that pilot fatigue typically occurs during back-side-of-the-clock operations and after long periods of time-since-awake.

The pilots would like to thank the FAA for providing this forum and the air carriers for contributing to the debate. We hope that this ARAC has demonstrated to all interested parties how unregulated scheduling can lead to dangerously high levels of pilot fatigue for reserve pilots. We urge the FAA to quickly remedy this very serious safety problem.

PART I: PROPOSED REGULATORY LANGUAGE

121.xxx Reserve Rest

(a) Except as provided in paragraphs (b) and (d), no certificate holder may schedule any flight crewmember and no flight crewmember may accept an assignment to reserve status unless a minimum prospective Protected Time Period (PTP) of 10 hours during a 24-consecutive hour period is scheduled. The Protected Time Period must begin at the same time during any scheduled period of consecutive days of reserve status and the flight crewmember must be given no less than 24 hours notice of the Protected Time Period.

(b) A certificate holder may reschedule a specific Protected Time Period during any scheduled period of consecutive days of reserve by the following:

(1) Rescheduling the beginning of a Protected Time Period a maximum of three hours later without prior notification.

(2) Rescheduling the beginning of a Protected Time Period a maximum of three hours earlier if the flight crewmember is provided 6 hours notice prior to the beginning of the originally scheduled Protected Time Period.

(3) Rescheduling the Protected Time Period by more than 3 hours once during any 7 consecutive days by providing the flight crewmember 10 hours notice.

(c) A certificate holder may assign a flight crewmember and a flight crewmember may accept an assignment for flight time in scheduled air transportation or other commercial flying if such assignment is permitted by this subpart;

(1) If the assignment is scheduled to be completed within 16 hours after the end of the preceding Protected Time Period; however.

(2) If the flight crewmember is given a flight assignment for any part of the period of 0200 to 0600 hours, any such flight assignment must be scheduled to be completed within 14 hours after the end of the preceding Protected Time Period. The operator with the concurrence of the administrator and the pilot group may designate any 4-hour period for all operations between 0000-0600 hours in place of 0200-0600 hours.

These limitations may be extended up to 2 hours for operational delays.

(d) When there are no other reserve pilots who have sufficient reserve availability periods to complete an assignment, the certificate holder may schedule a flight crew member for an assignment for flight time in scheduled air transportation or other flying permitted by this subpart, provided that the crew member is given a minimum of 14 hours of advance notice and is released to protected time at the time of the notice.

(e) Each certificate holder shall prospectively relieve each flight crewmember assigned to reserve for at least 24 consecutive hours during any 7 consecutive days.

(f) For augmented International operations, a certificate holder may assign a flight crewmember and a flight crewmember may accept an assignment for flight time in scheduled air transportation or other commercial flying as follows:

(1) For single augmentation, the assignment must be scheduled to be completed within 18 hours after the end of the preceding Protected Time Period; or

(2) For double augmentation, the assignment must be scheduled to be completed within 22 hours after the end of the preceding Protected Time Period.

These limitations may be extended up to 2 hours for operational delays.

DEFINITIONS

Operational Delay – Any delay that would cause the Reserve Crewmember to be extended beyond the applicable duty limit for up to two hours; except a delay caused by changing the Reserve's original flight assignment.

Protected Time Period (PTP) – Same as 121.471(b)(6), NPRM 95-18, except "has no responsibility for work" replaced by "has no responsibility for duty."

Reserve Availability Period (RAP) – The period of time from the end of the PTP to the time that the reserve crewmember must complete flight duty.

Reserve Time – Same as 121.471(b)(7), NPRM 95-18, except "two hours" for report time versus "one hour."

Standby Duty – Same as 121.47(b)(9), NPRM 95-18, except "less than two hours" to report versus "one hour."

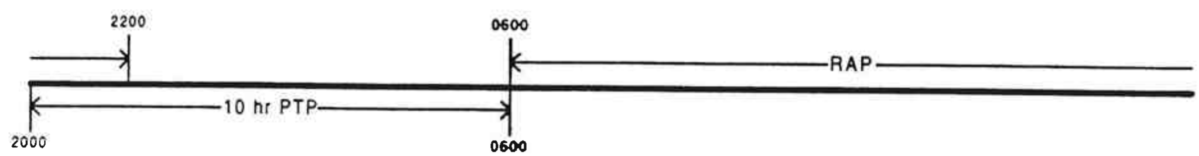
Part II: Pilots' Proposal with Intent, Examples, and Rationale

121.xxx Reserve Rest

(a) ***Except as provided in paragraphs (b) and (d), no certificate holder may schedule any flight crewmember and no flight crewmember may accept an assignment to reserve status unless a minimum prospective Protected Time Period (PTP) of 10 hours during a 24-consecutive hour period is scheduled. The Protected Time Period must begin at the same time during any scheduled period of consecutive days of reserve status and the flight crewmember must be given no less than 24 hours notice of the Protected Time Period.***

Intent: To ensure that all reserve pilots are scheduled for and receive a prospective, and predictable, 10-hour opportunity every reserve day to obtain 8 hours of sleep and to maintain circadian stability.

Example:
Pilot - PTP 2000-0600



Rationale: The human body requires an average of 8 hours of uninterrupted, restorative sleep in a 24 hour period when sleeping during normal sleeping hours. When attempting to sleep outside of normal sleeping hours, 8 hours of sleep is still required. However, scientific data indicates additional time is needed to obtain the required 8 hours of sleep. The 10 hour Protected Time Period (PTP) would, therefore, include an opportunity to prepare for and actually receive 8 hours of restorative sleep in all circumstances. Additionally, a 10-hour PTP was selected with the assumption that the minimum required rest for all pilots would be 10 hours (See NPRM 95-18). A 10-hour PTP would maintain consistency of rest for all pilots. Starting consecutive PTPs at the same time is imperative to maintaining circadian stability. The desired method of assigning PTP would be when the crewmember is assigned reserve. A minimum of 24 hours notification of a Protected Time Period will provide an opportunity to prepare for impending reserve days. [1]

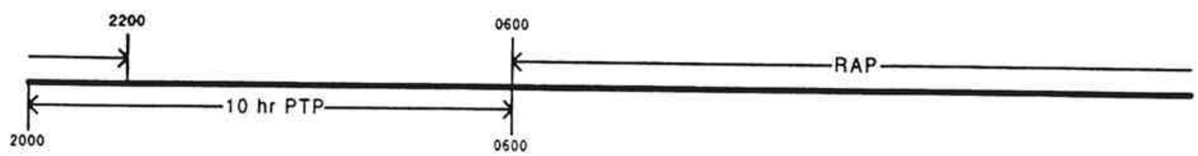
(b) A certificate holder may reschedule a Protected Time Period during any scheduled period of consecutive days of reserve by the following:

Intent: To provide the reserve pilot with a predictable, prospective rest period and also give the operator scheduling flexibility to accommodate unforeseen circumstances. Rescheduling a PTP +/- 3 hours is only applicable to that PTP. Remaining reserve days in a block would begin at the original start time. Shifting of a PTP does not extend a Reserve Availability Period (RAP).

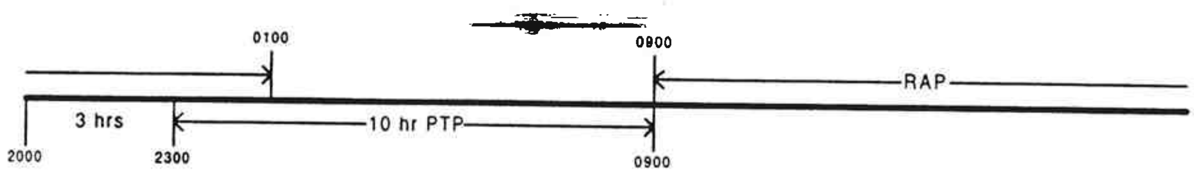
(1) Rescheduling the beginning of a Protected Time Period a maximum of three hours later without prior notification.

Example:
(In this example, under no circumstances may a PTP start time be later than 2300)

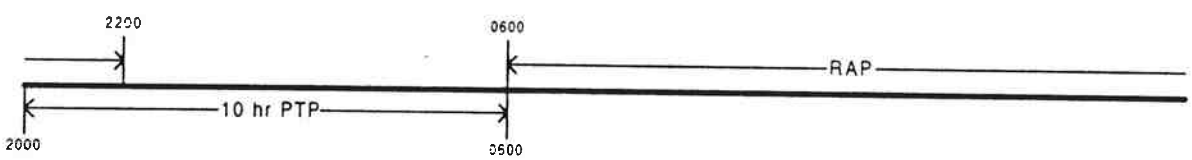
Day 1
PTP 2000 to 0600 (original PTP)



Day 2
PTP 2300 to 0900



Day 3
PTP 2000 to 0600

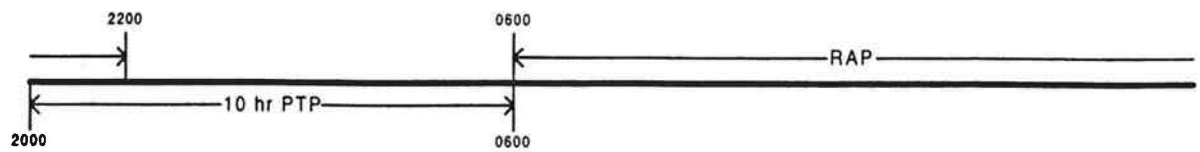


Rationale: Delaying a sleep opportunity, up to three hours, is not excessively disruptive to circadian stability. In this case, no prior notification is required.

(2) Rescheduling the beginning of a Protected Time Period a maximum of 3 hours earlier if the flight crewmember is provided 6 hours notice prior to the beginning of the originally scheduled Protected Time Period.

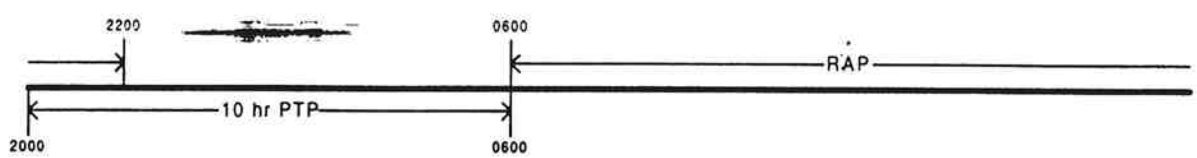
Example:
(In this example, under no circumstances may a PTP start time be earlier than 1700)

Day 1
PTP 2000 to 0600 (original PTP)



Day 2
PTP 1700 to 0300

Day 3
PTP 2000 to 0600



Rationale: Moving a sleep opportunity earlier, up to three hours, is disruptive to circadian stability. To accommodate and prepare for this rescheduled sleep opportunity additional notice is required.

(3) ***Rescheduling the Protected Time Period by more than 3 hours once during any 7 consecutive days by providing the flight crewmember 10 hours notice.***

Rationale: Changing a sleep opportunity more than +/- 3 hours is very disruptive to circadian stability. For extreme circumstances beyond the control of the operator (i.e., inclement weather, closed airports, etc.) an operator has the ability to reschedule a PTP more than 3 hours from the original start time. A minimum of 10 hours prior notification of the new PTP is required to allow the pilot a period of time to adjust for the rescheduled sleep opportunity. This provision is restricted to once in every 7 days because it is so detrimental to circadian stability. This restriction also would preclude the operator from arbitrarily utilizing this provision and yet allows the certificate holder the flexibility to operate under extreme circumstances.[2]

(c) ***A certificate holder may assign a flight crewmember and a flight crewmember may accept an assignment for flight time in scheduled air transportation or other commercial flying if such assignment is permitted by this subpart;***

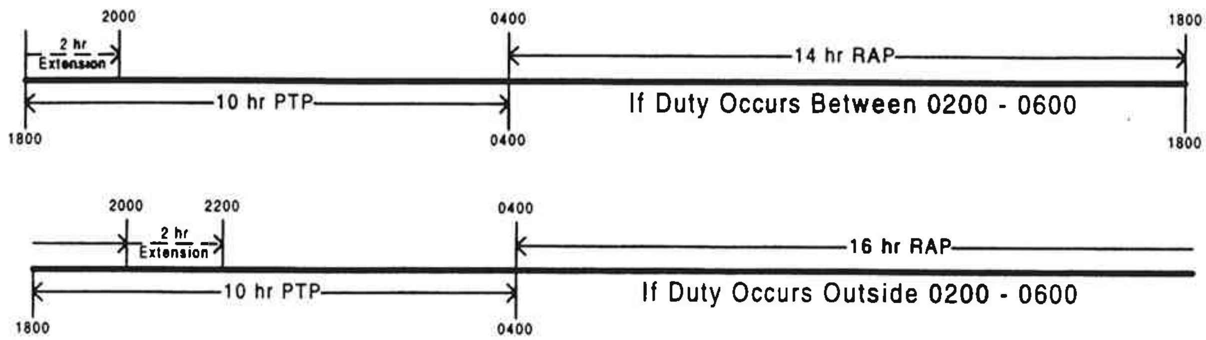
(1) ***If the assignment is scheduled to be completed within 16 hours after the end of the preceding Protected Time Period;***

Intent: To establish a "Reserve Availability Period" (RAP).[3]

Example:

(2) ***If the flight crewmember is given a flight assignment for any part of the period of 0200 to 0600 hours, any such flight assignment must be scheduled to be completed within 14 hours after the end of the preceding Protected Time Period. The operator with the concurrence of the administrator and the pilot group may designate any 4-hour period for all operations between 0000-0600 hours in place of 0200-0600 hours.***

Examples:



These limitations may be extended up to 2 hours for operational delays.

Rationale: Time-since-awake contributes to fatigue. This section acknowledges time-since-awake by limiting the RAP to 16 hours if the pilot is afforded the opportunity to sleep during a normal sleep period. The science further indicates fatigue occurs sooner when given a sleep opportunity at a time other than normal sleeping hours. This section addresses that fact by reducing the RAP to 14 hours should duty occur during this normal sleep period.[4]

(d) ***When there are no other reserve pilots who have sufficient reserve availability periods to complete an assignment, the certificate holder may schedule a flight crew member for an assignment for flight time in scheduled air transportation or other flying permitted by this subpart, provided that the crew member is given a minimum of 14 hours of advance notice and is released to protected time at the time of the notice.***

Intent: All pilots are originally scheduled in a PTP system. Circadian stability is ensured by all pilots having a definitive, prospective sleep opportunity. When all such pilots have been utilized, 14 hours notice may be used by the operator to assign a pilot to a flight. Once notified of a flight assignment a crewmember is released from further responsibility until he reports for duty. While this method of assigning reserve is less than desirable, it enables the certificate holder to continue operations as necessary.

Rationale: While advance notice can present a sleep opportunity, scientific research is very clear that circadian factors make it very difficult and sometimes impossible to take advantage of it. For example, consider a pilot who finishes his PTP at 0800 and is then contacted by the carrier for an assignment that reports at 2200. This would be an application of 14 hours advance notice. Circadian factors make it very difficult, if not impossible, for the pilot to sleep again until later, typically during the afternoon circadian low point (1500 – 1800) or earlier if possible. However, by receiving the notice early, he can schedule his morning activity accordingly to best prepare himself for the afternoon sleep opportunity (like a line-holder does). Typically, he would go to bed around 1500 – 1600 and set the alarm clock for 1900 – 2000 to provide enough time to shower, dress, eat, and report for duty. Even with 14 hours of advance notice, this pilot could only expect to sleep 4 – 5 hours prior to reporting for a back-side-of-the-clock assignment that could last until 1200 the following day. It should be apparent that less than 14 hours notice could result in less than 4- 5 hours of sleep and raise the probability of serious pilot fatigue during the assignment.

The above example was discussed during the Denver ARAC meeting. At one point, Dr. Don Hudson was asked for his expert opinion regarding what should be required for a minimum amount of advance notice. Dr. Hudson's response was 13 to 14 hours.[5]

(e) ***Each certificate holder shall prospectively relieve each flight crewmember assigned to reserve for at least 24 consecutive hours during any 7 consecutive days.***

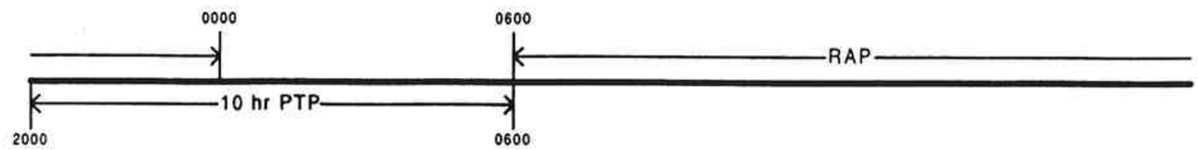
Intent: All reserve pilots must receive a prospective 24 hour period free from duty during any 7 consecutive days.

Rationale: Pilots assigned to reserve status must be continually prepared for any flight duty. These pilots should be relieved from this obligation for 24 hours during any 7 consecutive days. The pilot must be notified prior to the beginning of that off duty period.

(f) ***For augmented International operations, a certificate holder may assign a flight crewmember and a flight crewmember may accept an assignment for flight time in scheduled air transportation or other commercial flying as follows:***

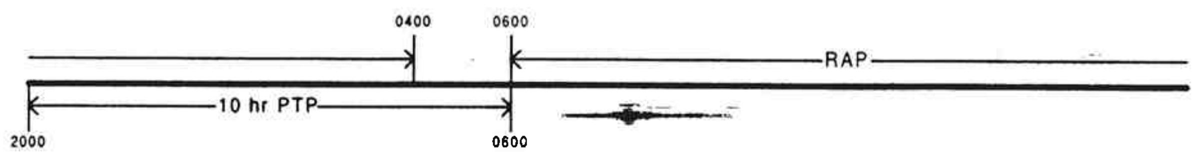
(1) ***For single augmentation, the assignment must be scheduled to be completed within 18 hours after the end of the preceding Protected Time Period; or***

Example:



(2) ***For double augmentation, the assignment must be scheduled to be completed within 22 hours after the end of the preceding Protected Time Period.***

Example:



These limitations may be extended up to 2 hours for operational delays.

Intent: To establish a Reserve Availability Period (RAP) for long-haul international reserve pilots.

Rationale: Long-haul international flights necessarily involve back-side-of-the-clock flying. Therefore, for a single pilot augmentation, we added 4 hours to the 14-hour back-side-of-the-clock duty period and 8 hours for double augmentation. This is in accord with the NASA TM. [6]

Scientific Support

---

[1] *121.xxx Reserve Rest*

(a) ***Except as provided in paragraphs (b) and (d), no certificate holder may schedule any flight crewmember and no flight crewmember may accept an assignment to reserve status unless a minimum prospective Protected Time Period (PTP) of 10 hours during a 24-consecutive hour period is scheduled. The Protected Time Period must begin at the same time during any scheduled period of consecutive days of reserve status and the flight crewmember must be given no less than 24 hours notice of the Protected Time Period.***

Scientific support:
(a) 10 hour Protected Time Period to provide an opportunity to obtain 8 hours of sleep.

> Each individual has a basic sleep requirement that provides for optimal levels of performance and physiological alertness during wakefulness. On average, this is 8 hours of sleep in a 24-hour period, with a range of sleep needs greater than and less than this amount. Losing as little as 2 hours of sleep will result in acute sleep loss, which will induce fatigue and degrade subsequent waking performance and alertness.

NASA TM, ¶1.1.1, p.2.

> **Off-duty period (acute sleep and awake-time-off requirements)** - Therefore, the off-duty period should be a minimum of 10 hours uninterrupted within any 24-hour period, to include an 8-hour sleep opportunity[.]

NASA TM, ¶2.1.2, p. 5

> Standard Sleep Requirements and Off-Duty Period - Research by Drs. Carskadon & Dement, 1982 and Wehr et al., 1993 support a minimum of 8 hours of sleep based upon a range of studies that use several approaches including:
>
> - Historical levels of sleep
> - Measures of daytime alertness
> - Sleep levels achieved when given the opportunity to sleep as long as desired

Battelle Report, p. 15.

> . . . There appears to be substantial evidence that a minimum of eight hours of sleep is required for most people to achieve effective levels of alertness and performance.

Battelle Report, p. 21.

> . . . It is important to realize that an individual working nights is at risk for significant sleepiness for two distinct reasons: . . . an individual working successive nights is forced to obtain sleep during the daylight hours at a time when the circadian pre-disposition to sleep is minimal. . . . As mentioned, sleep under these circumstances is typically fragmented. sleep state architecture is distorted, and the restorative nature of sleep . . . is reduced.

A Scientific Review of Proposed Regulations Regarding Flight Crewmember Duty period Limitations, The Flight Duty Regulation Scientific Study Group, ¶2.6, p. 5-6.

> Minimum rest periods should be adjusted upward for sleep periods that include the time of peak circadian alertness (4 – 6 PM.).
>
> <u>Reserve time arrangements should be adjusted so that protected windows during the time of peak circadian alertness are extended to compensate for decreased efficiency of sleep during that time.</u> (Emphasis added.)

Scientific Study Group, ¶¶ 5.1.2, 5.1.4, p. 11.

<u>Remarks of Dr. Dement:</u>

Q: . . . One of the most basic tasks is for us to agree on a recommendation for a sleep opportunity . . . to afford every reserve pilot the opportunity of a protected time period so that he or she is absolutely insulated from contact from the operator. How many hours do you recommend for a minimum fixed sleep opportunity?

A: I will start out by assuming that we would take 8 hours of sleep as the most common requirement. Then you need to add to that in order to be able to get the proper amount of sleep. In your situation, I would think it would be a little larger than it might be for someone who really wasn't doing anything. So, I'd add a couple of hours to get the proper amount of sleep.

Appendix D, p. 4.

Q: Dr. Dement, . . . we're really at the point now where we're going beyond the philosophy and we're trying to put our finger on numeric values. Our position at least from the pilots' standpoint, is that we see the need for a 10-hour sleep opportunity knowing that the opportunity may not always be at the best time of the day. We're facing an industry position that is looking for 8 hours as the minimum. Our position is predicated on the fact that 8 hours may be adequate if it overlaps the WOCL. But since we don't know for sure when we're going to have that opportunity, we believe that, or we think that having that extra 2 hours is going to give us a little more of a buffer, especially when it comes during the daytime. Would you consider that to be a conservative and a justified position?

A: Absolutely. I don't think you could possibly assume someone is going to fall asleep instantly and then sleep continuously for 8 hours. not even under the most ideal circumstances. Maybe it should be longer.

Appendix D, pp. 5-6.

Scientific support:
(a) Scheduling the Protected Time Period for the same time each day

> **Time-of-day / Circadian Physiology Affects Sleep and Waking Performance -** . . . Time-of-day or circadian effects are important considerations in addressing 24 hour operational requirements because circadian rhythms do not adjust rapidly to change.
>
> . . . Thus, circadian disruption can lead to acute sleep deficits, cumulative sleep loss, decreases in performance and alertness, and various health problems . . . Therefore, circadian stability is another consideration in duty and rest scheduling.

NASA recommends a sleep opportunity that is predictable (24 hours notice recommended), <u>does not vary more than 3 hours on subsequent days to ensure circadian stability</u>, and is protected from interruption. (Emphasis added.)
NASA TM, ¶1.3, p. 3-4; ¶2.6.2, p. 8.

> **Conclusion –** Reserve assignments should attempt to maintain a consistent 24 hour cycle.

Battelle Report, p. 28.

<u>Remarks of Dr. Dement</u>

Q: Dr. Dement, there's one area that we really haven't touched upon at this point and I don't want to miss. These are questions regarding the maintenance of circadian stability. In your opinion, why is maintaining circadian stability so important?

A: Well because usually... and by that you mean your sleep opportunities and your wake opportunities are in that period of stability, then you have the best sleep and the best wake. If you get out of that cycle, then both sleep and wake will be impaired.

Q: What happens to the body as you change a person's cycle?

A: All sorts of things happen, but the major thing of course is that you are now trying to sleep when the body wants to be awake and you're trying to be awake when the body wants to be asleep because you left the circadian stability that you talked about.

Appendix D, pp. 16-17.

(3) ***Rescheduling the Protected Time Period by more than 3 hours once during any 7 consecutive days by providing the flight crewmember 10 hours notice.***

Scientific support:

(b) Limiting the movement of the Protected Time Period to Plus or Minus 3 hours

> . . . the 8-hour sleep opportunity should not vary by more than 3 hours on subsequent days to ensure circadian stability. . . .

NASA TM, ¶2.6.2, p. 8.

Remarks of Dr. Dement

Q: . . . we're trying to insure that the protected time period, the rest period, stayed the same from day to day, assuming the reserve crewmember is not called. Or for that matter when he is called, he goes back into his cycle. We're attempting to try to snap him back to as close to that original cycle and maintain that same rhythm from day to day. NASA has findings on that. Their recommendation was to maintain that circadian stability plus or minus 3 hours. Do you agree or disagree?

A: I absolutely agree that's better than no stability. Obviously the smaller that number, the better. I think practically it couldn't be zero, but I think we tend to feel there's kind of a daily flexibility within that range, like 0 to 3 hours, 0 to 2 hours. To go outside of that is, again, inviting a condition of sleep deprivation. So deliberately creating a bad situation.

Appendix D, pp. 16-17.

3 (c) ***A certificate holder may assign a flight crewmember and a flight crewmember may accept an assignment for flight time in scheduled air transportation or other commercial flying if such assignment is permitted by this subpart;***

(1) ***If the assignment is scheduled to be completed within 16 hours after the end of the preceding Protected Time Period;***

Scientific support:

(c) 16 hour Reserve Availability Period Limitation

> **Continuous Hours of Wakefulness/Duty Can Affect Alertness and Performance** - Extended wakefulness and prolonged periods of continuous performance or vigilance will engender sleepiness and fatigue.
>
> **Extended flight duty period –** An extended flight duty period should be limited to 12 hours within a 24-hour period to be accompanied by additional restrictions and compensatory off-duty periods. This limit is based on scientific findings from a variety of sources, including data from aviation, that demonstrate a significant increased vulnerability to performance-impairing fatigue after 12 hours. It is readily acknowledged that in current practice, flight duty periods extend to 14 hours in regular operations. However, the available scientific data support a guideline different from current operational practice. The data indicate that performance-impairing fatigue does increase beyond the 12-hour limit and could reduce the safety margin.

NASA TM, ¶¶ 1.4, 2.3.4, pp. 4, 6.

NASA does not provide a specific recommendation for the duration of a Reserve Availability Period. However, it follows that NASA's recommended maximum duty limit of 12 hours plus 2 hours for operational delays (total - 14 hours) obviously requires a pilot to be awake at least that much time. By adding report time to NASA's recommended maximum duty limit, it is apparent that NASA's duty limit is commensurate with our proposed 16-hour reserve availability period limit for un-augmented flying.

> The results of an NTSB analysis of domestic air carrier accidents occurring from 1978 to 1990 suggest that time since awake (TSA) was the dominant fatigue-related factor in these accidents (NTSB, 1994). Performance decrements of high time-since-awake crews tended to result from ineffective decision-making rather than deterioration of aircraft handling skills. . . . There did appear to be two peaks in accidents: in the morning when time since awake is low and the crew has been on duty for about three to four hours, and when time-since-awake was high, above 13 hours. Similar accident peaks in other modes of transportation and industry have also been reported (Folkard, 1997). Akerstedt & Kecklund (1989) studied prior time awake (four to 12 hours) and found a strong correlation of accidents

> with time since awake for all times of the day. Belenky et al. (1994) found that flight time hours (workload) greatly increase and add to the linear decline in performance associated with time since awake.

Battelle Report, p. 13.

> Some symptoms of fatigue are similar to other physiological conditions. For example, with fatigue one's ability to attend to auxiliary tasks becomes more narrow, very much analogous to the effects of alcohol (Huntley et al., 1973; Moskowitz, 1973), hypoxia (McFarland 1953), and heat stress (Bursill, 1958).

Battelle Report, p. 5.

Australian researchers Drew Dawson and Kathryn Reid (1997) evaluated performance after 17 hours of wakefulness and found performance degraded to a level equal to that caused by a blood alcohol concentration (BAC) of 0.05 percent. At 24 hours, performance decrements were equivalent to that of a 0.10 BAC. After ten hours of sleeplessness, the decline in performance averaged .74 percent per hour. Their study titled *Fatigue, Alcohol and Performance Impairment* appeared in Nature, Vol. 338, July-August 1997. (See Appendix E). These findings were replicated and extended by Nichole Lamond and Drew Dawson in 1998. (See Appendix F).

> If an individual has been awake for 16 to 18 hours, decrements in alertness and performance are intensified. If time awake is extended to 20 to 24 hours, alertness can drop more than 40 percent (WRAIR, 1997; Morgan et al.. 1974; Wehr, 1996).
> . . .

Battelle Report, p. 25.

The NTSB cited pilot fatigue as the probable cause of the crash of a DC-8 at Guantanamo Bay in 1993. The individual crewmembers were continuously awake for 19, 21, and 23.5 hours prior to the accident.
Mark R. Rosekind, et al., ***Crew fatigue factors in the Guantanamo Bay aviation accident.***
(See Appendix G).

Remarks of Dr. Dement

Q: Dr. Dement, after our reserve pilots receive their sleep opportunity, they become available for duty. We call the availability period the "reserve availability period" and that's basically the time they are available for work, for flying. After the sleep opportunity, what would you consider to be a safe limit of time since awake for a crewmember?

For the 10-hour (sleep opportunity) period?

Yes.

A: Fourteen hours. And I wouldn't say that's 100% safe but if you have a number, that adds up to the 24-hour day. It ought to be reasonably safe.

Q: Where do you get your number from?

A: Well, it comes mainly in my head from circadian type 24-hour studies to see the pattern of the manifestation of the drive to sleep versus the awakening effect of the biological clock. If you're getting outside the 24-hour cycle, then you're going to have periods of greater risk. . . .

Q: That assumes that the individual wakes up as soon as his protected time period is over. So in other words, you see a complimentary factor: 9 hours of rest should dictate a 15-hour availability period?

A: Yes. I think most people would agree that would be the ideal.

Q: Going beyond that, what is probably the most greatest points of contention right now – the debate between the pilots and the industry operators – is the fact that the operators would like to extend this reserve availability period in excess of what you say is 14 or 15 or 16 hours, whatever the case may be, to a larger increment, extending that reserve availability period based upon an advance notice of a nap opportunity. In other words, a pilot comes on call at 8:00 a.m. He is then told at 9:00 a.m. that he is to report for duty 5 hours later. The industry's position is that the notice constitutes an opportunity for additional rest which then would be utilized to add more restorative energy or analogous to putting more charge into a battery, and then carry that pilot into more of an extended duty period with an additional amount of time.... up to in certain cases 24 hours of duty. What is your feeling on that type of scenario?

A: To me, that's a recipe for disaster because if you have a responsible, professional pilot -- who has a reasonable schedule, - who is not horribly sleep deprived, and who has a fairly stable circadian rhythm, then the likelihood that he can get adequate sleep by trying to nap I think is relatively small. I would not depend on it at all. I would think also to have to do it sort of unexpectedly like this....Oh! Take a nap....Only people who are very sleep deprived....

Q: Let's say I have a 10-hour sleep opportunity: 10 p.m. to 8 a.m. That means I'm available for 14 hours unless they fly me into the next 10 p.m. slot tonight. Could I not get a call say at noon and say instead of you being off tonight at 10 p.m., we want you to work until seven tomorrow morning but you aren't going to go to work until 10:00 that night. So they call me at noon, they give a 10-hour notice that I'm not going to have to go to work until 10 hours from noon, so at 2200 I report for work, and they want me to fly until 0800. So that would be a total of 24 hours from the time I theoretically woke up and I've had a 10-hour notice that I was going to be flying this fatiguing schedule. Would that be safe?

A: Well, I wouldn't be on your plane. No. I think that's almost insanity in the sense of saying that is safe. First of all, naps can't be depended on – even under ideal circumstances – to get you through this period when the biological clock alerting is gone, when you're alone with your sleep debt so to speak, during the WOCL. There's no way that isn't going to be dangerous. . . .

Appendix D, pp. 8-9.

(2) ***If the flight crewmember is given a flight assignment for any part of the period of 0200 to 0600 hours, any such flight assignment must be scheduled to be completed within 14 hours after the end of the preceding Protected Time Period. The operator with the concurrence of the administrator and the pilot group may designate any 4-hour period for all operations between 0000-0600 hours in place of 0200-0600 hours.***

Scientific support:
(c) Reducing the Reserve Availability Period by two hours during Back-Side-Of-The-Clock Operations (0200 – 0600)

> **Off-duty period (following standard flight duty periods during window of circadian low)** - Extensive scientific research, including aviation data, demonstrate that maintaining wakefulness during the window of circadian low is associated with higher levels of performance-impairing fatigue than during daytime wakefulness. . . .
>
> **Definition: "window of circadian low"** - The window of circadian low is best estimated by the hours between 0200 and 0600 for individuals adapted to a usual day-wake/night-sleep schedule. This estimate of the widow is calculated from scientific data on the circadian low of performance, alertness, subjective report (i.e. peak fatigue), and body temperature. . . .

NASA TM, ¶¶ 2.1.4, 2.3.2, pp. 5-6.

> The ingredient of day versus night long-haul flights raises a second concern, the time-of-day departure. Because sleepiness and fatigue are strongly related to circadian rhythmicity, they should not be controlled by regulations, which ignore time-of-day in favor of elapsed time. . . . For the sake of efficiency and safety, it is incumbent upon regulatory authorities to include time-of-day as a factor in designing flight crew duty and rest limitations.

R. Curtis Graeber, et al., *Aircrew Sleep and Fatigue in Long-Haul Flight Operations*, Tokyo, Japan (October 26-29, 1987), p. 13.

Back of the Clock Operations, Circadian Rhythm and Performance

There is a substantial body of research that shows decreased performance during night shifts as compared with day shifts. The reasons for this decreased performance include:

- Circadian pressure to sleep when the individual is attempting to work.
- Circadian pressure to be awake when the individual is attempting to sleep.
- Time since awake may be substantial if the individual is up all day before reporting for the night shift.
- Cumulative sleep debt increase throughout the shift.

Research conducted by Monk et al. (1989) indicates that subjective alertness is under the control of the endogenous circadian pacemaker and one's sleep-wake cycle (time since awake). When time since awake is long and coincides with the circadian low there is a very sharp drop in alertness, a strong tendency to sleep and a significant drop in performance (Perelli, 1980). Alertness is relatively high when the circadian rhythm is near the acrophase and time since awake is small. Monk (1996) argues that this cycle is consistent with the NTSB (1994) finding of a peak accident rate occurring in the evening. . . .

Battelle Report, p. 23.

Microsleeps have been shown to be a useful approach to assessing the effects of time of day on sleepiness levels. EEG brain wave changes confirm that pilots experience greater sleepiness and decreased alertness between 2:00 to 4:00 a.m. (Gundel, 1995). . . .

Battelle Report, p. 9.

. . . In determining maximum limits for extended duty periods, consideration also needs to be given to other fatigue-related factors that could contribute to excessive fatigue levels during extended duty periods, including number of legs, whether the flight impinges on the window of circadian low (WOCL), and time since awake. (Emphasis added.)

Battelle Report, p. 14.

Night operations are physiologically different than day operations due to circadian trough and sleep loss. This carries a higher physiological cost and imposes greater risks of accidents. One of the most established safety issues is working in the circadian trough between 0200 and 0600. During this period workers experience considerable sleepiness, slower response times, increased errors and accidents (Mitler, 1991; Pack, 1994). Many recent accidents from various transportation modes have been associated with this circadian trough (Lauber & Kayten, 1988). Lyman and Orlady (1981), in their analysis of the Aviation Safety Reporting System researcher state that 31 percent of incidents occurring between 2400 to 0600 hours were fatigue related.

In Japan, 82.4 percent of drowsiness-related near accidents in electric motor locomotive drivers (Kogi & Ohta, 1975) occur at night. Other landmark studies over the past several decades have documented the increase in accidents and error making. Klein et al. (1970) argue that their research with simulators proves that night flights are a greater risk than day flights. Their research found 75- to 100-percent mean performance efficiency decrements in simulator flights during the early morning hours, regardless of external factor such as darkness or increasing night traffic or possible weather conditions.

. . . A study of naval watch keepers found that between 0400 to 0600, response rates drop 33 percent, false reports rates 31 percent, and response speed eight percent, compared with rates between 2000 to 2200 hours (Smiley, 1996).

Samel et al. (1996) determined that many pilots begin night flights already having been awake more than 15 hours. The study confirms the occurrence of as many as five micro-sleeps per hour per pilot after five hours into a night flight. . . . The authors concluded that "During day time, fatigue-dependent vigilance decreases with task duration. and fatigue becomes critical after 12 hours of constant work. During night hours fatigue increases faster with ongoing duty. This led to the conclusion that 10 hours of work should be the maximum for night flying."

[Note Samel's conclusion - Reduce the duty period from 12 to 10 hours.]

> Gander et al. (1991) found in an air carrier setting that at least 11 percent of pilots studied fell asleep for an average of 46 minutes. Similarly, Luna et al. (1997) found that U.S. Air Force air traffic controller [sic] fell asleep an average of 55 minutes on night shift. A possible explanation for these sleep occurrences, in addition to circadian nadir, is the finding of Samel et al. that many pilots begin their night flights after being awake for as long as 15 hours.

Battelle Report, pp. 24-25.

> Duty periods conducted during the WOCL already carry a fatigue penalty due to the circadian cycle. Consequently, duty periods involving WOCL should be reduced. (Emphasis added.)

Battelle Report, p. 28.

> . . . flight duty regulations that adequately account for circadian modulation in the capacity of sleep and in human performance have been used in the United Kingdom for 6 years . . . and by account appear to be working well. The Study Group is aware of no qualitative reason why adjustments such as those incorporated in the UK regulations could not be used in the US as well.

Scientific Study Group, ¶4.2, p. 10.

> **Flight duty periods during window of circadian low.**
> . . . Therefore, it is recommended that in a 7-day period, there be no extended flight duty period that encroaches on any portion of the window of circadian low.

[Note: a standard flight duty period should not exceed 10 hours within a 24-hour period.]
NASA TM, ¶¶ 2.3.5.B.; 2.3.3.

(d) When there are no other reserve pilots who have sufficient reserve availability periods to complete an assignment, the certificate holder may schedule a flight crew member for an assignment for flight time in scheduled air transportation or other flying permitted by this subpart, provided that the crew member is given a minimum of 14 hours of advance notice and is released to protected time at the time of the notice.

<u>Scientific support:</u>
(d) Minimum of 14 Hours Advance notice

> Considerable research into other arenas has taught us that individuals are better able to cope with unusual or extended duty schedules when they can plan for them in advance. This forewarning allows them to develop time-linked performance goals and to schedule their rest and activity optimally before reporting for duty.

R. Curtis Graeber, et al., *Aircrew Sleep and Fatigue in Long-Haul Flight Operations*, Tokyo, Japan (October 26-29, 1987), p. 12.

> ... In other words, simply being off duty was not a sufficient condition for crew members to be able to fall asleep. . . .

Philippa N. Gander, et al., *Crew Factors in Flight Operations: VIII. Factors Influencing Sleep Timing and Subjective Sleep Quality in Commercial Long-Haul Flight Crews* (December 1991), p. 29.

> . . . In the limited time remaining, he attempts to sleep irrespective of his physiological readiness to sleep (circadian phase) and the local time, both of which may compromise the quality and quantity of sleep he is able to obtain.

Philippa N. Gander, et al., *Crew Factors in Flight Operations: VIII. Factors Influencing Sleep Timing and Subjective Sleep Quality in Commercial Long-Haul Flight Crews* (December 1991), p. 31.

This reinforces the importance of ensuring that adequate time is available for sleep.

> **Conclusions – . . .** Flight and duty time regulations can be interpreted as a means of ensuring that reasonable minimum rest periods are respected. However, the perspective highlighted by this study is that the time available for sleep is less than the scheduled time off duty. . . .

Philippa N. Gander, et al., *Crew Factors in Flight Operations: VIII. Factors Influencing Sleep Timing and Subjective Sleep Quality in Commercial Long-Haul Flight Crews* (December 1991), p. 33.

Remarks of Dr. Dement

Q: How about that the flight is going to happen. There is going to be every day in America, pilots that report to work at 2300 or whatever and fly until 0800 the next morning. Now, what's different about the man who knows a week, a month in advance that this is going to be his schedule and the reserve pilot who finds out at noon after having woken up at 8 a.m.? What would be the difference?

A: You know that the time you do all of the things you can to move toward a better situation . . . You can never get to perfection, but the more practice, the more warning, the better you'll be able to handle it. Some people learn that there is a time when it's quiet and if I do this, I can pretty much depend that I will fall asleep. It's not 100% but you kind of learn that or you practice or whatever. But if it's without warning, all bets are off.

Q: Dr. Dement, you've kind of led the discussion into another area of this rulemaking that has to do with an alternative method. Assuming that the pilots in this protected time period method were depleted, the carriers then want to give pilots advance notice to cover any mission or any assignment. They are looking at 10 hours as the criteria. We don't believe that to be adequate based upon . . .

Are you talking 10-hour warning?

Ten-hour warning, yes. To do anything.

A: That would be 100% wrong.

Q: Why?

A: Well, because the 10 hours could fall sort of toward the beginning of what we call "clock dependent learning." There's no way you could sleep. And then you go into your duty period at the worse possible time you could have in that situation.

Q: What sort of time would you think would be adequate to give a guy enough time to get an opportunity to rest so that he would be safer than 10 hours?

A: Twenty-four hours. At least a day before. Wouldn't you think? I don't see how you can get notified as the day is beginning and feel you could depend on being able to take a nap. If it happened every day or somehow you know that you could certainly get the probability up, but it's not something that you could ever really control. Again, there ought to be a better way.

Appendix D, pp. 10-11.

Q: We're shooting around the subject. I hate to break any of this up, but this question has been plaguing this committee. The industry keeps harping on the fact that there should be no difference between the schedule holder who knows he's got to fly from midnight to 8:00 a.m. If he can do it safely, why can't a reserve that wakes up at the same time in the morning (8:00 a.m. or 6:00 a.m.). Why is it not safe for this reserve pilot who does it with notice?

A: I don't think it's safe for either pilot. Maybe a little less dangerous in the sense of performance, etc. But I think at least he has preparation, warning, etc. and knows his own strengths and weaknesses whereas the other pilot I think is always without warning and has really no chance to prepare. I don't think the two groups are the same.

Q: Are you implying that the preparation should actually start the previous night?

A: Yes. If I was going to drive all night, I wouldn't want someone to tell me that day.

Q: They're really killing us for making that same argument. I mean we make that argument across the table and we get smiles and nods of the head and shrugs of the shoulders from the other side. They say it's not a valid argument. That's always what they come up with.

A: They say it's not a valid argument? It is a supremely valid argument. I mean that's just like saying down is up.

Appendix D, p. 13.

6 (*f*) ***For augmented International operations, a certificate holder may assign a flight crewmember and a flight crewmember may accept an assignment for flight time in scheduled air transportation or other commercial flying as follows:***

> ***(1) For single augmentation, the assignment must be scheduled to be completed within 18 hours after the end of the preceding Protected Time Period; or***
>
> ***(2) For double augmentation, the assignment must be scheduled to be completed within 22 hours after the end of the preceding Protected Time Period.***

These limitations may be extended up to 2 hours for operational delays.

Scientific support:
(f) (1) and (2) augmented crews

> **Extended flight duty period: additional flight crew** - Additional flight crew afford the opportunity for each flight crew member to reduce the time at the controls and provide for sleep during a flight duty period. Consequently, with additional flight crew and an opportunity for sleep, it would be expected that fatigue would accumulate more slowly. In such circumstances, flight duty periods can be increased beyond the recommended limit of 12 hours within each 24-hour period. For each additional flight crew member who rotates into the flight deck positions, the flight duty period can be extended by 4 hours as long as the following requirements are met: 1) each flight crew member be provided one or more on-duty sleep opportunities; and 2) when the extended flight duty period is 14 hours or longer, adequate sleep facilities (supine position) are provided that are separated and screened from the flight deck and passengers. Controlled rest on the flight deck is not a substitute for the sleep opportunities or facilities required for additional flight crew members.

NASA TM, ¶ 2.3.6, p. 7.

APPENDIX A

NASA Technical Memorandum 110404

Principles and Guidelines for Duty and Rest Scheduling in Commercial Aviation

David F. Dinges, University of Pennsylvania Medical School, Philadelphia, Pennsylvania
R. Curtis Graeber, Boeing Commercial Airplane Group, Seattle, Washington
Mark R. Rosekind, Ames Research Center, Moffett Field, California
Alexander Samel, and Hans M. Wegmann, DLR-Institute of Aerospace Medicine, Cologne, Germany

May 1996

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

Table of Contents

PREFACE

This document is intended to provide scientific input to the issue of duty and rest scheduling of flight crews in commercial aviation. It is available to any interested party that is addressing these complex issues.

The global aviation industry requires 24-hour activities to meet operational demands. To address this challenge, a scientific working group with expertise relevant to these demands met to develop principles and guidelines for duty and rest scheduling in commercial aviation.

Scientific Working Group Methodology. First, the group identified areas of scientific knowledge relevant to flight safety. This included identifying areas where relevant data were available and also areas where no scientific data currently exist. Based on current scientific knowledge, general principles directly related to aviation operational considerations were established. With the general principles as a basis, specific principles, guidelines, and recommendations for duty and rest scheduling in commercial aviation were developed. There was no intention to create regulatory policy. This was beyond the scope of the scientific working group. Although the group is aware of current operational practices, it adhered to the preset guideline of requiring scientific data relevant to specific recommendations. The group noted that there may not be a single solution to the challenges posed by the 24-hour demands of the aviation industry. Therefore, other industry strategies are suggested to complement the duty and rest scheduling guidelines. Throughout this process, input was obtained from individuals with extensive operational experience and familiarity with these issues.

Scientific Basis for Principles and Guidelines. The scientific working group was composed of scientists actively involved in examining these issues in aviation settings. The group intends to produce two documents based on their work. This first document is intended to be concise, to be focused on operational considerations, and to provide scientific input to this complex issue. The second document will follow and will provide the specific scientific references that support the principles and guidelines outlined here. This second document will be longer and will focus on the scientific considerations related to these issues. It is planned that an initial draft of this second document will be available within approximately 12 months.

Implementation. It is acknowledged that implementation of these principles and guidelines may require additional considerations. These considerations include economic, legal, cost/benefit, and other factors. It was beyond the scope of the scientific working group to address these issues, and they are left to appropriate operational and regulatory expertise for deliberation.

The scientific working group met as individuals and not as representatives of any organization or of a particular position on any issue. Therefore, the views and opinions expressed in this document are those of the scientific working group and do not necessarily reflect those of any organization.

In alphabetical order, the scientific working group included: David F. Dinges, Ph.D., R. Curtis Graeber, Ph.D., Mark R. Rosekind, Ph.D., Alexander Samel, Ph.D., and Hans M. Wegmann, M.D. To refer questions about this document to the scientific working group, please use either of the following points of contact:

Mark R. Rosekind, Ph.D.
NASA Ames Research Center
Mail Stop 262-4
Moffett Field, CA 94035-1000
(415) 604-3921 (Office)
(415) 604-3729 (Fax)

Hans M. Wegmann, M.D.
DLR–Institute of Aerospace Medicine
Linder Hoehe
D-51147 Koeln
Germany
49 2203 601 1 ext. 3667 (Office)
49 2203 696 372 (Fax)

Principles and Guidelines for Duty and Rest Scheduling in Commercial Aviation

David F. Dinges, R. Curtis Graeber, Mark R. Rosekind,
Alexander Samel, and Hans M. Wegmann
(in alphabetical order)

INTRODUCTION

Twenty-four Hour Requirements of the Aviation Industry

The aviation industry requires 24-hour activities to meet operational demands. Growth in global long-haul, regional, overnight cargo, and short-haul domestic operations will continue to increase these round-the-clock requirements. Flight crews must be available to support 24-hour-a-day operations to meet these industry demands. Both domestic and international aviation can also require crossing multiple time zones. Therefore, shift work, night work, irregular work schedules, unpredictable work schedules, and time zone changes will continue to be commonplace components of the aviation industry. These factors pose known challenges to human physiology, and because they result in performance-impairing fatigue, they pose a risk to safety. It is critical to acknowledge and, whenever possible, incorporate scientific information on fatigue, human sleep, and circadian physiology into 24-hour aviation operations. Utilization of such scientific information can help promote crew performance and alertness during flight operations and thereby maintain and improve the safety margin.

Challenges to Human Physiology

Throughout aviation history, operational capabilities and technology have evolved dramatically, while human physiological capabilities have not. Flight operations can engender fatigue, sleep loss, and circadian disruption and these physiological factors can result in decreased performance and reduced alertness during operations. Over the past 40 years, scientific knowledge about sleep, circadian physiology, sleepiness/alertness, and the performance decrements associated with these factors has increased significantly. Scientific research has extended its examination of these factors to operational environments, including field and simulator studies. These studies have confirmed the presence in aviators of performance-impairing fatigue resulting from the sleep loss, circadian disruption, and workload engendered by current flight and duty practices.

Humans are central to aviation operations and continue to perform critical functions to meet the 24-hour requirements of the industry. Therefore, human physiological capabilities, and limitations, remain crucial factors in maintaining safety and productivity in aviation.

Principles Based on Scientific Knowledge

Though research on fatigue, sleep and circadian physiology, and shift work schedules has generated an extensive body of scientific knowledge, the application of this information to the requirements of operational settings is relatively new. While acknowledgment of this scientific information is increasing, its transfer to operations (e.g., scheduling, regulatory considerations, personal strategies, countermeasures) offers the greatest potential for its benefit. Current federal regulations and industry scheduling practices rarely acknowledge or incorporate such knowledge. The primary purpose of this document is to outline scientifically-based principles that can be applied to the duty and rest scheduling requirements of the aviation industry.

Shared Responsibility

There is no one absolute or perfect solution to the demands of duty and rest scheduling in aviation. It is critical that safety be acknowledged as a shared responsibility among all the industry participants. Each component of the aviation system should be examined for avenues to incorporate scientific information and to apply guidelines and strategies that will maximize performance and alertness during flight operations. Regulatory considerations, scheduling practices, personal strategies, and technology design are specific components of the industry that could be subject to such an examination.

Each of these components is complex and presents unique challenges. This document is focused on scientifically-based principles and guidelines for duty and rest scheduling. However, it is acknowledged that regulatory action involves many considerations, such as legal, economic, and current practice. It is the intent of this document that relevant scientific information be considered in the regulatory domain.

"Safe" can be Difficult to Quantify

Determining a "safe" operation is a complex task. Aircraft accidents are such rare occurrences that they may not provide the best outcome variable to estimate safe operations. The aviation industry and flying public demand a high margin of safety and redundancy. Among modes of transportation, the aviation industry's reputation for safety is well-deserved. As many segments of the industry increase their activities, as technology enables longer flights, and as overall growth continues, the challenge will be to maintain, and where possible, improve the safety margin. The fatigue factors addressed in these principles can create a vulnerability for decrements in performance and alertness that can reduce the safety margin. Guidelines designed to specifically address these factors can help to minimize this vulnerability.

Objectives

The primary objective of this document is to provide empirically derived principles and guidelines for duty and rest scheduling in commercial aviation. In the first section, scientifically-based principles related to operational issues posed by the aviation industry are outlined. In the second section, the principles are applied to guidelines for duty and rest scheduling in commercial aviation, with specifics provided where appropriate and available. In the third section, a brief overview of other potential industry strategies to address these issues is provided.

1.0 GENERAL PRINCIPLES

1.1 Sleep, Awake Time Off, and Recovery are Primary Considerations

1.1.1 Sleep– Sleep is a vital physiological need. Sleep is necessary to maintain alertness and performance, positive mood, and overall health and well-being. Each individual has a basic sleep requirement that provides for optimal levels of performance and physiological alertness during wakefulness. On average, this is 8 hours of sleep in a 24-hour period, with a range of sleep needs greater than and less than this amount. Losing as little as 2 hours of sleep will result in acute sleep loss, which will induce fatigue and degrade subsequent waking performance and alertness. Over days, sleep loss—any amount less than is required—will accrue into a cumulative sleep debt. The physiological need for sleep created by a deficit can only be reversed by sleep. An individual who has obtained required sleep will be better prepared to perform after long hours awake or altered work schedules than one who is operating with a sleep deficit.

1.1.2 Awake time off– Fatigue-related performance decrements are traditionally defined by declines in performance as a function of time spent on a given task. Breaks from continuous performance of a required task, such as monitoring, are important to maintain consistent and appropriate levels of performance. Therefore, awake time off is introduced here to describe time spent awake and free of duty. Thus both awake time off and sleep are needed to ensure optimum levels of performance.

1.1.3 Recovery– Recovery from an acute sleep deficit, cumulative sleep debt, prolonged performance requirement, or extended hours of continuous wakefulness is another important consideration. Operational requirements can engender each of these factors and it is important that a recovery period provide an opportunity to acquire recovery sleep and to re-establish normal levels of performance and alertness.

Required sleep and appropriate awake time off promote performance and alertness. These are especially critical when challenged with extended periods of wakefulness (i.e., duty) and circadian disruption (i.e., altered work/rest schedule). Recovery is important to reduce cumulative effects and to return an individual to usual levels of performance and alertness.

1.2 Frequent Recovery Periods are Important

More frequent recovery periods reduce cumulative fatigue more effectively than less frequent ones. For example, weekly recovery periods afford a higher likelihood of relieving acute fatigue than monthly recovery periods. Consequently, guidelines that ensure minimum days off per week are critical for minimizing cumulative fatigue effects over longer periods of time (e.g., month, year).

1.3 Time-of-day/Circadian Physiology Affects Sleep and Waking Performance

There is a clock in the human brain, as in other organisms, that regulates 24-hour patterns of body functions. This clock controls not only sleep and wakefulness alternating in parallel with the environmental light/dark cycle, but also the oscillatory nature of most physiological, psychological, and behavioral functions. The wide range of body functions controlled by the 24-hour clock includes body temperature, hormone secretion, digestion, physical and mental performance, mood, and many others. On a 24-hour basis, these functions fluctuate in a regular pattern with a high level at one time of day and a low level at another time. The circadian (*circa* = around, *dies* = day) pattern of wakefulness and sleep is programmed for wakefulness during the day and sleep at night. The circadian clock repeats this pattern on a daily basis. Certain hours of the 24-hour cycle, that is 0200 to 0600, are identified as a time when the body is programmed to sleep and during which performance is degraded. Time-of-day or circadian effects are important considerations in addressing 24-hour operational requirements because circadian rhythms do not adjust rapidly to change.

For example, an individual operating during the night is maintaining wakefulness in direct opposition to physiological programming to be asleep. Physiological, psychological, and behavioral functions are set by the circadian system to a low status that cannot be compensated by being awake and active. Conversely, the same individual sleeping during the day is in direct opposition to physiological programming to be awake. The circadian system provides a high level of functioning during day that counteracts the ability to sleep. Thus, circadian disruption can lead to acute sleep deficits, cumulative sleep loss, decreases in performance and alertness, and various health problems (e.g., gastrointestinal complaints). Therefore, circadian stability is another consideration in duty and rest scheduling.

1.4 Continuous Hours of Wakefulness/Duty Can Affect Alertness and Performance

Extended wakefulness and prolonged periods of continuous performance or vigilance on a task will engender sleepiness and fatigue. Across duty periods, these effects can accumulate further. One approach to minimize the accumulation of these effects is to limit the duty time (i.e., continuous hours of wakefulness during operations). Acute effects can be addressed through daily limitations while cumulative effects can be addressed by weekly limitations. There is more scientific data available to support guidelines for acute limitations than to determine specific cumulative limitations. Nevertheless, cumulative limitations (weekly and beyond) remain an important consideration for minimizing accumulation of fatigue effects.

1.5 Human Physiological Capabilities Extend to Flight Crews

Fatigue has its basis in physiological limits and performance deficits reflect these physiological limits. Flight crews' human physiology is not different from that of other humans. Therefore, it must be expected that the same fatigue-producing factors affecting performance and alertness in experimental subjects, physicians on-call, shift workers, military personnel, and others also affect flight crews. It follows that scientific findings relevant to human physiological capabilities and performance deficits from fatigue, sleep loss, and circadian physiology extend to flight crews.

1.6 Flight Crews are Made Up of Individuals

There are considerable individual differences in the magnitude of fatigue effects on performance, physiological alertness, and subjective reports of fatigue. These differences extend to the effects of sleep loss, night work, and considerations of required sleep and recovery time for an individual. Individual differences can vary as a function of age, sleep requirement, experience, overall health, and other factors. Individuals can also vary in their participation in off-duty activities that engender fatigue during a subsequent duty period (e.g., commuting across long distances immediately prior to starting a duty period).

1.7 Differences and Variability Preclude an Absolute Solution

It must be acknowledged that the aviation industry represents a diverse range of required work demands and operational environments. Sections 1.5 and 1.6 highlight the diverse situations and individuals that are encompassed by generalized guidelines. This further illustrates that guidelines and regulations cannot completely cover all personnel or operational conditions and that there is no single absolute solution to these issues.

2.0 SPECIFIC PRINCIPLES, GUIDELINES, AND RECOMMENDATIONS

The following are specific principles, guidelines, and recommendations to address the 24-hour duty and rest scheduling requirements of the aviation industry. These principles and guidelines, based on the General Principles introduced in section 1.0, are intended to provide a consistent margin of safety across aviation operations. Therefore, they are intended for application to minimum flight crew complements of two or more. Similarly, they are intended for consistent application across Part 121 and Part 135 operations. There is no scientific basis to differentiate between these operations. These specific principles and guidelines also apply across all flying duty of flight crew members required to perform Part 91 or military flight operations before or after scheduled commercial operations.

In order to provide specific guidelines, it is necessary to define the terms used in these guidelines. Altering these definitions may invalidate the principles that follow.

2.1 Off-Duty Period

2.1.1 Definition: "off-duty"– A continuous period of uninterrupted time during which a crew member is free of all duties.

2.1.2 Off-duty period (acute sleep and awake-time-off requirements)– The off-duty period should allow for three components. The first critical component of the off-duty period is an 8-hour sleep opportunity. The general principles clearly describe that an acute sleep deficit and a cumulative sleep debt can degrade performance and alertness. Also, it should be recognized that an appropriate "spin down" time may be required to fall asleep. The second component is awake time off, an opportunity to break from the continuous performance of required tasks. The third component is the other activities necessary during an off-duty period. These other necessary activities can include transportation to and from layover accommodations, hotel check in/out, meals, shower, and personal hygiene. Therefore, the off-duty period should be a minimum of 10 hours uninterrupted within any 24-hour period, to include an 8-hour sleep opportunity, awake time off, and time for other necessary activities. (In the case of extended flight duty period, see section 2.3.5.)

2.1.3 Off-duty period (recovery requirement)– The general principles outline the importance of recovery to minimize the cumulative effects of sleep loss and fatigue. Two consecutive nights of usual sleep is a minimum requirement to stabilize sleep patterns and return waking performance and alertness to usual levels. Two consecutive nights of recovery sleep can provide recovery from sleep loss. Therefore, the standard off-duty period for recovery should be a minimum of 36 continuous hours, to include two consecutive nights of recovery sleep, within a 7-day period.

2.1.4 Off-duty period (following standard flight duty periods during window of circadian low*)– Extensive scientific research, including aviation data, demonstrate that maintaining wakefulness during the window of circadian low is associated with higher levels of performance-impairing fatigue than during daytime wakefulness. Therefore, flight duty periods that occur during the window of circadian low have a higher potential for fatigue and increased requirement for recovery. It is recommended that if two or more flight duty periods within a 7-day period encroach on all or any portion of the window of circadian low, then the standard off-duty period (36 continuous hours within 7 days) be extended to 48 hours recovery.

2.2 Duty Periods

2.2.1 Definition: "duty"– Any task a crew member is required by the operator to perform, including flight time, administrative work, training, deadheading, and airport standby reserve.

2.2.2 Definition: "duty period"– A continuous period of time during which tasks are performed for the operator, determined from report time until free from all required tasks.

---

* For definition of "window of circadian low," see section 2.3.2.

2.2.3 Duty period– To reduce vulnerability to performance-impairing fatigue from extended hours of continuous wakefulness and prolonged periods of continuous performance requirements, cumulative duty per 24 hours should be limited. It is recommended that this limit not exceed 14 hours within a 24-hour period. (In the case of additional flight crew, see section 2.3.6.)

2.3 Flight Duty Periods

2.3.1 Definition: "flight duty period"– The period of time that begins when a crew member is required to report for a duty period that includes one or more flights and ends at the block-in time of the final flight segment. At a minimum, this period includes required pre-flight activities and flight time.

2.3.2 Definition: "window of circadian low"– The window of circadian low is best estimated by the hours between 0200 and 0600 for individuals adapted to a usual day-wake/night-sleep schedule. This estimate of the window is calculated from scientific data on the circadian low of performance, alertness, subjective report (i.e., peak fatigue), and body temperature. For flight duty periods that cross 3 or fewer time zones, the window of circadian low is estimated to be 0200 to 0600 home-base/domicile time. For flight duty periods that cross 4 or more time zones, the window of circadian low is estimated to be 0200 to 0600 home-base/domicile time for the first 48 hours only. After a crew member remains more than 48 hours away from home-base/domicile, the window of circadian low is estimated to be 0200 to 0600 referred to local time at the point of departure.

2.3.3 Standard flight duty period– To reduce vulnerability to performance-impairing fatigue from extended hours of continuous wakefulness and prolonged periods of continuous performance requirements, cumulative flight duty per 24 hours should be limited. It is recommended that for standard operations, this cumulative flight duty period not exceed 10 hours within a 24-hour period. Standard operations include multiple flight segments and day or night flying.

2.3.4 Extended flight duty period– An extended cumulative flight duty period should be limited to 12 hours within a 24-hour period to be accompanied by additional restrictions and compensatory off-duty periods. This limit is based on scientific findings from a variety of sources, including data from aviation, that demonstrate a significantly increased vulnerability for performance-impairing fatigue after 12 hours. It is readily acknowledged that in current practice, flight duty periods extend to 14 hours in regular operations. However, the available scientific data support a guideline different from current operational practice. The data indicate that performance-impairing fatigue does increase beyond the 12-hour limit and could reduce the safety margin.

2.3.5 Extended flight duty period: restrictions and compensatory off-duty periods– If the cumulative flight duty period is extended to 12 hours then the following restrictions and compensatory off-duty periods should be applied.

A. Cumulative effects: maximum cumulative hours of extension. Over time, extended flight duty periods can result in cumulative effects of fatigue. To support operational flexibility and still minimize the potential for cumulative effects, it is recommended that extended flight duty periods can be scheduled for a cumulative total of 4 hours within a 7-day period. For example, there could be two 2-hour extensions of the standard 10-hour flight duty period (2 x 2 = 4 hr) or four 1-hour extensions (4 x 1 = 4 hr).

B. Flight duty periods during window of circadian low. As described in Section 2.1.4, the window of circadian low (as defined in Section 2.3.2) is associated with higher levels of performance-impairing fatigue. Therefore, it is recommended that in a 7-day period, there be no extended flight duty period that encroaches on any portion of the window of circadian low.

C. Restricted number of landings during window of circadian low. If an extended flight duty period contains a single continuous block-to-block flight period greater than 10 hours that encroaches on any portion of the window of circadian low, then it is recommended that flight crew members be restricted to no additional landings following the flight.

D. Recovery: compensatory off-duty period. To promote recovery from the acute fatigue associated with an extended flight duty period, additional off-duty time is recommended. The subsequent 10-hour required off-duty period should be extended by the time duration of the flight duty period extension. For example, an extended flight duty period of 11.5 hours would be accompanied by the subsequent off duty period being extended to 11.5 hours.

2.3.6 Extended flight duty period: additional flight crew– Additional flight crew afford the opportunity for each flight crew member to reduce the time at the controls and provide for sleep during a flight duty period. Consequently, with additional flight crew and an opportunity for sleep, it would be expected that fatigue would accumulate more slowly. In such circumstances, flight duty periods can be increased beyond the recommended limit of 12 hours within each 24-hour period. For each additional flight crew member who rotates into the flight deck positions, the flight duty period can be extended by 4 hours as long as the following requirements are met: 1) each flight crew member be provided one or more on-duty sleep opportunities; and 2) when the extended flight duty period is 14 hours or longer, adequate sleep facilities (supine position) are provided that are separated and screened from the flight deck and passengers. Controlled rest on the flight deck is not a substitute for the sleep opportunities or facilities required for additional flight crew members.

If an extended flight duty period is increased according to the above requirements, the maximum flight duty period limit supersedes the 14-hour duty period limit (section 2.2).

2.3.7 Flight duty period (cumulative)– A 24-hour cumulative flight duty period limit, a minimum off-duty period per 24 hours, and a specified off-duty recovery period per 7 days focus specifically on short-term vulnerabilities and considerations. To minimize fatigue that is not compensated by short-term recovery and to reduce excessive accumulation across longer periods of time, cumulative flight duty period limitations are recommended. There is not sufficient scientific data to provide specific guidance in this area. However, the general principles apply. For example, when determining cumulative flight duty limitations, shorter time frames should be considered. Therefore, in addition to 30-day and yearly cumulative flight duty period limitations, a 2-week limit should also be set. Also, these cumulative flight duty period limitations should be adjusted downward across the longer time period. Rather than just multiplying the 2-week cumulative flight duty period limitation to calculate the 30-day and yearly amounts, the 30-day amount should be decreased a percentage from the 2-week amount. The yearly cumulative flight duty period limitation should be decreased a percentage from the 30-day amount. This will further reduce the potential for long-term accumulation of fatigue factors.

2.4 Exceptions Due to Unforeseen Operational Circumstances

Exceptions allow the flexibility needed to respond to unforeseen circumstances beyond the control of the operator that occur during operations. They are not intended for use in regular practice. These exceptions must not be scheduled.

2.4.1 Reduced off-duty period (exception)– To support operational flexibility, it is recognized that due to circumstances beyond the control of the operator, it may be necessary to reduce an off-duty period to 9 hours. This reduction would occur only in response to an unforeseen operational requirement. In this situation, the subsequent off-duty period should be extended to 11 hours.

2.4.2 Extended flight duty period (exception)– To support operational flexibility, an extended flight duty period can be increased by up to a maximum of 2 hours due to unforeseen circumstances beyond the control of the operator. The subsequent required off-duty period should be increased by the time by which the flight duty period is increased.

2.5 Time Differences

In general, the longer a flight crew member is away from the home-base/domicile time zone, the more recovery time is needed for readjustment back to home-base/domicile time. Therefore, it is recommended that for flight duty periods that cross 4 or more time zones, and that involve 48 hours or more away from the home-base/domicile time zone, a minimum of 48 hours off-duty be allowed upon return to home base/domicile time.

2.6 Reserve Status

Flight crew members on reserve status provide a critical element to operational flexibility and the opportunity to meet unanticipated needs. It is important that flight crew members on reserve status obtain required sleep prior to a flight duty period.

2.6.1 Definition: "airport standby reserve"– A reserve flight crew member required to be available (on standby) at an airport for assignment to a flight duty period.

An airport standby reserve flight crew member should be considered on duty and the previous duty period guidelines apply.

2.6.2 Definition: "on-call reserve"– A reserve flight crew member required to be available to an operator (away from the airport) for assignment to a flight duty period.

On-call reserve status should not be considered duty. However, it is important that the flight crew member has an opportunity to obtain sleep prior to an assigned flight duty period. Two specific principles should be applied. The flight crew member should be provided a: 1) predictable and 2) protected 8-hour sleep opportunity. "Predictable" indicates that the flight crew member should have prior information (24 hours notice is recommended) as to when the 8-hour sleep opportunity can be obtained within the 24-hour on-call reserve time. The 8-hour sleep opportunity should not vary by more than 3 hours on subsequent days to ensure circadian stability. "A protected 8-hour sleep opportunity" should be protected from interruption by assignment to a flight duty period. Any approach that meets the requirements of these two principles could be utilized.

2.7 Summary Overview: Guidelines and Recommendations

Figure 1 provides a summary overview of the guidelines and recommendations discussed in this document.

	Off-Duty Period			Duty Period		Flight Duty Period			
	Per 24-hr period	Per week	Other	Per 24-hr period	Weekly, Monthly, Annually	Per 24-hr period	Per week	Monthly, Annually	
Scheduled	1) 10 hrs. 2) 10+ hrs (following extended flight duty period).	1) At least 36 continuous hours, to include 2 consecutive nights of recovery sleep, in a 7-day period. 2) 48 continuous hours in a 7-day period (following flight duty period in circadian low).	48 continuous hours upon return home following flight duty period across multiple time zones.	14 hrs.	There is not sufficient scientific data to provide specific guidance in this area.	10 hrs.		There is not sufficient scientific data to provide specific guidance in this area; however, cumulative flight duty period limitations should be adjusted downward over increasing time frames.	Standard
						12 hrs (requires restricted landings, maximum cumulative hours, compensatory off-duty time). For each additional flight crew member, flight duty time can be increased by 4 hrs (requires sleep opportunity for each crew member, and for FDPs > 14 hrs, a bunk facility).	Maximum of 4 cumulative hours of extension.		Extended
Unscheduled	9 hrs (subsequent off-duty period increased to 11 hrs).					Extended FDP can be increased by up to 2 hrs (subsequent off-duty period increased by an equal amount).			Exceptions Due to Unforseen Circumstances

Figure 1. Summary overview of guidelines and recommendations.

3.0 OTHER INDUSTRY STRATEGIES

A general principle previously stated is that addressing issues of fatigue, sleep loss, and circadian disruption in the aviation industry is a shared responsibility. These principles and guidelines for duty and rest scheduling are intended to provide scientific input to the regulatory process that addresses these issues in aviation. However, there is no single solution to the challenges posed by the 24-hour demands of the aviation industry. To highlight this shared responsibility, several other industry strategies for addressing these issues will be described. These are intended to complement the recommendations listed above.

3.1 Education and Training

An important first step for the industry is to become informed about the extensive knowledge now available regarding fatigue, sleep, and circadian physiology as it relates to performance and aviation operations. This knowledge can then be incorporated into daily operations. The information can be useful in providing specific recommendations for personal strategies to manage performance and alertness in flight operations. Education and training modules to meet this need are available and currently implemented successfully within the industry.

3.2 Scheduling Practices

The scientific information available can be particularly useful in guiding rational and physiologically-based scheduling practices. Scheduling is a complex and multi-determined process. However, it is possible and essential to include scientific data on human physiology as a factor for consideration. Obviously, priorities need to be established, and cost/benefit considerations are critical. There are examples of successful integration of scientific information on fatigue into schedule construction.

3.3 Controlled Rest on the Flight Deck

Scientific data obtained during flight operations have clearly demonstrated the effectiveness of a planned cockpit rest period to promote performance and alertness in nonaugmented long-haul flight operations. Controlled rest is a single operational strategy and is not an answer to all fatigue engendered by flight operations. It is absolutely not intended as a substitute for additional flight crew, appropriate rest facilities, or as support for extended duty. All possible strategies that maintain or improve the safety margin should be considered.

3.4 Operational Countermeasures

A variety of other strategies for use during flight operations should be examined and utilized where appropriate. This includes the design and use of technology to promote performance and alertness during operations. Varying work demands or other creative uses of flight deck automation could be developed to maintain alertness and performance. Several activities in this area are underway with some successful applications currently in use.

3.5 Future Developments

There are a number of other possibilities that are in different stages of development. Provocative laboratory studies of several countermeasures are often cited. However, validation of their effectiveness and safety in operational settings is still needed prior to widespread implementation. Research continues and may provide further findings on countermeasures relevant to regulatory, scheduling, personal strategies, and technology approaches to manage alertness in aviation operations.

REPORT DOCUMENTATION PAGE

OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 1996	Technical Memorandum

4. TITLE AND SUBTITLE

Principles and Guidelines for Duty and Rest Scheduling in Commercial Aviation

5. FUNDING NUMBERS

505-64-53

6. AUTHOR(S)

David F. Dinges, R. Curtis Graeber, Mark R. Rosekind, Alexander Samel, and Hans M. Wegmann

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Ames Research Center
Moffett Field, CA 94035-1000

8. PERFORMING ORGANIZATION REPORT NUMBER

A-961924

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM-110404

11. SUPPLEMENTARY NOTES

Point of Contact: Mark R. Rosekind, Ames Research Center, MS 262-4, Moffett Field, CA 94035-1000; (415) 604-3921

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified — Unlimited
Subject Category 51

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The aviation industry requires 24-hour activities to meet operational demands. Growth in global long-haul, regional, overnight cargo, and short-haul domestic operations will continue to increase these round-the-clock requirements. Flight crews must be available to support 24-hour-a-day operations to meet these industry demands. Both domestic and international aviation also can require crossing multiple time zones. Therefore, shift work, night work, irregular work schedules, unpredictable work schedules, and time zone changes will continue to be commonplace components of the aviation industry. These factors pose known challenges to human physiology, and because they result in performance-impairing fatigue, they pose a risk to safety. It is critical to acknowledge and, whenever possible, incorporate scientific information on fatigue, human sleep, and circadian physiology into 24-hour aviation operations. Utilization of such scientific information can help promote crew performance and alertness during flight operations and thereby maintain and improve the safety margin.

The primary objective of this document is to provide empirically derived principles and guidelines for duty and rest scheduling in commercial aviation. In the first section, scientifically-based principles related to operational issues posed by the aviation industry are outlined. In the second section, the principles are applied to guidelines for duty and rest scheduling in commercial aviation, with specifics provided where appropriate and available. In the third section, a brief overview of other potential industry strategies to address these issues is provided.

14. SUBJECT TERMS

Fatigue, Circadian rhythms, Duty and Rest, Scheduling

15. NUMBER OF PAGES

15

16. PRICE CODE

A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		

APPENDIX B

An Overview of the Scientific Literature Concerning Fatigue, Sleep, and the Circadian Cycle

Prepared for the Office of the Chief Scientific and Technical Advisor for Human Factors Federal Aviation Administration

By

Battelle Memorial Institute
JIL Information Systems

January 1998

An Overview of the Scientific Literature Concerning Fatigue, Sleep, and the Circadian Cycle

Introduction

This document provides a brief review of the scientific research relating to issues of pilot fatigue arising from crew scheduling practices. A massive amount of research has been conducted on such issues as the environmental conditions that contribute to the occurrence of fatigue, acute and chronic sleep debt and their effects on performance, and the influence of the circadian cycle on alertness. This paper attempts to identify major trends in this literature that might be of value in addressing scheduling regulatory issues.

The paper is organized into seven sections. The first section, "What is Fatigue," attempts to provide a functional definition of fatigue that serves to define the scope of issues that need to be considered, including variables that contribute to the occurrence of fatigue and methodologies for assessing the impact of fatigue on human functioning.

Section two, "Indications and Effects of Fatigue," briefly reviews the human performance and physiological indicators of fatigue. The intent is to identify possible decrements in performance that could have a safety impact. This section also briefly addresses the complexities involved in measuring fatigue levels. As this section explains, fatigue is a complex concept that does not always produce expected measurable decrements in performance.

Section three, "Fatigue and the Aviation Environment," addresses the issue of fatigue within the aviation environment. Before changes are made to existing regulations, the question of whether there is a problem that needs to be resolved should be addressed. Available research on the extent of fatigue within the aviation environment is reviewed. In addition, factors that complicate the assessment of the extent of the fatigue problem in an operational environment are also described.

A pilot's level of alertness at any time depends upon a complex interaction between a number of variables. Four variables, in particular, need to be considered: time on task, time since awake, any existing sleep debt, and the pilot's own circadian cycle. Section four, "Standard Duty Period," describes the research trends pertaining to time on task and time since awake while section five, "Standard Sleep Requirements," addresses acute and chronic sleep debt, including recommendations for sleep debt recovery. Section six, "The Circadian Cycle and Fatigue," which looks at the research on circadian cycles and their implications for back-of-the-clock and transmeridian flying. Finally, section seven, "Augmented Crews," looks at the limited data on the use of augmented crews to extend duty periods.

What Is Fatigue

The objective of the regulations proposed in the NPRM is to identify scheduling constraints that will minimize the impact of pilot fatigue that arises from duty time and sleep debt due to crew schedules. The term, "fatigue," has yet to be defined in a concrete fashion (Maher & McPhee, 1994); Mendelson, Richardson & Roth, 1996). Fatigue, as addressed in the human performance literature, refers to "deterioration in human performance, arising as a consequence of several potential factors, including sleepiness" (p. 2). Sleepiness, in contrast, has a more precise definition: "Sleepiness, according to an emerging consensus among sleep researchers and clinicians, is a basic physiological state (like) hunger or thirst. Deprivation or restriction of sleep increases sleepiness and as hunger or thirst is reversible by eating or drinking, respectively, sleep reverses sleepiness" (Roth et al., 1989, cited by Mendelson, Richardson & Roth, 1996, p. 2).

In keeping with current thinking on the concept of fatigue, Maher and McPhee's approach is used here:

> "Fatigue" must continue to have the status of a hypothetical construct, an entity whose existence and dimensions are inferred from antecedent and consequent events or variables" (p. 3-4).

This means that fatigue is treated as a concept that occurs in response to predefined conditions and has physiological and performance consequences. The antecedent conditions of interest here include:

- Time on task, including flight time and duty period duration
- Time since awake when beginning the duty period
- Acute and chronic sleep debt
- Circadian disruption, multiple time zones, and shift work.

The objectives of this document are to review the scientific research in order to:

- Identify the impact of these antecedent variables on human performance
- Relate these variables to appropriate physiological measures that have been demonstrated to be accompanied by decrements in human performance

Identify, to the extent possible, limitations and requirements concerning duty period durations, minimum sleep requirements, etc. that should be reflected in the regulations.

Indications and Effects of Fatigue

The massive literature on fatigue has identified a number of symptoms that indicate the presence of fatigue, including: increased anxiety, decreased short term memory, slowed reaction time, decreased work efficiency, reduced motivational drive, decreased vigilance, increased variability in work performance, increased errors of omission which increase to commission when time pressure is added to the task, and increased lapse with increasing fatigue in both number and duration (Mohler, 1966; Dinges, 1995). Many of these symptoms appear only after substantial levels of sleep deprivation have been imposed. A review of the literature that involved fatigue levels likely to be experienced by pilots suggests that a common fatigue symptom is a change in the level of acceptable risk an individual will tolerate.

Brown et al. (1970) had subjects drove for four 3-hour sessions. The performance measure used was a count of the number of occasions in which the subject executed what the experimenter considered a risky passing maneuver. When driving performance between the 1st and 4th sessions were compared, a 50% increase in the occurrence of risky passing maneuvers in later sessions, when subjects were presumably more fatigued, was obtained.

This change in the level of acceptable risk was confirmed by Barth et al. (1976) and Shingledecker and Holding (1974) who found that fatigue caused subjects to engage in greater risk taking activity in an effort to avoid additional effort. In the Shingledecker and Holding study, subjects performed 36 choice-of-probability (COPE) tasks, which involved locating a fault in one of three removable banks of one-watt resistors, each with varying degrees of probability that the bank had failed. Twenty-eight days separated the first and last three sets of six trial blocks. In this interim, the experimental group received 24 to 32 hours of continuous work on different monitoring-type fatiguing tasks immediately preceding the second trial block set, while the control group did not. The experimental group was found to shift their selections toward riskier, but less effortful strategies, and made more errors when compared with their own non-fatigued results or control group results. Also, subjects who reported they were tired, although not exposed to intentionally fatiguing activities, behaved similarly. Barth et al. performed a similar experiment, except that fatigue was induced by either a variable pitch/speed bicycle ergometer or a treadmill.

In the aviation domain, this strategy of avoiding effort when fatigued has recently been reported. Neri et al. (1992) found a change in strategy toward risk taking in naval pilots during carrier landings. Risk taking behavior also appears in the form of over reliance on automated systems (Graeber, 1988). This increased passivity, which takes the form of a mental aversion to or avoidance of further effort, is common in both the sleep deprived state and when the individual is experiencing the diurnal low point for body temperature during the circadian trough (Hamilton et al., 1972).

A report of some of the occurrences moments before the crash of the aircraft carrying Commerce

Secretary Ron Brown further illustrates the type of inaction typical of fatigue (Newman, 1996). Although the pilots detected an error on approach a full minute before the crash, they made no attempt to correct the error—a common characteristic of fatigue. This is due to a reduced level of adherence to one's normal standard and a reduced ability to cognitively make a connection between cause and effect. One may recognize a problem but not translate its effect due to lack of full comprehension of the situation or simple failure to initiate an action.

Related evidence exists that fatigued workers are satisfied with lower performance and that perceived errors go uncorrected. There is a "loss in the ability of the worker to perceive and adjust to new aspects of the task. The worker seems unable to shift quickly and effectively from one subpart to another" (Broadbent, 1953; cf. Horne, 1988). The latter quality has been found to be a factor when aircraft crews are concentrating on one problem and allow other problems to develop due to neglect.

In the case of the 1985 China Airlines Flight 006 mishap, the pilot became focused on the loss of power in one engine, neglecting other flight duty tasks. Major structural damage and 2 serious injuries occurred when the aircraft experienced more than 5 g's during its uncontrolled descent from 31,000 feet to 9,500 feet, before control was regained (Lauber & Kayten, 1988). Contributing fatigue factors to the accident were the Captain's failure to properly monitor the airplane's flight instruments, over-reliance on the autopilot after the loss of thrust due to engine failure, and performance of duties during the Captain's circadian trough. The accident occurred 4 to 5 hours after the time he had been beginning sleep during the 6 nights preceding the accident.

In the Guantanamo Naval Base accident, the pilot was so focused on finding a strobe light that he failed to respond to other crew members' warnings that they were approaching a stall speed (NTSB Aircraft Accident Report, 1993). In an investigation of Air Force C-5 mishaps or near mishaps, it was reported that 55 percent were related to attentional focus problems and 24 percent to decision making problems (Majors, 1984).

Some symptoms of fatigue are similar to other physiological conditions. For example, with fatigue one's ability to attend to auxiliary tasks becomes more narrow, very much analogous to the effects of alcohol (Huntley et al., 1973; Moskowitz, 1973), hypoxia (McFarland 1953), and heat stress (Bursill, 1958). Dawson and Reid (1997) evaluated performance after 17 hours awake and found performance degraded to a level equal to that caused by a blood alcohol concentration (BAC) of 0.05 percent. At 24 hours, performance decrements were equivalent to that of a 0.10 BAC. After ten hours of sleeplessness, the decline in performance averaged .74 percent per hour.

Finally, Harrison and Horne (1979) found that sleep loss resulted in a difficulty of generating the ideal word or phrase for the idea or thought the person wanted to convey. In addition, there was a loss in intonation and an overall dullness which suggested loss of interest. The authors suggest that this may very well result in personal communication problems in real life situations.

Effects of Fatigue and Sleep Loss on the Brain

Sleep is mainly a restorative process for brain function. Horne (1991) states that this restoration is primarily a function centered on the cerebral cortex of the brain. This is consistent with the findings of Perelli (1980), who found that a high time since awake significantly increased the threshold for information processing. Ptemitis (1981) found that dominant EEG frequencies in power plant operator shift workers showed a progressive decline, with each shift beginning in the morning and continuing to night shift. Morning shift employees showed EEG readings of 12-30 Hz, evening shift workers 6-12 Hz, and those on duty during the night shift, 2-6 Hz. Gevens et al. (1997) has shown that observable performance decrements are preceded by observable EEG brain wave changes that clearly indicate decreasing attentional focus. These EEG changes are observable some time before noticeable performance decrements occur. Howitt et al. (1978) measured EEG activity in operational pilots and found that under high workload situations the fatigued pilots' EEG rose to only half the level of those displayed by fresh pilots.

Another physiological measure of fatigue and sleep is brain glucose levels. All tissue of the body, whether it be heart muscle, kidneys, lungs, or the brain, works electrochemically, and conforms to one principle: the more work done, the more fuel used. Thus, by measuring glucose utilization, oxygen consumption, and blood flow in the brain, areas which are very active during various tasks can be determined.

Thomas et al. (1993), using positron emission topography (PET) scan has provided strong physiological evidence that sleep loss is accompanied by a decrease in brain glucose metabolism. The areas most involved were the prefrontal cortex, the inferior parietal cortex, and thalamus. During 48 hours sleep deprivation, the overall brain glucose utilization declined 7 percent, while in the areas of higher order thinking declines ranged from 10 to 17 percent (Thomas, 1997). Although these reductions seem relatively minor over a 48 hour period, Gold (1995) recently found that comparatively small blood glucose changes could significantly enhance cognitive performance in a variety of subjects including healthy young adults, elderly, and severe states of pathology such as Alzheimer's and Downs Syndrome patients.

PET scans of recovery sleep, taken sequentially through the night and synchronized with EEG changes, show that slow wave sleep appears to have its greatest effects on the same brain areas that Thomas et al (1993, 1997) showed were most affected by sleep loss (Braun et al., 1997). This indicates that areas of the brain involved in alertness, attentional focus, concentration, short term memory, drive and initiative, problem solving, complex reasoning, and decision making are the greatest beneficiaries of deep sleep (Lamberg, 1996).

Since the front brain is responsible for analysis of information, judgment, planning, decision making, and the initiation of actions, it is not surprising that NTSB found decision making abilities suffered with high time since awake.

> The orderly planning and sequencing of complex behaviors, the ability to attend to several components simultaneously, and then flexibly alter the focus of concentration, the capacity for grasping the context and gist of a complex situation, resistance to distraction and interference, the ability to follow multi-step instructions, the inhibition of immediate but inappropriate response tendencies, and the ability to sustain behavioral output... may each become markedly disrupted (Restak, 1988).

Many of the functions described by Restak are the same functions necessary to a pilot's ability to competently fly an aircraft.

Measuring Fatigue

Although the studies just listed do show performance decrements due to fatigue, other studies have shown no effect (e.g., Rosenthal, 1993), particularly when sleep loss levels up to 24 hours, or small chronic partial sleep loss levels of only one or two hours per day are used. The lack of definitive results in partial sleep deprivation studies may be due to differences in testing procedures. Rosenthal tested on four separate occasions, whereas others tested only once per day. In a more severe sleep deprivation study, Thorne (1983) made the testing instrument the primary task, which lasted 30 minutes of each hour. As sleep loss became increasingly greater, subjects became slower. Therefore, the time to complete the self-paced task increased about 70 percent, and at times doubled.

Evans et al. (1991), in a review of fatigue in combat, clearly stated that studies using embedded testing, such as Thorne (1983), Angus and Heslegrave (1985), and Mullaney et al. (1981), consistently show greater effects of fatigue and sleep loss performance decrements than short duration isolated intrusive tests. Belenky et al. (1986) notes that continuous embedded testing reveals larger performance decrements sooner than does intermittent testing. In Angus and Heslegrave (1985), analysis of results found a 28% decrement in encoding/decoding performance and a 43% decrement in logical reasoning after 24 hours awake. Haslam (1982), using non-embedded testing, found no decrements and 29%, respectively.

The greater sensitivity of embedded testing is not surprising given that they measure performance for a more prolonged period. Brief, intrusive psychometric tests, in contrast, are novel and act as a rest break, distraction, and temporary stimulus, thereby increasing short term mobilization of effort thus boosting performance. The use of such an instrument would function similar to the effect Chambers (1961) found in an industrial output study where output remains higher when a worker was switched to different jobs periodically than to stay at one job.

Another explanation for the varying effects of performance due to fatigue is that performance is, in part, dependent upon the circadian physiology of the subject. Subjects experiencing circadian dysrhythmia or operating during their circadian trough are more likely to yield substandard performance.

Also, motivation can play a major role in the relationship between fatigue and performance. "Both experimenter and subject motivation can have a large impact on results, particularly in the behavioral and subjective domains. Motivation effects are frequently most apparent near the end of studies (where performance improvement is sometimes found) but also may account for the difficulty in showing decrements early in periods of sleep loss" (Bonnet, 1994, p. 50).

In addition to embedded testing, other parameters considered to increase sensitivity in testing for fatigue and sleep loss performance decrements include continuous performance, prolonged vigilance, and multiple task jobs, similar to what is shown to work in decrement due to noise (Belenky 1986; Dejoy, 1984). Self-paced tasks have been reported to be less affected by sleep loss than tasks that are faster work-paced (Johnson & Naitoh, 1974). Fatigue effects tend to be minimal when tasks are self-paced, brief, highly motivating, and feedback is given. On the other hand, tasks which involve sustained vigilance and attention, the use of newly acquired skills, and new information retention tend to challenge short term memory. This is because work-paced tasks accelerate the rate of information processing, thereby decreasing the reserve capacity of brain function.

Roth et al. (1994) support long monotonous objective testing and the MSLT as good measures of sleep loss decrement and sleepiness, respectively. McFarland (1953) considered the deterioration of skills over time a promising framework for the study of fatigue. This has recently been attempted in aviation research by Neville et al. (1992) through the use of flight data recorders for measuring parameters of flight over time. This procedure may be the best avenue yet for truly measuring performance decrements in an operational setting.

Microsleeps

Performance measures have obvious value for assessing the effects of fatigue and sleep-related variables. Microsleeps are another useful approach. Microsleeps were first recognized by Bills (1931) and were first called "blocks." Over the intervening years they have also been called "gaps," "lapses" and, more recently, "microsleeps." The physiological drive to sleep can result in a microsleep lasting a few seconds to a few minutes. The latter terminology is the result of EEG recording showing that during these lapses in information processing, subjects momentarily slip into a light sleep. This occurs with the eyes open and usually without the knowledge of the individual, an observation first reported by Miles (1929). Bonnet and Moore (1982) found that before 50 percent of normal subjects became consciously aware of falling asleep, they had been asleep two to four minutes. These intermittent lapses in consciousness impair performance by leading to errors of omission due to missed information. In serial tasks that are work paced, microsleeps can also lead to error of commission and, if frequent enough or long enough, can lead to loss of situational awareness.

Microsleeps have been shown to be a useful approach to assessing the effects of time of day on sleepiness levels. EEG brain wave changes confirm that pilots experience greater sleepiness and decreased alertness between 2:00 to 4:00 a.m. (Gundel, 1995). Alpha waves in EEGs indicate micro events or micro sleeps and have been found to be three times greater during night than during day flights (Samel, 1995). Samel et al. (1997) found that during outbound flights, pilots experienced 273 microsleeps or an average of 1.38 microsleeps per pilot per hour. On return flights the following night, pilots experienced 544 microsleeps or 2.47 microsleeps per hour per pilot. Both feelings of fatigue and the occurrence of microsleeps increased as duty time progressed. Rosekind et al. (1994) also observed micro sleep in pilots and a progressive increase as flights progressed, particularly in the latter portion of the flight. These findings confirm both the physiological occurrence of microsleeps in commercial aviation pilots, and the accumulative nature of fatigue in successive night operations.

The beneficial effects of taking breaks have also been demonstrated by measuring microsleeps. Workers performing continuous tasks without breaks (Bills, 1931; Broadbent, 1958) or suffering from sleep loss began to demonstrate signs of micro sleeps much sooner than those with rest breaks or getting adequate rest, respectively (Kjellberg, 1977b).

The research cited in this section suggests that fatigue may be a factor in the aviation environment due to direct performance decrements and, indirectly, through microsleeps that disrupt pilot functioning. The next section looks at data relating to the occurrence of fatigue in the aviation environment.

Fatigue and The Aviation Environment

The unique characteristics of the aviation environment may make pilots particularly susceptible to fatigue. Environmental factors such as movement restriction, poor air flow, low light levels, background noise, and vibration are known causes of fatigue (Mohler, 1966). In addition, the introduction of advanced automation into the cockpit has changed the nature of the job for many pilots. Hands-on flying has been replaced by greater demands on the crew to perform vigilant monitoring of these systems, a task which people tend to find tiring if performed for long periods of time. For example, Colquhoun (1976) found that monotonous vigilance tasks could decrease alertness by 80 percent in one hour, which is correlated with increased EEG theta activity or sleep-like state. Since physical activity and interest in the task can help to minimize the decline in performance due to continuous work and sleep loss (Wilkinson, 1965; Lille, 1979), automation may contribute to increased drowsiness in pilots suffering from fatigue or sleep loss. Also, as will be shown below, these cognitive-based activities may be susceptible to the effects of fatigue.

Although these environmental characteristics are suggestive, the actual extent to which fatigue is a safety issue needs to be assessed. A study of ASRS incident reports suggested that 21% of incidents were fatigue-related. This figure was challenged by Baker (1996), who pointed out that the database is a biased system due to self reporting, and the data were further biased by the researchers' interpretation of the reports. Kirsch (1996) argues that the actual ASRS estimate is four to seven percent. Graeber (1985) clarifies the situation as follows:

> An initial analysis of NASA's Aviation Safety Reporting System (ASRS) in 1980 revealed that 3.8 percent (77) of the 2006 air transport crew member error reports received since 1976 were directly associated with fatigue (Lyman & Orlady, 1980). This may seem like a rather small proportion, but as the authors emphasize, fatigue is frequently a personal experience. Thus, while one crew member may attribute an error to fatigue, another may attribute it to a more directly perceived cause such as inattention or a miscommunication. When all reports which mentioned factors directly or indirectly related to fatigue are included, the percentage increases to 21.1 percent (426). These incidents tended to occur more often between 00:00 and 06:00 [local time] and during the descent, approach or landing phases of flight. Furthermore, a large majority of the reports could be classified as substantive, potentially unsafe errors and not just minor errors.

In a study of flightcrew-involved major accidents of domestic air carriers during the 1970 through 1990 period (NTSB, 1994), one conclusion pertained directly to the issue of fatigue: "Half the captains for whom data were available had been awake for more than 12 hours prior to their accidents. Half the first officers had been awake more than 11 hours. Crews comprising captains and first officers whose time since awakening was above the median for their crew position made more errors overall, and significantly more procedural and tactical decision errors" (p. 75). This finding suggests that fatigue may be an important factor in the carrier accidents. Because the study involved only domestic carrier accidents, it remains unclear as to whether other fatigue-related factors, such as long flight times and circadian disruption due to multiple time zones would also appear as causative factors. On the basis of this study, the NTSB recommended that the FAA address the issues of flight duty times and rest periods.

Although the results of this study are suggestive, the actual impact of fatigue has yet to be determined. Since no real effort has been made to identify the effects of fatigue in accident and incidence investigation, it is difficult to assess the magnitude of the problem. In addition, it is possible that self-reporting systems, such as ASRS, may be affected by the inability of people to accurately assess their own fatigue levels (Sasaki et al., 1986; Richardson et al., 1982; Dinges, 1989). Subjective evaluations of sleepiness have not been found to be reliable except in extreme sleepiness. Rosekind and Schwartz (1988) noted that the scientific literature generally demonstrates a discrepancy between subjective reports and psychophysiological measures, the result being underestimations of one's level of sleepiness (cf. Dement & Carskadon, 1981). Dement et al. (1978) and Roth et al. (1994) reported that some subjects judged themselves alert, when in fact they were in the process of falling sleep.

Graeber et al. (1986), summarizing the collaborative efforts between European, Japanese, and American investigators to evaluate sleep in long haul aircrews, reported that subjective evaluations are sometimes erroneous as to the true nature of the psychophysiological state of sleepiness. These results were obtained in two separate studies by Dement et al. (1986) and Sasaki et al. (1986). Mullaney et al. (1985) also found that subjects subjectively felt that they performed better under sleep loss conditions when paired with another subject, when in reality it had no effect on actual performance decrements. Rosekind et al. (1994) found pilots unable to subjectively evaluate changes in performance due to a short inflight nap. Although pilots did show physiological improvements in alertness, they could not subjectively notice a difference. Belenky et al. (1994) points out that due to the psychophysiology changes in higher order cognitive judgment areas with fatigue and sleep loss, these changes automatically preempt ones ability to evaluate his or her own performance accurately.

One possible reason for these findings is that the presence of certain factors masks sleepiness and the absence of other factors unmasks sleepiness. Environmental factors that have a masking affect include noise, physical activity, caffeine, nicotine, thirst, hunger, excitement, talking about something interesting, etc. For example, Howitt et al. (1978) found that sleep deprived pilots in operational settings felt no noticeable fatigue once flight preparations were under way and flight commenced. This explanation is supported by research that used the multiple sleep latency test (Dement et al., 1986, Sasaki et al., 1986; Rosekind et al., 1994; Roth et al., 1994). In contrast to the subjective evaluation, the multiple sleep latency test asks subjects to quietly lie down, close their eyes and try to sleep. This in essence removes many of the masking factors, whereas subjective alertness in relation to EEG recording appears to have better correlation because both can be recorded in the same environmental setting. Ogilvie et al. (1989) reported that subjective sleepiness responses to the Sanford Sleepiness Scale only reached significance when subjects were entering stage I sleep. Thus it may be that when EEG alpha and theta activity appears there is truly a feeling of sleepiness.

Although masking reduces perceived feelings of sleepiness, it does not counteract the effects of fatigue on performance. Kecklund and Akerstedt (1993) conclude that although sleep-deprived subjects may not feel their sleepiness or fatigue due to environmental variables, the sleep pressure is still latently present.

Standard Duty Period

The first regulatory issue that needs to be addressed concerns the duration of the standard duty period. "Standard" is used here to refer to duty periods that do not involve window of circadian low (WOCL) effects or time zone changes. The primary focus of the standard duty period issue addresses the buildup of fatigue as a function of performing the various tasks involved in a duty period Six factors that may need to be considered are:

- Time on task
- Time since awake
- Task type
- Duty period extension
- Cumulative duty times
- Environmental factors.

Each of these factors is discussed below.

Time-On-Task

There appears to be some consensus that the effects of time-on-task on performance are difficult to assess (e.g., Maher & McPhee, 1994) and are affected by a number of variables, including time of day, the nature of the task, the subject's motivational level, and if fatigue or sleep loss are already present (Dinges & Kribbs, 1991; Maher & McPhee, 1994; Mendelson, Richardson & Roth, 1996). In spite of this, performance on many laboratory tasks follows a similar curve (Vries-Griever & Meijman, 1987): relatively low starting performance, followed by optimal performance, which then declines due, presumably, to fatigue. The points at which optimal performance begins and then starts to degrade varies with the task. For some cognitive tasks, optimal performance is achieved after about five hours, then declines to its lowest levels after 12 to 16 hours on task (Spencer, 1987; Nicholson, 1987). Some tasks, such as monitoring tasks that require high levels of vigilance, show performance decrements after shorter durations. Colquhoun (1976) found that monotonous vigilance tasks could decrease alertness by 80 percent in one hour based on increased EEG theta activity which correlates with a sleep-like state. Reductions in task performance over time are also accompanied by an increased need to sleep, as shown by Lisper et al. (1986), who found that car drivers showed an increased likelihood of falling asleep after 9 hours of driving.

Time-on-task measures for a single task may have limited applicability to the aviation domain as the pilot's job involves performing a number of tasks during a given duty period. Switching between individual tasks may override some of the effects of fatigue due to time-on-task. Studies which have investigated the effects of extended shift durations on worker performance may be relevant as they assess fatigue and performance as a function of the set of tasks that are performed during a shift rather than performance decrements that accrue on a single task. In a manufacturing environment (Rosa & Bonnet, 1993), the number of errors made was relatively high at the beginning of the shift, then decreased because of re-familiarization with the task. Optimal levels were reached within a few hours, then declined over the eight-hour shift. In general, workers on 12-hour shifts became considerably more fatigued than in more traditional eight- to 10-hour shifts (Rosa & Colligan, 1987). This finding has been confirmed in nurses (Mills et al., 1983), industrial shift workers (Colligan & Tepas, 1986), night shift workers (Rosa & Colligan, 1987), sea watch workers (Colquhoun, 1985), and truck drivers (Hamelin, 1987). The latter study also found an increase in the number of accidents that occur when 12-hour shifts are used.

This increased likelihood of accident risk due to long duty periods has been found in other studies. The relative risk of an accident at 14 hours of duty rises to 2.5 times that of the lowest point in the first eight hours of duty. Askertedt (1995) reports accident risks to be threefold at 16 hours of duty, while Harris and Mackie (1972) found a threefold risk in just over 10 hours of driving. These levels of risk are similar to that associated with having narcolepsy or sleep apnea (Lavie et al., 1982), or a blood alcohol level of 0.10 percent. Wegmann et al. (1985), in a study of air carrier pilots, argued for a duty period of 10 hours with 8.5 hours or less of flight duty period.

Time Since Awake

The results of an NTSB analysis of domestic air carrier accidents occurring from 1978 to 1990 suggest that time since awake (TSA) was the dominant fatigue-related factor in these accidents (NTSB, 1994). Performance decrements of high time-since-awake crews tended to result from ineffective decision-making rather than deterioration of aircraft handling skills. These decrements were not felt to be related to time zone crossings since all accidents involved short haul flights with a maximum of two time zones crossed. There did appear to be two peaks in accidents: in the morning when time since awake is low and the crew has been on duty for about three to four hours, and when time-since-awake was high, above 13 hours. Similar accident peaks in other modes of transportation and industry have also been reported (Folkard, 1997). Akerstedt & Kecklund (1989) studied prior time awake (four to 12 hours) and found a strong correlation of accidents with time since awake for all times of the day. Belenky et al. (1994) found that flight time hours (workload) greatly increase and add to the linear decline in performance associated with time since awake.

Task Type

The effects of task type, as they contribute to the buildup of fatigue, need to be considered from two perspectives:

- Whether certain activities can be excluded from duty period time
- Whether certain activities are inherently more fatiguing and may need to be restricted.

The current regulations regulate only flight time. No limits are provided for duty time. The regulations proposed in the Notice of Proposed Rulemaking 95-18 (NPRM) allow for the concept of "assigned time," which also is unregulated as to maximum limits. The extent to which activities categorized as non-flight time or assigned time contribute to fatigue has yet to be empirically ascertained. However, it is clear that these activities would contribute to fatigue in the form of time since awake. Consequently, it may be appropriate to limit these activities in either of two ways:

- With respect to when they occur relative to flight time so as to avoid pilots achieving high time-since-awake levels during flight time periods.
- Provide maximum levels for these activities comparable to duty period time levels.

The second issue pertaining to task type concerns activities which are known to be inherently more fatiguing. One such activity is the approach and landing. Gander et al. (1994) found that increases in heart rate occurred during the approach and landing phases when compared with other duty period activities. Because heart rate increase is a common measure of workload, this suggests that proposals to limit landings for flights that have other known fatigue factors (e.g., time since awake, window of circadian low, extended flight duty periods) may be appropriate.

The relationship between task type and fatigue buildup in the aviation domain remains to be determined. The demands placed on long-haul pilots are clearly different from those of the regional carrier pilot flying many legs in a propeller-driven airplane with limited automation. Flights across the ocean typically involve a single leg of six or more hours. The main task-related fatigue sources in this case are boredom and cognitive fatigue due to vigilance. The regional pilot, in contrast, may be more susceptible to fatigue due to the high workload involved in performing six or more takeoffs and landings. For this reason, it may prove necessary to develop separate regulations that are appropriate for each major type of operation.

Duty Period Extensions

The research cited on duty period duration suggests that duty periods at or above 12 hours are associated with a higher risk of error. This factor, together with the time-since-awake factor, suggests that extended duty periods also involve a higher potential for crew error. In determining maximum limits for extended duty periods, consideration also needs to be given to other fatigue-related factors that could contribute to excessive fatigue levels during extended duty periods, including number of legs, whether the flight impinges on the window of circadian low (WOCL), and time since awake.

Cumulative Duty Time

No data were found that provide guidance for maximum duty times over longer time periods, such as one month or one year.

Environmental Factors

The physical environment of the cockpit is a source of other factors that can contribute to fatigue (Mohler, 1966). Factors such as vibration, poor ventilation, noise, and the availability of limited automation can contribute to the buildup of fatigue or accelerate its onset when coupled with time since awake, number of legs, and whether the flight involves the WOCL. This may have implications for regional carrier pilots who fly propeller-driven aircraft.

Conclusions

The research cited suggests an increase in the likelihood of error as duty periods are extended beyond 12 hours. This finding is especially critical for extended duty periods which are likely to occur under conditions (e.g., weather) that, in and of themselves, may increase the probability of crew error.

The interactions between multiple fatigue-related factors must also be considered. Separately, duty period duration, time since awake, number of legs, and environmental factors contribute to fatigue buildup. When any one of these factors reaches a high level, consideration should be given to reducing the maximum allowable levels on these other factors. Time since awake also has obvious implications for reserve assignments and for pilots who commute.

Standard Sleep Requirements

Standard Sleep Requirements and Off-Duty Period

There is a generally consistent body of research which demonstrates that most people require an average of 8 hours of sleep per night to achieve normal levels of alertness throughout daytime hours without drowsiness and to avoid the buildup of sleep debt (Carskadon & Dement, 1982; Wehr et al., 1993). This figure is based upon a range of studies that used several approaches, including:

- Historical levels of sleep
- Measures of daytime alertness
- Sleep levels achieved when given the opportunity to sleep as long as desired.

Webb and Agnew (1975) reported that habitual sleep around the turn of the century was about nine hours. A 1960 study of more than 800,000 Americans found that 13 percent of men and 15 percent of women, ages 35-65, slept less the seven hours with 48 percent of both obtaining less than eight hours of sleep per night (*Wake Up America*, 1993). By 1977, one in eight Americans reported getting six or fewer hours of sleep per night (Schoenborn & Danchik, 1980). By 1983, just six years later, that number had jumped to one in four (Schoenborn & Cohen, 1986).

The average distribution of habitual sleep ranges between 5.5 and 9.5 hours per night, and includes 95 percent of the adult population with an average of 7.5 hours (Horne, 1988). Most researchers seem to agree with this figure (Levine et al., 1988; Carskadon & Roth, 1991. Dinges et al., 1996; Bonnet & Arand, 1995). However, Webb (1985) reported considerable individual differences in habitual sleep in a sample of more than 30,000 individuals from 11 industrial countries. In this study two percent were reported to sleep less than five hours per night, while five percent reported sleeping more than 10 hours. These averages have been reported in similar findings across various population groups.

Most researchers advocate an average sleep requirement for adults of 7.5 to 8.0 hours per day (Levine et al., 1988; Carskadon, & Roth, 1991; Dinges et al., 1996). Although early on, Dement et al. (1986) indicated that 9 hours was necessary for optimal alertness throughout the day, Horne considered 6 hours "core sleep" sufficient. Although Horne's advocacy of 6 hours core sleep has detracted somewhat from what most sleep researchers now feel to be optimal sleep, it has not dislodged the weight of evidence.

Carskadon (1991) reports that 87 percent of college students habitually sleeping seven to 7.5 hours per night had difficulty staying awake in the afternoon with 60 percent reporting actually falling asleep. When compared with Horne's advocating only 6 hours of "core sleep," these responses seem to suggest that, although the subjects specify a habitual amount of sleep above Horne's putative 'core,' their sleep is insufficient. The six-hour core amount does not seem to apply to many, based upon the self-perceived adequacy of sleep.

Roehrs et al (1989) showed that when short or long sleepers were required to stay in bed for ten hours, all subjects slept about an hour longer than usual. The result was that all subjects improved in their alertness, vigilance, and reaction time needed for driving or monitoring modern control panels. Divided attention performance showed significant improvement, and central task performance showed somewhat better improvement than peripheral task performance. Daytime sleepiness decreased for both groups, but to a greater extent for the individuals who previously reported suffering from sleepiness. Subjects who were usually sleepy were more alert, and those who usually functioned at a high level became even sharper (Carskadon et al., 1979).

Allowing just one hour extra sleep per night over four night resulted in a progressive reduction in daytime sleepiness of nearly 30 percent when measured by the Multiple Sleep Latency Test (MSLT). Allowing sleepers who typically slept 7.5 hour per day to sleep *ad libitum*, other researchers found that sleep time increased 28 percent from 7.5 to 9.6 hours. (Taub, 1981: Webb & Agnew, 1975). Taub (1976) studied the magnitude of differences between regular (7 to 8 hours) sleepers and long (9.5 to 10.5 hours) sleepers when their sleep was phase shifted three hours forward or backward. They also examined changes when both groups had sleep periods extended or reduced. Although results showed degrees of impairment from the acute alterations in sleep pattern by both sleep groups, the 7-to-8 hour sleepers consistently showed greater impairment. Carskadon and Dement (1981, 1982) found that extending the total time in bed from eight hours to ten in 18 to 20 year old subjects allowed them to increase their total sleep time on average more than one hour. This resulted in a significant improvement in daytime alertness which only appeared after the second night of extended sleep, suggesting a repaying of sleep debt. The researchers felt that this improvement supported suggestions that eight hours of bed time may represent a chronic sleep deprivation condition in young adults. Scores on alertness showed a stair-step response with the length of sleep per night as well as with the number of nights. Thus scores for alertness were better for ten hours of sleep than for eight, eight were better than five, and two nights with five hours were better than seven nights with five hours which were better than scores with no sleep.

In a slightly different research design, Wehr (1993) found in a four-week test that young adults allowed to sleep as long as they desired, slept in excess of 10 hours a day during the first three days. This was followed by three days of about 9 hours. The remainder of the 28 days leveled off at an average of 8.5 hours per night. Their habitual base-line sleep was 7.2 hours. The initially higher level of sleep is interpreted as repayment of chronic sleep debt. A similar sleep requirement figure of 8.4 hours was reported by a Walter Reed research team (1997) in an interim report. Thus both sleep extension studies and historical data indicate that optimal sleep requirement appears to be between 8 to 9 hours sleep with an average of about 8.5 hours, considerably higher than habitual sleep figures.

The benefits of sleep are presently considered to be logarithmic in nature, with the initial hours showing significantly greater benefits that diminish as one approaches his or her optimal sleep level. This accounts for how many can sleep less and appear to still function normally. However the findings of Rohre (1989) and Taub and Berger (1976) indicate that during the first six hours of sleep, performance is restored to a satisfactory level under normal conditions, although alertness and vigor may still be diminished. In the hours beyond six hours of sleep the restoration process further restores alertness and vigor and the brain's capacity to handle situations above that of normal and for longer periods.

An example of this is best illustrated by Samel et al. (1997) where the second of two night flights showed a considerable reduction in tolerance and an increase in fatigue after only three hours of flight whereas on the first night fatigue did not set in until after 8 hours. Thus, the additional hours served as a reserve capacity against workload (Howitt et al., 1978) or hours of duty (Samel et al., 1997; Gundel et al., 1997).

Other Variables

Individual Differences In Sleep Requirements. Many of the studies described above showed that there appears to be a considerable variability in individual sleep needs. Thus, the eight-hour sleep requirement represents the average of sleep needs, but does not take into account of the needs of those individuals who require additional sleep and who represent a fair percent of the population.

Age-Related Changes In Sleep Requirements. With age there is a significant decline in habitual nightly sleep due to increased nighttime awakenings (Davis-Sharts, 1989; Webb & Campbell 1980; Carskadon et al., 1982; Miles & Dement, 1980; Carskadon et al., 1980). In older individuals, habitual nighttime sleep is accompanied by increased daytime fatigue, sleepiness, dosing, and napping. This increase in the number of sleep periods approximates normal sleep quantity and appears to indicate that sleep requirements remain the same over a person's adult lifetime (Miles & Dement, 1980; Habte-Gabr, 1991). These studies suggest that older crew members may have particular difficulties in achieving sufficient sleep as part of a normal duty schedule (cf. Carskadon, Brown & Dement, 1982).

Logistical Issues. A number of studies have investigated the issue of the amount of sleep that is actually achieved as a function of the length of the off-duty period. These studies demonstrate that off-duty periods that appear to provide an acceptable sleep opportunity may not, in reality, be sufficient. In one study, reductions in sleep of two to three hours per 24 hours occurred when the time between shifts or work was reduced to only nine hours (Knauth, 1983). In the NASA studies of short-haul pilots (Gander et al . 1994; Gander & Graeber, 1994), pilots reported an average of 12.5 hours off-duty time between duty periods, but only obtained 6.7 hours rest.

Observations of nurses on 12 hour shifts working 12.5 hours with 11.5 hours off between shifts obtained an average of 6.9 hours sleep (Mills et al., 1983). Another study of long-haul and short haul-truck drivers (WRAIR, 1997) showed that short-haul drivers with similar rest periods between shifts obtained even fewer sleep durations.

Commercial truck drivers' (FHWA, 1996; Mitler et al., 1997) sleep/off duty schedules are shown in Table 1. When truckers (C1-10) had 10.7 hours off duty between 10 hour day shifts, sleep durations of only 5.4 hours were achieved. On a 13-hour day shift (C4-13) with 8.9 hours off between duty periods, sleep durations averaged 5.1 hours. On 10-hour rotating shifts (C2-10) with 8.7 hours off duty, the sleep time was 4.8 hours and after a 13-hour night shift (C3-13) with 8.6 hours off, the resulting sleep diminished to only 3.8 hours. In quick changeovers with 8 hours off between shifts, Totterdell (1990) found that workers only acquired 5.14 hours sleep. Kurumatani (1994) found a correlation (r=.95) between the hours between shift and sleep duration. They concluded that at least 16 hours off duty time were needed between shifts to ensure 7-8 hour sleep, a conclusion reiterated in a recent review (Kecklund & Akerstedt, 1995).

Condition	Hours off-duty	Hours in Bed	Hours asleep
C1-10 day	10.7	5.8	5.4
C2-10 rotating	8.7	5.1	4.8
C3-13 night	8.6	4.4	3.8
C4-13 day	8.9	5.5	5.1

Table 1. Truck drivers shift type and off duty hours in relation to time spent in bed and sleep time. (1996)

A partial explanation for such small amounts of sleep between quick shift changeovers may be the result of apprehension or fear of over sleeping. Torsvall and Akerstdt (1988) showed that ships' engineers on call show reduced sleep but also a decreased quality of sleep which they attributed to apprehension. This has also been found in physicians in smaller hospitals and appears to be followed by increased sleepiness during the following day (Akerstedt & Gillberg, 1990).

Other reasons for the low levels of actual rest achieved is due to the other activities that must be performed during the off-duty period. For pilots on layovers, these activities include getting to and from the hotel, meals, and personal hygiene. These activities clearly take away from the time available to sleep (Samel et al., 1997).

Reduced Rest

Research on the effects of sleep reduction on physiological and task performance has failed to provide a consistent picture of how much sleep may be reduced before a significant impact on performance occurs. Some of the reasons for this were described previously in the section entitled "Measuring Fatigue." Carskadon and Dement (1981) reduced subjects' sleep to only five hours per night over seven days, resulting in a 60 percent increase in sleep tendency. Based on this study and others, Carskadon and Roth (1991) conclude that as little as two hours of sleep loss can result in both performance decrements and reductions in alertness. Wilkinson (1968) varied sleep quantity by allowing subjects 0, 1, 2, 3, 5, or 7.5 hours in which to sleep. Significant decreases in vigilance performance were found the following day when sleep was reduced below three hours for one night or fewer than five hours for two consecutive nights. Carskadon, Harvey and Dement (1981) found increased daytime sleepiness, as measured by the MSLT, after one night of sleep reduced to four hours in a group of 12-year-olds, although performance decrements were not found.

Restriction of sleep in young adults to just 5 hours increases sleepiness on the MSLT the next day by 25 percent and by 60 percent the seventh day (Carskadon & Dement, 1981). When sleep was reduced to five hours or less, performance and alertness suffered and sleepiness significantly increased (Wilkinson et al., 1966; Johnson, 1982: Carskadon & Roth, 1991; Gillberg & Akerstedt, 1994; Taub & Berger, 1973; Carskadon & Dement, 1981). A recent study of Australian truckers found that 20 percent of drivers sleep 6 hours or less and account for 40 percent of the hazardous events reported (Arnold et al., 1997). During Operation Desert Storm, the pilots of the Military Airlift Command flights obtaining only 11 hours sleep in 48 hours were found to be in danger of experiencing difficulties in concentrating and staying awake (Neville et al., 1992). Further pilot observations indicated that to prevent fatigue in these pilots, at least 17 hours of sleep in 48 hours (7.5 hours/ 24 hours) were required.

Dinges (1997) showed significant cumulative effects of sleep debt on waking functions when subjects were restricted from their usual 7.41 hours sleep to only 4.98 hours (sd .57 hrs) of usual sleep (67 percent). Across the seven or eight days of sleep restriction subjects showed increasing levels of subjective sleepiness, fatigue, confusion, tension, mental exhaustion indicators, stress, and lapses increasing in frequency and duration. These escalating changes provide strong evidence that partial sleep restriction similar to that experienced by pilots has cumulative effects similar to those found in total or more extreme partial restriction.

In contrast, Hockey's (1986) analysis of partial sleep deprivation study findings revealed minimal performance changes but there were significant reductions in vigilance, efficiency, and increased subjective sleepiness with and mood deterioration.

These results suggest that reducing rest by an hour should have little impact on a pilot's performance if the pilot is well rested prior to the reduced rest. If the pilot is suffering from sleep debt prior to the reduced rest, there may be an impact on the pilot's performance. If so, a reduced duty period should follow the reduced rest period in order to compensate for the possibility that the pilot may be more susceptible to time-since-awake effects.

Required Recovery Time

Complete recovery from a sleep debt may not occur after a single sleep period (Carskadon & Dement, 1979; Rosenthal et al., 1991). Typically, two nights of recovery are required (Carskadon & Dement, 1979; Kales et al., 1970), although the required recovery period may depend on the length of prior wakefulness (Carskadon & Dement, 1982). For example, Kales et al. (1970 found that restricting sleep to 5 hours per night for 7 days, which more closely resembles crew sleep patterns, required only a single extended night of sleep of 10 hours for full recovery. Morris (1996) found fatigue resulting from the loss of 4.5 hours of sleep in one night was not adequately restored in spite of 9 hours of sleep on one recovery night. Studies of C-141 crews flying to Southeast Asia during the Vietnam Conflict found that three nights were required before sleep returned to normal on the fourth night (Hartman, 1971). These results were observed even though the crews averaged 7.5 hours sleep per night.

The research also suggests that sleep debt following extended flight duty periods will only be effective if the sleep opportunity occurs at a time when the individual's circadian cycle will support effective utilization of that opportunity. The quantity of sleep gained depends more upon the circadian phase at which sleep is attempted rather than the length of prior wakefulness (Strogatz, Kronauer & Czcisler, 1986; Wever, 1985; Aschoff et al., 1975).

Conclusions

There appears to be substantial evidence that a minimum of eight hours of sleep is required for most people to achieve effective levels of alertness and performance. This rest level also enables the individual to cope with reduced rest should the need arise. Achieving the required eight hours under layover conditions depends upon the length of the off-duty period. The data suggest that an off-duty period of ten hours may not be sufficient to support an eight-hour sleep opportunity.

Reducing the rest period by an hour should have little effect on pilot alertness and performance if the individual is well rested. Reduced sleep, when accompanied by an existing sleep debt, diminishes performance and the ability of the individual to maintain alertness throughout the duty period, especially if a long time since awake is involved.

Recovery from sleep debt often requires two nights of rest. This result puts into question the effectiveness of extending the off-duty period following an extended duty period. Also, if no sleep debt is allowed to accumulate, it is not clear that weekly breaks are required. However, the data suggest that sleep debt is likely to accumulate if 10-hour off-duty periods are used.

The Circadian Cycle and Fatigue

Biological Circadian Rhythms

Chronobiology is the study of time-dependent changes in various levels of the physiologic organization from the organism as a whole, to the cell, to the genetic material itself. These changes regularly reoccur in a predictable rhythmic fashion and are referred to as oscillations.

The oscillations appear as waves, and the time to complete one full wave cycle is called a "period." They are divided into three groups by length of the rhythm. Ultradian are rhythms of 20 hours or less. Circadian encompasses rhythms between 20-28 hours, and Infradian are rhythms greater than 28 hours. The latter include rhythms called circaseptan (7 days, ± 3 days), circadiseptan (14 days ± 3 days), circavigintan (21 days, ± 3 days), circatrigintan (30 days, ± 5 days) and circaannual (one year, ± 3 months). According to Haus & Touitou (1994) there is evidence of 7 day, 30 day and annual rhythms in humans, as well as the circadian and ultradian rhythms.

Circadian rhythms have been recognized for decades. Yet the biological clock that regulates the 24-hour physiological and behavioral rhythms was not identified until the 1970s. These two bilaterally located nuclei called the suprachiasmic nuclei (SCN) are located above the optic chiasm in the anterior hypothalamus. These nuclei are considered the circadian pacemakers. Destruction of these nuclei produce an arrhythmia and severe disruption between behavior and physiological parameters including the timing of food intake and sleep. They appear not to regulate the amount of either of these behaviors (Turek & Reeth, 1996).

Signals produced by the SCN are both hormonal and neural. Grafted nuclei without neural connections restore circadian rhythms of eating and activity. Melatonin secretions, however, are not restored, suggesting neuron control. Melatonin receptors have been found in the SCN and appear to be part of a feedback mechanism that causes shifts in the circadian clock. The SCN has been found to possess its own built-in rhythm. Evidence gathered thus far indicates that SCN receive information about the light-dark cycle via two neural pathways from the optic nerve, one from the retinohypothalamic tract and the other through the geniculohypothalamic tract. The latter pathway appears to provide information or signals that help with reentrainment after a shift in the light-dark cycle. But recent research appears to indicate that other photo receptors may also be involved in the entrainment process (Campbell & Murphy, 1998)

Peak levels of physiological functioning occur during the light phase of the light/dark cycle. This synchronization of physiological rhythms enhances work performance during the daytime and supports sleep at night by turning down the metabolic thermostat. The internal synchronization of the variable metabolic parameters with the light/dark cycle are tuned for optimal functioning. Over 100 biological rhythms are genetically generated within the human body, then entrained or synchronized to better work in concert (Wehr, 1996; Takahasi, 1996). The greater the synchronization between hormone production, metabolic rate, enzyme and neurotransmitter synthesis, the higher the amplitude of the rhythm and the greater the communication between the body's cells. Thus, the maintenance of a strong circadian rhythm carries with it considerable ramifications for good health, well-being, and functioning (Wehr, 1996).

The suprachiasmic nuclei, together with the pineal gland, function as metabolic and behavioral concert conductors in cue with environmental factors such as light/dark, meal timing, social interaction, and physical activity. This synchronization of internal and behavioral with the external environment around the 24 hour day (*circa*=about: *dies*=day) is called circadian rhythm entrainment.

Although other internal and external factors do play a role, the light-dark cycle is the major entrainment factor for most of the animal kingdom. For humans, though, the light-dark cycle is felt to be a relatively weak synchronization of the human circadian rhythm for two reasons. Compared to other animals, the light sensitivity threshold as a synchronizing factor is considerably elevated. For comparison, the light intensity required for circadian synchronization in a hamster is only .5 lux, whereas for humans estimates range from 1200-2500 lux (Reinberg & Smolensky, 1994). This raises questions about the adequacy of indoor lighting. Second, man is the only species that lives outside of the day/night cycle.

Social environment appears to play a more important role in entrainment. Social factors that can alter the biological clock regulation of circadian rhythms include temperature, flight duty, stress, meal consumption, and food presentation (Samel & Wegmann, 1987). Exercise or activity also appears to help retrainment after circadian disruption. Ferrer et al. (1995) cite evidence that physical fitness predicts how well a person adapts to shift work changes regardless of its entrainment potential. Individuals who are physically fit and exercise regularly have higher circadian rhythm amplitudes than unfit individuals, and those with high circadian rhythm amplitudes are more tolerant of shift work (Ferrer et al., 1995). This helps to explain why age-related flattening of circadian rhythms is related to increased sleep difficulties, poor adjustment to night work and transmeridian flights in those over 50.

Back of the Clock Operations, Circadian Rhythm and Performance

There is a substantial body of research that shows decreased performance during night shifts as compared with day shifts. The reasons for this decreased performance include:

- Circadian pressure to sleep when the individual is attempting to work.
- Circadian pressure to be awake when the individual is attempting to sleep.
- Time since awake may be substantial if the individual is up all day before reporting for the night shift.
- Cumulative sleep debt increase throughout the shift.

Research conducted by Monk et al. (1989) indicates that subjective alertness is under the control of the endogenous circadian pacemaker and one's sleep-wake cycle (time since awake). When time since awake is long and coincides with the circadian low there is a very sharp drop in alertness, a strong tendency to sleep and a significant drop in performance (Perelli, 1980). Alertness is relatively high when the circadian rhythm is near the acrophase and time since awake is small. Monk (1996) argues that this cycle is consistent with the NTSB (1994) finding of a peak accident rate occurring in the evening. The strength of the circadian cycle is substantial. Akerstedt

(1989) argues that, up to 24 hours without sleep, circadian influences probably have greater effects than time since awake.

In Japan, 82.4 percent of drowsiness-related near accidents in electric motor locomotive drivers (Kogi & Ohta, 1975) occur at night. Other landmark studies over the past several decades have documented the increase in accidents and error making. Klein et al. (1970) argue that their research with simulators proves that night flights are a greater risk than day flights. Their research found 75- to 100-percent mean performance efficiency decrements in simulator flights during the early morning hours, regardless of external factor such as darkness or increasing night traffic or possible weather conditions.

Task performance in a variety of night jobs has been compared with performance of their daytime counterparts, and results consistently show deterioration of performance on the night shift. Browne (1949) studied telephone operators' response time in answering incoming calls in relation to the hour of the day and found the longest response times occurred between 0300 and 0400 hours. Bjerner et al. (1955) examined gas company hourly ledger computations of gas produced and gas used over an 18-year period and found that recording error were highest at 0300 hours with a smaller secondary peak at 1500 hours. Hildebrandt et al. (1974), investigating automatic train braking and acoustical warning signal alarms set-offs, also found two peaks at 0300 and 1500 hours in these safety-related events. Similar finding have been reported in truck accidents (Harris, 1977) and in Air Force aircraft accidents (Ribak et al., 1983). Other accident analyses of time of day and hours of work show that both circadian rhythm and hours of duty play a significant role in the occurrence of accidents (Folkard, 1997; Lenne et al., 1997). In addition, the incidence of accidental injury nearly doubles during the night shift compared to morning shift, while the severity of injury increases 23 percent (Smith et al., 1994). Night nurses make nearly twice the patient medication errors as day nurses and experience nearly three times the auto accidents commuting to and from work (Gold et al., 1993).

Akerstedt (1988) reviewed the effects of sleepiness from night shift work and found that the potentially hazardous situation resulting from increased sleepiness during night shift is real and underestimated. Akerstedt (1988) also reports that fatigue in shift workers is higher than in day workers, highest in night workers, followed by morning workers. Overall, sleepiness among night workers is estimated to be around 80 to 90 percent. Roth et al. (1994) indicate that rates for workers falling asleep on the job while on night shift have been reported to be as high as 20 percent.

Night operations are physiologically different than day operations due to circadian trough and sleep loss. This carries a higher physiological cost and imposes greater risks of accidents. One of the most established safety issues is working in the circadian trough between 0200 and 0600. During this period workers experience considerable sleepiness, slower response times, increased errors and accidents (Mitler, 1991; Pack, 1994). Many recent accidents from various transportation modes have been associated with this circadian trough (Lauber & Kayten, 1988).

Lyman and Orlady (1981), in their analysis of the Aviation Safety Reporting System researcher state that 31 percent of incidents occurring between 2400 to 0600 hours were fatigue related.

Gander et al. (1996) found that overnight cargo pilots exhibited partial adaptation to night work with a nearly 3-hour phase shift in the lowest body temperature, with subjective fatigue and activation peaking shortly thereafter. Despite this, pilots still experienced a three-fold increase in multiple sleep episodes (53 percent versus 17 percent) and a 1.2 hour sleep debt per night compared with pre-trip sleep length.

In some cases, the high fatigue levels found may be due to time since the last sleep. Pokorny et al. (1981) analyzed bus driver accidents over a five-year period and found that, although the time of day affected some incidents, one of the most important factors in driver accidents was how early drivers reported to work. Those reporting in between 0500-0600 had about six times as many the accidents as those reporting between 0700-0800. A peak in accidents also occurred two to four hours after beginning the shift.

If an individual has been awake for 16 to 18 hours, decrements in alertness and performance are intensified. If time awake is extended to 20 to 24 hours, alertness can drop more than 40 percent (WRAIR, 1997; Morgan et al., 1974; Wehr, 1996). A study of naval watch keepers found that between 0400 to 0600, response rates drop 33 percent, false reports rates 31 percent, and response speed eight percent, compared with rates between 2000 to 2200 hours (Smiley, 1996).

Samel et al. (1996) determined that many pilots begin night flights already having been awake more than 15 hours. The study confirms the occurrence of as many as five micro-sleeps per hour per pilot after five hours into a night flight. They also found that 62 percent of all pilots studied rated their fatigue great enough to be unable to fly any longer after their night flight. This explains earlier findings in long haul return night flights that showed significant physiological markers of higher stress. Upon return to home base after flying two night flights (outbound and return) pilots average 8 to 9 hours of sleep debt. Although flights varied from north-south and east-west with layover length from 14 hours to 4.5 days, sleep debt appeared similar. East-west flights had significantly longer layovers but were disruptive to circadian rhythms. The authors concluded that "During day time, fatigue-dependent vigilance decreases with task duration, and fatigue becomes critical after 12 hours of constant work. During night hours fatigue increases faster with ongoing duty. This led to the conclusion that 10 hours of work should be the maximum for night flying."

Gander et al. (1991) found in an air carrier setting that at least 11 percent of pilots studied fell asleep for an average of 46 minutes. Similarly, Luna et al. (1997) found that U.S. Air Force air traffic controller fell asleep an average of 55 minutes on night shift. A possible explanation for these sleep occurrences, in addition to circadian nadir, is the finding of Samel et al. that many pilots begin their night flights after being awake for as long as 15 hours.

The effect of time since the last sleep is even greater if a sleep debt already exists. An NTSB heavy trucks accident analysis (NTSB. 1996) clearly shows that "back of the clock" driving with a sleep debt carries a very high risk. Of 107 single-vehicle truck accidents. 27 drivers exceeded the hours of duty. Ninety-two percent (26) of these had fatigue-related accidents. The NTSB report also shows that 67 percent of truck drivers with irregular duty or sleep patterns had fatigue-related accidents compared to 38 percent in drivers with regular duty or sleep patterns. Irregularity resulted in a decrease of 1.6 hours on average in sleep with a total of only 6.1 hours compared to 7.7 hours in regular pattern drivers. The NTSB report indicated that they could not determine whether irregular duty/sleep patterns per se led to fatigue but some experimental data support this notion. The findings of the NTSB not only found shifted sleep patterns but this shift was coupled with sleep loss. Taub and Berger (1974), while maintaining sleep length, shifted sleep times and found that performance on vigilance, calculation tasks, and mood were significantly impaired. Furthermore, Nicholson et al. (1983) showed that irregular sleep/work resulted in increasing performance impairments which was further increased by time on task, cumulative sleep loss, and working through the circadian nadir.

Performance can also be affected by cumulative fatigue buildup across multiple days. Gundel (1995) found that pilots flying two consecutive nights with 24 hours between flights slept about two and a half hours less during their daytime layovers (8.66 hours versus 6.15 hours), and experienced a significant decline in alertness on the second night flight. Alertness during the first six hours in both flights appeared to be the same. The latter part of the second flight showed increased desynchronization of EEG alpha wave activity, indicating lower levels of alertness. Spontaneous dozing indicated an increased susceptibility sleep. Subjectively, pilots felt greater fatigue on the second night. Therefore, with time since awake being the same, sleep quality and quantity during the daytime layover resulted in increased fatigue.

Samel et al. (1997) monitored 11 night flight rotations from Frankfort to Mahe/Seychelles crossing three time zones. Pilots slept on average eight hours on baseline nights. On layover, sleep was reduced to 6.3 hours. Pilots arrived at SEZ after 22 hours of being awake (except for approximate 1.5 hour nap prior to departure). Fatigue scores increased over both outbound and inbound flights with 12.4 micro-sleeps per pilot outbound and 24.7 on return. Prior to the outbound FRA-SEZ flight 85 percent of pilots felt rested whereas on return only 30 percent reported feeling so. These studies document that night flights are associated with reduced sleep quantity and quality, and are accompanied by cumulative sleep debt.

Borowsky and Wall (1983) found that flight-related accidents in Navy aircraft were significantly higher in flights originating between 2400 and 0600 hours. The higher mishap incidence was felt to be the result of circadian desynchronization and disrupted sleep-wake cycle. Sharppell and Neri (1993) divided the operational day of navy pilots in Desert Shield and Desert Storm operations in to four quartiles beginning at 0601-1200 with 0001 to 0600 being the fourth quartile. They found that there was a progressive increase in pilots' subjective need for rest between flights as flights originated later and later in the day from quartile 1 to quartile 4. In addition multiple missions and cumulative days flying also increased the pilots subjective need for additional rest between missions. The latter effect is the cumulative effect of fatigue. As sleep time increased before a flight the subjective rest needed before the next flight decreased.

Sleep Patterns During The Day

Simply providing pilots with the opportunity to rest during the day may not be sufficient to compensate for the demands of night flying. Night workers have been shown to sleep on average one and a half hours less each day than day workers (Minors & Waterhouse, 1984). Depending on type of shift and rotation, there can be as much as three hours sleep deficit. Czeisler et al. (1980) showed that sleep duration was dependent on the circadian phase. Thus daytime sleep was significantly reduced compared to night time sleep.

The propensity to sleep is high during the night and low during the day. But there is a gradient effect in sleepiness. Between six and 12 hours awake, sleepiness in control subjects increased seven percent; between six and 18 hours, 28-37 percent (Minor & Waterhouse, 1987; Minor et al.; 1986). This is the result of a myriad of other rhythms—hormonal, secretory, temperature—that orchestrate an internal environment for action during the day and for rest at night. The effect of circadian rhythm on performance is illustrated in the findings of a sleep deprivation study on multi-task performance. Czeizler et al. (1994) points out that alertness and performance would normally decline as a function of time since awake, except when coupled to the circadian rise in body temperature, the two functions stay relatively stabile through most of the waking hours. The beginning of a drop in alertness starts three to four hours prior to normal bedtime. At bedtime there is a sudden and dramatic—18-20 percent—fall in performance and alertness, coinciding with the rapid drop in body temperature.

Night work which requires daytime sleep has been shown to reduce the amount of sleep obtained whether on permanent night or rotating shifts (Colligan & Tepas, 1986). In quick changeovers with 8 hours off between shifts, Totterdell (1990) found workers only acquired 5.14 hours sleep. Kurumatani (1994) observed that workers getting off at 1600 hrs and required to began again at 2400 hours slept 2.35 hrs. On a similar shift change but getting off 1200 hrs and returning to duty at 2400 hrs workers were only able to get 3.0 hrs sleep. These researchers found a correlation ($r=.95$) between the hours between shift and sleep duration. They concluded that at least 16 hours off duty time were needed between shifts to insure 7-8 hour sleep, a conclusion reiterated in a recent review (Kecklund & Akerstedt, 1995).

Transmeridian Operations

Transmeridian operations create similar problems in attempting to work when the body wants to sleep and sleep when the body wants to be awake. The biggest challenge posed by multiple time-zone flights is the time required for the body to adjust to the new time zone. The period of adjustment appears to depend on the direction of travel. Adjustment appears to be faster after westward flights than eastward flights (Klein & Wegmann. 1980). Adjustment following westward flights appears to occur at a rate of about 1.5 hours per day while eastward-flight adjustment occurs at about 1 hour per day. This may be due to the body's inherent tendency to lengthen its period beyond 24 hours. which coincides with westward flights. These data also suggest that phase shifts below six hours can have a significant impact (Aschoff et al., 1975).

Aside from the obvious implications for transmeridian operations, these data also apply to reserve pilots whose protected sleep opportunity may vary as to its occurrence across assignments. Even if a protected time period is predictable, unless it includes the night hours, it may not provide an effective opportunity for sleep and thus may not lessen fatigue.

Conclusions

The following conclusions can be drawn from the research cited above:

- An individual's WOCL should be defined on the basis of the time zone where he/she resides, which may be different from the home domicile.
- Duty periods conducted during WOCL already carry a fatigue penalty due to the circadian cycle. Consequently, duty periods involving WOCL should be reduced.
- The number of duty periods involving WOCL that must be performed without time off should be limited.
- Because the circadian cycle is longer than 24 hours. each duty period should start later than the previous duty period.
- Reserve assignments should attempt to maintain a consistent 24-hour cycle.
- Direction of rotation for both back-of-the-clock flying and direction of transmeridian operations should be considered. Given the body's preference for extending the day, backward rotation should be used when possible.
- Transmeridian operations should be scheduled in accordance with either of two approaches:
  - For short periods, it may make sense to attempt to keep the pilot on home-domicile time.
  - For longer periods, reducing the duty period and providing more opportunities to sleep may be the best approach.

Augmented Crews

Little research has been performed to assess the effectiveness of managing fatigue through the use of augmented flight crews. However, two recent NASA projects have been initiated to study long-haul augmented flight operations (Rosekind et al., 1998). The first project used a survey to examine factors that promoted or interfered with sleep in crew quarters installed on aircraft. Results were collected from more than 1,400 crewmembers from three participating U.S. airlines. It was concluded that, even though some difficulties were noted, flight crewmembers were able to obtain a reasonable amount and quality of sleep while resting in on-board bunks. Further, the sleep obtained was associated with improved alertness and performance. This study also identified factors that could be used to develop strategies to obtain optimal sleep.

The second project was a field study that examined the quantity and quality of sleep obtained in on-board bunks during augmented, long haul flights. Data were collected from two airlines involved in different types of international operations, and a corporate operator. Preliminary results showed that crewmembers obtained a good quantity and quality of sleep. Additional analyses are presently being conducted.

Conclusion

A review of the scientific literature pertaining to fatigue, sleep, and circadian physiology was performed in order to identify the major issues that need to be considered in developing a regulatory approach to pilot fatigue and sleep debt. The conclusions developed for each issue reflect areas that might benefit from additional FAA consideration.

References

Akerstedt, T. (1989). A review of sleep/wake disturbances in connection with displaced work hours in flight operations. *Stress Research Reports*, No 218, National Institute for Psychological Factors and Health, Dept. Stress Research, Karolinska Institute, Sweden.

Akerstedt, T. (1995). Work injuries and time of day—National data. *Proceedings of a Consensus Development Symposium entitled "Work Hours, Sleepiness and Accidents"*. Stockholm, Sweden, 8-10 Sept. 1994:106. Cited by Rosa, R. R. (1995). Extended workshifts and excessive fatigue. *Journal of Sleep Research*, 4, 51-56.

Akerstedt, T., Gillberg, M. (1990). Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience*, 52, 29-37.

Angus. R. C., Heselgrave. R. J. (1985) Effects of sleep loss on sustained cognitive performance during a command and control situation *Behavior Research Methods, Instruments, and Computers*, 17, 55-67.

Angus. R. G., and Heselgrave R. J. (1983). The effects of sleep loss and sustained mental work: Implications for command & control performance. *Sustained Intensive Air Operations: Physiological and Performance Aspects*. AGARD Conference Proceedings No. 338, 11.1-11.21.

Arnold, P. K., Hartley, L. R., Corry, A., et al. (1997). Hours of work, and perceptions of fatigue among truck drivers. *Accident Analysis and Prevention*, 29, 471-477.

Aschoff, J.I, Giedke, H., Poppel, E., & Wever, R. (?). The influence of sleep-interruption and of sleep-deprivation on circadian rhythms in human performance.

Baker, T. L. (1996, June 19). Proposed changes in FAA flight and duty regulations: A scientific critique of supporting evidence. In: *Comments Of The Air Transport Association of America to FAA Notice 95-18. FAA Docket No. 28081*.

Barth, J., Holding, D. H., & Stamford, B. A. (1976). Risk versus effort in the assessment of motor fatigue. *Journal of Motor Behavior*, 8, 189-194.

Belenky, G., Balkin, T., Krueger, G., Headley, D., Solick, R. (1986). *Effects of Continuous Operations (CONOPS) on Soldier and Unit Performance Phase I Review of the Literature*. Ft. Leavenworth, KS: US Army Combined Arms Combat Developments Activity.

Belenky, G., Penetar, D. M., Thorne, D., Popp, K., Leu, J., Thomas, M., Sing, H., Balkin, T., Wesensten, N., Redmond, D. (1994). The Effects of Sleep Deprivation On Performance During Continuous Combat Operations. In *Food Components to Enhance Performance*, (1994) National Academy Press. Washington DC Pg 127-135

Bills, A. G. (1931). Blocking: A new principle in mental fatigue. *American Journal of Psychology*, 43, 230-245.

Bjerner, B., Holm, A., Swensson, A. (1955). Diurnal variation in mental performance: a study of three-shift workers. *British Journal of Industrial Medicine*, 12(2): 103-10.

Bonnet, M. H. (1994). Sleep deprivation. In M. H. Kryger, T. Roth, & W. C. Dement (Eds.), *Principles and Practice of Sleep Medicine (2nd Edition)*. Philadelphia: W.B. Sauders.

Bonnet, M. H., Arand, D. L. (1995). We are chronically sleep deprived. *Sleep*, 18(10): 908-911.

Bonnet, M. H & Moore, S. E. (1982). The threshold of sleep: Perception of sleep as a function of time asleep and auditory threshold. *Sleep*, 5, 267-276.

Borowsky, M. S., Wall, R. (1983). Naval aviation mishaps and fatigue. *Aviation, Space, and Environmental Medicine*, 54: 535-538.

Braun, A. R., Balkin, T. J., Wesensten, N. J., Carson, R. E., Varga, M., Baldwin, P., Selbie, S., Belenky, G., Herscovitch, P. (1997). Regional Cerebral Blood Flow Throughout the Sleep-Wake Cycle: An $H_2{}^{15}0$ PET Study. *Brain*, 120, 1173-1197.

Broadbent, D. E. (1953). Neglect of the surrounding in relation to fatigue decrements in output. In W. F. Floyd & A. T. Welford (Eds.), *Symposium on Fatigue*. London: Lewis.

Broadbent, D. E. (1958). *Perception and Communication*. Pergamon.

Brown, I. D., Tickner, A. H., & Simmons, D. C. (1970). Effect of prolonged driving on overtaking criteria. *Ergonomics*, 13, 239-242.

Browne, R. C. (1949). The day and night performance of teleprinter switchboard operators. *Occupational Psychology*, 23(2): 121-6.

Bursill, A. E. (1958). The restriction of peripheral vision during exposure to hot and humid conditions. *Quarterly Journal of Experimental Psychology*, 10, 113-129.

Campbell, S. S., & Murphy, P. J. (1998). Extraocular circadian phototransduction in humans. *Science*, 279 (5349).

Carskadon, M. A., & Dement, W. C. (1979). Sleep tendency during extension of nocturnal sleep *Sleep Research*, 8: 147.

Carskadon, M., Brown, E. D., & Dement, W. C. (1982). Sleep fragmentation in the elderly: relationship to daytime sleep tendency. *Neurobiology of aging*, 3, 321-7.

Carskadon, M. A., & Dement, W. C. (1979). Effects of total sleep loss on sleep tendency. *Perceptual & Motor Skills*, 48, 495–506, 1979.

Carskadon, M. A., & Dement, W. C. (1981). Cumulative effects of sleep restriction on daytime sleepiness. *Psychophysiology*, 18, 107–113.

Carskadon M. A., & Dement, W. C. (1982). Nocturnal determinants of daytime sleepiness. *Sleep*. 5, S73–81.

Carskadon MA, & Roth T. (1991). Sleep restriction. In T. H. Monk (Ed.), *Sleep, Sleepiness and*

Performance. Chichester: Wiley.

Carskadon, M. A., Brown, E., & Dement, W. C. (1982). Sleep fragmentation in the elderly: Relationships to daytime sleep tendency. *Neurobiology of Aging*. 3, 321-327.

Carskadon, M. A., Harvey, K., & Dement, W. C. (1981). Sleep loss in young adolescents. *Sleep*. 4, 299-312.

Carskadon, M. A., van den Hoed, J., Dement, W. C. (1980). Sleep and daytime sleepiness in the elderly. *Journal of Geriatric Psychiatry*, 13, 135-151.

Chambers, E. A. (1961). Industrial Fatigue. *Occupational Psychology*, 35, 44-57.

Colligan, M., Tepas, D. (1986). The stress of hours of work. *American Industrial Hygiene Association Journal*, 47, 686-695.

Colquhoun, P. (1976). Psychological and psychophysiological aspects of work and fatigue. *Activitas Nervosa Superior*, 18, 257-263.

Colquhoun, W. P. (1985) In S. Folkard & T. H. Monk (Eds.), *Hours of Work*.

Czeisler, C. A., Dijk, D. J., & Duffy, J. F. (1994). EntrainedpPhase of the circadian pacemaker serves to stabilize alertness and performance throughout the habitual waking day. In R. D. Ogilvie & J. R. Harsh (Eds.), *Sleep Onset: Normal and Abnormal Processes*. American Psychological Association.

Czeisler, C. A., Weitzman, E. D., Moore-Ede, M. C., Zimmerman, J. C., & Knauer, R. S. (1980) Human sleep. Its duration and organization depend on its circadian phase. *Science*. 210, 1264-1267

Davis-Sharts, J. (1989). The elder and critical care: Sleep and mobility issues. *Nursing Clinics of North America*, 24, 755-767.

Dawson, D., & Reid, K. (1997). Fatigue, alcohol and performance impairment. *Nature*, 388, 235.

Dejoy, D. M. The nonauditory effects of noise: Review and perspectives for research. *Journal of Auditory Research*, 24, 123-150.

Dement, W. C., Carskadon, M. A. (1981) An essay on sleepiness. In M. Baldy-Moulinier (Ed.), Actualites en medecine experimentale, en hommage au Professeur P. Passouant (pp. 47-71). Montpellier: Euromed. From *Sleep: A Scientific Perspective* pp.53-54.

Dement, W. C., Carskadon, M. A., Richardson, G. S. (1978). Excessive daytime sleepiness in the sleep apnea syndrome. C. Guilleminault & W. C. Dement (Eds.). Sleep Apnea Syndromes. New York, Alan R. Liss.

Dement, W. C., Seidel, W. F., Cohen, S. A., Bliwise, N. G., Carskadon, M. A. (1986). Sleep and wakefulness in aircrew before and after transoceanic flights. *Aviation, Space, and Environmental Medicine*, 57, B14-B28.

Dinges, D. F. (1989). The nature of sleepiness: causes, contexts, and consequences. In A. J. Stunkard & A. Baum (Eds), Perspectives in Behavioral Medicine: Eating, Sleeping, and Sex. Hillsdale, NJ: Erlbaum.

Dinges, D. F. (1995). Performance effects of fatigue. *Fatigue Symposium Proceedings*. Washington, DC: National Transportation Safety Board.

Dinges, D. F., Graeber, R. C., et al. (1996). Principles and guidelines for duty and rest scheduling in commercial aviation. *NASA Technical Memorandum 110404*, Para 1.1.1.

Dinges DF and Kribbs NB. (1991). Performing while sleepy: effects of experimentally-induced sleepiness. In T. H. Monk (Ed.), *Sleep, Sleepiness and Performance*. Chichester: Wiley.

Dinges DF, Pack F, Williams K, Gillen KA, Powell JW, Ott GE, et al. (1997). Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4–5 hours per night. *Sleep*, 20, 267–277.

Evans, S. M., Mackie, R. R., & Wylie, C. D. (1991, August). *Fatigue Effects on human performance in combat: A literature review*. US Army Research Institute for the Behavioral and Social Sciences, ARI Research Note 91-90.

Ferrer, C. F., Bisson, R. U., & French, J. (1995). Circadian rhythm desynchronosis in military deployments: a review of current strategies. *Aviation, Space, and Environmental Medicine*, 66, 571-578.

Folkard S. (1997). Black times: Temporal determinants of transport safety. *Accident Analysis and Prevention*, 29, 417-430.

Gander, P. H., Graeber, R. C., Connell, L. J., & 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 103852*.

Gander, P. H., Graeber, R. C., Foushee, H. C., Lauber, J. K., & Connell, L. J. (1994). Crew

Factors in Flight Operations II: Psychophysiological responses to short-haul air transport operations. *NASA Technical Memorandum 1:5856.*

Gevins, A., Leong, H., Du, R., Smith, M. E., Le, J., DuRousseau, D., Zhang, J., Libove, J. (1995). Toward measurement of brain function in operational environments. *Biological Psychology*, 40, 169-186.

Gold, P. E. (1995). Role of glucose in regulating the brain and cognition. *American Journal of Clinical Nutrition*, 61; Suppl:pgs. S987-S995.

Graeber, R. C. (1985). Proceedings of the Flight Safety Foundation 38th International Air Safety Seminar.

Graeber, R. C. (1988). Air crew fatigue and circadian rhythmicity. In *Human Factors in Aviation* (pp. 305-344). Academic Press.

Graeber, R. C., Lauber, J. K., Connell, L. J., Gander, P. H. (1986). International aircrew sleep and wakefulness after multiple time zone flights: A cooperative study. *Aviation, Space, and Environmental Medicine*, 57, B3-B9.

Gundel, A., Drescher, J., Maab, H., Samel, A., Vejvoda, M. (1995). Sleepiness of civil airline pilots during two consecutive night flights of extended duration. Biological Psychology, 40, 131-141.

Habte-Gabr, E., Wallace, R. B., Colsher, P. L., Hulbert, J. R., White, L. R., Smith, I. M. (1991). Sleep patterns in rural elders: demographic, health, and psychobehavioral correlates. *Journal of Clinical Epidemiology*, 44, 5-13.

Hamelin, P. (1987) Lorry Driver's Time Habits in Work and Their Involvement in Traffic Accidents. *Ergonomics*, 30, 1323-33.

Hamilton, P., Wilkinson, R. T., & Edwards, R. S. (1972). A study of four days partial sleep deprivation. In W. P. Colquhoun (Ed.), *Aspects of Human Efficiency* (pp. 101-113).

Harris, W. (1977). Fatigue, circadian rhythm, and truck accidents. In: *Vigilance: Theory, Operational Performance, and Physiological Correlates*, (Ed.) Mackie, R. R., 133-147, Plenum Press, NY.

Harris, W., & Mackie, R. R. (1972). *A study of the relationships among fatigue, hours of service, and safety of operations of trucks and bus driving.* (Report No. BMCS-RD-71-2.) Washington, DC: United States Department of Transportation, Federal Transit Administration, Bureau of Motor Carrier Safety.

Harrison, Y., Horne, J. A. (1997). Sleep deprivation affects speech. *Sleep*. 20. 871-877.

Hartman, B. O. (1971). Field study of transport aircrew workload and rest. *Aerospace Medicine*. 42(8): 817-821.

Haus, E., & Touitou, Y. (1994). Principles of clinical chronobiology. In: *Biologic Rhythms in Clinical and Laboratory Medicine*, (Eds.) Touitou, Y., Haus. E., & Springer-Verlag, 6-34.

Hildebrandt, G., Rohmert, W., & Rutenfranz, J. (1974). 12 & 24 H rhythms in error frequency of locomotive drivers and the influence of tiredness. *International Journal of Chronobiology*, 2(2): 175-180.

Hockey, G. R. J. (1986). Changes in operator efficiency as a function of environmental stress, fatigue, and circadian rhythms. In K. R. Boff, L. Kaufman & J. P. Thomas (Eds.), *Handbook of Perception and Human Performance, Vol. II, Cognitive Processes and Performance*. John Wiley and Sons, New York.

Horne, J. A. (1988). Sleep loss and "divergent" thinking ability. *Sleep*. 11, 528-536.

Horne J. A. (1991). Dimensions to sleepiness. In T. H. Monk (Ed.), Sleep, Sleepiness and Performance. Chichester: Wiley.

Howitt, J. S., Hay, A. E., Shergold, G. R., & Ferres, H. M. (1978). Workload and fatigue—In-flight EEG changes. *Aviation, Space, and Environmental Medicine*. 49. 1197-1202.

Huntley M. S., & Perrine, M. W. (1973). A behavioral mechanism of alcohol-related accidents. In M. E. Chafetz (Ed.), *Proceedings of the First Annual Alcoholism Conference of the National Institute of Alcohol Abuse and Alcoholism. Research on Alcoholism: Clinical Problems and Special Populations*.

Johnson, L. C. (1982). Sleep Deprivation and Performance. In W. B. Webb (Ed.), *Biological Rhythms, Sleep, and Performance*. New York: John Wiley & Sons.

Johnson, L. C., Naitoh, P. (1974). *The Operational Consequences of Sleep Deprivation and Sleep Deficit*. AGARDograph No. 193, p.1-43.

Kales A, Tan T, Kollar EJ, et al. (1970). Sleep patterns following 205 hours of sleep deprivation. Psychosom Med, 32, 189–200.

Kecklund, G., & Akerstedt, T. (1995). Effect of timing of shifts on sleepiness and sleep duration. *Journal of Sleep Research*, 4, 47-50.

Kirsch, A. D. (1996, June 19). Report on the statistical methods employed by the U.S. FAA in its cost/benefit analysis of the proposed "Flight Crewmember Duty Period Limitations, Flight Time Limitations and Rest Requirements", Docket No. 28081. In: *Comments Of The Air Transport Association of America to FAA Notice 95-18, FAA Docket No. 28081.* Appendix D pp. 1-36.

Kjellberg, A. (1977). Sleep deprivation and some aspects of performance II. Lapses and other attentional effects. *Waking & Sleeping*, 1, 145-148

Kjellberg, A. (1977b). (see pg 44-20 in Handbook of Perception and Human Performance Vol. 2)

Klein, K. E., & Wegmann, H. M. (1980). Significance of circadian rhythms in aerospace operations. NATO AGARDograph Number 247. Neuilly sur Seine, France: NATO AGARD.

Kogi, K., & Ohta, T. (1975). Incidence of near accidental drowsing in locomotive driving during a period of rotation. *Journal Human Ergology*, 4(1): 65-76.

Kurumatani, N., Koda, S., Nakagiri, S., et al. (1994) The effects of frequently rotating shiftwork on sleep and the family life of hospital nurses. Ergonomics, Jun; 37(6):995-1007.

Lamberg, L. (1996). Knitting up the raveled sleeve of care: Role of sleep and effects of its lack examined. Oct 16; 276(15): 1205-1207.

Lauber JK and Kayten PJ. (1988). Sleepiness, circadian dysrhythmia, and fatigue in transportation system accidents. *Sleep*, 11(6):503–512.

Lavie, P., Kremerman, S., & Wiel, M. (1982). Sleep disorders and safety at work in industry workers. *Accident Analysis & Prevention*, 14, 311-314.

Lenne, M. G., Triggs, T. J., & Redman, J. R. (1997). Time of day variations in driving performance. *Accident Analysis and Prevention*, 29(4): 431-437.

Levine, B., Roehrs, T., Zorick, F., & Roth, T. (1988). Daytime sleepiness in young adults. *Sleep*, 11: 39-46.

Lille, F., Cheliout, F., Burnod, V., Hazeman, P. (1979). Effects of aging and occupational activity on active wakefulness. *Gerontology*, 25, 337-344.

Lisper, H. O., Laurell, H., & van Loon, J. (1986). Relation between time of falling asleep behind the wheel on a closed track and changes in subsidiary reaction time during prolonged driving on a motorway. *Ergonomics*, 29, 445-453.

Luna, T. D., French, J., & Mitcha, J. L. (1997). A study of USAF air traffic controller shiftwork: sleep, fatigue, activity, and mood analyses. *Aviation, Space, and Environmental Medicine*, 68(1) 18-23.

Lyman, E. G., Orlady, H. W. (1981, March 31). *Fatigue and Associated Performance Decrements in Air Transport Operations*. NASA Ames Research Center, Battelle Columbus Laboratories, ASRS Office.

Maher, K., & McPhee, B. (1994, April). *Flight crew duty and rest*. Sidney, Australia: Worksafe Australia.

McFarland, R. A. (1953). *Operational Aspects of Fatigue In Human Factors in Air Transportation*.

Miles, W. (1929). Sleeping with the eyes open. *Scientific American*, 140, 489-492.

Miles, L., & Dement, W. C. (1980). Sleep and aging. *Sleep*, 3, 1-220.

Mills, M. E., Arnold, B., Wood, C. M. (1983). Core-12: A Controlled Study of the Impact of 12-Hour Scheduling. *Nursing Research*, 32, 356-361.

Minors, D. S., & Waterhouse, J. M. (1984). The sleep-wakefulness rhythm, exogenous and endogenous factors (in man). *Experientia*, 40(5): 410-416.

Mitler, M. M. (1991). Two-peak 24-hour patterns in sleep, mortality, and error. In: *Sleep and Health Risk* (Eds.) Peter, J. H., Pengel, T., Podszus, T., von Wichert, P., & Springer-Verlag, NY. 65-77.

Mitler, M. M., Miller, J. C., Lipsitz, J. J., Walsh, J. K., Wylie, C. D. (1997). The Sleep Of Long-Haul Truck Drivers. *New England Journal of Medicine*, 337, 756-761.

Mohler, S. R. (1966). Fatigue in aviation activities. *Aerospace Medicine*, 37, 722-732.

Morris, T. L., Miller, J. C. (1996). Electroculographic and performance indices of fatigue during simulated flight. *Biological Psychology*, 42, 343-360.

Moskowitz, H. (1973). A behavioral mechanism of alcohol-related accidents. In M. E. Chafetz, (Ed.). *Proceedings of the First Annual Alcoholism Conference of the National Institute of Alcohol Abuse and Alcoholism. Research on Alcoholism: Clinical Problems and Special Populations*.

Mullaney, D. J., Fleck, P. A., Okudaira, N., Kripke, D. F. (1985). An Automated System for

Administering Continuous Workload and for Measuring Sustained Continuous Performance. *Behavioral Research Methods, Instruments, & Computers*, 17, 16-18.

Mullaney, D. J., Kripke, D. R., Fleck, P. (1991, August). Sleep loss effects on continuous sustained performance. Technical Report #1. San Diego: University of California Department of Psychiatry. (1981). Cited in Evans, S. M., Mackie, R. R., Wylie, C. D. *Fatigue Effects on Human Performance In Combat: A Literature Review*. US Army Research Institute for the Behavioral and Social Sciences, ARI Research Note 91-90.

National Commission on Sleep Disorders Research. (1993). *Wake Up America: A National Sleep Alert. Report of the National Commission on Sleep Disorders Research. Executive Summary and Executive Rreport.* Washington, DC: National Commission on Sleep Disorders Research.

National Transportation Safety Board. (1994, January). *A Review of Flightcrew-involved, Major Accidents of U.S. Air Carriers, 1978 Through 1990.* Safety Study: NTSB/SS-94-01.

Neri, D. F. Shappell, S. A., & DeJohn, C. A. (1992). Simulated sustained flight operations and performance. Part 1: Effects of fatigue. *Military Psychology*.

Neville, K. J., French, J., Bisson, R. U., Boll, P. A., Storm, W. F. (1992). Sleep and Flight Duration Effects On The Subjective Fatigue Of Pilots During Operation Desert Storm. *Proceedings of the Human Factors Society*, 102-105.

Nicholson, A. N. (1987). Sleep and wakefulness of the airline pilot. *Aviation, Space and Environmental Medicine*, 58, 395-401.

Nicholson, A. N., Stone, B. M., Borland, R. G., & Spencer, M. B. (1983). Adaptation to irregularity of rest and activity. In: *Sustained Intensive Air Operations: Physiological and Performance Aspects. AGARD Conference Proceedings*, No. 338, 12.1-12.6.

Ogilvie, R. D., Wilkinson, R. T. and Allison, S. L. (1989). The detection of sleep onset. Behavioral, physiological and subjective convergence. *Sleep*, 12, 458-474.

Pack, A. M., Cucchiara, A., Schwab, C. W., Rodgman, E., & Pack, A. I. (1994). Characteristics of accidents attributed to the driver having fallen asleep. *Sleep Research*, 23.

Perelli, L. P. (1980, December). *Fatigue Stressors in Simulated Long Duration Flight: Effects on Performance, Information Processing, Subjective Fatigue and Physiological Costs.* School of Aerospace Medicine, Brooks Air Force Base. Report No. SAM-TR-80-49.

Pokorny, M. L. I., Blom, D. H. J., van Leeuwen, P. (1981a). Analysis of Traffic Accident Data (From Bus Drivers)—An Alternative Approach (I). In A. Reinberg, N. Vieux & P. Andlauer

(Eds.). Night and Shift Work.

Pokorny, M. L. I., Blom, D. H. J., van Leeuwen, P (1981b). Analysis of Traffic Accident Data (From Bus Drivers)—An Alternative Approach (II). In A. Reinberg, N. Vieux & P. Andlauer (Eds.). Night and Shift Work.

Ptemitis, C. (1981). Shiftwork: Workload, fatigue and states of vigilance. In A. Reinbert, N. Vievn & P. Andlaver (Eds.), *Night and Shift Work: Biological and Social Aspects.*

Reinberg, A. E., & Smolensky, M. H. (1994). Night and shift work and transmeridian and space flights. In: *Biologic Rhythms in Clinical and Laboratory Medicine*, Springer-Verlag, NY, 243-255.

Restak, Richard M. (1988). *The Mind*. Bantam Books, NY. New York.

Ribak, J., Ashkenazi, I. E., et al. (1983). Diurnal rhythmicity and air force flight accidents due to pilot error. *Aviation, Space, and Environmental Medicine*, 54(12): 1096-1099.

Richardson, G. S., Carskadon, M. A., Orav, E. J., & Dement, W. C. (1982). Circadian variation of sleep tendency in elderly and young adult subjects. *Sleep*, 5, S82-94.

Roehrs T, Timms V, Zwyghuizen-Doorenbos A, and Roth T. (1989). Sleep extension in sleepy and alert normals. *Sleep*. 12, 449–457.

Rosa, R. R., & Bonnet, M. H. (1993). Performance and alertness on 8 h and 12 h rotating shifts at a natural gas utility. *Ergonomics*, 36, 1177-93.

Rosa, R. R., Colligan, M. J. (1987). Sleep quantity and quality under 8-hour and 12-hour rotating shift schedules. *Sleep Research*, 16, 811.

Rosekind, M. R., & Schwartz, G. E. (1988). Perception of sleep and wakefulness. I. Accuracy and certainty of subjective judgments. *Sleep Research*, 17, 89.

Rosekind, M. R., Graeber, R. C., Dinges, D. F., Connell, L. J., Roundtree, M. S., Spinweber, C. L., Gillen, K. A. (1994, July). *Crew factors in flight operations IX: Effects of planned cockpit rest on crew performance and alertness in long-haul operations.* NASA Technical Memorandum 108839.

Rosenthal, L., Merlotti, L., Roehrs, T. A., & Roth, T. (1991). Enforced 24-hour recovery following sleep deprivation. *Sleep*, 14, 448-453.

Roth, T., Roehrs, T. A., Carskadon, M. A., Dement, W. C. (1994). Daytime Sleepiness and

Alertness. In M. H. Kryger. T. Roth & W. C. Dement (Eds.). *Principles and Practice of Sleep Medicine*. WB Saunders Co.

Samel. A., & Wegmann. H. M. (1987). Desynchronization and internal dissociation in aircrew. *Ergonomics*. 30. 1395-1404.

Samel. A., Wegmann. H. M., & Vejvoda, M. (1996). Aircrew fatigue in long-haul operations. *Accident. Analysis & Prevention*, 29, 439-452.

Samel. A., Wegmann, H. M., Vejvoda, M. (1995). Jet lag and sleepiness in aircrew. *Journal of Sleep Research*, 4, 30-36.

Samel, A., Wegmann, H. M., Drescher, V. M., Gundel, A., Manzey, D., Wenzel, J. (1997). Two-Crew Operations: Stress and Fatigue During Long-Haul Night Flights. *Aviation, Space, and Environmental Medicine*, 68, 679-87.

Sasaki, M., Kurosaki. Y., Mori. A., Endo, S. (1986a). Patterns of Sleep-Wakefulness Before and After Transmeridian Flight in Commercial Airline Pilots. *Aviation, Space, and Environmental Medicine*, 57, B29-B42.

Sasaki M, Kurosaki Y, Mori A, and Endo S. (1986b). *Patterns of Sleep-Wakefulness Before and After Transmeridian Flight in Commercial Airline Pilots. Crew Factors in Flight Operations: IV. Sleep and Wakefulness in International Aircrews*, RC Graeber (Ed.), NASA Technical Memorandum No. 88231. Moffett Field. CA:Ames Research Center

Schoenborn. C. A. & Cohen. B. H. (1986). *Trends in Smoking. Alcohol Consumption. and Other Health Practices Among U.S. Adults 1977 and 1983*. National Center for Health Statistics. U.S. Department of Health and Human Services. Hyattsville. MD No 118 1-16.

Schoenborn. C. A. & Danchik. K. M. (1980). *Health practices among adults: United States. 1977*. Advance data. National Center for Health Statistics. U.S. Department of Health and Human Services. Hyattsville. MD. 64: 1-10.

Shappell. S. A., & Neri. D. F. (1993). Effect of combat on aircrew subjective readiness during Operations Desert Shield and Desert Storm. *International Journal of Aviation Psychology*, 3,231-25.

Shingeldecker. C. A., & Holding, D. H. (1974). Risk and effort measure of fatigue. *Journal of Motor Behavior*. 6. 17-25.

Smiley, A. (1996. November). *Interpretation of Operator Performance Data. In: Operator Performance Measurement: Developing Commonality Across Transportation Modes* -

Proceedings of a September 1994 Workshop. DOT Human Factors Coordinating Committee Final Report.

Smith, L., Folkard, S., Poole, C. J. M. (1994). Increased injuries on night shift. *Lancet*, 344, 1137-1139.

Spencer, M. B. (1987). The influence of irregularity of rest and activity on performance: a model based on time since sleep and time of day. *Ergonomics*, 30, 1275-1286.

Takahasi, J. S. (1996). The biological clock: It's all in the genes. In R. M. Buijo, A. Kalsbeek, H. J. Romijn, C. M. Pennartz & M. Mirmiran (Eds.), *Hypothalamic Integration of Circadian Rhythms*.

Taub, J. M. (1981) Behavioral and Psychobiological Effect Of Ad-libitum Extended-delayed Sleep. In I. Karacan (Ed.), *Psychophysiological aspects of sleep*. Park Ridge, N. J.: Noyes Medical Publications.

Taub, J. M., & Berger, R. J. (1973). Performance and Mood Following Variations in the Length and Timing of Sleep. *Psychophysiology*, 10, 559-570.

Taub, J. M., & Berger, R. J. (1976) The effects of changing the phase and duration of sleep. *Journal of Experimental Psychology*, 2: 30-41.

Thomas, M. L. (1997). *Brain and Behavioral Effects of Prolonged Wakefulness in Humans: A Positron Emission Tomography Study of Brain Glucose Metabolism During Task Performance After 48 hours of Sleep Loss*. Unpublished doctoral dissertation. George Mason University.

Thomas, M. L., Sing, H. C., Belenky, G., et al. (1993). Cerebral Glucose Utilization During Task Performance and Prolonged Sleep Loss. *Journal of Cerebral Blood Flow and Metabolism*. 13(Suppl 1), S531.

Thorne, D., Genser, S., Sing, H., & Hegge, F. (1983). Plumbing human performance limits during 72 hours of high task load. *Proceedings of the 24th DRG Seminar on The Human As A Limiting Element In Military Systems, Volume 1*. Toronto, Canada, May 2-4.

Torsvall, L., & Akerstedt, T. (1988). Disturbed sleep while being on-call: An EEG study of ships' engineers. *Sleep*, 11, 35-38.

Totterdell, P., & Folkard, S. (1990). The Effects of Changing From a Weekly Rotating to a Rapidly Rotating Shift Schedule. In G. Costa (Ed.), Shiftwork: Health, Sleep, and Performance.

Turek, F. W., & Van Reeth, O. (1996) Circadian rhythms. In M. J. Regly & C. M. Blatteis (Eds.), *Handbook of Physiology: Environmental Physiology*.

Webb, W. B. (1985). Sleep in industrial setting in the Northern Hemisphere. *Psychological Reports*, 57, 591-589.

Webb, W. B., & Agnew, H. W. (1975) Are we chronically sleep deprived? *Bulletin of the Psychonomic Society*, 6, 47-48.

Webb, W., & Campbell, S. (1980). Duration of non-laboratory sleep in an aging population. *Sleep Research*, 9, 118.

Wegmann, H. M., Gundel, A., Naumann, M., Samel, A., Schwartz, E., & Vejvoda, M. (1986). Sleep, sleepiness, and circadian rhythmicity in aircrews operating on transatlantic routes. *Aviation, Space and Environmental Medicine*, 55, 1085-96.

Wegmann, H. M., Klein, K.E. (1985). Jet lag and aircrew scheduling. Folkard & T. Hmonk (Eds.). *Hours of work*. Chichester: Wiley. (pp. 263-276).

Wehr, T. A. (1996). The clock for all seasons in the human brain. In R. M. Buijs, A. Kalsbeek, H. J. Romijn, C. M. A. Pennartz, & M. Mirmiran (Eds.), Hypothalamic integration of circadian rhythms.

Wehr, T. A., Moul, D. E., Barbato, G., Giesen, H. A., Seidel, J. A., Barker, C., et al. (1993). Conservation of photoperiod-responsive mechanisms in humans. *American Journal of Physiology*, 265, R846–57.

Wilkinson, R. T. (1968) Sleep deprivation. Performance tests for partial and selective sleep deprivation. *Progress in Clinical Psychology*, 8, 28-43.

Wilkinson RT, Edwards RS, & Haines E (1966) Performance following a night of reduced sleep. *Psychonomic Science*, 5, 471—472.

WRAIR (1997, October). Interim report: A dose/response study of sleep and wakefulness. Phase I: Actigraphic assessment of CMV drivers over 20 consecutive days. Walter Reed Army Institute of Research, Washington, DC.

APPENDIX C

A Scientific Review of Proposed Regulations regarding Flight Crewmember Duty Period Limitations

Docket #28081

The Flight Duty Regulation Scientific Study Group[†]

Preparation of this document was supported by a grant from the Independent Pilots Association

Running title: Review of proposed flight duty regulations

Correspondence to : Gary S. Richardson, MD
Endocrine-Hypertension Division
Brigham and Women's Hospital
221 Longwood Avenue
Boston, MA 02115

[†] Co-Chairs: Wallace A.Mendelson, MD, Cleveland Clinic Foundation; Gary S. Richardson, MD, Brigham & Women's Hospital and Harvard Medical School; Thomas Roth, PhD, Henry Ford Hospital.

THE FLIGHT DUTY REGULATION SCIENTIFIC STUDY GROUP

Co-Chairs: **Wallace B. Mendelson, MD,** is the Director of the Sleep Research Laboratory and Professor of Psychiatry and the University of Chicago. He is an internationally recognized authority on sleep disorders, particularly insomnia, and on the pharmacology of sleep and wakefulness. He has been an officer on the executive boards of both the Sleep Research Society and the American Sleep Disorders Association, and participated in the formulation of national policy on the diagnosis and treatment of sleep disorders.

Gary S. Richardson, MD, is Associate Physician at Brigham and Women's Hospital in the Section on Circadian and Sleep Disorders Medicine, and an Instructor in Medicine at Harvard Medical School. He is an internationally recognized authority on circadian rhythms in human sleep and alertness, and has served as a consultant to the Department of Transportation and industry on the effects of shift work and sleep deprivation on human health and performance. He has been an officer on the executive board of the Sleep Research Society.

Thomas Roth, PhD, is Director of Research for the Henry Ford Health System in Detroit. He is also Director of the sleep disorders program and an internationally recognized authority on sleep, sleepiness and human performance. He is past president of both the Sleep Research Society and the American Sleep Disorders Association, and is Chairman of the Advisory Council for the Center for Sleep Disorders Research within the National Institutes of Health. Dr. Roth has served as a consultant to the Department of Transportation, National Highway Traffic Safety Association and NASA.

Members:

Ruth Benca, MD, PhD
University of Wisconsin/Madison
Madison, WI 53792

Cynthia Dorsey, PhD
McLean Hospital
Belmont, MA 02178

Barbara Phillips, MD, MSPH
Good Samaritan Hospital
Lexington, KY 40508

Timothy Roehrs, PhD
Henry Ford Hospital
Detroit, MI 48202

Mary A. Carskadon, PhD
Bradley Hospital
East Providence, RI 02915

Mark Mahowald, MD
Hennepin County Medical Center
Minneapolis, MN 55415

James Walsh, PhD
St. Luke's Hospital
Chesterfield, MO 63017

Gary Zammit, PhD
St.Luke's-Roosevelt Hospital
New York, NY 10025

1. Introduction

This document is intended to provide a review of the proposed flight-duty regulations for flight crewmembers as defined by the Federal Aviation Administration (FAA) in the Notice of Proposed Rule-making (NPRM) (1). The Flight-Duty Regulation Scientific Study Group (the "Study Group") was organized in response to a request by the Independent Pilots Association (IPA) for a scientific review of the NPRM, including a detailed determination of the extent to which the proposed regulations adequately address the problems of fatigue and sleep deprivation in flight crew, and the extent to which they appropriately utilize available scientific information, both that expressly cited in the NPRM and the larger body of scientific literature regarding the origins of human fatigue in sustained operations.

The Study Group consists of members of the scientific community with research interests in the fields of human sleep and circadian physiology, and sleep disorders medicine. While some of the members of the Study Group have participated in an advisory or review capacity in the evaluation of extended duty limitations in other work settings, including other transportation sectors, none of the members has had previous involvement in the development of these flight-duty regulations or in the NASA research projects cited as providing the specific foundation for the current NPRM. Thus, it is the intent of the Study Group that this document will constitute a new and independent review, incorporating the perspectives provided by regulatory efforts in other industries and by research performed in other related areas.

Another important principle guiding our review and assessment of the proposed regulations requires express statement at this point. It is the position of the Study Group that the success of any attempt to regulate duty schedules to guarantee adequate rest depends jointly upon the provision of adequate opportunity for rest within the schedule, and upon the responsible cooperation of the regulated individual. However, personal behavior cannot practically be regulated. Experience with attempts to provide improved rest opportunities in other settings demonstrates that time provided for sleep is often used for other things, effectively defeating the intent of the original provision. The solution to this limitation is a continued emphasis on education of the regulated group regarding the nature of the problem and their role in its solution. However, the Study Group feels strongly that the possibility of compromise of allocated rest time should not relieve regulatory authority of the responsibility for insuring that adequate time is provided for rest.

Finally, it is also important to state in this introduction that, despite its evident limitations, the proposed NPRM represents unambiguously important and valuable progress. The Study Group unanimously feel that the FAA is to be applauded for persisting in this effort, and for producing a set of proposed regulations that attempt to incorporate current understanding of human sleep physiology. To our view, this incorporation is not as complete as it can or should be, and the issues identified in this review are meant as suggestions for improvement in the proposed regulations. It is our hope that many of the important adjustments can be included in the final set of rules produced by this effort, whereas other issues clearly represent deficits in the current scientific database. These will require additional research attention before they can be addressed in future rule-making efforts.

The goal of providing safe travel 24 hours a day requires optimum crew alertness and performance at all times. Since human alertness is highly dependent on the complex regulatory system governing sleep and wakefulness, we will begin this review by summarizing current understanding of the physiologic systems regulating sleep and wakefulness, and the factors that contribute to human fatigue. In subsequent sections, we will 1) summarize the adequacy of the proposed changes in flight duty regulations (1) in addressing the relevant aspects of human physiology, and 2) summarize areas where we believe that the proposed regulations can and should be revised and expanded to better address these issues with the goal of optimization of aircrew alertness and air travel safety.

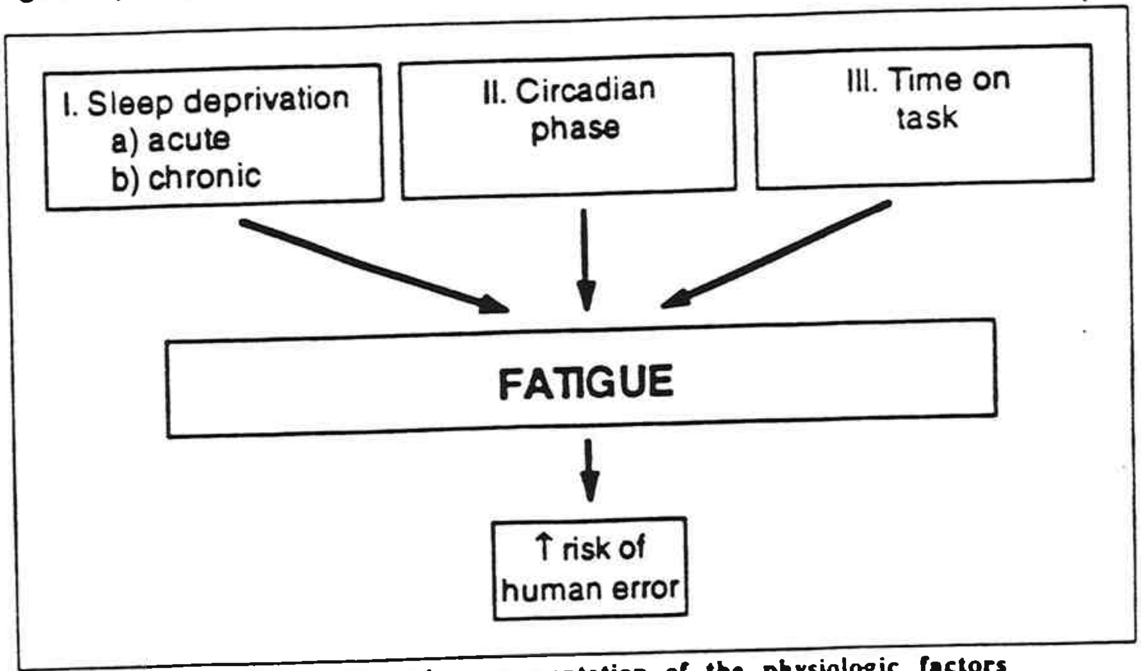


Figure 2-1: Schematic representation of the physiologic factors contributing to human fatigue in sustained operations

2. Scientific Background

2.1. A working definition of fatigue

Much of the literature cited in support of the proposed modifications to the FAA regulations variably use the terms "fatigue" and "sleepiness" to describe the physiological condition arising from inadequate prior sleep and/or the condition that occurs when wakefulness is forced during phases of the circadian cycle appropriate to sleep. The implication of this usage is that these terms are interchangeable, whereas a closer evaluation indicates that they are not, and confusion of the two terms impairs the discussion of the physiologic basis of performance errors and the appropriate focus for interventions. Sleepiness has a precise definition:

> "Sleepiness, according to an emerging consensus among sleep researchers and clinicians, is a basic physiological state (like) hunger or thirst. Deprivation or restriction of sleep increases sleepiness, and as hunger or thirst is reversible by eating or drinking, respectively, sleep reverses sleepiness."*

By contrast, the term "fatigue", as it is used in the human performance context, does not have a precise physiologically-based definition. Instead, fatigue is used in a broader sense to describe deterioration in human performance, arising as a consequence of several potential factors, including sleepiness. When the intent is to prevent human error, it is necessary to go beyond the broad definition and identify the specific physiologic components which then become the target for intervention. This review will reserve the term fatigue for the general condition in which performance is impaired, and will identify and focus upon three contributors to human fatigue, the control and limitation of which is necessary to the optimization of performance of crew members in air flight (Figure 2-1).

---

* From Roth, T., *et al.*, Daytime sleepiness and alertness. In *Principles and Practice of Sleep Medicine*, M.H. Kryger, T. Roth, and W.C. Dement, Eds. 1989, W.B.Saunders: Philadelphia. p. 14-23.

2.2. Homeostatic regulation of sleep

As suggested, the most prominent among potential causes of fatigue is a decline in human alertness (or an increase in sleepiness) occurring as a consequence of sleep deprivation. Sleep deprivation can be thought of as an inadequate fulfillment of the homeostatic need for sleep(2), either over the short term ("acute sleep deprivation"; Figure 2-1) or gradual sleep deprivation over the longer term ("chronic sleep deprivation"; Figure 2-1).

The homeostatic mechanism is reflected in common sense observation that an individual who does not get adequate sleep prior to performing a task will be sleepy, and performance of the task will be impaired. In designing appropriate schedules to determine what is "adequate sleep", several factors need to be considered: 1) although the average amount of sleep needed for daily alertness is typically a little less than eight hours, there is tremendous individual variation. Thus what may be sufficient for one individual may not be enough for another; 2) The effectiveness of sleep in maintaining daytime alertness changes across the lifetime, and declines in older age (3). This suggests that in older crew members the need for adequate pre-flight sleep is particularly important: 3) Complete recovery from operating with an inadequate amount of sleep ("sleep deprivation") does not occur after a single sleep period (4, 5). Two or three sleep cycles are usually required before normal levels of alertness are achieved following sleep deprivation. 4) There is evidence that sedatives including sleeping pills or alcohol have profoundly greater effects, and may have longer duration of action, in a person who has had inadequate sleep (6). Thus the duration of time needed for safe performance following use of such compounds may be prolonged in a person who took them in a state of sleep deprivation.

2.3. Circadian modulation of sleep, sleepiness and performance.

The second factor in determining the levels of sleepiness is the phase of the human circadian clock (Figure 2-1). Circadian rhythmicity is the term used to describe diurnal variations in physiologic functions that derive from time-keeping systems within the organism. Circadian rhythms are apparent in the physiology of virtually all plants and animals, and this ubiquity suggests that internal time-keeping was an important adaptation to the 24-hour variation in the external environment (7). In mammals, including humans, circadian rhythms are controlled by sophisticated neural clocks located at the base of the brain that use photic information from the retina to orient physiologic rhythms with respect to external time. In diurnal ("day-active") species such as the human, the circadian clock is oriented so that alertness, metabolic activity, and various other functions increase by day to facilitate the physical activity and behaviors exhibited at those times (8). By night, alertness is decreased and metabolic activities are commensurably reduced to facilitate sleep and conserve metabolic energy. Laboratory studies of the influence of the circadian clock typically rely on continuous body temperature measurements to track the clock's influence on metabolism. Core body temperature is remarkably rhythmic in humans when it is measured in conditions carefully designed to eliminate outside influences.

The circadian rhythm of body temperature has a peak between the hours of 4 and 6 PM in the evening, and a trough approximately 12 hours later at 4 to 6 AM. While the exact position of these reference points may vary from individual to individual, in healthy adults, they are remarkably consistent within a relatively narrow range. Studies of human performance as a function of time of day have demonstrated clear circadian rhythms in several different types of performance functions. For the most part, this variation mirrors the circadian variation in sleepiness (*i.e.* minimum in performance capacity in the early morning hours (between 4 and 6 AM) coincident with minimum body temperature and maximum sleepiness) (9). These data are consistent with the generally accepted hypothesis that important circadian variation in performance is a secondary consequence of the circadian variation in sleepiness.

Further, an extensive body of laboratory data has established that human circadian clocks rely upon light-dark variation to orient circadian rhythmicity relative to external time (10). A dependence of this effect on the intensity of the light means the external sunlight exposure typically dictates the orientation of an individual's circadian clock. Studies of the relationship between circadian orientation and light-dark cycles have progressed to the point where it is now possible to make reasonable estimates of the effect of transmeridian travel, with the consequent alterations in light-dark exposure, on internal circadian orientation and the dependent rhythms in alertness and performance (11).

Studies of the circadian system lead to several conclusions relevant to extended-duty paradigms such as those in aviation: 1) Attention only to the needs of the homeostatic system will not result in adequate alertness. Thus a crew member who works in the early morning hours of 4 - 6 AM will not necessarily be as alert as one working during daylight hours, even if both had been off-duty for the same amount of time prior to work. 2) When flight plans involve transmeridian travel, duty requirements may lead the crew to need to function at times in which the body's propensity is to sleep; 3) When crew land at transmeridian destinations, their internal circadian systems may be out of phase with those of the new local environment (12). Thus they may be in their own internal sleep phase when it is daytime at the new destination.

Further, several factors need to be considered in designing schedules that allow for these circadian processes. The first is that there is a great deal of individual variation in the ability to adapt to changing schedules of this type (13). In addition to this individual variability the ability to adapt to changing shift schedules declines with age. Hence older crew members are more likely to experience difficulty adjusting to new time periods of sleep and waking. Second, the ability to adjust to new time schedules depends on the direction of transmeridian travel. In general, short-term changes of four or more time zones in eastward travel are more difficult to adapt to than equivalent westward travel. The implication of this is that recommendations for adequate rest may need to be tailored specifically for the direction of travel. Third, recovery sleep itself is influenced by the time of the circadian day (14). Thus a 10 hour period for recovery sleep in a new time zone will not initially be as effective in restoring alertness as an equivalent recovery period in the home time zone. Fourth, the use of hypnotic medication (sleeping pills) may improve sleep in adverse phases of the circadian cycle, but the relationship of this improved sleep to subsequent performance is complex and still under study (15). Finally, one environmental factor-- the amount and timing of exposure to sunlight (or equivalent bright artificial light)-- can greatly influence the ability to adapt to new sleep and waking schedules (16). Thus exposure to sunlight, or the use of appropriately timed artificial light, may be useful in helping an individual receive adequate sleep. Conversely, inappropriate exposure to bright light may inhibit that individual's ability to receive adequate rest.

2.4. Time on task

The third factor that can contribute to fatigue is the duration of time spent working without significant interruption ("time-on-task; Figure 2-1). Evidence suggests that a complex relationship exists between task efficiency, as measured by the probability of error, and time spent working on the task. In studies of manufacturing settings, the probability of error begins at a relatively high level at the beginning of the shift ("re-familiarization"), rapidly declines to optimal levels within a few hours, then steadily increases over the remainder of the (typical) eight-hour shift ("task fatigue"). Studies of longer shift durations consistently suggest the rate at which performance deteriorates may increase for durations beyond 8 hours and this has been an important factor in efforts to limit maximal shift duration in a variety of settings (17).

Time-on-task effects are the least studied and least understood of the factors contributing to human fatigue. For example, unlike sleep deprivation which can only be reversed by sleep, performance deterioration associated with prolonged task duration appears to be task specific, reversing with time away from the task, even if the time is spent with other waking activities. But important data about the nature of this effect, particularly as it might relate to complex tasks such as those performed by flight crews, is not yet available. It is not clear, for example, whether inherently variable tasks can modulate the rate at which performance deteriorates. Further, there are important methodological issues that have not all been addressed in available studies of time-on-task effects. For long task durations, *i.e.* 8 or more hours, sleep deprivation and circadian phase effects will necessarily vary significantly over the course of the task, confounding interpretation of performance changes. Studies systematically varying circadian and sleep deprivation (homeostatic) influences to isolate the time-on-task effects have not yet been performed. Pending collection of such data, ideally specific to flight crew job requirements, available time-on-task data nonetheless raise significant general concerns about sustained shift durations, particularly those greater than 10 hours.

An additional important factor in the determination of time on task effects is task intensity. Fatigue generally accumulates faster in high intensity tasks than in low intensity tasks, suggesting that maximum task durations should be adjusted according for task intensity. However, in practice, task intensity can be very difficult to measure. Within aviation, this principle has been used to justify adjustments of maximum shift duration as a function of the number of landings on the widely accepted premise that landings are the most intensive aspect of aviation.

2.5. Interactions

Beyond their direct relationship to human fatigue and the probability of error, each of the physiologic axes identified above also interacts with the others to potentiate adverse effects. Thus, the extent of sleepiness and performance impairment produced by moderate sleep deprivation is greater at 4 AM than it is at 4 PM. Similarly, the rate at which time-on-task effects on performance accumulate depends both on the circadian phase at which the task is performed, and on the extent of prior sleep deprivation on the part of the person performing it. The importance of the circadian system in modulating both alertness and the ability to sleep results in another important interaction. In addition to the direct adverse effect on alertness and performance, work on the "back side of the clock" over a number of successive nights results in chronic sleep deprivation as a consequence of impaired ability to sleep during the day. This sleep deprivation can then potentiate the performance impairment on later night shifts.

These interactions have made it difficult to isolate the physiologic contributors to fatigue in the laboratory and assess their relative magnitude and importance; for example, how much sleep deprivation is equivalent to work at the circadian nadir? Without more data on this issue, the only effective strategy for intervention requires addressing each of the three axes as completely as possible.

2.6. Shift-work

The focus of this effort on the scheduling of flight crews occurs in the context of general concern about extended duty, night work, and consequent sleep deprivation in a large number of occupations with public safety implications (18). A growing number of US. workers are called upon to routinely work other than regular daylight hours. It is estimated that some twelve million people in the United States now fit this broad definition of shiftworker (19). A number of strategies have evolved to provide for extended duty and nighttime coverage of the growing variety of service and manufacturing settings that require continuous staffing. The most common of these is the "rotating" shift schedule in which crews of workers work successive shifts for one or more weeks at a time. The shifts typically are days (8 AM to 4 PM), evenings (4 PM to midnight) and nights (midnight to 8 AM). While rotating shifts of this kind, varying slightly with regard to starting time and direction of rotation, probably the most common implementation for continuous coverage, a number of other approaches have been used as well. As a consequence, specific data regarding the impact of a given shift schedule, or even specific shift durations, on human performance, sleepiness, or other human factors are not always available. It is also important to realize that generalization from research results regarding a specific schedule to all shift work is rarely justified.

It is recognized that night-work can be deleterious to workers' safety and productivity in part because of the increased risk of performance errors during the early morning hours (between 4 and 6 AM). While various shift work schedules may be capable of modulating this risk to a greater or lesser degree, recent work on the importance of sunlight to human circadian function (see above) has established that this nighttime vulnerability to error persists even in shiftworkers with years of night work experience. It is important to realize that an individual working nights is at risk for significant sleepiness for two distinct reasons: First, work during the early morning hours (between 4 and 6 AM) is associated with the previously-described circadian increase in sleepiness and sleepiness mediated performance errors. In addition, an individual working successive nights is forced to obtain sleep during the daylight hours at a time when the circadian pre-disposition to sleep is minimal (20). As mentioned, sleep under these circumstances is typically fragmented, sleep state architecture is distorted and the restorative nature of sleep (per hour of sleep attempted) is reduced. Thus, over time, the night shift worker accrues cumulative sleep deprivation which when added to the circadian sleep effects can produce profound impairment. A consequence of this is that the unifying aspect of successful strategies for combating the increase in performance errors by shift-workers on the night shift is to maximize the amount of sleep obtained, compensating as much as possible for the inefficiency of daytime sleep through sleep extension, napping *etc.*, and preventing the accumulation of significant chronic sleep deprivation.

2.7. Fatigue and safety in flight operations

While the problems of sleep deprivation and night-work are certainly not unique to aviation, there can be little doubt regarding the significance of the problem that crew fatigue poses for the aviation industry. Laboratory simulator studies have demonstrated that compliance with current flight-duty regulations and work schedules does not protect against significant sleep deprivation and unacceptable levels of fatigue in flight crews (21). A growing number of field studies have documented that crews are experiencing serious sleepiness during flight operations, and NASA's Aviation Safety Reporting System (ASRS) identified 221 incident reports (over an eight year period) in which crew fatigue contributed to problems during flight operations (1). Finally, the National Transportation Safety Board (NTSB) has identified crew fatigue as a material contributing factor in more than one recent accident. Together, these findings indicate that fatigue is a significant safety issue in the aviation industry, and that the current regulations regarding limitations on flight-duty schedules are an important factor in the genesis of that fatigue.

One important challenge posed by the NPRM is the identification of outcome measures to be used to determine the impact of revised regulations. While available measures have adequately documented the presence of a problem, they would appear to be inadequate for the task of assessing change over a two or three year span immediately following implementation of new flight-duty regulations. The relative rarity of aviation accidents studied by the NTSB makes this measure too insensitive to detect changes that might reasonably be expected to occur in response to small proactive interventions such as a two hour reduction in maximum duty time for example. At the same time, the potential bias inherent in the ASRS database makes these data too subjective. The Study Group feels strongly that an important priority for the immediate future should be the identification and validation of proxy measures of crew fatigue that can be used to effectively monitor the impact of this and future revisions without relying on catastrophic outcomes as the only accepted dependent measure.

3. Summary of proposed guidelines

The FAA cites the NASA technical memorandum "Principles and Guideline for Duty and Rest Scheduling in Commercial Aviation" (22) as the primary source in the preparation of the NPRM (1), although there are important differences between the NASA recommendations and the final NPRM document. The NPRM guidelines address duty period, flight, time, and rest requirements. Secondarily, they discuss reserve periods as well as cumulative duty periods for a week and a month.

There are two important general features of the proposed guidelines. The first is the predication of duty limitations on total duty instead of just flight time. Specific regulations of duty durations specify separate upper limits for total duty time (without an intervening period of rest) and for total flight time within the longer duty segment. The second important general change is the consolidation of regulations for various types of flight operations covered by Part 121 (covering domestic, flag and supplemental flight operations) and elimination of differences between relevant parts of the Part 121 regulations and the Part 135 regulations (covering commuter and on-demand flights). This results in simplification and greatly improved consistency in flight regulations.

TABLE 3-1: SUMMARY OF PROPOSED REGULATIONS

	Description	
1. Flight duty duration	**Crew size**	**Max.duration (duty/flight)**
	1	14/8
	2	14/10
	3	16/12
	3[1]	18/16
	4[1]	24/18
2. Minimum rest duration	**Crew size**	**Min. duration (hours)**
	1	10
	2	10
	3	14
	3[1]	18
	4[1]	22
3. Flight time limits	**Time frame**	**Max. flight time (hours)**
	Per week	32
	Per month	100
	Per year	1200

[1] *With facilities for sleeping in flight*

The new regulations are intended as "...a preventative measure designed to address the potential safety problems associated with fatigue-based performance decrements...by requiring certain scheduling limitations and minimum rest periods." Before assessing the extent to which the proposed regulations accomplish this goal, it is necessary to stipulate their specific provisions. An abbreviated summary of the relevant sections of the NPRM follows (see Table 3-1).

3.1. Revised Flight-Duty Durations

Under the proposed regulations, the base duration of the duty period (2 pilot crew) would be 14 hours. This would include 10 hours of flight time. Importantly, depending on crew size, availability of on-flight sleeping quarters, and operational delays, this can be extracted to 26 hours of duty time and 20 hours of flight time. Increasing crew to three pilots raises duty period to 16 hours, availability of sleep opportunity to 18 hours, and 4 person crews to 24 hours. Any one of these limits can be increased by 2 hours for unplanned operational delay.

3.2. Rest Period

The basic unit of rest, associated with the basic 2 person crew, 14 hour duty period, is 10 hours. Depending on the duration of the duty period, the requirement of the rest period could be as long as 24 hours. It must be recognized that these rules are for the subsequent rest period. Regulations do not specify minimum rest for subsequent duty. Thus, it is possible to have a 10 hour rest period during daytime hours followed by a 26 hour duty period. All rest period requirements can be reduced by up to 1 hour because of operational delays that can increase duty duration by up to 2 hours.

3.3. Stand-By Assignments

Reserve time in this proposal is a period of time when a flight crew member is not on duty but nonetheless must be able to report upon notice (*i.e.* greater than one hour), for a duty period. The guidelines explicitly reject relating amount of time of notice to time of day. Rather, it relates amount of time of advance notification to the maximum duration of the subsequent duty period. With less than 4 hours of notice, only a 6 hours duty period is allowed. As notification period goes to ten or more hours, a full duty period, up to 26 hours depending on circumstances, is allowable. An alternative to this standby schedule is maintaining a constant 6 hour protected time (by request) for each 24 hours of reserve time. During this time, the certificate holder may not contact the crew member to place them on duty. This 6 hour period must be assigned before the crew member begins the reserve time assignment. The duty period must be completed in 18 hours within the reserve time and must be in accordance with the general guidelines.

3.4. Cumulative Limits

The cumulative limits for flight hours are set at 32 hours for any 7 day period, and 100 hours for any calendar month. The yearly period is set by multiplying the monthly requirement by 12 (*i.e.* 1200 hours).

4. Evaluation of proposed regulations

It is important to reiterate and emphasize the Study Group's position that the proposed regulations as defined in the current NPRM on the whole represent an important advance over existing flight-duty regulations. The principal improvement lies in the new dependence of the regulations on total duty time, rather than just flight time, in setting limits on maximum work duration. As reviewed above, this is a much more physiologically sound approach, reflecting the importance that all work time has in the generation of fatigue.

The Study Group did, however, find several specific aspects of the proposed regulations that should be improved upon and/or appear to deviate from the FAA's stated intention "...to incorporate (whenever possible) scientific information on fatigue and human sleep physiology into regulations on flight crew scheduling." (1). Adjustments to the final regulations should address each of the issues identified below.

In comparing the proposed regulations to the stated goals outlined in the introduction to the NPRM and to available data in the scientific literature, the Study Group identified two important general issues.

4.1. Excessive duty duration

While regulation of the maximum duration of total duty time (rather than just flight time) represents an important improvement from the perspective of the limits of human physiology, the actual duration of the proposed work periods substantially exceeds what can reasonably be justified by scientific data on human performance and fatigue. In light of substantial evidence indicating that work durations in excess of 12 hours are associated with a significant increase in the probability of human error independent of circadian phase and prior sleep wake history (13, 23), there can be little scientific justification for baseline work durations of 14 hours, let alone the greater durations permitted under operational delay conditions. The specific duty and time limitations are the same as those specified in the NASA recommendations (22), although there are potentially important differences between the NASA recommendations and the NPRM in the definition of flight time. While the NASA document recognizes the importance of limiting maximum shift duration (Section 1.4; p 4), it provides no evidence in support of the statement that 14 hours within a 24-our period is sufficient limitation (Section 2.2.3), nor was the Study Group able to identify research to suggest that these shift durations might be acceptable in the unique aviation setting. In this regard, it is important to note that these duty periods are significantly longer than those being applied in a range other work settings where regulatory attention has been focused on the problem of fatigue-related performance decrements, including most other transportation sectors.

Absent research data to the contrary, the only relevant findings suggest that performance deteriorates significantly for shift durations greater than 12 hours, and the recommended limits for duty time in the NPRM are not consistent with the implications of those findings. As outlined above, it is not clear whether the variability of task inherent in the flight-duty assignment, *i.e.* shorter durations of flight time within the context of the longer duty schedule, might mitigate the deterioration in performance associated with shifts of equivalent duration in other work settings, however scientific endorsement of the safety of these shift durations must await empirical confirmation of such an effect.

Similarly, the extraordinary duty durations under circumstances where crew number is augmented and/or arrangements for sleep during flight are provided are inadequately justified by available scientific data. It is certainly not clear, based on a review of the studies published by NASA or any other group to date, that augmenting the crew results in a material increase in tolerance for sleep deprivation that would justify an increase in shift duration of the specified magnitude. Other concerns of the Study Group pertain to the specific arrangements for sleep for augmented crews in extended duty durations. The Study Group is very concerned about the adequacy of sleeping arrangements that will be provided in these situations so that crew members can obtain some sleep while relieved by the extra crew. To our review, provision of such facilities addresses only one of several important concerns about the impact of extended duty arrangements. It remains to be determined whether adequate sleep can and will be obtained under operational conditions. While available data on cockpit napping have demonstrated that brief naps have a clearly beneficial effect over the short term on crew alertness (24), published studies have not yet shown that this improvement is sufficient in magnitude and duration to allow a significantly sleep-deprived crew member to return to duty. The second half of this concern is that several studies in other contexts have demonstrated that simply providing the opportunity for sleep in the extended-duty setting does not guarantee that such sleep will actually be obtained. Without express stipulation about the amount and scheduling of rest/sleep to be obtained by crew members, it is our concern that the revised regulations sanction extraordinarily long extended duty arrangements without providing any reasonable likelihood that adequate sleep will be obtained.

Finally, the provisions for rest do not appear adequate to compensate for the clearly heroic demands of duty durations of up to 26 hours. Rest allowances are adjusted for the rest periods following extended duty, not for the rest period preceding it. Thus for crewmembers moving among assignments of varying duration, it is possible to be called upon to work very long shift durations of 24 - 26 hours after limited (as few as 9 hours; "reduced rest"), with no stipulation that this time be provided at a circadian phase conducive to sleep.

In summary of this first concern, the Study Group does not feel there is adequate scientific justification for duty durations greater than 12 hours. Nor is the Study Group confident that compensatory arrangements of extra crew, sleeping quarters in flight, and extended rest provide adequate protection from the extreme fatigue associated with very long work schedules permitted under the proposed regulations.

4.2. No adjustment for "back side of the clock"

Our second major concern is that the proposed regulations make no effort to adjust prescribed limits on work duration or rest duration based on the time of day at which those activities are scheduled. This is the most disappointing omission, and particularly difficult to understand in light of the express predication of the revised regulations on the NASA-Ames database, a body of research that has done much to characterize the dependence of sleep and performance in the aviation setting on human circadian phase. Based both on the NASA studies and the larger body of scientific evidence developed in this area, there can be no doubt about the importance and relevance of circadian physiology to the modulation of human performance and the tendency to human error, and to the ability to obtain sleep and thereby reverse performance decrements arising as a consequence of sleep deprivation.

It is clear that application of circadian physiology to this regulatory effort raises several practical issues. First, regulations that account for time-of-day in provisions for work duration and rest are necessarily more complicated than the proposed set, particularly when transmeridian travel is taken into account. Second, it may prove difficult to develop consensus definitions for the circadian periods of maximal sleepiness and maximal alertness, as well as the precise extent of the adjustments of work and rest duration, respectively, that would be required during those windows. While the Study Group does not feel it is qualified to address detailed issues of practicality, our response to this concern would be that flight duty regulations that adequately account for circadian modulation in the capacity for sleep and in human performance have been used in the United Kingdom for 6 years (since May, 1990), and by account appear to be working well. The Study Group is aware of no qualitative reason why adjustments such as those incorporated in the UK regulations could not be used in the US as well.

4.3. Interactions

While the Study Group feels that each of the identified issues warrants specific modifications of the proposed regulations, the interactions between the two relevant physiologic axes, as reviewed above, greatly compound the concern. With inadequate restrictions on work duration and no compensation for circadian phase, the regulations permit "worst case scenarios" that are well outside scientifically supported limits. For example, without adjustments of rest period duration for circadian phase incompatible with sleep, it is possible to have a routine 14 hour night shift, followed by a rest period of ten hours from 12 noon to 10 PM, *i.e.* precisely coincident with the circadian phase at which sleep is least possible ("the forbidden zone"), followed by a 26 hour shift (assuming operational delay). As stated, provision of in-flight time for sleep can not be assumed to adequately protect against the performance decrements that marathon duty of this kind will inevitably produce.

Similarly, much of the concern about shift duration stems from the absence of any adjustment of duration for the time of day. While future studies could demonstrate that a succession of 14 hour flight-duty day shifts allow maintenance of acceptable performance limits, it is very unlikely that a succession of 14 hour night shifts will be similarly validated. Unless maximum shift durations are kept well within human performance limits, *i.e.* less than 12 hours*, some adjustment for the compounding effects of time-of-day needs to be included.

The Study Group recognizes that worst case scenarios are not likely to be representative of typical flight crew shift durations. However, it is opinion of the Study Group that no reliable protection against such potentially dangerous extremes of scheduling can be had without express adjustments of duty time and rest time for the dictates of the circadian clock, and significant reductions in the maximum length of the duty period.

4.4. Reserve Time

The Study Group has separate but related concerns about the proposed regulations regarding Reserve Time. As reviewed above, two distinct approaches for the protection of rest time within the reserve window are permitted. In the first, termed "variable notice", the maximum length of a duty assignment decreases with the length of the advance notice provided. In the alternate arrangement, termed "protected window", crew members on reserve are assigned a pre-identified six hour window during which they cannot be called. In this specification, the proposed regulation is notably different from the recommendation of the NASA group which called for an eight hour protected period. The window is the same during each successive day on reserve.

The Study Group is concerned that the variable notice arrangement is based on the unproved supposition that sleep deprivation resulting from a short-notice call can be adequately compensated for

---

* Twelve hours is felt to be the maximum safe shift duration in many shiftwork settings, e.g. nursing. However, there are data demonstrating an increase in performance errors between 8 and 12 hours of shift duration, suggesting to some that the appropriate maximum shift duration in safety-sensitive shiftwork settings should be 8 hours (17).

by reducing the duration of work required. At its extreme, this arrangement would allow a pilot to work for up to 6 hours with effectively no notice, *i.e.* advance notice equivalent to the time required to report to the place of assignment. Presuming worst case timing in which the crew member was called immediately prior to the habitual daily sleep period, continuous wakefulness of more than 22 hours (presuming an eight-hour habitual sleep period) by the end of the 6 hour shift. There is no reason to believe that the reduced shift duration adequately compensates for the performance impairment associated with acute sleep deprivation of this kind.

The Study Group prefers the protected window arrangement, as specifically defined in the NPRM, because the greatest possible extent of sleep deprivation is limited to 18 hours (presuming that the crew member using protected time for sleep). For protected windows during the day, and particularly those during the circadian window of maximal alertness, six hours would not appear to be sufficient to allow adequate rest on repetitive basis.

One major improvement and important safeguard in the current NPRM reserve arrangements is the requirement that a normal rest period precede each reserve assignment. Specific concerns about either reserve arrangement are mitigated by this protection, which should serve as an adequate safeguard against extremes of sleep deprivation, even if subsequent duty assignments occurring during either reserve arrangement are adversely timed.

5. Recommendations

The Study Group concludes that the proposed flight-duty regulations represent an important advance in the effort to define physiologically sound limits that minimize fatigue and optimize flight crew performance and aviation safety. Criticisms of the specific regulations reviewed above are not meant to be construed as a preference for the status quo. Instead, the Study Group urges expedient implementation of the proposed regulations, with the following modifications:

5.1. Recommended revisions to the proposed regulations:

5.1.1. Maximum duty durations should all be adjusted downward to levels in accordance with available data on the relationship between shift duration and degradation of performance. Circadian variation in susceptibility to this degradation should be accommodated with reduced maximums for shifts that include the time of peak circadian sleepiness (4 – 6 AM).

5.1.2. Minimum rest periods should be adjusted upward for sleep periods that include the time of peak circadian alertness (4 – 6 PM).

5.1.3. The provision allowing extension of duty maximums up to 24 hours (26 with operational delay) in augmented crews and in assignments that include facilities for in-flight sleep should not be implemented until scientific evidence is available demonstrating that in flight arrangements preserve alertness at acceptable levels, *i.e.* at levels equivalent to that on the routine shift durations.

5.1.4. Reserve time arrangements should be adjusted so that protected windows during the time of peak circadian alertness are extended to compensate for decreased efficiency of sleep during that time.

5.2. Recommendations for future revisions:

Several of these issues illustrate the need for additional data, and even with adjustments recommended here, specific limits on duty duration and minimum rest duration will represent quantitative implementations of solutions for which there is currently only qualitative scientific support. Therefore, the Study Group also recommends this set of recommendations be viewed as the first step in a continuous process. Specifically,

5.2.1. NASA, in its capacity as independent scientific resource, should be commissioned to gather additional data on this issue with the following priorities;

5.2.1.1. Identification and characterization of a suitable surrogate outcome measure that can substitute for actual accidents and self-reported incidents as a measure of fatigue in flight crews. This proxy measure will then be assessed to continuously monitor the extent of fatigue and the impact of this and future regulatory adjustments.

5.2.1.2. Determination of the impact of duty period duration on performance, independent of sleep deprivation and circadian phase effects. The impact of varying percentages of flight time within a duty period should also be assessed.

5.2.1.3. Determination of the impact of varying workload on performance, with particular attention to the role of landings and sustained flight.

5.2.1.4. Assessment of the protective effect of augmented flight crews and provision of facilities for in-flight sleep on crew alertness with the intent of determining the extent to which duty and flight durations can be safely extended.

5.2.2. An independent scientific panel should review the data collected by NASA on a regular basis with the intent of providing a comprehensive and detailed set of recommended revisions to the regulations within three years from the time at which these recommendations are ultimately implemented.

6. References

1. US Govt Federal Aviation Administration, Flight Crewmember Duty Period Limitations, Flight Time Limitations and Rest Requirements. Notice of proposed rulemaking (NPRM). *Federal Register* 1995;60(244):65951-60.

2. Borbely AA, Baumann F, Brandeis D, Strauch I, Lehmann D, Sleep deprivation: effect on sleep stages and EEG power density in man. *Electroencephalography & Clinical Neurophysiology* 1981;51(5):483-95.

3. Carskadon MA, Brown ED, Dement WC, Sleep fragmentation in the elderly: relationship to daytime sleep tendency. *Neurobiology of Aging* 1982;3(4):321-7.

4. Carskadon MA,Dement WC, Effects of total sleep loss on sleep tendency. *Perceptual & Motor Skills* 1979;48(2):495-506.

5. Rosenthal L, Merlotti L, Roehrs TA, Roth T, Enforced 24-hour recovery following sleep deprivation. *Sleep* 1991;14(5):448-53.

6. Borbely AA, Balderer G, Trachsel L, Tobler I, Effect of midazolam and sleep deprivation on day-time sleep propensity. *Arzneimittel-Forschung* 1985;35(11):1696-9.

7. Moore-Ede MC, Czeisler CA, Richardson GS, Circadian timekeeping in health and disease. *N. Engl. J. Med.* 1983;309:469-76 & 530-6.

8. Richardson GS, Carskadon MA, Orav EJ, Dement WC, Circadian variation of sleep tendency in elderly and young adult subjects. *Sleep* 1982;5(Suppl. 2):82-94.

9. Czeisler CA, Johnson MP, Duffy JF, Brown EN, Ronda JM, Kronauer RE, Exposure to bright light and darkness to treat physiologic maladaptation to night work [see comments]. *New England Journal of Medicine* 1990;322(18):1253-9.

10. Czeisler CA, Allan JS, Strogatz SH, et al., Bright light resets the human circadian pacemaker independent of the timing of the sleep-wake cycle. *Science* 1986;233(4764):667-71.

11. Czeisler CA, Kronauer RE, Allan JS, et al., Bright light induction of strong (type 0) resetting of the human circadian pacemaker. *Science* 1989;244(4910):1328-33.

12. NASA, *Pilot fatigue and circadian desynchronosis*, . 1980, Ames Research Center: Moffett Field, CA.

13. Folkard S, Effects on performance efficiency. In: Colquhoun P, Costa, Folkard S,Knauth R, eds.*Shiftwork: Theory and Practice*. Frankfurt am Main:Peter Lang, 1995:in press.

14. Daan S, Beersma DG, Borbely AA, Timing of human sleep: recovery process gated by a circadian pacemaker. *American Journal of Physiology* 1984;246(2 Pt 2):R161-83.

15. Walsh JK, Schweitzer PK, Anch AM, Muehlbach MJ, Jenkins NA, Dickins QS, Sleepiness/alertness on a simulated night shift following sleep at home with triazolam. *Sleep* 1991;14(2):140-6.

16. Eastman CI, Boulos Z, Terman M, Campbell SS, Dijk DJ, Lewy AJ, Light treatment for sleep disorders: consensus report. VI. Shift work. *Journal of Biological Rhythms* 1995;10(2):157-64.

17. Rosa RR,Bonnet MH, Performance and alertness on 8 h and 12 h rotating shifts at a natural gas utility. *Ergonomics* 1993;36(10):1177-93.

18. U.S. Congress Office of Technology Assessment, *Biological Rhythms: Implications for the Worker*, . 1991, U.S.Government Printing Office.

19. Mellor EF, Shift work and flexitime: How prevalent are they? *Monthly Labor Review* 1986(Nov/86):pp14-21.

20. Akerstedt T, Sleepiness as a consequence of shift work. *Sleep* 1988;11(1):17-34.

21. Rosekind MR, Gander PH, Miller DL, et al., Fatigue in operational settings: examples from the aviation environment. *Human Factors* 1994;36(2):327-38.

22. Rosekind M, Wegmann H, Dinges D, Graeber R, Samel A, Principles and Guidelines for Duty and Rest Scheduling in Commercial Aviation. *NASA Technical Memorandum* 1995;in press.

23. Sanquist TF, Raby M, Lee JD. *United States Coast Guard Alertness and Fatigue Research Program.* in *Human Factors on Board: The Influence of the Man-Machine Interface on Safety of Navigation.* 1995. Bremen, Germany.

24. Rosekind M, Graeber R, Dinges D, et al., Crew Factors in Flight Operations IX: Effects of planned cockpit rest on crew performance and alertness in long-haul operations. *NASA Technical Memorandum* 1994;108839:1-64.

APPENDIX D

Remarks by Dr. William Dement to the ARAC Working Group Pilot Representatives on December 1, 1998 at ALPA HQ, Washington, D.C.

I'm very pleased to present Dr. William Dement of Stanford University who's here to answer some of our questions regarding sleep science. Dr. Dement is considered the father of modern sleep medicine. He earned his M.D. and Ph.D. from the University of Chicago where he first began to study sleep. In 1963 he became the director of Stanford University's Sleep Research and Clinical Programs and continues in that post today. He was Chairman of the National Commission on Sleep Disorders Research from 1990 – 1992; a Commission chartered by Congress. He is the author of a definitive textbook on the diagnosis and treatment of sleep disorders and has written or co-authored more than 500 scientific publications. Dr. Dement, welcome and thank you for your time and being here today.

Thank you. For many years, the people who were interested in circadian rhythms and the people who were interested in sleep were fairly separate. Now there's actually a scientific meeting going on in Bethesda hosted by the National Institute of Health and the National Science Foundation in which circadian rhythm issues and sleep issues are considered to be complementary parts of one scientific discipline. This has been happening over the past 10-15 years.

One of the things that I'm trying to deal with is the fact that the study of sleep, the scientific study, and the applications / operational situations coincided later than some of the other disciplines. To get really into the mainstream of the scientific knowledge and the applications, ...this has been what I've been most interested in trying to help accomplish during the past 20 years,... and the first effort was to try to create a federal agency that would really be responsible for sleep and circadian issues, research, applications and education. Our efforts to do this led to the response of Congress to create a Commission, not to create an agency but to create a commission.

It turned out to be really a good thing because many of us had been in the ivory tower and this Commission really put us out in the field, hearing stories from people who have been involved in accidents, hearing what life is like in the trenches so to speak. That certainly made an enormous difference to me in appreciating, in a much more human way, the difficulties and the problems. We presented recommendations to Congress and it kind of coincided with the budget crisis, and dare I say, the Republican revolution so that only one key recommendation was passed. But there is now a federal agency – The National Center on Sleep Disorders Research – which, small, although it may be, is certainly a great start, and has on its plate some of the concerns that affect you. It also has the legislative mandate to interact with the Department of transportation and other agencies that are involved in these issues. I just wish it was much. much larger, and we're still working in that direction.

I wanted to say three or four things about sleep. First of all, I'll preface this by saying last year when we changed to daylight savings time, there was a National Sleep Awareness Week sponsored by the National Sleep Foundation, which by the way, is a major resource in the education and is based in Washington, DC. It created a sleep IQ test for the American public. The American public did more poorly than chance on this test. Not only then is there a pervasive lack of awareness by the general public, but there's also the presence of certain mythologies which then lead you to pick wrong answers more frequently than by chance alone. A lot of those mythologies are still in the transportation industry. I think there is no question about that.

The first thing that most people should be aware of is very simple: what is sleep? The fundamental difference between wake and sleep (and there's some very elegant research being presented about what actually goes on in the brain at that momentary transition) is that first, the transition is very rapid and can take place in less than a second. One moment you are awake and conscious of the outer world and then next moment you are asleep and unconscious of the outer world. When you're very fatigued, you can go to sleep instantly, and at that moment you don't see anything or hear anything. That's what makes falling asleep so very dangerous because you will not respond to a signal. The only thing that a stewardess could do is to wake you up. Often in a fatigued person, the awakening stimulus must be very, very intense.

So, anyone who thinks that moving towards sleep is in the least little bit safe is completely wrong if you want a human being to function at any level at all. The transition is very, very rapid.

Then there's the period of fatigue that I like to call "fatal fatigue" which is approaching the moment of sleep and depending on the degree of fatigue, can be fairly rapid. But that's a period of great impairment where you miss signals, you misjudge, your memory is impaired, your reaction time is elevated, etc. You are now very close to the threshold of unconsciousness....the moment of sleep.

There's a very dramatic study that I'd like to tell you about because it should stick in your memory. You have someone lying on a table with the eyelids taped open and a 50,000 power strobe light 6" from the nose. When that thing flashes, the table almost wiggles. He is supposed to press a little switch when it flashes, and you'll be making it flash and suddenly the person will not press the switch, apparently wide-awake. You ask him, "Why didn't you press the switch?" "Well, the light didn't flash." And if you look at the brain wave recording you'll see that there's a micro sleep right at the moment the light flashed. So that's how powerful that is. There's been a recent study in heavy trucks with brain wave recording in the cab as the drivers are driving, and yes indeed there are lots of micro sleeps there. They really do occur.

The second thing is that all sleep researchers now accept the concept of "sleep debt." Each individual needs a certain amount of sleep each day on the average to avoid accumulating a sleep debt. That sleep debt can accumulate over a long period of time. It can accumulate in relatively small amounts so it's kind of insidious, or of course it can accumulate very rapidly. You find frequently that many people have been partially sleep deprived for long periods of time. They aren't aware of this as fully as they ought to be you would think.

There's lots of evidence showing that you can get rid of that debt and how much extra sleep you have to have to get rid of it. The best type of research that demonstrates that is to show the increase in the tendency to fall asleep -- the *power* of the tendency to fall asleep – as you add hours to the sleep debt. Eventually, the person will finally fall asleep, no matter what. They can be walking and fall asleep. But if you put someone in an ad-lib situation, just take any one of you, and say, "Now you're in a situation where you have to sleep." You're going to be in a bedroom with no lights. All you can do is sleep. Then you will see all this extra sleep will take place. That's the debt....the amount of sleep that you should have received on a daily basis. That's usually astoundingly large.

In studies of this sort, you can show that a person thinks they're perfectly normal in terms of the way they feel. However, if they reduce the sleep debt, their performance will improve. The question is how much debt is anyone carrying at any particular time. The main thing is don't do anything that might increase it. That's my fundamental principle.

Finally, the circadian rhythm - I think that everyone has known that there is a biological clock. Since 1971, the location has been known in the brain, there have been a lot of electrodes and genetic studies, etc. Exactly how the clock functions to create a circadian rhythm of sleep and wakefulness has been understood relatively recently. This has been learned through the study of experimental animals. The best results are obtained with primates. So if you eliminate the primate biological clock, what's the result? They fall asleep all the time. They'll fall asleep, stay asleep, wake up, fall asleep, wake up, etc. The circadian rhythm of sleep is completely eliminated and you lose periods of sustained wakefulness. So that the concept today is that the clock participates in the daily regulation of sleep and wakefulness by alerting the brain at certain times. And you know those as, in other words, the forbidden zone for sleep,... the second wind that a lot of people get at the end of the day. But the clock does not put you to sleep. When the clock turns off in effect, when this alerting influence ends, a person is left with this gigantic sleep debt. That's what I've heard you refer to as "WOCL." That's the period where you find the least alerting of the activity clock, the most unopposed manifestation to the effects of accumulated sleep debt. and the greatest likelihood of falling asleep.

So those are the three main things. These are established facts. I don't think the scientific evidence is conclusive and those are the things we take into consideration when we try to apply the knowledge to the practical or operational situation. Any questions on that?

People say, "Can you accumulate a debt for a year?" We don't know because those studies haven't been done. But there's no evidence whatsoever that says "No, it levels off," or "No, it changes." All the evidence says that you keep accumulating a debt as long as you keep losing sleep below your specific daily requirement. There's no evidence that you can change this. I suppose you could ski or play basketball as opposed to just sit in a hot room and that would make a little difference but that doesn't change your sleep requirement.

Anybody got any questions?

I've got a question. Napping: does that in any way alleviate the sleep debt?

Let's say you have a 40-hour sleep debt and you have a ten-minute nap. So now your sleep debt might be 39 hours and 50 minutes. It wouldn't make any difference there. A lot of the napping is done after lunch. Most people, and especially younger people – and I don't know what the average age is in this group – but younger people have strong clock-dependent alerting late in the day. So you have sort of an illusion. You happen to take a nap just before the clock turns on. Is the alerting partly a result of the nap or not? Mostly not, but I would say until proven otherwise that a nap, if it is good sleep (which it usually isn't) is minute per minute doing what sleep would do, but it's usually nowhere near the total amount that you require.

Dr. Dement, I have a list of questions that pertain to our task of helping to define flight time and duty time regulations and if I could just take the liberty of asking these particular questions and open up the floor for any other remaining questions that other people may have. One of the most basic tasks is for us to agree on a recommendation for a sleep opportunity,.... to afford every reserve pilot the opportunity of a protected time period so that he or she is absolutely insulated from contact from the operator. How many hours do you recommend for a minimum fixed sleep opportunity?

I will start out by assuming that we would take 8 hours of sleep as the most common requirement. Then you need to add to that in order to be able to get the proper amount of sleep. In your situation, I would think it would be a little larger than it might be for someone who really wasn't doing anything. So I'd add a couple of hours to get the proper amount of sleep.

Are there any findings as far as the amount of sleep loss or the ability to sleep during less than desirable times of the day and what a person could expect?

Well, there's an ideal time to sleep and then everything else is less than ideal. Sometimes it's devastatingly less than ideal.

Well, how much so? If you had an opportunity to sleep during the day and you were given an 8-hour sleep opportunity, could you expect to get 8 hours of sleep during that opportunity?

No, I'd say absolutely not. If that happened, it would be an incredible exception. There's a ton of evidence on that also.

How about if you were getting a 10 hour sleep opportunity?

No, I don't think so. There have been a lot of studies on sleep reversal. You simply reverse the sleep period and this is now a model of insomnia. If you have to sleep in the daytime, you have insomnia in effect. The ideal time to sleep if you have a stable circadian rhythm is to stay near the circadian rhythm.

The 8 hours of ideal sleep, is it possible from your studies you can nail down any specific 8-hour period or is it variable for individuals?

Well, it may vary a little bit. Within a very narrow range I wouldn't say....I would say for most people, it's from 11 – 12 PM to 7 – 8 AM. For the vast majority, that's the ideal sleep period. People will ask why they are the exception, but you're not dealing with exceptions here.

When you're forced to have to sleep if you're flying at night and you're sleeping in the day, I guess what you're really saying is that the chances are you're going to become somewhat sleep deprived over time.

That's right.

And so the only way you correct that, no matter how much time you are getting to sleep, you're still going to be somewhat sleep deprived. So the only way you're going to break that cycle is periodically if you have a certain amount of time off and you sleep during what might be considered your normal sleep period to restore that.

Well, at the present time that really is the only effective way. I think that we take the position that there's never an adjustment to that type of schedule. You referred to night duty...and you would think that if a person did it all the time they ought to adjust, ..but all the studies always show impairment in sleep loss.

Dr. Dement, ...we're really at the point now where we're going beyond the philosophy and we're trying to put our finger on numeric values. Our position at least from the pilots' standpoint, is that we see the need for a 10-hour sleep opportunity knowing that the opportunity may not always be at the best time of the day. We're facing an industry position that is looking for 8 hours as the minimum. Our position is predicated on the *fact that 8 hours may be adequate if it overlaps the WOCL. But since we don't know for sure when we're going to have that opportunity, we believe that, or we think that having that extra 2 hours is going to give us a little more of a buffer, especially when it comes during the daytime. Would you consider that to be a conservative and a justified position?*

Absolutely. I don't think you could possibly assume someone is going to fall asleep instantly and then sleep continuously for 8 hours, not even under the most ideal circumstances. Maybe it should be longer.

By the same token, say that same individual who was supposed to sleep had the perfect time during the day and was supposed to sleep during the day, hadn't slept the previous night and he had normal sleeping hours because he was not disturbed for any duty assignment. What effect does that have on his subsequent rest period?

In the ideal situation if someone sleeps the normal amount at night, they can't sleep at all during the day. We are pretty much a sleep-deprived nation so that we do have this mid day dip in alertness. Most people say they get drowsy after lunch. That's sleep deprivation. If you were not dealing with someone who is extremely sleep deprived, then I would say sleeping a normal amount at night becomes very difficult, or it should become very difficult to sleep in the daytime. That is a fact if the carryover sleep debt isn't large. it's definitely more sensitive to stimuli, etc. and you're fighting the biological clock for much of the day.

Have you ever conducted these tests when they're wearing a uniform?

[Laughter] Well, we did some testing but I think they took them off when they went to bed.

I fly at night all the time and only get rest during the day. I heard that if you sleep during the optimum time of day, you really need to have about a 10-hour period in which to get your 7 ½ or 8 hours of sleep. If you do not ever have the opportunity to sleep for 7 – 10 days in a row, you are never able to sleep during the optimum time. I heard you say that you always need more than 10 hours to get even reasonable sleep even though you probably never will achieve adequate sleep. Can you put any kind of a number on the gross amount of time you could have available for sleep opportunity to try to restore sleep?

The problem is that there becomes inefficiency. You don't want to spend 16 hours in bed to get 8 hours of sleep. There just isn't a good solution to be perfectly honest. The main thing you need to know then is first, at what period of the day in your clock (God knows where your clock is) there is some period when it's the most difficult to sleep. Hopefully you know that about yourself. Obviously you avoid that. If you can schedule more than 10 hours, not at that time, then you yourself will need to determine if you can do it in a minimum of 10 hours, or does it take 13. That would be a horrible life.. to spend all that time in bed.

I'm typically so sleep deprived that [can't understand rest of statement.]

Years ago, just to make a dramatic point, we were approached before we knew about sleep debt, before we could measure sleepiness. It was in the 60s we were approached by a company that had a billion-dollar bed (ceramic bead bed – billions of little beads. They use them now for burn patients. It's supposed to be the most comfortable surface ever. So we got a group of students. We had a regular bed, the cold concrete floor condition and the beaded bed. To our utter amazement, sleep was the same in all three conditions. The students who were doing this were on spring break, they probably had a 100-hour sleep debt, they could probably sleep anywhere, and that to me is a symptom of grave concern. If you could sleep anywhere.. anytime you are very sleep deprived....that's not good. That's another mythology. People get so macho. Saying that they can sleep anywhere is like saying they were drunk or they could drive when they're drunk. People misunderstand that. That's a symptom of severe sleep deprivation.

I have a couple questions. First of all, if we consider we are dealing with an individual who had no accrued sleep debt and that individual awoke in the morning, what does the science say about the amount of time awake that individual would have before, or is there any kind of .....

Well, probably if he's getting up in the daytime, that person could not possibly sleep in the daytime.

I'm not talking about sleeping. How long could he be awake before he.....

Oh, well, maybe 16 hours would be the usual time he's awake. One of the things that we -- at least I and I think most of my colleagues -- agree on is that all wakefulness is sleep deprivation. In the model of sleep regulation, you need that accumulated sleep debt of 16 hours to, in a sense, power the sleep of the night.

If you didn't have a sleep debt, how many hours would you have to be awake before you could be able to take a nap? Is there any measurement that has been done?

First of all, it's so difficult to get a human being in a state of no sleep debt. I'm not sure that it has ever happened. The closest we've come are in the study I briefly alluded to where the people had to spend 14 hours in bed in the dark every night for 5 weeks. At the end of those last few weeks, we think they were getting up with 0 sleep debt. It would take them 2 hours to fall asleep and they had terrible sleep because they tried to do it in 14 hours. If you have a minimum sleep debt, then I would say I don't think you could fall asleep....it would be the whole day I would think before you could really confidently fall asleep. One of the things I'm not 100% sure is how much monotony and sensory isolation can you tolerate before you have a micro sleep? Two or three hours? Under ordinary circumstances, daytime sleep is difficult.

Is there anything definitive that says which of these two situations would be more fatiguing: an individual who has to stay up until 3:00 a.m. or an individual who is forced to wake up at 3:00 a.m.?

That's a good question. I would think both would be fatigued and it's so the pattern might be a little different, but it would depend on how much sleep they had prior to that. I would think though that going into action at 3:00 a.m. for most people you'd be extremely impaired. On the other hand, some people, as you get after midnight, become extremely impaired also. I don't think they've ever been compared head to head, but those are the kinds that would impair performance. Period. There's a thought that people somehow get enough adrenaline. Certainly students in exam week somehow get so stressed and so anxious that they seem to be able to go a little longer. It's obvious that they're paying a price when you look at them afterwards. That's not something to rely on. To me, it's only when you're trying to rescue people or something that you would want to do that sort of thing.

Dr. Dement, after our reserve pilots receive their sleep opportunity, they become available for duty. We call the availability period the "reserve availability period" and that's basically the time they are available for work, for flying. After the sleep opportunity, what would you consider to be a safe limit of time since awake for a crewmember?

For the 10-hour period?

Yes.

Fourteen hours. And I wouldn't say that's 100% safe but if you have a number, that adds up to the 24-hour day. It ought to be reasonably safe.

Where do you get your number from?

Well, it comes mainly in my head from circadian type 24-hour studies to see the pattern of the manifestation of the drive to sleep versus the awakening effect of the biological clock. If you're getting outside the 24-hour cycle, then you're going to have periods of greater risk. I realize that operationally that's probably difficult, but....

That assumes that the individual wakes up as soon as his protected time period is over. So in other words, you see a complimentary factor: 9 hours of rest should dictate a 15-hour availability period?

Yeah. I think most people would agree that would be the ideal.

Going beyond that, what is probably the most greatest points of contention right now – the debate between the pilots and the industry operators – is the fact that the operators would like to extend this reserve availability period in excess of what you say is 14 or 15 or 16 hours, whatever the case may be, to a larger increment, extending that reserve availability period based upon an advance notice of a nap opportunity. In other words, a pilot comes on call at 8:00 a.m. He is then told at 9:00 a.m. that he is to report for duty 5 hours later. The industry's position is that the notice constitutes an opportunity for additional rest which then would be utilized to add more restorative energy, or analogous to putting more charge into a battery, to carry that pilot into more of an extended duty period with an additional amount of time.... up to in certain cases 24 hours of duty. What is your feeling on that type of scenario?

To me, that's a recipe for disaster because if you have a responsible, professional pilot -- who has a reasonable schedule, I guess – who is not horribly sleep deprived, and who has a fairly stable circadian rhythm, then the likelihood that he can get adequate sleep by trying to nap I think is relatively small. I would not depend on it at all. I would think also to have to do it sort of unexpectedly like this....Oh! Take a nap....Only people who are very sleep deprived....

Can I ask that question a different way?

Sure.

Let's say I have a 10-hour sleep opportunity: 10 p.m. to 8 a.m. That means I'm available for 14 hours unless they fly me into the next 10 p.m. slot tonight. Could I not get a call say at noon and say instead of you being off tonight at 10 p.m., we want you to work until seven tomorrow morning but you aren't going to go to work until 10:00 that night. So they call me at noon, they give a 10-hour notice that I'm not going to have to go to work until 10 hours from noon, so at 2200 I report for work, and they want me to fly until 0800. So that would be a total of 24 hours from the time I theoretically woke up and I've had a 10-hour notice that I was going to be flying this fatiguing schedule. Would that be safe?

Well, I wouldn't be on your plane. No. I think that's almost insanity in the sense of saying that is safe. First of all, naps can't be depended on – even under ideal circumstances – to get you through this period when the biological clock alerting is gone, when you're alone with your sleep debt so to speak, during the WOCL. There's no way that isn't going to be dangerous. Yes, there may be exceptions, but it's always going to be dangerous. The likelihood is not good that you would be able to have some kind of good luck that you did sleep a lot, and that has gotten you through. First of all, you would not be at your peak performance. There is just no way. You cannot achieve peak performance during that period of time. Maybe for 10 minutes. The notion that you can depend on getting adequate sleep I think is just wrong. You can go into a laboratory and you can do some studies and you can demonstrate that occasionally someone will perform pretty well, but that's not 100% ever. It's never getting back to peak performance and it's under the luxurious circumstances of no interruptions, no noise, etc. I wouldn't ever think that napping could make it safe going through the night.

How about that the flight is going to happen. There is going to be every day in America, pilots that report to work at 2300 or whatever and fly until 0800 the next morning. Now, what's different about the man who knows a week, a month in advance that this is going to be his schedule and the reserve pilot who finds out at noon after having woken up at 8 a.m.? What would be the difference?

You know that the time you do all of the things you can to move toward a better situation....You can never get to perfection, but the more practice, the more warning, the better you'll be able to handle it. Some people learn that there is a time when it's quiet and if I do this, I can pretty much depend that I will fall asleep. It's not 100% but you kind of learn that or you practice or whatever. But if it's without warning, all bets are off.

Dr. Dement, you've kind of led the discussion into another area of this rulemaking that has to do with an alternative method. Assuming that the pilots in this protected time period method were depleted, the carriers then want to give pilots advance notice to cover any mission or any assignment. They are looking at 10 hours as the criteria. We don't believe that to be adequate based upon....

Are you talking 10-hour warning?

Ten-hour warning, yes. To do anything.

That would be 100% wrong.

Why?

Well, because the 10 hours could fall sort of toward the beginning of what we call "clock dependent learning." There's no way you could sleep. And then you go into your duty period at the worse possible time you could have that situation.

What sort of time would you think would be adequate to give a guy enough time to get an opportunity to rest so that he would be safer than 10 hours?

Twenty-four hours. At least a day before. Wouldn't you think? I don't see how you can get notified as the day is beginning and feel you could depend on being able to take a nap. If it happened every day or somehow you know that you could certainly get the probability up, but it's not something that you could ever really control. Again, there ought to be a better way.

That's the problem: a better way. Understandably, that's not desirable but the question is: how do you best prepare for that?

You're saying if the notice is given with the 10-hour window?

Management would like a 10-hour notice.

It would seem to me that a better approach would be to have a 24-hour window or some longer period. Say you get notified the day before. I suppose there are emergencies and so on, and you would be called for those exceptions... and a pilot would have so many exceptions over such and such portions of time depending on the emergencies and whatever constraints....

Some types of operations operate without a schedule.

That's the worst.

I have 2 questions, doctor. First, a person that has adequate sleep wakes up non- sleep deprived at 8:00 a.m. Fourteen hours later it's 2200 and he's driving home from dinner with his wife. Is he impaired?

I have to say it depends on his age probably. The impairment is starting probably. You don't go straight down; you go down with an accelerating level of impairment. Most of the studies in the laboratory say depending upon where your mid day dip is, your performance will start decreasing in the late evening.

We're not familiar with the mid-day dip. The late evening is ....?

I'm thinking 10:00.

If a person was to fly so as to stop flying at 8:00 a.m. and he was to fly throughout the 0200 – 0600 time frame, what time should he be waking up in order to be best prepared for that flight that lands at 8:00 a.m.?

I know you said he's flying. He's waking up?

No. When should he wake up to be best prepared for a flight that would include landing at 8:00 a.m.? If he starts at midnight. How do you get prepared for that even if (I'm not talking about reserve or anything)...What should a pilot do, how should he plan his day to wake up at the right time to be most alert at 8:00 a.m.?

First of all, why does he have to wake up at 8:00?

No, no. He's flying at 8:00. He's flying from midnight to 8:00.

Oh, okay. But basically what should he do the day before if it's a midnight flight? I assume sleep as late as possible.

On his normal sleep cycle like you first said?

Yeah.

And then what?

And he's free all day?

Yeah. He doesn't have to do anything....

If he knows that he has this post prandial period of diminished alertness , I would try to take a nap at that point in time.

Late afternoon?

Yeah.

I don't know what postprandial....

It means after lunch. Parenthetically, I've been working with students and I've been finding (because I've been working with very small groups) that if they start by learning how much sleep they need as an individual, when is their time of peak learning, when is their circadian nadir, they are able to make some choices in preparation for exams, etc. that are a great improvement over their previous situation where they didn't know these things. What you're trying to do is to get your sleep debt as low as possible and utilize what you know about yourself to accomplish that. Part of it would be, as a responsible pilot, you would do that as kind of a lifestyle. Maybe the lifestyle is changing a little bit but you're always trying to keep your sleep debt low so you never have to do something like when you are already really dangerous because your sleep debt may be 40 or 50 hours imperceptibly accumulated. Then again I'd tell you the best preparation is to get as much sleep the night before. The pilots in this NASA layover study seem to be pretty good at taking naps. Not perfect, but pretty good. We decided the reason for that is they were sleep deprived. They could take a nap. So there's that sort of tradeoff. Then the issue is whether or not the sleep closer to the duty period is necessarily better. I don't think it matters. When you start that period, what is your sleep debt when you're going to go into that WOCL, if you will. Whether it's low because you napped or low because you got lots of sleep the night before doesn't matter. Both would be the best.

Should you stay up until 3:00 a.m. so you can sleep later in the afternoon?

Not necessarily, no.

Should you stick with normal sleeping and then try to get a nap before you go to work?

Yeah, I would say as much sleep as possible. But here again you need to know yourself a little bit. But that's not what rulemaking is all about. Rulemaking is what fits everybody. Because of the uncertainty of being able to take a nap, I mean it's uncertain for me and I think it's uncertain for pilots. Although again, since pilots are generally more sleep deprived, they are more able to nap. If you felt able to take a nap with absolute certainty, then you should take a nap. But also get your needed amount of sleep the night before.

We're shooting around the subject. I hate to break any of this up, but this question has been plaguing this committee. The industry keeps harping on the fact that there should be no difference between the schedule holder who knows he's got to fly from midnight to 8:00 a.m. If he can do it safely, why can't a reserve that wakes up at the same time in the morning (8:00 a.m. or 6:00 a.m.). Why is it not safe for this reserve pilot who does it with notice?

I don't think it's safe for either pilot. Maybe a little less dangerous in the sense of performance, etc. But I think at least he has preparation, warning, etc. and knows his own strengths and weaknesses whereas the other pilot I think is always without warning and has really no chance to prepare. I don't think the two groups are the same.

Are you implying that the preparation should actually start the previous night?

Yes. If I were going to drive all night, I wouldn't want someone to tell me that day.

They're really killing us for making that same argument. I mean we make that argument across the table and we get smiles and nods of the head and shrugs of the shoulders from the other side. They say it's not a valid argument. That's always what they come up with.

They say it's not a valid argument? It is a supremely valid argument. I mean that's just like saying down is up.

Along the same lines, how much is the psychological aspect of this preparation that we're talking about in the same situation that we're currently discussing play. In other words, the line holder as we know it, gets notice of his schedule a week, a month in advance and can somewhat physically prepare himself. He knows that three nights from now, I've got to fly this God-awful all nighter trip so what you said, he sleeps as late as he can (10:00, 11:00 if he can). The reserve on the other hand is mentally unable to prepare himself. I know that I've got to go through this with

But he knows that day.

No. He might know a week or a month in advance so he's had ... that's what I'm getting at.

The reserve pilot or the regular pilot?

I'm talking about the reserve now. On the other hand, he gets a call at 8:00 a.m. or 9:00 a.m. and they say, "Guess what, John? You've lost the lottery. You get to go fly tonight." It's always, "Oh my God!" Now I'm the unlucky one. He can only minimally physically prepare but how much psychologically does it affect him that he's now surprised of the fact that he's got to go do this flight? Does this have much to do with his ability to clear himself and be ready to go and fly this thing?

No, I don't think it'd be negligible. I'm not quite sure. He could either be depressed, I suppose or angry. But I think that we don't feel that revving yourself up or being determine or anything else can really oppose a period of circadian nadir and....

So, it would be a minimal factor....

Yeah, I would think so. Usually these are very short lasting things. For example, I've been interested in when Stanford University gets a lot of Nobel Prizes and the call tends to come in the middle of the night because it's from Sweden. And it's interesting to me who falls asleep immediately afterwards and who doesn't. Again, they tend to fall asleep with this incredible, exciting news because it's at that WOCL time. We have to tell them they shouldn't call during the WOCL.

One thing we were talking about....Let's say we are in a circumstance where we're in this situation where we're going to have to deal with this. You got notice you're going to have to fly the back side of the clock, this time that we don't want. Is it fair to say that based on the studies that limiting the length of that time, the shorter the length of time that you operate the safer you are, and the longer you're exposed to being on duty the worse off it is?

Oh sure. Absolutely.

It seems like common sense. Fairly obvious. One other quick question. It seems to be the way you were going is that how much notice you're given is not as important as when the notice falls. In other words, when the opportunity to rest based on this notice of assignment, is that a fair assumption?

Well, the two aren't exactly the same. I don't mean to imply that when....I mean, the longer you have, the better. I guess I don't understand your question.

Well, that's kind of what I'm getting at. I guess it is....

I mean, generally you don't get the notice in the middle of the night, do you?

Well, it would kind of depend....we're dealing with round-the-clock operations so we may have situations where an individual's protected time period this time he's supposed to be sleeping actually starts at 7:00 a.m. and goes to 3:00 in the afternoon. So he might get notice in the middle of the night for an assignment that comes subsequent to that later on. So we're dealing with round-the-clock operations and no guarantees.....

I would think notice in the middle of the night is useless. First of all, you disturb the sleep and secondly it doesn't really help you with the next day any more than notice at 8:00.

Taking for a moment that you're not asleep, I mean that it's not your normal sleep time. I guess what you're saying is that 14 hours notice or 12 would be better than 10 most likely....

Yeah. All other things being equal.

Did you ever fly the midnight flights?

No, not anymore.

Especially after today, right?

Doctor, I'd like to think we'd be able to negotiate something like you said: a 10-hour rest period and a 14-hour maximum reserve availability period, but unfortunately, that's a very high expectation. What we will be facing is longer periods of reserve availability. Based on the fact that we will be facing potentially onerous, long periods of time since awake, long reserve availability periods, do you think that being afforded a greater amount of sleep opportunity will give us more of a protection against that longer duty? Is there a relationship as far as the amount of restorative sleep as preparation for longer period of duty?

Yes. The less sleep you have the harder it is. Period.

So, in other words, if we were forced to accept by the rulemaking office these longer periods of duty in excess of 16 hours or 14 hours, then it would behoove the agency to look at providing pilots with as much rest as possible to prepare themselves for that type of duty?

Absolutely. When you've been in this business as long as I have, to think that anyone could even think of the opposite is ....

I'm assuming that it's mythology that if a person can't sleep, that the person tries to sleep and just lies there and does nothing and stares at the ceiling and count sheep or whatever, does that have any type of restorative abilities?

There's no evidence that anything but sleep has any restorative value. Years and years ago people thought physical rest was important. But in a kind of normal range of human activities, only sleep is. Obviously you can get muscle strain and run 50 miles you're going to be in the hospital, but rest is useless in terms of substituting for sleep.

Dr. Dement, there's one area that we really haven't touched upon at this point and I don't want to miss. These are questions regarding the maintenance of circadian stability. In your opinion, why is maintaining circadian stability so important?

Well because usually... and by that you mean your sleep opportunities and your wake opportunities are in a period of stability, then you have the best sleep and the best wake. If you get out of that cycle, then both sleep and wake will be impaired.

Well, when I think about that in the context of what we're trying to insure in our recommendations,.. we're trying to insure that the protected time period, the rest period, stayed the same from day to day, assuming the reserve crewmember is not called. Or for that matter when he is called, he goes back into his cycle. We're attempting to try to snap him back to as close to that original cycle and maintain that same rhythm from day to day. NASA has findings on that. Their recommendation was to maintain that circadian stability plus or minus 3 hours. Do you agree or disagree?

I absolutely agree that's better than no stability. Obviously the smaller that number, the better. I think practically it couldn't be zero, but I think we tend to feel there's kind of a daily flexibility within that range, like 0 to 3 hours, 0 to 2 hours. To go outside of that is, again, inviting a condition of sleep deprivation. So deliberately creating a bad situation.

What happens to the body as you change a person's cycle?

All sorts of things happen, but the major thing of course is that you are now trying to sleep when the body wants to be awake and you're trying to be awake when the body wants to be asleep because you left the circadian stability that you talked about.

[Question cannot be heard]

No, I think in summary, ...science is really clarifying these issues that people have been struggling with for many years, and there is always a resistance to change. But I think one of the things that we confronted in our Congressional commission is that a lot of the bad effects of sleep loss and impaired performance are frequently not obvious because there has not been a history of really looking for them. One of the studies that impressed me the most in that regard was an anonymous survey of hospital house staff. I don't remember the exact question, but it was that 42% in this anonymous survey had killed a patient as a result of a fatigued-based error. Well, who knows that? Who wants to know it? If we had the power to really take a look at the price of fatigue, it would be enormous. I think these things are just beginning to emerge and they seem to threaten management, threaten economic realities, but I think once there's this move toward help and peak performance and utilizing all this scientific knowledge that everyone will benefit. There will be ways to deal with these things and it will get better and better and the benefits will be recognized more and more. I think one of the problems in the trucking industry is the same kind of thing: what's the cause of all the crashes? Frequently, these causes aren't really assessed, and the public doesn't recognize the liability, but it's coming. I'm sure at some point it's better to be safe than to be sorry. Because sorry is lawsuits and lost lives, tremendous damage to property. Those things are going to be equated sooner or later.

END TAPE

APPENDIX E

Fatigue, Alcohol and Performance Impairment
Nature, Volume 388, July-August 1997

Reduced opportunity for sleep and reduced sleep quality are frequently related to accidents involving shift-workers[1-3]. Poor-quality sleep and inadequate recovery leads to increased fatigue, decreased alertness and impaired performance in a variety of cognitive psychomotor tests[4]. However, the risks associated with fatigue are not well quantified. Here we equate the performance impairment caused by fatigue with that due to alcohol intoxication, and show that moderate levels of fatigue produce higher levels of impairment than the proscribed level of alcohol intoxication.

Forty subjects participated in two counterbalanced experiments. In one they were kept awake for 28 hours (from 8:00 until 12:00 the following day), and in the other they were asked to consume 10-15g alcohol at 30-min intervals from 8:00 until their mean blood alcohol concentration reached 0.10%. We measured cognitive psychomotor performance at half-hourly intervals using a computer-administered test of hand-eye coordination (an unpredictable tracking task). Results are expressed as a percentage of performance at the start of the session.

Performance decreased significantly in both conditions. Between the tenth and twenty-sixth hours of wakefulness, mean relative performance on the tracking task decreased by 0.74% per hour. Regression analysis in the sustained wakefulness condition revealed a linear correlation between mean relative performance and hours of wakefulness that accounted for roughly 90% of the variance (Fig. 1a).

Regression analysis in the alcohol condition indicated a significant linear correlation between subject's mean blood alcohol concentration and mean relative performance that accounted for roughly 70% of the variance (Fig. 1b). For each 0.01% increase in blood alcohol, performance decreased by 1.16%. Thus, at a mean blood alcohol concentration of 0.10%, mean relative performance on the tracking task decreased, on average by 11.6%.

Equating the two rates at which performance declined (percentage decline per hour of wakefulness and percentage decline with change in blood alcohol concentration), we calculated that the performance decrement for each hour of wakefulness between 10 and 26 hours was equivalent to the performance decrement observed with a 0.004% rise in blood alcohol concentration. Therefore, after 17 hours of sustained wakefulness (3:00) cognitive psychomotor performance decreased to a level equivalent to the performance impairment observed at a blood alcohol concentration of 0.05%. This is the proscribed level of alcohol intoxication in many western industrialized countries. After 24 hours of sustained wakefulness (8:00) cognitive psychomotor performance decreased to a level equivalent to the performance deficit observed at a blood alcohol concentration of roughly 0.10%.

Plotting mean relative performance and blood alcohol concentration 'equivalent' against hours of wakefulness (Fig. 2), it is clear that the effects of moderate sleep loss on performance are similar to moderate alcohol intoxication. As about 50% of shift-workers do not sleep on the day before the first night-shift[5], and levels of fatigue on subsequent night-shifts can be even higher[6], our data indicate that the performance impairment associated with shift-work could be even greater than reported here.

Our results underscore the fact that relatively moderate levels of fatigue impair performance to an extent equivalent to or greater than is currently acceptable for alcohol intoxication. By expressing fatigue-related impairment as a 'blood-alcohol equivalent', we can provide policy-makers and the community with an easily grasped index of the relative impairment associated with fatigue.

[Note: Retyped. Endnotes and Figures 1 and 2 are illegible and have been omitted.]

Drew Dawson
The Centre for Sleep Research
The Queen Elizabeth Hospital
Woodville, 5011 South Australia
e-mail: ddawson@tqeh.smtp.tgeh.sa.gov.au

Kathryn Reid
Department of Obstetrics and Gynecology
The Queen Elizabeth Hospital
Woodville, 5011 South Australia

APPENDIX F

Quantifying the Performance Impairment associated with Sustained Wakefulness

Nicole Lamond and Drew Dawson

The Centre for Sleep Research. The Queen Elizabeth Hospital, South Australia

Sustained Wakefulness and Performance

Address all correspondence to Drew Dawson, The Centre for Sleep Research, The Queen Elizabeth Hospital, Woodville Rd. Woodville SA 5011. Australia.

Phone: +61 8 8222 6624 Fax: +61 8 8222 6623

Acknowledgments. Research supported by the Australian Research Council.

SUMMARY

The present study systematically compared the effects of sustained wakefulness and alcohol intoxication on a range of neurobehavioural tasks. By doing so, it was possible to quantify the performance impairment associated with sustained wakefulness and express it as a blood alcohol impairment equivalent. Twenty-two healthy subjects, aged 19 to 26 years, participated in three counterbalanced conditions. In the sustained wakefulness condition, subjects were kept awake for twenty-eight hours. In the alcohol and placebo conditions, subjects consumed either an alcoholic or non-alcoholic beverage at 30 minute intervals, until their blood alcohol concentration reached 0.10%. In each session, performance was measured at hourly intervals using four tasks from a standardised computer-based test battery. Analysis indicated that the placebo beverage did not significantly effect mean relative performance. In contrast, as blood alcohol concentration increased performance on all the tasks, except for one, significantly decreased. Similarly, as hours of wakefulness increased performance levels for four of the six parameters significantly decreased. More importantly, equating the performance impairment in the two conditions indicated that, depending on the task measured, approximately 20 to 25 hours of wakefulness produced performance decrements equivalent to those observed at a BAC of 0.10%. Overall, these results suggest that moderate levels of sustained wakefulness produce performance equivalent to or greater than those observed at levels of alcohol intoxication deemed unacceptable when driving, working and/or operating dangerous equipment.

KEY WORDS sustained wakefulness, alcohol intoxication, performance impairment

INTRODUCTION

The negative impact of sleep loss and fatigue on neurobehavioural performance is well documented (Gillberg *et al*., 1994; Mullaney *et al*., 1983; Tilley and Wilkinson, 1984). Studies have clearly shown that sustained wakefulness significantly impairs several components of performance, including response latency and variability, speed and accuracy, hand-eye coordination, decision-making and memory (Babkoff *et al*., 1988; Linde and Bergstrom, 1992; Fiorica *et al*., 1968). Nevertheless, understanding of the relative performance decrements produced by sleep loss and fatigue among policy-makers, and within the community, is poor.

By contrast, the impairing effects of alcohol intoxication are generally well accepted by the community and policy makers, resulting in strong enforcement of laws mandating that individuals whose blood alcohol concentration exceeds a certain level be restricted from driving, working and/or operating dangerous equipment. Consequently, several studies have used alcohol as a standard by which to compare impairment in psychomotor performance caused by other substances (Heishman *et al*., 1989; Dick *et al*. 1984; Thapar *et al*., 1995). By using alcohol as a reference point, such studies have provided more easily grasped results regarding the performance impairment associated with such substances.

In an attempt to provide policy makers and the community with an easily understood index of the relative risks associated with sleep loss and fatigue, Dawson and Reid (1997) equated the performance impairment of fatigue and alcohol intoxication using a computer-based unpredictable tracking task. By doing so, the authors demonstrated that one night of sleep deprivation produces performance impairment greater than is currently acceptable for alcohol intoxication.

While this initial study clearly established that fatigue and alcohol intoxication have quantitatively similar effects, it should be noted that performance on only one task was investigated. Thus, it is unclear at present whether these results are restricted to hand-eye coordination, or characteristic of the general cognitive effects of fatigue. While it is generally accepted that sleep loss and fatigue are associated with impaired neurobehavioural performance, recent research suggests that tasks may differ substantially in their sensitivity to sleep loss. Studies addressing this issue have suggested that tasks which are complex, high in workload, relatively monotonous and which require continuous attention are most vulnerable to sleep deprivation (Johnson, 1982; Wilkinson, 1964).

As conditions that cause deterioration in one particular function of performance may leave others unaffected, it is unreasonable to assume that one could predict all the effects of sleep loss from a single performance test. Thus, the current study sought to replicate and extend the initial findings of Dawson and Reid (1997) by systematically comparing the effects of sleep deprivation and alcohol intoxication on a range of performance tasks.

METHOD

Subjects

Twenty-two participants, aged 19 to 26 years, were recruited for the study using advertisements placed around local universities. Volunteers were required to complete a general health questionnaire and sleep/wake diary prior to the study. Subjects who had a current health problem, and/or a history of psychiatric or sleep disorders were excluded. Subjects who smoked cigarettes or who were taking medication known to interact with alcohol were also excluded. Participants were social drinkers who did not regularly consume more than six standard drinks per week.

Performance Battery

Neurobehavioural performance was measured using a standardised computer based test battery. The apparatus for the battery consists of an IBM compatible computer, microprocessor unit, response boxes and computer monitor. Based on a standard information processing model (Wickens, 1984), the battery sought to provide a broad sampling of various components of neurobehavioural performance. Four of twelve possible performance tests were used, such that the level of cognitive complexity ranged from simple to more complex (as listed below). Since speed and accuracy scores can be effected differently by sleep deprivation (Angus and Heslegrave, 1985. Webb and Levy, 1982), tasks that assessed both were investigated.

The simple sensory comparison task required participants to focus on an attention fixing spot displayed on the monitor for 750ms. Following this, a line of stimulus characters, divided into three blocks of either numbers, letters or a mixture was displayed. Participants were then required to respond to a visual cue, which appeared in the position of one of the stimulus blocks, be naming the block which had been there. Verbal response were scored as correct, partially correct or incorrect.

The unpredictable tracking task (three-minute trials) was performed using a joystick to control the position of a tracking cursor by centring it on a constantly moving target. Percentage of time on target was the performance measure.

The vigilance task (three and a half minute trials) required subjects to press one of six black buttons or a single red button, depending on which light was illuminated. If a single light was illuminated, subjects were required to press the corresponding black button underneath it. If however, two lights were illuminated simultaneously, subjects were required to press the red button. For this report, two vigilance measures were evaluated: 1) the number of correct responses (accuracy), and 2) increases in the duration of responses (response latency).

The grammatical reasoning task required subjects to indicate whether a logical statement, displayed on the monitor, was true or false. Subjects were presented with 32 statements per trial, and instructed to concentrate on accuracy, rather than speed. Both accuracy (percentage of correct responses) and response latency were evaluated in this report.

During test sessions, subjects were seated in front of the workstation in an isolated room, free of distraction, and were instructed to complete each task once (tasks were presented in a random order to prevent order effects). Each test session lasted approximately 15 minutes. Subjects received no feedback during the study, in order to avoid knowledge of results affecting performance levels.

Procedure

Subjects participated in a randomised cross-over design involving three experimental conditions: 1) an alcohol intoxication condition, 2) a placebo condition, and 3) a sustained wakefulness condition. During the week prior to commencement of the experimental conditions, all participants were individually trained on the performance battery, to familiarise themselves with the tasks and to minimise improvements in performance resulting from learning. Subjects were required to repeat each test until their performance reached a plateau.

The subjects reported to the laboratory at 8:00pm on the night prior to each condition. Prior to retiring at 11:00pm, subjects were required to complete additional practice trials on each tasks. Subjects were woken at 7.00am, following a night of sleep, and allowed to breakfast and shower prior to a baseline testing session, which started at 8:00am.

Alcohol Intoxication Condition

Subjects completed a performance testing session hourly. Following the 9.00am testing session each subject was required to consume an alcoholic beverage, consisting of 40 percent vodka and a non-caffeinated softdrink mixer, at half hourly intervals. Twenty minutes after the consumption of each drink, blood alcohol concentrations (BAC) were estimated using a standard calibrated breathalyser (Lion Alcolmeter S-D2, Wales), accurate to 0.005% BAC. When a BAC of 0.10% was reached no further alcohol was given. Subjects were not informed of their BAC at anytime during the experimental period.

Placebo Condition

The procedure for the placebo condition was essentially identical to the alcohol condition. Subjects in the placebo condition had the rim of their glass dipped in ethanol to give the impression that it contained alcohol To ensure that subjects remained blind to the treatment condition to which they had been allocated, approximately equal numbers of subjects received alcohol or placebo in any given laboratory session.

Sustained Wakefulness Condition

Subjects were deprived of sleep for one night. During this time, they completed a performance testing session every hour. In between their testing sessions, subjects could read, write, watch television or converse with other subjects, but were not allowed to exercise, shower or bath. Food and drinks containing caffeine were prohibited the night before and during the experimental conditions.

Statistical Analysis

To control for inter-individual variability on neurobehavioural performance, test scores for each subject were expressed relative to the average test scores they obtained during the baseline

(8:00am) testing session of each condition. Relative scores within each interval (hour of wakefulness or 0.05% BAC intervals) were then averaged to obtain the mean relative performance across subjects. Neurobehavioural performance data in the sustained wakefulness and alcohol intoxication conditions were then collapsed into two-hour bins and 0.02% BAC intervals, respectively.

Evaluation of systematic changes in each performance parameter across time (hours of wakefulness) or blood alcohol concentration were assessed separately by repeated-measures analysis of variance (ANOVA), with significance levels corrected for sphericity by Greenhouse-Geisser epsilon.

Linear regression analysis was used to determine the relationship between test performance, hours of wakefulness and alcohol intoxication. The relationship between neurobehavioural performance and both hours of wakefulness and BAC are expressed as a percentage drop in performance for each hour of wakefulness or each percentage increase in BAC, respectively. For each performance parameter, the percentage drop in test performance in each of the two conditions was also equated, and the effects of sustained wakefulness on performance expressed as a BAC equivalent

RESULTS

Alcohol Intoxication Condition

Table 1 displays the results of the ANOVAs run on each performance variable as a function of BAC. Five of the six performance parameters significantly ($p = 0.0008$-0.0001) decreased as BAC increased, with poorest performance resulting at a BAC of 0.10 or greater.

The linear relationship between increasing BAC and performance impairment was analysed by regressing mean relative performance against BAC for each 0.02% interval. As is evident in Table 2, there was a significant ($p = 0.0132$-0.0002) linear correlation between BAC and mean relative performance for all of the variables except one. It was found that for each 0.01% increase in BAC, the decrease in performance relative to baseline ranged from 0.29 to 2.68%.

Placebo Condition

To ensure that differences in performance reflected only the effects of actual alcohol intoxication a placebo condition was incorporated into the study. As indicated in Table 1, mean relative performance in the placebo condition did not significantly vary.

Sustained Wakefulness Condition

Table 1 displays the results of the ANOVAs for each performance variable as a function of hours of wakefulness. Four of the six performance parameters showed statistically significant ($p = 0.0001$) variation by hours of wakefulness. In general, the hours-of-wakefulness effect on each performance parameter was associated with poorest performance resulting after 25 to 27 hours of wakefulness

Since there is a strong non-linear component to the performance data, which remained at a fairly stable level throughout the period which coincides with their normal waking day, the performance decrement per hour of wakefulness, was calculated using a linear regression between the seventeenth (equivalent to 11:00pm) and twenty-seventh hour of wakefulness.

As indicated in Table 2, regression analyses revealed a significant linear correlation ($p = 0.0011$-0.0001) between mean relative performance and hours of wakefulness for four of the six performance variables. Between the seventeenth and twenty-seventh hours of wakefulness, the decrease in performance relative to baseline ranged from 0.61 to 3.35% per hour (Table 2).

Sustained Wakefulness and Alcohol Intoxication

The primary aim of the present study was to express the effects of SW on a range of neurobehavioural performance tasks as a blood alcohol equivalent. Figures 1-6 illustrate the comparative effects of alcohol intoxication and sustained wakefulness on the six performance parameters. When compared to the impairment of performance caused by alcohol at a BAC of 0.10%, the same degree of impairment was produced after 20.3 (grammatical reasoning response latency), 22.3 (vigilance accuracy), 24.9 (vigilance response latency) or 25.1 (tracking accuracy) hours. Even after 28 hours of sustained wakefulness, neither of the remaining two performance variables (grammatical reasoning accuracy and simple sensory comparison) decreased to a level equivalent to the impairment observed at a BAC of 0.10%.

DISCUSSION

In the present study moderate levels of alcohol intoxication had a clearly measurable effect on neurobehavioural performance. We observed that as blood alcohol concentration increased performance on all the tasks, except for one, significantly decreased. A similar effect was observed in the sustained wakefulness condition. As hours of wakefulness increased performance levels for four of the six parameters significantly decreased. Comparison of the two effects indicated that moderate levels of sustained wakefulness produce performance decrements comparable to those observed at moderate levels of alcohol intoxication in social drinkers.

As previous research has found that some individuals tend to perform in a manner that is consistent with the expectation that they are intoxicated due to alcohol consumption (Brechenridge and Dodd, 1991), a placebo condition was included in this study. We found that the placebo beverage did not significantly effect mean relative performance. Thus, it was assumed that performance decrements observed during the alcohol condition were caused solely by increasing blood alcohol concentration. Moreover, it is worth noting that the placebo condition in this study generally did not create the perception of alcohol consumption. Furthermore, when participants had already experienced the alcohol condition, and thus the effects of alcohol on their subsequent behaviour and performance, placebo beverages were even less convincing, suggesting that inclusion of a placebo condition is not necessary in future studies of a similar nature.

In general, increasing blood alcohol concentrations were associated with a significant linear decrease in neurobehavioural performance. At a BAC of 0.10% mean relative performance was impaired by approximately 6.8% and 14.2% (grammatical reasoning accuracy and response latency, respectively), 2.3% and 20.5% (vigilance accuracy and response latency, respectively) or 21.4% (tracking). Overall, the decline in mean relative performance ranged from approximately 0.29% to 2.68% per 0.01% BAC. These results are consistent with previous findings that suggest that alcohol produces a dose-dependent decrease in neurobehavioural performance (Billings *et al.*, 1991).

In contrast, mean relative performance in the sustained wakefulness condition showed three distinct phases. Neurobehavioural performance remained at a relatively stable level during the period which coincided with the normal waking day (0 to 17 hours). In the second phase, performance decreased linearly, with poorest performance generally occurring after 25 to 27 hours of wakefulness. It was observed that mean relative performance increased again after 26 to 28 hours of wakefulness presumably reflecting either the well reported circadian variation in neurobehavioural performance (Folkard and Tottersdell, 1993) or an end of testing session effect.

The linear decrease in performance observed for four of the measures in this study is consistent with previous studies documenting neurobehavioural performance decreases for periods of sustained wakefulness between 12 and 86 hours (Linde *et al.* 1992, Storer *et al.* 1989; Fiorica *et al.* 1968). Between the seventeenth and twenty-seventh hours of wakefulness, mean relative performance significantly decreased at a rate of approximately 2.61% (grammatical reasoning response latency), 0.61 and 1.98% (vigilance accuracy and response latency, respectively) or 3.36% (tracking) per hour.

While the results in each of the experimental conditions are interesting in themselves, and have been previously been established, the primary aim of the present study was to compare the effects of alcohol intoxication and sustained wakefulness. Equating the effects of the two conditions indicated that 17 to 27 hours of sustained wakefulness (from 7:00pm to 10:00am) and moderate alcohol consumption have quantitatively similar effects on neurobehavioural performance. Indeed, the findings of this study suggest that after only 20 hours of sustained wakefulness performance impairment may be equivalent to that observed at a BAC of 0.10%.

This study has confirmed the suggestion made by Dawson and Reid (1997) that moderate levels of sustained wakefulness produce performance decrements equivalent to or greater than those observed at levels of alcohol intoxication deemed unacceptable when driving, working and/or operating dangerous equipment. More importantly, however, this study was designed to determine whether the results of Dawson and Reid (1997) were an isolated finding, or characteristic of the general cognitive effects of sleep deprivation. Using the degree of impairment caused by alcohol that produced a BAC of 0.10% as a standard, this study systematically compared the effects of sustained wakefulness on a range of neurobehavioural tasks. Results indicate that while, in general, sustained wakefulness had a detrimental effect on psychomotor performance, the specific components of performance differed in their degree of sensitivity to sleep deprivation.

The observed differences between the performance tasks with respect to the vulnerability to sleep deprivation can be explained by their relative degrees of complexity. That is to say, the more complex neurobehavioural parameters measured in the present study were more sensitive to sleep deprivation than were the simpler performance parameters. While only 20.3 hours of sustained wakefulness was necessary to produce a performance decrement on the most complex task (grammatical reasoning) equivalent to the impairment observed at a BAC of 0.10%, it was after 22.3 and 24.9 hours of sustained wakefulness that a similar result was seen in a less complex task (vigilance accuracy and response latency, respectively). Furthermore, on the unpredictable tracking task, a slightly less complex task than vigilance, a decrement in performance equivalent to that observed at a BAC of 0.10% was produced after 25.1 hours of wakefulness.

It was observed that, despite a slight downward trend, performance on the simplest of the four tasks did not significantly decrease, even following twenty-eight hours of sustained wakefulness. In contrast, performance on this task was significantly impaired after a dose of alcohol that produced a BAC of 0.10% (or greater). These results are in line with the suggestion that simple tasks are less sensitive to sleep deprivation (Johnson, 1982). Indeed, we believe it likely that impairment of performance on this task may have occurred if we had extended the period of sustained wakefulness. It is interesting to note that several studies (e.g. Dinges *et al.*, 1988) have reported that tasks similarly lacking in complexity, such as simple reaction time tasks, are affected early and profoundly by sleep loss, thus strongly suggesting that monotony may increase sensitivity to sustained wakefulness. Indeed, the fact that this task was not vulnerable to sustained wakefulness may possibly be explained by the interesting and challenging properties of the task.

It is also noteworthy that, while we observed a decrease in accuracy on the grammatical reasoning task, impairment of this performance parameter was not comparable to that produced by a BAC of 0.10%. While this may at first contradict the suggestion that in this study vulnerability to sustained wakefulness was, to a large degree, determined by task complexity, it should be noted that participants were instructed to concentrate on accuracy rather than speed when completing the grammatical reasoning task. Thus, our particular instructions to participants may explain, at least in part, this irregularity. Alternatively, this finding is in line with the suggestion of a natural 'speed-accuracy trade-off'. Similar results have been observed in several studies, which report a decline in speed of performance, but not accuracy, when sleep-deprived subjects are required to perform a logical-reasoning task (Angus and Heslegrave, 1985; Webb and Levy, 1982).

Interestingly, this was not the case with the vigilance task. In this instance, despite instruction to concentrate primarily on accuracy, this component was slightly more vulnerable to sleep deprivation than was response latency. The absence of a trade-off on this task may be explained by the different properties of the vigilance and grammatical reasoning tasks. In accordance with the distinction raised by Broadbent (1953), the latter of these tasks can be defined as an unpaced task, in which the subject determines the rate of stimuli presentation. In contrast, the vigilance task can be defined as a paced task, in which stimuli are presented at a speed controlled by the experimenter. In line with this distinction, our findings are consistent with those of Broadbent (1953) who observed that while a paced task rapidly deteriorated during the experimental period, in terms of speed, an unpaced version of the same task did not

A further explanation for the differences observed between these two tasks, may relate to the extremely monotonous nature of the vigilance task. Indeed, we believe it likely that subjects were more motivated to perform well on the grammatical reasoning task, which was generally considered more interesting and challenging. Hence degree of motivation may explain why measures of both speed and accuracy decreased on the vigilance task, while on the former task, accuracy remained relatively stable. This suggestion is in line with previous studies which have found that motivation can, to a degree, counteract the effects of sleep loss (Horne and Pettitt, 1985).

Taken together, the results from this study support the suggestion that even moderate levels of sustained wakefulness produce performance decrements greater than is currently acceptable for alcohol intoxication. Furthermore, our findings suggest that while sleep deprivation has a generally detrimental effect on neurobehavioural performance, specific components of performance differ in their sensitivity to sustained wakefulness

Since approximately 50 percent of shiftworkers typically spend at least twenty-four hours awake on the first night shift in a roster (Tepas *et al.*, 1981), these findings have important implications within the shiftwork industry. Indeed, the results of this study, if generalised to an applied setting, suggest that on the first night shift, on a number of tasks, a shiftworker would show a neurobehavioural performance decrement similar to or greater than is acceptable for alcohol intoxication.

While the current study supports the idea that sustained wakefulness may carry a risk comparable with moderate alcohol intoxication, it is difficult to know to what degree these results can be generalised to "real-life" settings. Indeed, laboratory measures and environments usually bear little resemblance to actual tasks and settings. Furthermore, while our study used a battery of tests to evaluate the effects of sustained wakefulness on performance, their is no guarantee that all the functions involved in "real-life tasks", such as driving, were utilised and assessed. An alternative approach would be to simulate the actual task, as accurately as possible. Given that, for practical and ethical reasons, it is difficult to experimentally study the relationship between sustained wakefulness and actual driving, simulators of varying realism have been used. Thus, protocols using simulators could be used to model "real-life" settings and establish a more accurate estimate of the BAC equivalence for the performance decrement associated with sleep loss and fatigue.

REFERENCES

Angus, R.G. and Heslegrave, R.J. Effects of sleep and sustained cognitive performance during a command and control simulation. *Behavioural Research Methods, Instruments and Computers*, 1985, 17: 55-67.

Babkoff, H., Mikulincer, M., Caspy, T., Kempinski, D. and Sing, H. The topology of performance curves during 72 hours of sleep loss: A memory and search task. *The Quarterly Journal of Experimental Psychology*, 1988, 324: 737-756.

Brechenridge, R. and Dodd, M. Locus of control and alcohol placebo effects on performance in a driving simulator. *Perceptual and Motor Skills*, 1991, 72: 751-756.

Broadbent, D.E. Noise, paced performance, and vigilance tasks. *British Journal of Psychology*, 1953, 44: 295-303.

Dawson, D. and Reid, K. Fatigue, alcohol and performance impairment. *Nature*, 1997, 388: 235.

Dick, R.B., Setzer, J.V., Wait, R., Hayden, M.B., Taylor, B.J., Tolos, B. and Putz-Anderson, V. Effects of acute exposure to toluene and methyl ethyl ketone on psychomotor performance. *Archives of Occupational and Environmental Health*, 1984, 54: 91-109.

Dinges, D.F., Whitehouse, W.G., Orne, E.C. and Orne, M.T. The benefits of a nap during prolonged work and wakefulness. *Work and Stress*, 1988. 2: 139-153

Fiorica, V., Higgins, E.A., Iampietro, P.F., Lategola, M.T. and Davis, A.W. Physiological responses of man during sleep deprivation. *Journal of Applied Physiology*, 1968,24(2): 169-175

Folkard, S., Totterdell, P., Minors, D. and Waterhouse, J. Dissecting circadian performance rhythms: Implications for shiftwork. *Ergonomics*, 1993. 36(1-3): 283-8

Gillberg, M., Kecklund, G. and Akerstedt, T. Relations between performance and subjective ratings of sleepiness during a night awake. *Sleep*, 1994, 17(3): 236-41.

Heishman, S.J., Stitzer, M.L. and Bigelow, G.E. Alcohol and marijuana: Comparative dose effect profiles in humans. *Pharmacology Biochemistry and Behaviour*, 1989. 31: 649-655.

Horne, J.A. and Pettitt, A.N. High incentive effects on vigilance performance during 72 hours of total sleep deprivation. *Acta psychologica*, 1985. 58, 123-139

Johnson, L.C. Sleep deprivation and performance. In: W. B. Webb (Ed.) *Biological rhythms, Sleep and Performance*. Wiley, New York. 1982.

Linde, L. and Bergstrom, M. The effect of one night without sleep on problem-solving and immediate recall. *Psychological Research*, 1992. 54(2): 127-36

Mullaney, D.J., Kripke, D.F., Fleck, P.A. and Johnson, L.C. Sleep loss and nap effects on sustained continuous performance. *Psychophysiology*, 1983, 20: 643-651.

Storer, J., Floyd, H., Gill, W., Giusti, C. And Ginsberg, H. Effects of sleep deprivation on cognitive ability and skills of paediatric residents. *Academic Medicine*, 1989, 64: 29-32.

Thapar, P., Zacny, J.P., Thompson, W. and Apfelbaum, J.L. Using alcohol as a standard to assess the degree of impairment induced by sedative and analgesic drugs used in ambulatory surgery *Anesthesiology*, 1995, 82(1): 53-59.

Tilley, A.J. and Wilkinson, R.T. The effects of a restricted sleep regime on the composition of sleep and on performance. *Psychophysiology*, 1984, 21: 406-412.

Webb, W. and Levy, C. Age, sleep deprivation and performance. *Psychophysiology*, 1982, 19(3): 272-276.

Wickens, C. *Engineering psychology and human performance*. C.E. Merill, Columbus, 1984.

Wilkinson, R.T. Effects of up to 60 hours sleep deprivation on different types of work. *Ergonomics*, 1964, 7: 175-186.

TABLE 1. Summary of ANOVA results for neurobehavioural performance variables

Performance Variable	Placebo		Alcohol Intoxication		Sustained Wakefulness	
	$F_{7,147}$	P[a]	$F_{5,105}$	P[a]	$F_{13,273}$	P[a]
GRG Response Latency	0.82	NS	4.96	0.0021	13.77	0.0001
GRG Accuracy	0.63	NS	6.88	0.0001	2.20	NS
VIG Response Latency	2.19	NS	43.09	0.0001	33.74	0.0001
VIG Accuracy	2.02	NS	7.99	0.0008	11.04	0.0001
Unpredictable Tracking	2.63[b]	NS	5.32	0.0008	10.09	0.0001
Simple Sensory Comparison	0.78	NS	1.88	NS	1.47	NS

GRG, grammatical reasoning. VIG, vigilance

[a] corrected by Greenhouse-Geisser epsilon; [b] based on data from twenty subjects.

TABLE 1. Summary of linear regression analysis of neurobehavioural performance variables

Performance Parameter	DF	F	P	R2	%Decrease
SW Condition					(per hour)
GRG Response Latency	1,4	70.61	0.0011	0.95	2.69
GRG Accuracy	1,4	3.64	NS	--	--
VIG Response Latency	1,4	98.54	0.0006	0.96	1.98
VIG Accuracy	1,4	81.79	0.0008	0.95	0.61
Unpredictable Tracking	1,4	70.93	0.011	0.95	3.36
Simple Sensory	1,4	4.71	NS	--	--
Alcohol Condition					(per0.01% BAC)
GRG Response Latency [b]	1,2	74.30	0.0132	0.97	2.37
GRG Accuracy	1,4	31.07	0.0051	0.89	0.68
VIG Response Latency	1,4	12.65	0.0002	0.98	2.05
VIG Accuracy [a]	1,3	212.37	0.0007	0.99	0.29
Unpredictable Tracking [a]	1,3	238.52	0.0006	0.99	2.68
Simple Sensory	1,4	5.37	NS	--	--

[a] Based on data from 0.02%-0.10% BAC; [b] Based on data from 0.04%-0.10% BAC

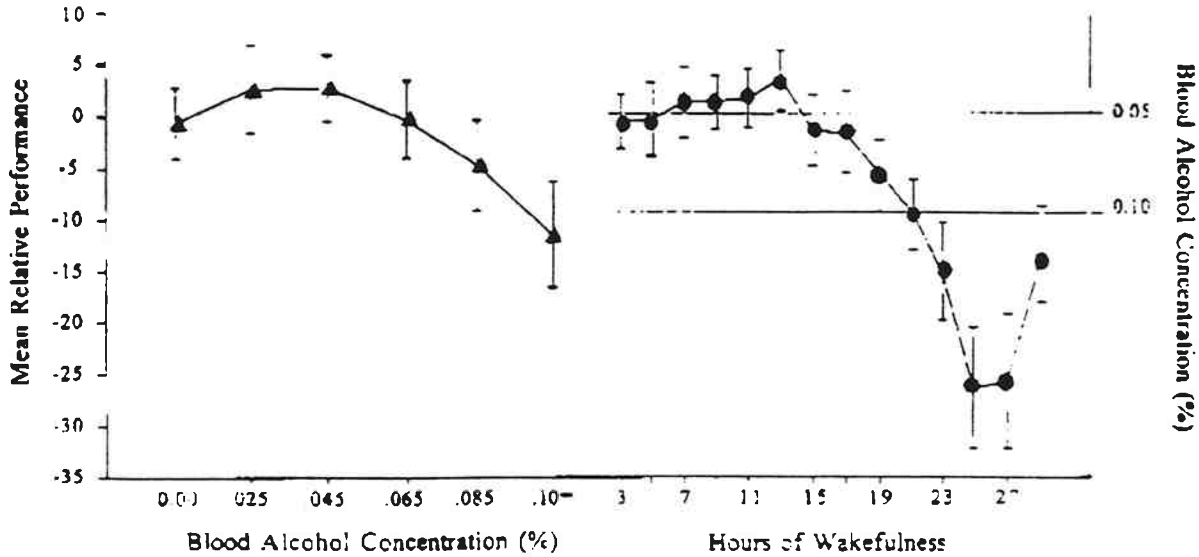


FIG. 1. Mean relative performance levels for the response latency component of the grammatical reasoning task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ± one s.e.m.

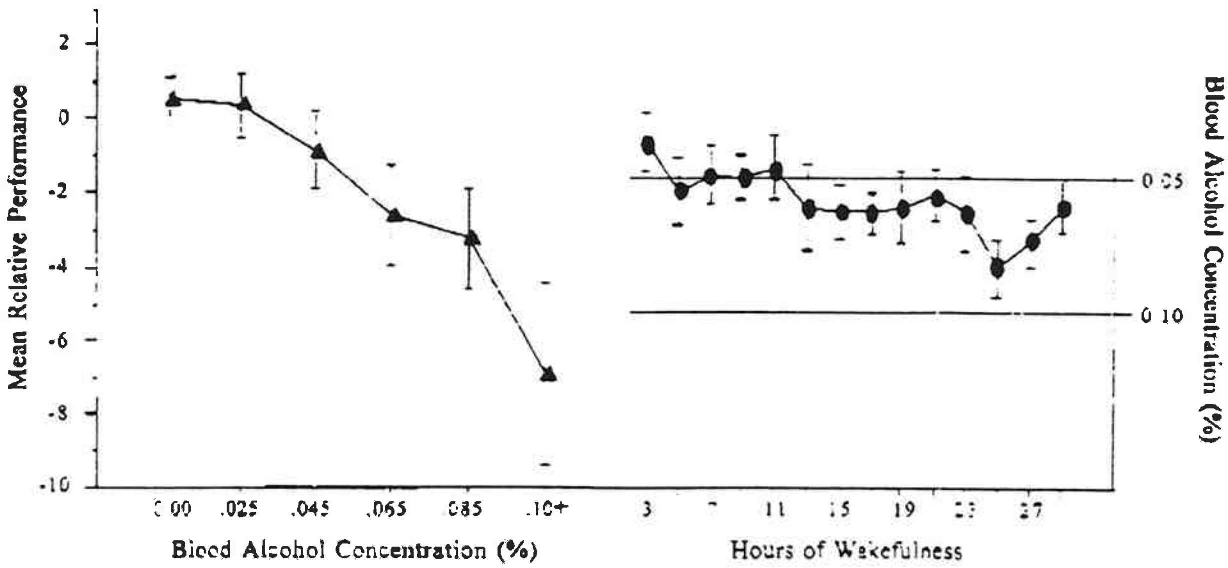


FIG. 2. Mean relative performance levels for the accuracy component of the grammatical reasoning task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ± one s.e.m.

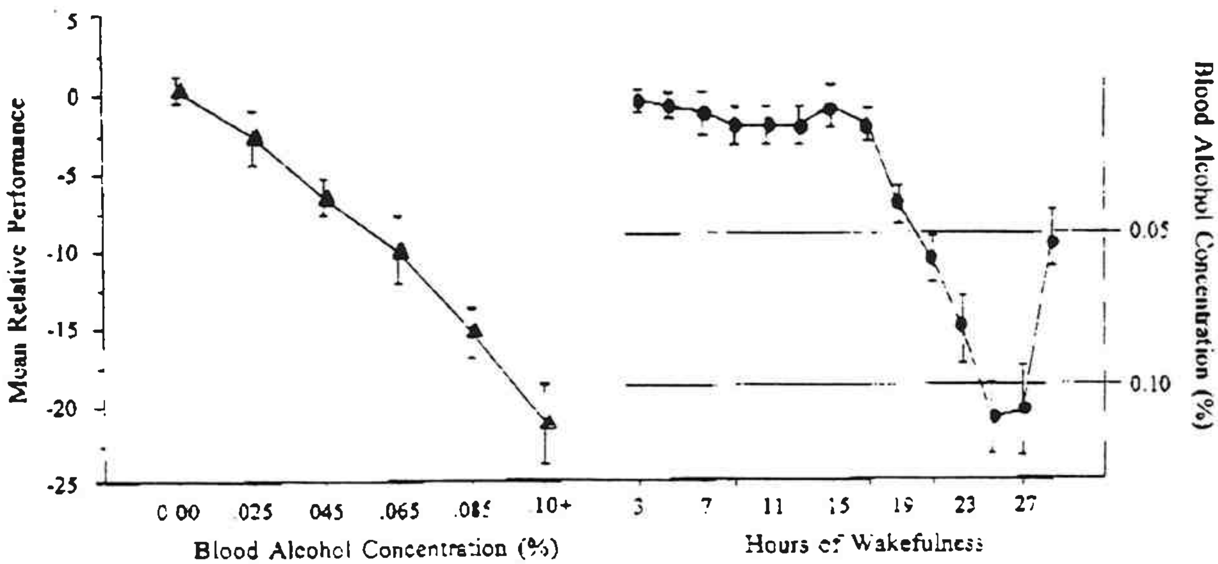


FIG. 3. Mean relative performance levels for the response latency component of the vigilance task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ± one s.e.m.

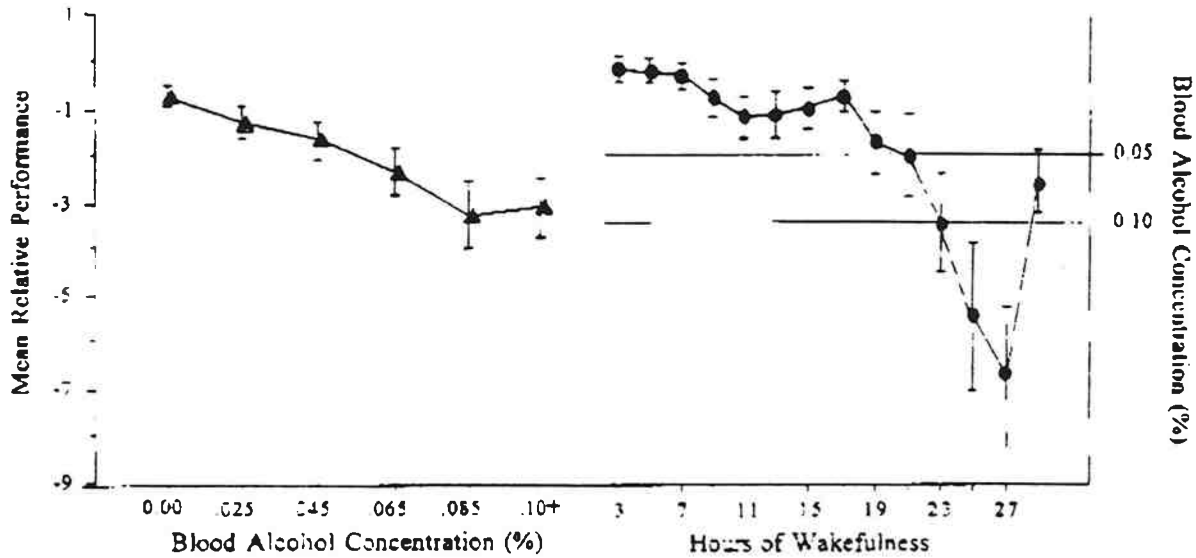


FIG. 4. Mean relative performance levels for the accuracy component of the vigilance task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ± one s.e.m.

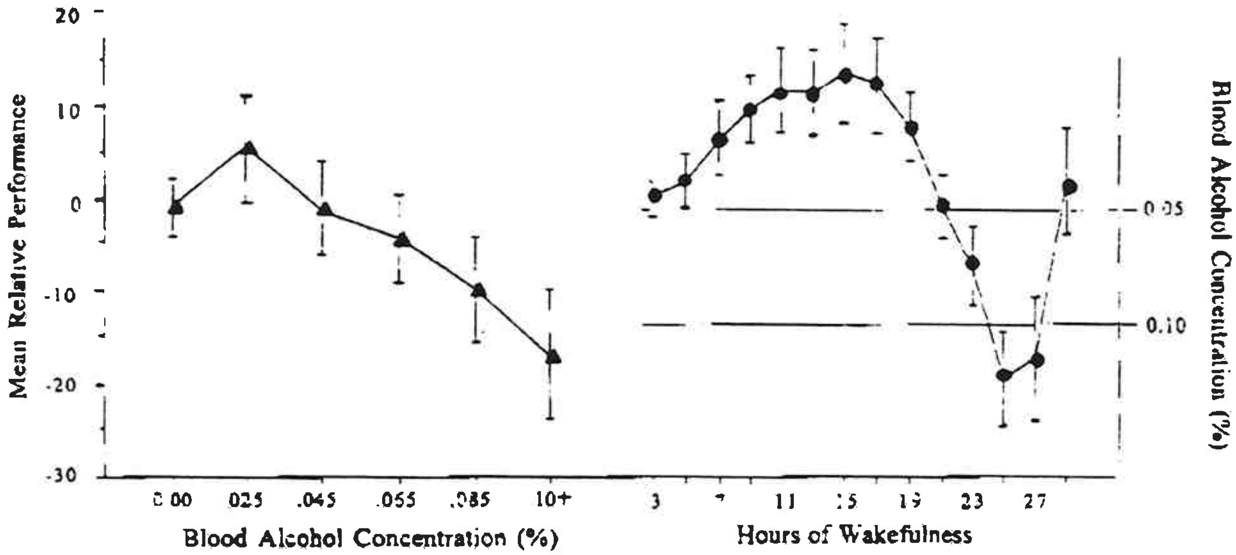


FIG. 5. Mean relative performance levels for the unpredictable tracking task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ± one s.e.m.

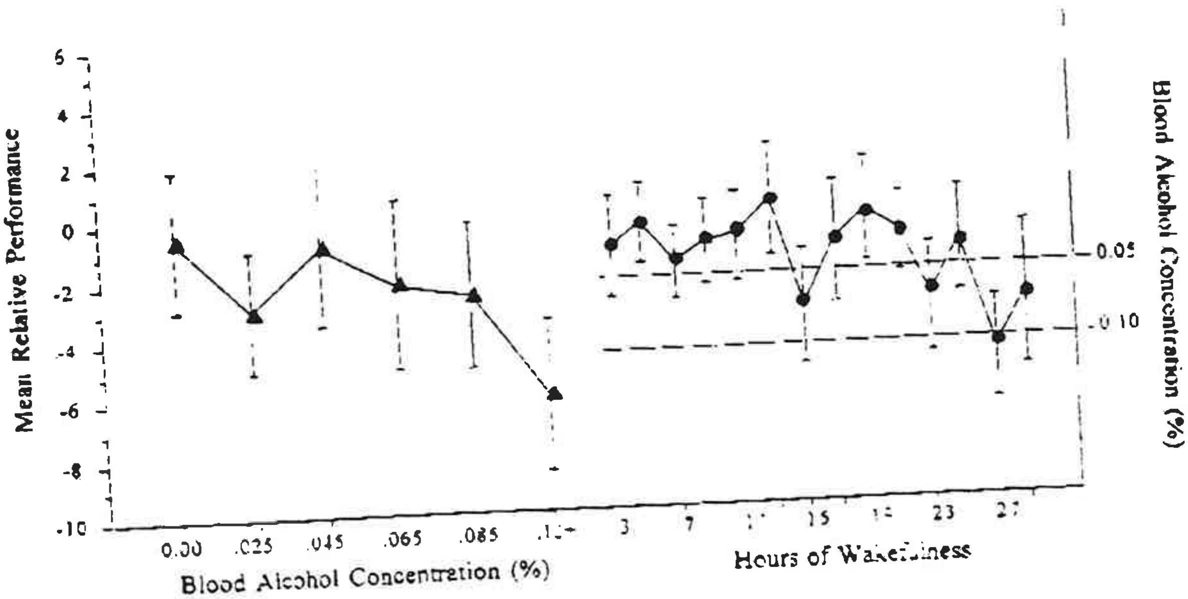


FIG. 6. Mean relative performance levels for the simple sensory comparison task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ± one s.e.m.

APPENDIX G

Crew fatigue factors in the Guantanamo Bay aviation accident

Mark R. Rosekind, PhD.
NASA Ames Research Center

Kevin B. Gregory, Donna L. Miller
Sterling Software

Elizabeth L. Co
San Jose State University Foundation

J. Victor Lebacqz, PhD.
NASA Ames Research Center

Malcolm Brenner
National Transportation Safety Board

On August 18, 1993, at 1656 eastern daylight time, a military contract flight crashed while attempting to land at the U.S. Naval Air Station, Guantanamo Bay, Cuba. The airplane, a Douglas DC-8-61 freighter, was destroyed by impact forces and fire. The three flight crewmembers sustained serious injuries. The National Transportation Safety Board (NTSB), an independent agency of the United States government, conducted an official investigation to determine the cause of the accident and to make recommendations to prevent a recurrence (1). At the request of the NTSB, the NASA Ames Fatigue Countermeasures Program analyzed the crew fatigue factors to examine their potential role in the accident. Three principal sources of information were made available from the NTSB accident investigation to NASA Ames for analysis: 1) Human Performance Investigator's Factual Report,
2) Operations Group Chairman's Factual Report, and 3) Flight 808 Crew Statements.

Based on scientific data related to sleep and circadian rhythms, the NASA Ames Fatigue Countermeasures Program identified three core physiological factors to examine when investigating the role of fatigue in an incident or accident. These factors have subsequently been expanded to four, to explicitly include a factor examined but not previously reported. The four fatigue factors to examine in incident/accident investigations are: 1) acute sleep loss/cumulative sleep debt, 2) continuous hours of wakefulness, 3) time of day/circadian effects, and 4) presence of sleep disorder. These factors were examined and the sleep/wake histories for the flight crew prior to the accident are presented in Figure 1.

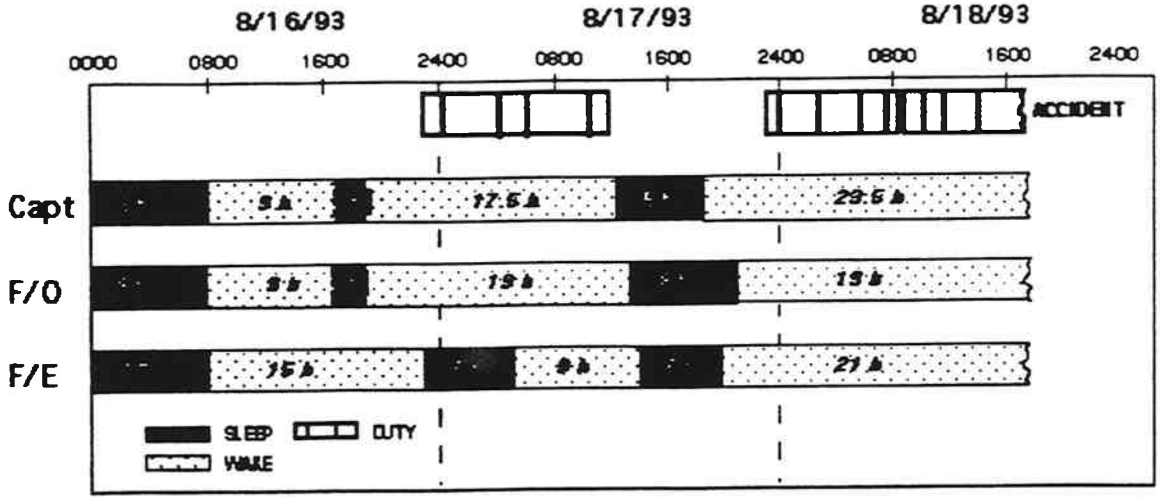


Figure 1. Crew Sleep/Wake Histories

The crew had been off-duty up to 2 days prior to the accident trip and then flown overnight cargo schedules for the two nights prior to the accident, and had been assigned the accident trip unexpectedly on the morning of August 18, shortly after being released from duty. The extra trip involved segments from Atlanta to Norfolk, VA to Guantanamo Bay back to Atlanta, approximately 12 hrs of flight time in 24 hrs of duty. The figure provides information on the fatigue factors: 1) the individual crew members had an acute sleep loss (i.e., 5,6,8 hrs of daytime sleep), 2) were continuously awake 19, 21, and 23.5 hrs prior to the accident, and 3) the accident occurred just prior to 5 pm local time during the afternoon window of sleepiness (this did not represent a time zone change for this US East coast crew). Upon inquiry, there were no reported symptoms or signs of a sleep disorder. Therefore, all three of the initial fatigue factors were operating in this accident.

There were two principal sources of data available on flight crew performance in the accident: cockpit voice recorder (CVR) and Captain's testimony at the NTSB public hearing. There were four performance effects related to fatigue that significantly contributed to the accident: 1) degraded decision-making, 2) visual/cognitive fixation, 3) poor communication/coordination, and 4) slowed reaction time.

A complete description of flight operations, fatigue factors, performance effects, and accident investigation findings are available in the full NTSB accident report (1). Based on the findings, the NTSB determined that the probable cause of this accident included the impaired judgment, decision-making, and flying abilities of the captain and flightcrew due to the effects of fatigue. This was the first time in a major U.S. aviation accident that the NTSB cited fatigue in the probable cause. As a result of this investigation, the NTSB recommended that the Federal Aviation Administration (FAA) expedite the review and upgrade of Flight/Duty Time Limitations of the Federal Aviation Regulations to ensure that they incorporate the results of the latest research on fatigue and sleep issues. The NTSB reiterated a recommendation to require U.S. air carriers 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. This NTSB investigation and the NASA guidelines to examine fatigue factors, provides a model for investigating and documenting the role of fatigue in operational incidents and accidents.

---

(1) National Transportation Safety Board. Aircraft accident report: uncontrolled collision with terrain, American International Airways Flight 808, Douglas DC-8-61, N814CK, U.S. Naval Air Station, Guantanamo Bay, Cuba, August 18, 1993. Washington, DC: National Transportation Safety Board, 1994; NTSB/AAR-94/04.

AIR LINE PILOTS ASSOCIATION, INTERNATIONAL

535 HERNDON PARKWAY □ P.O. BOX 1169 □ HERNDON, VIRGINIA 20172-1169 □ 703-689-2270
FAX 703-481-2478

February 19, 1999

TO: Captain Rich Rubin, APA
Captain Robert Landa, SWAPA
Captain Don Kingery, IACP
Captain Dave Wells, FPA
Ms. Lauri Esposito, IPA
Mr. Don Treichler, IBT

For your records, I enclose a copy of the Reserve Duty/Rest Requirements Working Group submission regarding reserve rest. The ARAC Working Group Pilot Members Submission contains the final Lamond/Dawson report which was produced as Appendix F. You should discard the copy of the submission that was mailed to you on or about January 9.

Sincerely,

Aggie Toone

Aggie Toone, Paralegal
Legal Department

:avt
Enclosure

AIR CARRIER OPERATIONS ISSUES GROUP

FAA AVIATION RULEMAKING ADVISORY COMMITTEE (ARAC)

RESERVE DUTY/REST REQUIREMENTS WORKING GROUP

Donald E. Hudson, M.D., Labor Co-Chairman
H. Clayton Foushee, Ph.D.,
Industry/Management Co-Chairman
Phil Harter, Moderator

LETTER FROM BILL EDMUNDS TO THOMAS MCSWEENEY, FEB. 9, 1999

AIR LINE PILOTS ASSOCIATION, INTERNATIONAL
535 HERNDON PARKWAY ☐ P.O. BOX 1169 ☐ HERNDON, VIRGINIA 20172-1169 ☐ 703-689-2270
FAX 703-689-4370

February 9, 1999

Mr. Thomas E. McSweeny
Associate Administrator for Regulation and Certification
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, D.C. 20591

Dear Mr. McSweeny:

The Air Carrier Operations Issues Group of the FAA's Aviation Rulemaking Advisory Committee (ARAC) received a task to recommend to the FAA a performance-based or other regulatory scheme whereby the public is ensured that each flight crewmember is provided with sufficient rest to safely perform flight deck duties at a minimal cost to certificate holders and operators. The Reserve Duty/Rest Requirements Working Group was established to perform this task.

Two co-chairmen were appointed to this working group: H. Clayton Foushee, Ph.D., with Northwest Airlines, and Donald E. Hudson, M.D., with Aviation Medicine Advisory Service. Realizing the difficult and contentious nature of the task, the services of Mr. Phil Harter, with The Mediation Consortium, were enlisted as moderator. We want to thank the FAA for graciously making Mr. Harter available.

The task was to address all commercial aviation operations under both Part 121 and 135 rules. The great majority of the time was spent developing proposals for Part 121 scheduled operations.

Scientific Literature

The working group did not conduct a detailed review of the scientific literature available on fatigue. The working group was able to agree on two broad scientific principles in regard to fatigue:

- Humans generally need the opportunity to acquire approximately eight hours of sleep per 24 hour period, and
- Fatigue is more probable during the time encompassing approximately 0200 to 0600, which roughly corresponds to the low point in an average human's circadian cycle.

The working group agreed that reserve duty is neither rest nor duty.

The industry/labor representatives include detailed scientific citations in their submission.

Reserve Scheduling

There are a wide variety of reserve rest schemes currently in use in the industry. The industry/management representatives prefer a flexible scheduling approach with approval given by the FAA at individual airlines for individual operations. The industry/labor representatives prefer a more structured approach.

After several public meetings: two basic scheduling schemes were proposed for providing reserve pilots the opportunity for rest or limiting the duty day based upon the amount of advance notice of flight assignment:

- A scheduled protected time period for all reserve pilots with the use of advance notification to either cancel a scheduled protected time period or to utilize a reserve on a sliding scale where the length of the duty day would be dependent on the amount of advance notification, and
- Limiting the duty day based upon the amount of advance notification for a flight assignment.

Consensus

ARAC proposals are based on developing consensus within the working group. The services of Mr. Harter were used to assist in this regard. After a great deal of discussion and give-and-take on the part of all concerned, the working group realized that consensus would not be possible. At that point, the labor and management representatives were asked to develop proposals that would address their individual concerns and issues.

These proposals are presented to provide the FAA the various industry concerns and the rationale for their respective positions.

Industry Proposals

The industry/management representatives final proposal for Part 121 scheduled operations provides a minimum eight hour rest period or 10 hours of advance notification, under most circumstances, prior to a flight assignment.

Industry/management representatives (Helicopter Association International) propose a scheme for Part 135 on-demand air charter operations which include scheduled reserve and extended reserve, with provisions for operational delays.

Industry/management representatives (National Air Transport Association and National Business Aircraft Association) also address such reserve-related issues as rest, opportunity time, duty, and standby in Part 135 unscheduled operations.

Industry/labor representatives propose a minimum prospective protected time period of 10 hours during a 24-consecutive hour period for all Part 121 operations. The protected time period may be rescheduled only under specific circumstances and an available duty assignment is limited in relation to the preceding protected time period.

Industry/labor representatives (International Brotherhood of Teamsters, et al.) propose that protected time period and reserve availability period methodologies apply to all commercial air carriers. They proposed that non-scheduled and Part 135 carriers be provided an alternative method for reserve assignments where it can be validated that the previous methodology cannot be applied.

This summary of industry proposals is necessarily very abbreviated and may miss some essential concerns and elements. It is provided only to give a flavor for the detailed proposals.

Economic Impact

Industry/management representatives compiled economic data pertaining to the cost of their proposal for Part 121 scheduled operations. They estimate there would be approximately $100 million in incremental costs to the major operators that provided economic data, primarily Air Transport Association member airlines.

No economic data were provided by smaller Part 121 or Part 135 operators.

The working group was unable to provide additional economic analyses comparing the various proposals.

Summary

A great deal of honest effort and serious consideration went into developing these proposals. The working group engaged in an intense meeting schedule, essentially monthly, and much work was performed preparing for meetings. The working group is to be commended for this dedication.

Special thanks are due to Dr. Foushee and Dr. Hudson for their dedication and sincere efforts on behalf of bringing this task to fruition.

While the casual observer may see great differences among these proposals, it is essential to concentrate on the common elements. They can serve as a basis for action by the FAA in the rulemaking arena.

Thank you for the opportunity to be of service.

Sincerely,

William W. Edmunds, Jr., Chairman
ARAC Air Carrier Operations Issues Group

Enclosure

MEMO FROM DR. HUDSON, FEB. 1, 1999

Date: February 1, 1999

To: Air Carrier Operations Group

From: Donald E. Hudson, M.D.
Labor Co-Chairman ARAC Reserve Duty Working Group

It was my privilege to again serve as Co-Chairman of another ARAC Working Group, this time dealing with reserve rest issues for professional pilots. It was also rewarding to again work with Dr. Clay Foushee, with whom I shared office space at NASA Ames Research Center in the mid-1980's. In addition, Phil Harter did an admirable job moderating this sometimes contentious gathering.

The diversity of today's aviation environment was reflected in the representatives of the group and it was clear from the outset that there were a great variety of operational schemes in use for scheduling reserve pilots. Most of the meeting time was spent in attempting to reach agreement on a general scheme for Part 121 Scheduled Operators, it being felt that consensus was more probable in that arena. However, I was disappointed and dismayed that, once again, a general consensus in the ARAC between labor and management representatives proved elusive despite good faith efforts by many talented people on both sides of these issues.

At the first meeting, it was decided not to do a comprehensive review of the scientific literature on fatigue, despite the specific direction to do so in the Federal Register. The rationale at the time being that a detailed review of the scientific literature was unnecessary and, indeed, might be an actual impediment to reaching consensus recommendations. It was felt by both Dr. Foushee and myself that the two sides were not that far apart and a discussion of the operational fatigue research, especially that conducted over the last 15 years, would lead to disagreements over relatively minor points. In retrospect, that was a serious error. As the discussions continued into the fall of 1998, it became clear there were *fundamental* misunderstandings and differences of opinion about the research data and it's applicability to flight time/duty time regulations for pilots. This led to assertions that the scientific literature can be interpreted in a variety of equally plausible ways and was thus not very useful in providing guidance for drafting practical regulations. That conclusion is not shared by any of the reputable scientists who have conducted the operational research and it is not the view of the labor representatives nor the Battelle Group in their recent recommendations to FAA.

To their credit, the management group did acknowledge the need to provide an opportunity for a pilot to obtain 8 hours of sleep in a 24 four period but had great difficulty coming to terms with the physiological fact that *where* that opportunity occurs in the circadian cycle is as vital a parameter as the number of hours available. The research data indicates that humans show significant decrements in performance after prolonged periods of wakefulness. As we all know, commercial aviation can be a very unforgiving environment and this puts a heavy burden on FAA regulators who must try to ensure that safety is not unduly compromised.

The labor submission to ARAC is based on the available scientific data and research in this field – which continues in countries around the world. It is designed to make every effort to ensure that, as much as possible, only crewmembers with opportunity to receive adequate rest are available for duty. It is also designed to prohibit operations that have the real potential to push the human operators to fly when physiologically impaired. The scientific basis for these recommendations is referenced and included in the proposal. I would suggest the management side challenge themselves to similarly measure their proposal by the yardstick of the scientific data as well.

Any new regulations written to address the pressing issue of pilot fatigue *must* be based on our knowledge of the deleterious effects of fatigue on human physiology. The only constant in this discussion is the physiology of the human operator – the pilot. All other considerations, including economics and efficiency are important but not decisive.

It is discouraging to note that it is now 5 years to the day since the last ARAC Fatigue Working Group submitted it's proposals to FAA – and we still do not have a final rule on Flight Time Duty Time. New regulations dealing with Reserve Rest are a vital part of any new rulemaking process and I urge FAA to consider the various proposals and the available scientific data – and act swiftly to address this pressing problem.

Donald P. Hudson

Donald E. Hudson, M.D.
ARAC RDWG Labor Co-Chairman

ARAC WORKING GROUP PILOT MEMBERS SUBMISSION, JAN. 8, 1999

ARAC WORKING GROUP
PILOT MEMBERS SUBMISSION

VIA OVERNIGHT DELIVERY

Dr. Donald E. Hudson
Aviation Medicine Advisory Group
14707 East 2nd Avenue
Suite 200
Aurora, CO 80011

Dr. Clay Foushee
Northwest Airlines
901 15th Street, N.W.
Suite 310
Washington, DC 20005

Gentlemen:

The 78,000 airline pilots who were represented at the ARAC Working Group welcome the opportunity to provide their unified position regarding a reserve rest regulation. We are pleased that the Working Group was able to reach a consensus that pilots who are assigned reserve duty should have a protected rest period during every 24 hours. However, we are very disappointed that we were unable to reach a consensus as to the "scheme" that would best provide the required rest.

We believe that the efforts of the Working Group will prove helpful to the FAA in formulating a final regulation. The differing positions of the parties have been narrowed and clearly identified. It is now up to the FAA to timely promulgate a final regulation.

Respectfully submitted,

Captain Rich Rubin
Allied Pilots Association (APA)

Frank Williamson
Captain Frank Williamson
Air Line Pilots Association (ALPA)

Robert Landa
Captain Robert Landa
Southwest Pilots Association (SWAPA)

Don Kingery
Captain Don Kingery
Independent Association of Continental Pilots (IACP)

Captain Dave Wells
Fedex Pilots Association (FPA)

Lauri Esposito
Lauri Esposito
Independent Pilots Association (IPA)

D R Treichler
Don Treichler
International Brotherhood of Teamsters (IBT)

Aviation Rulemaking Advisory Committee
Reserve Rest Working Group

Proposal of 77,955 Airline Pilots
January 8, 1999

Airline	Pilots	Airline	Pilots
Air Wisconsin	240	Mesa	1095
Alaska	1153	Mesaba	804
Allegheny	354	Midway	174
Aloha	192	Midwest Express	262
Aloha Island Air	64	Northwest	6103
America West	1532	Piedmont	368
American	9508	Polar Air Cargo	186
American Eagle	2055	PSA	254
Atlantic Coast	694	Reeve	33
Atlantic Southeast	763	Reno	302
Business Express	372	Ross	19
Carnival	219	Ryan International	257
CCAir	172	Skyway	132
Comair	1000	Southwest	2735
Continental	4769	Spirit	154
Continental Express	1010	Sun Country	213
Delta	9188	Tower Air	206
DHL	395	Trans States	806
Emery Worldwide	451	TWA	2516
Express	329	United	9621
Federal Express	3611	UPS	2100
Hawaiian	285	USAirways	5092
IBT	6000	USAirways Shuttle	167

TABLE OF CONTENTS

AVIATION RULEMAKING ADVISORY COMMITTEE
RESERVE REST WORKING GROUP

PROPOSAL OF 77,955 AIRLINE PILOTS
January 8, 1999

PREAMBLE

This document is submitted on behalf of approximately 78,000 commercial airline pilots. The proposal that follows contains our recommendations for Federal Aviation Regulations concerning rest requirements and duty limitations for reserve pilots. It is applicable to all Domestic and International Part 121 operations under FAR Subparts Q, R, and S. Part 135 regulations should be revised to provide a level of safety equivalent to this proposal.

Our proposal is presented in two parts. Part I is the proposed regulatory language. Part II provides our intent, examples, and rationale. The scientific support for our proposal is included in the endnotes.

We are pleased that both pilots and air carriers were able to agree on the following elements of a proposed reserve rest rule:

1. A pilot should be scheduled by the operator to receive a protected time period as an opportunity to sleep for every day of reserve duty. The operator may not contact the pilot during this period.
2. An operator should limit the movement of a pilot's protected time period during consecutive days of reserve duty to ensure circadian stability.
3. A reserve pilot's availability for duty should be limited to prevent pilot fatigue as a result of lengthy periods of time-since-awake.

4. Sufficient advance notice of a flight assignment can provide a reserve pilot with a sleep opportunity.

We believe that it is incumbent upon the Federal Aviation Administration (FAA) to include time-of-day as a factor in designing duty and rest limitations. A substantial body of research and pilot reports shows that a decrease in performance frequently occurs during "back-side-of-the-clock" operations due to circadian factors. To address this issue, our proposal provides for a reduction in the reserve availability period when scheduled duty touches the 0200 – 0600 time period, or what the scientists refer to as the "window of circadian low."

Our submission refers to several documents that have provided us with a foundation of scientific support. Prominent among them is NASA Technical Memorandum 110404, *Principles and Guidelines for Duty and Rest Scheduling in Commercial Aviation,* (May 1996). This document, herein referred to as NASA TM, offers NASA's specific recommendations on duty and rest limitations based on more than 20 years of extensive research into the cause and prevention of pilot fatigue. It is attached hereto as Appendix A.

Another reference is *An Overview of the Scientific Literature Concerning Fatigue, Sleep, and the Circadian Cycle,* Battelle Memorial Institute Study (January 1998). This study, herein referred to as the Battelle Study, commissioned by the FAA's Office of the Chief Scientific and Technical Advisor for Human Factors, provides an in-depth review of scientific research concerning sleep and fatigue. Drawing upon 165 scientific references, the Battelle Report identifies major trends in the scientific literature, and has provided valuable information and conclusions. This study is attached as Appendix B.

Another reference is *A Scientific Review of Proposed Regulations Regarding Flight Crewmember Duty Period Limitations*, Docket #28081, The Flight Duty Regulation scientific Study Group. This study was sponsored by the Independent Pilots Association to provide a scientific review of NPRM 95-18. It is referred to as the Scientific Study Group and is attached as Appendix C.

The pilots met with sleep expert, Dr. William Dement, Director of Sleep Research and Clinical Programs at Stanford University. The transcript of that meeting appears in Appendix D.

We have attached an article titled *Fatigue, Alcohol, and Performance Impairment* that summarizes a study conducted by The Centre for Sleep Research at the Queen Elizabeth Hospital in South Australia in Appendix E. This study quantifies the performance impairment associated with sustained wakefulness in terms of equivalent percent blood alcohol impairment. A subsequent study, titled *Quantifying the Performance Impairment associated with Sustained Wakefulness*, by Lamond and Dawson replicates this study and extends the initial findings. It is attached as Appendix F.

The NTSB requested that the FAA conduct an expedited review of the FARs after pilot fatigue and continuous hours of wakefulness were found to be key findings in the crash of a DC-8 at Guantanamo Bay, Cuba in 1993. A NASA/NTSB report titled *Crew fatigue factors in the Guantanamo Bay aviation accident* is attached as Appendix G.

Several airlines have switched to reserve pilot schemes very similar to the one we propose. These carriers include Continental Airlines, UPS, America West, Alaska Airlines, and British Airways. The reserve pilots at these airlines have protected time periods of 8 to 12 hours with reserve availability periods of 14 to 18 hours.

We owe a debt of gratitude to the many pilots who provided us with reports of their encounters with pilot fatigue. These reports reveal that pilot fatigue typically occurs during back-side-of-the-clock operations and after long periods of time-since-awake.

The pilots would like to thank the FAA for providing this forum and the air carriers for contributing to the debate. We hope that this ARAC has demonstrated to all interested parties how unregulated scheduling can lead to dangerously high levels of pilot fatigue for reserve pilots. We urge the FAA to quickly remedy this very serious safety problem.

PART I: PROPOSED REGULATORY LANGUAGE

121.xxx Reserve Rest

(a) Except as provided in paragraphs (b) and (d), no certificate holder may schedule any flight crewmember and no flight crewmember may accept an assignment to reserve status unless a minimum prospective Protected Time Period (PTP) of 10 hours during a 24-consecutive hour period is scheduled. The Protected Time Period must begin at the same time during any scheduled period of consecutive days of reserve status and the flight crewmember must be given no less than 24 hours notice of the Protected Time Period.

(b) A certificate holder may reschedule a specific Protected Time Period during any scheduled period of consecutive days of reserve by the following:

(1) Rescheduling the beginning of a Protected Time Period a maximum of three hours later without prior notification.

(2) Rescheduling the beginning of a Protected Time Period a maximum of three hours earlier if the flight crewmember is provided 6 hours notice prior to the beginning of the originally scheduled Protected Time Period.

(3) Rescheduling the Protected Time Period by more than 3 hours once during any 7 consecutive days by providing the flight crewmember 10 hours notice.

(c) A certificate holder may assign a flight crewmember and a flight crewmember may accept an assignment for flight time in scheduled air transportation or other commercial flying if such assignment is permitted by this subpart;

(1) If the assignment is scheduled to be completed within 16 hours after the end of the preceding Protected Time Period; however,

(2) If the flight crewmember is given a flight assignment for any part of the period of 0200 to 0600 hours, any such flight assignment must be scheduled to be completed within 14 hours after the end of the preceding Protected Time Period. The operator with the concurrence of the administrator and the pilot group may designate any 4-hour period for all operations between 0000-0600 hours in place of 0200-0600 hours.

These limitations may be extended up to 2 hours for operational delays.

(d) When there are no other reserve pilots who have sufficient reserve availability periods to complete an assignment, the certificate holder may schedule a flight crew member for an assignment for flight time in scheduled air transportation or other flying permitted by this subpart, provided that the crew member is given a minimum of 14 hours of advance notice and is released to protected time at the time of the notice.

(e) Each certificate holder shall prospectively relieve each flight crewmember assigned to reserve for at least 24 consecutive hours during any 7 consecutive days.

(f) For augmented International operations, a certificate holder may assign a flight crewmember and a flight crewmember may accept an assignment for flight time in scheduled air transportation or other commercial flying as follows:

(1) For single augmentation, the assignment must be scheduled to be completed within 18 hours after the end of the preceding Protected Time Period; or

(2) For double augmentation, the assignment must be scheduled to be completed within 22 hours after the end of the preceding Protected Time Period.

These limitations may be extended up to 2 hours for operational delays.

DEFINITIONS

Operational Delay – Any delay that would cause the Reserve Crewmember to be extended beyond the applicable duty limit for up to two hours; except a delay caused by changing the Reserve's original flight assignment.

Protected Time Period (PTP) – Same as 121.471(b)(6), NPRM 95-18, except "has no responsibility for work" replaced by "has no responsibility for duty."

Reserve Availability Period (RAP) – The period of time from the end of the PTP to the time that the reserve crewmember must complete flight duty.

Reserve Time – Same as 121.471(b)(7), NPRM 95-18, except "two hours" for report time versus "one hour."

Standby Duty – Same as 121.47(b)(9), NPRM 95-18, except "less than two hours" to report versus "one hour."

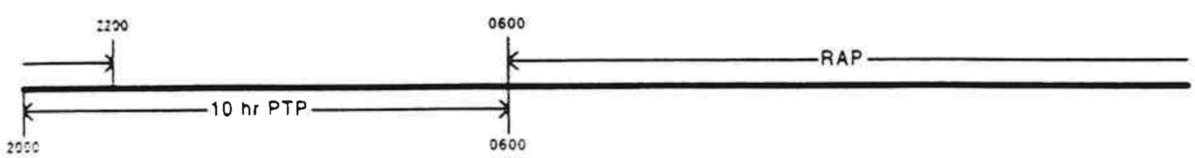
Part II: Pilots' Proposal with Intent, Examples, and Rationale

121.xxx Reserve Rest

(a) ***Except as provided in paragraphs (b) and (d), no certificate holder may schedule any flight crewmember and no flight crewmember may accept an assignment to reserve status unless a minimum prospective Protected Time Period (PTP) of 10 hours during a 24-consecutive hour period is scheduled. The Protected Time Period must begin at the same time during any scheduled period of consecutive days of reserve status and the flight crewmember must be given no less than 24 hours notice of the Protected Time Period.***

Intent: To ensure that all reserve pilots are scheduled for and receive a prospective, and predictable, 10-hour opportunity every reserve day to obtain 8 hours of sleep and to maintain circadian stability.

Example:
Pilot - PTP 2000-0600



Rationale: The human body requires an average of 8 hours of uninterrupted, restorative sleep in a 24 hour period when sleeping during normal sleeping hours. When attempting to sleep outside of normal sleeping hours, 8 hours of sleep is still required. However, scientific data indicates additional time is needed to obtain the required 8 hours of sleep. The 10 hour Protected Time Period (PTP) would, therefore, include an opportunity to prepare for and actually receive 8 hours of restorative sleep in all circumstances. Additionally, a 10-hour PTP was selected with the assumption that the minimum required rest for all pilots would be 10 hours (<u>See</u> NPRM 95-18). A 10-hour PTP would maintain consistency of rest for all pilots. Starting consecutive PTPs at the same time is imperative to maintaining circadian stability. The desired method of assigning PTP would be when the crewmember is assigned reserve. A minimum of 24 hours notification of a Protected Time Period will provide an opportunity to prepare for impending reserve days. [1]

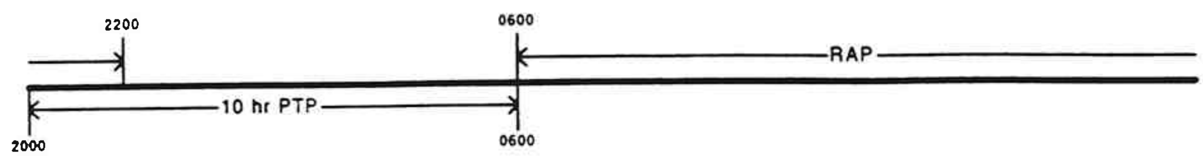
(b) ***A certificate holder may reschedule a Protected Time Period during any scheduled period of consecutive days of reserve by the following:***

Intent: To provide the reserve pilot with a predictable, prospective rest period and also give the operator scheduling flexibility to accommodate unforeseen circumstances. Rescheduling a PTP +/- 3 hours is only applicable to that PTP. Remaining reserve days in a block would begin at the original start time. Shifting of a PTP does not extend a Reserve Availability Period (RAP).

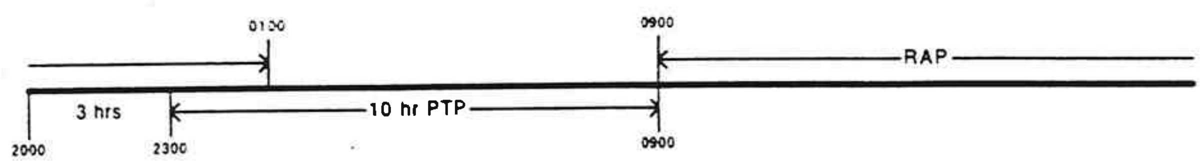
(1) ***Rescheduling the beginning of a Protected Time Period a maximum of three hours later without prior notification.***

Example:
(In this example, under no circumstances may a PTP start time be later than 2300)

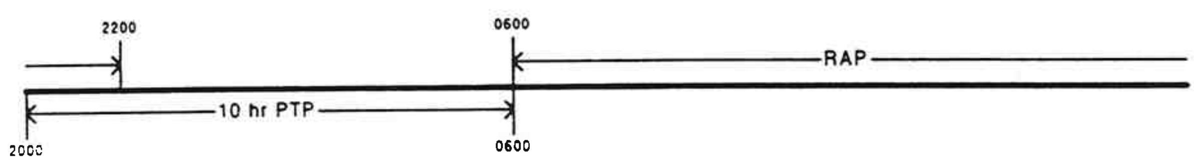
Day 1
PTP 2000 to 0600 (original PTP)



Day 2
PTP 2300 to 0900



Day 3
PTP 2000 to 0600

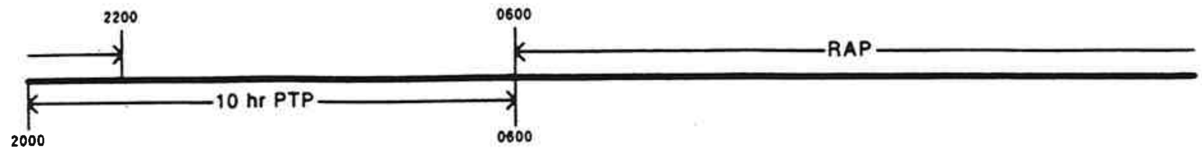


Rationale: Delaying a sleep opportunity, up to three hours, is not excessively disruptive to circadian stability. In this case, no prior notification is required.

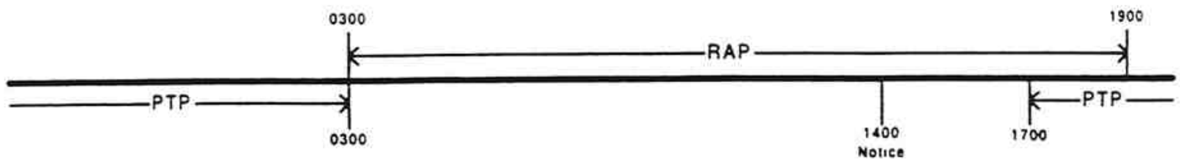
(2) Rescheduling the beginning of a Protected Time Period a maximum of 3 hours earlier if the flight crewmember is provided 6 hours notice prior to the beginning of the originally scheduled Protected Time Period.

Example:
(In this example, under no circumstances may a PTP start time be earlier than 1700)

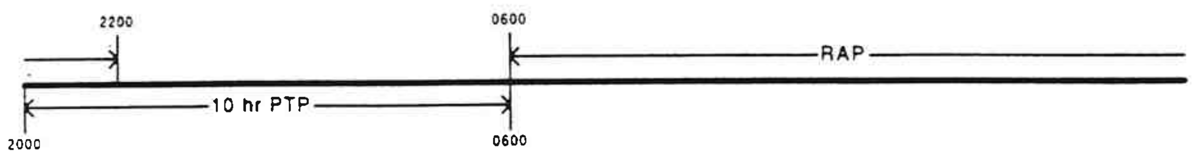
Day 1
PTP 2000 to 0600 (original PTP)



Day 2
PTP 1700 to 0300



Day 3
PTP 2000 to 0600



Rationale: Moving a sleep opportunity earlier, up to three hours, is disruptive to circadian stability. To accommodate and prepare for this rescheduled sleep opportunity additional notice is required.

(3) ***Rescheduling the Protected Time Period by more than 3 hours once during any 7 consecutive days by providing the flight crewmember 10 hours notice.***

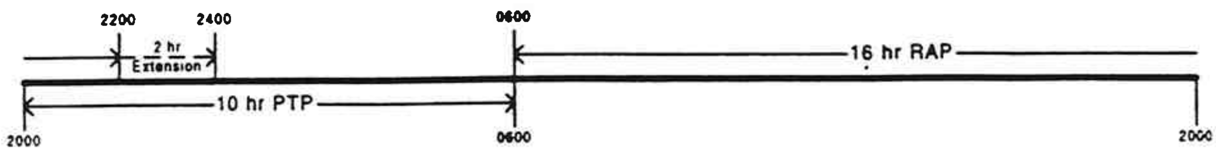
Rationale: Changing a sleep opportunity more than +/- 3 hours is very disruptive to circadian stability. For extreme circumstances beyond the control of the operator (i.e., inclement weather, closed airports, etc.) an operator has the ability to reschedule a PTP more than 3 hours from the original start time. A minimum of 10 hours prior notification of the new PTP is required to allow the pilot a period of time to adjust for the rescheduled sleep opportunity. This provision is restricted to once in every 7 days because it is so detrimental to circadian stability. This restriction also would preclude the operator from arbitrarily utilizing this provision and yet allows the certificate holder the flexibility to operate under extreme circumstances.[2]

(c) ***A certificate holder may assign a flight crewmember and a flight crewmember may accept an assignment for flight time in scheduled air transportation or other commercial flying if such assignment is permitted by this subpart;***

(1) ***If the assignment is scheduled to be completed within 16 hours after the end of the preceding Protected Time Period;***

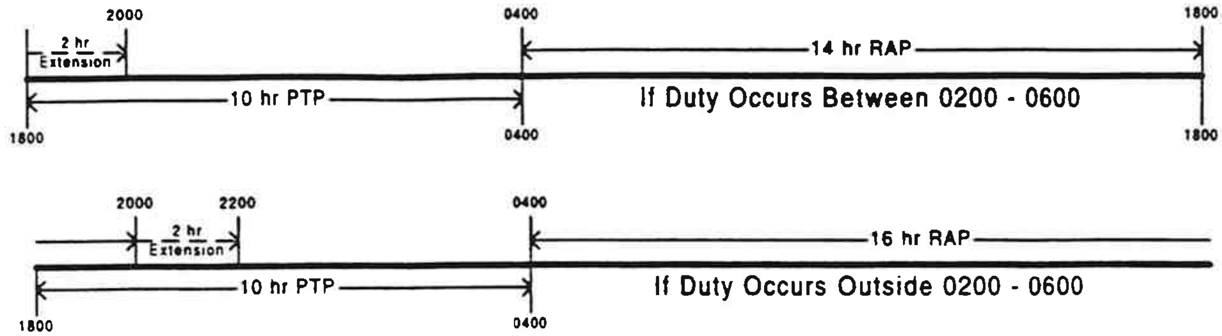
Intent: To establish a "Reserve Availability Period" (RAP).[3]

Example:



(2) ***If the flight crewmember is given a flight assignment for any part of the period of 0200 to 0600 hours, any such flight assignment must be scheduled to be completed within 14 hours after the end of the preceding Protected Time Period. The operator with the concurrence of the administrator and the pilot group may designate any 4-hour period for all operations between 0000-0600 hours in place of 0200-0600 hours.***

Examples:



These limitations may be extended up to 2 hours for operational delays.

Rationale: Time-since-awake contributes to fatigue. This section acknowledges time-since-awake by limiting the RAP to 16 hours if the pilot is afforded the opportunity to sleep during a normal sleep period. The science further indicates fatigue occurs sooner when given a sleep opportunity at a time other than normal sleeping hours. This section addresses that fact by reducing the RAP to 14 hours should duty occur during this normal sleep period.[4]

(d) ***When there are no other reserve pilots who have sufficient reserve availability periods to complete an assignment, the certificate holder may schedule a flight crew member for an assignment for flight time in scheduled air transportation or other flying permitted by this subpart, provided that the crew member is given a minimum of 14 hours of advance notice and is released to protected time at the time of the notice.***

Intent: All pilots are originally scheduled in a PTP system. Circadian stability is ensured by all pilots having a definitive, prospective sleep opportunity. When all such pilots have been utilized, 14 hours notice may be used by the operator to assign a pilot to a flight. Once notified of a flight assignment a crewmember is released from further responsibility until he reports for duty. While this method of assigning reserve is less than desirable, it enables the certificate holder to continue operations as necessary.

Rationale: While advance notice can present a sleep opportunity, scientific research is very clear that circadian factors make it very difficult and sometimes impossible to take advantage of it. For example, consider a pilot who finishes his PTP at 0800 and is then contacted by the carrier for an assignment that reports at 2200. This would be an application of 14 hours advance notice. Circadian factors make it very difficult, if not impossible, for the pilot to sleep again until later, typically during the afternoon circadian low point (1500 – 1800) or earlier if possible. However, by receiving the notice early, he can schedule his morning activity accordingly to best prepare himself for the afternoon sleep opportunity (like a line-holder does). Typically, he would go to bed around 1500 – 1600 and set the alarm clock for 1900 – 2000 to provide enough time to shower, dress, eat, and report for duty. Even with 14 hours of advance notice, this pilot could only expect to sleep 4 – 5 hours prior to reporting for a back-side-of-the-clock assignment that could last until 1200 the following day. It should be apparent that less than 14 hours notice could result in less than 4- 5 hours of sleep and raise the probability of serious pilot fatigue during the assignment.

The above example was discussed during the Denver ARAC meeting. At one point, Dr. Don Hudson was asked for his expert opinion regarding what should be required for a minimum amount of advance notice. Dr. Hudson's response was 13 to 14 hours.[5]

(e) ***Each certificate holder shall prospectively relieve each flight crewmember assigned to reserve for at least 24 consecutive hours during any 7 consecutive days.***

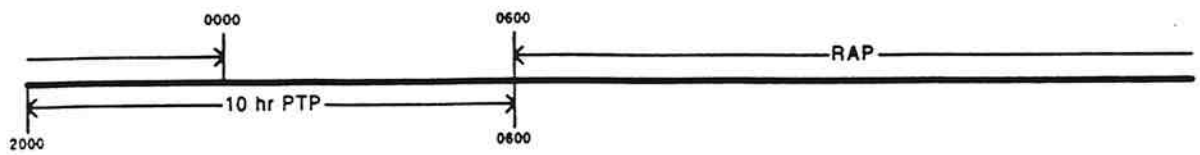
Intent: All reserve pilots must receive a prospective 24 hour period free from duty during any 7 consecutive days.

Rationale: Pilots assigned to reserve status must be continually prepared for any flight duty. These pilots should be relieved from this obligation for 24 hours during any 7 consecutive days. The pilot must be notified prior to the beginning of that off duty period.

(f) For augmented International operations, a certificate holder may assign a flight crewmember and a flight crewmember may accept an assignment for flight time in scheduled air transportation or other commercial flying as follows:

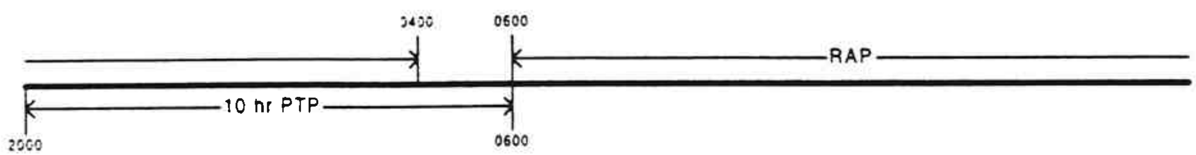
(1) For single augmentation, the assignment must be scheduled to be completed within 18 hours after the end of the preceding Protected Time Period; or

Example:



(2) For double augmentation, the assignment must be scheduled to be completed within 22 hours after the end of the preceding Protected Time Period.

Example:



These limitations may be extended up to 2 hours for operational delays.

Intent: To establish a Reserve Availability Period (RAP) for long-haul international reserve pilots.

Rationale: Long-haul international flights necessarily involve back-side-of-the-clock flying. Therefore, for a single pilot augmentation, we added 4 hours to the 14-hour back-side-of-the-clock duty period and 8 hours for double augmentation. This is in accord with the NASA TM. [6]

---

[1] *121.xxx Reserve Rest*

(a) ***Except as provided in paragraphs (b) and (d), no certificate holder may schedule any flight crewmember and no flight crewmember may accept an assignment to reserve status unless a minimum prospective Protected Time Period (PTP) of 10 hours during a 24-consecutive hour period is scheduled. The Protected Time Period must begin at the same time during any scheduled period of consecutive days of reserve status and the flight crewmember must be given no less than 24 hours notice of the Protected Time Period.***

Scientific support:

(a) 10 hour Protected Time Period to provide an opportunity to obtain 8 hours of sleep.

> Each individual has a basic sleep requirement that provides for optimal levels of performance and physiological alertness during wakefulness. On average, this is 8 hours of sleep in a 24-hour period, with a range of sleep needs greater than and less than this amount. Losing as little as 2 hours of sleep will result in acute sleep loss, which will induce fatigue and degrade subsequent waking performance and alertness.

NASA TM, ¶1.1.1, p.2.

> **Off-duty period (acute sleep and awake-time-off requirements)** - Therefore, the off-duty period should be a minimum of 10 hours uninterrupted within any 24-hour period, to include an 8-hour sleep opportunity[.]

NASA TM, ¶2.1.2, p. 5

> Standard Sleep Requirements and Off-Duty Period - Research by Drs. Carskadon & Dement, 1982 and Wehr et al., 1993 support a minimum of 8 hours of sleep based upon a range of studies that use several approaches including:
>
> - Historical levels of sleep
> - Measures of daytime alertness
> - Sleep levels achieved when given the opportunity to sleep as long as desired

Battelle Report, p. 15.

> . . . There appears to be substantial evidence that a minimum of eight hours of sleep is required for most people to achieve effective levels of alertness and performance.

Battelle Report, p. 21.

> . . . It is important to realize that an individual working nights is at risk for significant sleepiness for two distinct reasons: . . . an individual working successive nights is forced to obtain sleep during the daylight hours at a time when the circadian pre-disposition to sleep is minimal. . . . As mentioned, sleep under these circumstances is typically fragmented, sleep state architecture is distorted, and the restorative nature of sleep . . . is reduced.

A Scientific Review of Proposed Regulations Regarding Flight Crewmember Duty period Limitations, The Flight Duty Regulation Scientific Study Group, ¶2.6, p. 5-6.

> Minimum rest periods should be adjusted upward for sleep periods that include the time of peak circadian alertness (4 – 6 PM.).
>
> <u>Reserve time arrangements should be adjusted so that protected windows during the time of peak circadian alertness are extended to compensate for decreased efficiency of sleep during that time.</u> (Emphasis added.)

Scientific Study Group, ¶¶ 5.1.2, 5.1.4, p. 11.

<u>Remarks of Dr. Dement:</u>

Q: . . . One of the most basic tasks is for us to agree on a recommendation for a sleep opportunity . . . to afford every reserve pilot the opportunity of a protected time period so that he or she is absolutely insulated from contact from the operator. How many hours do you recommend for a minimum fixed sleep opportunity?

A: I will start out by assuming that we would take 8 hours of sleep as the most common requirement. Then you need to add to that in order to be able to get the proper amount of sleep. In your situation, I would think it would be a little larger than it might be for someone who really wasn't doing anything. So, I'd add a couple of hours to get the proper amount of sleep.

Appendix D, p. 4.

Q: Dr. Dement, . . . we're really at the point now where we're going beyond the philosophy and we're trying to put our finger on numeric values. Our position at least from the pilots' standpoint, is that we see the need for a 10-hour sleep opportunity knowing that the opportunity may not always be at the best time of the day. We're facing an industry position that is looking for 8 hours as the minimum. Our position is predicated on the fact that 8 hours may be adequate if it overlaps the WOCL. But since we don't know for sure when we're going to have that opportunity, we believe that, or we think that having that extra 2 hours is going to give us a little more of a buffer, especially when it comes during the daytime. Would you consider that to be a conservative and a justified position?

A: Absolutely. I don't think you could possibly assume someone is going to fall asleep instantly and then sleep continuously for 8 hours, not even under the most ideal circumstances. Maybe it should be longer.

Appendix D, pp. 5-6.

Scientific support:
(a) Scheduling the Protected Time Period for the same time each day

> **Time-of-day / Circadian Physiology Affects Sleep and Waking Performance -** **. . .** Time-of-day or circadian effects are important considerations in addressing 24 hour operational requirements because circadian rhythms do not adjust rapidly to change.
>
> . . . Thus, circadian disruption can lead to acute sleep deficits, cumulative sleep loss, decreases in performance and alertness, and various health problems . . . Therefore, circadian stability is another consideration in duty and rest scheduling.

NASA recommends a sleep opportunity that is predictable (24 hours notice recommended), <u>does not vary more than 3 hours on subsequent days to ensure circadian stability</u>, and is protected from interruption. (Emphasis added.)
NASA TM, ¶1.3, p. 3-4; ¶2.6.2, p. 8.

> **Conclusion –** Reserve assignments should attempt to maintain a consistent 24 hour cycle.

Battelle Report, p. 28.

<u>Remarks of Dr. Dement</u>

Q: Dr. Dement, there's one area that we really haven't touched upon at this point and I don't want to miss. These are questions regarding the maintenance of circadian stability. In your opinion, why is maintaining circadian stability so important?

A: Well because usually... and by that you mean your sleep opportunities and your wake opportunities are in that period of stability, then you have the best sleep and the best wake. If you get out of that cycle, then both sleep and wake will be impaired.

Q: What happens to the body as you change a person's cycle?

A: All sorts of things happen, but the major thing of course is that you are now trying to sleep when the body wants to be awake and you're trying to be awake when the body wants to be asleep because you left the circadian stability that you talked about.

Appendix D, pp. 16-17.

(3) ***Rescheduling the Protected Time Period by more than 3 hours once during any 7 consecutive days by providing the flight crewmember 10 hours notice.***

<u>Scientific support:</u>

(b) Limiting the movement of the Protected Time Period to Plus or Minus 3 hours

> . . . the 8-hour sleep opportunity should not vary by more than 3 hours on subsequent days to ensure circadian stability. . . .

NASA TM, ¶2.6.2, p. 8.

<u>Remarks of Dr. Dement</u>

Q: . . . we're trying to insure that the protected time period, the rest period, stayed the same from day to day, assuming the reserve crewmember is not called. Or for that matter when he is called, he goes back into his cycle. We're attempting to try to snap him back to as close to that original cycle and maintain that same rhythm from day to day. NASA has findings on that. Their recommendation was to maintain that circadian stability plus or minus 3 hours. Do you agree or disagree?

A: I absolutely agree that's better than no stability. Obviously the smaller that number, the better. I think practically it couldn't be zero, but I think we tend to feel there's kind of a daily flexibility within that range, like 0 to 3 hours, 0 to 2 hours. To go outside of that is, again, inviting a condition of sleep deprivation. So deliberately creating a bad situation.

Appendix D, pp. 16-17.

(c) A certificate holder may assign a flight crewmember and a flight crewmember may accept an assignment for flight time in scheduled air transportation or other commercial flying if such assignment is permitted by this subpart;

(1) If the assignment is scheduled to be completed within 16 hours after the end of the preceding Protected Time Period;

Scientific support:

(c) 16 hour Reserve Availability Period Limitation

> **Continuous Hours of Wakefulness/Duty Can Affect Alertness and Performance** - Extended wakefulness and prolonged periods of continuous performance or vigilance will engender sleepiness and fatigue.
>
> **Extended flight duty period** – An extended flight duty period should be limited to 12 hours within a 24-hour period to be accompanied by additional restrictions and compensatory off-duty periods. This limit is based on scientific findings from a variety of sources, including data from aviation, that demonstrate a significant increased vulnerability to performance-impairing fatigue after 12 hours. It is readily acknowledged that in current practice, flight duty periods extend to 14 hours in regular operations. However, the available scientific data support a guideline different from current operational practice. The data indicate that performance-impairing fatigue does increase beyond the 12-hour limit and could reduce the safety margin.

NASA TM, ¶¶ 1.4, 2.3.4. pp. 4, 6.

NASA does not provide a specific recommendation for the duration of a Reserve Availability Period. However, it follows that NASA's recommended maximum duty limit of 12 hours plus 2 hours for operational delays (total - 14 hours) obviously requires a pilot to be awake at least that much time. By adding report time to NASA's recommended maximum duty limit, it is apparent that NASA's duty limit is commensurate with our proposed 16-hour reserve availability period limit for un-augmented flying.

> The results of an NTSB analysis of domestic air carrier accidents occurring from 1978 to 1990 suggest that time since awake (TSA) was the dominant fatigue-related factor in these accidents (NTSB, 1994). Performance decrements of high time-since-awake crews tended to result from ineffective decision-making rather than deterioration of aircraft handling skills. . . . There did appear to be two peaks in accidents: in the morning when time since awake is low and the crew has been on duty for about three to four hours, and when time-since-awake was high, above 13 hours. Similar accident peaks in other modes of transportation and industry have also been reported (Folkard, 1997). Akerstedt & Kecklund (1989) studied prior time awake (four to 12 hours) and found a strong correlation of accidents

> with time since awake for all times of the day. Belenky et al. (1994) found that flight time hours (workload) greatly increase and add to the linear decline in performance associated with time since awake.

Battelle Report, p. 13.

> Some symptoms of fatigue are similar to other physiological conditions. For example, with fatigue one's ability to attend to auxiliary tasks becomes more narrow, very much analogous to the effects of alcohol (Huntley et al., 1973; Moskowitz, 1973), hypoxia (McFarland 1953), and heat stress (Bursill, 1958).

Battelle Report, p. 5.

Australian researchers Drew Dawson and Kathryn Reid (1997) evaluated performance after 17 hours of wakefulness and found performance degraded to a level equal to that caused by a blood alcohol concentration (BAC) of 0.05 percent. At 24 hours, performance decrements were equivalent to that of a 0.10 BAC. After ten hours of sleeplessness, the decline in performance averaged .74 percent per hour. Their study titled *Fatigue, Alcohol and Performance Impairment* appeared in Nature, Vol. 338, July-August 1997. (See Appendix E). These findings were replicated and extended by Nichole Lamond and Drew Dawson in 1998. (See Appendix F).

> If an individual has been awake for 16 to 18 hours, decrements in alertness and performance are intensified. If time awake is extended to 20 to 24 hours, alertness can drop more than 40 percent (WRAIR, 1997; Morgan et al., 1974; Wehr, 1996).
>
> . . .

Battelle Report, p. 25.

The NTSB cited pilot fatigue as the probable cause of the crash of a DC-8 at Guantanamo Bay in 1993. The individual crewmembers were continuously awake for 19, 21, and 23.5 hours prior to the accident.
Mark R. Rosekind, et al., *Crew fatigue factors in the Guantanamo Bay aviation accident*. (See Appendix G).

Remarks of Dr. Dement

Q: Dr. Dement, after our reserve pilots receive their sleep opportunity, they become available for duty. We call the availability period the "reserve availability period" and that's basically the time they are available for work, for flying. After the sleep opportunity, what would you consider to be a safe limit of time since awake for a crewmember?

For the 10-hour (sleep opportunity) period?

Yes.

A: Fourteen hours. And I wouldn't say that's 100% safe but if you have a number, that adds up to the 24-hour day. It ought to be reasonably safe.

Q: Where do you get your number from?

A: Well, it comes mainly in my head from circadian type 24-hour studies to see the pattern of the manifestation of the drive to sleep versus the awakening effect of the biological clock. If you're getting outside the 24-hour cycle, then you're going to have periods of greater risk. . . .

Q: That assumes that the individual wakes up as soon as his protected time period is over. So in other words, you see a complimentary factor: 9 hours of rest should dictate a 15-hour availability period?

A: Yes. I think most people would agree that would be the ideal.

Q: Going beyond that, what is probably the most greatest points of contention right now – the debate between the pilots and the industry operators – is the fact that the operators would like to extend this reserve availability period in excess of what you say is 14 or 15 or 16 hours, whatever the case may be, to a larger increment, extending that reserve availability period based upon an advance notice of a nap opportunity. In other words, a pilot comes on call at 8:00 a.m. He is then told at 9:00 a.m. that he is to report for duty 5 hours later. The industry's position is that the notice constitutes an opportunity for additional rest which then would be utilized to add more restorative energy or analogous to putting more charge into a battery, and then carry that pilot into more of an extended duty period with an additional amount of time.... up to in certain cases 24 hours of duty. What is your feeling on that type of scenario?

A: To me, that's a recipe for disaster because if you have a responsible, professional pilot – who has a reasonable schedule, - who is not horribly sleep deprived, and who has a fairly stable circadian rhythm, then the likelihood that he can get adequate sleep by trying to nap I think is relatively small. I would not depend on it at all. I would think also to have to do it sort of unexpectedly like this....Oh! Take a nap....Only people who are very sleep deprived....

Q: Let's say I have a 10-hour sleep opportunity: 10 p.m. to 8 a.m. That means I'm available for 14 hours unless they fly me into the next 10 p.m. slot tonight. Could I not get a call say at noon and say instead of you being off tonight at 10 p.m., we want you to work until seven tomorrow morning but you aren't going to go to work until 10:00 that night. So they call me at noon, they give a 10-hour notice that I'm not going to have to go to work until 10 hours from noon, so at 2200 I report for work, and they want me to fly until 0800. So that would be a total of 24 hours from the time I theoretically woke up and I've had a 10-hour notice that I was going to be flying this fatiguing schedule. Would that be safe?

A: Well, I wouldn't be on your plane. No. I think that's almost insanity in the sense of saying that is safe. First of all, naps can't be depended on – even under ideal circumstances – to get you through this period when the biological clock alerting is gone, when you're alone with your sleep debt so to speak, during the WOCL. There's no way that isn't going to be dangerous. . . .

Appendix D, pp. 8-9.

(2) ***If the flight crewmember is given a flight assignment for any part of the period of 0200 to 0600 hours, any such flight assignment must be scheduled to be completed within 14 hours after the end of the preceding Protected Time Period. The operator with the concurrence of the administrator and the pilot group may designate any 4-hour period for all operations between 0000-0600 hours in place of 0200-0600 hours.***

Scientific support:

(c) Reducing the Reserve Availability Period by two hours during Back-Side-Of-The-Clock Operations (0200 – 0600)

> **Off-duty period (following standard flight duty periods during window of circadian low)** - Extensive scientific research, including aviation data, demonstrate that maintaining wakefulness during the window of circadian low is associated with higher levels of performance-impairing fatigue than during daytime wakefulness. . . .
>
> **Definition: "window of circadian low"** - The window of circadian low is best estimated by the hours between 0200 and 0600 for individuals adapted to a usual day-wake/night-sleep schedule. This estimate of the widow is calculated from scientific data on the circadian low of performance, alertness, subjective report (i.e. peak fatigue), and body temperature. . . .

NASA TM, ¶¶ 2.1.4, 2.3.2, pp. 5-6.

> The ingredient of day versus night long-haul flights raises a second concern, the time-of-day departure. Because sleepiness and fatigue are strongly related to circadian rhythmicity, they should not be controlled by regulations, which ignore time-of-day in favor of elapsed time. . . . For the sake of efficiency and safety, it is incumbent upon regulatory authorities to include time-of-day as a factor in designing flight crew duty and rest limitations.

R. Curtis Graeber, et al., *Aircrew Sleep and Fatigue in Long-Haul Flight Operations*, Tokyo, Japan (October 26-29, 1987), p. 13.

Back of the Clock Operations, Circadian Rhythm and Performance

There is a substantial body of research that shows decreased performance during night shifts as compared with day shifts. The reasons for this decreased performance include:

- Circadian pressure to sleep when the individual is attempting to work.
- Circadian pressure to be awake when the individual is attempting to sleep.
- Time since awake may be substantial if the individual is up all day before reporting for the night shift.
- Cumulative sleep debt increase throughout the shift.

Research conducted by Monk et al. (1989) indicates that subjective alertness is under the control of the endogenous circadian pacemaker and one's sleep-wake cycle (time since awake). When time since awake is long and coincides with the

> circadian low there is a very sharp drop in alertness, a strong tendency to sleep and a significant drop in performance (Perelli, 1980). Alertness is relatively high when the circadian rhythm is near the acrophase and time since awake is small. Monk (1996) argues that this cycle is consistent with the NTSB (1994) finding of a peak accident rate occurring in the evening. . . .

Battelle Report, p. 23.

> Microsleeps have been shown to be a useful approach to assessing the effects of time of day on sleepiness levels. EEG brain wave changes confirm that pilots experience greater sleepiness and decreased alertness between 2:00 to 4:00 a.m. (Gundel, 1995). . . .

Battelle Report, p. 9.

> . . . In determining maximum limits for extended duty periods, consideration also needs to be given to other fatigue-related factors that could contribute to excessive fatigue levels during extended duty periods, including number of legs, whether the flight impinges on the window of circadian low (WOCL), and time since awake. (Emphasis added.)

Battelle Report, p. 14.

> Night operations are physiologically different than day operations due to circadian trough and sleep loss. This carries a higher physiological cost and imposes greater risks of accidents. One of the most established safety issues is working in the circadian trough between 0200 and 0600. During this period workers experience considerable sleepiness, slower response times, increased errors and accidents (Mitler, 1991; Pack, 1994). Many recent accidents from various transportation modes have been associated with this circadian trough (Lauber & Kayten, 1988). Lyman and Orlady (1981), in their analysis of the Aviation Safety Reporting System researcher state that 31 percent of incidents occurring between 2400 to 0600 hours were fatigue related.
>
> In Japan, 82.4 percent of drowsiness-related near accidents in electric motor locomotive drivers (Kogi & Ohta, 1975) occur at night. Other landmark studies over the past several decades have documented the increase in accidents and error making. Klein et al. (1970) argue that their research with simulators proves that night flights are a greater risk than day flights. Their research found 75- to 100-percent mean performance efficiency decrements in simulator flights during the early morning hours, regardless of external factor such as darkness or increasing night traffic or possible weather conditions.
>
> . . . A study of naval watch keepers found that between 0400 to 0600, response rates drop 33 percent, false reports rates 31 percent, and response speed eight percent, compared with rates between 2000 to 2200 hours (Smiley, 1996).
>
> Samel et al. (1996) determined that many pilots begin night flights already having been awake more than 15 hours. The study confirms the occurrence of as many as five micro-sleeps per hour per pilot after five hours into a night flight. . . . The authors concluded that "During day time, fatigue-dependent vigilance decreases

with task duration, and fatigue becomes critical after 12 hours of constant work. During night hours fatigue increases faster with ongoing duty. This led to the conclusion that 10 hours of work should be the maximum for night flying."

[Note Samel's conclusion - Reduce the duty period from 12 to 10 hours.]

Gander et al. (1991) found in an air carrier setting that at least 11 percent of pilots studied fell asleep for an average of 46 minutes. Similarly, Luna et al. (1997) found that U.S. Air Force air traffic controller [sic] fell asleep an average of 55 minutes on night shift. A possible explanation for these sleep occurrences, in addition to circadian nadir, is the finding of Samel et al. that many pilots begin their night flights after being awake for as long as 15 hours.

Battelle Report, pp. 24-25.

Duty periods conducted during the WOCL already carry a fatigue penalty due to the circadian cycle. Consequently, duty periods involving WOCL should be reduced. (Emphasis added.)

Battelle Report, p. 28.

. . . flight duty regulations that adequately account for circadian modulation in the capacity of sleep and in human performance have been used in the United Kingdom for 6 years . . . and by account appear to be working well. The Study Group is aware of no qualitative reason why adjustments such as those incorporated in the UK regulations could not be used in the US as well.

Scientific Study Group, ¶4.2, p. 10.

Flight duty periods during window of circadian low.
. . . Therefore, it is recommended that in a 7-day period, there be no extended flight duty period that encroaches on any portion of the window of circadian low.

[Note: a standard flight duty period should not exceed 10 hours within a 24-hour period.]
NASA TM, ¶¶ 2.3.5.B.; 2.3.3.

(d) ***When there are no other reserve pilots who have sufficient reserve availability periods to complete an assignment, the certificate holder may schedule a flight crew member for an assignment for flight time in scheduled air transportation or other flying permitted by this subpart, provided that the crew member is given a minimum of 14 hours of advance notice and is released to protected time at the time of the notice.***

Scientific support:

(d) Minimum of 14 Hours Advance notice

> Considerable research into other arenas has taught us that individuals are better able to cope with unusual or extended duty schedules when they can plan for them in advance. This forewarning allows them to develop time-linked performance goals and to schedule their rest and activity optimally before reporting for duty.

R. Curtis Graeber, et al., *Aircrew Sleep and Fatigue in Long-Haul Flight Operations.* Tokyo, Japan (October 26-29, 1987), p. 12.

> ... In other words, simply being off duty was not a sufficient condition for crew members to be able to fall asleep. . . .

Philippa N. Gander, et al., *Crew Factors in Flight Operations: VIII. Factors Influencing Sleep Timing and Subjective Sleep Quality in Commercial Long-Haul Flight Crews* (December 1991), p. 29.

> . . . In the limited time remaining, he attempts to sleep irrespective of his physiological readiness to sleep (circadian phase) and the local time, both of which may compromise the quality and quantity of sleep he is able to obtain.

Philippa N. Gander, et al., *Crew Factors in Flight Operations: VIII. Factors Influencing Sleep Timing and Subjective Sleep Quality in Commercial Long-Haul Flight Crews* (December 1991), p. 31.

This reinforces the importance of ensuring that adequate time is available for sleep.

> **Conclusions – . . .** Flight and duty time regulations can be interpreted as a means of ensuring that reasonable minimum rest periods are respected. However, the perspective highlighted by this study is that the time available for sleep is less than the scheduled time off duty. . . .

Philippa N. Gander, et al., *Crew Factors in Flight Operations: VIII. Factors Influencing Sleep Timing and Subjective Sleep Quality in Commercial Long-Haul Flight Crews* (December 1991), p. 33.

Remarks of Dr. Dement

Q: How about that the flight is going to happen. There is going to be every day in America, pilots that report to work at 2300 or whatever and fly until 0800 the next morning. Now, what's different about the man who knows a week, a month in advance that this is going to be his schedule and the reserve pilot who finds out at noon after having woken up at 8 a.m.? What would be the difference?

A: You know that the time you do all of the things you can to move toward a better situation . . . You can never get to perfection, but the more practice, the more warning, the better you'll be able to handle it. Some people learn that there is a time when it's quiet and if I do this, I can pretty much depend that I will fall asleep. It's not 100% but you kind of learn that or you practice or whatever. But if it's without warning, all bets are off.

Q: Dr. Dement, you've kind of led the discussion into another area of this rulemaking that has to do with an alternative method. Assuming that the pilots in this protected time period method were depleted, the carriers then want to give pilots advance notice to cover any mission or any assignment. They are looking at 10 hours as the criteria. We don't believe that to be adequate based upon . . .

Are you talking 10-hour warning?

Ten-hour warning, yes. To do anything.

A: That would be 100% wrong.

Q: Why?

A: Well, because the 10 hours could fall sort of toward the beginning of what we call "clock dependent learning." There's no way you could sleep. And then you go into your duty period at the worse possible time you could have in that situation.

Q: What sort of time would you think would be adequate to give a guy enough time to get an opportunity to rest so that he would be safer than 10 hours?

A: Twenty-four hours. At least a day before. Wouldn't you think? I don't see how you can get notified as the day is beginning and feel you could depend on being able to take a nap. If it happened every day or somehow you know that you could certainly get the probability up, but it's not something that you could ever really control. Again, there ought to be a better way.

Appendix D, pp. 10-11.

Q: We're shooting around the subject. I hate to break any of this up, but this question has been plaguing this committee. The industry keeps harping on the fact that there should be no difference between the schedule holder who knows he's got to fly from midnight to 8:00 a.m. If he can do it safely, why can't a reserve that wakes up at the same time in the morning (8:00 a.m. or 6:00 a.m.). Why is it not safe for this reserve pilot who does it with notice?

A: I don't think it's safe for either pilot. Maybe a little less dangerous in the sense of performance, etc. But I think at least he has preparation, warning, etc. and knows his own strengths and weaknesses whereas the other pilot I think is always without warning and has really no chance to prepare. I don't think the two groups are the same.

Q: Are you implying that the preparation should actually start the previous night?

A: Yes. If I was going to drive all night, I wouldn't want someone to tell me that day.

Q: They're really killing us for making that same argument. I mean we make that argument across the table and we get smiles and nods of the head and shrugs of the shoulders from the other side. They say it's not a valid argument. That's always what they come up with.

A: They say it's not a valid argument? It is a supremely valid argument. I mean that's just like saying down is up.

Appendix D, p. 13.

(f) For augmented International operations, a certificate holder may assign a flight crewmember and a flight crewmember may accept an assignment for flight time in scheduled air transportation or other commercial flying as follows:

(1) For single augmentation, the assignment must be scheduled to be completed within 18 hours after the end of the preceding Protected Time Period; or

(2) For double augmentation, the assignment must be scheduled to be completed within 22 hours after the end of the preceding Protected Time Period.

These limitations may be extended up to 2 hours for operational delays.

Scientific support:
(f) (1) and (2) augmented crews

> **Extended flight duty period: additional flight crew** - Additional flight crew afford the opportunity for each flight crew member to reduce the time at the controls and provide for sleep during a flight duty period. Consequently, with additional flight crew and an opportunity for sleep, it would be expected that fatigue would accumulate more slowly. In such circumstances, flight duty periods can be increased beyond the recommended limit of 12 hours within each 24-hour period. For each additional flight crew member who rotates into the flight deck positions, the flight duty period can be extended by 4 hours as long as the following requirements are met: 1) each flight crew member be provided one or more on-duty sleep opportunities; and 2) when the extended flight duty period is 14 hours or longer, adequate sleep facilities (supine position) are provided that are separated and screened from the flight deck and passengers. Controlled rest on the flight deck is not a substitute for the sleep opportunities or facilities required for additional flight crew members.

NASA TM, ¶ 2.3.6, p. 7.

APPENDIX A

NASA Technical Memorandum 110404

Principles and Guidelines for Duty and Rest Scheduling in Commercial Aviation

David F. Dinges, University of Pennsylvania Medical School, Philadelphia, Pennsylvania
R. Curtis Graeber, Boeing Commercial Airplane Group, Seattle, Washington
Mark R. Rosekind, Ames Research Center, Moffett Field, California
Alexander Samel, and Hans M. Wegmann, DLR-Institute of Aerospace Medicine, Cologne, Germany

May 1996

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

Table of Contents

PREFACE

This document is intended to provide scientific input to the issue of duty and rest scheduling of flight crews in commercial aviation. It is available to any interested party that is addressing these complex issues.

The global aviation industry requires 24-hour activities to meet operational demands. To address this challenge, a scientific working group with expertise relevant to these demands met to develop principles and guidelines for duty and rest scheduling in commercial aviation.

Scientific Working Group Methodology. First, the group identified areas of scientific knowledge relevant to flight safety. This included identifying areas where relevant data were available and also areas where no scientific data currently exist. Based on current scientific knowledge, general principles directly related to aviation operational considerations were established. With the general principles as a basis, specific principles, guidelines, and recommendations for duty and rest scheduling in commercial aviation were developed. There was no intention to create regulatory policy. This was beyond the scope of the scientific working group. Although the group is aware of current operational practices, it adhered to the preset guideline of requiring scientific data relevant to specific recommendations. The group noted that there may not be a single solution to the challenges posed by the 24-hour demands of the aviation industry. Therefore, other industry strategies are suggested to complement the duty and rest scheduling guidelines. Throughout this process, input was obtained from individuals with extensive operational experience and familiarity with these issues.

Scientific Basis for Principles and Guidelines. The scientific working group was composed of scientists actively involved in examining these issues in aviation settings. The group intends to produce two documents based on their work. This first document is intended to be concise, to be focused on operational considerations, and to provide scientific input to this complex issue. The second document will follow and will provide the specific scientific references that support the principles and guidelines outlined here. This second document will be longer and will focus on the scientific considerations related to these issues. It is planned that an initial draft of this second document will be available within approximately 12 months.

Implementation. It is acknowledged that implementation of these principles and guidelines may require additional considerations. These considerations include economic, legal, cost/benefit, and other factors. It was beyond the scope of the scientific working group to address these issues, and they are left to appropriate operational and regulatory expertise for deliberation.

The scientific working group met as individuals and not as representatives of any organization or of a particular position on any issue. Therefore, the views and opinions expressed in this document are those of the scientific working group and do not necessarily reflect those of any organization.

In alphabetical order, the scientific working group included: David F. Dinges, Ph.D., R. Curtis Graeber, Ph.D., Mark R. Rosekind, Ph.D., Alexander Samel, Ph.D., and Hans M. Wegmann, M.D. To refer questions about this document to the scientific working group, please use either of the following points of contact:

Mark R. Rosekind, Ph.D.
NASA Ames Research Center
Mail Stop 262-4
Moffett Field, CA 94035-1000
(415) 604-3921 (Office)
(415) 604-3729 (Fax)

Hans M. Wegmann, M.D.
DLR–Institute of Aerospace Medicine
Linder Hoehe
D-51147 Koeln
Germany
49 2203 601 1 ext. 3667 (Office)
49 2203 696 372 (Fax)

Principles and Guidelines for Duty and Rest Scheduling in Commercial Aviation

David F. Dinges, R. Curtis Graeber, Mark R. Rosekind,
Alexander Samel, and Hans M. Wegmann
(in alphabetical order)

INTRODUCTION

Twenty-four Hour Requirements of the Aviation Industry

The aviation industry requires 24-hour activities to meet operational demands. Growth in global long-haul, regional, overnight cargo, and short-haul domestic operations will continue to increase these round-the-clock requirements. Flight crews must be available to support 24-hour-a-day operations to meet these industry demands. Both domestic and international aviation can also require crossing multiple time zones. Therefore, shift work, night work, irregular work schedules, unpredictable work schedules, and time zone changes will continue to be commonplace components of the aviation industry. These factors pose known challenges to human physiology, and because they result in performance-impairing fatigue, they pose a risk to safety. It is critical to acknowledge and, whenever possible, incorporate scientific information on fatigue, human sleep, and circadian physiology into 24-hour aviation operations. Utilization of such scientific information can help promote crew performance and alertness during flight operations and thereby maintain and improve the safety margin.

Challenges to Human Physiology

Throughout aviation history, operational capabilities and technology have evolved dramatically, while human physiological capabilities have not. Flight operations can engender fatigue, sleep loss, and circadian disruption and these physiological factors can result in decreased performance and reduced alertness during operations. Over the past 40 years, scientific knowledge about sleep, circadian physiology, sleepiness/alertness, and the performance decrements associated with these factors has increased significantly. Scientific research has extended its examination of these factors to operational environments, including field and simulator studies. These studies have confirmed the presence in aviators of performance-impairing fatigue resulting from the sleep loss, circadian disruption, and workload engendered by current flight and duty practices.

Humans are central to aviation operations and continue to perform critical functions to meet the 24-hour requirements of the industry. Therefore, human physiological capabilities, and limitations, remain crucial factors in maintaining safety and productivity in aviation.

Principles Based on Scientific Knowledge

Though research on fatigue, sleep and circadian physiology, and shift work schedules has generated an extensive body of scientific knowledge, the application of this information to the requirements of operational settings is relatively new. While acknowledgment of this scientific information is increasing, its transfer to operations (e.g., scheduling, regulatory considerations, personal strategies, countermeasures) offers the greatest potential for its benefit. Current federal regulations and industry scheduling practices rarely acknowledge or incorporate such knowledge. The primary purpose of this document is to outline scientifically-based principles that can be applied to the duty and rest scheduling requirements of the aviation industry.

Shared Responsibility

There is no one absolute or perfect solution to the demands of duty and rest scheduling in aviation. It is critical that safety be acknowledged as a shared responsibility among all the industry participants. Each component of the aviation system should be examined for avenues to incorporate scientific information and to apply guidelines and strategies that will maximize performance and alertness during flight operations. Regulatory considerations, scheduling practices, personal strategies, and technology design are specific components of the industry that could be subject to such an examination.

Each of these components is complex and presents unique challenges. This document is focused on scientifically-based principles and guidelines for duty and rest scheduling. However, it is acknowledged that regulatory action involves many considerations, such as legal, economic, and current practice. It is the intent of this document that relevant scientific information be considered in the regulatory domain.

"Safe" can be Difficult to Quantify

Determining a "safe" operation is a complex task. Aircraft accidents are such rare occurrences that they may not provide the best outcome variable to estimate safe operations. The aviation industry and flying public demand a high margin of safety and redundancy. Among modes of transportation, the aviation industry's reputation for safety is well-deserved. As many segments of the industry increase their activities, as technology enables longer flights, and as overall growth continues, the challenge will be to maintain, and where possible, improve the safety margin. The fatigue factors addressed in these principles can create a vulnerability for decrements in performance and alertness that can reduce the safety margin. Guidelines designed to specifically address these factors can help to minimize this vulnerability.

Objectives

The primary objective of this document is to provide empirically derived principles and guidelines for duty and rest scheduling in commercial aviation. In the first section, scientifically-based principles related to operational issues posed by the aviation industry are outlined. In the second section, the principles are applied to guidelines for duty and rest scheduling in commercial aviation, with specifics provided where appropriate and available. In the third section, a brief overview of other potential industry strategies to address these issues is provided.

1.0 GENERAL PRINCIPLES

1.1 Sleep, Awake Time Off, and Recovery are Primary Considerations

1.1.1 Sleep– Sleep is a vital physiological need. Sleep is necessary to maintain alertness and performance, positive mood, and overall health and well-being. Each individual has a basic sleep requirement that provides for optimal levels of performance and physiological alertness during wakefulness. On average, this is 8 hours of sleep in a 24-hour period, with a range of sleep needs greater than and less than this amount. Losing as little as 2 hours of sleep will result in acute sleep loss, which will induce fatigue and degrade subsequent waking performance and alertness. Over days, sleep loss—any amount less than is required—will accrue into a cumulative sleep debt. The physiological need for sleep created by a deficit can only be reversed by sleep. An individual who has obtained required sleep will be better prepared to perform after long hours awake or altered work schedules than one who is operating with a sleep deficit.

1.1.2 Awake time off– Fatigue-related performance decrements are traditionally defined by declines in performance as a function of time spent on a given task. Breaks from continuous performance of a required task, such as monitoring, are important to maintain consistent and appropriate levels of performance. Therefore, awake time off is introduced here to describe time spent awake and free of duty. Thus both awake time off and sleep are needed to ensure optimum levels of performance.

1.1.3 Recovery– Recovery from an acute sleep deficit, cumulative sleep debt, prolonged performance requirement, or extended hours of continuous wakefulness is another important consideration. Operational requirements can engender each of these factors and it is important that a recovery period provide an opportunity to acquire recovery sleep and to re-establish normal levels of performance and alertness.

Required sleep and appropriate awake time off promote performance and alertness. These are especially critical when challenged with extended periods of wakefulness (i.e., duty) and circadian disruption (i.e., altered work/rest schedule). Recovery is important to reduce cumulative effects and to return an individual to usual levels of performance and alertness.

1.2 Frequent Recovery Periods are Important

More frequent recovery periods reduce cumulative fatigue more effectively than less frequent ones. For example, weekly recovery periods afford a higher likelihood of relieving acute fatigue than monthly recovery periods. Consequently, guidelines that ensure minimum days off per week are critical for minimizing cumulative fatigue effects over longer periods of time (e.g., month, year).

1.3 Time-of-day/Circadian Physiology Affects Sleep and Waking Performance

There is a clock in the human brain, as in other organisms, that regulates 24-hour patterns of body functions. This clock controls not only sleep and wakefulness alternating in parallel with the environmental light/dark cycle, but also the oscillatory nature of most physiological, psychological, and behavioral functions. The wide range of body functions controlled by the 24-hour clock includes body temperature, hormone secretion, digestion, physical and mental performance, mood, and many others. On a 24-hour basis, these functions fluctuate in a regular pattern with a high level at one time of day and a low level at another time. The circadian (*circa* = around, *dies* = day) pattern of wakefulness and sleep is programmed for wakefulness during the day and sleep at night. The circadian clock repeats this pattern on a daily basis. Certain hours of the 24-hour cycle, that is 0200 to 0600, are identified as a time when the body is programmed to sleep and during which performance is degraded. Time-of-day or circadian effects are important considerations in addressing 24-hour operational requirements because circadian rhythms do not adjust rapidly to change.

For example, an individual operating during the night is maintaining wakefulness in direct opposition to physiological programming to be asleep. Physiological, psychological, and behavioral functions are set by the circadian system to a low status that cannot be compensated by being awake and active. Conversely, the same individual sleeping during the day is in direct opposition to physiological programming to be awake. The circadian system provides a high level of functioning during day that counteracts the ability to sleep. Thus, circadian disruption can lead to acute sleep deficits, cumulative sleep loss, decreases in performance and alertness, and various health problems (e.g., gastrointestinal complaints). Therefore, circadian stability is another consideration in duty and rest scheduling.

1.4 Continuous Hours of Wakefulness/Duty Can Affect Alertness and Performance

Extended wakefulness and prolonged periods of continuous performance or vigilance on a task will engender sleepiness and fatigue. Across duty periods, these effects can accumulate further. One approach to minimize the accumulation of these effects is to limit the duty time (i.e., continuous hours of wakefulness during operations). Acute effects can be addressed through daily limitations while cumulative effects can be addressed by weekly limitations. There is more scientific data available to support guidelines for acute limitations than to determine specific cumulative limitations. Nevertheless, cumulative limitations (weekly and beyond) remain an important consideration for minimizing accumulation of fatigue effects.

1.5 Human Physiological Capabilities Extend to Flight Crews

Fatigue has its basis in physiological limits and performance deficits reflect these physiological limits. Flight crews' human physiology is not different from that of other humans. Therefore, it must be expected that the same fatigue-producing factors affecting performance and alertness in experimental subjects, physicians on-call, shift workers, military personnel, and others also affect flight crews. It follows that scientific findings relevant to human physiological capabilities and performance deficits from fatigue, sleep loss, and circadian physiology extend to flight crews.

1.6 Flight Crews are Made Up of Individuals

There are considerable individual differences in the magnitude of fatigue effects on performance, physiological alertness, and subjective reports of fatigue. These differences extend to the effects of sleep loss, night work, and considerations of required sleep and recovery time for an individual. Individual differences can vary as a function of age, sleep requirement, experience, overall health, and other factors. Individuals can also vary in their participation in off-duty activities that engender fatigue during a subsequent duty period (e.g., commuting across long distances immediately prior to starting a duty period).

1.7 Differences and Variability Preclude an Absolute Solution

It must be acknowledged that the aviation industry represents a diverse range of required work demands and operational environments. Sections 1.5 and 1.6 highlight the diverse situations and individuals that are encompassed by generalized guidelines. This further illustrates that guidelines and regulations cannot completely cover all personnel or operational conditions and that there is no single absolute solution to these issues.

2.0 SPECIFIC PRINCIPLES, GUIDELINES, AND RECOMMENDATIONS

The following are specific principles, guidelines, and recommendations to address the 24-hour duty and rest scheduling requirements of the aviation industry. These principles and guidelines, based on the General Principles introduced in section 1.0, are intended to provide a consistent margin of safety across aviation operations. Therefore, they are intended for application to minimum flight crew complements of two or more. Similarly, they are intended for consistent application across Part 121 and Part 135 operations. There is no scientific basis to differentiate between these operations. These specific principles and guidelines also apply across all flying duty of flight crew members required to perform Part 91 or military flight operations before or after scheduled commercial operations.

In order to provide specific guidelines, it is necessary to define the terms used in these guidelines. Altering these definitions may invalidate the principles that follow.

2.1 Off-Duty Period

2.1.1 Definition: "off-duty"– A continuous period of uninterrupted time during which a crew member is free of all duties.

2.1.2 Off-duty period (acute sleep and awake-time-off requirements)– The off-duty period should allow for three components. The first critical component of the off-duty period is an 8-hour sleep opportunity. The general principles clearly describe that an acute sleep deficit and a cumulative sleep debt can degrade performance and alertness. Also, it should be recognized that an appropriate "spin down" time may be required to fall asleep. The second component is awake time off, an opportunity to break from the continuous performance of required tasks. The third component is the other activities necessary during an off-duty period. These other necessary activities can include transportation to and from layover accommodations, hotel check in/out, meals, shower, and personal hygiene. Therefore, the off-duty period should be a minimum of 10 hours uninterrupted within any 24-hour period, to include an 8-hour sleep opportunity, awake time off, and time for other necessary activities. (In the case of extended flight duty period, see section 2.3.5.)

2.1.3 Off-duty period (recovery requirement)– The general principles outline the importance of recovery to minimize the cumulative effects of sleep loss and fatigue. Two consecutive nights of usual sleep is a minimum requirement to stabilize sleep patterns and return waking performance and alertness to usual levels. Two consecutive nights of recovery sleep can provide recovery from sleep loss. Therefore, the standard off-duty period for recovery should be a minimum of 36 continuous hours, to include two consecutive nights of recovery sleep, within a 7-day period.

2.1.4 Off-duty period (following standard flight duty periods during window of circadian low*)– Extensive scientific research, including aviation data, demonstrate that maintaining wakefulness during the window of circadian low is associated with higher levels of performance-impairing fatigue than during daytime wakefulness. Therefore, flight duty periods that occur during the window of circadian low have a higher potential for fatigue and increased requirement for recovery. It is recommended that if two or more flight duty periods within a 7-day period encroach on all or any portion of the window of circadian low, then the standard off-duty period (36 continuous hours within 7 days) be extended to 48 hours recovery.

2.2 Duty Periods

2.2.1 Definition: "duty"– Any task a crew member is required by the operator to perform, including flight time, administrative work, training, deadheading, and airport standby reserve.

2.2.2 Definition: "duty period"– A continuous period of time during which tasks are performed for the operator, determined from report time until free from all required tasks.

---

* For definition of "window of circadian low," see section 2.3.2

2.2.3 Duty period– To reduce vulnerability to performance-impairing fatigue from extended hours of continuous wakefulness and prolonged periods of continuous performance requirements, cumulative duty per 24 hours should be limited. It is recommended that this limit not exceed 14 hours within a 24-hour period. (In the case of additional flight crew, see section 2.3.6.)

2.3 Flight Duty Periods

2.3.1 Definition: "flight duty period"– The period of time that begins when a crew member is required to report for a duty period that includes one or more flights and ends at the block-in time of the final flight segment. At a minimum, this period includes required pre-flight activities and flight time.

2.3.2 Definition: "window of circadian low"– The window of circadian low is best estimated by the hours between 0200 and 0600 for individuals adapted to a usual day-wake/night-sleep schedule. This estimate of the window is calculated from scientific data on the circadian low of performance, alertness, subjective report (i.e., peak fatigue), and body temperature. For flight duty periods that cross 3 or fewer time zones, the window of circadian low is estimated to be 0200 to 0600 home-base/domicile time. For flight duty periods that cross 4 or more time zones, the window of circadian low is estimated to be 0200 to 0600 home-base/domicile time for the first 48 hours only. After a crew member remains more than 48 hours away from home-base/domicile, the window of circadian low is estimated to be 0200 to 0600 referred to local time at the point of departure.

2.3.3 Standard flight duty period– To reduce vulnerability to performance-impairing fatigue from extended hours of continuous wakefulness and prolonged periods of continuous performance requirements, cumulative flight duty per 24 hours should be limited. It is recommended that for standard operations, this cumulative flight duty period not exceed 10 hours within a 24-hour period. Standard operations include multiple flight segments and day or night flying.

2.3.4 Extended flight duty period– An extended cumulative flight duty period should be limited to 12 hours within a 24-hour period to be accompanied by additional restrictions and compensatory off-duty periods. This limit is based on scientific findings from a variety of sources, including data from aviation, that demonstrate a significantly increased vulnerability for performance-impairing fatigue after 12 hours. It is readily acknowledged that in current practice, flight duty periods extend to 14 hours in regular operations. However, the available scientific data support a guideline different from current operational practice. The data indicate that performance-impairing fatigue does increase beyond the 12-hour limit and could reduce the safety margin.

2.3.5 Extended flight duty period: restrictions and compensatory off-duty periods– If the cumulative flight duty period is extended to 12 hours then the following restrictions and compensatory off-duty periods should be applied.

A. *Cumulative effects: maximum cumulative hours of extension.* Over time, extended flight duty periods can result in cumulative effects of fatigue. To support operational flexibility and still minimize the potential for cumulative effects, it is recommended that extended flight duty periods can be scheduled for a cumulative total of 4 hours within a 7-day period. For example, there could be two 2-hour extensions of the standard 10-hour flight duty period (2 x 2 = 4 hr) or four 1-hour extensions (4 x 1 = 4 hr).

B. *Flight duty periods during window of circadian low.* As described in Section 2.1.4, the window of circadian low (as defined in Section 2.3.2) is associated with higher levels of performance-impairing fatigue. Therefore, it is recommended that in a 7-day period, there be no extended flight duty period that encroaches on any portion of the window of circadian low.

C. Restricted number of landings during window of circadian low. If an extended flight duty period contains a single continuous block-to-block flight period greater than 10 hours that encroaches on any portion of the window of circadian low, then it is recommended that flight crew members be restricted to no additional landings following the flight.

D. Recovery: compensatory off-duty period. To promote recovery from the acute fatigue associated with an extended flight duty period, additional off-duty time is recommended. The subsequent 10-hour required off-duty period should be extended by the time duration of the flight duty period extension. For example, an extended flight duty period of 11.5 hours would be accompanied by the subsequent off duty period being extended to 11.5 hours.

2.3.6 Extended flight duty period: additional flight crew– Additional flight crew afford the opportunity for each flight crew member to reduce the time at the controls and provide for sleep during a flight duty period. Consequently, with additional flight crew and an opportunity for sleep, it would be expected that fatigue would accumulate more slowly. In such circumstances, flight duty periods can be increased beyond the recommended limit of 12 hours within each 24-hour period. For each additional flight crew member who rotates into the flight deck positions, the flight duty period can be extended by 4 hours as long as the following requirements are met: 1) each flight crew member be provided one or more on-duty sleep opportunities; and 2) when the extended flight duty period is 14 hours or longer, adequate sleep facilities (supine position) are provided that are separated and screened from the flight deck and passengers. Controlled rest on the flight deck is not a substitute for the sleep opportunities or facilities required for additional flight crew members.

If an extended flight duty period is increased according to the above requirements, the maximum flight duty period limit supersedes the 14-hour duty period limit (section 2.2).

2.3.7 Flight duty period (cumulative)– A 24-hour cumulative flight duty period limit, a minimum off-duty period per 24 hours, and a specified off-duty recovery period per 7 days focus specifically on short-term vulnerabilities and considerations. To minimize fatigue that is not compensated by short-term recovery and to reduce excessive accumulation across longer periods of time, cumulative flight duty period limitations are recommended. There is not sufficient scientific data to provide specific guidance in this area. However, the general principles apply. For example, when determining cumulative flight duty limitations, shorter time frames should be considered. Therefore, in addition to 30-day and yearly cumulative flight duty period limitations, a 2-week limit should also be set. Also, these cumulative flight duty period limitations should be adjusted downward across the longer time period. Rather than just multiplying the 2-week cumulative flight duty period limitation to calculate the 30-day and yearly amounts, the 30-day amount should be decreased a percentage from the 2-week amount. The yearly cumulative flight duty period limitation should be decreased a percentage from the 30-day amount. This will further reduce the potential for long-term accumulation of fatigue factors.

2.4 Exceptions Due to Unforeseen Operational Circumstances

Exceptions allow the flexibility needed to respond to unforeseen circumstances beyond the control of the operator that occur during operations. They are not intended for use in regular practice. These exceptions must not be scheduled.

2.4.1 Reduced off-duty period (exception)– To support operational flexibility, it is recognized that due to circumstances beyond the control of the operator, it may be necessary to reduce an off-duty period to 9 hours. This reduction would occur only in response to an unforeseen operational requirement. In this situation, the subsequent off-duty period should be extended to 11 hours.

2.4.2 Extended flight duty period (exception)– To support operational flexibility, an extended flight duty period can be increased by up to a maximum of 2 hours due to unforeseen circumstances beyond the control of the operator. The subsequent required off-duty period should be increased by the time by which the flight duty period is increased.

2.5 Time Differences

In general, the longer a flight crew member is away from the home-base/domicile time zone, the more recovery time is needed for readjustment back to home-base/domicile time. Therefore, it is recommended that for flight duty periods that cross 4 or more time zones, and that involve 48 hours or more away from the home-base/domicile time zone, a minimum of 48 hours off-duty be allowed upon return to home base/domicile time.

2.6 Reserve Status

Flight crew members on reserve status provide a critical element to operational flexibility and the opportunity to meet unanticipated needs. It is important that flight crew members on reserve status obtain required sleep prior to a flight duty period.

2.6.1 Definition: "airport standby reserve"– A reserve flight crew member required to be available (on standby) at an airport for assignment to a flight duty period.

An airport standby reserve flight crew member should be considered on duty and the previous duty period guidelines apply.

2.6.2 Definition: "on-call reserve"– A reserve flight crew member required to be available to an operator (away from the airport) for assignment to a flight duty period.

On-call reserve status should not be considered duty. However, it is important that the flight crew member has an opportunity to obtain sleep prior to an assigned flight duty period. Two specific principles should be applied. The flight crew member should be provided a: 1) predictable and 2) protected 8-hour sleep opportunity. "Predictable" indicates that the flight crew member should have prior information (24 hours notice is recommended) as to when the 8-hour sleep opportunity can be obtained within the 24-hour on-call reserve time. The 8-hour sleep opportunity should not vary by more than 3 hours on subsequent days to ensure circadian stability. "A protected 8-hour sleep opportunity" should be protected from interruption by assignment to a flight duty period. Any approach that meets the requirements of these two principles could be utilized.

2.7 Summary Overview: Guidelines and Recommendations

Figure 1 provides a summary overview of the guidelines and recommendations discussed in this document.

		Off-Duty Period			Duty Period		Flight Duty Period		
		Per 24-hr period	Per week	Other	Per 24-hr period	Weekly, Monthly, Annually	Per 24-hr period	Per week	Monthly, Annually
Scheduled	Standard	1) 10 hrs. 2) 10+ hrs (following extended flight duty period).	1) At least 36 continuous hours, to include 2 consecutive nights of recovery sleep, in a 7-day period. 2) 48 continuous hours in a 7-day period (following flight duty period in circadian low).	48 continuous hours upon return home following flight duty period across multiple time zones.	14 hrs.	There is not sufficient scientific data to provide specific guidance in this area.	10 hrs.		There is not sufficient scientific data to provide specific guidance in this area; however, cumulative flight duty period limitations should be adjusted downward over increasing time frames.
	Extended						12 hrs (requires restricted landings, maximum cumulative hours, compensatory off-duty time). For each additional flight crew member, flight duty time can be increased by 4 hrs (requires sleep opportunity for each crew member, and for FDPs > 14 hrs, a bunk facility).	Maximum of 4 cumulative hours of extension.	
Unscheduled	Exceptions Due to Unforseen Circumstances	9 hrs (subsequent off-duty period increased to 11 hrs).					Extended FDP can be increased by up to 2 hrs (subsequent off-duty period increased by an equal amount).		

Figure 1. Summary overview of guidelines and recommendations.

3.0 OTHER INDUSTRY STRATEGIES

A general principle previously stated is that addressing issues of fatigue, sleep loss, and circadian disruption in the aviation industry is a shared responsibility. These principles and guidelines for duty and rest scheduling are intended to provide scientific input to the regulatory process that addresses these issues in aviation. However, there is no single solution to the challenges posed by the 24-hour demands of the aviation industry. To highlight this shared responsibility, several other industry strategies for addressing these issues will be described. These are intended to complement the recommendations listed above.

3.1 Education and Training

An important first step for the industry is to become informed about the extensive knowledge now available regarding fatigue, sleep, and circadian physiology as it relates to performance and aviation operations. This knowledge can then be incorporated into daily operations. The information can be useful in providing specific recommendations for personal strategies to manage performance and alertness in flight operations. Education and training modules to meet this need are available and currently implemented successfully within the industry.

3.2 Scheduling Practices

The scientific information available can be particularly useful in guiding rational and physiologically-based scheduling practices. Scheduling is a complex and multi-determined process. However, it is possible and essential to include scientific data on human physiology as a factor for consideration. Obviously, priorities need to be established, and cost/benefit considerations are critical. There are examples of successful integration of scientific information on fatigue into schedule construction.

3.3 Controlled Rest on the Flight Deck

Scientific data obtained during flight operations have clearly demonstrated the effectiveness of a planned cockpit rest period to promote performance and alertness in nonaugmented long-haul flight operations. Controlled rest is a single operational strategy and is not an answer to all fatigue engendered by flight operations. It is absolutely not intended as a substitute for additional flight crew, appropriate rest facilities, or as support for extended duty. All possible strategies that maintain or improve the safety margin should be considered.

3.4 Operational Countermeasures

A variety of other strategies for use during flight operations should be examined and utilized where appropriate. This includes the design and use of technology to promote performance and alertness during operations. Varying work demands or other creative uses of flight deck automation could be developed to maintain alertness and performance. Several activities in this area are underway with some successful applications currently in use.

3.5 Future Developments

There are a number of other possibilities that are in different stages of development. Provocative laboratory studies of several countermeasures are often cited. However, validation of their effectiveness and safety in operational settings is still needed prior to widespread implementation. Research continues and may provide further findings on countermeasures relevant to regulatory, scheduling, personal strategies, and technology approaches to manage alertness in aviation operations.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
May 1996

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Principles and Guidelines for Duty and Rest Scheduling in Commercial Aviation

5. FUNDING NUMBERS
505-64-53

6. AUTHOR(S)
David F. Dinges, R. Curtis Graeber, Mark R. Rosekind, Alexander Samel, and Hans M. Wegmann

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Ames Research Center
Moffett Field, CA 94035-1000

8. PERFORMING ORGANIZATION REPORT NUMBER
A-961924

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-110404

11. SUPPLEMENTARY NOTES
Point of Contact: Mark R. Rosekind, Ames Research Center, MS 262-4, Moffett Field, CA 94035-1000; (415) 604-3921

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified — Unlimited
Subject Category 51

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The aviation industry requires 24-hour activities to meet operational demands. Growth in global long-haul, regional, overnight cargo, and short-haul domestic operations will continue to increase these round-the-clock requirements. Flight crews must be available to support 24-hour-a-day operations to meet these industry demands. Both domestic and international aviation also can require crossing multiple time zones. Therefore, shift work, night work, irregular work schedules, unpredictable work schedules, and time zone changes will continue to be commonplace components of the aviation industry. These factors pose known challenges to human physiology, and because they result in performance-impairing fatigue, they pose a risk to safety. It is critical to acknowledge and, whenever possible, incorporate scientific information on fatigue, human sleep, and circadian physiology into 24-hour aviation operations. Utilization of such scientific information can help promote crew performance and alertness during flight operations and thereby maintain and improve the safety margin.

The primary objective of this document is to provide empirically derived principles and guidelines for duty and rest scheduling in commercial aviation. In the first section, scientifically-based principles related to operational issues posed by the aviation industry are outlined. In the second section, the principles are applied to guidelines for duty and rest scheduling in commercial aviation, with specifics provided where appropriate and available. In the third section, a brief overview of other potential industry strategies to address these issues is provided.

14. SUBJECT TERMS
Fatigue, Circadian rhythms, Duty and Rest, Scheduling

15. NUMBER OF PAGES
15

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18

APPENDIX B

An Overview of the Scientific Literature Concerning Fatigue, Sleep, and the Circadian Cycle

Prepared for the Office of the Chief Scientific
and Technical Advisor for Human Factors
Federal Aviation Administration

By

Battelle Memorial Institute
JIL Information Systems

January 1998

An Overview of the Scientific Literature Concerning Fatigue, Sleep, and the Circadian Cycle

Introduction

This document provides a brief review of the scientific research relating to issues of pilot fatigue arising from crew scheduling practices. A massive amount of research has been conducted on such issues as the environmental conditions that contribute to the occurrence of fatigue, acute and chronic sleep debt and their effects on performance, and the influence of the circadian cycle on alertness. This paper attempts to identify major trends in this literature that might be of value in addressing scheduling regulatory issues.

The paper is organized into seven sections. The first section, "What is Fatigue," attempts to provide a functional definition of fatigue that serves to define the scope of issues that need to be considered, including variables that contribute to the occurrence of fatigue and methodologies for assessing the impact of fatigue on human functioning.

Section two, "Indications and Effects of Fatigue," briefly reviews the human performance and physiological indicators of fatigue. The intent is to identify possible decrements in performance that could have a safety impact. This section also briefly addresses the complexities involved in measuring fatigue levels. As this section explains, fatigue is a complex concept that does not always produce expected measurable decrements in performance.

Section three, "Fatigue and the Aviation Environment," addresses the issue of fatigue within the aviation environment. Before changes are made to existing regulations, the question of whether there is a problem that needs to be resolved should be addressed. Available research on the extent of fatigue within the aviation environment is reviewed. In addition, factors that complicate the assessment of the extent of the fatigue problem in an operational environment are also described.

A pilot's level of alertness at any time depends upon a complex interaction between a number of variables. Four variables, in particular, need to be considered: time on task, time since awake, any existing sleep debt, and the pilot's own circadian cycle. Section four, "Standard Duty Period," describes the research trends pertaining to time on task and time since awake while section five, "Standard Sleep Requirements," addresses acute and chronic sleep debt, including recommendations for sleep debt recovery. Section six, "The Circadian Cycle and Fatigue," which looks at the research on circadian cycles and their implications for back-of-the-clock and transmeridian flying. Finally, section seven, "Augmented Crews," looks at the limited data on the use of augmented crews to extend duty periods.

What Is Fatigue

The objective of the regulations proposed in the NPRM is to identify scheduling constraints that will minimize the impact of pilot fatigue that arises from duty time and sleep debt due to crew schedules. The term, "fatigue," has yet to be defined in a concrete fashion (Maher & McPhee, 1994); Mendelson, Richardson & Roth, 1996). Fatigue, as addressed in the human performance literature, refers to "deterioration in human performance, arising as a consequence of several potential factors, including sleepiness" (p. 2). Sleepiness, in contrast, has a more precise definition: "Sleepiness, according to an emerging consensus among sleep researchers and clinicians, is a basic physiological state (like) hunger or thirst. Deprivation or restriction of sleep increases sleepiness and as hunger or thirst is reversible by eating or drinking, respectively, sleep reverses sleepiness" (Roth et al., 1989, cited by Mendelson, Richardson & Roth, 1996, p. 2).

In keeping with current thinking on the concept of fatigue, Maher and McPhee's approach is used here:

> "Fatigue" must continue to have the status of a hypothetical construct, an entity whose existence and dimensions are inferred from antecedent and consequent events or variables" (p. 3-4).

This means that fatigue is treated as a concept that occurs in response to predefined conditions and has physiological and performance consequences. The antecedent conditions of interest here include:

- Time on task, including flight time and duty period duration
- Time since awake when beginning the duty period
- Acute and chronic sleep debt
- Circadian disruption, multiple time zones, and shift work

The objectives of this document are to review the scientific research in order to:

- Identify the impact of these antecedent variables on human performance
- Relate these variables to appropriate physiological measures that have been demonstrated to be accompanied by decrements in human performance

Identify, to the extent possible, limitations and requirements concerning duty period durations, minimum sleep requirements, etc. that should be reflected in the regulations.

Indications and Effects of Fatigue

The massive literature on fatigue has identified a number of symptoms that indicate the presence of fatigue, including: increased anxiety, decreased short term memory, slowed reaction time, decreased work efficiency, reduced motivational drive, decreased vigilance, increased variability in work performance, increased errors of omission which increase to commission when time pressure is added to the task, and increased lapse with increasing fatigue in both number and duration (Mohler, 1966; Dinges, 1995). Many of these symptoms appear only after substantial levels of sleep deprivation have been imposed. A review of the literature that involved fatigue levels likely to be experienced by pilots suggests that a common fatigue symptom is a change in the level of acceptable risk an individual will tolerate.

Brown et al. (1970) had subjects drove for four 3-hour sessions. The performance measure used was a count of the number of occasions in which the subject executed what the experimenter considered a risky passing maneuver. When driving performance between the 1st and 4th sessions were compared, a 50% increase in the occurrence of risky passing maneuvers in later sessions, when subjects were presumably more fatigued, was obtained.

This change in the level of acceptable risk was confirmed by Barth et al. (1976) and Shingledecker and Holding (1974) who found that fatigue caused subjects to engage in greater risk taking activity in an effort to avoid additional effort. In the Shingledecker and Holding study, subjects performed 36 choice-of-probability (COPE) tasks, which involved locating a fault in one of three removable banks of one-watt resistors, each with varying degrees of probability that the bank had failed. Twenty-eight days separated the first and last three sets of six trial blocks. In this interim, the experimental group received 24 to 32 hours of continuous work on different monitoring-type fatiguing tasks immediately preceding the second trial block set, while the control group did not. The experimental group was found to shift their selections toward riskier, but less effortful strategies, and made more errors when compared with their own non-fatigued results or control group results. Also, subjects who reported they were tired, although not exposed to intentionally fatiguing activities, behaved similarly. Barth et al. performed a similar experiment, except that fatigue was induced by either a variable pitch/speed bicycle ergometer or a treadmill.

In the aviation domain, this strategy of avoiding effort when fatigued has recently been reported. Neri et al. (1992) found a change in strategy toward risk taking in naval pilots during carrier landings. Risk taking behavior also appears in the form of over reliance on automated systems (Graeber, 1988). This increased passivity, which takes the form of a mental aversion to or avoidance of further effort, is common in both the sleep deprived state and when the individual is experiencing the diurnal low point for body temperature during the circadian trough (Hamilton et al., 1972).

A report of some of the occurrences moments before the crash of the aircraft carrying Commerce

Secretary Ron Brown further illustrates the type of inaction typical of fatigue (Newman, 1996). Although the pilots detected an error on approach a full minute before the crash, they made no attempt to correct the error—a common characteristic of fatigue. This is due to a reduced level of adherence to one's normal standard and a reduced ability to cognitively make a connection between cause and effect. One may recognize a problem but not translate its effect due to lack of full comprehension of the situation or simple failure to initiate an action.

Related evidence exists that fatigued workers are satisfied with lower performance and that perceived errors go uncorrected. There is a "loss in the ability of the worker to perceive and adjust to new aspects of the task. The worker seems unable to shift quickly and effectively from one subpart to another" (Broadbent, 1953; cf. Horne, 1988). The latter quality has been found to be a factor when aircraft crews are concentrating on one problem and allow other problems to develop due to neglect.

In the case of the 1985 China Airlines Flight 006 mishap, the pilot became focused on the loss of power in one engine, neglecting other flight duty tasks. Major structural damage and 2 serious injuries occurred when the aircraft experienced more than 5 g's during its uncontrolled descent from 31,000 feet to 9,500 feet, before control was regained (Lauber & Kayten, 1988). Contributing fatigue factors to the accident were the Captain's failure to properly monitor the airplane's flight instruments, over-reliance on the autopilot after the loss of thrust due to engine failure, and performance of duties during the Captain's circadian trough. The accident occurred 4 to 5 hours after the time he had been beginning sleep during the 6 nights preceding the accident.

In the Guantanamo Naval Base accident, the pilot was so focused on finding a strobe light that he failed to respond to other crew members' warnings that they were approaching a stall speed (NTSB Aircraft Accident Report, 1993). In an investigation of Air Force C-5 mishaps or near mishaps, it was reported that 55 percent were related to attentional focus problems and 24 percent to decision making problems (Majors, 1984).

Some symptoms of fatigue are similar to other physiological conditions. For example, with fatigue one's ability to attend to auxiliary tasks becomes more narrow, very much analogous to the effects of alcohol (Huntley et al., 1973; Moskowitz, 1973), hypoxia (McFarland 1953), and heat stress (Bursill, 1958). Dawson and Reid (1997) evaluated performance after 17 hours awake and found performance degraded to a level equal to that caused by a blood alcohol concentration (BAC) of 0.05 percent. At 24 hours, performance decrements were equivalent to that of a 0.10 BAC. After ten hours of sleeplessness, the decline in performance averaged .74 percent per hour.

Finally, Harrison and Horne (1979) found that sleep loss resulted in a difficulty of generating the ideal word or phrase for the idea or thought the person wanted to convey. In addition, there was a loss in intonation and an overall dullness which suggested loss of interest. The authors suggest that this may very well result in personal communication problems in real life situations.

Effects of Fatigue and Sleep Loss on the Brain

Sleep is mainly a restorative process for brain function. Horne (1991) states that this restoration is primarily a function centered on the cerebral cortex of the brain. This is consistent with the findings of Perelli (1980), who found that a high time since awake significantly increased the threshold for information processing. Ptemitis (1981) found that dominant EEG frequencies in power plant operator shift workers showed a progressive decline, with each shift beginning in the morning and continuing to night shift. Morning shift employees showed EEG readings of 12-30 Hz, evening shift workers 6-12 Hz, and those on duty during the night shift, 2-6 Hz. Gevens et al. (1997) has shown that observable performance decrements are preceded by observable EEG brain wave changes that clearly indicate decreasing attentional focus. These EEG changes are observable some time before noticeable performance decrements occur. Howitt et al. (1978) measured EEG activity in operational pilots and found that under high workload situations the fatigued pilots' EEG rose to only half the level of those displayed by fresh pilots.

Another physiological measure of fatigue and sleep is brain glucose levels. All tissue of the body, whether it be heart muscle, kidneys, lungs, or the brain, works electrochemically, and conforms to one principle: the more work done, the more fuel used. Thus, by measuring glucose utilization, oxygen consumption, and blood flow in the brain, areas which are very active during various tasks can be determined.

Thomas et al. (1993), using positron emission topography (PET) scan has provided strong physiological evidence that sleep loss is accompanied by a decrease in brain glucose metabolism. The areas most involved were the prefrontal cortex, the inferior parietal cortex, and thalamus. During 48 hours sleep deprivation, the overall brain glucose utilization declined 7 percent, while in the areas of higher order thinking declines ranged from 10 to 17 percent (Thomas, 1997). Although these reductions seem relatively minor over a 48 hour period, Gold (1995) recently found that comparatively small blood glucose changes could significantly enhance cognitive performance in a variety of subjects including healthy young adults, elderly, and severe states of pathology such as Alzheimer's and Downs Syndrome patients.

PET scans of recovery sleep, taken sequentially through the night and synchronized with EEG changes, show that slow wave sleep appears to have its greatest effects on the same brain areas that Thomas et al (1993, 1997) showed were most affected by sleep loss (Braun et al., 1997). This indicates that areas of the brain involved in alertness, attentional focus, concentration, short term memory, drive and initiative, problem solving, complex reasoning, and decision making are the greatest beneficiaries of deep sleep (Lamberg, 1996).

Since the front brain is responsible for analysis of information, judgment, planning, decision making, and the initiation of actions, it is not surprising that NTSB found decision making abilities suffered with high time since awake.

> The orderly planning and sequencing of complex behaviors. the ability to attend to several components simultaneously, and then flexibly alter the focus of concentration. the capacity for grasping the context and gist of a complex situation, resistance to distraction and interference, the ability to follow multi-step instructions, the inhibition of immediate but inappropriate response tendencies, and the ability to sustain behavioral output... may each become markedly disrupted (Restak, 1988).

Many of the functions described by Restak are the same functions necessary to a pilot's ability to competently fly an aircraft.

Measuring Fatigue

Although the studies just listed do show performance decrements due to fatigue, other studies have shown no effect (e.g., Rosenthal, 1993), particularly when sleep loss levels up to 24 hours, or small chronic partial sleep loss levels of only one or two hours per day are used. The lack of definitive results in partial sleep deprivation studies may be due to differences in testing procedures. Rosenthal tested on four separate occasions, whereas others tested only once per day. In a more severe sleep deprivation study, Thorne (1983) made the testing instrument the primary task, which lasted 30 minutes of each hour. As sleep loss became increasingly greater, subjects became slower. Therefore, the time to complete the self-paced task increased about 70 percent, and at times doubled.

Evans et al. (1991), in a review of fatigue in combat, clearly stated that studies using embedded testing, such as Thorne (1983), Angus and Heslegrave (1985), and Mullaney et al. (1981), consistently show greater effects of fatigue and sleep loss performance decrements than short duration isolated intrusive tests. Belenky et al. (1986) notes that continuous embedded testing reveals larger performance decrements sooner than does intermittent testing. In Angus and Heslegrave (1985), analysis of results found a 28% decrement in encoding/decoding performance and a 43% decrement in logical reasoning after 24 hours awake. Haslam (1982), using non-embedded testing, found no decrements and 29%, respectively.

The greater sensitivity of embedded testing is not surprising given that they measure performance for a more prolonged period. Brief, intrusive psychometric tests, in contrast, are novel and act as a rest break, distraction, and temporary stimulus, thereby increasing short term mobilization of effort thus boosting performance. The use of such an instrument would function similar to the effect Chambers (1961) found in an industrial output study where output remains higher when a worker was switched to different jobs periodically than to stay at one job.

Another explanation for the varying effects of performance due to fatigue is that performance is.

in part, dependent upon the circadian physiology of the subject. Subjects experiencing circadian dysrhythmia or operating during their circadian trough are more likely to yield substandard performance.

Also, motivation can play a major role in the relationship between fatigue and performance. "Both experimenter and subject motivation can have a large impact on results, particularly in the behavioral and subjective domains. Motivation effects are frequently most apparent near the end of studies (where performance improvement is sometimes found) but also may account for the difficulty in showing decrements early in periods of sleep loss" (Bonnet, 1994, p. 50).

In addition to embedded testing, other parameters considered to increase sensitivity in testing for fatigue and sleep loss performance decrements include continuous performance, prolonged vigilance, and multiple task jobs, similar to what is shown to work in decrement due to noise (Belenky 1986; Dejoy, 1984). Self-paced tasks have been reported to be less affected by sleep loss than tasks that are faster work-paced (Johnson & Naitoh, 1974). Fatigue effects tend to be minimal when tasks are self-paced, brief, highly motivating, and feedback is given. On the other hand, tasks which involve sustained vigilance and attention, the use of newly acquired skills, and new information retention tend to challenge short term memory. This is because work-paced tasks accelerate the rate of information processing, thereby decreasing the reserve capacity of brain function.

Roth et al. (1994) support long monotonous objective testing and the MSLT as good measures of sleep loss decrement and sleepiness, respectively. McFarland (1953) considered the deterioration of skills over time a promising framework for the study of fatigue. This has recently been attempted in aviation ~~research by~~ Neville et al. (1992) through the use of flight data recorders for measuring parameters of flight over time. This procedure may be the best avenue yet for truly measuring performance decrements in an operational setting.

Microsleeps

Performance measures have obvious value for assessing the effects of fatigue and sleep-related variables. Microsleeps are another useful approach. Microsleeps were first recognized by Bills (1931) and were first called "blocks." Over the intervening years they have also been called "gaps," "lapses" and, more recently, "microsleeps." The physiological drive to sleep can result in a microsleep lasting a few seconds to a few minutes. The latter terminology is the result of EEG recording showing that during these lapses in information processing, subjects momentarily slip into a light sleep. This occurs with the eyes open and usually without the knowledge of the individual, an observation first reported by Miles (1929). Bonnet and Moore (1982) found that before 50 percent of normal subjects became consciously aware of falling asleep, they had been asleep two to four minutes. These intermittent lapses in consciousness impair performance by leading to errors of omission due to missed information. In serial tasks that are work paced, microsleeps can also lead to error of commission and, if frequent enough or long enough, can lead to loss of situational awareness.

Microsleeps have been shown to be a useful approach to assessing the effects of time of day on sleepiness levels. EEG brain wave changes confirm that pilots experience greater sleepiness and decreased alertness between 2:00 to 4:00 a.m. (Gundel, 1995). Alpha waves in EEGs indicate micro events or micro sleeps and have been found to be three times greater during night than during day flights (Samel, 1995). Samel et al. (1997) found that during outbound flights, pilots experienced 273 microsleeps or an average of 1.38 microsleeps per pilot per hour. On return flights the following night, pilots experienced 544 microsleeps or 2.47 microsleeps per hour per pilot. Both feelings of fatigue and the occurrence of microsleeps increased as duty time progressed. Rosekind et al. (1994) also observed micro sleep in pilots and a progressive increase as flights progressed, particularly in the latter portion of the flight. These findings confirm both the physiological occurrence of microsleeps in commercial aviation pilots, and the accumulative nature of fatigue in successive night operations.

The beneficial effects of taking breaks have also been demonstrated by measuring microsleeps. Workers performing continuous tasks without breaks (Bills, 1931; Broadbent, 1958) or suffering from sleep loss began to demonstrate signs of micro sleeps much sooner than those with rest breaks or getting adequate rest, respectively (Kjellberg, 1977b).

The research cited in this section suggests that fatigue may be a factor in the aviation environment due to direct performance decrements and, indirectly, through microsleeps that disrupt pilot functioning. The next section looks at data relating to the occurrence of fatigue in the aviation environment.

Fatigue and The Aviation Environment

The unique characteristics of the aviation environment may make pilots particularly susceptible to fatigue. Environmental factors such as movement restriction, poor air flow, low light levels, background noise, and vibration are known causes of fatigue (Mohler, 1966). In addition, the introduction of advanced automation into the cockpit has changed the nature of the job for many pilots. Hands-on flying has been replaced by greater demands on the crew to perform vigilant monitoring of these systems, a task which people tend to find tiring if performed for long periods of time. For example, Colquhoun (1976) found that monotonous vigilance tasks could decrease alertness by 80 percent in one hour, which is correlated with increased EEG theta activity or sleep-like state. Since physical activity and interest in the task can help to minimize the decline in performance due to continuous work and sleep loss (Wilkinson, 1965; Lille, 1979), automation may contribute to increased drowsiness in pilots suffering from fatigue or sleep loss. Also, as will be shown below, these cognitive-based activities may be susceptible to the effects of fatigue.

Although these environmental characteristics are suggestive, the actual extent to which fatigue is a safety issue needs to be assessed. A study of ASRS incident reports suggested that 21% of incidents were fatigue-related. This figure was challenged by Baker (1996), who pointed out that the database is a biased system due to self reporting, and the data were further biased by the researchers' interpretation of the reports. Kirsch (1996) argues that the actual ASRS estimate is four to seven percent. Graeber (1985) clarifies the situation as follows:

> An initial analysis of NASA's Aviation Safety Reporting System (ASRS) in 1980 revealed that 3.8 percent (77) of the 2006 air transport crew member error reports received since 1976 were directly associated with fatigue (Lyman & Orlady, 1980). This may seem like a rather small proportion, but as the authors emphasize, fatigue is frequently a personal experience. Thus, while one crew member may attribute an error to fatigue, another may attribute it to a more directly perceived cause such as inattention or a miscommunication. When all reports which mentioned factors directly or indirectly related to fatigue are included, the percentage increases to 21.1 percent (426). These incidents tended to occur more often between 00:00 and 06:00 [local time] and during the descent, approach or landing phases of flight. Furthermore, a large majority of the reports could be classified as substantive, potentially unsafe errors and not just minor errors.

In a study of flightcrew-involved major accidents of domestic air carriers during the 1970 through 1990 period (NTSB, 1994), one conclusion pertained directly to the issue of fatigue: "Half the captains for whom data were available had been awake for more than 12 hours prior to their accidents. Half the first officers had been awake more than 11 hours. Crews comprising captains and first officers whose time since awakening was above the median for their crew position made more errors overall, and significantly more procedural and tactical decision errors" (p. 75). This finding suggests that fatigue may be an important factor in the carrier accidents. Because the study involved only domestic carrier accidents, it remains unclear as to whether other fatigue-related factors, such as long flight times and circadian disruption due to multiple time zones would also appear as causative factors. On the basis of this study, the NTSB recommended that the FAA address the issues of flight duty times and rest periods.

Although the results of this study are suggestive, the actual impact of fatigue has yet to be determined. Since no real effort has been made to identify the effects of fatigue in accident and incidence investigation, it is difficult to assess the magnitude of the problem. In addition, it is possible that self-reporting systems, such as ASRS, may be affected by the inability of people to accurately assess their own fatigue levels (Sasaki et al., 1986; Richardson et al., 1982; Dinges, 1989). Subjective evaluations of sleepiness have not been found to be reliable except in extreme sleepiness. Rosekind and Schwartz (1988) noted that the scientific literature generally demonstrates a discrepancy between subjective reports and psychophysiological measures, the result being underestimations of one's level of sleepiness (cf. Dement & Carskadon, 1981). Dement et al. (1978) and Roth et al. (1994) reported that some subjects judged themselves alert, when in fact they were in the process of falling sleep.

Graeber et al. (1986), summarizing the collaborative efforts between European, Japanese, and American investigators to evaluate sleep in long haul aircrews, reported that subjective evaluations are sometimes erroneous as to the true nature of the psychophysiological state of sleepiness. These results were obtained in two separate studies by Dement et al. (1986) and Sasaki et al. (1986). Mullaney et al. (1985) also found that subjects subjectively felt that they performed better under sleep loss conditions when paired with another subject, when in reality it had no effect on actual performance decrements. Rosekind et al. (1994) found pilots unable to subjectively evaluate changes in performance due to a short inflight nap. Although pilots did show physiological improvements in alertness, they could not subjectively notice a difference. Belenky et al. (1994) points out that due to the psychophysiology changes in higher order cognitive judgment areas with fatigue and sleep loss, these changes automatically preempt ones ability to evaluate his or her own performance accurately.

One possible reason for these findings is that the presence of certain factors masks sleepiness and the absence of other factors unmasks sleepiness. Environmental factors that have a masking affect include noise, physical activity, caffeine, nicotine, thirst, hunger, excitement, talking about something interesting, etc. For example, Howitt et al. (1978) found that sleep deprived pilots in operational settings felt no noticeable fatigue once flight preparations were under way and flight commenced. This explanation is supported by research that used the multiple sleep latency test (Dement et al., 1986, Sasaki et al., 1986; Rosekind et al., 1994; Roth et al., 1994). In contrast to the subjective evaluation, the multiple sleep latency test asks subjects to quietly lie down, close their eyes and try to sleep. This in essence removes many of the masking factors, whereas subjective alertness in relation to EEG recording appears to have better correlation because both can be recorded in the same environmental setting. Ogilvie et al. (1989) reported that subjective sleepiness responses to the Sanford Sleepiness Scale only reached significance when subjects were entering stage I sleep. Thus it may be that when EEG alpha and theta activity appears there is truly a feeling of sleepiness.

Although masking reduces perceived feelings of sleepiness, it does not counteract the effects of fatigue on performance. Kecklund and Akerstedt (1993) conclude that although sleep-deprived subjects may not feel their sleepiness or fatigue due to environmental variables, the sleep pressure is still latently present.

Standard Duty Period

The first regulatory issue that needs to be addressed concerns the duration of the standard duty period. "Standard" is used here to refer to duty periods that do not involve window of circadian low (WOCL) effects or time zone changes. The primary focus of the standard duty period issue addresses the buildup of fatigue as a function of performing the various tasks involved in a duty period Six factors that may need to be considered are

- Time on task
- Time since awake
- Task type
- Duty period extension
- Cumulative duty times
- Environmental factors.

Each of these factors is discussed below.

Time-On-Task

There appears to be some consensus that the effects of time-on-task on performance are difficult to assess (e.g., Maher & McPhee, 1994) and are affected by a number of variables, including time of day, the nature of the task, the subject's motivational level, and if fatigue or sleep loss are already present (Dinges & Kribbs, 1991; Maher & McPhee, 1994; Mendelson, Richardson & Roth, 1996). In spite of this, performance on many laboratory tasks follows a similar curve (Vries-Griever & Meijman, 1987): relatively low starting performance, followed by optimal performance, which then declines due, presumably, to fatigue. The points at which optimal performance begins and then starts to degrade varies with the task. For some cognitive tasks, optimal performance is achieved after about five hours, then declines to its lowest levels after 12 to 16 hours on task (Spencer, 1987; Nicholson, 1987). Some tasks, such as monitoring tasks that require high levels of vigilance, show performance decrements after shorter durations. Colquhoun (1976) found that monotonous vigilance tasks could decrease alertness by 80 percent in one hour based on increased EEG theta activity which correlates with a sleep-like state. Reductions in task performance over time are also accompanied by an increased need to sleep, as shown by Lisper et al (1986), who found that car drivers showed an increased likelihood of falling asleep after 9 hours of driving

Time-on-task measures for a single task may have limited applicability to the aviation domain as the pilot's job involves performing a number of tasks during a given duty period. Switching between individual tasks may override some of the effects of fatigue due to time-on-task. Studies which have investigated the effects of extended shift durations on worker performance may be relevant as they assess fatigue and performance as a function of the set of tasks that are performed during a shift rather than performance decrements that accrue on a single task. In a manufacturing environment (Rosa & Bonnet, 1993), the number of errors made was relatively high at the beginning of the shift, then decreased because of re-familiarization with the task. Optimal levels were reached within a few hours, then declined over the eight-hour shift. In general, workers on 12-hour shifts became considerably more fatigued than in more traditional eight- to 10-hour shifts (Rosa & Colligan, 1987) This finding has been confirmed in nurses (Mills et al., 1983), industrial shift workers (Colligan & Tepas, 1986), night shift workers (Rosa & Colligan, 1987), sea watch workers (Colquhoun, 1985), and truck drivers (Hamelin, 1987). The latter study also found an increase in the number of accidents that occur when 12-hour shifts are used.

This increased likelihood of accident risk due to long duty periods has been found in other studies. The relative risk of an accident at 14 hours of duty rises to 2.5 times that of the lowest point in the first eight hours of duty. Askertedt (1995) reports accident risks to be threefold at 16 hours of duty, while Harris and Mackie (1972) found a threefold risk in just over 10 hours of driving. These levels of risk are similar to that associated with having narcolepsy or sleep apnea (Lavie et al., 1982), or a blood alcohol level of 0.10 percent. Wegmann et al. (1985), in a study of air carrier pilots, argued for a duty period of 10 hours with 8.5 hours or less of flight duty period.

Time Since Awake

The results of an NTSB analysis of domestic air carrier accidents occurring from 1978 to 1990 suggest that time since awake (TSA) was the dominant fatigue-related factor in these accidents (NTSB, 1994). Performance decrements of high time-since-awake crews tended to result from ineffective decision-making rather than deterioration of aircraft handling skills. These decrements were not felt to be related to time zone crossings since all accidents involved short haul flights with a maximum of two time zones crossed. There did appear to be two peaks in accidents: in the morning when time since awake is low and the crew has been on duty for about three to four hours, and when time-since-awake was high, above 13 hours. Similar accident peaks in other modes of transportation and industry have also been reported (Folkard, 1997). Akerstedt & Kecklund (1989) studied prior time awake (four to 12 hours) and found a strong correlation of accidents with time since awake for all times of the day. Belenky et al. (1994) found that flight time hours (workload) greatly increase and add to the linear decline in performance associated with time since awake.

Task Type

The effects of task type, as they contribute to the buildup of fatigue, need to be considered from two perspectives:

- Whether certain activities can be excluded from duty period time
- Whether certain activities are inherently more fatiguing and may need to be restricted.

The current regulations regulate only flight time. No limits are provided for duty time. The regulations proposed in the Notice of Proposed Rulemaking 95-18 (NPRM) allow for the concept of "assigned time," which also is unregulated as to maximum limits. The extent to which activities categorized as non-flight time or assigned time contribute to fatigue has yet to be empirically ascertained. However, it is clear that these activities would contribute to fatigue in the form of time since awake. Consequently, it may be appropriate to limit these activities in either of two ways

- With respect to when they occur relative to flight time so as to avoid pilots achieving high time-since-awake levels during flight time periods.
- Provide maximum levels for these activities comparable to duty period time levels.

The second issue pertaining to task type concerns activities which are known to be inherently more fatiguing. One such activity is the approach and landing. Gander et al. (1994) found that increases in heart rate occurred during the approach and landing phases when compared with other duty period activities. Because heart rate increase is a common measure of workload, this suggests that proposals to limit landings for flights that have other known fatigue factors (e.g., time since awake, window of circadian low, extended flight duty periods) may be appropriate.

The relationship between task type and fatigue buildup in the aviation domain remains to be determined. The demands placed on long-haul pilots are clearly different from those of the regional carrier pilot flying many legs in a propeller-driven airplane with limited automation. Flights across the ocean typically involve a single leg of six or more hours. The main task-related fatigue sources in this case are boredom and cognitive fatigue due to vigilance. The regional pilot, in contrast, may be more susceptible to fatigue due to the high workload involved in performing six or more takeoffs and landings. For this reason, it may prove necessary to develop separate regulations that are appropriate for each major type of operation.

Duty Period Extensions

The research cited on duty period duration suggests that duty periods at or above 12 hours are associated with a higher risk of error. This factor, together with the time-since-awake factor, suggests that extended duty periods also involve a higher potential for crew error. In determining maximum limits for extended duty periods, consideration also needs to be given to other fatigue-related factors that could contribute to excessive fatigue levels during extended duty periods, including number of legs, whether the flight impinges on the window of circadian low (WOCL), and time since awake.

Cumulative Duty Time

No data were found that provide guidance for maximum duty times over longer time periods, such as one month or one year.

Environmental Factors

The physical environment of the cockpit is a source of other factors that can contribute to fatigue (Mohler. 1966). Factors such as vibration, poor ventilation, noise, and the availability of limited automation can contribute to the buildup of fatigue or accelerate its onset when coupled with time since awake, number of legs, and whether the flight involves the WOCL. This may have implications for regional carrier pilots who fly propeller-driven aircraft.

Conclusions

The research cited suggests an increase in the likelihood of error as duty periods are extended beyond 12 hours. This finding is especially critical for extended duty periods which are likely to occur under conditions (e.g., weather) that, in and of themselves, may increase the probability of crew error.

The interactions between multiple fatigue-related factors must also be considered. Separately, duty period duration, time since awake, number of legs, and environmental factors contribute to fatigue buildup. When any one of these factors reaches a high level, consideration should be given to reducing the maximum allowable levels on these other factors. Time since awake also has obvious implications for reserve assignments and for pilots who commute.

Standard Sleep Requirements

Standard Sleep Requirements and Off-Duty Period

There is a generally consistent body of research which demonstrates that most people require an average of 8 hours of sleep per night to achieve normal levels of alertness throughout daytime hours without drowsiness and to avoid the buildup of sleep debt (Carskadon & Dement. 1982. Wehr et al.. 1993). This figure is based upon a range of studies that used several approaches. including:

- Historical levels of sleep
- Measures of daytime alertness
- Sleep levels achieved when given the opportunity to sleep as long as desired.

Webb and Agnew (1975) reported that habitual sleep around the turn of the century was about nine hours. A 1960 study of more than 800,000 Americans found that 13 percent of men and 15 percent of women, ages 35-65, slept less the seven hours with 48 percent of both obtaining less than eight hours of sleep per night (*Wake Up America*, 1993). By 1977, one in eight Americans reported getting six or fewer hours of sleep per night (Schoenborn & Danchik, 1980) By 1983, just six years later, that number had jumped to one in four (Schoenborn & Cohen, 1986)

The average distribution of habitual sleep ranges between 5.5 and 9.5 hours per night, and includes 95 percent of the adult population with an average of 7.5 hours (Horne, 1988). Most researchers seem to agree with this figure (Levine et al., 1988; Carskadon & Roth, 1991. Dinges et al., 1996; Bonnet & Arand, 1995). However, Webb (1985) reported considerable individual differences in habitual sleep in a sample of more than 30,000 individuals from 11 industrial countries. In this study two percent were reported to sleep less than five hours per night, while five percent reported sleeping more than 10 hours. These averages have been reported in similar findings across various population groups.

Most researchers advocate an average sleep requirement for adults of 7.5 to 8.0 hours per day (Levine et al., 1988; Carskadon, & Roth, 1991; Dinges et al., 1996). Although early on, Dement et al. (1986) indicated that 9 hours was necessary for optimal alertness throughout the day, Horne considered 6 hours "core sleep" sufficient. Although Horne's advocacy of 6 hours core sleep has detracted somewhat from what most sleep researchers now feel to be optimal sleep, it has not dislodged the weight of evidence.

Carskadon (1991) reports that 87 percent of college students habitually sleeping seven to 7.5 hours per night had difficulty staying awake in the afternoon with 60 percent reporting actually falling asleep. When compared with Horne's advocating only 6 hours of "core sleep," these responses seem to suggest that, although the subjects specify a habitual amount of sleep above Horne's putative 'core,' their sleep is insufficient. The six-hour core amount does not seem to apply to many, based upon the self-perceived adequacy of sleep.

Roehrs et al (1989) showed that when short or long sleepers were required to stay in bed for ten hours, all subjects slept about an hour longer than usual. The result was that all subjects improved in their alertness, vigilance, and reaction time needed for driving or monitoring modern control panels. Divided attention performance showed significant improvement, and central task performance showed somewhat better improvement than peripheral task performance. Daytime sleepiness decreased for both groups, but to a greater extent for the individuals who previously reported suffering from sleepiness. Subjects who were usually sleepy were more alert, and those who usually functioned at a high level became even sharper (Carskadon et al., 1979).

Allowing just one hour extra sleep per night over four night resulted in a progressive reduction in daytime sleepiness of nearly 30 percent when measured by the Multiple Sleep Latency Test (MSLT). Allowing sleepers who typically slept 7.5 hour per day to sleep *ad libitum*, other researchers found that sleep time increased 28 percent from 7.5 to 9.6 hours. (Taub, 1981; Webb & Agnew, 1975). Taub (1976) studied the magnitude of differences between regular (7 to 8 hours) sleepers and long (9.5 to 10.5 hours) sleepers when their sleep was phase shifted three hours forward or backward. They also examined changes when both groups had sleep periods extended or reduced. Although results showed degrees of impairment from the acute alterations in sleep pattern by both sleep groups, the 7-to-8 hour sleepers consistently showed greater impairment. Carskadon and Dement (1981, 1982) found that extending the total time in bed from eight hours to ten in 18 to 20 year old subjects allowed them to increase their total sleep time on average more than one hour. This resulted in a significant improvement in daytime alertness which only appeared after the second night of extended sleep, suggesting a repaying of sleep debt. The researchers felt that this improvement supported suggestions that eight hours of bed time may represent a chronic sleep deprivation condition in young adults. Scores on alertness showed a stair-step response with the length of sleep per night as well as with the number of nights. Thus scores for alertness were better for ten hours of sleep than for eight, eight were better than five, and two nights with five hours were better than seven nights with five hours which were better than scores with no sleep.

In a slightly different research design, Wehr (1993) found in a four-week test that young adults allowed to sleep as long as they desired, slept in excess of 10 hours a day during the first three days. This was followed by three days of about 9 hours. The remainder of the 28 days leveled off at an average of 8.5 hours per night. Their habitual base-line sleep was 7.2 hours. The initially higher level of sleep is interpreted as repayment of chronic sleep debt. A similar sleep requirement figure of 8.4 hours was reported by a Walter Reed research team (1997) in an interim report. Thus both sleep extension studies and historical data indicate that optimal sleep requirement appears to be between 8 to 9 hours sleep with an average of about 8.5 hours, considerably higher than habitual sleep figures.

The benefits of sleep are presently considered to be logarithmic in nature, with the initial hours showing significantly greater benefits that diminish as one approaches his or her optimal sleep level. This accounts for how many can sleep less and appear to still function normally. However the findings of Rohre (1989) and Taub and Berger (1976) indicate that during the first six hours of sleep, performance is restored to a satisfactory level under normal conditions, although alertness and vigor may still be diminished. In the hours beyond six hours of sleep the restoration process further restores alertness and vigor and the brain's capacity to handle situations above that of normal and for longer periods.

An example of this is best illustrated by Samel et al. (1997) where the second of two night flights showed a considerable reduction in tolerance and an increase in fatigue after only three hours of flight whereas on the first night fatigue did not set in until after 8 hours. Thus, the additional hours served as a reserve capacity against workload (Howitt et al., 1978) or hours of duty (Samel et al., 1997; Gundel et al., 1997).

Other Variables

Individual Differences In Sleep Requirements. Many of the studies described above showed that there appears to be a considerable variability in individual sleep needs. Thus, the eight-hour sleep requirement represents the average of sleep needs, but does not take into account of the needs of those individuals who require additional sleep and who represent a fair percent of the population.

Age-Related Changes In Sleep Requirements. With age there is a significant decline in habitual nightly sleep due to increased nighttime awakenings (Davis-Sharts, 1989; Webb & Campbell 1980; Carskadon et al., 1982; Miles & Dement, 1980; Carskadon et al., 1980). In older individuals, habitual nighttime sleep is accompanied by increased daytime fatigue, sleepiness, dosing, and napping. This increase in the number of sleep periods approximates normal sleep quantity and appears to indicate that sleep requirements remain the same over a person's adult lifetime (Miles & Dement, 1980; Habte-Gabr, 1991). These studies suggest that older crew members may have particular difficulties in achieving sufficient sleep as part of a normal duty schedule (cf. Carskadon, Brown & Dement, 1982).

Logistical Issues. A number of studies have investigated the issue of the amount of sleep that is actually achieved as a function of the length of the off-duty period. These studies demonstrate that off-duty periods that appear to provide an acceptable sleep opportunity may not, in reality, be sufficient. In one study, reductions in sleep of two to three hours per 24 hours occurred when the time between shifts or work was reduced to only nine hours (Knauth, 1983). In the NASA studies of short-haul pilots (Gander et al., 1994; Gander & Graeber, 1994), pilots reported an average of 12.5 hours off-duty time between duty periods, but only obtained 6.7 hours rest.

Observations of nurses on 12 hour shifts working 12.5 hours with 11.5 hours off between shifts obtained an average of 6.9 hours sleep (Mills et al., 1983). Another study of long-haul and short haul-truck drivers (WRAIR, 1997) showed that short-haul drivers with similar rest periods between shifts obtained even fewer sleep durations.

Commercial truck drivers' (FHWA, 1996; Mitler et al., 1997) sleep/off duty schedules are shown in Table 1. When truckers (C1-10) had 10.7 hours off duty between 10 hour day shifts, sleep durations of only 5.4 hours were achieved. On a 13-hour day shift (C4-13) with 8.9 hours off between duty periods, sleep durations averaged 5.1 hours. On 10-hour rotating shifts (C2-10) with 8.7 hours off duty, the sleep time was 4.8 hours and after a 13-hour night shift (C3-13) with 8.6 hours off, the resulting sleep diminished to only 3.8 hours. In quick changeovers with 8 hours off between shifts, Totterdell (1990) found that workers only acquired 5.14 hours sleep. Kurumatani (1994) found a correlation (r=.95) between the hours between shift and sleep duration. They concluded that at least 16 hours off duty time were needed between shifts to ensure 7-8 hour sleep, a conclusion reiterated in a recent review (Kecklund & Akerstedt, 1995).

Condition	Hours off-duty	Hours in Bed	Hours asleep
C1-10 day	10.7	5.8	5.4
C2-10 rotating	8.7	5.1	4.8
C3-13 night	8.6	4.4	3.8
C4-13 day	8.9	5.5	5.1

Table 1. Truck drivers shift type and off duty hours in relation to time spent in bed and sleep time. (1996)

A partial explanation for such small amounts of sleep between quick shift changeovers may be the result of apprehension or fear of over sleeping. Torsvall and Akerstdt (1988) showed that ships' engineers on call show reduced sleep but also a decreased quality of sleep which they attributed to apprehension. This has also been found in physicians in smaller hospitals and appears to be followed by increased sleepiness during the following day (Akerstedt & Gillberg, 1990).

Other reasons for the low levels of actual rest achieved is due to the other activities that must be performed during the off-duty period. For pilots on layovers, these activities include getting to and from the hotel, meals, and personal hygiene. These activities clearly take away from the time available to sleep (Samel et al., 1997).

Reduced Rest

Research on the effects of sleep reduction on physiological and task performance has failed to provide a consistent picture of how much sleep may be reduced before a significant impact on performance occurs. Some of the reasons for this were described previously in the section entitled "Measuring Fatigue." Carskadon and Dement (1981) reduced subjects' sleep to only five hours per night over seven days, resulting in a 60 percent increase in sleep tendency. Based on this study and others, Carskadon and Roth (1991) conclude that as little as two hours of sleep loss can result in both performance decrements and reductions in alertness. Wilkinson (1968) varied sleep quantity by allowing subjects 0, 1, 2, 3, 5, or 7.5 hours in which to sleep. Significant decreases in vigilance performance were found the following day when sleep was reduced below three hours for one night or fewer than five hours for two consecutive nights. Carskadon, Harvey and Dement (1981) found increased daytime sleepiness, as measured by the MSLT, after one night of sleep reduced to four hours in a group of 12-year-olds, although performance decrements were not found.

Restriction of sleep in young adults to just 5 hours increases sleepiness on the MSLT the next day by 25 percent and by 60 percent the seventh day (Carskadon & Dement, 1981). When sleep was reduced to five hours or less, performance and alertness suffered and sleepiness significantly increased (Wilkinson et al., 1966; Johnson, 1982; Carskadon & Roth, 1991; Gillberg & Akerstedt, 1994; Taub & Berger, 1973; Carskadon & Dement, 1981). A recent study of Australian truckers found that 20 percent of drivers sleep 6 hours or less and account for 40 percent of the hazardous events reported (Arnold et al., 1997). During Operation Desert Storm, the pilots of the Military Airlift Command flights obtaining only 11 hours sleep in 48 hours were found to be in danger of experiencing difficulties in concentrating and staying awake (Neville et al., 1992). Further pilot observations indicated that to prevent fatigue in these pilots, at least 17 hours of sleep in 48 hours (7.5 hours/ 24 hours) were required.

Dinges (1997) showed significant cumulative effects of sleep debt on waking functions when subjects were restricted from their usual 7.41 hours sleep to only 4.98 hours (sd .57 hrs) of usual sleep (67 percent). Across the seven or eight days of sleep restriction subjects showed increasing levels of subjective sleepiness, fatigue, confusion, tension, mental exhaustion indicators, stress, and lapses increasing in frequency and duration. These escalating changes provide strong evidence that partial sleep restriction similar to that experienced by pilots has cumulative effects similar to those found in total or more extreme partial restriction.

In contrast, Hockey's (1986) analysis of partial sleep deprivation study findings revealed minimal performance changes but there were significant reductions in vigilance, efficiency, and increased subjective sleepiness with and mood deterioration

These results suggest that reducing rest by an hour should have little impact on a pilot's performance if the pilot is well rested prior to the reduced rest. If the pilot is suffering from sleep debt prior to the reduced rest, there may be an impact on the pilot's performance. If so, a reduced duty period should follow the reduced rest period in order to compensate for the possibility that the pilot may be more susceptible to time-since-awake effects.

Required Recovery Time

Complete recovery from a sleep debt may not occur after a single sleep period (Carskadon & Dement, 1979; Rosenthal et al., 1991). Typically, two nights of recovery are required (Carskadon & Dement, 1979; Kales et al., 1970), although the required recovery period may depend on the length of prior wakefulness (Carskadon & Dement, 1982). For example, Kales et al. (1970 found that restricting sleep to 5 hours per night for 7 days, which more closely resembles crew sleep patterns, required only a single extended night of sleep of 10 hours for full recovery. Morris (1996) found fatigue resulting from the loss of 4.5 hours of sleep in one night was not adequately restored in spite of 9 hours of sleep on one recovery night. Studies of C-141 crews flying to Southeast Asia during the Vietnam Conflict found that three nights were required before sleep returned to normal on the fourth night (Hartman, 1971). These results were observed even though the crews averaged 7.5 hours sleep per night.

The research also suggests that sleep debt following extended flight duty periods will only be effective if the sleep opportunity occurs at a time when the individual's circadian cycle will support effective utilization of that opportunity. The quantity of sleep gained depends more upon the circadian phase at which sleep is attempted rather than the length of prior wakefulness (Strogatz, Kronauer & Czcisler, 1986; Wever, 1985; Aschoff et al., 1975).

Conclusions

There appears to be substantial evidence that a minimum of eight hours of sleep is required for most people to achieve effective levels of alertness and performance. This rest level also enables the individual to cope with reduced rest should the need arise. Achieving the required eight hours under layover conditions depends upon the length of the off-duty period. The data suggest that an off-duty period of ten hours may not be sufficient to support an eight-hour sleep opportunity.

Reducing the rest period by an hour should have little effect on pilot alertness and performance if the individual is well rested. Reduced sleep, when accompanied by an existing sleep debt, diminishes performance and the ability of the individual to maintain alertness throughout the duty period, especially if a long time since awake is involved

Recovery from sleep debt often requires two nights of rest. This result puts into question the effectiveness of extending the off-duty period following an extended duty period. Also, if no sleep debt is allowed to accumulate, it is not clear that weekly breaks are required. However, the data suggest that sleep debt is likely to accumulate if 10-hour off-duty periods are used.

The Circadian Cycle and Fatigue

Biological Circadian Rhythms

Chronobiology is the study of time-dependent changes in various levels of the physiologic organization from the organism as a whole, to the cell, to the genetic material itself. These changes regularly reoccur in a predictable rhythmic fashion and are referred to as oscillations.

The oscillations appear as waves, and the time to complete one full wave cycle is called a "period." They are divided into three groups by length of the rhythm. Ultradian are rhythms of 20 hours or less. Circadian encompasses rhythms between 20-28 hours, and Infradian are rhythms greater than 28 hours. The latter include rhythms called circaseptan (7 days, ± 3 days), circadiseptan (14 days ± 3 days), circavigintan (21 days, ± 3 days), circatrigintan (30 days, ± 5 days) and circaannual (one year, ± 3 months). According to Haus & Touitou (1994) there is evidence of 7 day, 30 day and annual rhythms in humans, as well as the circadian and ultradian rhythms.

Circadian rhythms have been recognized for decades. Yet the biological clock that regulates the 24-hour physiological and behavioral rhythms was not identified until the 1970s. These two bilaterally located nuclei called the suprachiasmic nuclei (SCN) are located above the optic chiasm in the anterior hypothalamus. These nuclei are considered the circadian pacemakers. Destruction of these nuclei produce an arrhythmia and severe disruption between behavior and physiological parameters including the timing of food intake and sleep. They appear not to regulate the amount of either of these behaviors (Turek & Reeth, 1996).

Signals produced by the SCN are both hormonal and neural. Grafted nuclei without neural connections restore circadian rhythms of eating and activity. Melatonin secretions, however, are not restored, suggesting neuron control. Melatonin receptors have been found in the SCN and appear to be part of a feedback mechanism that causes shifts in the circadian clock. The SCN has been found to possess its own built-in rhythm. Evidence gathered thus far indicates that SCN receive information about the light-dark cycle via two neural pathways from the optic nerve, one from the retinohypothalamic tract and the other through the geniculohypothalamic tract. The latter pathway appears to provide information or signals that help with reentrainment after a shift in the light-dark cycle. But recent research appears to indicate that other photo receptors may also be involved in the entrainment process (Campbell & Murphy, 1998).

Peak levels of physiological functioning occur during the light phase of the light/dark cycle. This synchronization of physiological rhythms enhances work performance during the daytime and supports sleep at night by turning down the metabolic thermostat. The internal synchronization of the variable metabolic parameters with the light/dark cycle are tuned for optimal functioning. Over 100 biological rhythms are genetically generated within the human body, then entrained or synchronized to better work in concert (Wehr, 1996; Takahasi, 1996). The greater the synchronization between hormone production, metabolic rate, enzyme and neurotransmitter synthesis, the higher the amplitude of the rhythm and the greater the communication between the body's cells. Thus, the maintenance of a strong circadian rhythm carries with it considerable ramifications for good health, well-being, and functioning (Wehr, 1996).

The suprachiasmic nuclei, together with the pineal gland, function as metabolic and behavioral concert conductors in cue with environmental factors such as light/dark, meal timing, social interaction, and physical activity. This synchronization of internal and behavioral with the external environment around the 24 hour day (*circa*=about: *dies*=day) is called circadian rhythm entrainment.

Although other internal and external factors do play a role, the light-dark cycle is the major entrainment factor for most of the animal kingdom. For humans, though, the light-dark cycle is felt to be a relatively weak synchronization of the human circadian rhythm for two reasons. Compared to other animals, the light sensitivity threshold as a synchronizing factor is considerably elevated. For comparison, the light intensity required for circadian synchronization in a hamster is only .5 lux, whereas for humans estimates range from 1200-2500 lux (Reinberg & Smolensky, 1994). This raises questions about the adequacy of indoor lighting. Second, man is the only species that lives outside of the day/night cycle.

Social environment appears to play a more important role in entrainment. Social factors that can alter the biological clock regulation of circadian rhythms include temperature, flight duty, stress, meal consumption, and food presentation (Samel & Wegmann, 1987). Exercise or activity also appears to help retrainment after circadian disruption. Ferrer et al. (1995) cite evidence that physical fitness predicts how well a person adapts to shift work changes regardless of its entrainment potential. Individuals who are physically fit and exercise regularly have higher circadian rhythm amplitudes than unfit individuals, and those with high circadian rhythm amplitudes are more tolerant of shift work (Ferrer et al., 1995). This helps to explain why age-related flattening of circadian rhythms is related to increased sleep difficulties, poor adjustment to night work and transmeridian flights in those over 50.

- Back of the Clock Operations, Circadian Rhythm and Performance

There is a substantial body of research that shows decreased performance during night shifts as compared with day shifts. The reasons for this decreased performance include

- Circadian pressure to sleep when the individual is attempting to work.
- Circadian pressure to be awake when the individual is attempting to sleep.
- Time since awake may be substantial if the individual is up all day before reporting for the night shift.
- Cumulative sleep debt increase throughout the shift.

Research conducted by Monk et al. (1989) indicates that subjective alertness is under the control of the endogenous circadian pacemaker and one's sleep-wake cycle (time since awake). When time since awake is long and coincides with the circadian low there is a very sharp drop in alertness, a strong tendency to sleep and a significant drop in performance (Perelli, 1980). Alertness is relatively high when the circadian rhythm is near the acrophase and time since awake is small. Monk (1996) argues that this cycle is consistent with the NTSB (1994) finding of a peak accident rate occurring in the evening. The strength of the circadian cycle is substantial. Akerstedt

(1989) argues that, up to 24 hours without sleep, circadian influences probably have greater effects than time since awake.

In Japan, 82.4 percent of drowsiness-related near accidents in electric motor locomotive drivers (Kogi & Ohta, 1975) occur at night. Other landmark studies over the past several decades have documented the increase in accidents and error making. Klein et al. (1970) argue that their research with simulators proves that night flights are a greater risk than day flights. Their research found 75- to 100-percent mean performance efficiency decrements in simulator flights during the early morning hours, regardless of external factor such as darkness or increasing night traffic or possible weather conditions.

Task performance in a variety of night jobs has been compared with performance of their daytime counterparts, and results consistently show deterioration of performance on the night shift. Browne (1949) studied telephone operators' response time in answering incoming calls in relation to the hour of the day and found the longest response times occurred between 0300 and 0400 hours. Bjerner et al. (1955) examined gas company hourly ledger computations of gas produced and gas used over an 18-year period and found that recording error were highest at 0300 hours with a smaller secondary peak at 1500 hours. Hildebrandt et al. (1974), investigating automatic train braking and acoustical warning signal alarms set-offs, also found two peaks at 0300 and 1500 hours in these safety-related events. Similar finding have been reported in truck accidents (Harris, 1977) and in Air Force aircraft accidents (Ribak et al., 1983). Other accident analyses of time of day and hours of work show that both circadian rhythm and hours of duty play a significant role in the occurrence of accidents (Folkard, 1997; Lenne et al., 1997). In addition, the incidence of accidental injury nearly doubles during the night shift compared to morning shift, while the severity of injury increases 23 percent (Smith et al., 1994). Night nurses make nearly twice the patient medication errors as day nurses and experience nearly three times the auto accidents commuting to and from work (Gold et al., 1993).

Akerstedt (1988) reviewed the effects of sleepiness from night shift work and found that the potentially hazardous situation resulting from increased sleepiness during night shift is real and underestimated. Akerstedt (1988) also reports that fatigue in shift workers is higher than in day workers, highest in night workers, followed by morning workers. Overall, sleepiness among night workers is estimated to be around 80 to 90 percent. Roth et al. (1994) indicate that rates for workers falling asleep on the job while on night shift have been reported to be as high as 20 percent.

Night operations are physiologically different than day operations due to circadian trough and sleep loss. This carries a higher physiological cost and imposes greater risks of accidents. One of the most established safety issues is working in the circadian trough between 0200 and 0600. During this period workers experience considerable sleepiness, slower response times, increased errors and accidents (Mitler, 1991; Pack, 1994). Many recent accidents from various transportation modes have been associated with this circadian trough (Lauber & Kayten, 1988).

Lyman and Orlady (1981), in their analysis of the Aviation Safety Reporting System researcher state that 31 percent of incidents occurring between 2400 to 0600 hours were fatigue related

Gander et al. (1996) found that overnight cargo pilots exhibited partial adaptation to night work with a nearly 3-hour phase shift in the lowest body temperature, with subjective fatigue and activation peaking shortly thereafter. Despite this, pilots still experienced a three-fold increase in multiple sleep episodes (53 percent versus 17 percent) and a 1.2 hour sleep debt per night compared with pre-trip sleep length.

In some cases, the high fatigue levels found may be due to time since the last sleep. Pokorny et al. (1981) analyzed bus driver accidents over a five-year period and found that, although the time of day affected some incidents, one of the most important factors in driver accidents was how early drivers reported to work. Those reporting in between 0500-0600 had about six times as many the accidents as those reporting between 0700-0800. A peak in accidents also occurred two to four hours after beginning the shift.

If an individual has been awake for 16 to 18 hours, decrements in alertness and performance are intensified. If time awake is extended to 20 to 24 hours, alertness can drop more than 40 percent (WRAIR, 1997; Morgan et al., 1974; Wehr, 1996). A study of naval watch keepers found that between 0400 to 0600, response rates drop 33 percent, false reports rates 31 percent, and response speed eight percent, compared with rates between 2000 to 2200 hours (Smiley, 1996).

Samel et al. (1996) determined that many pilots begin night flights already having been awake more than 15 hours. The study confirms the occurrence of as many as five micro-sleeps per hour per pilot after five hours into a night flight. They also found that 62 percent of all pilots studied rated their fatigue great enough to be unable to fly any longer after their night flight. This explains earlier findings in long haul return night flights that showed significant physiological markers of higher stress. Upon return to home base after flying two night flights (outbound and return) pilots average 8 to 9 hours of sleep debt. Although flights varied from north-south and east-west with layover length from 14 hours to 4.5 days, sleep debt appeared similar. East-west flights had significantly longer layovers but were disruptive to circadian rhythms. The authors concluded that "During day time, fatigue-dependent vigilance decreases with task duration, and fatigue becomes critical after 12 hours of constant work. During night hours fatigue increases faster with ongoing duty. This led to the conclusion that 10 hours of work should be the maximum for night flying."

Gander et al. (1991) found in an air carrier setting that at least 11 percent of pilots studied fell asleep for an average of 46 minutes. Similarly, Luna et al. (1997) found that U.S. Air Force air traffic controller fell asleep an average of 55 minutes on night shift. A possible explanation for these sleep occurrences, in addition to circadian nadir, is the finding of Samel et al. that many pilots begin their night flights after being awake for as long as 15 hours

The effect of time since the last sleep is even greater if a sleep debt already exists. An NTSB heavy trucks accident analysis (NTSB. 1996) clearly shows that "back of the clock" driving with a sleep debt carries a very high risk. Of 107 single-vehicle truck accidents. 27 drivers exceeded the hours of duty. Ninety-two percent (26) of these had fatigue-related accidents. The NTSB report also shows that 67 percent of truck drivers with irregular duty or sleep patterns had fatigue-related accidents compared to 38 percent in drivers with regular duty or sleep patterns. Irregularity resulted in a decrease of 1.6 hours on average in sleep with a total of only 6.1 hours compared to 7.7 hours in regular pattern drivers. The NTSB report indicated that they could not determine whether irregular duty/sleep patterns per se led to fatigue but some experimental data support this notion. The findings of the NTSB not only found shifted sleep patterns but this shift was coupled with sleep loss. Taub and Berger (1974), while maintaining sleep length, shifted sleep times and found that performance on vigilance, calculation tasks, and mood were significantly impaired. Furthermore, Nicholson et al. (1983) showed that irregular sleep/work resulted in increasing performance impairments which was further increased by time on task, cumulative sleep loss, and working through the circadian nadir.

Performance can also be affected by cumulative fatigue buildup across multiple days. Gundel (1995) found that pilots flying two consecutive nights with 24 hours between flights slept about two and a half hours less during their daytime layovers (8.66 hours versus 6.15 hours), and experienced a significant decline in alertness on the second night flight. Alertness during the first six hours in both flights appeared to be the same. The latter part of the second flight showed increased desynchronization of EEG alpha wave activity, indicating lower levels of alertness. Spontaneous dozing indicated an increased susceptibility sleep. Subjectively, pilots felt greater fatigue on the second night. Therefore, with time since awake being the same, sleep quality and quantity during the daytime layover resulted in increased fatigue.

Samel et al. (1997) monitored 11 night flight rotations from Frankfort to Mahe/Seychelles crossing three time zones. Pilots slept on average eight hours on baseline nights. On layover, sleep was reduced to 6.3 hours. Pilots arrived at SEZ after 22 hours of being awake (except for approximate 1.5 hour nap prior to departure). Fatigue scores increased over both outbound and inbound flights with 12.4 micro-sleeps per pilot outbound and 24.7 on return. Prior to the outbound FRA-SEZ flight 85 percent of pilots felt rested whereas on return only 30 percent reported feeling so. These studies document that night flights are associated with reduced sleep quantity and quality, and are accompanied by cumulative sleep debt.

Borowsky and Wall (1983) found that flight-related accidents in Navy aircraft were significantly higher in flights originating between 2400 and 0600 hours. The higher mishap incidence was felt to be the result of circadian desynchronization and disrupted sleep-wake cycle. Sharppell and Neri (1993) divided the operational day of navy pilots in Desert Shield and Desert Storm operations in to four quartiles beginning at 0601-1200 with 0001 to 0600 being the fourth quartile. They found that there was a progressive increase in pilots' subjective need for rest between flights as flights originated later and later in the day from quartile 1 to quartile 4. In addition multiple missions and cumulative days flying also increased the pilots subjective need for additional rest between missions. The latter effect is the cumulative effect of fatigue. As sleep time increased before a flight the subjective rest needed before the next flight decreased

Sleep Patterns During The Day

Simply providing pilots with the opportunity to rest during the day may not be sufficient to compensate for the demands of night flying. Night workers have been shown to sleep on average one and a half hours less each day than day workers (Minors & Waterhouse, 1984). Depending on type of shift and rotation, there can be as much as three hours sleep deficit. Czeisler et al. (1980) showed that sleep duration was dependent on the circadian phase. Thus daytime sleep was significantly reduced compared to night time sleep.

The propensity to sleep is high during the night and low during the day. But there is a gradient effect in sleepiness. Between six and 12 hours awake, sleepiness in control subjects increased seven percent; between six and 18 hours, 28-37 percent (Minor & Waterhouse, 1987; Minor et al., 1986). This is the result of a myriad of other rhythms—hormonal, secretory, temperature—that orchestrate an internal environment for action during the day and for rest at night. The effect of circadian rhythm on performance is illustrated in the findings of a sleep deprivation study on multi-task performance. Czeizler et al. (1994) points out that alertness and performance would normally decline as a function of time since awake, except when coupled to the circadian rise in body temperature, the two functions stay relatively stabile through most of the waking hours. The beginning of a drop in alertness starts three to four hours prior to normal bedtime. At bedtime there is a sudden and dramatic—18-20 percent—fall in performance and alertness, coinciding with the rapid drop in body temperature.

Night work which requires daytime sleep has been shown to reduce the amount of sleep obtained whether on permanent night or rotating shifts (Colligan & Tepas, 1986). In quick changeovers with 8 hours off between shifts, Totterdell (1990) found workers only acquired 5.14 hours sleep. Kurumatani (1994) observed that workers getting off at 1600 hrs and required to began again at 2400 hours slept 2.35 hrs. On a similar shift change but getting off 1200 hrs and returning to duty at 2400 hrs workers were only able to get 3.0 hrs sleep. These researchers found a correlation (r=.95) between the hours between shift and sleep duration. They concluded that at least 16 hours off duty time were needed between shifts to insure 7-8 hour sleep, a conclusion reiterated in a recent review (Kecklund & Akerstedt, 1995).

Transmeridian Operations

Transmeridian operations create similar problems in attempting to work when the body wants to sleep and sleep when the body wants to be awake. The biggest challenge posed by multiple time-zone flights is the time required for the body to adjust to the new time zone. The period of adjustment appears to depend on the direction of travel. Adjustment appears to be faster after westward flights than eastward flights (Klein & Wegmann. 1980). Adjustment following westward flights appears to occur at a rate of about 1.5 hours per day while eastward-flight adjustment occurs at about 1 hour per day. This may be due to the body's inherent tendency to lengthen its period beyond 24 hours, which coincides with westward flights. These data also suggest that phase shifts below six hours can have a significant impact (Aschoff et al., 1975).

Aside from the obvious implications for transmeridian operations, these data also apply to reserve pilots whose protected sleep opportunity may vary as to its occurrence across assignments. Even if a protected time period is predictable, unless it includes the night hours, it may not provide an effective opportunity for sleep and thus may not lessen fatigue.

Conclusions

The following conclusions can be drawn from the research cited above:

- **An individual's WOCL should be defined on the basis of the time zone where he/she resides, which may be different from the home domicile.**
- Duty periods conducted during WOCL already carry a fatigue penalty due to the circadian cycle. Consequently, duty periods involving WOCL should be reduced.
- The number of duty periods involving WOCL that must be performed without time off should be limited.
- Because the circadian cycle is longer than 24 hours, each duty period should start later than the previous duty period.
- Reserve assignments should attempt to maintain a consistent 24-hour cycle.
- Direction of rotation for both back-of-the-clock flying and direction of transmeridian operations should be considered. Given the body's preference for extending the day, backward rotation should be used when possible.
- Transmeridian operations should be scheduled in accordance with either of two approaches:
  - For short periods, it may make sense to attempt to keep the pilot on home-domicile time.
  - For longer periods, reducing the duty period and providing more opportunities to sleep may be the best approach.

Augmented Crews

Little research has been performed to assess the effectiveness of managing fatigue through the use of augmented flight crews. However, two recent NASA projects have been initiated to study long-haul augmented flight operations (Rosekind et al., 1998). The first project used a survey to examine factors that promoted or interfered with sleep in crew quarters installed on aircraft. Results were collected from more than 1,400 crewmembers from three participating U.S. airlines. It was concluded that, even though some difficulties were noted, flight crewmembers were able to obtain a reasonable amount and quality of sleep while resting in on-board bunks. Further, the sleep obtained was associated with improved alertness and performance. This study also identified factors that could be used to develop strategies to obtain optimal sleep.

The second project was a field study that examined the quantity and quality of sleep obtained in on-board bunks during augmented, long haul flights. Data were collected from two airlines involved in different types of international operations, and a corporate operator. Preliminary results showed that crewmembers obtained a good quantity and quality of sleep. Additional analyses are presently being conducted.

Conclusion

A review of the scientific literature pertaining to fatigue, sleep, and circadian physiology was performed in order to identify the major issues that need to be considered in developing a regulatory approach to pilot fatigue and sleep debt. The conclusions developed for each issue reflect areas that might benefit from additional FAA consideration.

References

Akerstedt, T. (1989). A review of sleep/wake disturbances in connection with displaced work hours in flight operations. *Stress Research Reports*. No 218. National Institute for Psychological Factors and Health, Dept. Stress Research, Karolinska Institute, Sweden.

Akerstedt, T. (1995). Work injuries and time of day—National data. *Proceedings of a Consensus Development Symposium entitled "Work Hours, Sleepiness and Accidents"*. Stockholm, Sweden, 8-10 Sept. 1994:106. Cited by Rosa, R. R. (1995). Extended workshifts and excessive fatigue. *Journal of Sleep Research*, 4, 51-56.

Akerstedt, T., Gillberg, M. (1990) Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience*, 52, 29-37.

Angus, R. C., Heselgrave, R. J. (1985) Effects of sleep loss on sustained cognitive performance during a command and control situation. *Behavior Research Methods, Instruments, and Computers*, 17, 55-67.

Angus, R. G., and Heselgrave R. J. (1983). The effects of sleep loss and sustained mental work: Implications for command & control performance. *Sustained Intensive Air Operations: Physiological and Performance Aspects*. AGARD Conference Proceedings No. 338, 11.1-11.21.

Arnold, P. K., Hartley, L. R., Corry, A., et al. (1997). Hours of work, and perceptions of fatigue among truck drivers. *Accident Analysis and Prevention*, 29, 471-477.

Aschoff, J.I, Giedke, H., Poppel, E., & Wever, R. (?). The influence of sleep-interruption and of sleep-deprivation on circadian rhythms in human performance.

Baker, T. L. (1996, June 19). Proposed changes in FAA flight and duty regulations: A scientific critique of supporting evidence. In: *Comments Of The Air Transport Association of America to FAA Notice 95-18. FAA Docket No. 28081.*

Barth, J., Holding, D. H., & Stamford, B. A. (1976). Risk versus effort in the assessment of motor fatigue. *Journal of Motor Behavior*, 8, 189-194.

Belenky, G., Balkin, T., Krueger, G., Headley, D., Solick, R. (1986). *Effects of Continuous Operations (CONOPS) on Soldier and Unit Performance. Phase I Review of the Literature.* Ft. Leavenworth, KS: US Army Combined Arms Combat Developments Activity.

Belenky, G., Penetar, D. M., Thorne, D., Popp, K., Leu, J., Thomas, M., Sing, H., Balkin, T., Wesensten, N., Redmond, D. (1994). The Effects of Sleep Deprivation On Performance During Continuous Combat Operations. In: *Food Components to Enhance Performance*. (1994) National Academy Press. Washington DC Pg 127-135

Bills, A. G. (1931). Blocking: A new principle in mental fatigue. *American Journal of Psychology*, 43, 230-245.

Bjerner, B., Holm, A., Swensson, A. (1955). Diurnal variation in mental performance: a study of three-shift workers. *British Journal of Industrial Medicine*, 12(2): 103-10.

Bonnet, M. H. (1994). Sleep deprivation. In M. H. Kryger, T. Roth, & W. C. Dement (Eds.), *Principles and Practice of Sleep Medicine (2nd Edition)*, Philadelphia. W.B. Sauders.

Bonnet, M. H., Arand, D. L. (1995). We are chronically sleep deprived. *Sleep*, 18(10): 908-911.

Bonnet, M. H & Moore, S. E. (1982). The threshold of sleep: Perception of sleep as a function of time asleep and auditory threshold. *Sleep*, 5, 267-276.

Borowsky, M. S., Wall, R. (1983). Naval aviation mishaps and fatigue. *Aviation, Space, and Environmental Medicine*, 54: 535-538.

Braun, A. R., Balkin, T. J., Wesensten, N. J., Carson, R. E., Varga, M., Baldwin, P., Selbie, S., Belenky, G., Herscovitch, P. (1997). Regional Cerebral Blood Flow Throughout the Sleep-Wake Cycle: An $H_2{}^{15}0$ PET Study. *Brain*, 120, 1173-1197.

Broadbent, D. E. (1953). Neglect of the surrounding in relation to fatigue decrements in output. In W. F. Floyd & A. T. Welford (Eds.), *Symposium on Fatigue*. London: Lewis.

Broadbent, D. E. (1958). *Perception and Communication*. Pergamon.

Brown, I. D., Tickner, A. H., & Simmons, D. C. (1970). Effect of prolonged driving on overtaking criteria. *Ergonomics*, 13, 239-242.

Browne, R. C. (1949). The day and night performance of teleprinter switchboard operators. *Occupational Psychology*, 23(2): 121-6.

Bursill, A. E. (1958). The restriction of peripheral vision during exposure to hot and humid conditions. *Quarterly Journal of Experimental Psychology*, 10, 113-129.

Campbell, S. S., & Murphy, P. J. (1998). Extraocular circadian phototransduction in humans. *Science*, 279 (5349).

Carskadon, M. A., & Dement, W. C. (1979). Sleep tendency during extension of nocturnal sleep. *Sleep Research*, 8: 147

Carskadon, M., Brown, E. D., & Dement, W. C. (1982). Sleep fragmentation in the elderly: relationship to daytime sleep tendency. *Neurobiology of aging*, 3, 321-7.

Carskadon, M. A., & Dement, W. C. (1979). Effects of total sleep loss on sleep tendency. *Perceptual & Motor Skills*, 48, 495–506, 1979.

Carskadon, M. A., & Dement, W. C. (1981). Cumulative effects of sleep restriction on daytime sleepiness. *Psychophysiology*, 18, 107–113.

Carskadon M. A., & Dement, W. C. (1982). Nocturnal determinants of daytime sleepiness. *Sleep*, 5, S73–81.

Carskadon MA, & Roth T. (1991). Sleep restriction. In T. H. Monk (Ed.), *Sleep, Sleepiness and*

Performance. Chichester: Wiley.

Carskadon, M. A., Brown, E., & Dement, W. C. (1982). Sleep fragmentation in the elderly. Relationships to daytime sleep tendency. *Neurobiology of Aging*, 3, 321-327.

Carskadon, M. A., Harvey, K., & Dement, W. C. (1981). Sleep loss in young adolescents. *Sleep*, 4, 299-312.

Carskadon, M. A., van den Hoed, J., Dement, W. C. (1980). Sleep and daytime sleepiness in the elderly. *Journal of Geriatric Psychiatry*, 13, 135-151.

Chambers, E. A. (1961). Industrial Fatigue. *Occupational Psychology*, 35, 44-57.

Colligan, M., Tepas, D. (1986). The stress of hours of work. *American Industrial Hygiene Association Journal*, 47, 686-695.

Colquhoun, P. (1976). Psychological and psychophysiological aspects of work and fatigue. *Activitas Nervosa Superior*, 18, 257-263.

Colquhoun, W. P. (1985) In S. Folkard & T. H. Monk (Eds.), *Hours of Work*.

Czeisler, C. A., Dijk, D. J., & Duffy, J. F. (1994). EntrainedpPhase of the circadian pacemaker serves to stabilize alertness and performance throughout the habitual waking day. In R. D. Ogilvie & J. R. Harsh (Eds.), *Sleep Onset: Normal and Abnormal Processes*. American Psychological Association.

Czeisler, C. A., Weitzman, E. D., Moore-Ede, M. C., Zimmerman, J. C., & Knauer, R. S. (1980). Human sleep. Its duration and organization depend on its circadian phase. *Science*, 210, 1264-1267.

Davis-Sharts, J. (1989). The elder and critical care. Sleep and mobility issues. *Nursing Clinics of North America*, 24, 755-767.

Dawson, D., & Reid, K. (1997). Fatigue, alcohol and performance impairment. *Nature*, 388, 235.

Dejoy, D. M. The nonauditory effects of noise: Review and perspectives for research. *Journal of Auditory Research*, 24, 123-150.

Dement, W. C., Carskadon, M. A. (1981) An essay on sleepiness. In M. Baldy-Moulinier (Ed.), Actualites en medecine experimentale, en hommage au Professeur P. Passouant (pp. 47-71). Montpellier: Euromed. From *Sleep: A Scientific Perspective* pp.53-54.

Dement, W. C., Carskadon, M. A., Richardson, G. S. (1978). Excessive daytime sleepiness in the sleep apnea syndrome. C. Guilleminault & W. C. Dement (Eds.). Sleep Apnea Syndromes. New York, Alan R. Liss.

Dement, W. C., Seidel, W. F., Cohen, S. A., Bliwise, N. G., Carskadon, M. A. (1986). Sleep and wakefulness in aircrew before and after transoceanic flights. *Aviation, Space, and Environmental Medicine*, 57, B14-B28.

Dinges, D. F. (1989). **The nature of sleepiness: causes, contexts, and consequences. In A. J. Stunkard & A. Baum (Eds), Perspectives in Behavioral Medicine: Eating, Sleeping, and Sex. Hillsdale, NJ: Erlbaum.**

Dinges, D. F. (1995). Performance effects of fatigue. *Fatigue Symposium Proceedings.* Washington, DC: National Transportation Safety Board.

Dinges, D. F., Graeber, R. C., et al. (1996). **Principles and guidelines for duty and rest scheduling** in commercial aviation. *NASA Technical Memorandum 110404*, Para 1.1.1.

Dinges DF and Kribbs NB. (1991). **Performing while sleepy: effects of experimentally-induced sleepiness. In T. H. Monk (Ed.), *Sleep, Sleepiness and Performance*. Chichester: Wiley.**

Dinges DF, Pack F, Williams K, Gillen KA, Powell JW, Ott GE, et al. (1997). Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4–5 hours per night. *Sleep*, 20, 267–277.

Evans, S. M., Mackie, R. R., & Wylie, C. D. (1991, August) *Fatigue Effects on human performance in combat: A literature review*. US Army Research Institute for the Behavioral and Social Sciences, ARI Research Note 91-90.

Ferrer, C. F., Bisson, R. U., & French, J. (1995). Circadian rhythm desynchronosis in military deployments: a review of current strategies. *Aviation, Space, and Environmental Medicine*, 66, 571-578.

Folkard S. (1997). Black times: Temporal determinants of transport safety. *Accident Analysis and Prevention*, 29, 417-430.

Gander, P. H., Graeber, R. C., Connell, L. J., & 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 103852*.

Gander, P. H., Graeber, R. C., Foushee, H. C., Lauber, J. K., & Connell, L. J. (1994). Crew

Factors in Flight Operations II: Psychophysiological responses to short-haul air transport operations. *NASA Technical Memorandum 1?5856.*

Gevins, A., Leong, H., Du, R., Smith, M. E., Le, J., DuRousseau, D., Zhang, J., Libove, J. (1995) Toward measurement of brain function in operational environments. *Biological Psychology*, 40, 169-186.

Gold, P. E. (1995). Role of glucose in regulating the brain and cognition. *American Journal of Clinical Nutrition*, 61; Suppl:pgs. S987-S995.

Graeber, R. C. (1985). Proceedings of the Flight Safety Foundation 38th International Air Safety Seminar.

Graeber, R. C. (1988). Air crew fatigue and circadian rhythmicity. In *Human Factors in Aviation* (pp. 305-344). Academic Press.

Graeber, R. C., Lauber, J. K., Connell, L. J., Gander, P. H. (1986). International aircrew sleep and wakefulness after multiple time zone flights: A cooperative study. *Aviation, Space, and Environmental Medicine*, 57, B3-B9.

Gundel, A., Drescher, J., Maab, H., Samel, A., Vejvoda, M. (1995). Sleepiness of civil airline pilots during two consecutive night flights of extended duration. Biological Psychology, 40, 131-141.

Habte-Gabr, E., Wallace, R. B., Colsher, P. L., Hulbert, J. R., White, L. R., Smith, I. M. (1991). Sleep patterns in rural elders: demographic, health, and psychobehavioral correlates. *Journal of Clinical Epidemiology*, 44, 5-13.

Hamelin, P. (1987). Lorry Driver's Time Habits in Work and Their Involvement in Traffic Accidents. *Ergonomics*, 30, 1323-33.

Hamilton, P., Wilkinson, R. T., & Edwards, R. S. (1972). A study of four days partial sleep deprivation. In W. P. Colquhoun (Ed.), *Aspects of Human Efficiency* (pp. 101-113).

Harris, W. (1977). Fatigue, circadian rhythm, and truck accidents. In: *Vigilance: Theory, Operational Performance, and Physiological Correlates*. (Ed.) Mackie, R. R., 133-147, Plenum Press, NY.

Harris, W., & Mackie, R. R. (1972). *A study of the relationships among fatigue, hours of service, and safety of operations of trucks and bus driving*. (Report No. BMCS-RD-71-2.) Washington, DC: United States Department of Transportation, Federal Transit Administration, Bureau of Motor Carrier Safety.

Harrison, Y., Horne, J. A. (1997). Sleep deprivation affects speech. *Sleep*. 20. 871-877

Hartman, B. O. (1971). Field study of transport aircrew workload and rest. *Aerospace Medicine*. 42(8): 817-821.

Haus, E., & Touitou, Y. (1994). Principles of clinical chronobiology. In: *Biologic Rhythms in Clinical and Laboratory Medicine*, (Eds.) Touitou, Y., Haus. E., & Springer-Verlag, 6-34.

Hildebrandt, G., Rohmert, W., & Rutenfranz, J. (1974). 12 & 24 H rhythms in error frequency of locomotive drivers and the influence of tiredness. *International Journal of Chronobiology*, 2(2): 175-180.

Hockey, G. R. J. (1986). Changes in operator efficiency as a function of environmental stress, fatigue, and circadian rhythms. In K. R. Boff, L. Kaufman & J. P. Thomas (Eds.), *Handbook of Perception and Human Performance, Vol. II, Cognitive Processes and Performance*. John Wiley and Sons, New York.

Horne, J. A. (1988). Sleep loss and "divergent" thinking ability. *Sleep*. 11, 528-536.

Horne J. A. (1991). Dimensions to sleepiness. In T. H. Monk (Ed.). Sleep, Sleepiness and Performance. Chichester: Wiley.

Howitt, J. S., Hay, A. E., Shergold, G. R., & Ferres, H. M. (1978) Workload and fatigue—In-flight EEG changes. *Aviation, Space, and Environmental Medicine*. 49. 1197-1202.

Huntley M. S., & Perrine, M. W. (1973). A behavioral mechanism of alcohol-related accidents In M. E. Chafetz (Ed.), *Proceedings of the First Annual Alcoholism Conference of the National Institute of Alcohol Abuse and Alcoholism. Research on Alcoholism: Clinical Problems and Special Populations*.

Johnson, L. C. (1982). Sleep Deprivation and Performance. In W. B. Webb (Ed.). *Biological Rhythms, Sleep, and Performance*. New York: John Wiley & Sons

Johnson, L. C., Naitoh, P. (1974). *The Operational Consequences of Sleep Deprivation and Sleep Deficit*. AGARDograph No. 193, p.1-43.

Kales A, Tan T, Kollar EJ, et al. (1970). Sleep patterns following 205 hours of sleep deprivation. Psychosom Med, 32, 189–200.

Kecklund, G., & Akerstedt, T. (1995). Effect of timing of shifts on sleepiness and sleep duration. *Journal of Sleep Research*, 4, 47-50.

Kirsch, A. D. (1996, June 19). Report on the statistical methods employed by the U.S. FAA in its cost/benefit analysis of the proposed "Flight Crewmember Duty Period Limitations. Flight Time Limitations and Rest Requirements". Docket No 28081. In: *Comments Of The Air Transport Association of America to FAA Notice 95-18, FAA Docket No. 28081*. Appendix D pp. 1-36.

Kjellberg, A. (1977). Sleep deprivation and some aspects of performance II. Lapses and other attentional effects. *Waking & Sleeping*, 1, 145-148

Kjellberg, A. (1977b). (see pg 44-20 in Handbook of Perception and Human Performance Vol. 2)

Klein, K. E., & Wegmann, H. M. (1980). Significance of circadian rhythms in aerospace operations. NATO AGARDograph Number 247. Neuilly sur Seine, France: NATO AGARD.

Kogi, K., & Ohta, T. (1975). Incidence of near accidental drowsing in locomotive driving during a period of rotation. *Journal Human Ergology*, 4(1): 65-76.

Kurumatani, N., Koda, S., Nakagiri, S., et al. (1994) The effects of frequently rotating shiftwork on sleep and the family life of hospital nurses. Ergonomics, Jun; 37(6):995-1007.

Lamberg, L. (1996). Knitting up the raveled sleeve of care: Role of sleep and effects of its lack examined. Oct 16; 276(15): 1205-1207.

Lauber JK and Kayten PJ. (1988). Sleepiness, circadian dysrhythmia, and fatigue in transportation system accidents. *Sleep*, 11(6):503–512

Lavie, P., Kremerman, S., & Wiel, M. (1982). Sleep disorders and safety at work in industry workers. *Accident Analysis & Prevention*, 14, 311-314.

Lenne, M. G., Triggs, T. J., & Redman, J. R. (1997). Time of day variations in driving performance. *Accident Analysis and Prevention*, 29(4): 431-437

Levine, B., Roehrs, T., Zorick, F., & Roth, T. (1988). Daytime sleepiness in young adults. *Sleep*, 11: 39-46.

Lille, F., Cheliout, F., Burnod, V., Hazeman, P. (1979). Effects of aging and occupational activity on active wakefulness. *Gerontology*, 25, 337-344.

Lisper, H. O., Laurell, H., & van Loon, J. (1986). Relation between time of falling asleep behind the wheel on a closed track and changes in subsidiary reaction time during prolonged driving on a motorway. *Ergonomics*, 29, 445-453

Luna, T. D., French, J., & Mitcha, J. L. (1997). A study of USAF air traffic controller shiftwork: sleep, fatigue, activity, and mood analyses. *Aviation, Space, and Environmental Medicine*, 68(1), 18-23.

Lyman, E. G., Orlady, H. W. (1981, March 31). *Fatigue and Associated Performance Decrements in Air Transport Operations.* NASA Ames Research Center, Battelle Columbus Laboratories, ASRS Office.

Maher, K., & McPhee, B. (1994, April). *Flight crew duty and rest.* Sidney, Australia: Worksafe Australia.

McFarland, R. A. (1953). *Operational Aspects of Fatigue In Human Factors in Air Transportation.*

Miles, W. (1929). Sleeping with the eyes open. *Scientific American*, 140, 489-492.

Miles, L., & Dement, W. C. (1980). Sleep and aging. *Sleep*, 3, 1-220.

Mills, M. E., Arnold, B., Wood, C. M. (1983). Core-12: A Controlled Study of the Impact of 12-Hour Scheduling. *Nursing Research*, 32, 356-361.

Minors, D. S., & Waterhouse, J. M. (1984). The sleep-wakefulness rhythm, exogenous and endogenous factors (in man). *Experientia*, 40(5): 410-416.

Mitler, M. M. (1991). Two-peak 24-hour patterns in sleep, mortality, and error. In: *Sleep and Health Risk* (Eds.) Peter, J. H., Pengel, T., Podszus, T., von Wichert, P., & Springer-Verlag, NY 65-77

Mitler, M. M., Miller, J. C., Lipsitz, J. J., Walsh, J. K., Wylie, C. D. (1997). The Sleep Of Long-Haul Truck Drivers. *New England Journal of Medicine*, 337, 756-761

Mohler, S. R. (1966). Fatigue in aviation activities. *Aerospace Medicine*, 37, 722-732.

Morris, T. L., Miller, J. C. (1996). Electroculographic and performance indices of fatigue during simulated flight. *Biological Psychology*, 42, 343-360.

Moskowitz, H. (1973). A behavioral mechanism of alcohol-related accidents. In M. E. Chafetz, (Ed.). *Proceedings of the First Annual Alcoholism Conference of the National Institute of Alcohol Abuse and Alcoholism. Research on Alcoholism: Clinical Problems and Special Populations.*

Mullaney, D. J., Fleck, P. A., Okudaira, N., Kripke, D. F. (1985). An Automated System for

Administering Continuous Workload and for Measuring Sustained Continuous Performance. *Behavioral Research Methods, Instruments, & Computers.* 17, 16-18.

Mullaney, D. J., Kripke, D. R., Fleck, P. (1991, August). Sleep loss effects on continuous sustained performance. Technical Report #1. San Diego: University of California Department of Psychiatry. (1981). Cited in Evans, S. M., Mackie, R. R., Wylie, C. D. *Fatigue Effects on Human Performance In Combat: A Literature Review.* US Army Research Institute for the Behavioral and Social Sciences, ARI Research Note 91-90.

National Commission on Sleep Disorders Research. (1993). *Wake Up America: A National Sleep Alert. Report of the National Commission on Sleep Disorders Research. Executive Summary and Executive Rreport.* Washington, DC: National Commission on Sleep Disorders Research.

National Transportation Safety Board. (1994, January). *A Review of Flightcrew-involved, Major Accidents of U.S. Air Carriers, 1978 Through 1990.* Safety Study: NTSB/SS-94-01.

Neri, D. F. Shappell, S. A., & DeJohn, C. A. (1992). Simulated sustained flight operations and performance. Part 1: Effects of fatigue. *Military Psychology.*

Neville, K. J., French, J., Bisson, R. U., Boll, P. A., Storm, W. F. (1992). Sleep and Flight Duration Effects On The Subjective Fatigue Of Pilots During Operation Desert Storm. *Proceedings of the Human Factors Society,* 102-105.

Nicholson, A. N. (1987). Sleep and wakefulness of the airline pilot. *Aviation, Space and Environmental Medicine,* 58, 395-401.

Nicholson, A. N., Stone, B. M., Borland, R. G., & Spencer, M. B. (1983). Adaptation to irregularity of rest and activity. In: *Sustained Intensive Air Operations: Physiological and Performance Aspects. AGARD Conference Proceedings,* No. 338, 12.1-12.6

Ogilvie, R. D., Wilkinson, R. T. and Allison, S. L. (1989). The detection of sleep onset: Behavioral, physiological and subjective convergence. *Sleep,* 12, 458-474.

Pack, A. M., Cucchiara, A., Schwab, C. W., Rodgman, E., & Pack, A. I. (1994). Characteristics of accidents attributed to the driver having fallen asleep. *Sleep Research,* 23.

Perelli, L. P. (1980, December). *Fatigue Stressors in Simulated Long Duration Flight: Effects on Performance, Information Processing, Subjective Fatigue and Physiological Costs.* School of Aerospace Medicine, Brooks Air Force Base. Report No. SAM-TR-80-49.

Pokorny, M. L. I., Blom, D. H. J., van Leeuwen, P. (1981a). Analysis of Traffic Accident Data (From Bus Drivers)—An Alternative Approach (I). In A. Reinberg, N. Vieux & P. Andlauer

(Eds.). Night and Shift Work.

Pokorny, M. L. I., Blom, D. H. J., van Leeuwen, P. (1981b). Analysis of Traffic Accident Data (From Bus Drivers)—An Alternative Approach (II). In A. Reinberg, N. Vieux & P. Andlauer (Eds.). Night and Shift Work.

Prernitis, C. (1981). Shiftwork: Workload, fatigue and states of vigilance. In A. Reinbert, N. Vievn & P. Andlaver (Eds.), *Night and Shift Work: Biological and Social Aspects*.

Reinberg, A. E., & Smolensky, M. H. (1994). Night and shift work and transmeridian and space flights. In: *Biologic Rhythms in Clinical and Laboratory Medicine*, Springer-Verlag, NY, 243-255.

Restak, Richard M. (1988). *The Mind*. Bantam Books, NY. New York.

Ribak, J., Ashkenazi, I. E., et al. (1983). Diurnal rhythmicity and air force flight accidents due to pilot error. *Aviation, Space, and Environmental Medicine*, 54(12): 1096-1099.

Richardson, G. S., Carskadon, M. A., Orav, E. J., & Dement, W. C. (1982). Circadian variation of sleep tendency in elderly and young adult subjects. *Sleep*, 5, S82-94.

Roehrs T, Timms V, Zwyghuizen-Doorenbos A, and Roth T. (1989). Sleep extension in sleepy and alert normals. *Sleep*, 12, 449–457.

Rosa, R. R., & Bonnet, M. H. (1993). Performance and alertness on 8 h and 12 h rotating shifts at a natural gas utility. *Ergonomics*, 36, 1177-93.

Rosa, R. R., Colligan, M. J. (1987). Sleep quantity and quality under 8-hour and 12-hour rotating shift schedules. *Sleep Research*, 16, 811.

Rosekind, M. R., & Schwartz, G. E. (1988). Perception of sleep and wakefulness. I. Accuracy and certainty of subjective judgments. *Sleep Research*, 17, 89.

Rosekind, M. R., Graeber, R. C., Dinges, D. F., Connell, L. J., Roundtree, M. S., Spinweber, C. L., Gillen, K. A. (1994, July). *Crew factors in flight operations IX: Effects of planned cockpit rest on crew performance and alertness in long-haul operations*. NASA Technical Memorandum 108839.

Rosenthal, L., Merlotti, L., Roehrs, T. A., & Roth, T. (1991). Enforced 24-hour recovery following sleep deprivation. *Sleep*, 14, 448-453.

Roth, T., Roehrs, T. A., Carskadon, M. A., Dement, W. C. (1994). Daytime Sleepiness and

Alertness. In M. H. Kryger, T. Roth & W. C. Dement (Eds.), *Principles and Practice of Sleep Medicine*. WB Saunders Co.

Samel, A., & Wegmann, H. M. (1987). Desynchronization and internal dissociation in aircrew. *Ergonomics*, 30, 1395-1404.

Samel, A., Wegmann, H. M., & Vejvoda, M. (1996). Aircrew fatigue in long-haul operations. *Accident. Analysis & Prevention*, 29, 439-452.

Samel, A., Wegmann, H. M., Vejvoda, M. (1995). Jet lag and sleepiness in aircrew. *Journal of Sleep Research*, 4, 30-36.

Samel, A., Wegmann, H. M., Drescher, V. M., Gundel, A., Manzey, D., Wenzel, J. (1997). Two-Crew Operations: Stress and Fatigue During Long-Haul Night Flights. *Aviation, Space, and Environmental Medicine*, 68, 679-87.

Sasaki, M., Kurosaki, Y., Mori, A., Endo, S. (1986a). Patterns of Sleep-Wakefulness Before and After Transmeridian Flight in Commercial Airline Pilots. *Aviation, Space, and Environmental Medicine*, 57, B29-B42.

Sasaki M, Kurosaki Y, Mori A, and Endo S. (1986b). *Patterns of Sleep-Wakefulness Before and After Transmeridian Flight in Commercial Airline Pilots. Crew Factors in Flight Operations: IV Sleep and Wakefulness in International Aircrews*, RC Graeber (Ed.), NASA Technical Memorandum No. 88231. Moffett Field, CA: Ames Research Center.

Schoenborn, C. A., & Cohen, B. H. (1986). *Trends in Smoking, Alcohol Consumption, and Other Health Practices Among U.S. Adults, 1977 and 1983*. National Center for Health Statistics, U.S. Department of Health and Human Services, Hyattsville, MD, No 118: 1-16.

Schoenborn, C. A., & Danchik, K. M. (1980). *Health practices among adults: United States 1977*. Advance data. National Center for Health Statistics, U.S. Department of Health and Human Services, Hyattsville, MD, 64: 1-10.

Shappell, S. A., & Neri, D. F. (1993). Effect of combat on aircrew subjective readiness during Operations Desert Shield and Desert Storm. *International Journal of Aviation Psychology*, 3,231-25.

Shingeldecker, C. A., & Holding, D. H. (1974). Risk and effort measure of fatigue. *Journal of Motor Behavior*, 6, 17-25.

Smiley, A. (1996, November). *Interpretation of Operator Performance Data. In: Operator Performance Measurement: Developing Commonality Across Transportation Modes -*

Proceedings of a September 1994 Workshop. DOT Human Factors Coordinating Committee Final Report

Smith, L., Folkard, S., Poole, C. J. M. (1994). Increased injuries on night shift. *Lancet*, 344, 1137-1139.

Spencer, M. B. (1987). The influence of irregularity of rest and activity on performance: a model based on time since sleep and time of day. *Ergonomics*, 30, 1275-1286.

Takahasi, J. S. (1996). The biological clock: It's all in the genes. In R. M. Buijo, A. Kalsbeek, H. J. Romijn, C. M. Pennartz & M. Mirmiran (Eds.), *Hypothalamic Integration of Circadian Rhythms*.

Taub, J. M. (1981) Behavioral and Psychobiological Effect Of Ad-libitum Extended-delayed Sleep. In I. Karacan (Ed.), *Psychophysiological aspects of sleep*. Park Ridge, N. J.: Noyes Medical Publications.

Taub, J. M., & Berger, R. J. (1973). Performance and Mood Following Variations in the Length and Timing of Sleep. *Psychophysiology*, 10, 559-570.

Taub, J. M., & Berger, R. J. (1976) The effects of changing the phase and duration of sleep. *Journal of Experimental Psychology*, 2: 30-41.

Thomas, M. L. (1997). *Brain and Behavioral Effects of Prolonged Wakefulness in Humans: A Positron Emission Tomography Study of Brain Glucose Metabolism During Task Performance After 48 hours of Sleep Loss*. Unpublished doctoral dissertation. George Mason University.

Thomas, M. L., Sing, H. C., Belenky, G., et al. (1993) Cerebral Glucose Utilization During Task Performance and Prolonged Sleep Loss. *Journal of Cerebral Blood Flow and Metabolism*, 13(Suppl 1), S531

Thorne, D., Genser, S., Sing, H., & Hegge, F. (1983). Plumbing human performance limits during 72 hours of high task load. *Proceedings of the 24th DRG Seminar on The Human As A Limiting Element In Military Systems, Volume 1*. Toronto, Canada, May 2-4

Torsvall, L., & Akerstedt, T. (1988). Disturbed sleep while being on-call: An EEG study of ships' engineers. *Sleep*, 11, 35-38.

Totterdell, P., & Folkard, S. (1990). The Effects of Changing From a Weekly Rotating to a Rapidly Rotating Shift Schedule. In G. Costa (Ed.), Shiftwork: Health, Sleep, and Performance

Turek. F. W., & Van Reeth. O (1996 Circadian rhythms. In M. J. Regly & C. M. Blatteis (Eds.). *Handbook of Physiology. Environmental Physiology.*

Webb. W. B. (1985) Sleep in industrial setting in the Northern Hemisphere. *Psychological Reports.* 57. 591-589.

Webb. W. B., & Agnew, H. W. (1975) Are we chronically sleep deprived? *Bulletin of the Psychonomic Society.* 6. 47-48.

Webb. W., & Campbell. S. (1980). Duration of non-laboratory sleep in an aging population. *Sleep Research,* 9, 118.

Wegmann. H. M., Gundel, A., Naumann, M., Samel, A., Schwartz, E., & Vejvoda, M. (1986). Sleep. sleepiness, and circadian rhythmicity in aircrews operating on transatlantic routes. *Aviation, Space and Environmental Medicine.* 55, 1085-96.

Wegmann. H. M., Klein. K.E. (1985). Jet lag and aircrew scheduling Folkard & T. Hmonk (Eds.). *Hours of work.* Chichester: Wiley. (pp. 263-276)

Wehr, T. A. (1996). The clock for all seasons in the human brain In R. M. Buijs, A. Kalsbeek, H. J. Romijn, C. M. A. Pennartz, & M. Mirmiran (Eds.), Hypothalamic integration of circadian rhythms.

Wehr. T. A., Moul, D. E., Barbato. G., Giesen. H. A., Seidel. J. A., Barker. C., et al. (1993) Conservation of photoperiod-responsive mechanisms in humans. *American Journal of Physiology.* 265, R846–57.

Wilkinson. R. T. (1965 Sleep deprivation. Performance tests for partial and selective sleep deprivation. *Progress in Clinical Psychology.* 8, 28-43

Wilkinson RT. Edwards RS. & Haines E. (1966) Performance following a night of reduced sleep. *Psychonomic Science.* 5. 471–472

WRAIR (1997, October). Interim report: A dose/response study of sleep and wakefulness. Phase I: Actigraphic assessment of CMV drivers over 20 consecutive days. Walter Reed Army Institute of Research. Washington, DC.

APPENDIX C

A Scientific Review of Proposed Regulations Regarding Flight Crewmember Duty Period Limitations

Docket #28081

The Flight Duty Regulation Scientific Study Group†

Preparation of this document was supported by a grant from the Independent Pilots Association

Running title: Review of proposed flight duty regulations

Correspondence to : Gary S. Richardson, MD
Endocrine-Hypertension Division
Brigham and Women's Hospital
221 Longwood Avenue
Boston, MA 02115

† Co-Chairs: Wallace A.Mendelson, MD, Cleveland Clinic Foundation; Gary S. Richardson, MD, Brigham & Women's Hospital and Harvard Medical School; Thomas Roth, PhD, Henry Ford Hospital.

THE FLIGHT DUTY REGULATION SCIENTIFIC STUDY GROUP

Co-Chairs: **Wallace B. Mendelson, MD,** is the Director of the Sleep Research Laboratory and Professor of Psychiatry and the University of Chicago. He is an internationally recognized authority on sleep disorders, particularly insomnia, and on the pharmacology of sleep and wakefulness. He has been an officer on the executive boards of both the Sleep Research Society and the American Sleep Disorders Association, and participated in the formulation of national policy on the diagnosis and treatment of sleep disorders.

Gary S. Richardson, MD, is Associate Physician at Brigham and Women's Hospital in the Section on Circadian and Sleep Disorders Medicine, and an Instructor in Medicine at Harvard Medical School. He is an internationally recognized authority on circadian rhythms in human sleep and alertness, and has served as a consultant to the Department of Transportation and industry on the effects of shift work and sleep deprivation on human health and performance. He has been an officer on the executive board of the Sleep Research Society.

Thomas Roth, PhD, is Director of Research for the Henry Ford Health System in Detroit. He is also Director of the sleep disorders program and an internationally recognized authority on sleep, sleepiness and human performance. He is past president of both the Sleep Research Society and the American Sleep Disorders Association, and is Chairman of the Advisory Council for the Center for Sleep Disorders Research within the National Institutes of Health. Dr. Roth has served as a consultant to the Department of Transportation, National Highway Traffic Safety Association and NASA.

Members:

Ruth Benca, MD, PhD
University of Wisconsin/Madison
Madison, WI 53792

Cynthia Dorsey, PhD
McLean Hospital
Belmont, MA 02178

Barbara Phillips, MD, MSPH
Good Samaritan Hospital
Lexington, KY 40508

Timothy Roehrs, PhD
Henry Ford Hospital
Detroit, MI 48202

Mary A. Carskadon, PhD
Bradley Hospital
East Providence, RI 02915

Mark Mahowald, MD
Hennepin County Medical Center
Minneapolis, MN 55415

James Walsh, PhD
St. Luke's Hospital
Chesterfield, MO 63017

Gary Zammit, PhD
St.Luke's-Roosevelt Hospital
New York, NY 10025

"Review of proposed flight duty regulations"
The Flight Duty Regulation Scientific Study Group

1. Introduction

This document is intended to provide a review of the proposed flight-duty regulations for flight crewmembers as defined by the Federal Aviation Administration (FAA) in the Notice of Proposed Rule-making (NPRM) (1). The Flight-Duty Regulation Scientific Study Group (the "Study Group") was organized in response to a request by the Independent Pilots Association (IPA) for a scientific review of the NPRM, including a detailed determination of the extent to which the proposed regulations adequately address the problems of fatigue and sleep deprivation in flight crew, and the extent to which they appropriately utilize available scientific information, both that expressly cited in the NPRM and the larger body of scientific literature regarding the origins of human fatigue in sustained operations.

The Study Group consists of members of the scientific community with research interests in the fields of human sleep and circadian physiology, and sleep disorders medicine. While some of the members of the Study Group have participated in an advisory or review capacity in the evaluation of extended duty limitations in other work settings, including other transportation sectors, none of the members has had previous involvement in the development of these flight-duty regulations or in the NASA research projects cited as providing the specific foundation for the current NPRM. Thus, it is the intent of the Study Group that this document will constitute a new and independent review, incorporating the perspectives provided by regulatory efforts in other industries and by research performed in other related areas.

Another important principle guiding our review and assessment of the proposed regulations requires express statement at this point. It is the position of the Study Group that the success of any attempt to regulate duty schedules to guarantee adequate rest depends jointly upon the provision of adequate opportunity for rest within the schedule, and upon the responsible cooperation of the regulated individual. However, personal behavior cannot practically be regulated. Experience with attempts to provide improved rest opportunities in other settings demonstrates that time provided for sleep is often used for other things, effectively defeating the intent of the original provision. The solution to this limitation is a continued emphasis on education of the regulated group regarding the nature of the problem and their role in its solution. However, the Study Group feels strongly that the possibility of compromise of allocated rest time should not relieve regulatory authority of the responsibility for insuring that adequate time is provided for rest.

Finally, it is also important to state in this introduction that, despite its evident limitations, the proposed NPRM represents unambiguously important and valuable progress. The Study Group unanimously feel that the FAA is to be applauded for persisting in this effort, and for producing a set of proposed regulations that attempt to incorporate current understanding of human sleep physiology. To our view, this incorporation is not as complete as it can or should be, and the issues identified in this review are meant as suggestions for improvement in the proposed regulations. It is our hope that many of the important adjustments can be included in the final set of rules produced by this effort, whereas other issues clearly represent deficits in the current scientific database. These will require additional research attention before they can be addressed in future rule-making efforts.

The goal of providing safe travel 24 hours a day requires optimum crew alertness and performance at all times. Since human alertness is highly dependent on the complex regulatory system governing sleep and wakefulness, we will begin this review by summarizing current understanding of the physiologic systems regulating sleep and wakefulness, and the factors that contribute to human fatigue. In subsequent sections, we will 1) summarize the adequacy of the proposed changes in flight duty regulations (1) in addressing the relevant aspects of human physiology, and 2) summarize areas where we believe that the proposed regulations can and should be revised and expanded to better address these issues with the goal of optimization of aircrew alertness and air travel safety.

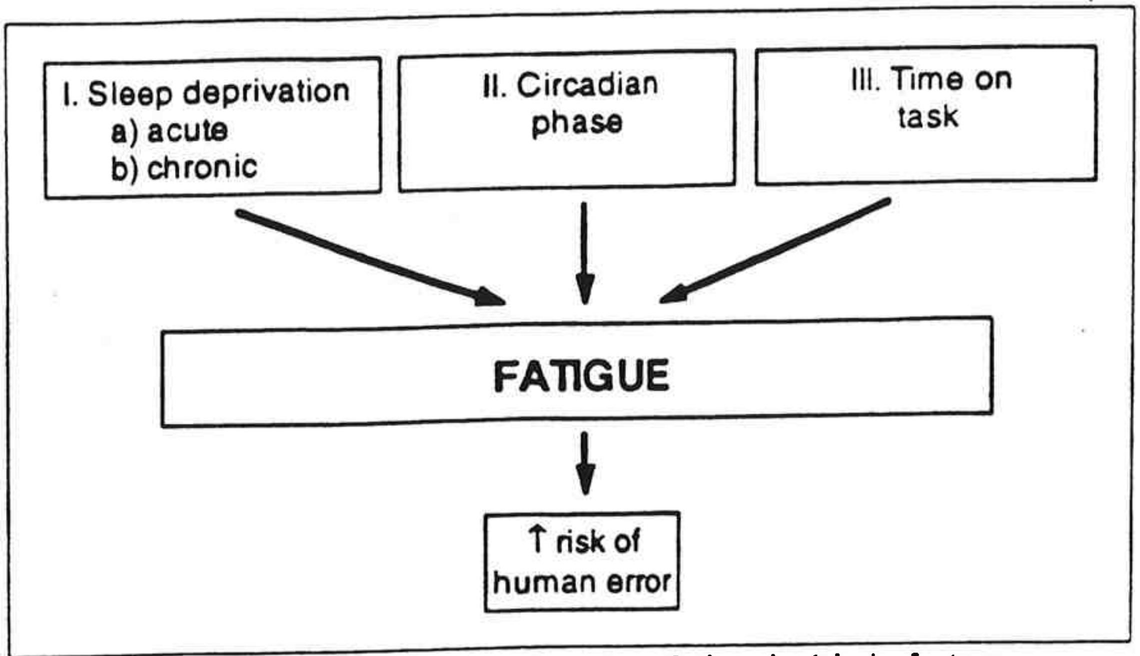


Figure 2-1: Schematic representation of the physiologic factors contributing to human fatigue in sustained operations

2. Scientific Background

2.1. A working definition of fatigue

Much of the literature cited in support of the proposed modifications to the FAA regulations variably use the terms "fatigue" and "sleepiness" to describe the physiological condition arising from inadequate prior sleep and/or the condition that occurs when wakefulness is forced during phases of the circadian cycle appropriate to sleep. The implication of this usage is that these terms are interchangeable, whereas a closer evaluation indicates that they are not, and confusion of the two terms impairs the discussion of the physiologic basis of performance errors and the appropriate focus for interventions. Sleepiness has a precise definition:

> "Sleepiness, according to an emerging consensus among sleep researchers and clinicians, is a basic physiological state (like) hunger or thirst. Deprivation or restriction of sleep increases sleepiness, and as hunger or thirst is reversible by eating or drinking, respectively, sleep reverses sleepiness."*

By contrast, the term "fatigue", as it is used in the human performance context, does not have a precise physiologically-based definition. Instead, fatigue is used in a broader sense to describe deterioration in human performance, arising as a consequence of several potential factors, including sleepiness. When the intent is to prevent human error, it is necessary to go beyond the broad definition and identify the specific physiologic components which then become the target for intervention. This review will reserve the term fatigue for the general condition in which performance is impaired, and will identify and focus upon three contributors to human fatigue, the control and limitation of which is necessary to the optimization of performance of crew members in air flight (Figure 2-1).

---

* From Roth, T., *et al.*, Daytime sleepiness and alertness. In *Principles and Practice of Sleep Medicine*, M.H. Kryger, T. Roth, and W.C. Dement, Eds. 1989, W.B.Saunders: Philadelphia. p. 14-23.

2.2. Homeostatic regulation of sleep

As suggested, the most prominent among potential causes of fatigue is a decline in human alertness (or an increase in sleepiness) occurring as a consequence of sleep deprivation. Sleep deprivation can be thought of as an inadequate fulfillment of the homeostatic need for sleep(2), either over the short term ("acute sleep deprivation"; Figure 2-1) or gradual sleep deprivation over the longer term ("chronic sleep deprivation"; Figure 2-1).

The homeostatic mechanism is reflected in common sense observation that an individual who does not get adequate sleep prior to performing a task will be sleepy, and performance of the task will be impaired. In designing appropriate schedules to determine what is "adequate sleep", several factors need to be considered: 1) although the average amount of sleep needed for daily alertness is typically a little less than eight hours, there is tremendous individual variation. Thus what may be sufficient for one individual may not be enough for another; 2) The effectiveness of sleep in maintaining daytime alertness changes across the lifetime, and declines in older age (3). This suggests that in older crew members the need for adequate pre-flight sleep is particularly important: 3) Complete recovery from operating with an inadequate amount of sleep ("sleep deprivation") does not occur after a single sleep period (4, 5). Two or three sleep cycles are usually required before normal levels of alertness are achieved following sleep deprivation. 4) There is evidence that sedatives including sleeping pills or alcohol have profoundly greater effects, and may have longer duration of action, in a person who has had inadequate sleep (6). Thus the duration of time needed for safe performance following use of such compounds may be prolonged in a person who took them in a state of sleep deprivation.

2.3. Circadian modulation of sleep, sleepiness and performance.

The second factor in determining the levels of sleepiness is the phase of the human circadian clock (Figure 2-1). Circadian rhythmicity is the term used to describe diurnal variations in physiologic functions that derive from time-keeping systems within the organism. Circadian rhythms are apparent in the physiology of virtually all plants and animals, and this ubiquity suggests that internal time-keeping was an important adaptation to the 24-hour variation in the external environment (7). In mammals, including humans, circadian rhythms are controlled by sophisticated neural clocks located at the base of the brain that use photic information from the retina to orient physiologic rhythms with respect to external time. In diurnal ("day-active") species such as the human, the circadian clock is oriented so that alertness, metabolic activity, and various other functions increase by day to facilitate the physical activity and behaviors exhibited at those times (8). By night, alertness is decreased and metabolic activities are commensurably reduced to facilitate sleep and conserve metabolic energy. Laboratory studies of the influence of the circadian clock typically rely on continuous body temperature measurements to track the clock's influence on metabolism. Core body temperature is remarkably rhythmic in humans when it is measured in conditions carefully designed to eliminate outside influences.

The circadian rhythm of body temperature has a peak between the hours of 4 and 6 PM in the evening, and a trough approximately 12 hours later at 4 to 6 AM. While the exact position of these reference points may vary from individual to individual, in healthy adults, they are remarkably consistent within a relatively narrow range. Studies of human performance as a function of time of day have demonstrated clear circadian rhythms in several different types of performance functions. For the most part, this variation mirrors the circadian variation in sleepiness (*i.e.* minimum in performance capacity in the early morning hours (between 4 and 6 AM) coincident with minimum body temperature and maximum sleepiness) (9). These data are consistent with the generally accepted hypothesis that important circadian variation in performance is a secondary consequence of the circadian variation in sleepiness.

Further, an extensive body of laboratory data has established that human circadian clocks rely upon light-dark variation to orient circadian rhythmicity relative to external time (10). A dependence of this effect on the intensity of the light means the external sunlight exposure typically dictates the orientation of an individual's circadian clock. Studies of the relationship between circadian orientation and light-dark cycles have progressed to the point where it is now possible to make reasonable estimates of the effect of transmeridian travel, with the consequent alterations in light-dark exposure, on internal circadian orientation and the dependent rhythms in alertness and performance (11).

Studies of the circadian system lead to several conclusions relevant to extended-duty paradigms such as those in aviation: 1) Attention only to the needs of the homeostatic system will not result in adequate alertness. Thus a crew member who works in the early morning hours of 4 - 6 AM will not necessarily be as alert as one working during daylight hours, even if both had been off-duty for the same amount of time prior to work. 2) When flight plans involve transmeridian travel, duty requirements may lead the crew to need to function at times in which the body's propensity is to sleep; 3) When crew land at transmeridian destinations, their internal circadian systems may be out of phase with those of the new local environment (12). Thus they may be in their own internal sleep phase when it is daytime at the new destination.

Further, several factors need to be considered in designing schedules that allow for these circadian processes. The first is that there is a great deal of individual variation in the ability to adapt to changing schedules of this type (13). In addition to this individual variability the ability to adapt to changing shift schedules declines with age. Hence older crew members are more likely to experience difficulty adjusting to new time periods of sleep and waking. Second, the ability to adjust to new time schedules depends on the direction of transmeridian travel. In general, short-term changes of four or more time zones in eastward travel are more difficult to adapt to than equivalent westward travel. The implication of this is that recommendations for adequate rest may need to be tailored specifically for the direction of travel. Third, recovery sleep itself is influenced by the time of the circadian day (14). Thus a 10 hour period for recovery sleep in a new time zone will not initially be as effective in restoring alertness as an equivalent recovery period in the home time zone. Fourth, the use of hypnotic medication (sleeping pills) may improve sleep in adverse phases of the circadian cycle, but the relationship of this improved sleep to subsequent performance is complex and still under study (15). Finally, one environmental factor-- the amount and timing of exposure to sunlight (or equivalent bright artificial light)-- can greatly influence the ability to adapt to new sleep and waking schedules (16). Thus exposure to sunlight, or the use of appropriately timed artificial light, may be useful in helping an individual receive adequate sleep. Conversely, inappropriate exposure to bright light may inhibit that individual's ability to receive adequate rest.

2.4. Time on task

The third factor that can contribute to fatigue is the duration of time spent working without significant interruption ("time-on-task; Figure 2-1). Evidence suggests that a complex relationship exists between task efficiency, as measured by the probability of error, and time spent working on the task. In studies of manufacturing settings, the probability of error begins at a relatively high level at the beginning of the shift ("re-familiarization"), rapidly declines to optimal levels within a few hours, then steadily increases over the remainder of the (typical) eight-hour shift ("task fatigue"). Studies of longer shift durations consistently suggest the rate at which performance deteriorates may increase for durations beyond 8 hours and this has been an important factor in efforts to limit maximal shift duration in a variety of settings (17).

Time-on-task effects are the least studied and least understood of the factors contributing to human fatigue. For example, unlike sleep deprivation which can only be reversed by sleep, performance deterioration associated with prolonged task duration appears to be task specific, reversing with time away from the task, even if the time is spent with other waking activities. But important data about the nature of this effect, particularly as it might relate to complex tasks such as those performed by flight crews, is not yet available. It is not clear, for example, whether inherently variable tasks can modulate the rate at which performance deteriorates. Further, there are important methodological issues that have not all been addressed in available studies of time-on-task effects. For long task durations, *i.e.* 8 or more hours, sleep deprivation and circadian phase effects will necessarily vary significantly over the course of the task, confounding interpretation of performance changes. Studies systematically varying circadian and sleep deprivation (homeostatic) influences to isolate the time-on-task effects have not yet been performed. Pending collection of such data, ideally specific to flight crew job requirements, available time-on-task data nonetheless raise significant general concerns about sustained shift durations, particularly those greater than 10 hours.

An additional important factor in the determination of time on task effects is task intensity. Fatigue generally accumulates faster in high intensity tasks than in low intensity tasks, suggesting that maximum task durations should be adjusted according for task intensity. However, in practice, task intensity can be very difficult to measure. Within aviation, this principle has been used to justify adjustments of maximum shift duration as a function of the number of landings on the widely accepted premise that landings are the most intensive aspect of aviation.

2.5. Interactions

Beyond their direct relationship to human fatigue and the probability of error, each of the physiologic axes identified above also interacts with the others to potentiate adverse effects. Thus, the extent of sleepiness and performance impairment produced by moderate sleep deprivation is greater at 4 AM than it is at 4 PM. Similarly, the rate at which time-on-task effects on performance accumulate depends both on the circadian phase at which the task is performed, and on the extent of prior sleep deprivation on the part of the person performing it. The importance of the circadian system in modulating both alertness and the ability to sleep results in another important interaction. In addition to the direct adverse effect on alertness and performance, work on the "back side of the clock" over a number of successive nights results in chronic sleep deprivation as a consequence of impaired ability to sleep during the day. This sleep deprivation can then potentiate the performance impairment on later night shifts.

These interactions have made it difficult to isolate the physiologic contributors to fatigue in the laboratory and assess their relative magnitude and importance; for example, how much sleep deprivation is equivalent to work at the circadian nadir? Without more data on this issue, the only effective strategy for intervention requires addressing each of the three axes as completely as possible.

2.6. Shift-work

The focus of this effort on the scheduling of flight crews occurs in the context of general concern about extended duty, night work, and consequent sleep deprivation in a large number of occupations with public safety implications (18). A growing number of US. workers are called upon to routinely work other than regular daylight hours. It is estimated that some twelve million people in the United States now fit this broad definition of shiftworker (19). A number of strategies have evolved to provide for extended duty and nighttime coverage of the growing variety of service and manufacturing settings that require continuous staffing. The most common of these is the "rotating" shift schedule in which crews of workers work successive shifts for one or more weeks at a time. The shifts typically are days (8 AM to 4 PM), evenings (4 PM to midnight) and nights (midnight to 8 AM). While rotating shifts of this kind, varying slightly with regard to starting time and direction of rotation, probably the most common implementation for continuous coverage, a number of other approaches have been used as well. As a consequence, specific data regarding the impact of a given shift schedule, or even specific shift durations, on human performance, sleepiness, or other human factors are not always available. It is also important to realize that generalization from research results regarding a specific schedule to all shift work is rarely justified.

It is recognized that night-work can be deleterious to workers' safety and productivity in part because of the increased risk of performance errors during the early morning hours (between 4 and 6 AM). While various shift work schedules may be capable of modulating this risk to a greater or lesser degree, recent work on the importance of sunlight to human circadian function (see above) has established that this nighttime vulnerability to error persists even in shiftworkers with years of night work experience. It is important to realize that an individual working nights is at risk for significant sleepiness for two distinct reasons: First, work during the early morning hours (between 4 and 6 AM) is associated with the previously-described circadian increase in sleepiness and sleepiness mediated performance errors. In addition, an individual working successive nights is forced to obtain sleep during the daylight hours at a time when the circadian pre-disposition to sleep is minimal (20). As mentioned, sleep under these circumstances is typically fragmented, sleep state architecture is distorted and the restorative nature of sleep (per hour of sleep attempted) is reduced. Thus, over time, the night shift worker accrues cumulative sleep deprivation which when added to the circadian sleep effects can produce profound impairment. A consequence of this is that the unifying aspect of successful strategies for combating the increase in performance errors by shift-workers on the night shift is to maximize the amount of sleep obtained, compensating as much as possible for the inefficiency of daytime sleep through sleep extension, napping *etc.*, and preventing the accumulation of significant chronic sleep deprivation.

2.7. Fatigue and safety in flight operations

While the problems of sleep deprivation and night-work are certainly not unique to aviation, there can be little doubt regarding the significance of the problem that crew fatigue poses for the aviation industry. Laboratory simulator studies have demonstrated that compliance with current flight-duty regulations and work schedules does not protect against significant sleep deprivation and unacceptable levels of fatigue in flight crews (21). A growing number of field studies have documented that crews are experiencing serious sleepiness during flight operations, and NASA's Aviation Safety Reporting System (ASRS) identified 221 incident reports (over an eight year period) in which crew fatigue contributed to problems during flight operations (1). Finally, the National Transportation Safety Board (NTSB) has identified crew fatigue as a material contributing factor in more than one recent accident. Together, these findings indicate that fatigue is a significant safety issue in the aviation industry, and that the current regulations regarding limitations on flight-duty schedules are an important factor in the genesis of that fatigue.

One important challenge posed by the NPRM is the identification of outcome measures to be used to determine the impact of revised regulations. While available measures have adequately documented the presence of a problem, they would appear to be inadequate for the task of assessing change over a two or three year span immediately following implementation of new flight-duty regulations. The relative rarity of aviation accidents studied by the NTSB makes this measure too insensitive to detect changes that might reasonably be expected to occur in response to small proactive interventions such as a two hour reduction in maximum duty time for example. At the same time, the potential bias inherent in the ASRS database makes these data too subjective. The Study Group feels strongly that an important priority for the immediate future should be the identification and validation of proxy measures of crew fatigue that can be used to effectively monitor the impact of this and future revisions without relying on catastrophic outcomes as the only accepted dependent measure.

3. Summary of proposed guidelines

The FAA cites the NASA technical memorandum "Principles and Guideline for Duty and Rest Scheduling in Commercial Aviation" (22) as the primary source in the preparation of the NPRM (1), although there are important differences between the NASA recommendations and the final NPRM document. The NPRM guidelines address duty period, flight, time, and rest requirements. Secondarily, they discuss reserve periods as well as cumulative duty periods for a week and a month.

There are two important general features of the proposed guidelines. The first is the predication of duty limitations on total duty instead of just flight time. Specific regulations of duty durations specify separate upper limits for total duty time (without an intervening period of rest) and for total flight time within the longer duty segment. The second important general change is the consolidation of regulations for various types of flight operations covered by Part 121 (covering domestic, flag and supplemental flight operations) and elimination of differences between relevant parts of the Part 121 regulations and the Part 135 regulations (covering commuter and on-demand flights). This results in simplification and greatly improved consistency in flight regulations.

TABLE 3-1: SUMMARY OF PROPOSED REGULATIONS

	Description	
1. Flight duty duration	**Crew size**	**Max.duration (duty/flight)**
	1	14/8
	2	14/10
	3	16/12
	3[1]	18/16
	4[1]	24/18
2. Minimum rest duration	**Crew size**	**Min. duration (hours)**
	1	10
	2	10
	3	14
	3[1]	18
	4[1]	22
3. Flight time limits	**Time frame**	**Max. flight time (hours)**
	Per week	32
	Per month	100
	Per year	1200

[1]*With facilities for sleeping in flight*

The new regulations are intended as "...a preventative measure designed to address the potential safety problems associated with fatigue-based performance decrements...by requiring certain scheduling limitations and minimum rest periods." Before assessing the extent to which the proposed regulations accomplish this goal, it is necessary to stipulate their specific provisions. An abbreviated summary of the relevant sections of the NPRM follows (see Table 3-1).

3.1. Revised Flight-Duty Durations

Under the proposed regulations, the base duration of the duty period (2 pilot crew) would be 14 hours. This would include 10 hours of flight time. Importantly, depending on crew size, availability of on-flight sleeping quarters, and operational delays, this can be extracted to 26 hours of duty time and 20 hours of flight time. Increasing crew to three pilots raises duty period to 16 hours, availability of sleep opportunity to 18 hours, and 4 person crews to 24 hours. Any one of these limits can be increased by 2 hours for unplanned operational delay.

3.2. Rest Period

The basic unit of rest, associated with the basic 2 person crew, 14 hour duty period, is 10 hours. Depending on the duration of the duty period, the requirement of the rest period could be as long as 24 hours. It must be recognized that these rules are for the subsequent rest period. Regulations do not specify minimum rest for subsequent duty. Thus, it is possible to have a 10 hour rest period during daytime hours followed by a 26 hour duty period. All rest period requirements can be reduced by up to 1 hour because of operational delays that can increase duty duration by up to 2 hours.

3.3. Stand-By Assignments

Reserve time in this proposal is a period of time when a flight crew member is not on duty but nonetheless must be able to report upon notice (*i.e.* greater than one hour), for a duty period. The guidelines explicitly reject relating amount of time of notice to time of day. Rather, it relates amount of time of advance notification to the maximum duration of the subsequent duty period. With less than 4 hours of notice, only a 6 hours duty period is allowed. As notification period goes to ten or more hours, a full duty period, up to 26 hours depending on circumstances, is allowable. An alternative to this standby schedule is maintaining a constant 6 hour protected time (by request) for each 24 hours of reserve time. During this time, the certificate holder may not contact the crew member to place them on duty. This 6 hour period must be assigned before the crew member begins the reserve time assignment. The duty period must be completed in 18 hours within the reserve time and must be in accordance with the general guidelines.

3.4. Cumulative Limits

The cumulative limits for flight hours are set at 32 hours for any 7 day period, and 100 hours for any calendar month. The yearly period is set by multiplying the monthly requirement by 12 (*i.e.* 1200 hours).

4. Evaluation of proposed regulations

It is important to reiterate and emphasize the Study Group's position that the proposed regulations as defined in the current NPRM on the whole represent an important advance over existing flight-duty regulations. The principal improvement lies in the new dependence of the regulations on total duty time, rather than just flight time, in setting limits on maximum work duration. As reviewed above, this is a much more physiologically sound approach, reflecting the importance that all work time has in the generation of fatigue.

The Study Group did, however, find several specific aspects of the proposed regulations that should be improved upon and/or appear to deviate from the FAA's stated intention "...to incorporate (whenever possible) scientific information on fatigue and human sleep physiology into regulations on flight crew scheduling." (1). Adjustments to the final regulations should address each of the issues identified below.

In comparing the proposed regulations to the stated goals outlined in the introduction to the NPRM and to available data in the scientific literature, the Study Group identified two important general issues.

4.1. Excessive duty duration

While regulation of the maximum duration of total duty time (rather than just flight time) represents an important improvement from the perspective of the limits of human physiology, the actual duration of the proposed work periods substantially exceeds what can reasonably be justified by scientific data on human performance and fatigue. In light of substantial evidence indicating that work durations in excess of 12 hours are associated with a significant increase in the probability of human error independent of circadian phase and prior sleep wake history (13, 23), there can be little scientific justification for baseline work durations of 14 hours, let alone the greater durations permitted under operational delay conditions. The specific duty and time limitations are the same as those specified in the NASA recommendations (22), although there are potentially important differences between the NASA recommendations and the NPRM in the definition of flight time. While the NASA document recognizes the importance of limiting maximum shift duration (Section 1.4; p 4), it provides no evidence in support of the statement that 14 hours within a 24-our period is sufficient limitation (Section 2.2.3), nor was the Study Group able to identify research to suggest that these shift durations might be acceptable in the unique aviation setting. In this regard, it is important to note that these duty periods are significantly longer than those being applied in a range other work settings where regulatory attention has been focused on the problem of fatigue-related performance decrements, including most other transportation sectors.

Absent research data to the contrary, the only relevant findings suggest that performance deteriorates significantly for shift durations greater than 12 hours, and the recommended limits for duty time in the NPRM are not consistent with the implications of those findings. As outlined above, it is not clear whether the variability of task inherent in the flight-duty assignment, *i.e.* shorter durations of flight time within the context of the longer duty schedule, might mitigate the deterioration in performance associated with shifts of equivalent duration in other work settings, however scientific endorsement of the safety of these shift durations must await empirical confirmation of such an effect.

Similarly, the extraordinary duty durations under circumstances where crew number is augmented and/or arrangements for sleep during flight are provided are inadequately justified by available scientific data. It is certainly not clear, based on a review of the studies published by NASA or any other group to date, that augmenting the crew results in a material increase in tolerance for sleep deprivation that would justify an increase in shift duration of the specified magnitude. Other concerns of the Study Group pertain to the specific arrangements for sleep for augmented crews in extended duty durations. The Study Group is very concerned about the adequacy of sleeping arrangements that will be provided in these situations so that crew members can obtain some sleep while relieved by the extra crew. To our review, provision of such facilities addresses only one of several important concerns about the impact of extended duty arrangements. It remains to be determined whether adequate sleep can and will be obtained under operational conditions. While available data on cockpit napping have demonstrated that brief naps have a clearly beneficial effect over the short term on crew alertness (24), published studies have not yet shown that this improvement is sufficient in magnitude and duration to allow a significantly sleep-deprived crew member to return to duty. The second half of this concern is that several studies in other contexts have demonstrated that simply providing the opportunity for sleep in the extended-duty setting does not guarantee that such sleep will actually be obtained. Without express stipulation about the amount and scheduling of rest/sleep to be obtained by crew members, it is our concern that the revised regulations sanction extraordinarily long extended duty arrangements without providing any reasonable likelihood that adequate sleep will be obtained.

Finally, the provisions for rest do not appear adequate to compensate for the clearly heroic demands of duty durations of up to 26 hours. Rest allowances are adjusted for the rest periods following extended duty, not for the rest period preceding it. Thus for crewmembers moving among assignments of varying duration, it is possible to be called upon to work very long shift durations of 24 - 26 hours after limited (as few as 9 hours; "reduced rest"), with no stipulation that this time be provided at a circadian phase conducive to sleep.

In summary of this first concern, the Study Group does not feel there is adequate scientific justification for duty durations greater than 12 hours. Nor is the Study Group confident that compensatory arrangements of extra crew, sleeping quarters in flight, and extended rest provide adequate protection from the extreme fatigue associated with very long work schedules permitted under the proposed regulations.

4.2. No adjustment for "back side of the clock"

Our second major concern is that the proposed regulations make no effort to adjust prescribed limits on work duration or rest duration based on the time of day at which those activities are scheduled. This is the most disappointing omission, and particularly difficult to understand in light of the express predication of the revised regulations on the NASA-Ames database, a body of research that has done much to characterize the dependence of sleep and performance in the aviation setting on human circadian phase. Based both on the NASA studies and the larger body of scientific evidence developed in this area, there can be no doubt about the importance and relevance of circadian physiology to the modulation of human performance and the tendency to human error, and to the ability to obtain sleep and thereby reverse performance decrements arising as a consequence of sleep deprivation.

It is clear that application of circadian physiology to this regulatory effort raises several practical issues. First, regulations that account for time-of-day in provisions for work duration and rest are necessarily more complicated than the proposed set, particularly when transmeridian travel is taken into account. Second, it may prove difficult to develop consensus definitions for the circadian periods of maximal sleepiness and maximal alertness, as well as the precise extent of the adjustments of work and rest duration, respectively, that would be required during those windows. While the Study Group does not feel it is qualified to address detailed issues of practicality, our response to this concern would be that flight duty regulations that adequately account for circadian modulation in the capacity for sleep and in human performance have been used in the United Kingdom for 6 years (since May, 1990), and by account appear to be working well. The Study Group is aware of no qualitative reason why adjustments such as those incorporated in the UK regulations could not be used in the US as well.

4.3. Interactions

While the Study Group feels that each of the identified issues warrants specific modifications of the proposed regulations, the interactions between the two relevant physiologic axes, as reviewed above, greatly compound the concern. With inadequate restrictions on work duration and no compensation for circadian phase, the regulations permit "worst case scenarios" that are well outside scientifically supported limits. For example, without adjustments of rest period duration for circadian phase incompatible with sleep, it is possible to have a routine 14 hour night shift, followed by a rest period of ten hours from 12 noon to 10 PM, *i.e.* precisely coincident with the circadian phase at which sleep is least possible ("the forbidden zone"), followed by a 26 hour shift (assuming operational delay). As stated, provision of in-flight time for sleep can not be assumed to adequately protect against the performance decrements that marathon duty of this kind will inevitably produce.

Similarly, much of the concern about shift duration stems from the absence of any adjustment of duration for the time of day. While future studies could demonstrate that a succession of 14 hour flight-duty day shifts allow maintenance of acceptable performance limits, it is very unlikely that a succession of 14 hour night shifts will be similarly validated. Unless maximum shift durations are kept well within human performance limits, *i.e.* less than 12 hours*, some adjustment for the compounding effects of time-of-day needs to be included.

The Study Group recognizes that worst case scenarios are not likely to be representative of typical flight crew shift durations. However, it is opinion of the Study Group that no reliable protection against such potentially dangerous extremes of scheduling can be had without express adjustments of duty time and rest time for the dictates of the circadian clock, and significant reductions in the maximum length of the duty period.

4.4. Reserve Time

The Study Group has separate but related concerns about the proposed regulations regarding Reserve Time. As reviewed above, two distinct approaches for the protection of rest time within the reserve window are permitted. In the first, termed "variable notice", the maximum length of a duty assignment decreases with the length of the advance notice provided. In the alternate arrangement, termed "protected window", crew members on reserve are assigned a pre-identified six hour window during which they cannot be called. In this specification, the proposed regulation is notably different from the recommendation of the NASA group which called for an eight hour protected period. The window is the same during each successive day on reserve.

The Study Group is concerned that the variable notice arrangement is based on the unproved supposition that sleep deprivation resulting from a short-notice call can be adequately compensated for

* Twelve hours is felt to be the maximum safe shift duration in many shiftwork settings, e.g. nursing. However, there are data demonstrating an increase in performance errors between 8 and 12 hours of shift duration, suggesting to some that the appropriate maximum shift duration in safety-sensitive shiftwork settings should be 8 hours (17).

by reducing the duration of work required. At its extreme, this arrangement would allow a pilot to work for up to 6 hours with effectively no notice, *i.e.* advance notice equivalent to the time required to report to the place of assignment. Presuming worst case timing in which the crew member was called immediately prior to the habitual daily sleep period, continuous wakefulness of more than 22 hours (presuming an eight-hour habitual sleep period) by the end of the 6 hour shift. There is no reason to believe that the reduced shift duration adequately compensates for the performance impairment associated with acute sleep deprivation of this kind.

The Study Group prefers the protected window arrangement, as specifically defined in the NPRM, because the greatest possible extent of sleep deprivation is limited to 18 hours (presuming that the crew member using protected time for sleep). For protected windows during the day, and particularly those during the circadian window of maximal alertness, six hours would not appear to be sufficient to allow adequate rest on repetitive basis.

One major improvement and important safeguard in the current NPRM reserve arrangements is the requirement that a normal rest period precede each reserve assignment. Specific concerns about either reserve arrangement are mitigated by this protection, which should serve as an adequate safeguard against extremes of sleep deprivation, even if subsequent duty assignments occurring during either reserve arrangement are adversely timed.

5. Recommendations

The Study Group concludes that the proposed flight-duty regulations represent an important advance in the effort to define physiologically sound limits that minimize fatigue and optimize flight crew performance and aviation safety. Criticisms of the specific regulations reviewed above are not meant to be construed as a preference for the status quo. Instead, the Study Group urges expedient implementation of the proposed regulations, with the following modifications:

5.1. Recommended revisions to the proposed regulations:

5.1.1. Maximum duty durations should all be adjusted downward to levels in accordance with available data on the relationship between shift duration and degradation of performance. Circadian variation in susceptibility to this degradation should be accommodated with reduced maximums for shifts that include the time of peak circadian sleepiness (4 – 6 AM).

5.1.2. Minimum rest periods should be adjusted upward for sleep periods that include the time of peak circadian alertness (4 – 6 PM).

5.1.3. The provision allowing extension of duty maximums up to 24 hours (26 with operational delay) in augmented crews and in assignments that include facilities for in-flight sleep should not be implemented until scientific evidence is available demonstrating that in flight arrangements preserve alertness at acceptable levels, *i.e.* at levels equivalent to that on the routine shift durations.

5.1.4. Reserve time arrangements should be adjusted so that protected windows during the time of peak circadian alertness are extended to compensate for decreased efficiency of sleep during that time.

5.2. Recommendations for future revisions:

Several of these issues illustrate the need for additional data, and even with adjustments recommended here, specific limits on duty duration and minimum rest duration will represent quantitative implementations of solutions for which there is currently only qualitative scientific support. Therefore, the Study Group also recommends this set of recommendations be viewed as the first step in a continuous process. Specifically,

5.2.1. NASA, in its capacity as independent scientific resource, should be commissioned to gather additional data on this issue with the following priorities;

5.2.1.1. Identification and characterization of a suitable surrogate outcome measure that can substitute for actual accidents and self-reported incidents as a measure of fatigue in flight crews. This proxy measure will then be assessed to continuously monitor the extent of fatigue and the impact of this and future regulatory adjustments.

5.2.1.2. Determination of the impact of duty period duration on performance, independent of sleep deprivation and circadian phase effects. The impact of varying percentages of flight time within a duty period should also be assessed.

5.2.1.3. Determination of the impact of varying workload on performance, with particular attention to the role of landings and sustained flight.

5.2.1.4. Assessment of the protective effect of augmented flight crews and provision of facilities for in-flight sleep on crew alertness with the intent of determining the extent to which duty and flight durations can be safely extended.

5.2.2. An independent scientific panel should review the data collected by NASA on a regular basis with the intent of providing a comprehensive and detailed set of recommended revisions to the regulations within three years from the time at which these recommendations are ultimately implemented.

6. References

1. US Govt Federal Aviation Administration, Flight Crewmember Duty Period Limitations, Flight Time Limitations and Rest Requirements. Notice of proposed rulemaking (NPRM). *Federal Register* 1995;60(244):65951-60.
2. Borbely AA, Baumann F, Brandeis D, Strauch I, Lehmann D, Sleep deprivation: effect on sleep stages and EEG power density in man. *Electroencephalography & Clinical Neurophysiology* 1981;51(5):483-95.
3. Carskadon MA, Brown ED, Dement WC, Sleep fragmentation in the elderly: relationship to daytime sleep tendency. *Neurobiology of Aging* 1982;3(4):321-7.
4. Carskadon MA,Dement WC, Effects of total sleep loss on sleep tendency. *Perceptual & Motor Skills* 1979;48(2):495-506.
5. Rosenthal L, Merlotti L, Roehrs TA, Roth T, Enforced 24-hour recovery following sleep deprivation. *Sleep* 1991;14(5):448-53.
6. Borbely AA, Balderer G, Trachsel L, Tobler I, Effect of midazolam and sleep deprivation on day-time sleep propensity. *Arzneimittel-Forschung* 1985;35(11):1696-9.
7. Moore-Ede MC, Czeisler CA, Richardson GS, Circadian timekeeping in health and disease. *N. Engl. J. Med.* 1983;309:469-76 & 530-6.
8. Richardson GS, Carskadon MA, Orav EJ, Dement WC, Circadian variation of sleep tendency in elderly and young adult subjects. *Sleep* 1982;5(Suppl. 2):82-94.
9. Czeisler CA, Johnson MP, Duffy JF, Brown EN, Ronda JM, Kronauer RE, Exposure to bright light and darkness to treat physiologic maladaptation to night work [see comments]. *New England Journal of Medicine* 1990;322(18):1253-9.
10. Czeisler CA, Allan JS, Strogatz SH, et al., Bright light resets the human circadian pacemaker independent of the timing of the sleep-wake cycle. *Science* 1986;233(4764):667-71.
11. Czeisler CA, Kronauer RE, Allan JS, et al., Bright light induction of strong (type 0) resetting of the human circadian pacemaker. *Science* 1989;244(4910):1328-33.
12. NASA, *Pilot fatigue and circadian desynchronosis*, . 1980, Ames Research Center: Moffett Field, CA.
13. Folkard S, Effects on performance efficiency. In: Colquhoun P, Costa, Folkard S,Knauth R, eds.*Shiftwork: Theory and Practice*. Frankfurt am Main:Peter Lang, 1995:in press.
14. Daan S, Beersma DG, Borbely AA, Timing of human sleep: recovery process gated by a circadian pacemaker. *American Journal of Physiology* 1984;246(2 Pt 2):R161-83.
15. Walsh JK, Schweitzer PK, Anch AM, Muehlbach MJ, Jenkins NA, Dickins QS, Sleepiness/alertness on a simulated night shift following sleep at home with triazolam. *Sleep* 1991;14(2):140-6.
16. Eastman CI, Boulos Z, Terman M, Campbell SS, Dijk DJ, Lewy AJ, Light treatment for sleep disorders: consensus report. VI. Shift work. *Journal of Biological Rhythms* 1995;10(2):157-64.
17. Rosa RR,Bonnet MH, Performance and alertness on 8 h and 12 h rotating shifts at a natural gas utility. *Ergonomics* 1993;36(10):1177-93.
18. U.S. Congress Office of Technology Assessment, *Biological Rhythms: Implications for the Worker*, . 1991, U.S.Government Printing Office.

19. Mellor EF, Shift work and flexitime: How prevalent are they? *Monthly Labor Review* 1986(Nov/86):pp14-21.

20. Akerstedt T, Sleepiness as a consequence of shift work. *Sleep* 1988;11(1):17-34.

21. Rosekind MR, Gander PH, Miller DL, et al., Fatigue in operational settings: examples from the aviation environment. *Human Factors* 1994;36(2):327-38.

22. Rosekind M, Wegmann H, Dinges D, Graeber R, Samel A, Principles and Guidelines for Duty and Rest Scheduling in Commercial Aviation. *NASA Technical Memorandum* 1995;in press.

23. Sanquist TF, Raby M, Lee JD. *United States Coast Guard Alertness and Fatigue Research Program.* in *Human Factors on Board: The Influence of the Man-Machine Interface on Safety of Navigation*. 1995. Bremen, Germany.

24. Rosekind M, Graeber R, Dinges D, et al., Crew Factors in Flight Operations IX: Effects of planned cockpit rest on crew performance and alertness in long-haul operations. *NASA Technical Memorandum* 1994;108839:1-64.

APPENDIX D

Remarks by Dr. William Dement to the ARAC Working Group Pilot Representatives on December 1, 1998 at ALPA HQ, Washington, D.C.

I'm very pleased to present Dr. William Dement of Stanford University who's here to answer some of our questions regarding sleep science. Dr. Dement is considered the father of modern sleep medicine. He earned his M.D. and Ph.D. from the University of Chicago where he first began to study sleep. In 1963 he became the director of Stanford University's Sleep Research and Clinical Programs and continues in that post today. He was Chairman of the National Commission on Sleep Disorders Research from 1990 – 1992; a Commission chartered by Congress. He is the author of a definitive textbook on the diagnosis and treatment of sleep disorders and has written or co-authored more than 500 scientific publications. Dr. Dement, welcome and thank you for your time and being here today.

Thank you. For many years, the people who were interested in circadian rhythms and the people who were interested in sleep were fairly separate. Now there's actually a scientific meeting going on in Bethesda hosted by the National Institute of Health and the National Science Foundation in which circadian rhythm issues and sleep issues are considered to be complementary parts of one scientific discipline. This has been happening over the past 10-15 years.

One of the things that I'm trying to deal with is the fact that the study of sleep, the scientific study, and the applications / operational situations coincided later than some of the other disciplines. To get really into the mainstream of the scientific knowledge and the applications, ...this has been what I've been most interested in trying to help accomplish during the past 20 years.... and the first effort was to try to create a federal agency that would really be responsible for sleep and circadian issues, research, applications and education. Our efforts to do this led to the response of Congress to create a Commission, not to create an agency but to create a commission.

It turned out to be really a good thing because many of us had been in the ivory tower and this Commission really put us out in the field, hearing stories from people who have been involved in accidents, hearing what life is like in the trenches so to speak. That certainly made an enormous difference to me in appreciating, in a much more human way, the difficulties and the problems. We presented recommendations to Congress and it kind of coincided with the budget crisis, and dare I say, the Republican revolution so that only one key recommendation was passed. But there is now a federal agency – The National Center on Sleep Disorders Research – which, small, although it may be, is certainly a great start, and has on its plate some of the concerns that affect you. It also has the legislative mandate to interact with the Department of transportation and other agencies that are involved in these issues. I just wish it was much, much larger, and we're still working in that direction.

The second thing is that all sleep researchers now accept the concept of "sleep debt." Each individual needs a certain amount of sleep each day on the average to avoid accumulating a sleep debt. That sleep debt can accumulate over a long period of time. It can accumulate in relatively small amounts so it's kind of insidious, or of course it can accumulate very rapidly. You find frequently that many people have been partially sleep deprived for long periods of time. They aren't aware of this as fully as they ought to be you would think.

There's lots of evidence showing that you can get rid of that debt and how much extra sleep you have to have to get rid of it. The best type of research that demonstrates that is to show the increase in the tendency to fall asleep -- the *power* of the tendency to fall asleep – as you add hours to the sleep debt. Eventually, the person will finally fall asleep, no matter what. They can be walking and fall asleep. But if you put someone in an ad-lib situation, just take any one of you, and say, "Now you're in a situation where you have to sleep." You're going to be in a bedroom with no lights. All you can do is sleep. Then you will see all this extra sleep will take place. That's the debt....the amount of sleep that you should have received on a daily basis. That's usually astoundingly large.

In studies of this sort, you can show that a person thinks they're perfectly normal in terms of the way they feel. However, if they reduce the sleep debt, their performance will improve. The question is how much debt is anyone carrying at any particular time. The main thing is don't do anything that might increase it. That's my fundamental principle.

Finally, the circadian rhythm - I think that everyone has known that there is a biological clock. Since 1971, the location has been known in the brain, there have been a lot of electrodes and genetic studies, etc. Exactly how the clock functions to create a circadian rhythm of sleep and wakefulness has been understood relatively recently. This has been learned through the study of experimental animals. The best results are obtained with primates. So if you eliminate the primate biological clock, what's the result? They fall asleep all the time. They'll fall asleep, stay asleep, wake up, fall asleep, wake up, etc. The circadian rhythm of sleep is completely eliminated and you lose periods of sustained wakefulness. So that the concept today is that the clock participates in the daily regulation of sleep and wakefulness by alerting the brain at certain times. And you know those as, in other words, the forbidden zone for sleep,... the second wind that a lot of people get at the end of the day. But the clock does not put you to sleep. When the clock turns off in effect, when this alerting influence ends, a person is left with this gigantic sleep debt. That's what I've heard you refer to as "WOCL." That's the period where you find the least alerting of the activity clock, the most unopposed manifestation to the effects of accumulated sleep debt, and the greatest likelihood of falling asleep.

Well, there's an ideal time to sleep and then everything else is less than ideal. Sometimes it's devastatingly less than ideal.

Well, how much so? If you had an opportunity to sleep during the day and you were given an 8-hour sleep opportunity, could you expect to get 8 hours of sleep during that opportunity?

No, I'd say absolutely not. If that happened, it would be an incredible exception. There's a ton of evidence on that also.

How about if you were getting a 10 hour sleep opportunity?

No, I don't think so. There have been a lot of studies on sleep reversal. You simply reverse the sleep period and this is now a model of insomnia. If you have to sleep in the daytime, you have insomnia in effect. The ideal time to sleep if you have a stable circadian rhythm is to stay near the circadian rhythm.

The 8 hours of ideal sleep, is it possible from your studies you can nail down any specific 8-hour period or is it variable for individuals?

Well, it may vary a little bit. Within a very narrow range I wouldn't say....I would say for most people, it's from 11 – 12 PM to 7 – 8 AM. For the vast majority, that's the ideal sleep period. People will ask why they are the exception, but you're not dealing with exceptions here.

When you're forced to have to sleep if you're flying at night and you're sleeping in the day, I guess what you're really saying is that the chances are you're going to become somewhat sleep deprived over time.

That's right.

And so the only way you correct that, no matter how much time you are getting to sleep, you're still going to be somewhat sleep deprived. So the only way you're going to break that cycle is periodically if you have a certain amount of time off and you sleep during what might be considered your normal sleep period to restore that.

Well, at the present time that really is the only effective way. I think that we take the position that there's never an adjustment to that type of schedule. You referred to night duty...and you would think that if a person did it all the time they ought to adjust, ..but all the studies always show impairment in sleep loss.

Dr. Dement, ...we're really at the point now where we're going beyond the philosophy and we're trying to put our finger on numeric values. Our position at least from the pilots' standpoint, is that we see the need for a 10-hour sleep opportunity knowing that the opportunity may not always be at the best time of the day. We're facing an industry position that is looking for 8 hours as the minimum. Our position is predicated on the

I'm typically so sleep deprived that [can't understand rest of statement.]

Years ago, just to make a dramatic point, we were approached before we knew about sleep debt, before we could measure sleepiness. It was in the 60s we were approached by a company that had a billion-dollar bed (ceramic bead bed – billions of little beads. They use them now for burn patients. It's supposed to be the most comfortable surface ever. So we got a group of students. We had a regular bed, the cold concrete floor condition and the beaded bed. To our utter amazement, sleep was the same in all three conditions. The students who were doing this were on spring break, they probably had a 100-hour sleep debt, they could probably sleep anywhere, and that to me is a symptom of grave concern. If you could sleep anywhere.. anytime you are very sleep deprived....that's not good. That's another mythology. People get so macho. Saying that they can sleep anywhere is like saying they were drunk or they could drive when they're drunk. People misunderstand that. That's a symptom of severe sleep deprivation.

I have a couple questions. First of all, if we consider we are dealing with an individual who had no accrued sleep debt and that individual awoke in the morning, what does the science say about the amount of time awake that individual would have before, or is there any kind of .....

Well, probably if he's getting up in the daytime, that person could not possibly sleep in the daytime.

I'm not talking about sleeping. How long could he be awake before he.....

Oh, well, maybe 16 hours would be the usual time he's awake. One of the things that we -- at least I and I think most of my colleagues -- agree on is that all wakefulness is sleep deprivation. In the model of sleep regulation, you need that accumulated sleep debt of 16 hours to, in a sense, power the sleep of the night.

If you didn't have a sleep debt, how many hours would you have to be awake before you could be able to take a nap? Is there any measurement that has been done?

First of all, it's so difficult to get a human being in a state of no sleep debt. I'm not sure that it has ever happened. The closest we've come are in the study I briefly alluded to where the people had to spend 14 hours in bed in the dark every night for 5 weeks. At the end of those last few weeks, we think they were getting up with 0 sleep debt. It would take them 2 hours to fall asleep and they had terrible sleep because they tried to do it in 14 hours. If you have a minimum sleep debt, then I would say I don't think you could fall asleep....it would be the whole day I would think before you could really confidently fall asleep. One of the things I'm not 100% sure is how much monotony and sensory isolation can

I wanted to say three or four things about sleep. First of all, I'll preface this by saying last year when we changed to daylight savings time, there was a National Sleep Awareness Week sponsored by the National Sleep Foundation, which by the way, is a major resource in the education and is based in Washington, DC. It created a sleep IQ test for the American public. The American public did more poorly than chance on this test. Not only then is there a pervasive lack of awareness by the general public, but there's also the presence of certain mythologies which then lead you to pick wrong answers more frequently than by chance alone. A lot of those mythologies are still in the transportation industry. I think there is no question about that.

The first thing that most people should be aware of is very simple: what is sleep? The fundamental difference between wake and sleep (and there's some very elegant research being presented about what actually goes on in the brain at that momentary transition) is that first, the transition is very rapid and can take place in less than a second. One moment you are awake and conscious of the outer world and then next moment you are asleep and unconscious of the outer world. When you're very fatigued, you can go to sleep instantly, and at that moment you don't see anything or hear anything. That's what makes falling asleep so very dangerous because you will not respond to a signal. The only thing that a stewardess could do is to wake you up. Often in a fatigued person, the awakening stimulus must be very, very intense.

So, anyone who thinks that moving towards sleep is in the least little bit safe is completely wrong if you want a human being to function at any level at all. The transition is very, very rapid.

Then there's the period of fatigue that I like to call "fatal fatigue" which is approaching the moment of sleep and depending on the degree of fatigue, can be fairly rapid. But that's a period of great impairment where you miss signals, you misjudge, your memory is impaired, your reaction time is elevated, etc. You are now very close to the threshold of unconsciousness....the moment of sleep.

There's a very dramatic study that I'd like to tell you about because it should stick in your memory. You have someone lying on a table with the eyelids taped open and a 50,000 power strobe light 6" from the nose. When that thing flashes, the table almost wiggles. He is supposed to press a little switch when it flashes, and you'll be making it flash and suddenly the person will not press the switch, apparently wide-awake. You ask him, "Why didn't you press the switch?" "Well, the light didn't flash." And if you look at the brain wave recording you'll see that there's a micro sleep right at the moment the light flashed. So that's how powerful that is. There's been a recent study in heavy trucks with brain wave recording in the cab as the drivers are driving, and yes indeed there are lots of micro sleeps there. They really do occur.

Going beyond that, what is probably the most greatest points of contention right now – the debate between the pilots and the industry operators – is the fact that the operators would like to extend this reserve availability period in excess of what you say is 14 or 15 or 16 hours, whatever the case may be, to a larger increment, extending that reserve availability period based upon an advance notice of a nap opportunity. In other words, a pilot comes on call at 8:00 a.m. He is then told at 9:00 a.m. that he is to report for duty 5 hours later. The industry's position is that the notice constitutes an opportunity for additional rest which then would be utilized to add more restorative energy, or analogous to putting more charge into a battery, to carry that pilot into more of an extended duty period with an additional amount of time.... up to in certain cases 24 hours of duty. What is your feeling on that type of scenario?

To me, that's a recipe for disaster because if you have a responsible, professional pilot -- who has a reasonable schedule, I guess – who is not horribly sleep deprived, and who has a fairly stable circadian rhythm, then the likelihood that he can get adequate sleep by trying to nap I think is relatively small. I would not depend on it at all. I would think also to have to do it sort of unexpectedly like this....Oh! Take a nap....Only people who are very sleep deprived....

Can I ask that question a different way?

Sure.

Let's say I have a 10-hour sleep opportunity: 10 p.m. to 8 a.m. That means I'm available for 14 hours unless they fly me into the next 10 p.m. slot tonight. Could I not get a call say at noon and say instead of you being off tonight at 10 p.m., we want you to work until seven tomorrow morning but you aren't going to go to work until 10:00 that night. So they call me at noon, they give a 10-hour notice that I'm not going to have to go to work until 10 hours from noon, so at 2200 I report for work, and they want me to fly until 0800. So that would be a total of 24 hours from the time I theoretically woke up and I've had a 10-hour notice that I was going to be flying this fatiguing schedule. Would that be safe?

Well, I wouldn't be on your plane. No. I think that's almost insanity in the sense of saying that is safe. First of all, naps can't be depended on – even under ideal circumstances – to get you through this period when the biological clock alerting is gone, when you're alone with your sleep debt so to speak, during the WOCL. There's no way that isn't going to be dangerous. Yes, there may be exceptions, but it's always going to be dangerous. The likelihood is not good that you would be able to have some kind of good luck that you did sleep a lot, and that has gotten you through. First of all, you would not be at your peak performance. There is just no way. You cannot achieve peak performance during that period of time. Maybe for 10 minutes. The notion that you can depend on getting adequate sleep I think is just wrong. You can go into a laboratory and you can

So those are the three main things. These are established facts. I don't think the scientific evidence is conclusive and those are the things we take into consideration when we try to apply the knowledge to the practical or operational situation. Any questions on that?

People say, "Can you accumulate a debt for a year?" We don't know because those studies haven't been done. But there's no evidence whatsoever that says "No, it levels off," or "No, it changes." All the evidence says that you keep accumulating a debt as long as you keep losing sleep below your specific daily requirement. There's no evidence that you can change this. I suppose you could ski or play basketball as opposed to just sit in a hot room and that would make a little difference but that doesn't change your sleep requirement.

Anybody got any questions?

I've got a question. Napping: does that in any way alleviate the sleep debt?

Let's say you have a 40-hour sleep debt and you have a ten-minute nap. So now your sleep debt might be 39 hours and 50 minutes. It wouldn't make any difference there. A lot of the napping is done after lunch. Most people, and especially younger people – and I don't know what the average age is in this group – but younger people have strong clock-dependent alerting late in the day. So you have sort of an illusion. You happen to take a nap just before the clock turns on. Is the alerting partly a result of the nap or not? Mostly not, but I would say until proven otherwise that a nap, if it is good sleep (which it usually isn't) is minute per minute doing what sleep would do, but it's usually nowhere near the total amount that you require.

Dr. Dement, I have a list of questions that pertain to our task of helping to define flight time and duty time regulations and if I could just take the liberty of asking these particular questions and open up the floor for any other remaining questions that other people may have. One of the most basic tasks is for us to agree on a recommendation for a sleep opportunity,.... to afford every reserve pilot the opportunity of a protected time period so that he or she is absolutely insulated from contact from the operator. How many hours do you recommend for a minimum fixed sleep opportunity?

I will start out by assuming that we would take 8 hours of sleep as the most common requirement. Then you need to add to that in order to be able to get the proper amount of sleep. In your situation, I would think it would be a little larger than it might be for someone who really wasn't doing anything. So I'd add a couple of hours to get the proper amount of sleep.

Are there any findings as far as the amount of sleep loss or the ability to sleep during less than desirable times of the day and what a person could expect?

could certainly get the probability up, but it's not something that you could ever really control. Again, there ought to be a better way.

That's the problem: a better way. Understandably, that's not desirable but the question is: how do you best prepare for that?

You're saying if the notice is given with the 10-hour window?

Management would like a 10-hour notice.

It would seem to me that a better approach would be to have a 24-hour window or some longer period. Say you get notified the day before. I suppose there are emergencies and so on, and you would be called for those exceptions... and a pilot would have so many exceptions over such and such portions of time depending on the emergencies and whatever constraints....

Some types of operations operate without a schedule.

That's the worst.

I have 2 questions, doctor. First, a person that has adequate sleep wakes up non- sleep deprived at 8:00 a.m. Fourteen hours later it's 2200 and he's driving home from dinner with his wife. Is he impaired?

I have to say it depends on his age probably. The impairment is starting probably. You don't go straight down; you go down with an accelerating level of impairment. Most of the studies in the laboratory say depending upon where your mid day dip is, your performance will start decreasing in the late evening.

We're not familiar with the mid-day dip. The late evening is ....?

I'm thinking 10:00.

If a person was to fly so as to stop flying at 8:00 a.m. and he was to fly throughout the 0200 – 0600 time frame, what time should he be waking up in order to be best prepared for that flight that lands at 8:00 a.m.?

I know you said he's flying. He's waking up?

No. When should he wake up to be best prepared for a flight that would include landing at 8:00 a.m.? If he starts at midnight. How do you get prepared for that even if (I'm not talking about reserve or anything)...What should a pilot do, how should he plan his day to wake up at the right time to be most alert at 8:00 a.m.?

fact that 8 hours may be adequate if it overlaps the WOCL. But since we don't know for sure when we're going to have that opportunity, we believe that, or we think that having that extra 2 hours is going to give us a little more of a buffer, especially when it comes during the daytime. Would you consider that to be a conservative and a justified position?

Absolutely. I don't think you could possibly assume someone is going to fall asleep instantly and then sleep continuously for 8 hours, not even under the most ideal circumstances. Maybe it should be longer.

By the same token, say that same individual who was supposed to sleep had the perfect time during the day and was supposed to sleep during the day, hadn't slept the previous night and he had normal sleeping hours because he was not disturbed for any duty assignment. What effect does that have on his subsequent rest period?

In the ideal situation if someone sleeps the normal amount at night, they can't sleep at all during the day. We are pretty much a sleep-deprived nation so that we do have this mid day dip in alertness. Most people say they get drowsy after lunch. That's sleep deprivation. If you were not dealing with someone who is extremely sleep deprived, then I would say sleeping a normal amount at night becomes very difficult, or it should become very difficult to sleep in the daytime. That is a fact if the carryover sleep debt isn't large, it's definitely more sensitive to stimuli, etc. and you're fighting the biological clock for much of the day.

Have you ever conducted these tests when they're wearing a uniform?

[Laughter] Well, we did some testing but I think they took them off when they went to bed.

I fly at night all the time and only get rest during the day. I heard that if you sleep during the optimum time of day, you really need to have about a 10-hour period in which to get your 7 ½ or 8 hours of sleep. If you do not ever have the opportunity to sleep for 7 – 10 days in a row, you are never able to sleep during the optimum time. I heard you say that you always need more than 10 hours to get even reasonable sleep even though you probably never will achieve adequate sleep. Can you put any kind of a number on the gross amount of time you could have available for sleep opportunity to try to restore sleep?

The problem is that there becomes inefficiency. You don't want to spend 16 hours in bed to get 8 hours of sleep. There just isn't a good solution to be perfectly honest. The main thing you need to know then is first, at what period of the day in your clock (God knows where your clock is) there is some period when it's the most difficult to sleep. Hopefully you know that about yourself. Obviously you avoid that. If you can schedule more than 10 hours, not at that time, then you yourself will need to determine if you can do it in a minimum of 10 hours, or does it take 13. That would be a horrible life.. to spend all that time in bed.

that WOCL, if you will. Whether it's low because you napped or low because you got lots of sleep the night before doesn't matter. Both would be the best.

Should you stay up until 3:00 a.m. so you can sleep later in the afternoon?

Not necessarily, no.

Should you stick with normal sleeping and then try to get a nap before you go to work?

Yeah, I would say as much sleep as possible. But here again you need to know yourself a little bit. But that's not what rulemaking is all about. Rulemaking is what fits everybody. Because of the uncertainty of being able to take a nap, I mean it's uncertain for me and I think it's uncertain for pilots. Although again, since pilots are generally more sleep deprived, they are more able to nap. If you felt able to take a nap with absolute certainty, then you should take a nap. But also get your needed amount of sleep the night before.

We're shooting around the subject. I hate to break any of this up, but this question has been plaguing this committee. The industry keeps harping on the fact that there should be no difference between the schedule holder who knows he's got to fly from midnight to 8:00 a.m. If he can do it safely, why can't a reserve that wakes up at the same time in the morning (8:00 a.m. or 6:00 a.m.). Why is it not safe for this reserve pilot who does it with notice?

I don't think it's safe for either pilot. Maybe a little less dangerous in the sense of performance, etc. But I think at least he has preparation, warning, etc. and knows his own strengths and weaknesses whereas the other pilot I think is always without warning and has really no chance to prepare. I don't think the two groups are the same.

Are you implying that the preparation should actually start the previous night?

Yes. If I were going to drive all night, I wouldn't want someone to tell me that day.

They're really killing us for making that same argument. I mean we make that argument across the table and we get smiles and nods of the head and shrugs of the shoulders from the other side. They say it's not a valid argument. That's always what they come up with.

They say it's not a valid argument? It is a supremely valid argument. I mean that's just like saying down is up.

you tolerate before you have a micro sleep? Two or three hours? Under ordinary circumstances, daytime sleep is difficult.

Is there anything definitive that says which of these two situations would be more fatiguing: an individual who has to stay up until 3:00 a.m. or an individual who is forced to wake up at 3:00 a.m.?

That's a good question. I would think both would be fatigued and it's so the pattern might be a little different, but it would depend on how much sleep they had prior to that. I would think though that going into action at 3:00 a.m. for most people you'd be extremely impaired. On the other hand, some people, as you get after midnight, become extremely impaired also. I don't think they've ever been compared head to head, but those are the kinds that would impair performance. Period. There's a thought that people somehow get enough adrenaline. Certainly students in exam week somehow get so stressed and so anxious that they seem to be able to go a little longer. It's obvious that they're paying a price when you look at them afterwards. That's not something to rely on. To me, it's only when you're trying to rescue people or something that you would want to do that sort of thing.

Dr. Dement, after our reserve pilots receive their sleep opportunity, they become available for duty. We call the availability period the "reserve availability period" and that's basically the time they are available for work, for flying. After the sleep opportunity, what would you consider to be a safe limit of time since awake for a crewmember?

For the 10-hour period?

Yes.

Fourteen hours. And I wouldn't say that's 100% safe but if you have a number, that adds up to the 24-hour day. It ought to be reasonably safe.

Where do you get your number from?

Well, it comes mainly in my head from circadian type 24-hour studies to see the pattern of the manifestation of the drive to sleep versus the awakening effect of the biological clock. If you're getting outside the 24-hour cycle. then you're going to have periods of greater risk. I realize that operationally that's probably difficult, but....

That assumes that the individual wakes up as soon as his protected time period is over. So in other words, you see a complimentary factor: 9 hours of rest should dictate a 15-hour availability period?

Yeah. I think most people would agree that would be the ideal.

It seems like common sense. Fairly obvious. One other quick question. It seems to be the way you were going is that how much notice you're given is not as important as when the notice falls. In other words, when the opportunity to rest based on this notice of assignment, is that a fair assumption?

Well, the two aren't exactly the same. I don't mean to imply that when....I mean, the longer you have, the better. I guess I don't understand your question.

Well, that's kind of what I'm getting at. I guess it is....

I mean, generally you don't get the notice in the middle of the night, do you?

Well, it would kind of depend....we're dealing with round-the-clock operations so we may have situations where an individual's protected time period this time he's supposed to be sleeping actually starts at 7:00 a.m. and goes to 3:00 in the afternoon. So he might get notice in the middle of the night for an assignment that comes subsequent to that later on. So we're dealing with round-the-clock operations and no guarantees.....

I would think notice in the middle of the night is useless. First of all, you disturb the sleep and secondly it doesn't really help you with the next day any more than notice at 8:00.

Taking for a moment that you're not asleep, I mean that it's not your normal sleep time. I guess what you're saying is that 14 hours notice or 12 would be better than 10 most likely...

Yeah. All other things being equal.

Did you ever fly the midnight flights?

No, not anymore.

Especially after today, right?

Doctor, I'd like to think we'd be able to negotiate something like you said: a 10-hour rest period and a 14-hour maximum reserve availability period, but unfortunately, that's a very high expectation. What we will be facing is longer periods of reserve availability. Based on the fact that we will be facing potentially onerous, long periods of time since awake, long reserve availability periods, do you think that being afforded a greater amount of sleep opportunity will give us more of a protection against that longer duty? Is there a relationship as far as the amount of restorative sleep as preparation for longer period of duty?

do some studies and you can demonstrate that occasionally someone will perform pretty well, but that's not 100% ever. It's never getting back to peak performance and it's under the luxurious circumstances of no interruptions, no noise, etc. I wouldn't ever think that napping could make it safe going through the night.

How about that the flight is going to happen. There is going to be every day in America, pilots that report to work at 2300 or whatever and fly until 0800 the next morning. Now, what's different about the man who knows a week, a month in advance that this is going to be his schedule and the reserve pilot who finds out at noon after having woken up at 8 a.m.? What would be the difference?

You know that the time you do all of the things you can to move toward a better situation....You can never get to perfection, but the more practice, the more warning, the better you'll be able to handle it. Some people learn that there is a time when it's quiet and if I do this, I can pretty much depend that I will fall asleep. It's not 100% but you kind of learn that or you practice or whatever. But if it's without warning, all bets are off.

Dr. Dement, you've kind of led the discussion into another area of this rulemaking that has to do with an alternative method. Assuming that the pilots in this protected time period method were depleted, the carriers then want to give pilots advance notice to cover any mission or any assignment. They are looking at 10 hours as the criteria. We don't believe that to be adequate based upon....

Are you talking 10-hour warning?

Ten-hour warning, yes. To do anything.

That would be 100% wrong.

Why?

Well, because the 10 hours could fall sort of toward the beginning of what we call "clock dependent learning." There's no way you could sleep. And then you go into your duty period at the worse possible time you could have that situation.

What sort of time would you think would be adequate to give a guy enough time to get an opportunity to rest so that he would be safer than 10 hours?

Twenty-four hours. At least a day before. Wouldn't you think? I don't see how you can get notified as the day is beginning and feel you could depend on being able to take a nap. If it happened every day or somehow you know that you

All sorts of things happen, but the major thing of course is that you are now trying to sleep when the body wants to be awake and you're trying to be awake when the body wants to be asleep because you left the circadian stability that you talked about.

[Question cannot be heard]

No, I think in summary, ...science is really clarifying these issues that people have been struggling with for many years, and there is always a resistance to change. But I think one of the things that we confronted in our Congressional commission is that a lot of the bad effects of sleep loss and impaired performance are frequently not obvious because there has not been a history of really looking for them. One of the studies that impressed me the most in that regard was an anonymous survey of hospital house staff. I don't remember the exact question, but it was that 42% in this anonymous survey had killed a patient as a result of a fatigued-based error. Well, who knows that? Who wants to know it? If we had the power to really take a look at the price of fatigue, it would be enormous. I think these things are just beginning to emerge and they seem to threaten management, threaten economic realities, but I think once there's this move toward help and peak performance and utilizing all this scientific knowledge that everyone will benefit. There will be ways to deal with these things and it will get better and better and the benefits will be recognized more and more. I think one of the problems in the trucking industry is the same kind of thing: what's the cause of all the crashes? Frequently, these causes aren't really assessed, and the public doesn't recognize the liability, but it's coming. I'm sure at some point it's better to be safe than to be sorry. Because sorry is lawsuits and lost lives, tremendous damage to property. Those things are going to be equated sooner or later.

END TAPE

First of all, why does he have to wake up at 8:00?

No, no. He's flying at 8:00. He's flying from midnight to 8:00.

Oh, okay. But basically what should he do the day before if it's a midnight flight? I assume sleep as late as possible.

On his normal sleep cycle like you first said?

Yeah.

And then what?

And he's free all day?

Yeah. He doesn't have to do anything....

If he knows that he has this post prandial period of diminished alertness , I would try to take a nap at that point in time.

Late afternoon?

Yeah.

I don't know what postprandial....

It means after lunch. Parenthetically, I've been working with students and I've been finding (because I've been working with very small groups) that if they start by learning how much sleep they need as an individual, when is their time of peak learning, when is their circadian nadir, they are able to make some choices in preparation for exams, etc. that are a great improvement over their previous situation where they didn't know these things. What you're trying to do is to get your sleep debt as low as possible and utilize what you know about yourself to accomplish that. Part of it would be, as a responsible pilot, you would do that as kind of a lifestyle. Maybe the lifestyle is changing a little bit but you're always trying to keep your sleep debt low so you never have to do something like when you are already really dangerous because your sleep debt may be 40 or 50 hours imperceptibly accumulated. Then again I'd tell you the best preparation is to get as much sleep the night before. The pilots in this NASA layover study seem to be pretty good at taking naps. Not perfect, but pretty good. We decided the reason for that is they were sleep deprived. They could take a nap. So there's that sort of tradeoff. Then the issue is whether or not the sleep closer to the duty period is necessarily better. I don't think it matters. When you start that period, what is your sleep debt when you're going to go into

APPENDIX E

Fatigue, Alcohol and Performance Impairment
Nature, Volume 388, July-August 1997

Reduced opportunity for sleep and reduced sleep quality are frequently related to accidents involving shift-workers[1-3]. Poor-quality sleep and inadequate recovery leads to increased fatigue, decreased alertness and impaired performance in a variety of cognitive psychomotor tests[4]. However, the risks associated with fatigue are not well quantified. Here we equate the performance impairment caused by fatigue with that due to alcohol intoxication, and show that moderate levels of fatigue produce higher levels of impairment than the proscribed level of alcohol intoxication.

Forty subjects participated in two counterbalanced experiments. In one they were kept awake for 28 hours (from 8:00 until 12:00 the following day), and in the other they were asked to consume 10-15g alcohol at 30-min intervals from 8:00 until their mean blood alcohol concentration reached 0.10%. We measured cognitive psychomotor performance at half-hourly intervals using a computer-administered test of hand-eye coordination (an unpredictable tracking task). Results are expressed as a percentage of performance at the start of the session.

Performance decreased significantly in both conditions. Between the tenth and twenty-sixth hours of wakefulness, mean relative performance on the tracking task decreased by 0.74% per hour. Regression analysis in the sustained wakefulness condition revealed a linear correlation between mean relative performance and hours of wakefulness that accounted for roughly 90% of the variance (Fig. 1a).

Regression analysis in the alcohol condition indicated a significant linear correlation between subject's mean blood alcohol concentration and mean relative performance that accounted for roughly 70% of the variance (Fig. 1b). For each 0.01% increase in blood alcohol, performance decreased by 1.16%. Thus, at a mean blood alcohol concentration of 0.10%, mean relative performance on the tracking task decreased, on average by 11.6%.

Equating the two rates at which performance declined (percentage decline per hour of wakefulness and percentage decline with change in blood alcohol concentration), we calculated that the performance decrement for each hour of wakefulness between 10 and 26 hours was equivalent to the performance decrement observed with a 0.004% rise in blood alcohol concentration. Therefore, after 17 hours of sustained wakefulness (3:00), cognitive psychomotor performance decreased to a level equivalent to the performance impairment observed at a blood alcohol concentration of 0.05%. This is the proscribed level of alcohol intoxication in many western industrialized countries. After 24 hours of sustained wakefulness (8:00) cognitive psychomotor performance decreased to a level equivalent to the performance deficit observed at a blood alcohol concentration of roughly 0.10%.

Plotting mean relative performance and blood alcohol concentration 'equivalent' against hours of wakefulness (Fig. 2), it is clear that the effects of moderate sleep loss on performance are similar to moderate alcohol intoxication. As about 50% of shift-workers do not sleep on the day before the first night-shift[5], and levels of fatigue on subsequent night-shifts can be even higher[6], our data indicate that the performance impairment associated with shift-work could be even greater than reported here.

Our results underscore the fact that relatively moderate levels of fatigue impair performance to an extent equivalent to or greater than is currently acceptable for alcohol intoxication. By expressing fatigue-related impairment as a 'blood-alcohol equivalent', we can provide policy-makers and the community with an easily grasped index of the relative impairment associated with fatigue.

[Note: Retyped. Endnotes and Figures 1 and 2 are illegible and have been omitted.]

Drew Dawson
The Centre for Sleep Research
The Queen Elizabeth Hospital
Woodville, 5011 South Australia
e-mail: ddawson@tqeh.smtp.tgeh.sa.gov.au

Kathryn Reid
Department of Obstetrics and Gynecology
The Queen Elizabeth Hospital
Woodville, 5011 South Australia

APPENDIX F

Quantifying the Performance Impairment associated with Sustained Wakefulness

Nicole Lamond and Drew Dawson

The Centre for Sleep Research, The Queen Elizabeth Hospital, South Australia

March / April 1998

Sustained Wakefulness and Performance

Address all correspondence to Drew Dawson, The Centre for Sleep Research, The Queen Elizabeth Hospital, Woodville Rd, Woodville SA 5011. Australia.

Phone: +61 8 8222 6624. Fax: +61 8 8222 6623.

Acknowledgments: Research supported by the Australian Research Council.

SUMMARY

The present study systematically compared the effects of sustained wakefulness and alcohol intoxication on a range of neurobehavioural tasks. By doing so, it was possible to quantify the performance impairment associated with sustained wakefulness and express it as a blood alcohol impairment equivalent. Twenty-two healthy subjects, aged 19 to 26 years, participated in three counterbalanced conditions. In the sustained wakefulness condition, subjects were kept awake for twenty-eight hours. In the alcohol and placebo conditions, subjects consumed either an alcoholic or non-alcoholic beverage at 30 minute intervals, until their blood alcohol concentration reached 0.10%. In each session, performance was measured at hourly intervals using four tasks from a standardised computer-based test battery. Analysis indicated that the placebo beverage did not significantly effect mean relative performance. In contrast, as blood alcohol concentration increased performance on all the tasks, except for one, significantly decreased. Similarly, as hours of wakefulness increased performance levels for four of the six parameters significantly decreased. More importantly, equating the performance impairment in the two conditions indicated that, depending on the task measured, approximately 20 to 25 hours of wakefulness produced performance decrements equivalent to those observed at a BAC of 0.10%. Overall, these results suggest that moderate levels of sustained wakefulness produce performance equivalent to or greater than those observed at levels of alcohol intoxication deemed unacceptable when driving, working and/or operating dangerous equipment.

KEY WORDS sustained wakefulness, alcohol intoxication, performance impairment

INTRODUCTION

The negative impact of sleep loss and fatigue on neurobehavioural performance is well documented (Gillberg *et al.*, 1994; Mullaney *et al.*, 1983; Tilley and Wilkinson, 1984). Studies have clearly shown that sustained wakefulness significantly impairs several components of performance, including response latency and variability, speed and accuracy, hand-eye coordination, decision-making and memory (Babkoff *et al.*, 1988; Linde and Bergstrom, 1992; Fiorica *et al.*, 1968). Nevertheless, understanding of the relative performance decrements produced by sleep loss and fatigue among policy-makers, and within the community, is poor.

By contrast, the impairing effects of alcohol intoxication are generally well accepted by the community and policy makers, resulting in strong enforcement of laws mandating that individuals whose blood alcohol concentration exceeds a certain level be restricted from driving, working and/or operating dangerous equipment. Consequently, several studies have used alcohol as a standard by which to compare impairment in psychomotor performance caused by other substances (Heishman *et al.*, 1989; Dick *et al.* 1984; Thapar *et al.*, 1995). By using alcohol as a reference point, such studies have provided more easily grasped results regarding the performance impairment associated with such substances.

In an attempt to provide policy makers and the community with an easily understood index of the relative risks associated with sleep loss and fatigue, Dawson and Reid (1997) equated the performance impairment of fatigue and alcohol intoxication using a computer-based unpredictable tracking task. By doing so, the authors demonstrated that one night of sleep deprivation produces performance impairment greater than is currently acceptable for alcohol intoxication.

While this initial study clearly established that fatigue and alcohol intoxication has quantitatively similar effects, it should be noted that performance on only one task was investigated. Thus, it is unclear at present whether these results are restricted to hand-eye coordination, or characteristic of the general cognitive effects of fatigue. While it is generally accepted that sleep loss and fatigue are associated with impaired neurobehavioural performance, recent research suggests that tasks may differ substantially in their sensitivity to sleep loss. Studies addressing this issue have suggested that tasks which are complex, high in workload, relatively monotonous and which require continuous attention are most vulnerable to sleep deprivation (Johnson, 1982; Wilkinson, 1964).

As conditions that cause deterioration in one particular function of performance may leave others unaffected. it is unreasonable to assume that one could predict all the effects of sleep loss from a single performance test. Thus, the current study sought to replicate and extend the initial findings of Dawson and Reid (1997) by systematically comparing the effects of sleep deprivation and alcohol intoxication on a range of performance tasks.

METHOD

Subjects

Twenty-two participants, aged 19 to 26 years, were recruited for the study using advertisements placed around local universities. Volunteers were required to complete a general health questionnaire and sleep/wake diary prior to the study. Subjects who had a current health problem, and/or a history of psychiatric or sleep disorders were excluded. Subjects who smoked cigarettes or who were taking medication known to interact with alcohol were also excluded. Participants were social drinkers who did not regularly consume more than six standard drinks per week.

Performance Battery

Neurobehavioural performance was measured using a standardised computer based test battery. The apparatus for the battery consists of an IBM compatible computer, microprocessor unit, response boxes and computer monitor. Based on a standard information processing model (Wickens, 1984), the battery sought to provide a broad sampling of various components of neurobehavioural performance. Four of twelve possible performance tests were used, such that the level of cognitive complexity ranged from simple to more complex (as listed below). Since speed and accuracy scores can be effected differently by sleep deprivation (Angus and Heslegrave, 1985; Webb and Levy, 1982), tasks that assessed both were investigated.

The simple sensory comparison task required participants to focus on an attention fixing spot displayed on the monitor for 750ms. Following this, a line of stimulus characters, divided into three blocks of either numbers, letters or a mixture was displayed. Participants were then required to respond to a visual cue, which appeared in the position of one of the stimulus blocks, by naming the block, which had been there. Verbal responses were scored as correct, partially correct or incorrect.

The unpredictable tracking task (three-minute trials) was performed using a joystick to control the position of a tracking cursor by centering it on a constantly moving target. Percentage of time on target was the performance measure.

The vigilance task (three and a half minute trials) required subjects to press one of six black buttons or a single red button. depending on which light was illuminated. If a single light was illuminated. subjects were required to press the corresponding black button underneath it. If however. two lights were illuminated simultaneously. subjects were required to press the red button. For this report. two vigilance measures were evaluated: 1) the number of correct responses (accuracy). and 2) increases in the duration of responses (response latency).

The grammatical reasoning task required subjects to indicate whether a logical statement, displayed on the monitor, was true or false. Subjects were presented with 32 statements per trial, and instructed to concentrate on accuracy. rather than speed. Both accuracy (percentage of correct responses) and response latency were evaluated in this report.

During test sessions, subjects were seated in front of the workstation in an isolated room, free of distraction, and were instructed to complete each task once (tasks were presented in a random order to prevent order effects). Each test session lasted approximately 15 minutes. Subjects received no feedback during the study, in order to avoid knowledge of results affecting performance levels.

Procedure

Subjects participated in a randomised cross-over design involving three experimental conditions: 1) an alcohol intoxication condition, 2) a placebo condition, and 3) a sustained wakefulness condition. During the week prior to commencement of the experimental conditions, all participants were individually trained on the performance battery, to familiarise themselves with the tasks and to minimise improvements in performance resulting from learning. Subjects were required to repeat each test until their performance reached a plateau.

The subjects reported to the laboratory at 8:00pm on the night prior to each condition. Prior to retiring at 11:00pm, subjects were required to complete additional practice trials on each tasks. Subjects were woken at 7:00am, following a night of sleep, and allowed to breakfast and shower prior to a baseline testing session, which started at 8:00am.

Alcohol Intoxication Condition

Subjects completed a performance testing session hourly. Following the 9:00am testing session, each subject was required to consume an alcoholic beverage, consisting of 40 percent vodka and a non-caffeinated softdrink mixer, at half hourly intervals. Twenty minutes after the consumption of each drink, blood alcohol concentrations (BAC) were estimated using a standard calibrated breathalyser (Lion Alcolmeter S-D2, Wales). accurate to 0.005% BAC. When a BAC of 0.10% was reached no further alcohol was given. Subjects were not informed of their BAC at anytime during the experimental period.

Placebo Condition

The procedure for the placebo condition was essentially identical to the alcohol condition. Subjects in the placebo condition had the rim of their glass dipped in ethanol to give the impression that it contained alcohol. To ensure that subjects remained blind to the treatment condition to which they had been allocated, approximately equal numbers of subjects received alcohol or placebo in any given laboratory session.

Sustained Wakefulness Condition

Subjects were deprived of sleep for one night. During this time, they completed a performance testing session every hour. In between their testing sessions, subjects could read, write, watch television or converse with other subjects, but were not allowed to exercise, shower or bath. Food and drinks containing caffeine were prohibited the night before and during the experimental conditions.

Statistical Analysis

To control for inter-individual variability on neurobehavioural performance, test scores for each subject were expressed relative to the average test scores they obtained during the baseline (8:00am) testing session of each condition. Relative scores within each interval (hour of wakefulness or 0.01% BAC intervals) were then averaged to obtain the mean relative performance across subjects. Neurobehavioural performance data in the sustained wakefulness and alcohol intoxication conditions were then collapsed into two-hour bins and 0.02% BAC intervals, respectively.

Evaluation of systematic changes in each performance parameter across time (hours of wakefulness) or blood alcohol concentration were assessed separately by repeated-measures analysis of variance (ANOVA), with significance levels corrected for sphericity by Greenhouse-Geisser epsilon.

Linear regression analysis was used to determine the relationship between test performance, hours of wakefulness and alcohol intoxication. The relationship between neurobehavioural performance and both hours of wakefulness and BAC are expressed as a percentage drop in performance for each hour of wakefulness or each percentage increase in BAC, respectively. For each performance parameter, the percentage drop in test performance in each of the two conditions was also equated, and the effects of sustained wakefulness on performance expressed as a BAC equivalent.

RESULTS

Alcohol Intoxication Condition

Table 1 displays the results of the ANOVAs run on each performance variable as a function of BAC. Five of the six performance parameters significantly ($p = 0.0008-0.0001$) decreased as BAC increased, with poorest performance resulting at a BAC of 0.10 or greater.

The linear relationship between increasing BAC and performance impairment was analysed by regressing mean relative performance against BAC for each 0.02% interval. As is evident in Table 2, there was a significant ($p = 0.0132-0.0002$) linear correlation between BAC and mean relative performance for all of the variables except one. It was found that for each 0.01% increase in BAC, the decrease in performance relative to baseline ranged from 0.29 to 2.68%.

Placebo Condition

To ensure that differences in performance reflected only the effects of actual alcohol intoxication a placebo condition was incorporated into the study. As indicated in Table 1, mean relative performance in the placebo condition did not significantly vary.

Sustained Wakefulness Condition

Table 1 displays the results of the ANOVAs for each performance variable as a function of hours of wakefulness. Four of the six performance parameters showed statistically significant ($p = 0.0001$) variation by hours of wakefulness. In general, the hours-of-wakefulness effect on each performance parameter was associated with poorest performance resulting after 25 to 27 hours of wakefulness.

Since there is a strong non-linear component to the performance data, which remained at a fairly stable level throughout the period which coincides with their normal waking day, the performance decrement per hour of wakefulness, was calculated using a linear regression between the seventeenth (equivalent to 11:00pm) and twenty-seventh hour of wakefulness.

As indicated in Table 2, regression analyses revealed a significant linear correlation ($p = 0.0011$-0.0001) between mean relative performance and hours of wakefulness for four of the six performance variables. Between the seventeenth and twenty-seventh hours of wakefulness, the decrease in performance relative to baseline ranged from 0.61 to 3.35% per hour (Table 2).

Sustained Wakefulness and Alcohol Intoxication

The primary aim of the present study was to express the effects of SW on a range of neurobehavioural performance tasks as a blood alcohol equivalent. Figures 1-6 illustrate the comparative effects of alcohol intoxication and sustained wakefulness on the six performance parameters. When compared to the impairment of performance caused by alcohol at a BAC of 0.10%, the same degree of impairment was produced after 20.3 (grammatical reasoning response latency), 22.3 (vigilance accuracy), 24.9 (vigilance response latency) or 25.1 (tracking accuracy) hours. Even after 28 hours of sustained wakefulness, neither of the remaining two performance variables (grammatical reasoning accuracy and simple sensory comparison) decreased to a level equivalent to the impairment observed at a BAC of 0.10%.

DISCUSSION

In the present study moderate levels of alcohol intoxication had a clearly measurable effect on neurobehavioural performance. We observed that as blood alcohol concentration increased performance on all the tasks, except for one, significantly decreased. A similar effect was observed in the sustained wakefulness condition. As hours of wakefulness increased performance levels for four of the six parameters significantly decreased. Comparison of the two effects indicated that moderate levels of sustained wakefulness produce performance decrements comparable to those observed at moderate levels of alcohol intoxication in social drinkers.

As previous research has found that some individuals tend to perform in a manner that is consistent with the expectation that they are intoxicated due to alcohol consumption (Brechenridge and Dodd, 1991), a placebo condition was included in this study. We found that the placebo beverage did not significantly effect mean relative performance. Thus, it was assumed that performance decrements observed during the alcohol condition were caused solely by increasing blood alcohol concentration. Moreover, it is worth noting that the placebo condition in this study generally did not create the perception of alcohol consumption. Furthermore, when participants had already experienced the alcohol condition, and thus the effects of alcohol on their subsequent behaviour and performance, placebo beverages were even less convincing, suggesting that inclusion of a placebo condition is not necessary in future studies of a similar nature.

In general, increasing blood alcohol concentrations were associated with a significant linear decrease in neurobehavioural performance. At a BAC of 0.10% mean relative performance was impaired by approximately 6.8% and 14.2% (grammatical reasoning accuracy and response latency, respectively), 2.3% and 20.5% (vigilance accuracy and response latency, respectively) or 21.4% (tracking). Overall, the decline in mean relative performance ranged from approximately 0.29% to 2.68% per 0.01% BAC. These results are consistent with previous findings that suggest that alcohol produces a dose-dependent decrease in neurobehavioural performance (Billings *et al.*, 1991).

In contrast, mean relative performance in the sustained wakefulness condition showed three distinct phases. Neurobehavioural performance remained at a relatively stable level during the period which coincided with the normal waking day (0 to 17 hours). In the second phase, performance decreased linearly, with poorest performance generally occurring after 25 to 27 hours of wakefulness. It was observed that mean relative performance increased again after 26 to 28 hours of wakefulness presumably reflecting either the well reported circadian variation in neurobehavioural performance (Folkard and Tottersdell, 1993) or an end of testing session effect.

The linear decrease in performance observed for four of the measures in this study is consistent with previous studies documenting neurobehavioural performance decreases for periods of sustained wakefulness between 12 and 86 hours (Linde *et al.* 1992; Storer *et al.* 1989; Fiorica *et al.* 1968). Between the seventeenth and twenty-seventh hours of wakefulness, mean relative performance significantly decreased at a rate of approximately 2.61% (grammatical reasoning response latency), 0.61 and 1.98% (vigilance accuracy and response latency, respectively) or 3.36% (tracking) per hour.

While the results in each of the experimental conditions are interesting in themselves, and have been previously established, the primary aim of the present study was to compare the effects of alcohol intoxication and sustained wakefulness. Equating the effects of the two conditions indicated that 17 to 27 hours of sustained wakefulness (from 12:00am to 10:00am) and moderate alcohol consumption have quantitatively similar effects on neurobehavioural performance. Indeed, the findings of this study suggest that after only 20 hours of sustained wakefulness performance impairment may be equivalent to that observed at a BAC of 0.10%.

This study has confirmed the suggestion made by Dawson and Reid (1997) that moderate levels of sustained wakefulness produce performance decrements equivalent to or greater than those observed at levels of alcohol intoxication deemed unacceptable when driving, working and/or operating dangerous equipment. More importantly, however, this study was designed to determine whether the results of Dawson and Reid (1997) were an isolated finding, or characteristic of the general cognitive effects of sleep deprivation. Using the degree of impairment caused by alcohol that produced a BAC of 0.10% as a standard, this study systematically compared the effects of sustained wakefulness on a range of neurobehavioural tasks. Results indicate that while, in general, sustained wakefulness had a detrimental effect on psychomotor performance, the specific components of performance differed in their degree of sensitivity to sleep deprivation.

The observed differences between the performance tasks with respect to the vulnerability to sleep deprivation can be explained by their relative degrees of complexity. That is to say, the more complex neurobehavioural parameters measured in the present study were more sensitive to sleep deprivation than were the simpler performance parameters. While only 20.3 hours of sustained wakefulness was necessary to produce a performance decrement on the most complex task (grammatical reasoning) equivalent to the impairment observed at a BAC of 0.10%, it was after

22.3 and 24.9 hours of sustained wakefulness that a similar result was seen in a less complex task (vigilance accuracy and response latency, respectively). Furthermore, on the unpredictable tracking task, a slightly less complex task than vigilance, a decrement in performance equivalent to that observed at a BAC of 0.10% was produced after 25.1 hours of wakefulness.

It was observed that, despite a slight downward trend, performance on the simplest of the four tasks did not significantly decrease, even following twenty-eight hours of sustained wakefulness. In contrast, performance on this task was significantly impaired after a dose of alcohol that produced a BAC of 0.10% (or greater). These results are in line with the suggestion that simple tasks are less sensitive to sleep deprivation (Johnson, 1982). Indeed, we believe it likely that impairment of performance on this task may have occurred if we had extended the period of sustained wakefulness. It is interesting to note that several studies (e.g. Dinges *et al.*, 1988) have reported that tasks similarly lacking in complexity, such as simple reaction time tasks, are affected early and profoundly by sleep loss, thus strongly suggesting that monotony may increase sensitivity to sustained wakefulness. Indeed, the fact that this task was not vulnerable to sustained wakefulness may possibly be explained by the interesting and challenging properties of the task.

It is also noteworthy that, while we observed a decrease in accuracy on the grammatical reasoning task, impairment of this performance parameter was not comparable to that produced by a BAC of 0.10%. While this may at first contradict the suggestion that in this study vulnerability to sustained wakefulness was, to a large degree, determined by task complexity, it should be noted that participants were instructed to concentrate on accuracy rather than speed when completing the grammatical reasoning task. Thus, our particular instructions to participants may explain, at least in part, this irregularity. Alternatively, this finding is in line with the suggestion of a natural 'speed-accuracy trade-off'. Similar results have been observed in several studies, which report a decline in speed of performance, but not accuracy, when sleep-deprived subjects are required to perform a logical-reasoning task (Angus and Heslegrave, 1985; Webb and Levy, 1982).

Interestingly, this was not the case with the vigilance task. In this instance, despite instruction to concentrate primarily on accuracy, this component was slightly more vulnerable to sleep deprivation than was response latency. The absence of a trade-off on this task may be explained by the different properties of the vigilance and grammatical reasoning tasks. In accordance with the distinction raised by Broadbent (1953), the latter of these tasks can be defined as an unpaced task, in which the subject determines the rate of stimuli presentation. In contrast, the vigilance task can be defined as a paced task, in which stimuli are presented at a speed controlled by the experimenter. In line with this distinction, our findings are consistent with those of Broadbent (1953) who observed that while a paced task rapidly deteriorated during the experimental period, in terms of speed, an unpaced version of the same task did not.

A further explanation for the differences observed between these two tasks, may relate to the extremely monotonous nature of the vigilance task. Indeed, we believe it likely that subjects were more motivated to perform well on the grammatical reasoning task, which was generally considered more interesting and challenging. Hence degree of motivation may explain why measures of both speed and accuracy decreased on the vigilance task, while on the former task, accuracy remained relatively stable. This suggestion is in line with previous studies that have found that motivation can, to a degree, counteract the effects of sleep loss (Horne and Pettitt, 1985).

Taken together, the results from this study support the suggestion that even moderate levels of sustained wakefulness produce performance decrements greater than is currently acceptable for alcohol intoxication. Furthermore, our findings suggest that while sleep deprivation has a generally detrimental effect on neurobehavioural performance, specific components of performance differ in their sensitivity to sustained wakefulness.

Since approximately 50 percent of shiftworkers typically spend at least twenty-four hours awake on the first night shift in a roster (Tepas *et al.*, 1981), these findings have important implications within the shiftwork industry. Indeed, the results of this study, if generalized to an applied setting, suggest that on the first night shift, on a number of tasks, a shiftworker would show a neurobehavioural performance decrement similar to or greater than is acceptable for alcohol intoxication.

While the current study supports the idea that sustained wakefulness may carry a risk comparable with moderate alcohol intoxication, it is difficult to know to what degree these results can be generalized to "real-life" settings. Indeed, laboratory measures and environments usually bear little resemblance to actual tasks and settings. Furthermore, while our study used a battery of tests to evaluate the effects of sustained wakefulness on performance, their is no guarantee that all the functions involved in "real-life tasks", such as driving, were utilized and assessed. An alternative approach would be to simulate the actual task, as accurately as possible. Given that, for practical and ethical reasons, it is difficult to experimentally study the relationship between sustained wakefulness and actual driving, simulators of varying realism have been used. Thus, protocols using simulators could be used to model "real-life" settings and establish a more accurate estimate of the BAC equivalence for the performance decrement associated with sleep loss and fatigue.

REFERENCES

Angus, R.G. and Heslegrave, R.J. Effects of sleep and sustained cognitive performance during a command and control simulation. *Behavioural Research Methods, Instruments and Computers*, 1985, 17: 55-67.

Babkoff, H., Mikulincer, M., Caspy, T., Kempinski, D. and Sing, H. The topology of performance curves during 72 hours of sleep loss: A memory and search task. *The Quarterly Journal of Experimental Psychology* , 1988, 324: 737-756.

Brechenridge, R. and Dodd, M. Locus of control and alcohol placebo effects on performance in a driving simulator. *Perceptual and Motor Skills*, 1991, 72: 751-756.

Broadbent, D.E. Noise, paced performance, and vigilance tasks. *British Journal of Psychology*, 1953, 44: 295-303.

Dawson, D. and Reid, K. Fatigue, alcohol and performance impairment. *Nature*, 1997, 388: 235.

Dick, R.B., Setzer, J.V., Wait, R., Hayden, M.B., Taylor, B.J., Tolos, B. and Putz-Anderson, V. Effects of acute exposure to toluene and methyl ethyl ketone on psychomotor performance. *Archives of Occupational and Environmental Health*, 1984, 54: 91-109.

Dinges, D.F., Whitehouse, W.G., Orne, E.C. and Orne, M.T. The benefits of a nap during prolonged work and wakefulness. *Work and Stress*, 1988, 2: 139-153.

Fiorica, V., Higgins, E.A., Iampietro, P.F., Lategola, M.T. and Davis, A.W. Physiological responses of man during sleep deprivation. *Journal of Applied Physiology*, 1968,24(2): 169-175.

Folkard, S., Totterdell, P., Minors, D. and Waterhouse, J. Dissecting circadian performance rhythms: Implications for shiftwork. *Ergonomics*, 1993, 36(1-3): 283-8.

Gillberg, M., Kecklund, G. and Akerstedt, T. Relations between performance and subjective ratings of sleepiness during a night awake. *Sleep*, 1994, 17(3): 236–41.

Heishman, S.J., Stitzer, M.L. and Bigelow, G.E. Alcohol and marijuana: Comparative dose effect profiles in humans. *Pharmacology, Biochemistry and Behaviour*, 1989, 31: 649-655.

Horne, J.A. and Pettitt, A. N. High incentive effects on vigilance performance during 72 hours of total sleep deprivation. *Acta psychologica*, 1985, 58, 123: 139.

Johnson, L.C. Sleep deprivation and performance. In: W. B. Webb (Ed.) *Biological rhythms, Sleep and Performance*. Wiley, New York, 1982.

Linde, L. and Bergstrom, M. The effect of one night without sleep on problem-solving and immediate recall. *Psychological Research*, 1992, 54(2): 127-36.

Mullaney, D.J., Kripke, D.F., Fleck, P.A. and Johnson, L.C. Sleep loss and nap effects on sustained continuous performance. *Psychophysiology*, 1983, 20: 643-651.

Storer, J., Floyd. H., Gill, W., Giusti. C. And Ginsberg. H. Effects of sleep deprivation on cognitive ability and skills of paediatric residents. *Academic Medicine*, 1989, 64: 29-32.

Thapar, P., Zacny, J.P., Thompson, W. and Apfelbaum, J.L. Using alcohol as a standard to assess the degree of impairment induced by sedative and analgesic drugs used in ambulatory surgery. *Anesthesiology*, 1995, 82(1): 53-59.

Tilley, A.J. and Wilkinson, R.T. The effects of a restricted sleep regime on the composition of sleep and on performance. *Psychophysiology*, 1984, 21: 406-412.

Webb, W. and Levy, C. Age, sleep deprivation and performance. *Psychophysiology*, 1982, 19(3): 272-276.

Wickens. C. *Engineering psychology and human performance*. C.E. Merill. Columbus. 1984.

Wilkinson. R.T. Effects of up to 60 hours sleep deprivation on different types of work. *Ergonomics*, 1964. 7: 175-186.

TABLE 1. Summary of ANOVA results for neurobehavioural performance variables

	Placebo		Alcohol Intoxication		Sustained Wakefulness	
Performance Variable	$F_{7,147}$	P[a]	$F_{5,105}$	P[a]	$F_{13,273}$	P[a]
GRG Response Latency	0.82	NS	4.96	0.0021	13.77	0.0001
GRG Accuracy	0.63	NS	6.88	0.0001	2.20	NS
VIG Response Latency	2.19	NS	43.09	0.0001	33.74	0.0001
VIG Accuracy	2.02	NS	7.99	0.0008	11.04	0.0001
Unpredictable Tracking	2.63[b]	NS	5.32	0.0008	10.09	0.0001
Simple Sensory Comparison	0.78	NS	1.88	NS	1.47	NS

GRG, grammatical reasoning; VIG, vigilance

[a] corrected by Greenhouse-Geisser epsilon; [b] based on data from twenty subjects.

TABLE 1. Summary of linear regression analysis of neurobehavioural performance variables

Performance Parameter	**DF**	**F**	**P**	**R2**	**%Decrease**
SW Condition					(per hour)
GRG Response Latency	1,4	70.61	0.0011	0.95	2.69
GRG Accuracy	1,4	3.64	NS	--	--
VIG Response Latency	1,4	98.54	0.0006	0.96	1.98
VIG Accuracy	1,4	81.79	0.0008	0.95	0.61
Unpredictable Tracking	1,4	70.93	0.011	0.95	3.36
Simple Sensory	1,4	4.71	NS	--	--
Alcohol Condition					(per0.01% BAC)
GRG Response Latency [b]	1,2	74.30	0.0132	0.97	2.37
GRG Accuracy	1,4	31.07	0.0051	0.89	0.68
VIG Response Latency	1,4	12.65	0.0002	0.98	2.05
VIG Accuracy [a]	1,3	212.37	0.0007	0.99	0.29
Unpredictable Tracking [a]	1,3	238.52	0.0006	0.99	2.68
Simple Sensory	1,4	5.37	NS	--	--

[a] Based on data from 0.02%-0.10% BAC; [b] Based on data from 0.04% -0.10% BAC

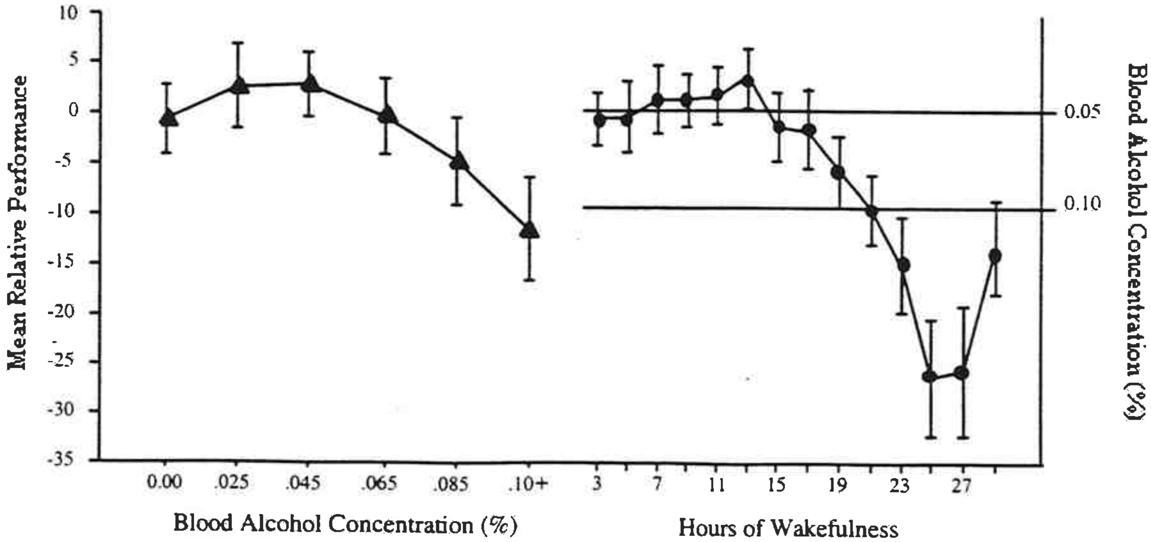


FIG. 1. Mean relative performance levels for the response latency component of the grammatical reasoning task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ± one s.e.m.

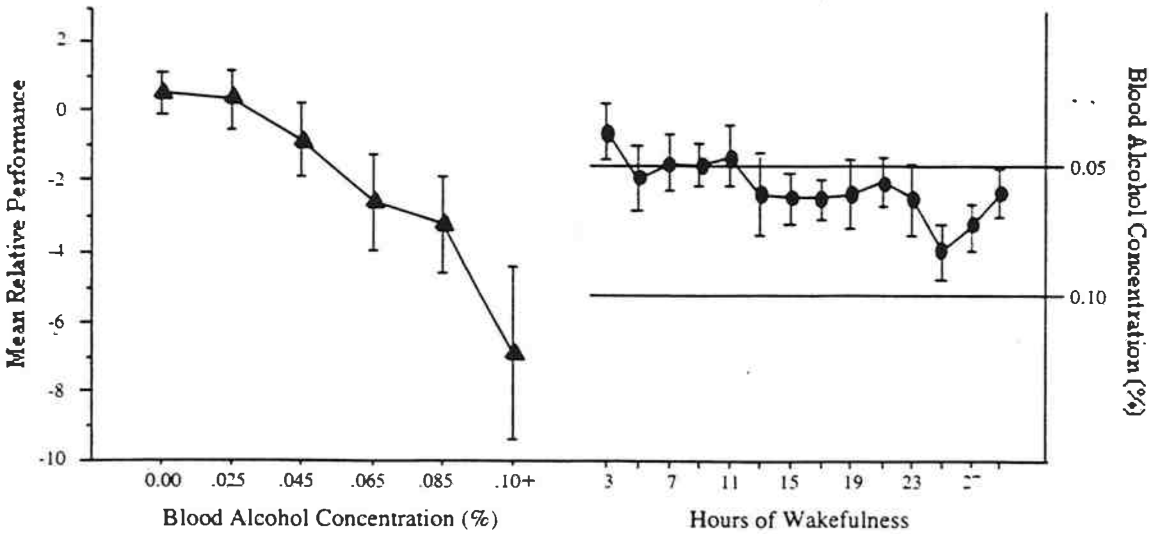


FIG. 2. Mean relative performance levels for the accuracy component of the grammatical reasoning task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ± one s.e.m.

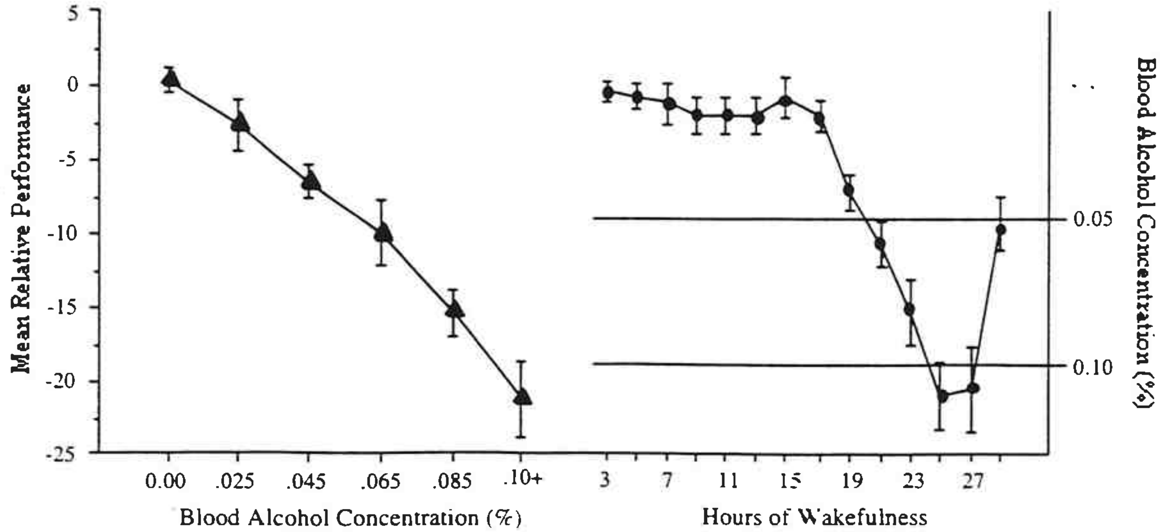


FIG. 3. Mean relative performance levels for the response latency component of the vigilance task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ± one s.e.m.

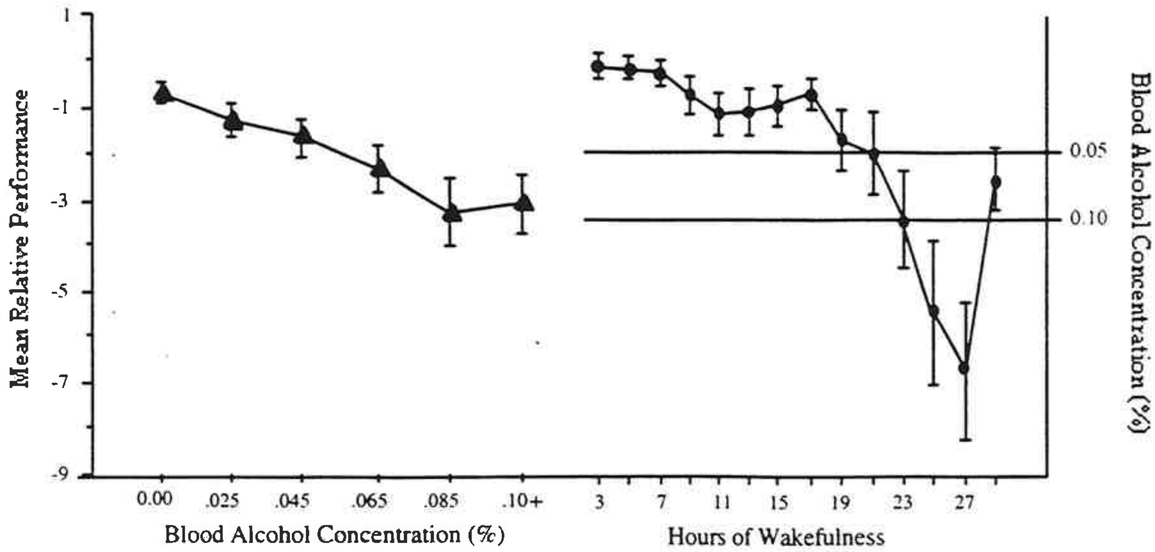


FIG. 4. Mean relative performance levels for the accuracy component of the vigilance task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ± one s.e.m.

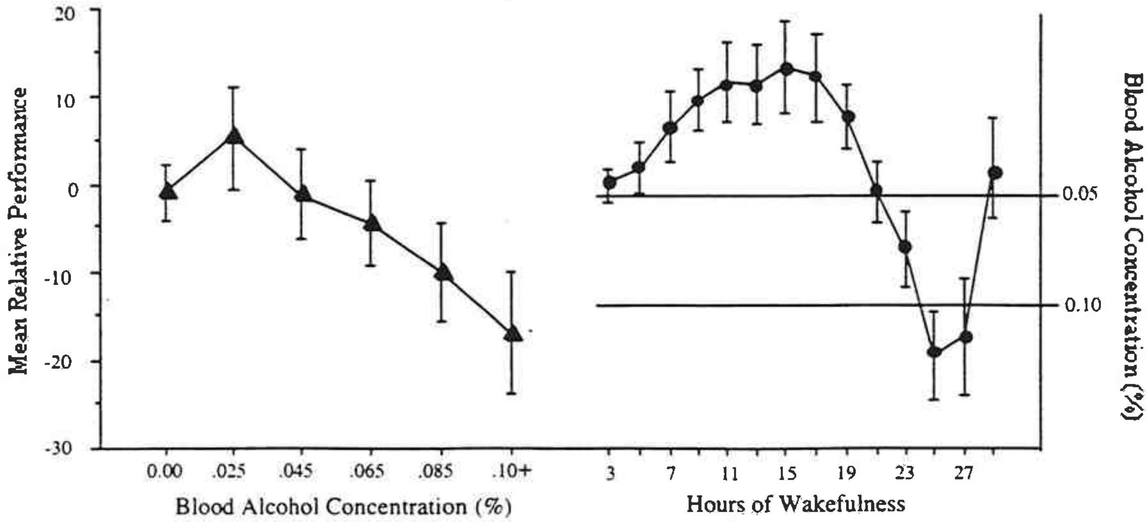


FIG. 5. Mean relative performance levels for the unpredictable tracking task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ± one s.e.m.

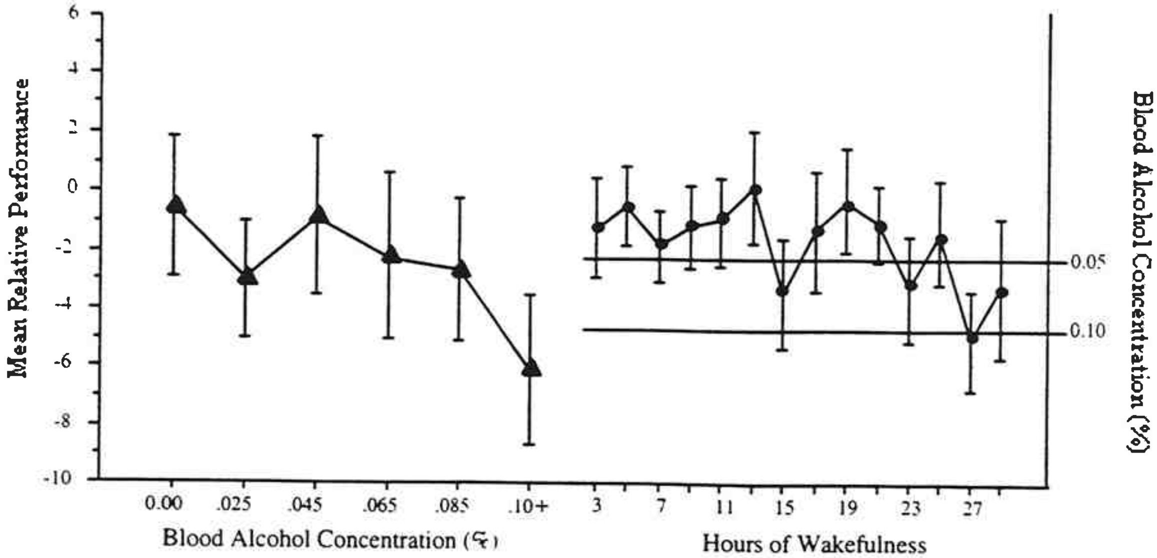


FIG. 6. Mean relative performance levels for the simple sensory comparison task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ± one s.e.m.

APPENDIX G

Crew fatigue factors in the Guantanamo Bay aviation accident

Mark R. Rosekind, PhD.
NASA Ames Research Center

Kevin B. Gregory, Donna L. Miller
Sterling Software

Elizabeth L. Co
San Jose State University Foundation

J. Victor Lebacqz, PhD.
NASA Ames Research Center

Malcolm Brenner
National Transportation Safety Board

On August 18, 1993, at 1656 eastern daylight time, a military contract flight crashed while attempting to land at the U.S. Naval Air Station, Guantanamo Bay, Cuba. The airplane, a Douglas DC-8-61 freighter, was destroyed by impact forces and fire. The three flight crewmembers sustained serious injuries. The National Transportation Safety Board (NTSB), an independent agency of the United States government, conducted an official investigation to determine the cause of the accident and to make recommendations to prevent a recurrence (1). At the request of the NTSB, the NASA Ames Fatigue Countermeasures Program analyzed the crew fatigue factors to examine their potential role in the accident. Three principal sources of information were made available from the NTSB accident investigation to NASA Ames for analysis: 1) Human Performance Investigator's Factual Report,
2) Operations Group Chairman's Factual Report, and 3) Flight 808 Crew Statements.

Based on scientific data related to sleep and circadian rhythms, the NASA Ames Fatigue Countermeasures Program identified three core physiological factors to examine when investigating the role of fatigue in an incident or accident. These factors have subsequently been expanded to four, to explicitly include a factor examined but not previously reported. The four fatigue factors to examine in incident/accident investigations are: 1) acute sleep loss/cumulative sleep debt, 2) continuous hours of wakefulness, 3) time of day/circadian effects, and 4) presence of sleep disorder. These factors were examined and the sleep/wake histories for the flight crew prior to the accident are presented in Figure 1.

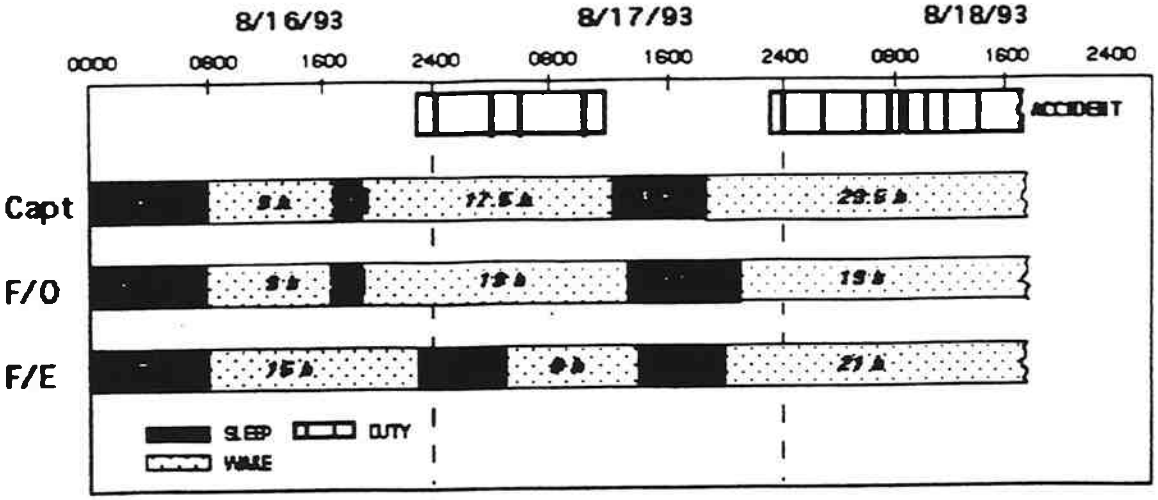


Figure 1. Crew Sleep/Wake Histories

The crew had been off-duty up to 2 days prior to the accident trip and then flown overnight cargo schedules for the two nights prior to the accident, and had been assigned the accident trip unexpectedly on the morning of August 18, shortly after being released from duty. The extra trip involved segments from Atlanta to Norfolk, VA to Guantanamo Bay back to Atlanta, approximately 12 hrs of flight time in 24 hrs of duty. The figure provides information on the fatigue factors: 1) the individual crew members had an acute sleep loss (i.e., 5,6,8 hrs of daytime sleep), 2) were continuously awake 19, 21, and 23.5 hrs prior to the accident, and 3) the accident occurred just prior to 5 pm local time during the afternoon window of sleepiness (this did not represent a time zone change for this US East coast crew). Upon inquiry, there were no reported symptoms or signs of a sleep disorder. Therefore, all three of the initial fatigue factors were operating in this accident.

There were two principal sources of data available on flight crew performance in the accident: cockpit voice recorder (CVR) and Captain's testimony at the NTSB public hearing. There were four performance effects related to fatigue that significantly contributed to the accident: 1) degraded decision-making, 2) visual/cognitive fixation, 3) poor communication/coordination, and 4) slowed reaction time.

A complete description of flight operations, fatigue factors, performance effects, and accident investigation findings are available in the full NTSB accident report (1). Based on the findings, the NTSB determined that the probable cause of this accident included the impaired judgment, decision-making, and flying abilities of the captain and flightcrew due to the effects of fatigue. This was the first time in a major U.S. aviation accident that the NTSB cited fatigue in the probable cause. As a result of this investigation, the NTSB recommended that the Federal Aviation Administration (FAA) expedite the review and upgrade of Flight/Duty Time Limitations of the Federal Aviation Regulations to ensure that they incorporate the results of the latest research on fatigue and sleep issues. The NTSB reiterated a recommendation to require U.S. air carriers 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. This NTSB investigation and the NASA guidelines to examine fatigue factors, provides a model for investigating and documenting the role of fatigue in operational incidents and accidents.

---

(1) National Transportation Safety Board. Aircraft accident report: uncontrolled collision with terrain, American International Airways Flight 808, Douglas DC-8-61, N814CK, U.S. Naval Air Station, Guantanamo Bay, Cuba, August 18, 1993. Washington, DC: National Transportation Safety Board, 1994; NTSB/AAR-94/04.

IBT PROPOSAL, JAN. 6, 1999

INTERNATIONAL
BROTHERHOOD OF TEAMSTERS
AFL-CIO

RAY W. BENNING, JR., Director
Airline Division
6242 Westchester Parkway, Suite 250
Los Angeles, CA 90045

TEL: (310) 645-9860
FAX: (310) 645-9869

January 6, 1999

Mr. Donald E. Hudson
Aviation Medical Advisory Group
14707 East 2nd Avenue
Suite 200
Aurora, CO 80011

Mr. Clay Foushee
Northwest Airlines
901 15th Street, NW
Suite 310
Washington, DC 20005

Gentlemen:

The undersigned (FPA, IACP, IPA, SWAPA, and IBT representing approximately 20,000 crewmembers) concur with the basic document submitted by the entire labor group concerning the issue of Reserve and Reserve Rest. This submission is supplementary to that document and it addresses additional methodology applicable to the Part 135 and non-scheduled carriers (non-scheduled as used herein applies to carriers currently operating under Part 121, Subpart S (supplemental rules) excluding such carriers as FEDEX, UPS, etc. that may operate under supplemental rules, but do so with a known published operating schedule).

It is recommended that the basic labor document, addressing a Protected Time Period (PTP) and Reserve Availability Period (RAP) methodology, apply to all carriers, i.e., scheduled, non-scheduled (as herein defined), and Part 135. Additionally, it is recommended that non-scheduled and Part 135 carriers be provided an alternative method for reserve assignments where it can be validated that the PTP-RAP methodology cannot be applied. An example requiring this alternative means would be an aircraft with one crew at a station with a prospective duty to operate the aircraft at an undetermined time.

The underlying rationale of the Flight and Duty Time ARAC working groups over the past seven years has been to ensure that crews are provided a reasonable sleep opportunity. The most effective means of rest is to provide a sleep opportunity at the same time each night. Recognizing that this is not always possible in the air transport industry, the PTP-RAP methodology and a reduced duty time, based on predetermined notice periods, represent two means of satisfying the underlying rationale of ensuring a reasonable sleep opportunity.

This alternative methodology greatly reduces the economic impact of regulatory reform on the non-scheduled and Part 135 segment of the air transport industry.

We believe that this submission should be helpful to the FAA in formulating a new rule that balances safety, economics, and the public interest. We are pleased that the FAA has addressed this issue and we are supportive of constructive change arising from the effort put forth by the respective groups and the Agency.

Dave Wells //s
FPA, CAPA

Lauri Esposito //s
IPA, CAPA

DR Treichler

D.R. Treichler
IBT, CAPA

Bob Landa //s
SWAPA, CAPA

Don Kingery //s
IACP (non-CAPA)

PROPOSED REGULATORY LANGUAGE

121.xxx Alternative Means of Obtaining Reserve Rest for Non-scheduled Operators (without a known schedule) and Part 135 Operators (separate subpart)

(a) Non-scheduled operators and Part 135 operators may schedule a flight crewmember and that flight crewmember may accept a reserve assignment as follows:

(1) The operator first must assign a PTP period, discussed elsewhere in this rule, provided the operator's flight assignments have a known departure time (schedule), and the operator may then schedule and a crewmember may accept any assignment provided elsewhere in this rule excluding (2) and (3) below;

(2) If unable to comply with (1) above, and an advance notice before departure of not less than 14 hours is provided the crewmember, an operator may schedule and a crewmember may accept any assignment provided elsewhere in this rule excluding (3) below; or

(3) If unable to comply with (1) and (2) above, an operator may assign and a crewmember may accept a reduced duty period as set forth below:

(a) With 8 to 13:59 hours advance notice, the scheduled duty period is limited to 12 hours, but may be extended to 14 hours for operational delays; or

(b) With 6 to 7:59 hours advance notice, the scheduled duty period is limited to 10 hours, but may be extended to 12 hours for operational delays; or

(c) With 4 to 5:59 hours advance notice, the scheduled duty period is limited to 8 hours, but may be extended to 10 hours for operational delays; or

(d) With less than 4 hours advance notice, the scheduled duty period is limited to 7 hours, but may be extended 1 hour for operational delays.

(e) For assignments in paragraph (2) and (3) (a) through (d) above, the operator must relieve the crewmember from all further responsibilities between advance notice and report time.

(f) Advance notice, as used in paragraphs (a) through (d) above, means the time from when a crewmember is alerted for an assignment until transportation local in nature is available at that hotel to transport that crewmember to his place of assignment. The duty period thereby commences with hotel pick up.

Appendix I

Reference Data Furnished by the IBT

1. Normal daily sleep - References vary from 7 hours and 20 minutes to approximately 8 hours and 10 minutes.

Coren, S., *Sleep Thieves,* (Toronto: Free Press, 1996) pp. 251-253
(7 to 8 hours and 10 minutes.)

Dinges, D. and R. Broughton, *Sleep and alertness: Chronobiological, behavioral and medical aspects of napping,* (New York: Raven Press, 1989)
(Average sleep for N. American and European adults were around 7 hours and 20 minutes.)

Wojtczak-Jaroszowa, J., *Physiological and Psychological Aspects of Night and Shift Work,* USDEW (NIOSH) 1977
("During normal night sleep, lasting about 7½ hours....")

2. Napping –

Op. Cit., Coren, S., pp. 222-223
(Naps before and during a shift have shown "modest success.")

Nicholson, A. and B. Stone, *Circadian Rhythms and Disturbed Sleep: Its Relevance to Transport Operations.* IJAS 1/3-D (Unknown publication date in approximately 1982
("...naps, sleeps of 3-4 hours and very long periods of sleep are all attempts to adapt to the irregularity of duty hours and time zone changes, and to ensure adequate rest before the next duty period. It would be reasonable to assume that the natural requirements for sleep are met in this way-even though the timing and duration of the sleep periods are radically changed.")

Nicholson, A., *Sleep and Wakefulness of the Airline Pilot,* Stewart Memorial Lecture presented February 11, 1986 at the Royal Aeronautical Society
("...with a 4 hour period of sleep during the evening, there was a sustained improvement in performance overnight" ....."...recent studies show how (*naps*) can improve alertness...There was a distinct improvement in their alertness during the day when a nap of 1 hour was taken in the morning. The effect was evident in the afternoon, as the nap seemed to encourage the rise in alertness, which normally occurs during the day. The duration of a nap may be critical if it is to be beneficial, and its effects may last for several hours.")

ARAC RESERVE DUTY WORKING GROUP INDUSTRY/MANAGEMENT REPORT

ARAC Reserve Duty Time Working Group
Industry/Management Report

Background and Introduction

The assignment of the Aviation Rulemaking Advisory Group (ARAC) Reserve Duty/Rest Working Group (RDWG) was announced by the Federal Aviation Administration (FAA) in the Federal Register on July 9, 1998. The task assigned and accepted by the RDWG was to provide a review and analysis of industry practice with regard to reserve pilot duty assignments and to provide recommendations to the ARAC and ultimately to the FAA on revisions to applicable Federal Aviation Regulations (FARs) governing reserve pilot flight and duty time assignments.

The RDWG was asked to report on six specific tasks and to complete the report by December 1, 1998. That date was subsequently extended to January 15, 1999.

When FAA issued the latest Notice of Proposed Rulemaking on Flight and Duty Time (NPRM 95-18), which included proposals for reserve rest rules in December, 1995, a large volume of comments were provided to the FAA that underscored the difficulty of crafting a rule which could reasonably allow for the wide array of differences between various types of operations (e.g. labor contracts, international vs. domestic, scheduled vs. non-scheduled, FAR Part 121 vs. 135, on-demand, supplemental, etc.). Thus, the task assignment drafted by the FAA also included a provision for the RDWG to provide recommendations that accommodated these differences in a reasonable fashion.

The first public meeting was held on August 12-13, 1998, and subsequent public meetings were held on September 1-2, October 1-2, October 29-30, and December 2-3. Numerous additional sub-group meetings were held at various times between the public meetings, which were all announced in the Federal Register. The RDWG was constituted by the ARAC with members representing a broad array of constituencies from various industry and labor groups. In addition, approximately 25-30 other stakeholders, government representatives, and other interested parties were present at one or more meetings during the RDWG deliberations.

Many different viewpoints were presented during the course of the RDWG discussions, and unfortunately, no overall consensus emerged. There were major differences between final labor and management proposals. In fact, by the end of the October 29-30 meeting, two distinctly different labor positions had emerged, and it is not clear that these differences were resolved by the final public meeting.

A single industry/management proposal covering FAR Part 121, scheduled operations was developed and agreed to by those members. That proposal is included in Attachment 1, a December 30, 1998 letter from the Air Transport Association (ATA) representative to me as industry/management co-chairman of the RDWG. Although it is referred to in Attachment 1 as the "ATA position," the proposal therein was developed by the entire RDWG industry/management group.

In addition, a consensus industry/management proposal was reached for Part 121, non-scheduled operations, which recognized that certain types of operations could not function under the same types of reserve rules appropriate to scheduled operations. At least several RDWG labor representatives also agreed to this proposal, despite the lack of an overall consensus. This proposal is included in Attachment 2.

It was also generally agreed by the industry/management group that the Part 121, scheduled reserve rest proposal should not apply to Part 135 operations for many of the same reasons. Two proposals were submitted for Part 135 operations, one by the Helicopter Association International (Attachment 3) and one for Part 135, non-scheduled operations by the National Air Tranportation Association and the National Business Aircraft Association (Attachment 4).

This report is organized below according to the six primary tasks as published in the Federal Register RDWG assignment. This industry/management report includes a summary of the views of the Air Transport Association of America, Helicopter Association International, National Air Carrier Association, National Air Transportation Association, National Business Aviation Association, and the Regional Airline Association, as well as the members of these organizations.

Industry/Management Responses to Specific Tasks

Task 1: Review of current scientific data on the effects of fatigue in reserve duty. Consider conflicting opinions.

The first public meeting included an extensive discussion of the relevant scientific literature, and whether any new data pertaining to this issue had emerged since the issuance of NPRM 95-18. It was generally agreed that there were no significant new scientific studies relevant to the reserve duty question published since that time.

It was frequently pointed out by the industry/management group that there have been no known accidents where the probable cause was deemed to be pilot fatigue associated with reserve duty assignments. In the minds of many RDWG members, this was relevant to the question of whether changes to the existing rules should be a regulatory priority.

Extensive discussions ensued that illustrated the fact that the scientific literature pertaining to this issue can be interpreted in a variety of ways. As a result, many different and sometimes inconsistent conclusions can be drawn, and thus, there are no clear answers from the body of scientific literature as to appropriate regulatory policy.

The RDWG did agree that there are two very broad scientific principles specifically relevant to reserve duty. First, it was agreed that humans generally need the opportunity to acquire approximately 8 hours of sleep per 24 hour period. Second, it was agreed that fatigue is more probable during the period of time encompassing approximately 0200 to 0600, which roughly corresponds to the low point in an "average" (across the population) human circadian cycle.

However, it was also noted that the scientific literature demonstrates that humans, in general and pilots in particular, are highly variable in their sleep habits, lifestyles, and circadian cycles. This phenomenon poses significant and difficult complications for FAA regulatory policy on flight and duty time. An appropriate rest opportunity (no matter how long) cannot guarantee that a particular reserve pilot will obtain appropriate sleep. In addition, because of the high degree of variability in individual sleep habits and lifestyles, it is difficult to know the nature and timing of a particular individual's circadian cycle. For example, since a large percentage of pilots commute across multiple time-zones to both reserve and scheduled duty assignments, it is difficult to assess the particular timing of an individual's circadian cycle vis a vis a particular flight assignment.

Thus, the rationale underlying the industry/management proposal is that, at best, reserve rest rules can only reasonably provide for an appropriate rest opportunity. They cannot guarantee that every individual pilot is "appropriately rested" prior to a flight assignment. It is incumbent upon each individual pilot to accept personal responsibility for obtaining adequate rest, given reasonable opportunities provided for rest.

The majority of RDWG members agreed that the ideal method for providing this opportunity is through the provision of a "protected time period" (PTP) of approximately 8 hours during which time a reserve would be undisturbed for the purpose of rest. It was also acknowledged that the PTP should not change more than a few hours from one day to the next. Consensus was reached that this is the most effective method in "normal," scheduled operations. However, because of the need for flexibility to recover from routine weather-related and other types of frequent disruptions, an alternative, acceptable method is to provide appropriate advance notification so that an individual has the opportunity to obtain rest.

In addition, it was recognized by most that a PTP-based reserve rest scheme would be difficult, if not impossible, to implement by many Part 121, non-scheduled operators and/or Part 135 operations (scheduled and non-scheduled) because of the small numbers of crews involved in such operations. Thus, an alternative was deemed to be necessary for non-scheduled and other Part 135 operations.

At the first public meeting, the RDWG reached a consensus that reserve duty is <u>neither duty nor is it rest</u>. It is also important to recognize that a reserve duty day is a work day, and should not be treated as a day off, regardless of whether a reserve pilot is called for a flight assignment. These observations point to the fact that there are often opportunities for rest during reserve availability periods (RAPs), since reserves are frequently not called for flight assignments until later in an availability period, due to the nature of network operations, if at all. Schedule disruptions are more common later in the day due to the "snowball effect," as various schedule discrepancies are compounded throughout the course of a normal operational day. It is incumbent upon those serving in reserve assignments to utilize all available opportunities for rest.

RDWG discussions of the scientific literature also included research by the National Aeronautics and Space Administration (NASA) which demonstrated that even brief naps (approximately 45 minutes) can significantly enhance alertness and serve as an effective countermeasure to fatigue. This underscores the responsibility reserve pilots have to utilize all available rest opportunities during RAPs.

Task 2: Analysis of current reserve schemes and operational situations

Extensive discussions of current practices illustrated that there is a wide variety of reserve schemes currently in place. This is due to the almost infinite differences in types of operations, negotiated contract-imposed work-rules, equipment types, areas served, etc. These discussions illustrated the difficulty of developing a single rule that would not impose a disproportionate impact upon a particular type of operation, and leads to the conclusion that a single rule would not be in the public interest.

It was further demonstrated by the management group that the majority of major airlines (affecting the vast majority of U.S. professional pilots) had negotiated work-rules governing reserve assignments that had factored in the characteristics of a particular organization's operation. Thus, it was asserted that any rule change must be broad and flexible enough to take these negotiated work-rules and operational differences into account without disproportionate impact on a particular carrier.

As a result of these discussions, industry/management members proposed that the best alternative for reserve flight and duty time rulemaking would be to allow individual operators to develop detailed, individually-tailored operations specifications governing reserve duty that would be approved by each organization's FAA Certificate Management Office. This approach is identical to the way FAA currently manages other operations specifications governing flight operations, training programs, and approved maintenance programs. It is also similar to FAA's program for approving advanced training programs, the advanced qualification program (AQP). While many RDWG members, representing all interests, understood the merits of this approach, consensus could not be reached. All industry/management representatives preferred this approach.

Task 3: Recommendations on standards and criteria

After several public meetings, two basic schemes were proposed for providing reserve pilots opportunities for rest or limiting the duty day based upon the amount of advance notice of a flight assignment. The first scheme involved providing a scheduled PTP for all reserve pilots, but also allowed the use of advance notification to either cancel a scheduled PTP or to utilize a reserve on a "sliding scale" where the length of the duty day would be dependent upon the amount of advance notification. It was generally recognized that these provisions were necessary to provide for the flexibility needed by operators to recover from disruptions to normal operations. It would be fair to say that the full RDWG reached a consensus on this conceptual approach. The second scheme simply limited the duty day based upon the amount of advance notification. The latter is very similar to regulations proposed in NPRM 95-18.

After extensive discussions, the RDWG agreed to attempt to reach a consensus for Part 121, scheduled operations on the first scheme, where most pilots would receive a PTP, with an appropriate mechanism for the utilization of advance notification in lieu of PTPs under circumstances associated with deviations from normal operations. The second scheme was proposed as an alternative for Part 121, non-scheduled, and Part 135 operations.

The industry/management proposal for Part 121, scheduled operations is presented in Attachment 1. Attachment 2 contains the Part 121, non-scheduled proposal. As previously mentioned, it was difficult to ascertain whether there was a single agreed upon labor proposal by the end of the last public meeting. The basic differences between the final positions of various labor proposals and the industry/management proposal were associated with the amount of time devoted to PTPs, length of RAPs, and the amount of advance notification necessary to cancel PTPs, modify RAPs, as well as how advance notification should affect the amount of allowable duty time.

Industry/management RDWG members firmly maintain that their final proposal for 121, scheduled operations to provide a minimum 8 hour rest period or 10 hours of advance notification, under most circumstances, prior to a flight assignment is consistent with the state of scientific knowledge and provides more than adequate protection for reserve pilots to complete a flight assignment safely and legally. It is significant that the final RDWG industry/management proposal is far more restrictive with respect to rules governing reserve assignments than either those proposed by the FAA in NPRM 95-18 or current rules, neither of which have provisions for PTPs covering the vast majority of reserve pilots in U.S. domestic service.

The final labor proposal(s) included longer PTPs, longer and more extensive advance notification requirements, shorter RAPs, and restrictions on allowable duty time based upon time of day. The industry/management RDWG members maintain that the benefits which might possibly be derived from the labor proposal(s)' more restrictive parameters are suspect, at best, and not supported either by the scientific literature or by the safety record, in light of the substantial additional burden that would be placed up the industry and the U.S. air transportation system (see task 5 below).

Task 4: Recommendations on how FAA will measure compliance

With regard to the industry/management proposals, there was no disagreement within the RDWG that the FAA would be able to measure compliance in the same way it currently assesses flight and duty time regulatory compliance. It was noted that most automated record keeping systems could be modified to accommodate the proposed changes within 6 to 12 months from the date of publication, depending upon the complexity of a new rule.

Task 5: Economic Impact

Industry/management representatives compiled the available economic data pertaining to the costs of the proposal provided in Attachment 1. It was estimated that the cost of that rule change would be approximately $100 million in incremental costs to the major operators that provided economic data (primarily ATA member airlines). Most of these costs are necessitated by the requirement to hire additional reserve pilots and the associated costs of training both the additional new pilots required and part of the existing pilot population because of the "upward bumping" phenomenon created by most contract-imposed seniority systems during periods when new pilots are being hired.

No economic data were provided by smaller Part 121 operators, Part 135 operations, or other types of operations, but it is probable that the total cost to industry would be significantly greater than $100 million. In addition, it was maintained that some smaller unscheduled operators might have to cease operations under some of the labor proposals. It was also asserted that these proposals would substantially alter the nature of many collective bargaining agreements.

The RDWG was unable to perform additional detailed economic analyses comparing the various proposals. This was due to the fact that: 1) these analyses are very complex and time-consuming, and 2) it was difficult to ascertain how to conduct comparative analyses of competing labor proposals, because a single labor proposal had not emerged by the deadline associated with the final public meeting and the task assignment.

However, exploratory analyses did indicate that very small increases in PTPs, advance notification requirements, and corresponding decreases in RAPs (as outlined in the labor proposal closest to the industry/management proposal) caused significant increases in the number of reserves required to cover current operations. As an illustration of why this dramatic increase occurs, one major air carrier currently staffs about 45 different reserve positions because it operates many different types of aircraft and has multiple crew bases. These circumstances are common to most major airlines (e.g. the number of reserve positions equals the number of crew bases times the number of seat positions in each base--captain vs. first officer vs. second officer--times the number of aircraft types operating in each base). In most cases, there are only a handful of reserves in each category (often as few as 1). One major carrier has estimated that it costs approximately $1 million in salary, benefits, and training costs (initial and upward bumping) for every 7 pilots it initially hires. For this carrier, a one or two hour increase in PTP duration and corresponding reductions in RAPs from the industry/management proposal would require it to add at least one reserve to every category. As a result, the minimum incremental cost for this single airline would be $6-7 million, assuming only one reserve is necessary in each category. These incremental costs over and above the final industry/management proposal are expected to be similar for each major airline. Thus, the potential incremental costs of competing labor proposal(s) could be perhaps double (in the "best" case) or significantly more (in the "worst" case) than the cost estimates associated with the industry/management proposal.

Alternatively, a carrier could choose not to staff the additional reserves that would be required to cover contingencies imposed by more stringent reserve rest requirements. Of course, this would cause significantly more flight cancellations than are common under current rules and a resulting negative impact on the U.S. air transportation system.

In summary, even small (1 or 2 hr.) increases in advance notification requirements, PTPs, or corresponding reductions in RAP, or duty day would cause an operator to add additional reserves in each reserve category to provide at least minimal coverage. The associated incremental costs would be substantial over and above the final RDWG industry/ management proposal.

Reserve pilots, by definition, are necessary because an operator never knows when or if they will be required. In normal operations many, if not most, reserve pilots are never called for an assignment. In short, the economic consequences of the industry/management proposal are significant, but all competing labor proposals are significantly more costly. Thus, the arguably questionable benefits of any rule change must be carefully considered in light of the large additional economic burden imposed upon air transportation providers.

Task 6: Assessment of record-keeping burden

The RDWG was unable to assess the specific additional record-keeping burden since a consensus was not reached on a proposed rule. However, as previously reported, any rule change would require each operator to make changes to it's record-keeping system, which would result in some incremental cost.

In addition, it is expected that FAA would need to either add additional inspectors to monitor compliance with more complex rules than those presently in place, or alternatively, FAA would be required to reduce surveillance in other areas. The RDWG was not in a position to advise the ARAC or the FAA on this internal policy matter.

Respectfully submitted,

H. Clayton Foushee
ARAC RDWG Industry/Management Co-Chairman

Attachment 1

Air Transport Association

December 30, 1998

Mr. H. Clayton Foushee
Vice President-Regulatory Affairs
Northwest Airlines
901 15th Street, N.W. Suite 310
Washington, DC 20005

Dear Clay:

As co-chairman of the Aviation Rulemaking Advisory Committee (ARAC) Working Group on Pilot Reserve Rest, you are aware that the final meeting of that group was held on December 2, 1998. The working group was originally given a task deadline of October, but that date was extended until December. Notwithstanding the extension and despite a good-faith effort from all who participated, a consensus position was not reached.

The ATA reserve rest proposal, discussed at length during the ARAC Working Group meetings, effectively addresses the issue of prospective rest for pilots in reserve status. Attached is the final ATA proposal. which represents the collective position of our member airlines. Our proposal calls for a Protected Time Period (PTP) for each reserve pilot of a minimum of eight consecutive hours. This period of pre-scheduled rest is time when a pilot is free from all duty and has no present responsibility for work. ATA operators anticipate that the majority of reserve pilots will fall into this category.

By definition, reserve pilots are needed to protect schedule integrity when unpredictable events occur. To account for these irregularities, ATA operators require greater flexibility than is afforded by simply scheduling reserve pilots with protected rest periods. Therefore, a system is needed that provides both the flexibility necessary to maintain a reliable operation that meets consumer needs, and that also provides reserve pilots an opportunity for rest.

FAA interpretations have consistently stated that if the time between notification for a flight assignment and reporting for duty were of sufficient length to meet existing rest requirements, then that period would qualify as an opportunity for rest. The ATA

Air Transport Association of America
1301 Pennsylvania Ave., NW – Suite 1100 Washington, DC 20004-1707
(202) 626-4000

proposal includes a provision that provides the pilot with a minimum ten-hour advance notification. Once notified, the pilot would be free from reserve status and all responsibility for work. Notification under the advance notice concept would permit the pilot to be utilized for any legal flight assignment because the pilot has an opportunity for full rest prior to reporting for the assignment.

It is worth noting that the advance notice proposal is not without additional complexity or cost. As stated earlier, our members have indicated that that most reserve pilots will be provided with pre-scheduled or protected rest periods (PTP). A review of historical reserve utilization appears to support this hypothesis.

In order to provide a limit to the time, in which a pilot may be utilized in a specific reserve or duty assignment, a concept called Reserve Availability Period (RAP) is included in the ATA proposal. This limits the pilot's assignment to nineteen hours from the end of the previous protected rest period.

> *Note: The 19 hour proposed maximum Reserve Availability Period (RAP) is consistent with the 16 hour period between consecutive Protected Time Periods (PTP) plus the ability to reschedule the subsequent PTP by 3 hours. Any maximum PAP of less than 19 hours cannot be justified and will have considerable economic impact on operators.*

In summary, the ATA Reserve Rest proposal satisfies the ARAC task assignment as it appeared in the July 9, Federal Register. Reserve pilots are provided with an opportunity for prospective rest that is not available to them under the current rule. This proposal also provides a solution to reserve rest that is consistent with a long list of FAA interpretations. In developing this proposal, ATA member airlines considered many factors including safety, effectiveness, flexibility, cost, administration, compliance and FAA enforcement.

Sincerely,

for:

Captain Paul Railsback
Chairman, ATA Reserve Rest
Task Force

Encl.

ARAC Reserve Duty and Rest Requirements Working Group

DEFINITIONS

The following definitions for ***rest*** and ***duty*** apply to Subparts Q, R, and S and are identical to existing definitions in Subpart P.

Duty Period - The period of elapsed time between reporting for an assignment involving flight time and release from that assignment by the certificate holder conducting domestic, flag or supplemental operations. The time is calculated using either Coordinated Universal Time or local time to reflect the total elapsed time.

Protected Time Period (PTP) - A period of time during a reserve assignment that provides a flight crewmember with an opportunity to rest. A certificate holder may not contact a flight crewmember during his or her PTP, and a crewmember may not have responsibility for work during his/her PTP.

Reserve Availability Period (RAP) - The period of time from the end of one protected time period to the time that the reserve flight crewmember must complete reserve or flight duty and start his/her next PTP.

Reserve Flight Crewmember - A flight crewmember that does not have a flight duty assignment and has a present responsibility for flight duty if called, but who is not on standby duty

Rest Period - The period free of all restraint or duty for a certificate holder conducting domestic, flag or supplemental operations and free of all responsibility for work or duty should the occasion arise.

Standby Duty – A period of time when a flight crewmember is required to report for a flight assignment in less than 1 hour from the time of notification. It also includes time when a flight crewmember is required to report to and remain at a specific facility (e.g. airport, crew lounge) designated by the certificate holder. Standby duty is considered part of a duty period. Standby duty ends when the flight crewmember is relieved from duty associated with an actual flight, or is otherwise relieved from duty.

ARAC Reserve Duty and Rest Requirements Working Group

RESERVE REST PROPOSAL

PART 121, SCHEDULED

Rest Period:

Each flight crewmember assigned to reserve duty will be provided with a scheduled rest period of at least eight consecutive hours during each reserve day, free of all duty with the carrier, so that the flight crewmember will have an opportunity to rest.

- The carrier may reschedule the rest period by as much as three hours earlier or later than the beginning time of the preceding rest period provided that notice is given prior to commencement of the next scheduled rest period.
- The carrier may reschedule the rest period with at least ten hours advance notice prior to the commencement of the next scheduled rest period.

Advance Notice:

Advance notice to a reserve flight crewmember of a flight assignment by the air carrier provides the flight crewmember an opportunity for rest.

- If the reserve flight crewmember is provided with 10 or more hours advance notice, that flight crewmember may be assigned any legal flight assignment.
- Contact may not be made with the reserve flight crewmember during a scheduled rest period for the purpose of providing advance notice.

Reserve Availability Period:

The Reserve Availability Period is the period of time from the end of the rest period to the time that the reserve flight crewmember must complete reserve or flight duty.

The reserve flight crewmember's reserve availability period may not exceed 19 hours except as permitted below. Actual flight duty time may be extended an additional two hours for reasons beyond the control of the air carrier such as weather, ATC, or mechanical delays. With advance notice of less than ten hours, the reserve availability period may be adjusted as follows, allowing for an opportunity for rest in preparation for the assignment:

- If at least 8 hours notice is given, the scheduled reserve availability period may not exceed 24 hours, except that the actual reserve availability period may be extended an additional 2 hours due to operational circumstances beyond the control of the operator.

- If at least 6 hours notice is given, the scheduled reserve availability period may not exceed 22 hours, except that the actual reserve availability period may be extended an additional 2 hours due to operational circumstances beyond the control of the operator.

- If at least 4 hours notice is given, the scheduled reserve availability period may not exceed 20 hours, except that the actual reserve availability period may be extended an additional 2 hours due to operational circumstances beyond the control of the operator.

The above reserve Availability Rules apply to international flights except where the reserve flight crewmember is assigned to an augmented crew, in which case, the flight and duty time rules of §121.483 and §121.485 apply for the entire flight duty assignment.

* * *

Attachment 2

Alternative Reserve Duty and Rest Proposal for Non-Scheduled Operations

(a) A certificate holder may apply the following reserve scheme for non-scheduled operations in lieu of the protected time reserve scheduling requirements for domestic or flag operations..

(b) Each flight crewmember must be given a 10-hour rest period before any reserve time assignment.

(c) If the reserve flight crewmember is provided with 10 or more hours advance notice, that flight crewmember may be assigned any legal flight assignment.

(d) The certificate holder may provide advance notice of an assignment to duty involving flight and provide an additional time of not less than one hour to report with the following limitations.

(1) If at least 8 hours advance notice is given, the scheduled duty period is limited to 12 hours, but may be extended to 14 hours for operational delays.

(2) If at least 6 hours notice is given, the scheduled duty period is limited to 10 hours, but may be extended to 12 for operational delays.

(3) If at least 4 hours notice is given, the scheduled duty period is limited to 8 hours, but may be extended to 10 for operational delays.

(4) If less than 4 hours notice is given, the scheduled duty period is limited to 7 hours, but may be extended to 8 for operational delays.

(e) The certificate holder must relieve the crewmember from all further responsibilities between advance notice and report time. [End]

Attachment 3

Helicopter
Association
International

1635 Prince Street, Alexandria, Virginia 22314-2818 Telephone: (703) 683-4646 Fax (703) 683-4745

January 14, 1999

Dr. H. Clayton Foushee
Vice President-Regulatory Affairs
Northwest Airlines
901 15th Street, NW. Suite 310
Washington, DC 20005

Re: *ARAC Flight Crew Reserve Time Working Group:*
HAI Proposal for a Rule Applicable to Part 135 On-Demand Air Charter

Dear Clay:

On August 5, 1998, FAA invited Helicopter Association International (HAI) to serve on a working group of the Aviation Rulemaking Advisory Committee (ARAC) to consider flight crew reserve time requirements. HAI herewith tenders its proposal for the structure and content of a Flight Crew Reserve Time regulation applicable to on-demand air charter operations conducted under 14 CFR Part 135.

HAI's proposal reflects many hours of thought, discussion and negotiation focused on optimizing flight safety, flight crew lifestyle concerns and operational flexibility in the context of the unique demands of Part 135 air charter operations. As you know, HAI fully supports the proposal for scheduled domestic operations conducted under 14 CFR Part 121 described elsewhere in your report. HAI believes that proposal is an appropriate balancing of concerns in Part 121 domestic scheduled air carrier operations. However, HAI also believes that the proposed Part 121 solution will not work in the Part 135 context, in particular because the advance notice provisions of the Part 121 proposal are inconsistent with the on-demand nature of part 135 air charter operations.

HAI also supports the substance of the "Special Provisions for Air Ambulance Operations" proposed by the National Air Transportation Association (NATA) and National Business Aviation Association (NBAA). However, we believe that the approach outlined there is appropriate for all part 135 on-demand air charter operations.

Finally, HAI thanks you and Dr. Don Hudson for your very capable, even-handed, and very patient leadership of the Working Group. Your efforts as co-chairs have been greatly appreciated.

Sincerely,

Roy Resavage
President

ARAC Flight Crew Reserve Time Working Group
HAI Proposal for a Rule Applicable to Part 135 On-Demand Air Charter

HAI proposes a rule on Part 135 Flight Crew Reserve Time structured in three parts:

1. **Scheduled Reserve**

Under 14 CFR part 135, an on-demand air charter operator may assign a pilot to "scheduled reserve."

- No period of scheduled reserve may exceed 14 hours in any 24 hour period.
- Each period of scheduled reserve must be preceded by a "protected time period" of at least 10 consecutive hours in length.
- No combination of "scheduled reserve" and assigned duty may exceed 20 consecutive hours.
- Under "scheduled reserve," the pilot's duty period begins when the pilot receives a call from the operator to report for work.

2. **Extended Reserve**

An operator may assign a qualifying pilot to a period of "extended reserve." Under extended reserve, a pilot may be assigned to hold herself:

- Able to be contacted by the operator;
- Remain fit to fly (to the extent that this is within the control of the pilot); and
- Remain within a reasonable response time of the aircraft,

all without triggering the start of any period of "duty" under the Part 135 flight crew duty time regulations.

a. Duty under Extended Reserve

- Under "extended reserve," the pilot's duty period begins when the pilot receives a call from the operator to report for work.
- When a pilot completes a period of duty under extended reserve, that pilot shall enter a protected time period of at least 10 consecutive hours before next being available for contact by the operator.

b. Limitation on Extended Reserve

- Assignment to extended reserve may not exceed 15 consecutive days.

- If assignment to extended reserve is for a period of not more than six consecutive days, the flight crew member shall enter a protected time period of at least 24 consecutive hours before next being available for contact by the operator.

- If assignment to extended reserve is for a period of more than six consecutive days, one additional period of 24 consecutive hours shall be added to the protected time period for each 3 days, or any portion of three days, of extended reserve assignment over six days.

3. **Operational Delay**

- The limitations stated in paragraphs 1 and 2 above may be extended by a maximum of 2 hours to meet operational delays.

- The limitations stated in paragraphs 1 and 2 above may be extended by air medical service operators as reasonable and necessary to complete a medical transport operation.

Attachment 4

NATA

NATIONAL AIR
TRANSPORTATION
ASSOCIATION

4226 King Street
Alexandria, Virginia 22302
(703) 845-9000 FAX (703) 845-8176

January 15, 1999

Mr. H. Clayton Foushee
Vice President, Regulatory Affairs
Northwest Airlines
901 15th Street, NW
Suite 310
Washington, DC 20005

Dear Clay,

Enclosed, you will find the National Air Transportation Association (NATA) and National Business Aviation Association (NBAA) proposal for the Aviation Rulemaking Advisory Committee Reserve Duty/Rest Working Group.

This concept paper reflects the issues unique to the on-demand air charter industry and explains the operator and pilot relationship where reserve concepts are concerned. While the proposal articulates the manner in which both NATA and NBAA believe reserve-related issues for Part 135 unscheduled operators should be handled, this proposal should not be viewed as suggested regulatory language. Please forward this proposal to the ARAC Executive Committee for submission to the Federal Aviation Administration.

Thank you for all your hard work as we addressed this complex issue.

Sincerely,

Andy Cebula

Andrew V. Cebula
Vice President

Enclosure
cc: Phil Harter, The Mediation Consortium

January 15, 1999

NATIONAL AIR TRANSPORTATION ASSOCIATION
&
NATIONAL BUSINESS AVIATION ASSOCIATION
PROPOSAL FOR RESERVE–RELATED ISSUES IN FAR PART 135 UNSCHEDULED OPERATORS

THE CONCEPT:

Under FAR Part 135, a flight crewmember's reserve issues consist of:

1. Rest
   - required rest (per current regulations)
2. Opportunity Time
   - can be contacted for a possible duty assignment
3. Duty
   - flying time
   - time required to prepare/conclude a flight
4. Standby
   - time required to wait for duty assignments

The purpose of this proposal is to define the elements of 'Standby' and 'Opportunity Time.' This clarification will provide the Part 135 certificate holder with the versatility to comply with the on-demand nature of unscheduled FAR Part 135 operations by having a pool of crewmembers who are on their own time, and free of all present duties of a certificate holder, unless the crewmember is contacted and the crewmember accepts a duty assignment. At the same time, this clarifies the crewmember's responsibilities to the Part 135 certificate holder and ensures adequate rest and fitness for duty assignments.

	OPPORTUNITY TIME	STANDBY	DUTY
What was the Previous Rest?	10 consecutive hours after a duty assignment	10 consecutive hours after a duty assignment	10 consecutive hours after a duty assignment
Is this Rest?	no	no	no
Is this Duty?	no	yes	yes
Can the Certificate Holder Contact Crewmember?	yes	yes	n/a
Is This Part of 14HR Duty Period?*	no	yes	yes

*SPECIAL PROVISIONS APPLY FOR AIR AMBULANCE FLIGHT OPERATIONS, SEE PAGE 3

Previous Rest

Following a duty assignment, the crewmember must have received at least 10 consecutive hours of Rest before assignment to 'Opportunity,' 'Standby,' or 'Duty' can occur.

Rest or Duty?

Opportunity Time: Opportunity time is not to be considered a duty assignment and does not fall under the duty time limitations. However, Opportunity Time is not Rest as defined by the regulations. It is an assignment unique to Part 135 unscheduled operators. When in Opportunity Time, the crewmember has no specific duties to the certificate holder until a duty assignment is accepted. Example of Opportunity Time: The certificate holder has no current duty or Standby assignment for the crewmember; however, should one arise, the certificate holder can contact the crewmember to determine if the crewmember can report for that duty.

Standby: Standby is considered a duty assignment. Upon being assigned to Standby, the 14-hour duty clock begins. This duty period ends when the crewmember is released by the certificate holder or the 14-hour duty period expires, whichever occurs first. Example of a Standby assignment: Crewmember is directed to wait at the airport for contact for a duty assignment and must report to that assignment within a reasonable time period.

Duty: Duty is the time a certificate holder has assigned a crewmember to specific duties and responsibilities. Duty time begins when a crewmember reports and ends when released or the duty period expires. Examples of duty are: flying, pre-flight and post-flight activities, training for the certificate holder.

Obligation to report

Opportunity Time: During Opportunity Time, the flight crewmember has no specific duties to the certificate holder; however, the certificate holder can contact the flight crewmember for a duty assignment should one arise. There is a responsibility on the crewmember to be fit for a duty assignment unless the flight crewmember is not capable of accepting a duty assignment based on an inability to meet the following, for example:

- Adequately rested for the planned duty assignment,
- No immediate physical impediments that would affect ability to perform the duty assignment, i.e., sprained ankle or broken arm, etc.,
- Not being detrimentally affected by a major life stress, i.e. death in the family, or divorce, etc., that would affect ability to perform the duty assignment, and
- Ability to report for duty within a reasonable amount of time as defined by the certificate holder.

Standby: The duty period begins when Standby is assigned. A crewmember in Standby must be able to complete any duty assignment within the original duty period.

Duty: Reporting is not applicable as the crewmember is presently on duty.

Part of Duty Period?

Opportunity Time: Opportunity Time is not considered part of the duty period and, therefore, does not count against the 14-hour duty clock.

Standby: This assignment is part of duty and can only continue for the duration of the normal duty period.

Special Provisions for Air Ambulance Operations

To accommodate the unique and critical flight operations conducted by Air Ambulance operators, these Part 135 on-demand air charter operators could operate under the following standby provisions without triggering duty time:

- an operator may contact the pilot for a duty assignment
- the pilot may be expected to remain fit for flight (to the extent that this is within the control of the pilot)
- the pilot may be expected to remain within a reasonable response time to the aircraft
- when operating under these provisions a duty period begins when the pilot is contacted and accepts an assignment

Such operations would be subject to the following constraints:

- following completion of a duty assigned during a period of extended reserve, the pilot will be provided at least 10 consecutive hours of rest before next being available for contact by the operator
- assignment to extended standby can consist of up to six consecutive days which shall be followed by a period of at least 24 hours of consecutive rest before next being available for contact by the operator
- Extension Provisions:
  The six-day period may be extended by the operator under the following conditions:
  1. Three additional days of extended standby may be assigned with the addition of another 24-hour period of rest.
  2. The maximum amount of extended standby will be 15 days followed by a mandatory 4 days of consecutive rest during which the operator may not contact the pilot.
- The duty period may be extended by Air Ambulance operators as reasonable and necessary to complete a medical transport operation.

[4910-13]

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

Flight Crewmember Flight Time Limitations and Rest Requirements

AGENCY: Federal Aviation Administration, DOT.

ACTION: Notice.

SUMMARY: This notice announces to the public the Federal Aviation Administration's intent to rigorously enforce the regulations concerning flight time limitations and rest requirements. These regulations have been under review for some time, and the FAA has stated with respect to reserve time assignments that if new rules were not adopted, the FAA intended to ensure that the current rules, as interpreted, are being correctly implemented. No new rules with regard to reserve time have been adopted. Therefore, the FAA is reiterating its longstanding interpretation of its regulations on this issue and is giving affected certificate holders and flight crewmembers notice of its intent to enforce its rules in accordance with this interpretation. This notice is being given so that those affected will have an opportunity to review their practices and, if necessary, come into full regulatory compliance.

DATES: This notice is effective on June 15, 1999.

FOR FURTHER INFORMATION CONTACT:

Alberta Brown, Air Transportation Division, AFS-200, 800 Independence Avenue, SW., Washington, DC 20591, Telephone (202) 267-8321.

SUPPLEMENTARY INFORMATION:

The Regulation

The Civil Aeronautics Act of 1938 (52 Stat. 1007; as amended by 62 Stat. 1216, 49 U.S.C. 551) and subsequently, the Federal Aviation Act of 1958 (now codified at 49 U.S.C. § 40101 et seq.) addressed the issue of regulating flight crewmember hours of service. The Federal Aviation Act, as amended, empowers and directs the Secretary of Transportation to establish "regulations in the interest of safety for the maximum hours or period of service of airmen and other employees of air carriers." 49 U.S.C. § 44701(a)(4). Moreover, the Act also provides the FAA with the authority to prescribe "regulations and minimum standards for other practices, methods, and procedures the

Administrator finds necessary for safety in air commerce and national security." 49 U.S.C. § 44701(a)(5).

The current rules specify flight time limitations and rest requirements for air carriers certificated to operate under part 121 (domestic: subpart Q; flag: subpart R; and supplemental: subpart S) and part 135 (subpart F). The FAA has consistently interpreted the term rest to mean that a flight crewmember is free from actual work for the air carrier or from the present responsibility for work should the occasion arise. Thus, the FAA previously has determined that a flight crewmember on reserve was not at rest if the flight crewmember had a present responsibility for work in that the flight crewmember had to be available for the carrier to notify of a flight assignment.

The FAA's current rules at 14 CFR § 121.471 set forth flight time limitations and rest requirements for domestic operations. Subsections (b) and (c) of this section have generated numerous interpretation requests from industry. These sections provide that:

> *Section 121.471 Flight time limitations and rest requirements: All flight crewmembers.*
>
> *(b) Except as provided in paragraph (c) of this section, no certificate holder conducting domestic operations may schedule a flight crewmember and no flight crewmember may accept an assignment for flight time during the 24 consecutive hours*

preceding the scheduled completion of any flight segment without a scheduled rest period during that 24 hours of at least the following:

(1) 9 consecutive hours of rest for less than 8 hours of scheduled flight time.

(2) 10 consecutive hours of rest for 8 or more but less than 9 hours of scheduled flight time.

(3) 11 consecutive hours of rest for 9 or more hours of scheduled flight time.

(c) A certificate holder may schedule a flight crewmember for less than the rest required in paragraph (b) of this section or may reduce a scheduled rest under the following conditions:

(1) A rest required under paragraph (b)(1) of this section may be scheduled for or reduced to a minimum of 8 hours if the flight crewmember is given a rest period of at least 10 hours that must begin no later than 24 hours after the commencement of the reduced rest period.

(2) A rest required under paragraph (b)(2) of this section may be scheduled for or reduced to a minimum of 8 hours if the flight crewmember is given a rest period of at least 11 hours that must begin no later than 24 hours after the commencement of the reduced rest period.

(3) A rest required under paragraph (b)(3) of this section may be scheduled for or reduced to a minimum of 9 hours if the flight crewmember is given a rest period of at least 12 hours that must begin no later than 24 hours after the commencement of the reduced rest period.

Similar language is contained in Sections 135.265(b) and (c). Also note the "look back" requirement in Section 135.267(d).

The FAA has consistently interpreted Section 121.471(b) and the corresponding Section 135.265(b) to mean that the certificate holder and the flight crewmember must be able to look back over the 24 consecutive hours preceding the scheduled completion of the flight segment and find the required scheduled rest period. This interpretation of rest also has been applied to pilots on "reserve time." Reserve time while not defined in 14 CFR is generally understood to be a period of time when a flight crewmember is not on duty but must be available to report upon notice for a duty period. Thus, a flight crewmember on reserve could not take a flight assignment, and the certificate holder could not schedule that crewmember for a flight assignment, unless the flight crewmember had a scheduled rest period such that at the end of the flight segment one could look back 24 hours and find the required amount of rest.

Compliance and Enforcement Plan

Flight crewmembers and their unions have raised concerns that scheduling processes used by some certificate holders may not ensure compliance with flight time restrictions and rest requirements when a flight crewmember is on reserve duty. Any noncompliance should be corrected without delay.

The FAA recognizes, however, that current processes for scheduling flight crewmembers have been in place for some time and that full compliance might not be able to be achieved immediately. The FAA therefore intends to take into consideration this fact and the certificate holder's good faith efforts to come into compliance in determining what, if any, enforcement action is appropriate if noncompliance is discovered. With regard to violations by individual flight crewmembers, the FAA will consider the circumstances of each case, including such factors as the employing certificate holder's efforts to come into compliance and the culpability of the individual.

If any certificate holder needs to make changes to its scheduling system, the FAA believes that full compliance can be achieved by all certificate holders within 180 calendar days. Until that time the FAA does not intend to target its inspection resources on this compliance issue. However, on December 12, 1999, the FAA intends to begin a comprehensive review of certificate holders' flight scheduling practices and expects to deal stringently with any violations discovered.

Issued in Washington, DC on June 10, 1999

/s/

L. Nicholas Lacey

Director, Flight Standards Service

12/1/98
New

ATA Proposed Reserve Rest Regulation

Rest Period:

Each flight crewmember assigned to reserve duty will be provided with a scheduled rest period of at least eight consecutive hours during each reserve day, free of all duty with the carrier so that the the flight crewmember will have an opportunity to rest.

- The carrier may reschedule the rest period by as much as three hours earlier or later than the beginning time of the preceding rest period provided that notice is given prior to commencement of the next scheduled rest period.
- The carrier may reschedule the rest period with at least ten hours advance notice prior to the commencement of the next scheduled rest period.

Advance Notice:

Advance notice to a reserve flight crewmember of a flight duty assignment by the air carrier provides the flight crewmember an opportunity for rest.

- If the reserve flight crewmember is provided with 10 or more hours of advance notice, that flight crewmember may be assigned any legal flight assignment.
- Contact may not be made with the reserve flight crewmember during a scheduled rest period for the purpose of providing advance notice.

Reserve Availability Period:

The Reserve Availability Period is the period of time from the end of the rest period to the time that the reserve flight crewmember must complete reserve or flight duty.

The reserve flight crewmember's reserve availability period may not exceed 19 -12 hours except as permitted below. Actual flight duty time may be extended an additional two hours for reasons beyond the control of the air carrier such as weather, ATC, or mechanical delays. With advance notice of less than ten hours, the reserve availability period may be extended as follows:

Brutal

Advance Notice	Reserve Availability Period
4 - 5:59 hours	20 hours scheduled + 2 in actual operation
6 - 7:59 hours	22 hours scheduled + 2 in actual operation
8 - 9:59 hours	24 hours scheduled + 2 in actual operation

The RAP applies to the first duty period of a flight assignment. Subsequent duty periods of the flight assignment are subject to FAR 121 Subpart Q, R or S, flight duty time rules, as applicable.

International Flight Crews:

The above RAP rules apply to international flights except where the reserve flight crewmember is assigned to an augmented crew under Subpart R or S in which case the flight and duty time rules of those Subparts apply for the entire flight duty assignment.

12/02/98

NATIONAL AIR CARRIER ASSOCIATION
RESERVE DUTY AND REST POSITION

Reserve Duty and Rest Working Group Meeting
September 2, 1998

The following is proposed as an amendment to FAR Part 121 to establish a formal reserve duty and rest regime for domestic, flag and supplemental operations.

121.xxx. Reserve Duty and Rest. Certificate holders may schedule flight crewmembers for reserve assignments using one of the following methods after providing the crewmember with a 12-hour notice of the particular reserve option that is being applied. Reserve options may not be changed without an intervening 12 hour rest.

(a) The certificate holder shall provide the flight crewmember with a scheduled rest period of not less than 8 hours within each 24 hour period of reserve; or

(b) The certificate holder may provide advance notice of an assignment to duty involving flight and provide an additional time of not less than one hour to report with the following limitations. The certificate holder must relieve the crewmember from all further responsibilities between advance notification and report time.

(1) If the flight crewmember receives at least 8 hours advance notice, the flight and duty limitations set forth in this Subpart apply.

(3) Less than 8 hours but more than 6 hours advance notice, the scheduled duty period is limited to 12 hours, but may be extended to 14 hours for operational delays.

(4) Less than 6 hours but more than 4 hours notice, the scheduled duty period is limited to 10 hours, but may be extended to 12 hours for operational delays.

~~(5)~~ Less than 4 hours, the scheduled duty period is limited to 8 hours, but may be extended to 10 hours for operational delays; or

(c) Where the operator is unable to provide a flight crewmember with one of the rest or notification periods described in (a) or (b) above, the crewmember is limited to no more than 72 hours in reserve status without a planned rest period of at least 24 consecutive hours. If the crewmember is assigned duty involving flight, the subsequent minimum rest period of this Subpart shall be increased by at least one-half the length of the preceding flight duty period.

January 6, 1999

Mr. Donald E. Hudson
Aviation Medical Advisory Group
14707 East 2nd Avenue
Suite 200
Aurora, CO 80011
20005

Mr. Clay Fourshee
Northwest Airlines
901 15th Street, NW
Suite 310
Washington, DC

Gentlemen:

The undersigned (FPA, IACP, IPA, SWAPA, and IBT representing approximately 20,000 crewmembers) concur with the basic document submitted by the entire labor group concerning the issue of Reserve and Reserve Rest. This submission is supplementary to that document and it addresses additional methodology applicable to the Part 135 and non-scheduled carriers (non-scheduled as used herein applies to carriers currently operating under Part 121, Subpart S (supplemental rules) excluding such carriers as FEDEX, UPS, etc. that may operate under supplemental rules, but do so with a known published operating schedule).

It is recommended that the basic labor document, addressing a Protected Time Period (PTP) and Reserve Availability Period (RAP) methodology, apply to all carriers, i.e., scheduled, non-scheduled (as herein defined), and Part 135. Additionally, it is recommended that non-scheduled and Part 135 carriers be provided an alternative method for reserve assignments where it can be validated that the PTP-RAP methodology cannot be applied. An example requiring this alternative means would be an aircraft with one crew at a station with a prospective duty to operate the aircraft at an undetermined time.

The underlying rationale of the Flight and Duty Time ARAC working groups over the past seven years has been to ensure that crews are provided a reasonable sleep opportunity. The most effective means of rest is to provide a sleep opportunity at the same time each night. Recognizing that this is not always possible in the air transport industry, the PTP-RAP methodology and a reduced duty time, based on predetermined notice periods, represent two means of satisfying the underlying rationale of ensuring a reasonable sleep opportunity.

This alternative methodology greatly reduces the economic impact of regulatory reform on the non-scheduled industry. We believe that this submission should be helpful to the FAA in formulating a new rule that balances safety, economics, and the public interest. We are pleased that the FAA has addressed this issue and we are supportive of constructive change arising from the effort put forth by the respective groups and the Agency.

Dave Wells //s
FPA, CAPA

Lauri Esposito //s
IPA, CAPA

D.R. Treichler
IBT, CAP.

Bob Landa //s
SWAPA, CAPA

Don Kingery //s
IACP (non-CAPA)

PROPOSED REGULATORY LANGUAGE

121.xxxAlternative Means of Obtaining Reserve Rest for Non-scheduled Operators (without a known schedule) and Part 135 Operators (separate subpart)

(a) Non-scheduled operators and Part 135 operators may schedule a flight crewmember and that flight crewmember may accept a reserve assignment as follows:

(1) The operator first must assign a PTP period, discussed elsewhere in this rule, provided the flight assignment has a known departure time (schedule), and the operator may then schedule and a crewmember may accept any assignment provided elsewhere in this rule excluding (2) and (3) below;

(2) If unable to comply with (1) above, and an advance notice before departure of not less than 14 hours is provided the crewmember, an operator may schedule and a crewmember may accept any assignment provided elsewhere in this rule excluding (3) below; or

(3) If unable to comply with (1) and (2) above, an operator may assign and a crewmember may accept a reduced duty period as set forth below:

(a) With 8 to 13:59 hours advance notice, the scheduled duty period is limited to 12 hours, but may be extended to 14 hours for operational delays; or

(b) With 6 to 7:59 hours advance notice, the scheduled duty period is limited to 10 hours, but may be extended to 12 hours for operational delays; or

(c) With 4 to 5:59 hours advance notice, the scheduled duty period is limited to 8 hours, but may be extended to 10 hours for operational delays; or

(d) With less than 4 hours advance notice, the scheduled duty period is limited to 7 hours, but may be extended 1 hour for operational delays.

(e) For assignments in paragraph (2) and (3) (a) through (d) above, the operator must relieve the crewmember from all further responsibilities between advance notice and report time.

The ALPA HANGAR
Volume 6, Number 2 June 25, 1999

ALPA Declares Preliminary Victory in Flight-Time/Duty-Time Battle

FAA Agrees to Enforce 1985 Rule on Pilot Rest

ALPA recently declared victory in its almost 15-year battle to compel FAA to "rigorously" enforce existing regulations on pilot flight-time/duty-time requirements. Improving pilot rest rules is one of ALPA's top safety priorities.

FAA Administrator Jane Garvey told ALPA President Duane Woerth in a June 3 letter that her agency will finally begin to enforce 1985 rules requiring pilots to receive a prescheduled and protected rest period during the 24 hours before a flight. "The FAA has said on more than one occasion that, all else failing, we would rigorously enforce the current (pilot rest) rule," Garvey said in her letter. "To emphasize our commitment, I plan to publish our intent to enforce the current rules in the *Federal Register*."

"ALPA has led the fight to correct inadequate duty and rest rules for years and we are elated that Administrator Garvey is committed to moving forward finally on this critical aviation safety issue."

Duane E. Woerth, ALPA President

Garvey also said FAA will issue a Supplemental Notice of Rulemaking altering its December 1995 proposal regarding regulations governing the amount of time pilots can fly and remain on duty without a mandated rest period.

The current regulations require that a reserve pilot be given at least nine hours of rest for every 24-hour work period. During this time, the pilot must be free of all official duties and cannot accept any assignments. The designated rest period can be reduced to eight hours if compensatory rest is provided the following day.

FAA has set a 180-day deadline, giving all U.S. carriers until Dec. 12, 1999 to comply with the rules. At that time the agency will " ... begin a comprehensive review of certificate holders' flight scheduling practices and expects to deal stringently with any violations discovered."

The FAA administrator's correspondence was in direct response to a May 13 letter from Capt. Woerth, asking Garvey to fulfill earlier promises to enforce the existing rules for pilot rest requirements. Woerth also urged FAA to forge ahead with other needed revisions that have hung in bureaucratic limbo for the past four years.

In addition, Woerth advocated that FAA perform a comparative risk assessment of pilot fatigue issues instead of a typical cost/benefit analysis. Such an assessment would be the first step in the development of any new and improved federal pilot fatigue rules.

The National Transportation Safety Board concurs with ALPA's position on flight and rest rules. On June 1, its chairman, Jim Hall, urged FAA to take immediate action on pilot fatigue regulations.

Back to ALPA Home Page

U.S. Department
of Transportation
**Federal Aviation
Administration**

800 Independence Ave., S.W.
Washington, D.C. 20591

JUN - 4 1999

Captain Rich Rubin
7700 N.E. 8th Court
Boca Raton, Florida 33487

Dear Captain Rubin:

This responds to your request for an interpretation of the Federal Aviation Regulations 14 C.F.R. § 121.471, Flight time limitations and rest requirements: All flight crewmembers. Section 121.471(b) states as follows:

Except as provided in paragraph (c) of this section, no certificate holder conducting domestic operations may schedule a flight crewmember and no flight crewmember may accept an assignment for flight time during the 24 consecutive hours preceding the scheduled completion of any flight segment without a scheduled rest period during that 24 hours of at least the following:

> (1) 9 consecutive hours of rest for less than 8 hours of scheduled flight time;
> (2) 10 consecutive hours of rest for 8 or more but less than 9 hours of scheduled flight time;
> (3) 11 consecutive hours of rest for 9 or more hours of scheduled flight time.

You present the following hypothetical:

> You begin reserve duty after completing a scheduled 48 hour 2 day off period. You are then assigned a block of five days reserve duty commencing at 0001 on day one until 2359 on day 5. You do not receive any notice of a prospective rest period by the air carrier for any of the five served duty days. You are not called for flight duty during day one of your reserve duty. On day two, you are called at 1900 for a flight duty period that will commence on day two at 2300 and will end at 0745 on day three.

Please note that you request an interpretation under 14 C.F.R. § 121.471(b), but state that you are an international captain for an air carrier. Section 121.471(b) only applies to domestic operations. Flight time limitations for flag (international) carriers are specified in Subpart R Part 121 of the Federal Aviation Regulations. Since you have specifically asked about the interpretation of § 121.471(b) in questions 1 -5, this interpretation is restricted to that section and the rest requirements for domestic operations. Additionally you use the term "flight duty" in your above hypothetical. The FAA uses the terms "flight time" and "rest" in § 121.471(b). For purposes of this interpretation, we have assumed your use of the term "flight duty" to be synonymous with the term "flight time." Finally, you have not specified what you mean when you use the term "reserve duty." Therefore, for purposes of this interpretation, we assume that this means you have a present responsibility for work should the occasion arise.

Question 1: Using the above example, would an air carrier be in compliance with the requirements of FAR 121.471(b)? Please explain.

No. We have consistently stated that reserve duty is not rest when the reserve flight crewmember must maintain accessibility (via telephone or pager/beeper) to the employer and there is a present responsibility to work. Therefore, the certificated carrier must provide an opportunity for the flight crewmember to obtain appropriate rest when scheduling the flight crewmember for flight time. In this instance, when you are called at 1900 for flight duty you receive 4 hours notice that you will be required to report for flight duty at 2300. Your flight duty will end at 0745 on day three; thus it will be 8 hours and 45 minutes long. In order to be in compliance with Section 121.471(b), the air carrier conducting domestic operations and the pilot must be able to look back over the 24 consecutive hours preceding the scheduled completion of the flight segment and find the required scheduled rest period. In this instance, looking back 24 hours from the end of the pilot's scheduled flight time (0745 on day three), the pilot only had 4 hours of rest - the time period between 1900- 2300[1]. The regulations (§ 121.471(b)(2)), however, require a pilot scheduled for more than 8 hours but less than 9 hours of flight time to have 10 consecutive hours of rest. Since you received only 4 hours of rest in the 24-hour period, the flight schedule would be in violation of Section 121.471(b)(2). Furthermore, the reduced rest provisions of Section 121.471(c)(2) would not be met with only 4 hours of rest.

[1] We assume that once you are notified at 1900 to report for a flight at 2300 that you no longer have a present responsibility for work between 1900 and 2300.

Question 2: Using the above example, would I [the pilot] be in violation of FAR 121.471(b) if I accepted the flight duty assignment that begins at 2300 on day two.

Section 121.471(b) applies to pilots and other flight crewmembers as well as the air carrier. Consequently, you would be in violation of this section if you accepted the flight assignment prior to completing the required rest period.

Question 3: Does the FAA expect an air carrier to schedule pilots in compliance with FAR 121.471(b)? If so, how is operator compliance measured and enforced?

The law requires an air carrier to schedule its pilots in compliance with the regulations - in this instance § 121.471. Section 121.471(b) applies to the air carrier. Thus, the air carrier is expected to schedule pilots in compliance with § 121.471(b) as well as all other pertinent Federal Aviation Regulations. Compliance is measured by analyzing the facts and the applicable safety regulations published in the Code of Federal Regulations. The Flight Standards Service is responsible for investigating alleged violations of § 121.471 and for initiating enforcement actions.

Question 4: Does the F AA expect crewmembers to comply with the requirements of FAR 121.471(b)? If so, how is crewmember compliance measured and enforced?

See the answer to Question No. 3.

Question 5: What does the FAA advise a reserve crewmember to do if he/she is scheduled for flight duty and he/she has not received an appropriate prospective rest period as required by FAR 121.471(b)?

You seek advice as to what a reserve crewmember should do if the rest specified in § 121.471 has not been provided. First, the reserve crewmember must determine whether all of the elements of § 121.471, including the reduced rest provisions in § 121.471(c), have been met. Second, if § 121.471(c) cannot be used, you are hereby advised that § 121.471(b) specifically prohibits a flight crewmember from accepting an assignment that violates this provision. In the event any flight crewmember finds himself/herself scheduled in violation of § 121.471, he/she should, at a minimum, advise the appropriate person at the air carrier. Depending on the air carrier's protocol, this may be the Chief Pilot, the Director of Operations or the Director of Safety. Additionally, a pilot always has a duty under § 91.13(a) to notify the certificate holder when he/she is too fatigued to fly.

Question 6: Can off duty time incurred during layovers fulfill the 24 hours off in 7-day rest requirement?

Yes. We assume that "off duty time" means that the pilot does not have a present responsibility for work should the occasion arise.

Question 7. If the answer to the above question is yes, what are the requirements for this rest period? Can pilots be reassigned during this period? Is it protected from interruption or contact?

The FAA has consistently interpreted "rest" to mean a continuous period of time during which the flight crewmember is free from all restraint by a certificate holder. This includes freedom from work and freedom from responsibility for work should the occasion arise. See Letter of Interpretation to James Baxter, March 25, 1997 (copy enclosed). Thus, a crewmember who was required to be near a phone, carry a beeper, or maintain contact by computer so that he would be available should the carrier need to notify him/her of a reassignment would not be on rest. However, there would be no rest violation where an air carrier does not impose any requirements on the crewmember during the rest period,

Subj: **Horizon compliance**
Date: 2/19/99 1:10:58 PM Eastern Standard Time
From: 74103.343@compuserve.com (Don Treichler)
Sender: 74103.343@compuserve.com (Don Treichler)
To: DJSTACEY@aol.com (INTERNET:DJSTACEY@aol.com)
CC: DJWMSW@aol.com (Dave Wells), 76364.2764@compuserve.com (Don Kingery), LLE516@aol.com (Lauri Esposito), SmcPhail@compuserve.com (Steve McPhail - SWPA), GSmith2617@aol.com (INTERNET:GSmith2617@aol.com)

Dear Doug:

On 2-18-99, I discussed Horizon Air compliance with the Calhoun letter of interpretation with Greg Simes, Horizon FAA POI. He stated that Horizon had not been required to comply with that letter except for the portion addressing pilots not receiving 24 consecutive hours off in seven consecutive days during the crossover from one month to the next. Apparently Horizon initially indicated that they would comply with that portion and then decided not to do so. Greg is proceeding with enforcement action on the latest submission violating that area. As for the portion of the enforcement letter, which states that in domestic operations you must be able to look at the previous 24 hour period and find a minimum of 8 hours of rest or you must terminate your flight, the Horizon POI stated that he has received no guidance from the FAA at the national level as to whether enforcement action is desirable or permissable. Bottomline appears to be that the FAA national intends to IGNORE the existing regulation as well as their consistent interpretations of it over the past 8 years and wait for rulemaking to resolve the issue. The FAA is likely to outsource an economic study of the reserve issue that will take until late 1999. Following that, the FAA likely will write a Supplementary Notice of Proposed Rulemaking (SNPRM) and provide 90 days for comment (and possibly another 90 days if someone so requests). All of this has occurred because the management side of the FAA rulemaking process has stated that enforcement would cost the airlines $100,000,000. This statement was made during ARAC meetings. I requested documentation of these figures and management agreed to supply the numbers. Later, in front of the FAA and labor, management refused to do so. Management refuses to do so to this very day. The reason they refuse is (a) the figure is totally inaccurate and (b) they wish to wait until the comment period for the SNPRM and use the figure again when there is no opportunity to challenge it. As a result, misinformation is allowed to stand unchallenged. Regretably, such action compromises safety.

Best regards,

Donald R. Treichler
International Representative
Teamsters Airline Division
7306 School House Lane
Roseville, CA 95747
Tel. 916-791-6747
Fax 2757

Previously, the Northwest Region Administrator advised members of congress that Horizon Air had agreed to comply with the letter of interpretation. This is not the case. You may use this e-mail as an attachment to any correspondence you may have with congressional members to ensure that they

U.S. Department
of Transportation
**Federal Aviation
Administration**

800 Independence Ave., S.W.
Washington, D.C. 20591

March 25, 1997

Mr. James Baxter
P. 0. Box 250578
San Francisco, CA 94125

Dear Mr. Baxter:

Thank you for your inquiry requesting an interpretation of rest and duty regulations in conjunction with non-flight assignments by the air carrier. Due to the loss of personnel over the past year and the urgency of other regulatory matters, we have been delayed in answering your inquiry. We thank you for your patience.

Your inquiry revolves around the definitions of "rest' and "duty" and the relationship between ground assignments and flight time duty. Interpretations of what constitutes "rest" or "duty" are the same under Part 121 or 135. The FAA has consistently interpreted "rest' as a continuous period of time during which the crewmember is free from all restraint by the certificate holder. This includes freedom from work and freedom from responsibility for work should the occasion arise. The FAA has also consistently interpreted "duty" to mean actual work for an air carrier or the present responsibility for work should the occasion arise. (Letter from Donald P. Byrne, Assistant Chief Counsel, Regulations and Enforcement Division, to Assistant Chief Counsel. AGL-7, dated July 5, 1991, letter from Donald P. Byrne to R.C. McConnick, dated June 25, 1996.)

You provided three situations in which you questioned whether the crewmember's assignment constituted "duty time." I will respond to your question regarding a reserve pilot's status first, as the rules here are plain. You inquired whether a crewmember who had flown for 3 days in a row, was on reserve a fourth day but did not fly, and then was scheduled to fly another four days, is legal. Under the definitions stated above, this pilot would be in violation of Section 135.265(d). Reserve duty is not rest, as the type of reserve duty you described requires that the crewmember be available to fly, should the opportunity arise. In this specific scenario, the crewmember would have been without rest for 8 days. While the crewmember could have flown for two days after the reserve day, on the 7th day the crewmember must be given the required rest before another flying assignment. Section 135.265(d) states that a crewmember must be relieved "from all further duty for a least 24 consecutive hours during any 7 consecutive days." It is possible for a crewmember to be scheduled on reserve for 7 days and not be in violation of the regulation as long as the crewmember does not fly (Letter from Donald P. Byrne, Assistant Chief Counsel, Regulations and Enforcement Division, to B. Stephen Fortenberry, dated June 24, 1991.) However, once the crewmember takes a flight in Part 135 operations, the rest requirements activate in order to ensure that the crewmember has had sufficient rest prior to the flight. Thus, if the crewmember has not had a scheduled rest period during the previous 7 days, the air carrier and crewmember could be held in violation of Part 135 265(d)

In your second and third situation you inquire whether ground school or a Crew Resource Management course would be considered duty. Again, duty must be thought of in relation to required rest. The FAA would not hold an air carrier or a crewmember in violation of Section 135265(d) if a crewmember was scheduled for 7 days or a month of ground school, CRM training or any other kind of ground assignment. As long as crewmembers are on the ground, they are not in violation of a rest and duty regulation. However, once again, once that crewmember takes a flight, rest regulations activate. At that time, if the crewmember had been in ground school for the previous 7 days, that crewmember would be in violation of Section 135.265(d) as he had not received the required 24 hours of rest in a consecutive 7-day period. An air carrier can schedule a crewmember to any kind of duty it desires for 6 consecutive days, but on the 7th day rest regulations will affect any flying assignment.

Since "rest" requires that a crewmember be free from all work obligations, ground school or CRM training would not qualify as "rest" once a crewmember initiates a flight. While it is not "duty," in the sense of flight duty, it is also not "rest."

Additionally, if a crewmember operates an aircraft with insufficient rest, a certificate holder or crewmember could be charged with a careless or reckless violation under Section 91.13. In a prior interpretation the FAA has stated that the "lack of rest of the pilot is certainly a circumstance which could endanger others, and it is not necessary that the situation devolve into actual endangerment for there to be a violation of FAR 91.13." (Letter from Donald P. Byrne, Assistant Chief Counsel, Regulations and Enforcement Division, to David Bodlak, dated October 28, 1991.)

This interpretation was prepared by Terry Turner, reviewed by Joseph Conte, Manager of the Operations Law Branch and concurred with by the Air Transportation Division of Flight Standards Service. We hope this interpretation will be of assistance to you.

Sincerely,

Donald P. Byrne
Assistant Chief Counsel