NASA TM -88231

NASA Technical Memorandum 88231

NASA-TM-88231 19860019141

Crew Factors in Flight Operations: IV. Sleep and Wakefulness in International Aircrews

R. Curtis Graeber

February 1986

National Aeronautics and
Space Administration

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PREFACE

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

It is the result of a joint multi-national effort to examine the effects of transmeridian flight on the sleep and wakefulness of aircrews operating international routes. The success of this work is testimony to the dedicated cooperation and support provided by a diverse set of individuals and organizations including airlines, aircrew professional associations, government agencies, research institutions, and universities in the United States, Japan, West Germany, and the United Kingdom. The scope and quality of the research would have been greatly reduced without their willingness to combine resources and talents in addressing this important aeromedical topic.

The report consists of an overview of the project, an operational summary, and a series of individual reports written by the each of the research groups. The operational summary describes the principal findings of the study and represents the consensus views of the study team as to the operationally relevant conclusions which can be drawn from the data. The results for each route are described in the individual laboratory papers which include core sets of comparable figures and analyses as well as additional findings specific to each laboratory's particular interests. These reports are accounts of studies on particular air carriers, and the interpretations and conclusions of their authors do not necessarily reflect the views of the other participating research centers.

While this publication describes the basic findings of the study, it is anticipated that other reports will be forthcoming to describe more detailed aspects of the results.

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*Our esteemed colleague, Dr. Shiro Endo of the Psychiatric Research Institute of Tokyo, passed away on December 10th, 1985. His contribution to this project marked only an endpoint of a distinguished research career. Dr. Endo was one of the first to focus attention on the importance of circadian rhythms for understanding human sleep. In his comprehensive approach to this relationship, he carried out the most extensive series of sleep studies ever conducted on the impact of transmeridian flight. His cheerful presence and valuable advice will be sadly missed by all of us.

DEDICATION

This publication is dedicated to Dr. Karl E. Klein, Director, DFVLR Institute for Aerospace Medicine, on the occasion of his sixtieth birthday, in acknowledgment of his pioneering contributions to the field of transmeridian flight.

International Aircrew Sleep and Wakefulness After Multiple Time Zone Flights: A Cooperative Study

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The papers in this report represent the joint efforts of an international research team of scientists and operations personnel from four different countries. These individuals, their associated airlines, and sponsoring agencies, have cooperated with the National Aeronautics and Space Administration over the past two years to carry out an extensive examination of sleep and wakefulness in international flight crews. This paper provides an overview of their collaborative endeavor, including its history and the standardization of procedures, and summarizes this center's views on the major findings of the independent laboratories. Further details concerning the methods and results of each research group are contained in their individual reports.

BACKGROUND

Optimal safety and efficiency in air carrier operations depend on flight crews being well rested and alert while performing duty in the cockpit. Consequently, significant efforts have been made to develop rest requirements to help ensure that crew members obtain adequate sleep between flights (14). For international aircrews, this requirement is complicated during layovers by the effects of multiple time zone changes. Their sleep is often disrupted because it is attempted during an inappropriate phase of the internal circadian rhythm or at times when the local population is awake and active.

Several efforts have been made to examine this problem in the operational environment. These studies have dramatically demonstrated the extent of sleep deficit which can result from flying transmeridian routes; however, most have relied on self-reported data obtained from sleep logs (8-11). Other investigators have applied standard electroencephalographic (EEG) recording techniques to examine the effects of transmeridian flight on sleep (4,5,7,13). While these few studies have provided the most objective data on sleep disruption and the concomitant changes in sleep architecture which occur in new time zones, their applicability to international flight crews is questionable. First, most subjects have been tourist volunteers unaccustomed to transmeridian flying on a regular basis. Second, upon arriving at their destination, they were restricted to sleeping at a time appropriate to local custom and were not allowed to sleep whenever they chose. Third, they were transported in the aircraft cabin, where sleeping was uncontrolled and the performance of flight duties was not required.

In light of these considerations, we initiated a comprehensive research effort to provide flight crews and operational managers with scientifically sound, useful data concerning the issue of layover sleep. International collaboration was sought in order to facilitate efficient data collection within the constraints of scheduled flight operations, and to enhance the feasibility of studying both eastward and westward flights crossing an equal number of time zones. These were the goals of an organizational meeting sponsored by NASA's Ames Research Center in October 1983. The attendees reflected a unique scientific, operational, and geographic mixture of organizations and individuals who recognized the rare opportunity to conduct such a study. Expertise in sleep research and time zone adjustment was provided by researchers from the DFVLR Institute for Aerospace Medicine (Dr. H.M. Wegmann), the Jikei University School of Medicine (Dr. M. Sasaki), and the Stanford University Medical Center (Dr. W. Dement). Operational input was provided by representatives from Lufthansa (Capt. M. Naumann), Japan Air Lines (Capt. H. Nagano and Mr. S. Nakai), and Pan American World Airways (Dr. J. McCann and Capt. W. Simons). This group, together with NASA personnel, developed an operationally feasible research plan which would provide the data necessary to obtain the first objective assessment of crew layover sleep after multiple time zone transitions.

A second planning meeting was held at NASA-Ames in February 1984 to finalize the study design, resolve technical details, and make logistical arrangements for carrying out the project. At this time, the scope of research was widened to include British participation as represented by the U.K Civil Aviation Authority (Drs. G. Bennett and R. Barnes), the Royal Air Force Institute of Aviation Medicine (Dr. A. Nicholson), and British Airways (Dr. R. Green and Capt. M. Jeffery). In addition, pilot group input and support was provided by the Air Line Pilots Associations of Great Britain (Capt. J. Fomes and Mr. D. LeBrecht) and the United States (Capt. R. Stone and Dr. R. Masters). Thus, the final cooperative effort included British, German, Japanese, and U.S. research teams, each associated with an international carrier and a source of support from their home country. While the scientific contributions of the investigators are recognized in the authorships of the following papers, much of the project's success can be attributed to the excellent advice and assistance provided by the other participants.

OBJECTIVES AND DESIGN

The overall goal of this layover (L/O) sleep study was to assess the changes in sleep quality associated with multiple time zone transitions. This objective incorporated several aims which dictated the research design. The first was to describe how sleep during a trip differs from sleep at home. The second aim was to determine how these differences are reflected in subsequent levels of "daytime" sleepiness (or alertness), and whether flight crews could subjectively assess these levels of sleepiness. Third, we sought to compare the effectiveness of different sleep-rest strategies in order to identify more successful coping techniques for recommendation to international flight crews.

The design concept centered on utilizing San Francisco (i.e., Stanford University) as a research hub where all participating airline crews would undergo either L/O or baseline EEG sleep recordings (See Fig. 1). The latter were carried out at perimeter laboratories located near the crews' home base. Each research team was responsible for collecting the baseline data for crew members from its associated airline and the L/O data for other crews arriving at that destination. These data consisted of standard polysomnographic recordings during "nocturnal" sleep followed by "daytime" multiple sleep latency tests (MSLTs) every two hours whenever the subjects were awake and not trying to sleep. The former provided objective measures of sleep quality and quantity, while the latter provided objective measures of "daytime" sleepiness for comparison with the subjects' own estimates. The MSLT measures the time a subject takes to fall asleep in a standard sleep laboratory environment. This presumably reflects the brain's physiological sleepiness and, thus, indirectly, prior sleep quality (1). By comparison, subjective estimates reflect a less stable state which can be influenced readily by environmental stimulation or voluntary muscular activity.

Throughout the study investigators attempted to minimize interference with the crew members' usual trip behavior. Although staying in a sleep laboratory precluded certain activities more easily accomplished while staying at a crew hotel, most subjects' needs were accomodated within the time limitations of the data collection schedule. Thus, crew members could implement whatever L/O coping strategies they had developed throughout their career and were encouraged to do so. No restrictions were placed on when they slept or how long they spent in bed. A variety of meals and snacks were available at any time of the day or night. Subjects could exercise moderately (e.g., walk, ride bicycles) between MSLTs, go shopping or visit local sites of interest. Although consumption of caffeinated beverages was prohibited (except in very limited amounts if withdrawal symptoms occurred), decaffeinated coffee and tea were freely available. Because alcohol can cause drowsiness and thus affect the MSLTs, alcohol consumption was prohibited except before bedtime. Then, in order to enable subjects to mimic their usual L/O behavior, they were allowed up to two glasses of beer or wine.

METHOD

In order to assure the comparability of data across laboratories, considerable effort was put into standardizing methods. As summarized in Table I, each participating laboratory carried out a core set of measurements which are described below. In addition, certain research teams collected ancillary data. Some of these latter procedures are described here, while others are described in the relevant papers.

Subjects

All subjects were active flight crew members (Captains, Co-pilots, and Flight Engineers), age 31 to 61 yrs (Fig.2), who regularly flew line trips for the participating airline. The method utilized for soliciting volunteers differed for each airline depending on operational factors related to bidding practices and labor agreements and on logistical considerations related to laboratory availability. In the case of two airlines (BA and PA), crews who had successfully bid the target trips were contacted by telephone and asked to volunteer individually. This often resulted in only one or two crew members from a particular flight staying in the L/O laboratory. In the case of the other two airlines (LH and JL), volunteers were first solicited and then assembled into crews so that two, if not three, crew members were together during the L/O recordings. Regardless of the recruitment procedure, the response was generally positive with the major reason for non-participation being the incompatibility of duty schedules with the requirements for days off before baseline or L/O recordings.

All volunteers were given a five-digit code known only to them, so that no data could be traced to a particular individual by name. Subject confidentiality was also protected by

TABLE I. PARTICIPATION SUMMARY

Airline	Measures	Flight	Time Change	Month	L/O	n
BA	P,LM,RSP MSLT RT*	LHR-SFO	-8h	Aug	48h	13
LH	P MSLT RT,HR,U	FRA-SFO SFO-FRA	-9 +9	Sept	48 48	12
JL	P,LM,RSP MSLT	NRT-SFO	+8	Oct	48	12
PA	P,LM,RSP MSLT RT*	SFO-LHR	+8	Aug-Sept	48 52 72	4 3 4
		SFO-NRT	-7	Nov	25	9

P = Polysomnography (EEG,EOG,EMG); LM = Leg movements during sleep;
RSP = Respiration during sleep; MSLT = Multiple sleep latency tests;
RT = Continuous rectal temperature; HR = Continuous heart rate;
U = 24h urine; * = Reduced n.

keeping no record of flight numbers or L/O dates. At the end of the L/O, all subjects were given the opportunity to review their recordings with a qualified researcher.

Core procedures

Participation schedule. Each subject was recorded polygraphically for two nights at the sleep laboratory near his homebase and during any sleep taken during the post-flight layover. This L/O lasted approximately 48h in all cases except at NRT, where operational requirements limited it to about 25h. Four LHR L/O subjects departed the laboratory after 48h and spent the remainder of the 72h L/O in the usual hotel. The first night of homebase recordings was termed the "adaptation night" since it was intended to eliminate the well known "first night" effect often seen in subjects during their initial stay in a sleep laboratory. After subjects become accustomed to the recording procedures and laboratory surroundings, their subsequent data is usually reliable. One subject experienced serious difficulty sleeping during this adaptation night and was consequently dropped from the study.

Ideally, subjects were supposed to spend two successive nights in the homebase laboratory, the second night being the baseline recording night. Furthermore, they were to have a mininmum of five non-flying days immediately before the baseline night and then commence the target trip on the day after finishing the baseline MSLT recordings. Unfortunately, due to standard duty schedules, only a few volunteers were able to fulfill this participation schedule. Therefore, a compromise schedule was adopted whereby subjects were required to complete at least the adaptation night before commencing the trip. The baseline recordings were to be completed within three weeks before or after the L/O trip, with a minimum of three non-flying days required before the baseline or L/O recordings. In the case of two airlines (LH and JL), the adaptation and baseline recordings always occurred in succession, but for one (LH) the baseline MSLTs preceded the baseline sleep recording instead of following it. Furthermore, crew members from the latter airline returned to the homebase laboratory immediately after the return flight for a 48h assessment of recovery sleep and daytime sleepiness. The procedures during this post-trip period mimicked those used during the L/O.

Sleep recordings. Crew members were asked to notify the technicians 15 min before they wished to sleep or nap so that all necessary recording preparations could be made. Time of awakening was spontaneous or by prearranged call. Standard polysomnographic techniques were used to record the following sleep related variables during all phases of the study: (a) electroencephalographic (EEG) activity from the C3-A2 or C4-A1 positions, (b) submental electromyographic (EMG) activity, and (c) bilateral electro-oculographic (EOG) activity. EEG activity from 01-A2 (or 02-A1) was also monitored until sleep onset. Recordings were made with silver or gold electrodes filled with electrode jelly and applied to the skin with collodion so that resistances of less than 10 Kohms were maintained. Chart speed was 10 mm/sec, except for some subjects from one airline (JL) who were recorded at 15 mm/sec due to differences in the available polygraphs. Polygraph calibration procedures were standardized so that the half-amplitude frequency response was 0.3-35 Hz for the EEG and EOG and 5-75 Hz for the EMG with a selective 50 or 60 Hz notch filter in each channel to eliminate interference from the local current supply. All sleep records were scored into 30 sec epochs according to the standard criteria of Rechtschaffen and Kales (12).

Multiple Sleep Latency Tests. MSLT recordings were carried out on the even GMT hour unless it occurred less than 30 min before or 15 min after a major sleep period. To minimize any unwanted influences on arousal level, alcohol consumption was prohibited between MSLTs, smoking was not permitted within 30 min before testing, and any physical exercise, showers, or meals had to be completed within 30 min before the next MSLT. Each test was preceded by 15 min of quiet indoor activity and 5 min of standard calibration procedures while the subject was in bed in a quiet darkened bedroom. He was then told to lie quietly, keep his eyes closed, and try to fall asleep. Polygraphic recording was limited to EEG activity from C3-A2 (or C4-A1) and O1-A2 (O2-A1) and bilateral EOG activity. The test was terminated when the on-line recording indicated the first three consecutive 30-sec epochs of any sleep stage or when 20 min had elapsed, whichever occurred first. The test was scored for the number of seconds that elapsed from lights-off until the first 30-sec epoch of any sleep stage. The EEG and EOG electrodes remained attached throughout the day unless there was a compelling reason to remove them.

Subjective Data Collection. Questionnaires were used to obtain subjective information before and after various recording procedures. Before each sleep recording subjects completed a pre-sleep questionnaire which included the Stanford Sleepiness Scale (SSS), a mood assessment scale, and a self-report of prior medication. After waking, they completed a second questionnaire which included self-reports on the amount and quality of sleep in addition to the SSS. Likewise, prior to each MSLT, the subjects rated fatigue and tension on 10cm analogue scales and completed a SSS. Finally, at the end of the Baseline and L/O stays, all crew members responded to an exit questionnaire in which they characterized their activities and the rest obtained during the stay.

Daily logbooks were used document the activities and sleep of the volunteers surrounding the baseline and L/O measurements. Entries were begun at least two days before baseline or departure from homebase and continued through the laboratory stay up to several days thereafter. In addition, all subjects completed the NASA Background Information Questionnaire which provided information on lifestyle, dietary habits, exercise, personality, morning-eveningness, and sleep habits.

Ancillary Measures

Additional sleep measures. To obtain clarifying data regarding awakenings, three additional measurements were obtained from crew members from three of the participating airlines (BA, JL, and PA). These measurements consisted of heart rate, respiration, and leg movements and were polygraphically recorded only during major sleeps and not during naps or MSLTs. Respiratory data was obtained from a nasal thermistor (air flow) and an abdominal strain gauge (respiratory effort), while leg movements were detected by bipolar anterior tibialis EMG.

Body temperature, heart rate, and urine. To obtain clarifying data regarding circadian rhythmicity, crew members from two airlines (BA and PA) were asked to wear rectal temperature sensors throughout their baseline and L/O stays in the laboratory. Willingness to participate in this aspect of the study did not preclude participation in the rest of the protocol. Volunteers wore a portable solid-state recorder (PMS-8, Vitalog Corp., Redwood City, CA) which was read out through a personal computer at the end of each visit.

For a third participating airline (LH), body temperature was recorded from all subjects throughout the length of the study, including both flights and a post-return 48h laboratory stay. These data were collected on cassette via a Medilog tape recorder (Oxford Medilog Inc.) which was also used to record continuous electrocardiograms. In addition, all urinary output was collected during this time to be subsequently analyzed for catecholamines and 17-OCHS levels.

Questionnaires

In order to determine the representativeness of the laboratory L/O compared to a L/O at the crew hotel, the subjects from three airlines (PA, LH, and JL) completed daily logbooks on trips to the L/O city during the previous month. In addition, crew members from one airline (JL) were interviewed by NASA researchers during the hotel L/O to further establish any critical requirements for making the sleep laboratory stay as representative as possible.

Standardization

Standardization across laboratories for all core and common ancillary procedures was facilitated by the use of standard written protocols and the exchange of scientific staff. Following the preliminary standardization meetings, each recording site was visited by both Stanford and NASA personnel. These visits served to resolve any procedural inconsistencies regarding subject-investigator interaction, data collection and scoring.

In order to minimize scorer variability, all baseline and L/O sleep and MSLT records from a particular airline were scored by the same individual from the homebase laboratory. Furthermore, ten percent of each laboratory's sleep and MSLT data were cross-scored by a member of the paired cooperating laboratory. All data were entered into a standard matrix score sheet for input into an archival database.

OVERVIEW OF RESULTS

The results for each of the five groups of crewmembers are described in detail by the individual laboratory reports which follow. In order to facilitate comparisons across the different flight schedules, each paper includes a core set of common figures including individual summaries of each subject's sleep-wake patterns during baseline and layover. In addition, a separate Operational Summary representing a consensus view is provided for those readers specifically interested in the implications of the research for flight operations and crew training.

In the view of the NASA investigators, the basic findings are relatively straightforward and remarkably consistent among the different flight crew samples. Most crew members were able to obtain adequate sleep during L/O whether by sleeping efficiently at selected times or by sleeping less efficiently but staying in bed longer than usual. Sleep quality decreased slightly in most cases but more so after eastward flights than after westward flights. These decreases were reflected in increased daytime sleepiness (MSLT) in the new time zone; however, the mean circadian sleepiness rhythm often persisted on homebase time after the flight, so that at least part of the increase in L/O sleepiness may have included the unshifted increase usually exhibited at that GMT time. Age was another factor that significantly affected sleep quality among the various groups. In confirmation of Preston's earlier observations (10), older subjects experienced less total sleep as well as poorer quality sleep. Evidence suggests that this decrement occurs predominantly in those crew members over fifty years of age.

Subjective measures led to less consistent conclusions. While certain groups rated their L/O sleep quality as better than baseline in contrast to their polysomnographic data, other groups' ratings reflected the poor sleep quality seen in the recordings. Crew members were even less able to predict their own daytime sleepiness, in that the subjective sleepiness ratings typically did not correlate with the more objective, MSLT measures.

In addition to the basic findings, we feel that several issues are raised by the overall results. Numerous studies have shown that the human circadian system is disrupted more by eastward than westward time zone shifts and takes longer to resynchronize after the former (6). Thus, it is not surprising that sleep patterns were more disturbed in crews flying eastward routes. Other research (2,3,15) has recently shown that sleep duration varies as a function of the phase of the circadian temperature rhythm, with longer sleeps occurring when temperature is decreasing and shorter sleeps occurring when subjects go to sleep near the time of the temperature trough. REM sleep is more concentrated near the time of this trough, so that the amount and timing of REM during sleep depends on when the subject sleeps in relation to his circadian temperature rhythm. Conversely, slow-wave sleep is more influenced by the length of prior wakefulness than by circadian phase position (4). These findings would predict (4,13) some of the observed alterations in sleep stages and quality (e.g., decreased amounts of REM sleep following eastward flights). However, most of the changes in sleep quality were not as extensive as one might expect from the literature. For some groups, there were no statistically significant changes in sleep stage percentages or latencies despite the substantial time zone shift. It is difficult to determine whether these relatively mild effects were due to some type of adaptation developed in response to repeated time zone shifts by flight crews. A partial explanation may lie in some subjects' relatively low baseline sleep durations used for comparison to L/O sleep.

There was a wide range of individual differences observed in sleep quality and efficiency. In addition to age, there is evidence from the Japanese crews to suggest that some of these differences may be due to individual variations in circadian type, i.e., morningness-eveningness preferences in lifestyle. Regardless, it is still not clear why certain individuals exhibited consistently poor sleep quality and excessive daytime sleepiness during baseline, L/O, or both. A detailed analysis of their data, including respiratory disturbances and periodic leg movements, in comparison to that of a similar age, non-pilot control group is currently underway.

One of the most striking findings was the similarity of the baseline daytime sleep latency curves (i.e., MSLT) among the different airline groups. Their average curves all exhibited a gradual increase in sleepiness throughout the day reaching a maximum during the late afternoon followed by a gradual decline into the evening. Despite the sampling limits imposed by irregular L/O sleep/wake patterns, it appears that these sleepiness rhythms persisted on homebase time after the time zone shift. Thus, it may be possible for crews to predict when it would be easier to fall asleep and thereby develop better strategies for sleeping or napping while away from home.

It is our belief that the clearest implications for L/O sleep strategies come from the data obtained after eastward night flights. As explained in the Operational Summary, adhering to more structured sleep schedules and limiting initial post-flight sleep would appear to facilitate the acquisition of adequate sleep during the L/O. The use of other strategies, e.g., maintaining a homebase sleep pattern, can be evaluated less readily because of the statistical limitations imposed by the relatively few crew members who chose a consistent alternative to sleeping at the local customary time. Further analyses will have to be conducted concerning the potential importance of other types of activities observed in these subjects (e.g., meal patterns, exercise).

These studies provide the first physiological documentation of the sleep problems associated with international flight operations. While there may always be some doubt regarding the ability to generalize from sleep in a laboratory to sleep in hotels, both the German and Japanese sleep log data strongly suggest that crew members' sleep-wake patterns are not very different under the two conditions Furthermore, it is likely that less ideal conditions for sleep often exist in the hotel environment, so that the results obtained here may represent a "best case". Similarly, the L/O recordings were made after the initial outbound flight of a trip and therefore do not represent the vast majority of long-haul L/Os which typically occur in the less ideal context of a series of multiple time zone flight segments. Nevertheless, we believe that these findings provide an operationally sound framework for addressing the issue of long-haul crew rest and for developing more effective ways to study sleep-related problems in human performance. This was the mandate placed upon us by NASA with respect to the issues of fatigue and circadian desynchronization in flight crews. The reader is referred to the individual laboratory papers for the views and opinions of the other participating investigators.

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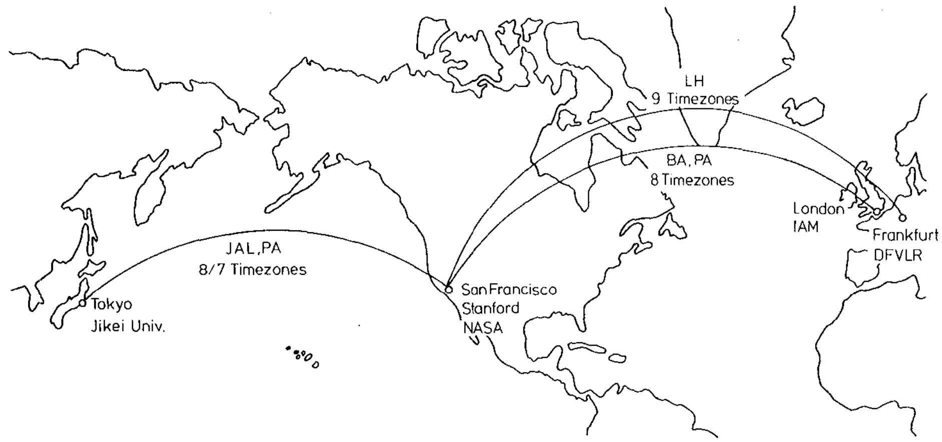

Figure 1. Schema of study design depicting participants, routes, and time zone transition (see text).

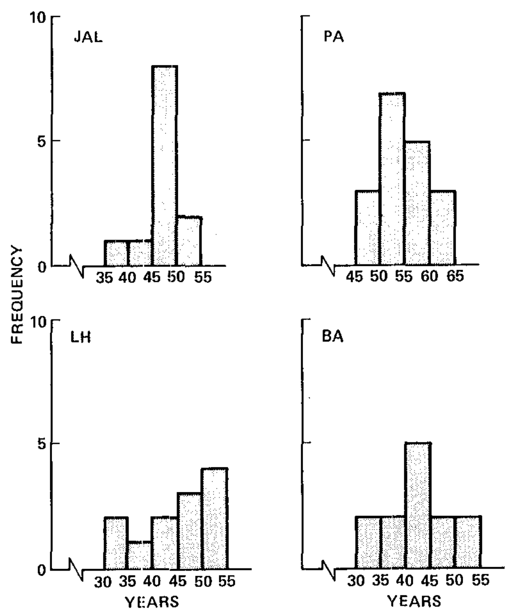

Figure 2. Crew member age distributions for participating airline subjects.

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International Cooperative Study of Air Crew Layover Sleep: Operational Summary

R.C. Graeber, W.C. Dement, A.N. Nicholson,
M. Sasaki, and H.M. Wegmann

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

Westward Flights

There was clear evidence that crew members experienced less sleep difficulties during layovers following westward flights (LHR-SFO, FRA-SFO, SFO-NRT) than after eastward flights. Following the westward flights almost all subjects went to bed soon after arrival (Fig. 1). During the first night, sleep appeared to be of generally good quality and not unduly disturbed except for increased wakefulness during the second half of the night. In comparison with baseline, subjects generally fell asleep faster and slept essentially the same amount as at homebase. Some even reported better sleep quality.

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

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

The strategy of taking a nap before departure after a westward layover appears important in view of the coming night flight with its prolonged period of wakefulness. Recent research suggests that such a nap will help reduce in-flight drowsiness and avoid potential performance deficits (3). A second aspect of planning strategies to cope with this flight schedule emphasizes the potential importance of time of the latter part of flight in relation to the crew members' circadian rhythms. Additional results obtained from some crews during the eastward return flight suggest that alertness improves as the circadian rhythms in body temperature and heart rate begin to rise. Therefore, certain schedules may be more desireable if they facilitate a nap before flight and take advantage of the circadian rise in alertness during the latter part of the flight.

Eastward Flights

Sleep patterns were much more variable and fragmented after eastward night flights (NRT-SFO, SFO-LHR, SFO-FRA) than after westward flights across an equivalent number of time zones (Fig. 2). There appears to have been a powerful influence which fractionated sleep, probably dependent on the difficulty which individuals experienced in shortening their day. Furthermore, the consequences of sleep pattern fragmentation were reflected in subsequent measures of daytime drowsiness.

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

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

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

Unless layover sleep is arranged in a satisfactory manner by an appropriate sleep-wake strategy, increased drowsiness is likely to occur during the subsequent long-haul flight. Other research (1,2) suggests that under acceptable operational circumstances, limited duration naps can be a helpful strategy to provide refreshment and improve alertness for a useful period of time. Although we do not have the appropriate data to address this issue directly, flight deck napping could be an important strategy if operationally feasible.

Individual Factors

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

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

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

Study Limitations

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

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

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

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

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

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

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WESTWARD FLIGHTS

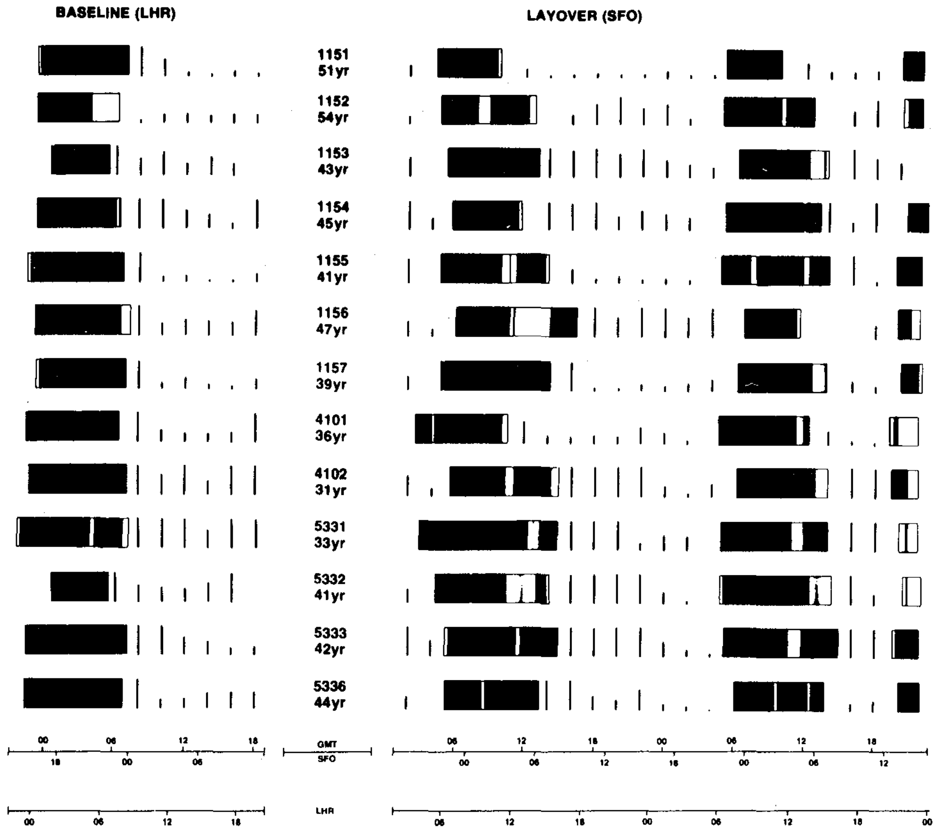

Figure 1. Sleep-wake patterns for individual crew members from three airlines during baseline and after westward flights. Vertical lines represent sleep latency tests, black bars indicate sleep. See respective papers for further details.

WESTWARD FLIGHTS

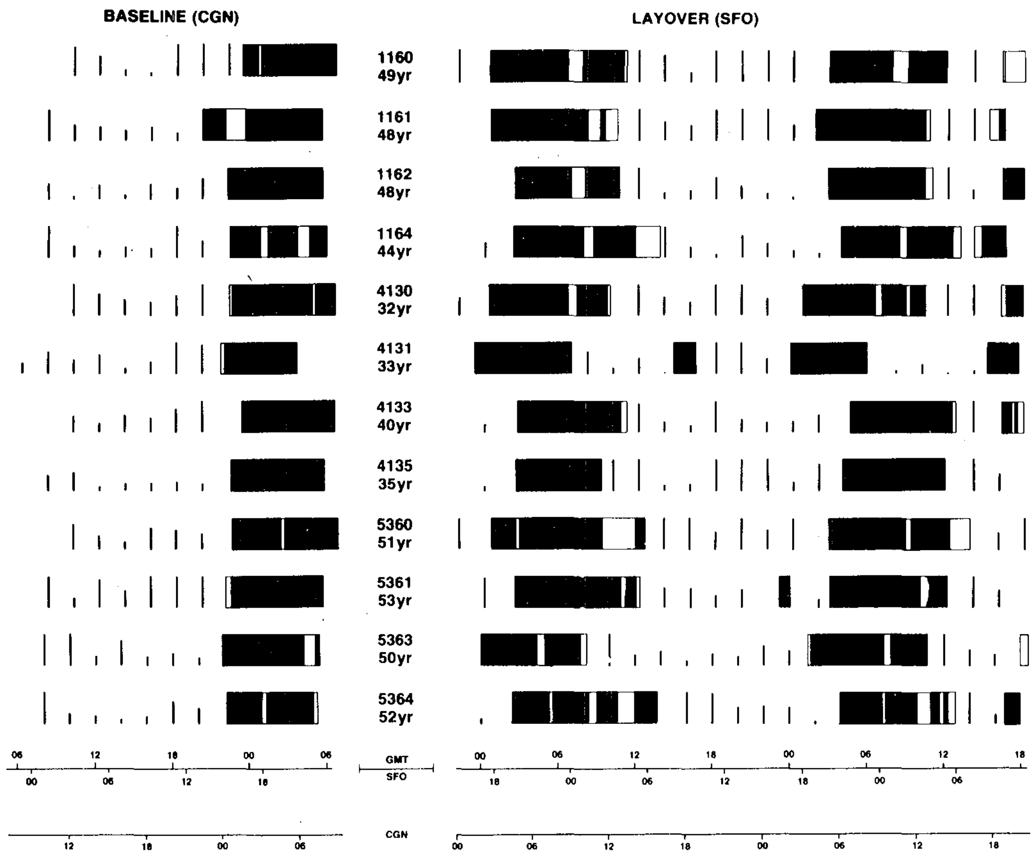

Figure 1. Continued.

WESTWARD FLIGHTS

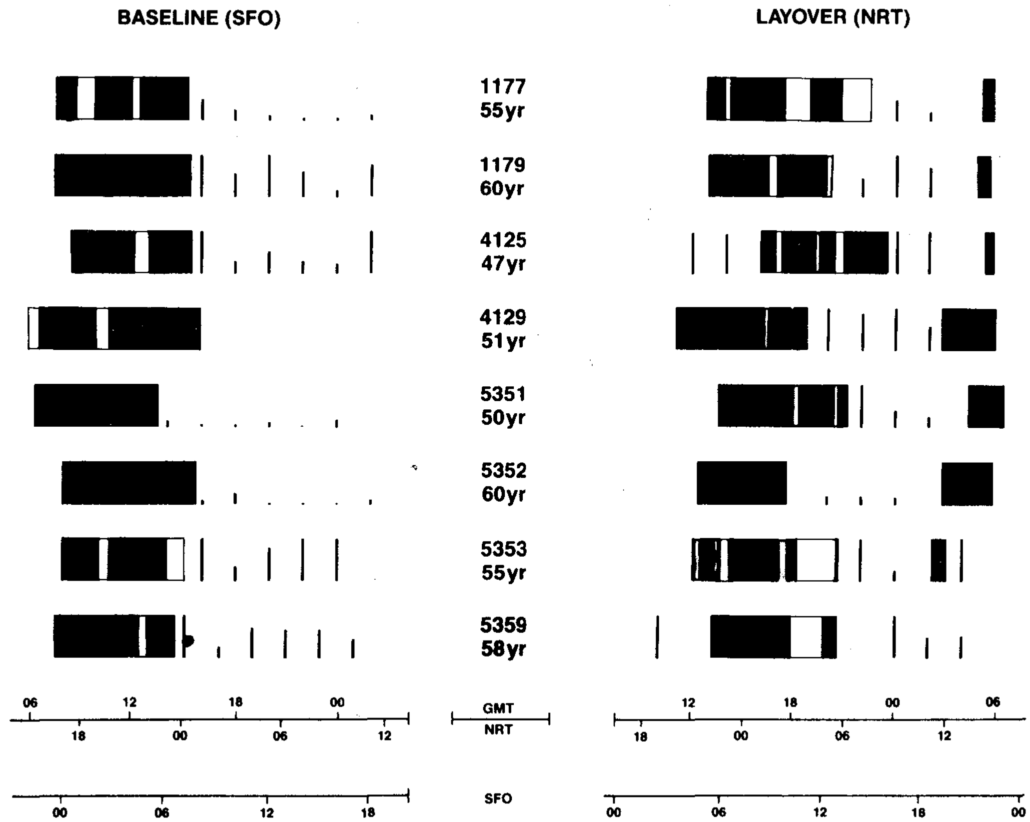

Figure 1. Concluded.

EASTWARD FLIGHTS

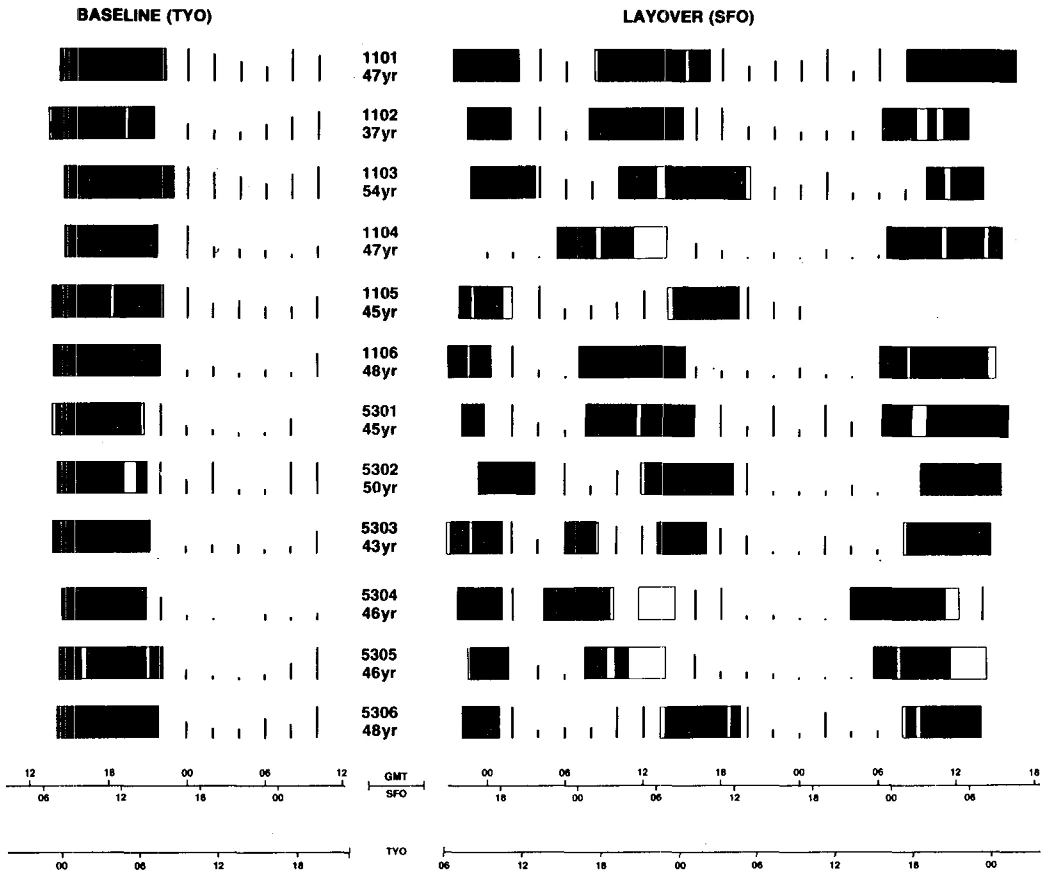

Figure 2. Sleep-wake patterns for individual crew members from two airlines during baseline and after eastward flights. Representations as in Fig. 1.

EASTWARD FLIGHTS

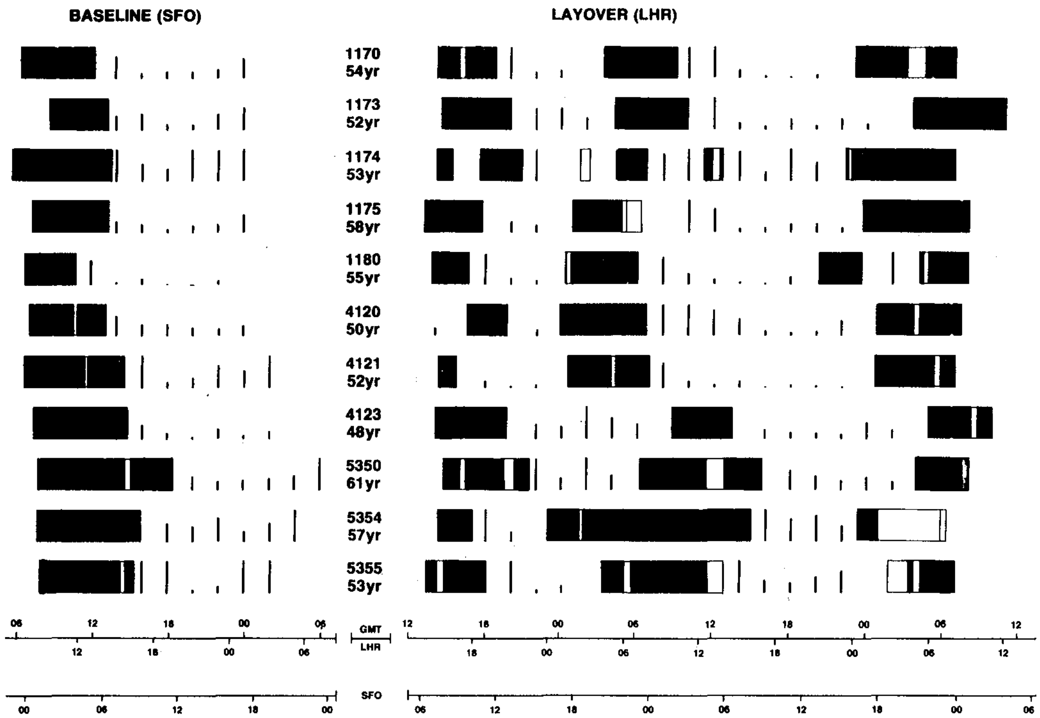

Figure 2. Concluded.

Sleep and Wakefulness in Aircrew Before and After Transoceanic Flights

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ABSTRACT

Aircrew were studied before and after flying one of two routes: San Francisco (SFO) to London (LHR) or SFO to Tokyo (NRT). After an adaptation night, sleep and daytime sleepiness were objectively measured in SFO and during the first layover (L/O) of the target trip. Baseline sleep was slightly shorter than normally reported for similar age subjects and, for several reasons, is not an ideal basis for subsequent comparison. Nevertheless, L/O sleep periods tended to provide either less total sleep or less efficient sleep. Crew members' estimates of their sleep duration correlated well with objective measures, but their estimates of daytime sleepiness correlated poorly with objectively measured sleepiness. During baseline there was a significant midday sleep tendency as measured by the Multiple Sleep Latency Test. This tendency occurred at almost the same time (GMT) on the second L/O day in LHR. Since sleepiness has a persistent rhythm which is maximal twice per day, it is suggested that L/O sleep periods be taken at these times of maximal sleepiness and that peak workload should coincide with the subsequent periods of maximal alertness. Although the overall quality of sleep diminished only slightly on this L/O, it is possible that if this relatively small loss accumulated over successive L/Os, the effects on daytime sleepiness could be measureable.

INTRODUCTION

Recently there has been considerable scientific and public interest in the jet lag syndrome and the effects of rapid transmeridian flight on sleep and wakefulness. Although it is widely believed that such travel interferes substantially with the usual pattern of sleep and wakefulness, most investigations of the phenomenon have been limited to laboratory simulations or field studies focusing on subjective measures and simple performance tasks (19, 27, 29).

It is well known that subjective descriptions of sleep can be very inaccurate and misleading (10, 24). Since 1968, published scoring procedures (21) and derived parameters of all-night recordings of EEG and other physiological variables have been universally accepted as the objective standard for documenting sleep quality. However, very little work has been done applying this approach to the operationally relevant questions about sleep quality after rapid time zone change (23). A major reason for this paucity is the logistical difficulty of standardizing and maintaining laboratories in different countries, with the attendant differences in laboratory environments, staff, procedures, language, etc.

Nonetheless, objective knowledge is urgently needed for those occupations which demand a high level of performance, and where the consequences of performance failure are very costly. Long-haul (transoceanic) cockpit crews constitute one of the most sensitive and critical of these occupations. In fact, the layover (L/O) sleep of operating cockpit aircrews has never been studied objectively. In the worst case, after crossing 8-10 time zones, a crew member might be unable to sleep at all during the L/O because of the residual stimulation of the flight and landing compounded by environmental disturbance (light and noise) and trying to sleep at an inappropriate phase of the circadian rhythm. Conversely, other crew members may experience no sleep difficulties because as veteran pilots they have learned to cope with the problems associated with repeated multiple time zone transitions.

As an initial step toward resolving these issues, the National Aeronautics and Space Administration assumed the responsibility for organizing research on sleep quality in international flight operations. As detailed in the overview by Graeber et al., the logistical problems of carrying out such a study in the field were formidable indeed. After many discussions and planning meetings, two major implicit priorities emerged: [1] to demonstrate that an international cooperative, sleep/wake study could be carried out and generate valid scientific data, and [2] to select an initial project which would be sufficiently tractable for the first investigation.

The explicit goals of the project were [1] to accurately document sleep quality during trips in comparison to home sleep; [2] to examine the variation in, and effectiveness of, flight crew sleep/nap strategies; and, [3] to validate the accuracy of subjective fatigue ratings by comparing them with objective measures of sleepiness. Accordingly, this study carries out observations on sleep and wakefulness in aircrew in their home time zone and during their first L/O in a new time zone, i.e., after the first flight of a multi-segment trip. This selection clearly does not target the most likely period of sleep/wake impairment for crews carrying out a complex schedule of rest and duty, i.e., at the end of multiple transmeridian flights and L/Os. However, in the context of mounting an international study of such magnitude, it offers the clearest opportunity for testing this approach and for obtaining the first objective realistic data.

Sleep quality assessment issues. Most people make a daily assessment of their previous night's sleep on a casual and intuitive basis. Their judgment is subjective and undoubtedly based upon the number of times they think they have awakened, feelings of restoration and sleep depth, and the amount of drowsiness experienced the next day. The popular notion that sleep has a restorative function underlies these judgments, i.e., better sleep leads to alert energetic wakefulness and indirectly to high levels of performance. We cannot define any kind of sleep to be of high quality if there is substantial sleepiness the next day, even though such sleep may be adequate for certain kinds of performance. Thus, it is clear that sleep quality must be measured in the context of the entire 24h day or the overall patterns of work and rest.

Given that the only known function of sleep is to promote wakefulness, one obvious measure of sleep quality is the quality of the wakefulness throughout the following day. Subjective measures of wakefulness, e.g., Stanford Sleepiness Scale (14), have several drawbacks. First, the subject must be able to distinguish physical fatigue from sleepiness, i.e., the need for rest versus sleep. Second, the pejorative connotation of "sleepy" may cause denial in some subjects. Third, momentary excitement may mask the awareness of sleepiness, or, conversely, boredom may be perceived as having caused sleepiness rather than having merely unmasked it.

To overcome these limitations, investigators have employed performance tests and physiological measures of central nervous system function to objectively assess the "quality" of wakefulness. Though widely used and operationally relevant, performance tests have serious limitations in terms of test standardization and individual levels of skill, learning speed, and motivation. Furthermore, no matter how sophisticated the test apparatus or simulator, the subject always knows he is being tested, watched, and measured. Generalizing results beyond the laboratory is such cases must remain dubitable.

In recent years, a more satisfactory approach to the quality of sleep and subsequent wakefulness has been developed, called the Multiple Sleep Latency Test (MSLT). The MSLT essentially extends into the day the same techniques used to study sleep at night. The procedure measures the tendency to fall asleep in a standard manner throughout the daytime following a night of sleep (4). By experimentally varying the prior night's sleep, investigators can objectively measure the consequences on physiological alertness (or, conversely, drowsiness) during the daytime (6, 8). Unlike performance, daytime physiological alertness has the remarkable advantage of being determined almost totally by the quality of prior sleep. This approach has allowed sleep researchers to formulate a clear consensus definition of high quality sleep and to measure quantitatively the range of decrement in this function as a consequence of systematic reductions in sleep amount and continuity. Thus, sleep is judged to be optimal or of high quality when it promotes optimal daytime alertness.

The MSLT approach to gauging sleep/wake functions and judging sleep quality is noncontroversial and widely accepted as a clinical tool. Its application to operational situations is less widely accepted. However, extensive research (c.f., 4) has firmly established that the average level of daytime alertness is directly related to the amount of sleep at night and is reduced by sleep fragmentation, even if the total amount of sleep is not decreased (5). Since phase shifts in the timing of the major sleep period (e.g., after transmeridian flight) often cause sleep loss and interruption, the MSLT approach would appear to be a reasonable way to assess L/O sleep in addition to standard polysomnographic recording of the major sleep episodes.

MATERIALS AND METHODS

Baseline. The procedures consisted of the "core measures", outlined in the preceding paper by Graeber et al., plus concurrent sleep period measures of respiration, leg movement and heart rate (15). The sleep data related to respiration and leg movements will be addressed in a subsequent paper by the international group. Pre-sleep questionnaires assessed alcohol and medication use, sleepiness, and mood. Post-sleep questionnaires provided subjective assessments of sleep. The tendency to fall asleep during the "daytime" was objectively measured by administering the Multiple Sleep Latency Test (MSLT) (7) on even GMT hours during waking periods. The MSLT included two channels for EEG (C3/A2, 01/A2) and two channels for eye movements (ROC/A1, LOC/A2). Subjective daytime sleepiness, alertness, and tenseness were assessed immediately before each sleep latency test. During the baseline day, subjects also completed a background questionnaire.

Adaptation to the sleep recording procedure (an overnight stay in the sleep laboratory) and the baseline recordings of sleep and daytime sleepiness were carried out at Stanford. Subjects slept in individual light-proof bedrooms which were quiet and air conditioned. Recordings were made on 8-channel Grass 7D polygraphs, and the time of awakening was spontaneous or by call, as the subject chose. Baseline sleep recordings were conducted only after a minimum 3-day non-flying period (the mean was 7.5 days) and included the MSLT throughout the next day. The baseline in some cases preceded and in other cases followed the target trip, usually within 3 weeks (Fig. 1). Pilots were on duty during the flight preceding the L/O recording (not necessarily continuously since all these flights included relief crews).

Flight and layover. Table I describes the subjects flying the two routes under study. The 11 pilots flying from SFO to LHR were scheduled to depart at 1730h Pacific Daylight Time (PDT) and to arrive at 1126h British Summer Time, the scheduled duration of the flight being 9h 56min with a time zone change of +8h. Upon arrival, (about 0330h PDT) they were driven to the sleep laboratory of the Royal Air Force Institute of Aviation Medicine in Farnborough, where recordings were made on a Grass 8-10 EEG machine. The duration of the L/O varied from 48 to 72h (see Results), after which all subjects returned directly to the PDT time zone.

The 8 pilots flying from SFO to NRT were scheduled to depart at 1200h Pacific Standard Time (PST) and to arrive at 1550h local time, the scheduled duration of the flight

TABLE I. SUBJECT CHARACTERISTICS.

	SFO-LHR	SFO-NRT
Rank		
Captains	5	2
First Officers	3	2
Flight Engineers	3	4
Age (yrs)		
45-50	1	2
51-55	6	3
56-60	2	3
61-65	1	0
Mean	54.3	53.6
Weight (lbs)		
125-149	1	1
150-174	4	4
175-199	4	1
200-225	1	2
Mean	177	175
Body Mass Index*	3.53	3.43

* calculated as (weight/height^2) X 100.

being 10h 50min with a time zone change of -7h. Upon arrival (about 2250 PST) they stayed at their usual L/O hotel near the Narita International Airport, where their rooms were located in a separate wing reserved for air crews and connected by cable to Nihon-Kodon model 5210 polygraphs in an adjoining room. The duration of this L/O was 25h, after which all subjects returned to the airport for duty on a subsequent flight to another Asian destination. The staff for this temporary sleep laboratory was drawn from the Stanford Sleep Research Center and the NASA Ames Research Center.

During both L/Os, subjects were entirely free to choose their own sleep/wake times and could, if they wished, request to be awakened by the technician at a particular time. Alcohol was not allowed during the baseline recordings, but up to two glasses of wine or beer prior to a major sleep period were allowed during the L/O. Subjects were asked to avoid caffeine on all recording days, but not during the flight preceding the L/O.

All recordings (home and abroad) were scored (21) by the same person. "Persistent sleep latency" was defined as the time from "lights out" to the beginning of 10 consecutive min. of sleep. "Lights out" was literally the time the crew member turned out the light to begin trying to sleep and did not include the time in bed beforehand. "Lights out" was set as the start of stage 1 sleep for the single case in which a subject fell asleep while reading. An "awakening" was defined as any occurrence of a 30-sec. epoch scored as wake if it was immediately preceded by any sleep stage.

Statistical Analysis. Repeated measures analysis of variance was used on all variates to assess baseline to L/O changes in sleep pattern, daytime sleepiness, and subjective sleep quality. Mean differences between baseline and L/O sleep periods were examined using procedures that control for "false positive" significant differences (12). When missing data resulted in unequal cell sizes, the Tukey-Kramer method for testing mean differences was used (16). Transformations were applied when necessary to correct for non-normal distribution of data (3); back-transformed means are presented in all tables. A two-factor analysis of variance with subjects and time-of-day as factors was used on log-transformed sleep latency scores to assess daytime sleepiness. All analyses of variance were performed separately for both SFO-based routes.

The relation between subjective and objective assessments of sleep latency and total sleep time was examined using linear regression. A similar method was used to examine daytime sleep latency and subjective ratings of daytime sleepiness. Separate analyses were performed for baseline and L/O sleep periods for each of the two routes. Analyses were repeated on a combined sample (both SFO-based routes) and for all five routes combined across all participating airlines and laboratories.

A preliminary set of analyses was performed on the entire sample (all five routes) in order to determine which aspects of nocturnal sleep influence subjective assessments of sleep quality. Pearson product-moment correlation coefficients between sleep quality and nocturnal sleep variables were calculated. Correlations reaching an alpha =.05 level of significance identified potential predictors. These potential predictors were then entered into a step-wise multiple regression procedure. Maximum R^2 improvement techniques were used to select the "best" predictive model of sleep quality (13). Analyses were performed separately for baseline and L/O sleep.

RESULTS

Objectively Measured Sleep. Figures 2 and 3 depict the sleep/wake patterns of each crew member during baseline and L/O. For the Tokyo L/O, all but one subject obtained sleep just before departing NRT, and no one attempted to sleep between 0000-0200 GMT (1600-1800 PST). For the London (Farnborough) L/O, all crew members but one successfully attempted to sleep within two hours after arriving at the laboratory. Thereafter, three of the subjects (#1173, 4123, 5350) appeared to delay bedtime as if keeping home time, while the others appeared to select bedtimes more or less according to local time. Throughout the entire L/O, 9 of the 11 subjects attempted three distinct sleep periods. The break between these sleep periods occurred at about 2200 GMT on L/O day 1 and between 1600-2000 GMT on L/O day 2. Within the three usual sleep priods, the two other subjects (#1180 and #1174) appeared to split one or more of their sleeps; for computational purposes, the sleeps (but not intervening wakes) of these "split" sleeps have been combined and treated as a single sleep period. Also, six of the subjects had over 48h L/O in London: either 52h (#1173 and #4123) or 72h (#1180, #4121, #5354 and #5355). Those with a 72h L/O spent only the first 48h at Farnborough and then were moved to a London hotel; the two crew members with a 52h L/O had sleep periods that extended into their "extra" 4h, but it is otherwise uncertain to what extent the variable duration may have influenced their choice of sleep patterns. A check of the daily activity logs kept during flight indicated that 7 of the 11 crew members flying to London, and 6 of the 8 flying to Tokyo took naps in first-class seats during part of their approximately 3h off-duty (see Table II).

Remarkably, total sleep time generally decreased from adaptation to baseline (Table II). Although the mean difference was not statistically significant (t-test), the change was opposite the expected direction. A Sign Test (26) suggests that SFO-NRT subjects were more likely to have less sleep on baseline than adaptation ($p=.008$) than were SFO-LHR subjects ($p=.77$).

For the SFO-LHR group, baseline sleep averaged 6.35h with an efficiency equal to 89.4% of the time in bed. Total sleep time and sleep efficiency were comparable to normal males of similar ages [28] (Table III). Comparing baseline to the three L/O sleep periods (Table IV), analysis of variance revealed no significant differences except for the first L/O sleep, where total recording time was significantly shorter than for the other sleep periods and total sleep time was significantly less than for baseline. Furthermore, 9 of the 11 subjects awoke from their first L/O sleep spontaneously. The overall efficiency of L/O sleep (cumulative sleep time/cumulative recording time) however, significantly declined from baseline. Yet, the percentages of sleep stages, persistent sleep latencies, and number of awakenings did not significantly change (Table IV; Figs. 4 and 6). The differences between baseline and L/O median sleep stage latencies shown in Fig. 5 did not reach significance when analysis of variance was applied to either the log transformed or median data.

For the SFO-NRT group, baseline sleep averaged 6.82h with an efficiency equal to 84.8% of the time in bed). In contrast to the LHR group, sleep efficiency, but not total sleep time, was significantly lower compared to normal males of similar ages (28) (Table III). Compared to baseline (Table V), the first L/O sleep contained significantly less total sleep time but not less time in bed. Although mean sleep efficiency was therefore decreased, the change was not statistically significant. Once again, the majority (6 of 8 subjects) awoke from their first L/O sleep spontaneously. The percentage of slow wave sleep (SWS) was

TABLE II. NOCTURNAL SLEEP DATA FOR INDIVIDUAL SUBJECTS.

Route/ Subject	Adaptation SE	Adaptation TST	Baseline SE	Baseline TST	Naps on Flight (estimated TST)	Sleep 1 SE	Sleep 1 TST	layover Sleep 2 SE	layover Sleep 2 TST	Sleep 3 SE	Sleep 3 TST
SFO-LHR											
1170	77.7	353	80.7	316	0	72.4	204	84.5	295	72.2	362
1173	94.7	269	91.3	266	120	94.7	321	89.5	328	91.0	422
1174	88.3	395	90.4	433	0	76.7	278	43.3	136	84.1	450
1175	89.5	412	91.1	336	60	86.7	241	68.3	221	92.6	473
1180	84.7	301	90.4	234	120	81.4	148	91.7	320	83.1	405
4120	85.9	388	89.5	343	no data	94.6	184	92.7	400	88.0	357
4121	93.0	522	94.8	452	30	85.2	76	92.9	364	91.4	358
4123	79.4	392	92.4	423	120	78.0	293	86.4	274	80.5	252
5350	78.0	369	77.9	509	0	66.7	278	78.9	466	83.6	217
5354	89.0	512	94.5	475	60	92.6	158	90.0	874	17.4	71
5355	79.8	353	90.2	410	120	83.6	251	71.0	436	56.0	181
SFO-NRT											
1177	88.6	418	79.1	375	100	64.8	379	90.6	48		
1179	91.4	545	90.1	443	0	86.4	376	71.6	39		
4125	84.4	454	77.8	356	20	82.9	376	55.2	22		
4129	91.0	517	79.4	492	60	85.9	410	86.7	178		
5351	95.3	441	95.2	428	no data	95.2	440	85.4	123		
5352	97.4	462	95.2	458	100	99.1	314	97.3	178		
5353	78.6	324	71.9	320	15	54.6	300	67.3	50		
5359	89.4	422	91.0	399	30	69.5	318	--	--		

TST = total sleep time (min); SE = sleep efficiency (TST/recording time X 100)

TABLE III. COMPARISON OF MEAN BASELINE SLEEP DATA WITH PUBLISHED DATA (28) FOR "NORMAL" MALE SLEEPERS OF SIMILAR AGE.

Variable	Williams et al. (n=12)	SFO-to-LHR (n=11)	SFO-to-NRT (n=8)
Mean age (yr) and range ( )	54.4 (50-59)	54 (48-61)	54 (47-60)
Mean TRT (min) and SD ( )	422.6 (44.9)	428.9 (108)	482.0 (58.4)*
Mean TST (min) and SD ( )	389.8 (49.5)	381.5 (88.5)	408.8 (56.9)
Mean SE (%) and SD ( )	92(4)	89.4 (5.3)	85.0 (8.9)*

* $p<0.05$
TRT = total recording time; TST = total sleep time; SE = TST/TRT X 100

higher, while REM sleep was lower during the short, second L/O sleep (or nap) than for baseline sleep (Fig. 4). As in the LHR group, persistent sleep latencies, sleep stage latencies (Fig. 5), and the number of awakenings per hour of sleep did not significantly change after the flight (Table V). Individual data on total sleep duration and sleep efficiency are presented in Table II.

Subjective assessments of sleep. Neither group showed notable changes in subjective assessments of sleep quality (Fig. 6), total sleep, or sleep latency from baseline to L/O (Table VI).

Multiple sleep latency tests. The first sleep latency test began up to two hours after the individual pilot awakened, which varied considerably (see Figs. 2 and 3). For the SFO-LHR group, mean daily MSLT values did not significantly differ between the baseline, first, and second L/O waking periods (Table VII). During the baseline recordings, daytime sleepiness varied during the day ($F_{5,50}$=6.53, p<.001), with contrast statistics showing that the first and last sleep latency tests were significantly higher than tests 2,3 and 4. That is, subjects tended to be most sleepy in the middle of the day (Fig. 7). This pattern of sleepiness persisted in the new time zone in accordance with home time. Comparing the time (GMT) of maximal daytime sleepiness for each SFO-LHR subject during baseline and again on the second L/O day (an averaged time was used for two equally low sleep

TABLE IV. MEAN NOCTURNAL SLEEP PARAMETERS, SFO-LHR (n=11).

	Baseline	L1	L2	L3	Cumulative L/O	F-Value	Contrasts B vs L1	B vs L2	B vs L3	B vs L
Persistent SL	12.46	8.01	15.60	19.80	-	3.52*	NS	NS	NS	-
Stage 1%	18.86	19.24	15.90	17.94	18.06	1.18	-	-	-	NS
Stage 2%	51.29	43.46	52.10	47.98	48.93	2.46	-	-	-	NS
Stage 3 & 4%	7.64	14.42	8.82	13.78	11.31	2.00	-	-	-	NS
REM%	19.52	18.79	20.40	17.23	20.11	0.46	NS	NS	NS	NS
Number Wakes/Hr During Sleep	1.82	2.84	3.07	5.92	3.71	1.45	-	-	-	-
Sleep Efficiency	89.30	82.39	83.80	74.13	80.86	1.67	NS	NS	NS	*
Minutes Total Sleep	381.48	221.01	375.68	322.60	-	3.01*	*	NS	NS	-
Total Recording Time	428.91	271.73	455.91	418.36	-	4.04*	*	NS	NS	-

* p<0.05; - = not tested; SL = sleep latency

latencies), the correlation was +.60 ($p<.05$), with the time of the maximal sleepiness during L/O day 2 advanced by an average of 1h. There were insufficient data to test this relation reliably on the first L/O day. With reference to time since sleep, however, subjects during L/O did not show the usual rise in the MSLT profile toward the end of L/O day 2 (Fig. 8). Furthermore, several crew members were consistently sleepy (low MSLT scores) during this day.

For the SFO-NRT group, overall daytime sleepiness (measured by the mean daily MSLT value) was significantly less during L/O than baseline (Table VII). During the baseline recordings, daytime sleepiness varied during the day ($F_{5,29}=2.79$, $p<.05$), with contrast statistics showing that the first sleep latency test was significantly higher than test 5 (Fig. 7), a somewhat weaker pattern than found in the SFO-LHR group. Due to the brevity of the L/O and the variety of individual sleep-wake patterns (see Fig. 2), there were insufficient data to reliably test whether the times of maximal daytime sleepiness were correlated during baseline and L/O.

Subjective daytime sleepiness. Neither group exhibited changes in subjective sleepiness from baseline to L/O (Table VII). For the SFO-NRT group, self-rated tension was significantly less during L/O.

TABLE V. MEAN NOCTURNAL SLEEP PARAMETERS, SFO-NRT (n=8).

	Baseline	L/O 1	L/O 2	Cumulative L/O	F-Value	Contrasts B vs L1	B vs L2	B vs L
Persistent SL	13.40	9.12	12.18	-	0.33	-	-	-
Stage 1%	14.29	16.65	12.82	14.29	1.27	-	-	-
Stage 2%	55.93	42.83	47.29	43.87	3.58^{T}	NS	NS	*
Stage 3 & 4%	9.36	19.36	30.36	20.61	6.64*	NS	*	T
REM%	19.22	18.09	4.92	16.43	28.54***	NS	*	NS
Number Wakes/Hr Sleep	2.68	3.81	4.09	3.94	0.75	-	-	-
Sleep Efficiency	84.82	79.11	78.52	78.68	0.83	-	-	-
Minutes Total Sleep	408.79	364.32	92.44	-	160.12***	*	*	-
Total Recording Time	482.00	467.38	110.14	-	81.30***	-	*	-

* $p<0.05$; *** $p<0.001$; T = $p<0.10$; NS = $p>0.10$; - = not tested

Relation of subjective and objective measures. Linear regression was used to examine the relation between objective and subjective measures of sleep latency and total sleep time. In this procedure, the value called R^2 measures the degree of association between the variables. Thus, if $R^2=0$, there is no relation, whereas $R^2=1$ indicates the strongest possible relation. Separate analyses were conducted for each of the two SFO-based routes, and no statistically significant differences between groups were found for the slopes and intercepts of the fitted models. Therefore, analysis of the pooled data across routes will be presented below. Subjective estimates of total sleep time were reliable during L/O ($R^2=.77$, $p<.001$) but were less so during baseline ($R^2=.34$, $p<.01$). Subjective estimates of sleep latency were reliable during baseline ($R^2=.86$, $p<.001$) but less so during L/O ($R^2=.14$, $p<.01$).

Results based on the composite subject group. Analysis of the sleep data combined from all subjects (N=56) across all participating airlines revealed that age had a significant impact on recorded sleep. For the baseline recordings, age was significantly ($p<0.05$) correlated (Kendall Tau B statistic) with an increased number of awakenings per hour of sleep (r=.21), a higher percentage of stage 1, or drowsy, sleep (r=.21), lower percentages of stages 3+4 (SWS) sleep (r=-.19), and lower sleep efficiency (r=-.20). A negative correlation indicates that values decreased with age. No significant quadratic or cubic relations were found for these variables. These age-related findings are consistent with previous reports of poorer quality sleep in older individuals (17). In spite of these results for objective sleep measures, age was not a significant correlate of subjective sleep quality (r=-.11, $p>.2$).

In examining the relationship between subjective and objective measures for the whole group (N=56), subjective estimates of total sleep time were found to be reliable for L/O ($R^2=.79$, $p<.001$) and less so for baseline ($R^2=.34$, $p<.01$). Combined across baseline and L/O conditions, the data fitted the relation: $y = 47+.90x$, where y is the subjective and x is the actual total sleep time. From a calculation of confidence intervals (2), it may be concluded that a pilot has a 95% chance of correctly estimating objective total sleep time within 30 mins. Subjective estimates of sleep latency were not so reliable. Combined across baseline and L/O conditions, the data fitted the relation: $\log y = 2.15+.34 \log x$, where y is the subjective and x is the objective persistent sleep latency ($R^2=.20$, $p<.001$). From a calculation of confidence intervals it may be concluded that the tendency to subjectively overestimate sleep latency increases the longer it takes to fall asleep.

To determine which objective sleep variables best predicted subjective sleep quality in the group as a whole (N=56), those variates significantly correlated with sleep quality were entered into a stepwise regression. For baseline, the variables entered included percent stage 1, sleep efficiency, total wake time, latency to persistent sleep, percent stage 3+4, and number of wakes per hour of sleep. For L/O, these variables were percent stage 1, sleep efficiency, total wake time, latency to persistent sleep, total sleep time, and percent REM sleep. Stepwise regression for baseline showed that latency to persistent sleep, percent stage 1, and number of wakes per hour of sleep best predicted subjective sleep quality, together accounting for 30% of the variance. For L/O, latency to persistent sleep, sleep efficiency and total sleep time were the best predictors of subjective sleep quality, together accounting for 29% of the variance.

Subjective estimates of daytime sleepiness, on the other hand, did not predict sleepiness as measured objectively by the MSLT (combined across conditions, N=56,

TABLE VI. MEAN SUBJECTIVE SELF-RATED SLEEP ASSESSMENTS.

	Baseline	L/O 1	L/O 2	L/O 3	F-Value	Contrasts B vs L1	B vs L2	B vs L
SFO-LHR								
Sleep Latency	23.81	21.16	21.33	15.80	0.97	-	-	-
Sleep Time	397.27	249.09	372.73	332.30	2.67 T	NS	NS	NS
Sleep Quality	48.91	52.27	60.09	58.70	0.63	-	-	-
SFO-NRT								
Sleep Latency	14.15	14.30	13.74		0.01	-	-	
Sleep Time	423.75	386.33	96.43		72.16***	NS	*	
Sleep Quality	44.38	60.56	62.43		1.87	-	-	

* $p<0.05$; *** $p<0.001$; T = $p<0.10$; NS = $p>0.10$

TABLE VII. MEAN SUBJECTIVE AND OBJECTIVE DAYTIME SLEEPINESS MEASURES.

	Baseline	L/O 1	Cumulative L/O 2	L/O	F-Value	Contrasts B vs L1	B vs L2	B vs L
SFO-LHR								
SSS	2.48	2.92	2.52	2.61	3.11 T	NS	NS	NS
Tension	27.83	27.75	26.60	25.89	0.13	-	-	-
Sleep Latency	7.03	6.62	6.36	6.55	0.11	-	-	-
SFO-NRT								
SSS	2.72			2.69	0.01			
Tension	26.20			18.49	10.84**			
Sleep Latency	5.36			10.28	8.57*			

* $p<0.05$; ** $p<0.01$; T = $p<0.10$; NS = $p>0.10$
SSS = Stanford Sleepiness Scale

R^2=.01). Neither the objective nor the subjective measures of sleepiness were linearly correlated with self-rated tension (Spearman rho = .01 and .03, respectively). This finding agrees with our previous report that tension does not appear to influence daytime sleepiness as measured by the MSLT (24).

DISCUSSION

Baseline sleep and wakefulness. There are two ways to judge the quality of sleep in experimental situations. The first is by comparison to conventional standards, ill defined as they may be. Thus, roughly 6-8h of sleep in a 24h period followed by a reasonable level of physiological alertness might be judged "adequate" for most operational purposes. Nine hours followed by full physiological alertness during the entire waking period might be judged "high quality." The second way is by comparison to "normal" basal conditions in the same subjects. Both comparisons have advantages and disadvantages. In our study, we will discuss L/O sleep from both perspectives.

The baseline sleep of our subjects (N=19) did not provide as good a basis for comparison as would have been desirable. Because of the well-known "first night effect" (1), it is surprising that the total sleep time on baseline nights did not improve from the adaptation nights. This parameter is therefore most likely spurious in the group data. Twelve of the 19 crew members were awakened by the technician at a pre-arranged time at their request and presumably would have otherwise slept longer. Several of these subjects apparently requested early awakenings in order to complete the baseline MSLT procedure earlier on the following day. The remaining seven awoke spontaneously, although for five of them, the spontaneous decision to end their sleep was earlier than the morning "wake-up" time they had requested the night before. The net result was that subjects tended to spend less time in bed on the baseline night than on the adaptation night. Five of the 19 subjects also showed a sleep efficiency more than three standard deviations below published norms for this age range.

That some crew members had very low MSLT mean scores also clouds interpretation of these baseline data. Similar MSLT levels have been reported following acute total sleep loss or substantial continuous sleep loss. Although the overall assessments from the exit questionnaires suggest the sleep was typical, we are uncertain of the degree to which the duty patterns immediately before baseline recordings may have had residual effects that diminished baseline sleep quality. In particular, the baseline measurements may have been affected by circadian desynchronization or displacement which would result in artificially low daytime MSLT scores due to the persistence of the shifted alertness rhythm. In our data, the baseline MSLT of most SFO-LHR subjects exhibited the normal dip in alertness at the appropriate local time. This was not as consistent in the SFO-NRT group, however, suggesting that data from the westward group should be viewed with more caution than data from the eastward group.

Accordingly, judgements concerning the adequacy of L/O sleep in comparison to baseline sleep in these group must be tentative. Even though certain parameters (e.g., fragmentation, efficiency) might be more appropriate than total sleep time, one must recognize that sleep, at any particular time, is a function of the prior history of the individual, and thus sleep can often appear to be of spuriously high quality because of prior cummulative sleep loss. If baseline values were indeed representative of usual sleep at home, there would be reason to further study the possibility of persistent fatigue in some aircrew members. However, we should note in this context that several subjects whose MSLT scores were markedly impaired during baseline did not show a similar impairment during waking periods in the L/O situation.

Layover sleep and wakefulness. After decades of speculation about the quality of L/O sleep, we now have objective documentation from sleep laboratories. From the perspective of fearing that some pilots might not sleep at all during L/Os, one of the clearest findings in this study is that sleep in the new time zones was not substantially worse than the baseline sleep recorded at Stanford. Nonetheless, some comparisons were significantly worse. Perhaps the most important was reduced sleep efficiency in the SFO-LHR group, which supports the belief that eastbound flight is more disruptive of sleep periods than westbound flight. In addition, the significant shortening -- despite sleep loss -- of the first L/O sleep in the SFO-LHR group was not compensated by extra long sleep periods on subsequent nights, so it is unclear how this sleep loss was carried over time. The increase in stage 3+4 sleep (SWS) in the SFO-NRT group might be best interpreted as the consequence of sleep loss; a similar, but non-significant, increase was seen in the SFO-LHR group.

The conclusion from these relatively small changes in objective sleep is that, by utilizing their own prior experience, these aircrews obtained more or less adequate sleep for this particular L/O. In other words, both by implicit internal standards and by comparison to baseline, the sleep during the first L/O is probably adequate for the next flight, but definitely less than optimal. A more definitive statement would require measures of physiological alertness and performance during the subsequent crew duty period.

Subjective measures of sleep and wakefulness. Based on data from the composite airline group, subjects were reasonably accurate in judging the amount of sleep. Generally, most other subjects tend to underestimate (10,24). This finding augers well for studies of pilots relying on questionnaire data. It may be noted, however, that the decrease in total sleep time for SFO-LHR L/O sleep 1 was statistically significant only for the objective but not the subjective measure. Thus, though correlated, the greater variance in subjective assessments requires the use of larger numbers of subjects for equivalent statistical power. Sleep latency estimates, however, may be less useful in this regard. Their global assessment of sleep quality did relate to objective sleep parameters, but subjects may may weigh these parameters differently before and after a time zone shift.

Self-rated alertness during waking hours correlated only weakly with objective MSLT measures. In this respect, these subjects are similar to other populations we have studied (24). In the context of flight operations the importance of this weak relationship between subjective and objective sleepiness hinges on whether objectively measured sleepiness is in turn related to vigilance. Previous studies by our group suggest that increased sleepiness is accompanied by decreased vigilance (25), but the suggestion of a causal relation between sleepiness and performance lapses is still under study (9).

As we have found previously (24), self-rated tension did not correlate with either subjectively or objectively measured daytime sleepiness; indeed, the SFO-NRT group exhibited a significant drop in tension from baseline to L/O, whereas their mean MSLT scores increased.

In judging the overall quality of L/O sleep, we also note that average alertness during the periods of wakefulness was not significantly less than baseline. Some subjects, however, did exhibit levels of sleepiness either during baseline or L/O (or sometimes both) that suggested substantial chronic sleep loss. Furthermore, during the second L/O day (SFO-LHR group), the usual decrease in sleepiness seen toward the end of the day (Fig. 7) was not apparent (Fig. 8).

The outstanding result from statistical analysis of our group data is that the quality of sleep in the new time zones was only slightly worse than "baseline" sleep recorded at Stanford. As this was unexpected, some further comments are in order. First, these findings definitely apply only to the first L/O; it is quite possible that sleep quality would diminish with successive time zone changes and that efforts to optimize the timing of sleep could be hampered by sleep loss. Second, the L/O sleep we recorded in the laboratory may be less disturbed than hotel L/O sleep; against this interpretation, however, it must be noted that the small SFO-NRT group was recorded in a hotel and did not sleep significantly worse on this account. Most important is the likelihood that the "baseline" night did not represent a true baseline. Surprisingly, the mean total sleep time for adaptation was greater than the baseline mean. Thus, the adaptation night may represent a more valid basal night of sleep. Finally, it should be noted that alcohol, nominally used by some subjects to "unwind" after a flight, may have had some role as an hypnotic (its use was limited to two measures only before sleep periods during L/O).

Another important point is that the quality of sleep at any particular time may not reveal an accumulating deficit. The assumption here is that the trip did not begin with a sleep debt. We do not know this. Inspection of the MSLT scores during the second L/O day (SFO-LHR route) suggests an accumulating sleep debt. With a mode of 7 tests per subject, six subjects had very low values on the last 4 or more tests.

Individual differences. The 19 subjects in our study showed a wide range of responses to the long-haul L/O situation as well as a wide range of individual values during homebase sleep. For example, there were five L/O sleep periods (attempts) over 5h in duration, for which sleep percentages were under 70%, and many were below 80%. The lowest percentage for sleep periods over 4h was 54.6% of 9.8 h. Conversely, there were a number of occasions in which more than 90% of a substantial sleep period was spent asleep. The number of wakes during L/O sleep ranged from fewer than 10 to more than 50. One subject slept 874 min. in a sleep period of 971 min.

Reasons for individual differences in the quality of L/O sleep are not clear. Further analysis of the respiratory and leg movement data, along with similar control data now being collected from an equivalent age group at IAM Farnborough, should help to clarify the nature of these differences.

Biphasic sleepiness rhythm. It is now widely accepted that the tendency to sleep increases markedly every 12h, i.e., the circadian rhythm of sleepiness is biphasic. As Fig. 9, from Richardson et al. (22), illustrates, the U-shape of the daytime MSLT curve is usually unambiguous following a major sleep period at night. With a modest reduction in the usual amount of sleep, the mid-day dip in alertness becomes more pronounced. This is obviously the time when it would be easier to initiate a nap.

The trough or evening rise of the MSLT curve can be used to judge a subject's phase position. For instance, the time of baseline mid-day sleepiness was found to predict the time of maximal sleepiness during the second L/O day for the SFO-LHR subjects. If we assume that phase position changes little from the home environment to the first L/O, were the crew members sleeping at optimal times? For the SFO-NRT group the answer is clearly no. The flights took off at 1200 PST from SFO, lasted almost 11h, and arrived in NRT at approximately 1600 NRT time. Approximately 16h elapsed between getting up in SFO and arriving in NRT. Yet, the subjects delayed their first sleep from 4h to more than 9h after arrival, presumably to calm down after the excitement of the trip, or to foster synchrony in the new time zone, and/or to increase sleep loss and therefore the likelihood of sleeping. However, since the first L/O sleep is shorter than baseline and the terminations are all spontaneous, we may conclude that the sleep attempt was at a non-optimal period. If the L/O sleep were advanced to 1900 NRT time, it would likely be longer, and the opportunity of taking a longer pre-flight sleep might be increased. Some subjects remarked that they purposely shortened their first sleep to ensure that sleep would occur during the pre-flight nap (due to the presence of sleep loss). However, the duration of their second L/O sleep period was also far from optimal. The average amount was only 92 min., and the efficiency was low. Thus, from the point of view of strategy, the L/O sleep for the SFO-NRT group could be improved.

The eastward flight also showed clear evidence that sleep scheduling and L/O strategy were not optimal. The first L/O sleep, which began at approximately 1500 GMT, was significantly shorter than baseline; once again, most of the crew (8 subjects) specifically indicated that they would take *ad lib* sleep, yet they all awakened spontaneously and got out of bed after a reduced sleep duration. In three cases, where crew members had asked to be aroused, they awoke spontaneously substantially before their requested time. Given the rhythm of sleep tendency, the eastward crew should also have gone to bed substantially earlier, if possible. Since the L/Os were substantially longer on the eastward flights than the westward flights, it is likely that the determinants of L/O sleep strategy were different from the westward flight. The tendency seemed to be for a second L/O sleep period approximately 12h later and a third L/O sleep to coincide more with the period before departure. Periods of severe sleepiness were seen primarily during the second L/O day and continued throughout the long period of wakefulness (Fig. 8).

Layover sleep debt. We have pointed out that the amount of baseline sleep in SFO-based crew members is almost certainly less than their usual amount. The MSLT results do not necessarily give a clear indication of this since extreme sleepiness due to partial sleep loss takes several days to develop. Nonetheless, to our surprise, some subjects were extremely sleepy on the baseline measures.

The timing of L/O sleeps is such that each L/O sleep period could represent a successive 24h period. This would mean that the amount of sleep per 24h averages 5.3h. This amount eventually leads to severe impaired alertness in the laboratory (6). If the SFO-LHR subjects were leaving the laboratory to fly for 9-10h, it is likely they would experience severe sleepiness. The same applies to the SFO-NRT group. In the latter, the brief pre-flight sleep would not be adequate for a 9-10h return flight; however, these subjects were scheduled for shorter flights (2.5-5.0h) within the Asian continent.

Operational recommendations. Our major overall recommendation is that the biphasic (12h) rhythm of sleep tendency should be recognized as a sleep opportunity and be translated into operational strategies. That is, L/O sleep periods should coincide with the twice daily periods of maximal sleepiness. Similarly, when possible, work schedules might be optimally adjusted to ensure that peak workloads occur during the twice daily periods of maximal alertness. At present, however, we cannot predict with assurance how the biphasic sleepiness rhythm would shift after several repeated time zone changes.

Given all these considerations, and in view of similar laboratory studies in which performance is optimized for reasonable amounts of time following short sleeps, e.g., during the evening prior to a night of wakefulness (18), our second recommendation represents a radical approach with significant operational implications for long-haul flights. First, it is quite possible that if sleep periods are scheduled optimally, e.g., at the two troughs of the biphasic alertness cycle, that two periods of 2-6h (totalling approximately 8h per 24h) would suffice to maintain performance indefinitely during subsequent periods of alertness (8-10h) and should be deliberately scheduled. The problems of sleep loss and fatigue during transoceanic travel might thus be greatly minimized. As noted above, the only caveat in this recommendation is that the schedule could not be temporally rigid, because the underlying rhythm might phase advance or phase delay. As Sasaki et al. have shown in their adjoining paper, the MSLT can be a very useful indicator of phase position and thus could provide guidance on when to sleep.

It is not clear to us why regulations prohibit scheduled napping by single crew members in the cockpit during transoceanic flight at cruise levels. Indeed, there are numerous anecdotes that napping does, in fact, take place. Given that some pilots purposefully resort to sleep loss to try to ensure sleep during the pre-flight nap period, it would certainly be preferable instead to schedule times to permit napping. Finally, all crew members commented on their need to "unwind" after a flight; however, the time required to "unwind" could delay going to bed at an optimal time to sleep. Rather than use precious time for this purpose, it might be better in certain circumstances to facilitate sleep with a low dose of a rapidly eliminated benzodiazapine hypnotic (11, 25) under the direction and advice of a physician. Such an approach might have a role in L/O sleep, if utilized occasionally on a limited basis. In this regard, the use of alcohol for the purpose of "unwinding" is not advised because of its known tendency to disrupt sleep patterns (20) and its potential for abuse in uncontrolled settings.

Furthermore, we believe that the adjustment of flight times on this route should be explored. With regard to the flight from San Francisco to London, it would seem appropriate to delay the flight, so that departure would occur during the evening period of maximal alertness. The crew of the SFO-LHR flight should be strongly recommended to take a midday nap on the day before the flight. The Tokyo flight, by contrast, might depart a little earlier so that crew can begin their sleep period earlier.

Future studies. Field studies involving complex physiological data gathering are typically very difficult and often impossible. However, this series of reports is solid testimony that field studies of international flight operations can be successfully carried out; that the full cooperation of scientific and operational communities can be obtained on a multinational basis; that meticulous standardization of methods can be accomplished in the face of formidable barriers; and that reliable data can be gathered. Other issues, such as cooperative planning, ongoing continuous international communication, flexibility, commitment to deal with emergencies and the unusual demands of the study, all can be resolved.

This international study represents the first report of comprehensive, objective EEG recordings of long-haul layover sleep in operating cockpit crews. The implications for investigating and understanding sleep/wake patterns include all sorts of operational situations, e.g., the rapid deployment of troops, international "shuttle diplomacy," various transportation operations, and rescue missions. More immediate, however, are the implications of this study for a cumulative effect of multiple L/Os and chronic schedule disruption. In a schedule that does not involve circadian disruption, the effects of partial sleep loss on daytime alertness are known to be cumulative (6). The first L/O is likely to be the optimal situation in any long complex schedule of work and rest. Therefore, sleep and alertness are likely to deteriorate in multiple L/Os, and studies of such trips will be needed to resolve the issue of cumulative effects within long-haul trips.

ACKNOWLEDGEMENTS

We wish to thank the staff of the RAF Institute of Aviation Medicine, Farnborough, for carrying out the recordings when the crews were in the United Kingdom; Nihon-Kodon (Japan), which supplied polysomnographs for recordings in Japan; Dr. M. Sasaki and his staff at JAL for making the necessary arrangements for those recordings; and Dr. R.C. Graeber for his expert editorial assistance. We especially wish to thank the volunteer pilots and flight engineers of Pan American World Airways and its flight operations managers for their enthusiastic and overall support of this project. The study was supported by the National Aeronautics and Space Administration, Aeronautical Human Factors Research Office, Ames Research Center Cooperative Agreement NCC 2-302. W.C. Dement is supported in part by National Institute of Mental Health Research Scientist Award MH 05804.

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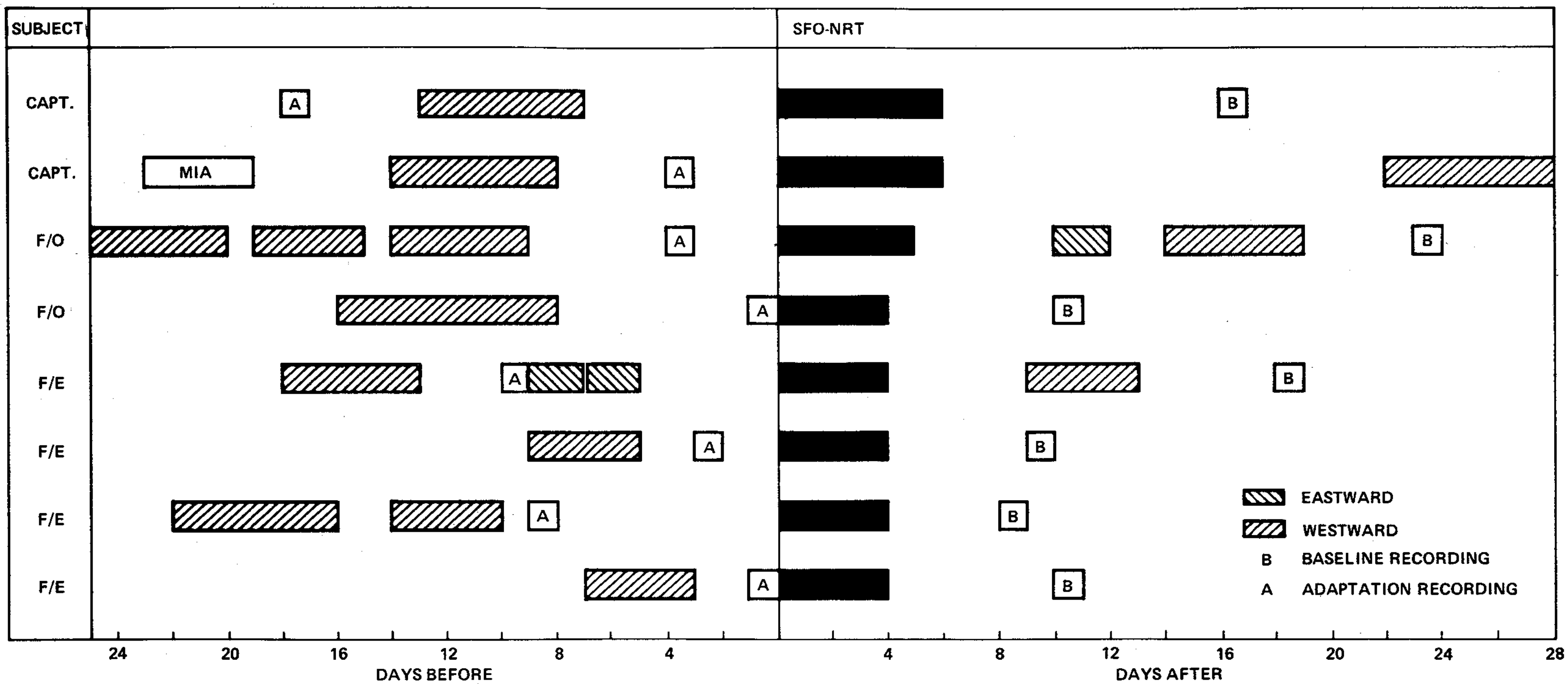

Figure 1. Duty schedules of crew members preceding adaptation, baseline, and L/O sleep recordings in Tokyo (NRT) or London (LHR). MIA = travel as passenger to Miami, FL, for training.

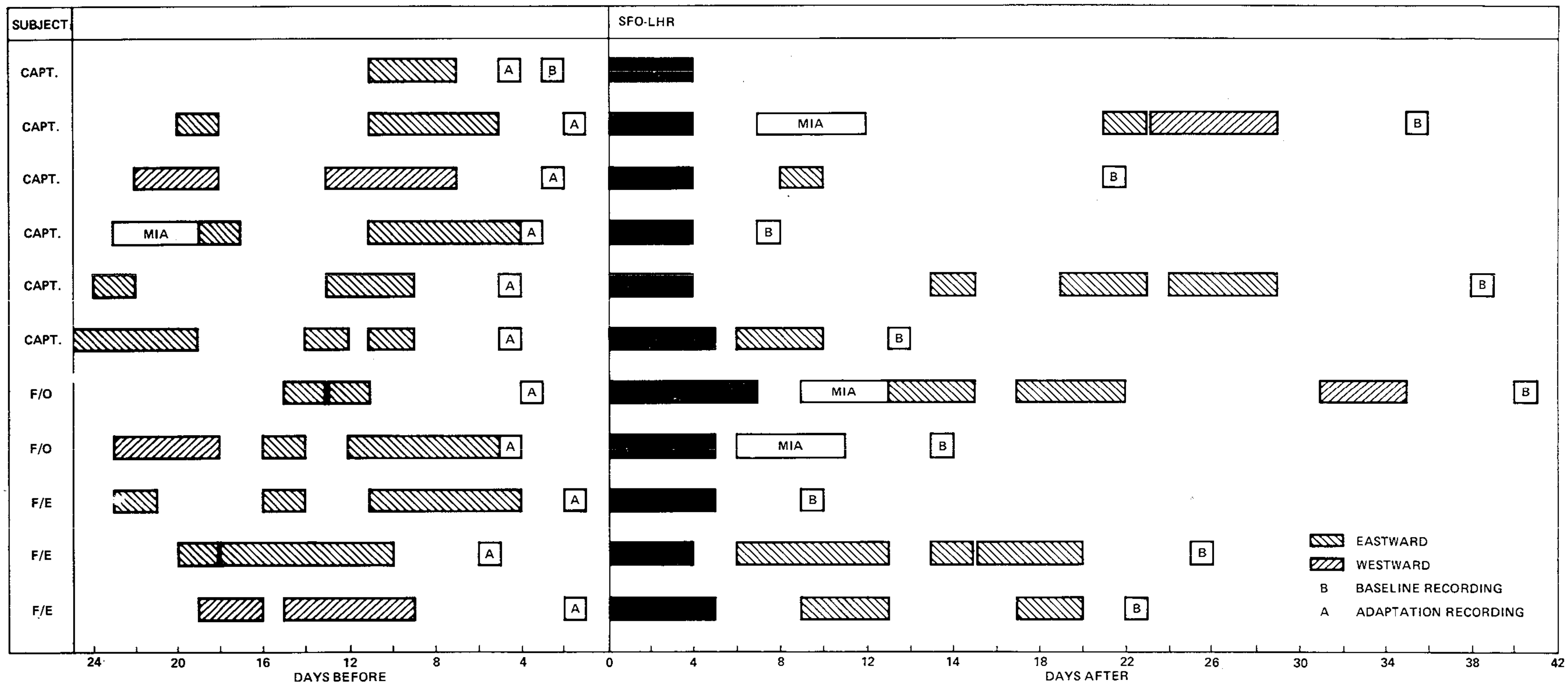

Figure 1. Concluded.

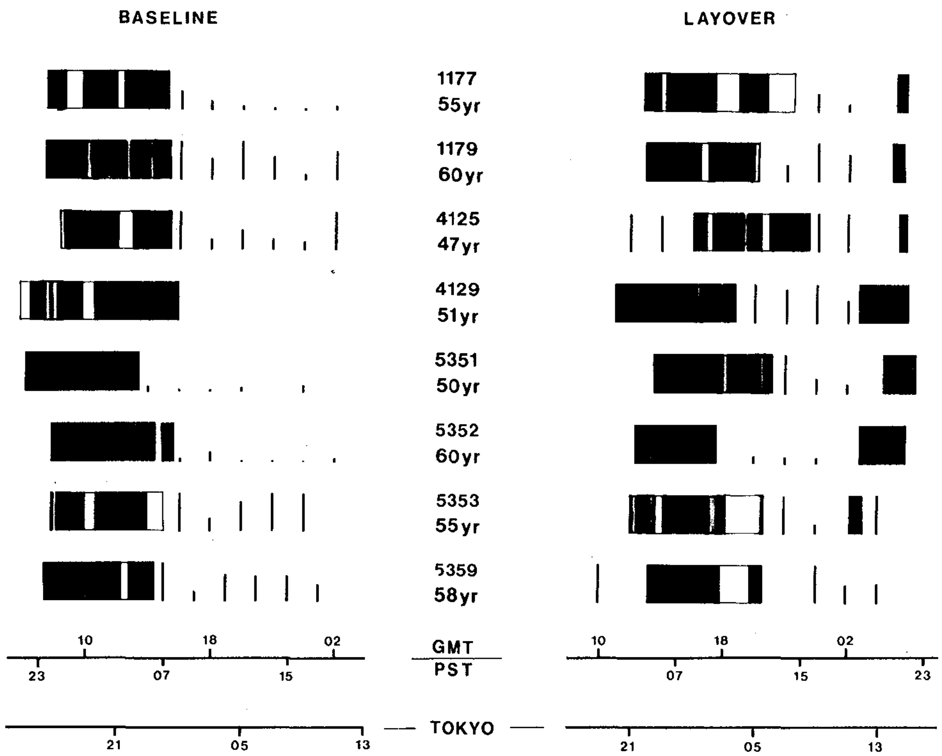

Figure 2. Sleep periods and MSLT results for subjects on the SFO-NRT route. Inside rectangles: black = sleep, gray = 10 min. or more of light sleep (stage 1) mixed with wakefulness, and white ≐ wakefulness while in bed. Vertical lines represent sleep latency test, the height of each being proportional to the time taken to fall asleep (i.e., the tallest lines inply no measureable sleep tendency).

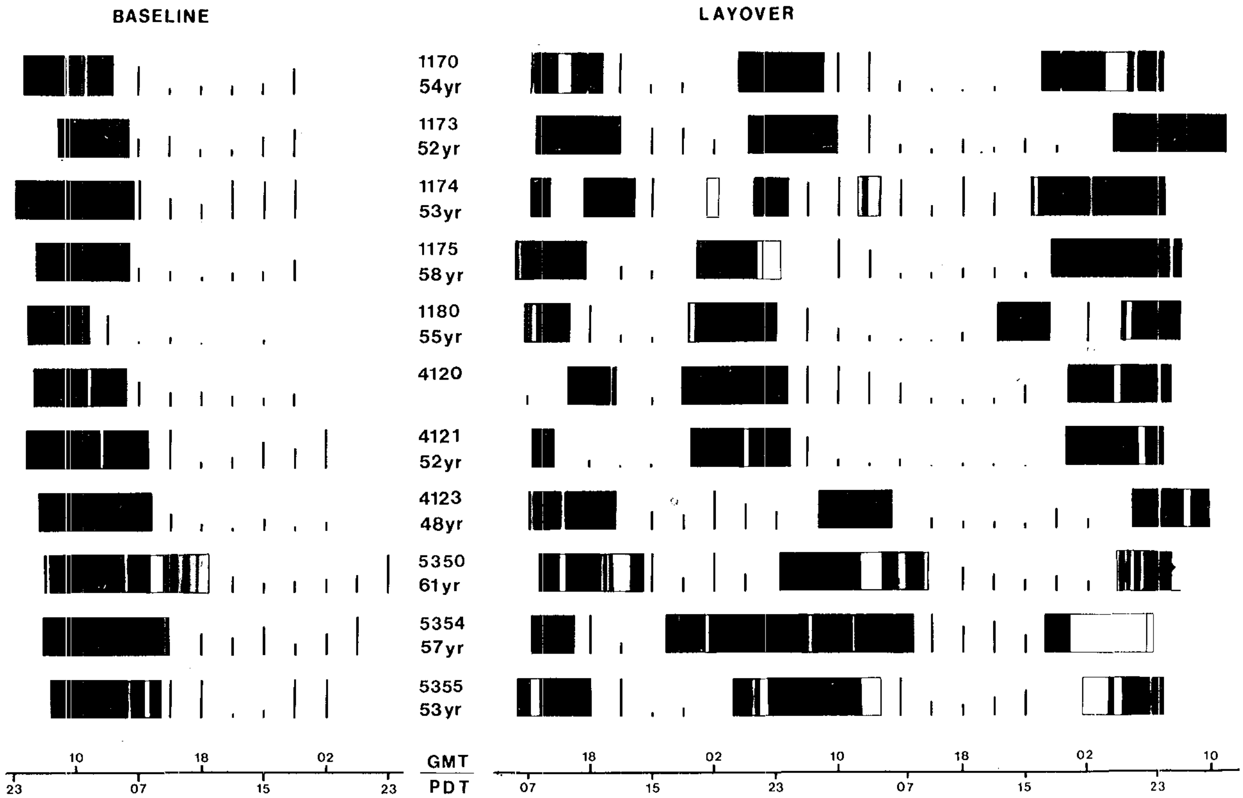

Figure 3. Sleep periods and MSLT results for crew members on the SFO-LHR route. Representions as in Fig. 2. No. 4129 unavailable for MSLT; No. 1179 reached age 60y and retired between L/O and baseline.

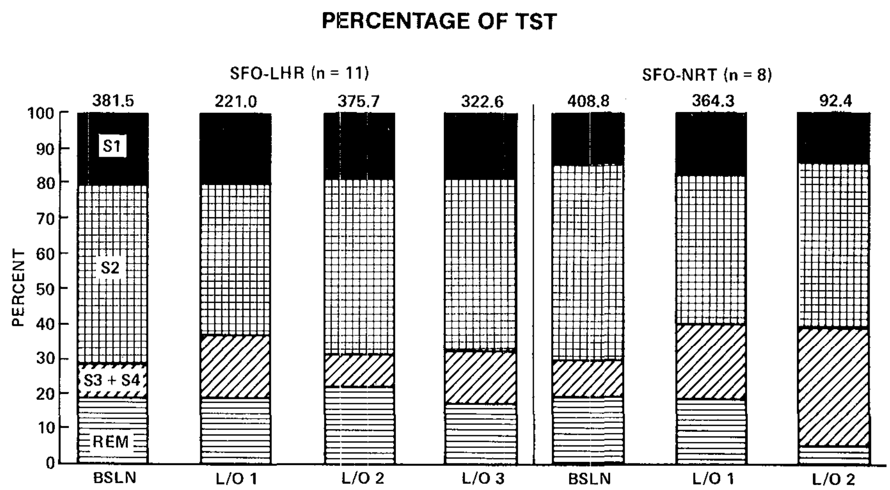

Figure 4. Distribution of percent sleep stages for both routes. Mean sleep duration (min) at top of each column. BSLN = baseline, successive L/O sleeps indicated by number. See Tables IV and V for statistical comparisons.

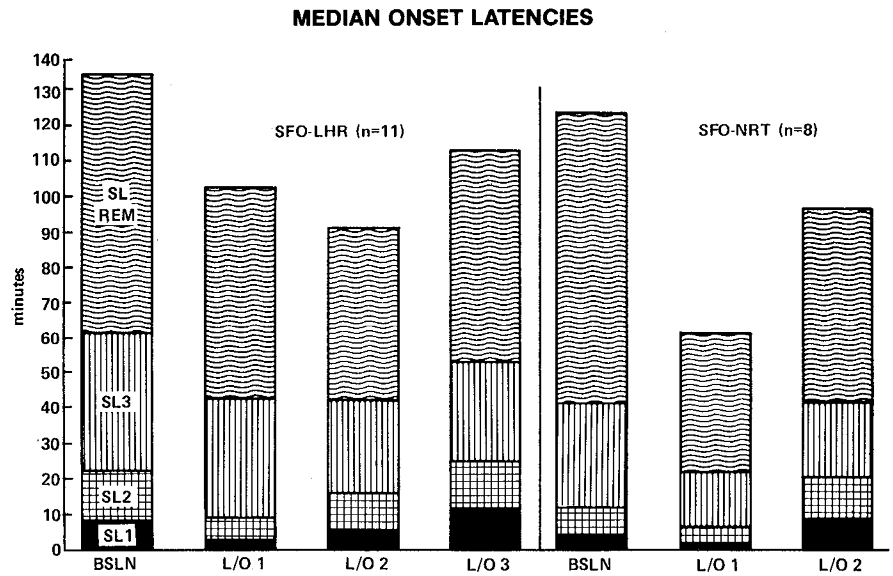

Figure 5. Median sleep onset latencies for each sleep stage. No significant changes from baseline.

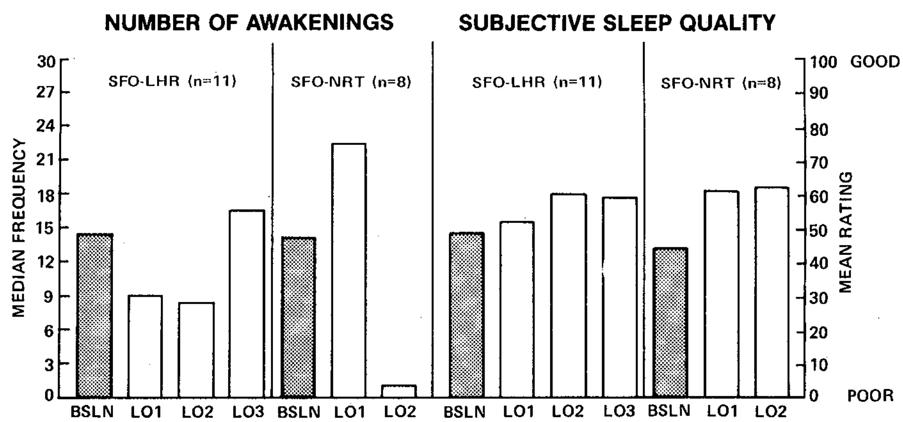

Figure 6. Median number of awakenings and mean subjective sleep quality ratings. There were no significant changes from baseline either in subjective sleep quality or in the number of awakenings normalized per hour of sleep.

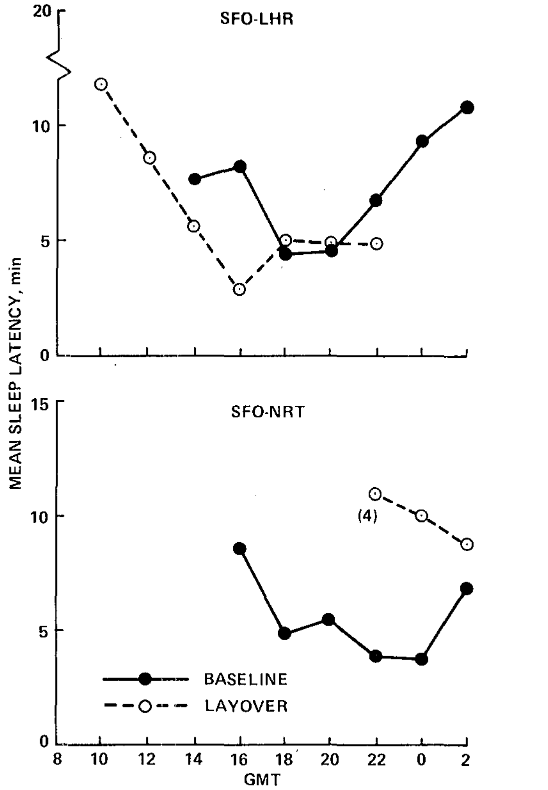

Figure 7. The profile of daytime sleepiness (MSLT) during baseline and layover recordings arranged according to GMT for both routes. Scores were log-transformed for statistical tests, and the back-transformed means are presented here based on a N of at least 5 except where indicated.

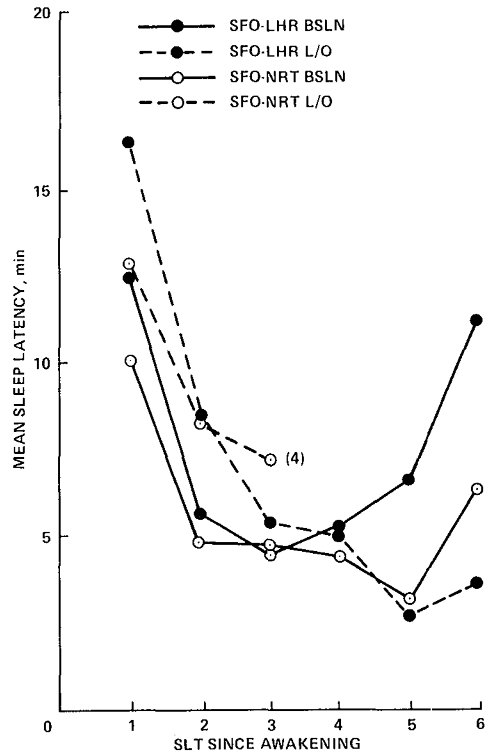

Figure 8. The MSLT profile during baseline and L/O day 2 for both routes, averaged according to time since waking, and transformed as in Fig. 7. During L/O in LHR, subjects (N=11) had at least 4 MSLTs, and on tests 5 and 6, N=9 and 7, N=7 for NRT L/O profile.

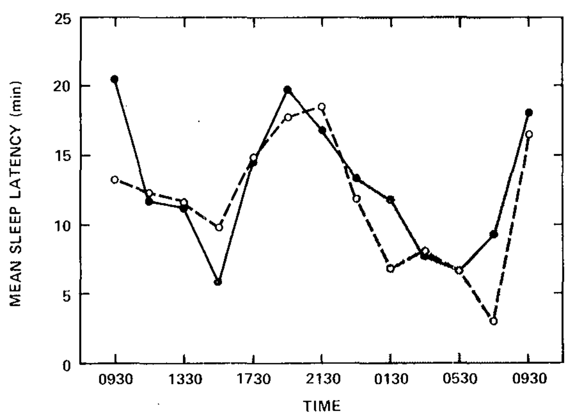

Figure 9. The 24-h biphasic rhythm of sleep tendency (21). Mean sleep latencies for young (open circles, mean = 21y, N=8) and old (filled circles, mean = 70y, N=10) subjects who received a normal MSLT during the day, followed by four brief awakenings at 2-h intervals during the night (shaded). After 15 min. kept awake, the latency to return to sleep was measured. There were no significant differences in sleep stage at awakening for each night measure. With permission from Raven Press.

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Patterns of Sleep-Wakefulness Before and After Transmeridian Flight in Commercial Airline Pilots

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ABSTRACT

This study investigated changes in sleep-wake rhythms due to time zone changes. The subjects were 12 commercial airline cockpit crew members on active duty who spent their baseline nights in a sleep facility in Tokyo. After flying from Tokyo to San Francisco, they underwent two consecutive nights of sleep polysomnography and daytime sleep latency tests (MSLTs). During the San Francisco layover slight changes in sleep quality were observed. REM sleep (%) was decreased, while slow wave sleep (%) tended to increase during the major sleeps. Subjective sleep quality assessments also exhibited a decrease in comparison to the baseline values. Daytime sleepiness as measured by MSLTs was generally greater in the latter half of the awake period during layover as compared with baseline. When the subjects were divided into Morning or Evening types, the daytime MSLTs of each type showed different patterns. The former displayed a decreasing L-shaped trend, while the latter showed a pronounced W-shaped pattern. These results suggest that further investigation of the individual differences in circadian phase position may be important for understanding the effects of multiple time zone flights.

INTRODUCTION

We have been conducting research on "jet lag" since 1976 (2,7) and have demonstrated that sleep rhythms are clearly disturbed after transmeridian flights. In our studies, however, the subjects consisted mainly of young subjects who were not crew members, and emphasis was placed on the changes in sleep stages rather than on the overall changes in the sleep-wake rhythms (8).

The present study is designed to investigate the transient sleep-wake changes and the following daytime sleepiness of experienced long-haul commercial airline pilots resulting from a single change of time zones while on active duty. In addition, we examined the variation in sleep strategies used by the international crew members.

SUBJECTS AND METHODS

The subjects were twelve Japan Air Lines male crew members on active duty, six pilots (captains) and six flight engineers (age 37 - 54y), flying between Tokyo and San Francisco. They weighed between 57 and 76 (mean 66.5) kg, and their heights were between 165 and 175 (mean 169.5) cm. They had served as cockpit crew for 15 to 29 years and ranged in total flying time from 6400 to 13700 hours. The median time was 9300 hours. Most of this flying was in B-747 and DC-8 aircraft with 83% of them having 2000 to 5000 hours in B-747s and 58% having 3000 to 6000 hours in DC-8s.

At first, a preliminary questionnaire survey, daily activities log and interview were completed to document the variability among pilots in their sleep habits, life style, homebase morning-evening characteristics and typical layover (L/O) behavior patterns. Next, polysomnographic sleep recordings with pre-sleep and post-sleep questionnaires and Multiple Sleep Latency Tests (MSLTs) were conducted according to the schedule in Fig. 1. Each subject visited the temporary sleep recording facility at Haneda Tokyu Hotel for the adaptation and 24-h baseline recordings and went to the Stanford Sleep Research Center for L/O recordings. Fig. 2 shows the schedule for recording sleep polysomnography and the MSLTs during the 48-h adaptation-baseline and 48-h L/O periods.

Adaptation night. The subjects arrived at the hotel three hours before their usual bed time. The individual light-proof bedrooms were kept quiet, and temperature (22-23°C) and humidity (60%) were controlled. A Sanei EEG machine situated in an adjoining room was used to record EEG (C3/A2), (C4/A1), EOG (ROC/A1, LOC/A2), chin EMG, and ECG. Respiratory activity (nasal thermistor and abdominal strain gauge) and bipolar anterior tibialis EMG were also recorded, but their data will be presented elsewhere. Chart speed was usually 15mm/sec, providing 30 second epochs for scoring, but 5 of the 12 subjects had their recordings done at 10mm/sec during L/O.

Bedtime and arising time were set according to the subject's usual habits. A pre-sleep questionnaire was completed before sleep recording began (Fig. 3). The time of awakening was spontaneous or by call, per the subject's request. In the morning, electrodes were removed, a post-sleep questionnaire was completed, and the session ended.

Baseline. During the following night and day, the baseline measurements of sleep and daytime sleepiness were made in the same hotel at Haneda Airport. The sleep polysomnography procedure was the same as for the first visit, but afterwards the subjects remained in the room the following day for six MSLTs. The MSLTs were administered at 2-h intervals on even GMT hours while the subject was awake. The MSLT recordings had four channels, including EEG (C3/A2, C4/A1), EOG (ROC/A1, LOC/A2). The Stanford Sleepiness Scale (SSS) and a 10-cm analogue fatigue scale were administered before the MSLTs.

The subjects' visits were mostly conducted within three weeks before the L/O but always following at least three off-duty days prior to the recordings. Each crew member's schedule preceding the adaptation and baseline recordings is shown in Fig. 4.

Flight. The subjects served as crew members on a B-747 overnight flight scheduled to depart Narita (NRT) at 1800h (0900 GMT) and arrive at San Francisco (SFO) at 1105h (1805 GMT). Since SFO was on Pacific Daylight Time (PDT), the time zone change was +8h. Due to unanticipated operational factors, some flight times differed slightly from this schedule. The crew was augmented by a second captain and flight engineer for a total of five crew members, with each crew member having approximately three hours off duty during the flight. The aircraft was equipped with two crew rest bunks located just behind the cockpit, and subjects were allowed to sleep there during their time off duty.

Layover night. Layover recordings commenced as soon as the subjects arrived at the Stanford sleep laboratory and continued until the subjects left for the return flight. Except for one crew, the flight's pilot and flight engineer participated in the L/O as a pair. During the approximately 48-h stay at Stanford, the individual subjects chose freely when to go to bed and when to try to sleep, when to get up, when to shower, and when to eat. The procedures for the sleep polysomnographic recordings, pre- and post-sleep questionnaires and MSLTs were the same as for the baseline night (Fig. 2).

RESULTS

Timing of sleep period and the sleep strategies. As shown in Fig. 5, the sleep log data revealed that individual crew member sleep-wake patterns were remarkably similar during the NRT-SFO trip regardless of whether they spent their L/O at the usual hotel or in the sleep laboratory. Fig. 6 represents the timing of the sleep periods and the results of the subsequent MSLTs for each subject during baseline and the L/O. All subjects slept during the usual or habitual time for nocturnal sleep under the baseline condition. During the flight, seven crew members reported napping 1.5 to 3.0h in the crew bunks, one (No. 5306) reported resting for 2h, and four (Nos. 1101, 1105, 1106, and 5304) reported no sleep.

During the L/O subjects utilized various sleep-wake strategies which are depicted in order from top to bottom in Fig. 6 (lower panel). Of the 12 participants, 11 went to sleep soon after arrival at the Stanford Sleep Research Center. Eight of these then took their nocturnal sleep at the appropriate local time. These eight can be further subdivided into two groups: (A) good continuous nocturnal sleepers and (B) fragmented nocturnal sleepers. Three other subjects, keeping home time, sleeplessly awaited the coming of the night of Tokyo local time, and then went to sleep. The last subject remained awake after his arrival at Stanford, perhaps due to a nap from 1700 - 1900 GMT on the aircraft, and then took his major sleep in accordance with appropriate local time.

Differences in objective sleep quality and subsequent daytime sleepiness were examined using one-way ANOVAs under three conditions: local-time-sleep good type (Group A), local-time-sleep fragmented type (group B), and home-time-sleep group (group H). The analysis revealed only one significant difference, that is, an increased latency to stage 3 in group B.

Analyses of sleep parameters. Table I presents the findings of paired t-test comparisons of the standard sleep parameters between the adaptation and baseline nights. As can be seen, "first night effects" are slightly evident for the sleep parameters of sleep efficiency, decreased amount of REM sleep and delayed REM latency, but none of these differences were statistically significant.

In order to evaluate the crew members' adaptation and baseline sleep, t-test comparisons were made with data from a group of healthy males, 40-49y old, studied by Williams et al. (9). Table II summarizes the findings for the means and SDs of the various sleep parameters. Except for the crew members spending more time in bed during adaptation and having shorter stage 3 latencies, homebase sleep in Tokyo did not differ from the mean values reported by Williams et al. Consequently, we assume that our subjects'

TABLE I. MEAN AND SD OF SLEEP PARAMETERS (n=12).

	Adaptation		Baseline		t
	Mean	SD	Mean	SD	
Minutes					
Time in bed (TIB)	489.6	41.4	458.9	39.2	1.77
Total sleep time (TST)	433.3	62.1	428.7	46.0	0.23
Sleep efficiency (SE)	88.5	10.6	93.3	4.8	1.50
Total stage 1 (TS1)	47.3	19.2	41.7	19.8	1.17
stage 2 (TS2)	237.6	46.7	230.8	33.3	0.58
stage 3 (TS3)	37.0	13.6	36.2	18.4	0.14
stage 4 (TS4)	25.1	17.8	25.1	21.8	0.00
SWS (TSSWS)	62.1	21.2	61.3	30.4	0.08
REM (TSREM)	86.3	27.3	95.1	16.4	1.04
Latency to stage 1 (SL1)	16.6	22.7	8.0	5.4	1.32
stage 2 (SL2)	5.0	5.4	5.3	3.3	0.13
stage 3 (SL3)	27.6	15.4	22.3	8.0	1.08
stage 4 (SL4)	49.9	38.7	39.9	30.2	0.74
REM (SLREM)	99.8	34.5	77.3	25.4	1.93
WT/S	29.9	25.7	18.6	20.3	1.35
WT/PS	9.8	23.4	3.6	4.5	0.98
Percentage					
% of stage 1 (S1%)	11.0	4.5	9.7	4.2	1.17
stage 2 (S2%)	54.7	6.1	54.2	7.7	0.22
stage 3 (S3%)	8.4	2.6	8.2	3.6	0.21
stage 4 (S4%)	6.1	5.2	5.9	5.2	0.17
SWS (SWS%)	14.5	5.1	14.1	6.3	0.22
REM (REM%)	19.8	5.3	22.2	3.4	1.55

WT/S = waketime during sleep; WT/PS = waketime post-sleep

sleep is within the normative range.

Figs. 7-9 present the changes in sleep parameters and subjective sleep quality during baseline and L/O conditions for the twelve subjects according to the sequence of major sleep. Under the L/O condition, sleep periods for all subjects were classified into major sleep spans. Except for one subject (No. 1104), sleep #1 denotes the sleep which occurred soon after arrival at Stanford, sleep #2 denotes the first night sleep, and sleep #3 denotes the second night sleep during the L/O. The following statistically significant changes (Wilcoxson test) were observed between baseline and one or more L/O sleeps: decreased subjective sleep quality (L/Os #1-3), shortened median slow-wave sleep (SWS) latency (#1), increased SWS (%) (#1), and decreased REM (%) (#1 and #2).

Table III compares the sleep parameters between the baseline and L/O conditions. Eight out of the twelve subjects were selected for analysis, while the other four were omitted

TABLE II. COMPARISON OF SLEEP PARAMETERS BETWEEN CREW MEMBERS (n=12) AND TEN 40-49 YEAR OLD MALES (Williams et al., 1974).

Source	Williams et al.		Adaptation		t	Baseline		t
	Mean	SD	Mean	SD		Mean	SD	
TIB	429.10	39.17	489.60	41.40	3.338**	458.90	39.20	1.695
TST	389.10	46.50	433.30	62.10	1.773	428.70	46.00	1.909
SE	0.91	0.06	0.89	0.11	0.491	0.93	0.05	0.800
SL1	10.00	7.87	16.60	22.70	0.837	8.00	5.40	0.672
SL2	5.55	2.90	5.00	5.40	0.276	5.30	3.30	0.127
SL3	37.40	21.16	27.60	15.40	1.197	22.30	8.00	2.180
SL4	33.00	14.40+	49.90	38.70	0.760	39.90	30.20	0.412
SLREM	71.65	32.77	99.80	34.50	1.860	77.30	25.40	0.434
NO. W	4.65	2.27	4.92	3.55	2.526	3.25	2.73	1.232
S1%	7.56	3.03	10.21	4.03	1.010	9.19	3.95	0.169
S2%	54.75	11.14	51.16	8.04	0.101	51.84	7.41	0.082
S3%	5.37	3.27	7.89	2.45	0.247	7.88	3.54	0.241
S4%	3.18	6.25	5.47	4.10	0.116	5.62	5.02	0.123
SWS%	8.54	6.84	13.36	4.18	0.222	13.50	6.06	0.228*
REM%	22.85	4.00	18.51	5.33	0.339	21.31	3.60	0.121

*$p<0.05$; **$p<0.01$; +n=4; NO. W = number of awakenings

because of insufficient data (Nos. 1104 and 1105) or fragmented sleep patterns (Nos. 5303 and 5304). Variance among the baseline and L/O sleeps #1, #2, and #3 was analyzed by a Repeated Measure Analysis of Variance (RMANOVA) followed by t-tests. Significant changes in sleep quality were limited to eight parameters: time in bed (TIB); total sleep time (TST); amount of stages 1,2, SWS (i.e., stages 3+4), and REM sleep; percentage REM; and persistent sleep latency (i.e., latency to the first consecutive 10 min. of sleep). The results of the t-tests further revealed that TST and amount of stages 1 and 2 decreased in major sleep #1 but recovered in sleeps #2 and #3; the amount of SWS sleep was also greater during sleeps #2 and #3 compared to sleep #1. These lower values for sleep #1 are consistent with the reduced TIB for this daytime post-flight sleep.

In contrast, the amount of REM sleep was less than baseline in all L/O sleep periods. The increases in TIB and TST during sleeps #2 and #3 were reflected in slightly higher amounts of REM sleep than during sleep #1 but still significantly less than during baseline. These changes in duration of REM sleep were also reflected in decreased percentages of REM sleep during L/O. The only change in sleep latency was a significant increase in persistent sleep latency for L/O sleep #2 in comparison to the other L/O sleeps. The increased number of awakenings shown in Table IV for sleep #2 suggests that the latter effect may be indicative of generally more restless sleep during sleep #2; however, the only significant differences in TWT or waketime during sleep were for increases in L/O sleep #3 compared to #1. Table IV also shows that the overall decrease in L/O REM sleep was concentrated in decreases during the second half (i.e., R3 and R4) of the sleep span.

Mean of daily MSLTs. Fig. 10 presents mean MSLT results under baseline and L/O

TABLE III. ANALYSIS OF SLEEP VARIABLES UNDER BASELINE AND LAYOVER CONDITIONS (n=8)+

Source	Baseline Mean (SD)	SFO1 Mean (SD)	SFO2 Mean (SD)	SFO3 Mean (SD)	ANOVA F	t-test BSLN SFO1	BSLN SFO2	BSLN SFO3	SFO1 SFO2	SFO1 SFO3	SFO2 SFO3
Minutes											
TIB	467.9	218.9	468.8	443.4	18.94**	11.29**	0.03	0.55	8.94**	4.15**	0.49
	(32.56)	(68.03)	(81.25)	(107.03)							
TST	431.3	204.2	403.3	366.9	11.84**	9.99**	0.66	1.48	4.91**	3.45*	0.74
	(47.80)	(64.42)	(122.61)	(101.33)							
SE	92.0	93.3	84.7	82.7	2.31						
	(4.47)	(2.70)	(18.77)	(10.76)							
Duration (min)											
TS1	37.4	28.7	48.8	53.0	4.21*	1.21	1.64	1.53	3.86**	2.89*	0.63
	(20.14)	(14.43)	(21.28)	(20.60)							
TS2	235.1	102.2	227.6	193.6	10.60**	6.97**	0.27	1.34	5.19**	3.30*	1.24
	(24.41)	(53.14)	(69.45)	(71.76)							
SWS	64.5	44.6	73.6	71.4	4.67*	2.20	0.86	1.02	4.18**	2.91*	0.25
	(23.01)	(22.17)	(30.92)	(21.87)							
REM	94.4	28.8	53.3	49.0	9.64**	7.30**	2.75*	3.89**	2.09	1.82	0.28
	(19.81)	(15.16)	(30.36)	(23.83)							
Latency (min)											
SL	7.5	5.6	14.9	5.9	4.86*	0.92	1.95	0.69	2.55*	0.16	3.71**
	(3.18)	(4.43)	(9.76)	(4.18)							
SL1	7.5	4.0	9.6	5.3	1.65						
	(3.18)	(3.27)	(5.15)	(2.94)							
SL2	11.1	7.9	10.8	9.3	0.75						
	(4.53)	(4.27)	(5.16)	(3.45)							
SLREM	77.1	91.0	75.2	91.5	0.33						
	(32.1)	(50.71)	(36.93)	(39.92)							
Percentage											
S1%	8.6	14.1	12.8	15.5	3.05						
	(4.22)	(5.30)	(4.90)	(8.75)							
S2%	54.7	48.8	57.1	51.6	1.82						
	(4.62)	(11.85)	(8.31)	(11.12)							
SWS%	14.8	21.8	17.7	20.1	2.73						
	(4.65)	(8.35)	(3.70)	(6.56)							
REM%	21.9	15.4	12.4	12.9	4.34*	2.17	2.95*	4.01**	0.88	0.94	0.18
	(4.20)	(8.08)	(5.57)	(5.30)							

+ Subj. #'s 1101, 1102, 1103, 1106, 5301, 5302, 5305, 5306.
*p<0.05; **p<0.01; SL = persistent sleep latency

conditions. It shows a concave trend, with the shortest sleep latency (i.e., maximal daytime sleepiness) at about 1500h Tokyo local time, and in the evening it rises approximately to the level of the morning measurements. After the first nocturnal sleep at Stanford, however, the

TABLE IV. ANALYSIS OF SLEEP VARIABLES UNDER BASELINE AND LAYOVER CONDITIONS (n=8).

Source	Baseline Mean (SD)	SFO 1 Mean (SD)	SFO 2 Mean (SD)	SFO 3 Mean (SD)	ANOVA F	t-test BSLN SFO1	BSLN SFO2	BSLN SFO3	SFO1 SFO2	SFO1 SFO3	SFO2 SFO3
Duration REM											
Total	94.4	28.8	53.3	49.0	9.64**	7.30**	2.75*	3.89**	2.09	1.82	0.28
	(19.81)	(15.16)	(30.36)	(28.83)							
Quartiles											
R1	13.8	0.0	10.8	9.4	3.66*	4.74**	0.58	0.78	2.89*	2.71*	0.27
	(8.20)	(0.00)	(10.55)	(9.86)							
R2	25.5	10.4	15.1	13.3	2.03						
	(11.89)	(12.53)	(12.31)	(10.61)							
R3	24.8	12.4	15.2	10.2	4.28*	2.33	3.14*	3.19*	0.52	1.04	1.07
	(8.10)	(8.84)	(10.13)	(7.30)							
R4	30.3	6.0	12.2	16.1	6.57**	3.74**	2.99*	2.57*	1.48	1.58	0.76
	(13.25)	(7.12)	(9.55)	(13.13)							
Waketime											
TWT	31.1	12.0	58.5	71.2	3.74*	3.56**	1.13	1.95	1.88	2.88*	0.86
	(19.57)	(8.91)	(69.55)	(55.22)							
WT/S	23.7	8.0	49.1	65.9	3.20*	2.78*	1.01	2.00	1.56	2.65*	1.15
	(19.49)	(9.31)	(7.18)	(56.42)							
WT/PS	0.0	0.0	0.0	0.0	0.00						
	(0.00)	(0.00)	(0.00)	(0.00)							
NO. W	7.5	6.0	11.3	11.6	1.90						
	(6.23)	(5.55)	(6.71)	(6.39)							
Quartiles											
W1	9.5	4.3	10.7	13.4	3.37*	4.07*	0.35	1.03	2.55*	2.88*	0.92
	(6.25)	(3.36)	(6.21)	(9.82)							
W2	3.0	2.0	14.9	21.5	2.95						
	(3.61)	(3.04)	(17.91)	(21.11)							
W3	4.8	0.9	11.5	11.9	1.21						
	(4.61)	(1.40)	(25.12)	(14.54)							
W4	13.8	4.8	20.3	24.4	0.94						
	(18.17)	(7.37)	(30.63)	(44.89)							

All entries are minutes, except No. W.
*$p<0.05$; **$p<0.01$; TWT = total wake time; WT/S = waketime during sleep;
WT/PS = waketime post-sleep

mean sleep latency showed a downward inclination at 1100h local San Francisco time and, although it increased slightly at 1900h local time, did not rise again to the level of the morning measurements.

Correlation of prior sleep parameters and MSLT scores. To determine whether changes in nocturnal sleep affected subsequent MSLT scores, Spearman rank-order correlations were computed for each of the eight subjects analyzed in Tables III and IV between mean daily MSLT score and each of the preceding nocturnal sleep parameters under baseline and L/O conditions. Table V shows that there were no significant correlations noted during baseline except that increased REM sleep latency (SLREM) was associated ($r=-.619$, $0.05<p<0.10$) with lower mean MSLT scores.

For L/O sleep #1, the relationship between MSLT score and REM sleep latency is reversed from that observed during baseline such that increased REM latencies were positively correlated with mean MSLT score ($p<0.05$). Increased TST, TS2, and TS4 were also positively correlated with mean MSLT score. Conversely, increased latency to stage 1 was highly negatively correlated ($r= -.927$) with mean MSLT score. For major sleep #2, mean MSLT was negatively correlated with stage 1(%) and positively correlated with TS2 and SL3. Thus, increases in stage 1(%) and latency to stage 1 were associated with a decrease in mean MSLT, whereas increases in the amounts of stages 2 or 4 or in the latencies to stage 3 or REM were related to an increase in mean MSLT. To sum up, in spite of the variety among individual subjects, these results suggest that increased disturbance within sleep (i.e., increased stage 1(%) or restless sleep) produced a heightened subsequent daytime sleepiness, while stable nocturnal sleep with increased stage 2 was associated with lower daytime sleepiness.

TABLE V. SPEARMAN RANK-ORDER CORRELATION OF PRIOR SLEEP PARAMETERS AND MEAN MSLT UNDER THREE CONDITIONS (n=8).

Sleep parameters	Baseline	SF0 1	SF0 2
TIB	.119	.738*	.357
TST	.143	.786*	.286
SE	.333	.347	.095
TS1	-.132	.228	-.167
TS2	.156	.857**	.857**
TS3	.286	.419	.000
TS4	-.012	.667*	.168
TSSWS	.275	.419	.048
TSREM	.238	-.119	-.167
SL1	-.086	-.927**	.542
SL2	-.602	-.048	.242
SL3	-.108	-.108	.667*
SL4	.216	.476	.204
SLREM	-.619	.667*	.429
WT/S	-.299	.277	-.119
WT/PS	-.344	.321	-.049
NO. W	-.386	.450	-.301
S1%	-.048	-.238	-.714*
S2%	.286	.310	.571
S3%	.357	-.204	-.214
S4%	-.072	.275	.190
SWS%	.167	.024	-.262
REM%	.000	-.405	-.262

*p<0.05; **p<0.01

Daily MSLT of "Morning" and "Evening" types. During baseline the subjects were administered a slightly modified version of the Horne-Ostberg (3) Morningness-Eveningness Questionnaire. They were subsequently divided into two types by a median split of their M-E scores. The six subjects who scored higher (57-63) were classified as "Morning" types and the six lower (44-53) as "Evening" types.

Fig. 11 compares the mean MSLT scores of the Morning and Evening types under baseline and L/O conditions; while Fig. 12 makes the same comparison for the individual MSLT scores. The Morning type subjects exhibited a typical concave MSLT pattern, called "type U", with the shortest sleep latency at about 1300-1500h Tokyo local time during the baseline condition. During the L/O, an abrupt drop occurred at around 1200h San Francisco time in all except one subject. We have chosen to refer to this type of MSLT curve as "type L" due to its shape.

The baseline MSLT scores of the Evening type subjects showed the usual "Type U" pattern but with a slightly later daily minimal time (about 1400-1600h) compared to the Morning type subjects. During the L/O, the curve dropped abruptly at about 1600h and 2100h San Francisco local time and then rose again. This type of MSLT curve we refer to as "type W".

Subjective assessments. Subjective sleep quality assessments were compared between the baseline (mean=77.37, SD=10.08) and L/O sleeps #1 (mean=59.00, SD=17.88), #2 (mean= 57.00, SD=18.79), and #3 (mean=60.38, SD=14.47). There were clear differences noted between the baseline and the subjectively poorer L/O sleeps #1 and #2 ($p<0.01$). The correlations between subjective and objective total sleep time were also compared under baseline and L/O sleep conditions. A significant correlation ($p<0.01$) was observed for each L/O condition (#1 r=.980, #2 r=.960, #3 r=.944), but not for baseline (r=.689).

Subjective daytime sleepiness was assessed by using the SSS and the analogue ALERT and TENSE scales. During the baseline at Tokyo no significant changes were noted in the assessment of TENSE, ALERT and SSS. During the L/O, however, SSS scores increased ($p<0.01$) (Table VI). With regard to the correlation among TENSE, ALERT, and SSS, a negative correlation was observed between ALERT and SSS under baseline and L/O conditions (BSLN r=-.850, $p<0.01$; #1 r=-.811, $p<0.01$; #2 r=-.750, $p<0.05$).

Subjective and objective assessments of daytime sleepiness were compared by correlating the mean daily MSLT score and the SSS. No significant correlation was observed under the baseline or L/O condition.

A representative case study. Fig. 13 presents the data for a typical subject. He was a healthy 37y-old male, 173cm in height and weighing 70kg, who had served as a pilot for 16 years accumulating about 6500h flight time. Six days after his return from a transmeridian flight, 24-h baseline sleep recordings and MSLTs were conducted at Haneda on Sept. 12-14. He departed NRT later than scheduled at 1900h (1000 GMT) and arrived at SFO at 1200h (1900 GMT) after sleeping on the airplane from 1700-1830 GMT. Then, 48-h L/O sleep recordings and MSLTs were carried out at Stanford on Oct. 14-16.

Fig. 13 shows the pattern of sleep stages and MSLTs under baseline and L/O

TABLE VI. MEAN AND SD OF ALERTNESS PARAMETERS UNDER THREE CONDITIONS (n=12)

	Baseline		Major sleep #1		Major sleep #2		ANOVA	t-test		
								BSLN vs #1	BSLN vs #2	#1 vs #2
	Mean	SD	Mean	SD	Mean	SD				
MSLT (min)	9.39	3.14	12.20	4.43	9.32	4.15	ns			
SSS	2.18	0.41	3.30	0.78	3.11	0.62	p<.01	p<.01	p<.01	ns
TENS	36.60	18.87	31.56	13.19	37.68	12.94	ns			

SSS = Stanford Sleepiness Scale rating; TENS = tenseness scale rating

conditions. His baseline sleep did not exhibit any sleep disorders. The MSLT scores showed the typical concave U-type pattern with a daily mean of more than 5 min. His L/O sleep #1 occurred soon after arrival at Stanford and was followed by a good nocturnal sleep at the appropriate local time. Seven daytime MSLTs were then administered before the second nocturnal sleep. As for the quality of this crew member's L/O sleep, the amount of REM sleep (%) decreased while SWS(%) increased, especially in sleep #1. The MSLT score showed an abrupt drop at 1300h local time and did not rise again, compared with that of the baseline. As can be seen in Fig. 13, L/O sleep #3 was more disturbed than sleep #2 in terms of decreased REM sleep and increased wake time. This subject's subjective daytime sleepiness, as assessed by SSS and the analogue fatigue scale, did not parallel his objective daytime sleepiness (i.e., MSLTs) during the L/O (Fig. 14).

DISCUSSION

In San Francisco, as compared with baseline nights in Tokyo, the basic finding regarding overall sleep quality was that it was mildly disturbed. Subjective sleep quality assessments decreased and objective sleep variables changed primarily as a function of decreased REM sleep during the L/O. It is possible that these changes in L/O sleep may have resulted from the maintenance of the home circadian rhythm in the new time zone. Retiring at 2300h in San Francisco, which corresponds to 1500h in Tokyo, means that a subject starts his sleep at a time which corresponds to an afternoon sleep by Tokyo time. According to recent studies (1), REM sleep decreases and Non-REM sleep increases in late afternoon sleep, regardless of total sleep deprivation.

Subjects were categorized into three groups by their strategies employed in choosing the sleep periods during the L/O. These strategy-groups were compared across sleep using ANOVA, and there were no significant changes except for an increased latency to stage 3 in group B.

Objective daytime sleepiness, as measured by MSLTs, manifested an increase in sleepiness during the L/O as compared with baseline. Subjective daytime sleepiness, as measured by the SSS, also reflected increased daytime sleepiness during the L/O period, but there was still some discrepancy between objective and subjective sleepiness evaluations under the L/O condition. Although a stable increased physiological tendency to fall asleep (i.e., decreased MSLT score) was observed during the L/O period, some of the subjects reported not feeling more sleepy under that condition. It is noteworthy that the subjects recognized the fact that subjective sleepiness and objective sleepiness are not parallel.

It has been reported that Morning-type and Evening-type individuals exhibit certain differences in the response of the circadian system to shift work (3-6). In our study, when subjects were divided into Morning and Evening types according to their Horne-Ostberg M-E score, slight differences were revealed in their MSLT curves, especially during L/O. It appears that Morning types experienced more daytime sleepiness than Evening types during the L/O condition. Further investigation on the role of a crew member's circadian phase type in sleepiness, performance, etc., would therefore seem to be important in attempting to better understand the ability of flight crews to cope with multiple time zone shifts.

ACKNOWLEDGMENTS

This work was carried out with the support of the U.S. National Aeronautics and Space Administration (NASA-Ames Cooperative Agreement NCC 2-302 with Stanford University School of Medcine). The authors are grateful to the staff of the Stanford Sleep Research Center who carried out the sleep and MSLT recordings while the crews were in the United States. The cooperation of the airline crews who volunteered for this study is particularly appreciated. The authors would like to thank Dr. R.C. Graeber for his support and inspiration in the writing of this paper.

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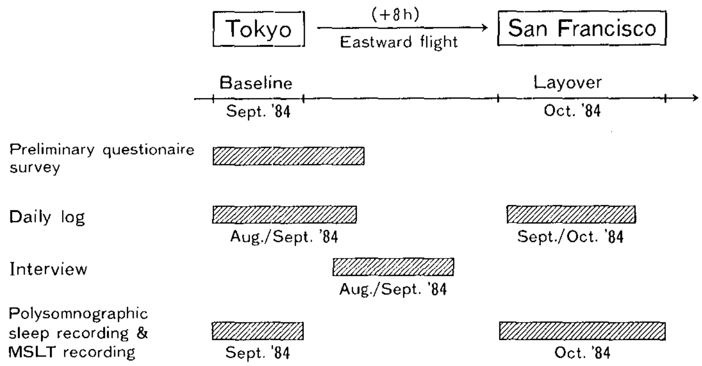

Fig 1. Schedule of the study from August to October 1984.

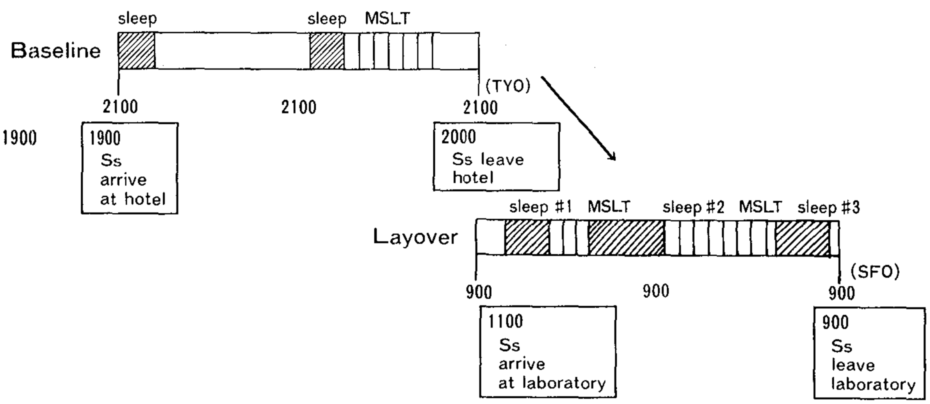

Fig 2. Schedule for recording sleep and MSLTs during 48h adaptation/baseline and 48h layover periods. Actual sleep time varied with subjects.

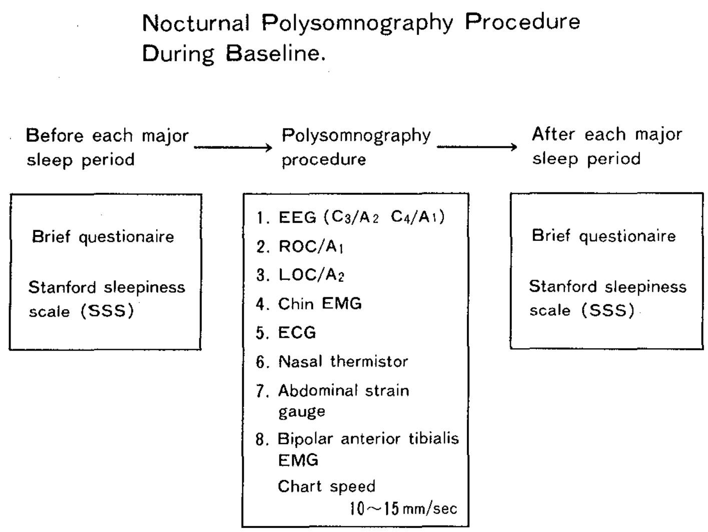

Fig 3. Nocturnal sleep polysomnography procedures and sleep questionnaires before and after major sleep during baseline and layover.

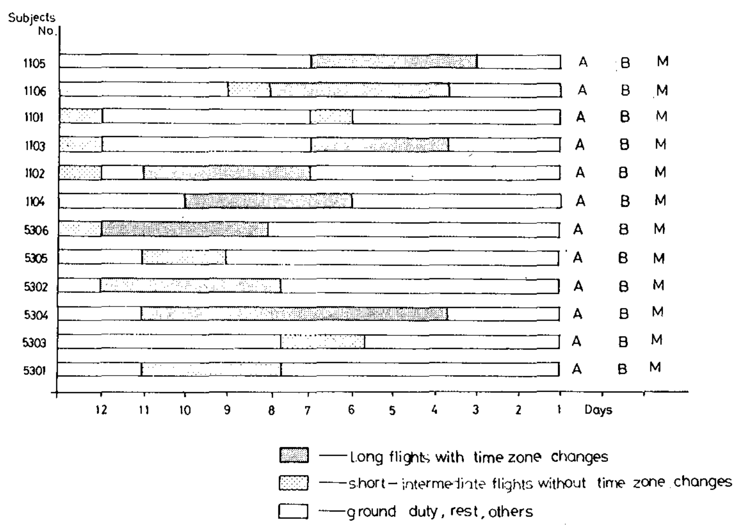

Fig 4. Duty schedules of subjects preceding the study. A = adaptation night, B = baseline night, and M = MSLTs.

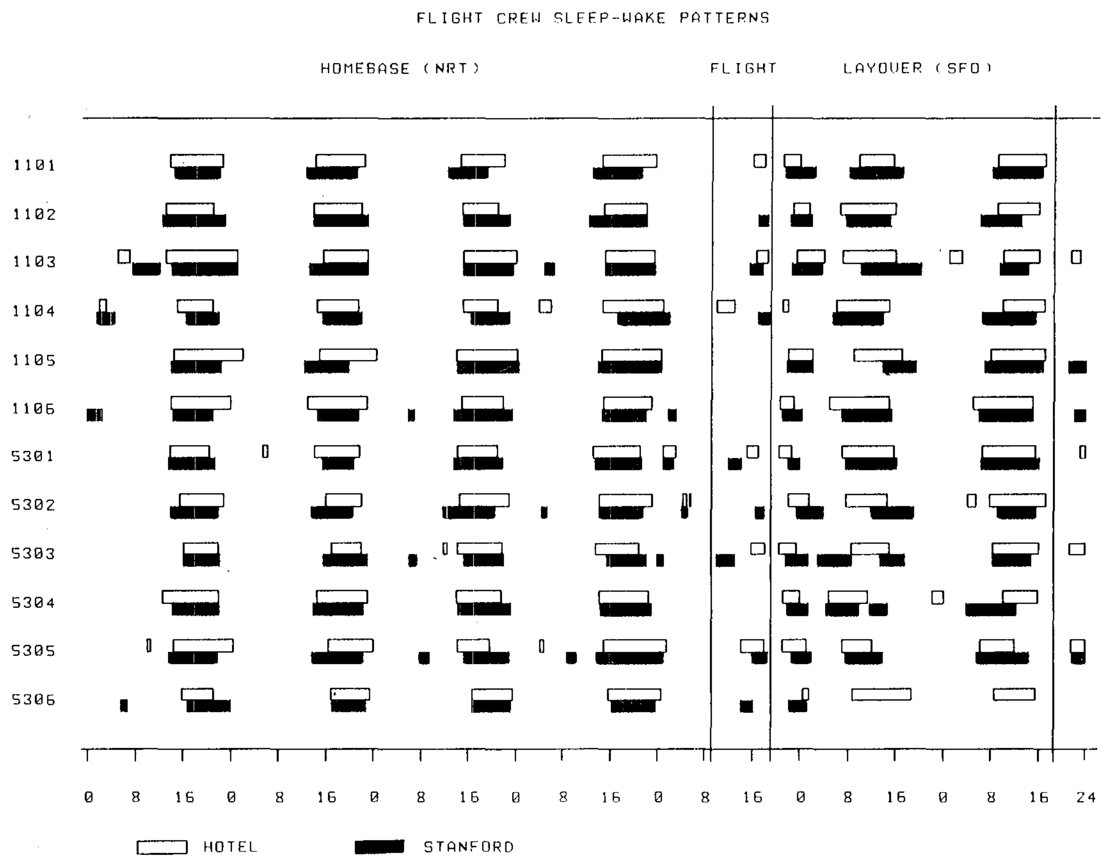

Fig 5. Sleep-wake patterns of subjects before and during two NRT-SFO trips, when the L/O was spent at a crew hotel or at the Stanford sleep laboratory.

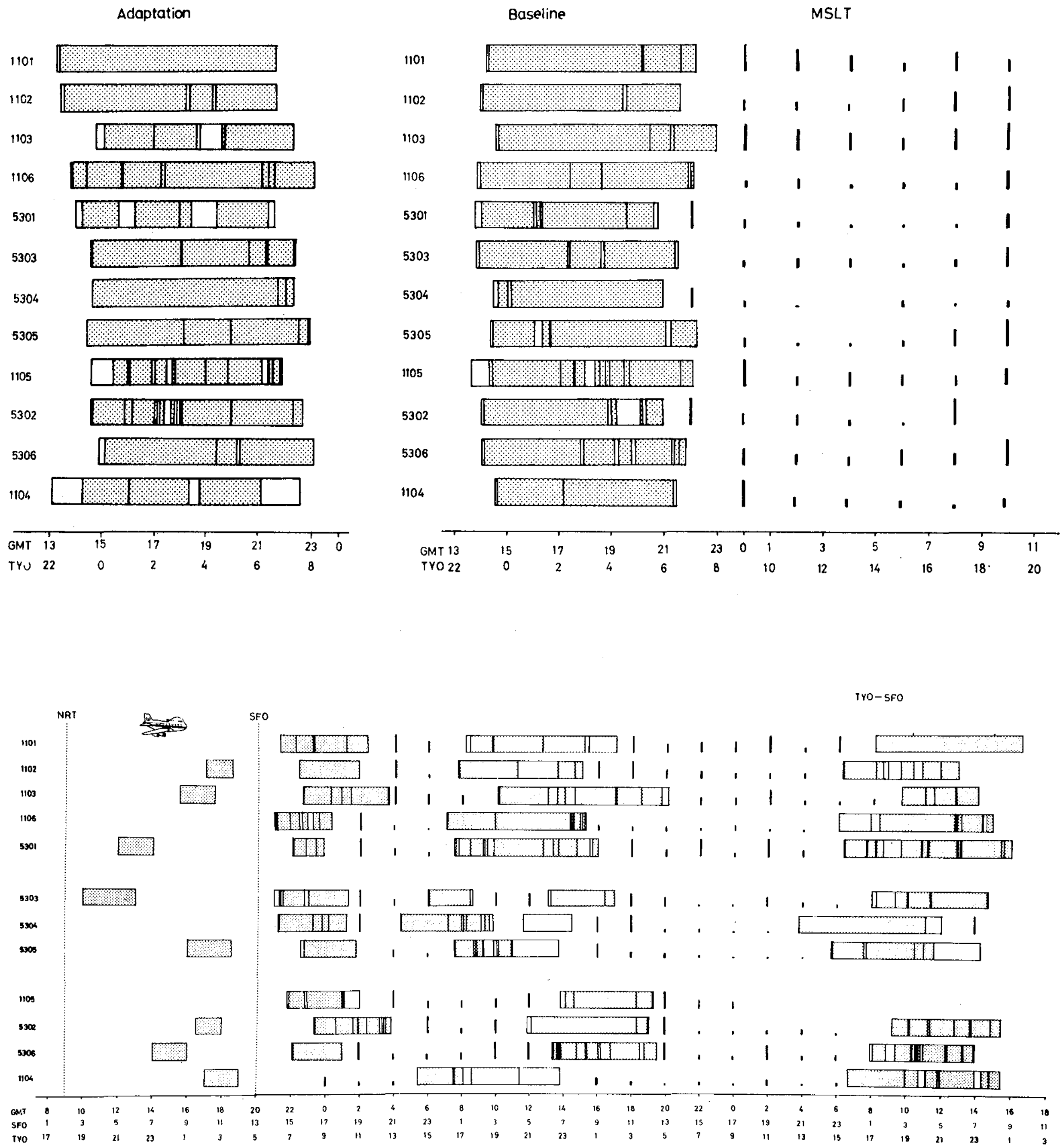

Fig 6. Timing of sleep periods and sleep strategies for individual subjects grouped according to similar layover patterns (see text). Rectangles indicate sleep periods with the shaded areas denoting sleep. The height of the vertical lines after sleep periods represent the sleep latency for that MSLT. Upper panel shows adaptation/baseline results, and lower panel shows in-flight and layover results.

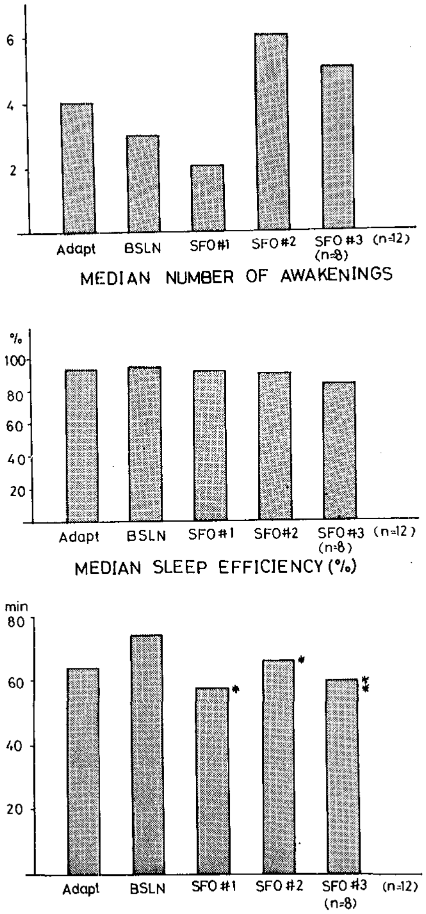

Fig. 7. Awakenings, sleep efficiency, and subjective sleep quality ratings under baseline and L/O conditions according to the sequence of major sleeps. Significant differences from baseline indicated by * ($p<0.05$) or ** ($p<0.01$).

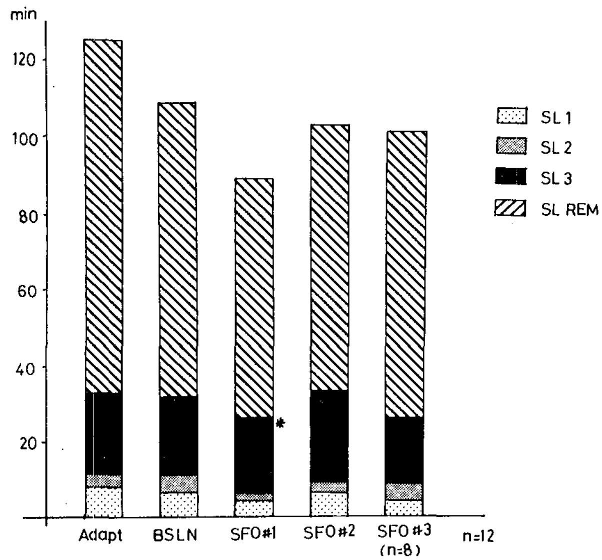

Fig. 8. Median onset latencies for sleep stages under baseline and L/O conditions according to the sequence of major sleeps. Significant differences from baseline indicated by *($p<0.05$).

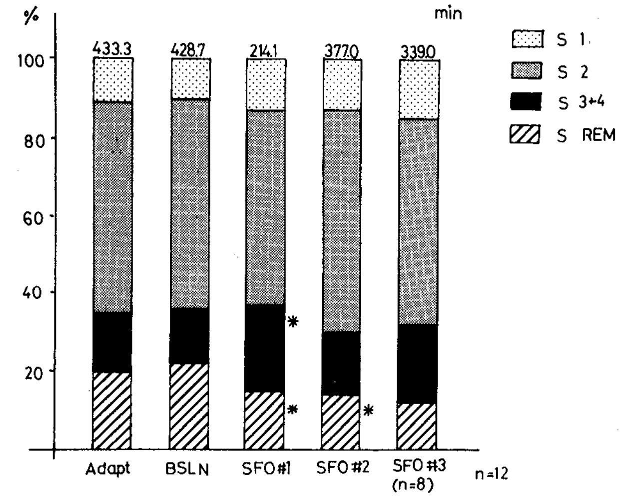

Fig 9. Mean percentages of total sleep time (TST) for each sleep stage under baseline and L/O conditions according to the sequence of major sleeps. Mean TST values (min) indicated at tops of bars. Significant differences between baseline and L/O #1 for TST ($p<0.01$), S3%, SWS%, and REM% ($p<0.05$), and between baseline and L/O #2 for REM% ($p<0.01$).

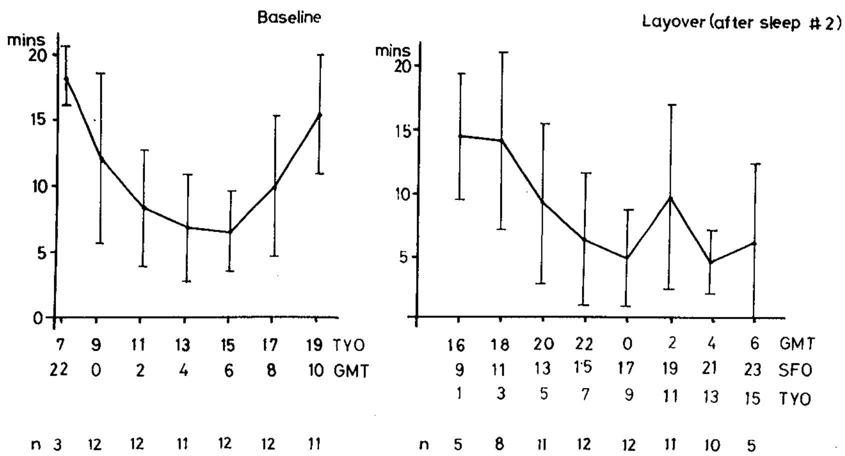

Fig 10. Mean (+SD) MSLT scores for crew members after baseline sleep in Tokyo and after first nocturnal sleep in San Francisco.

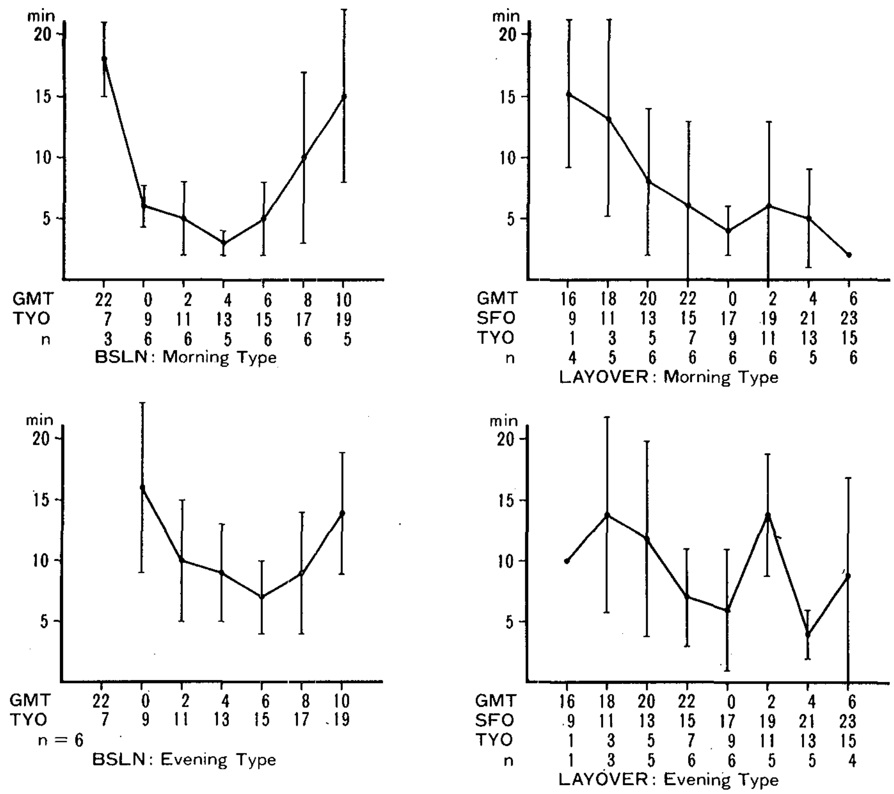

Fig 11. Comparison of mean MSLT scores of Morning and Evening types under baseline and layover conditions.

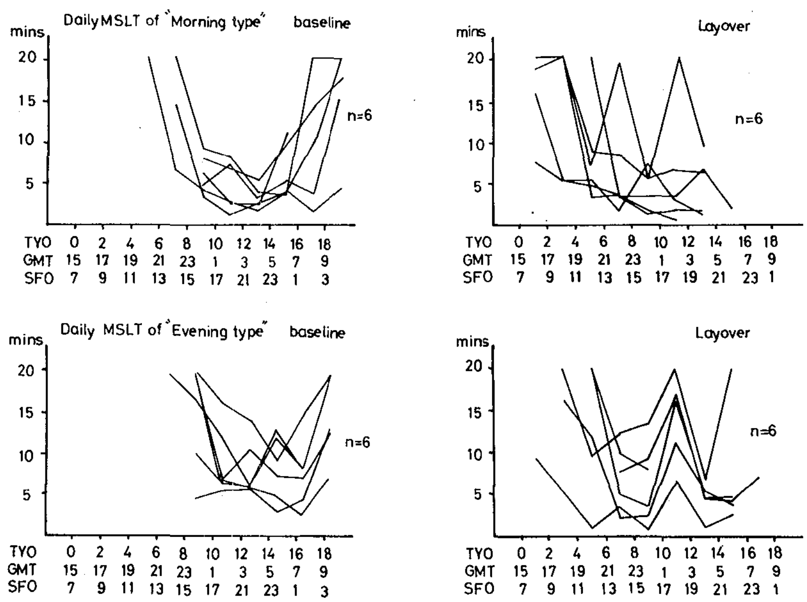

Fig 12. Comparison of individual MSLT scores of Morning and Evening types under baseline and layover conditions.

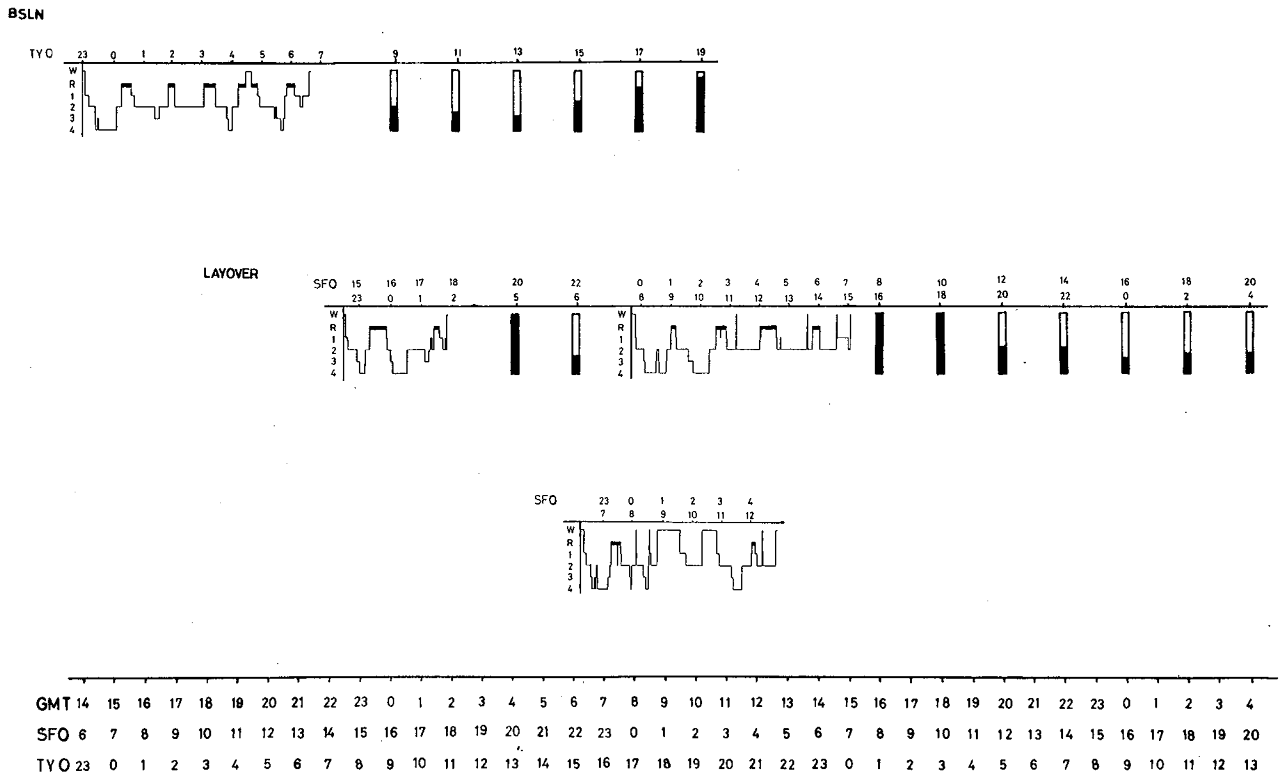

Fig 13. Sleep diagrams and subsequent MSLT scores of a typical subject.

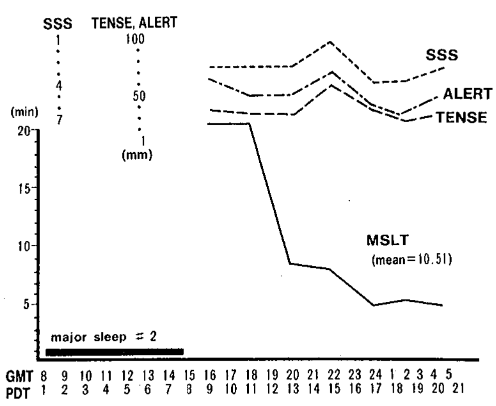

Fig 14. Subjective and objective daytime sleepiness of a typical subject.

Nocturnal Sleep and Daytime Alertness of Aircrew After Transmeridian Flights

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ABSTRACT

The nocturnal sleep and daytime alertness of aircrew were studied by electroencephalography and the multiple sleep latency test. After a transmeridian flight from London to San Francisco, sleep onset was faster, and although, there was increased wakefulness during the second half of the night, sleep duration and efficiency over the whole night were not changed. The progressive decrease in sleep latencies observed normally in the multiple sleep latency test during the morning continued throughout the day after arrival. Twelve out of thirteen subjects took a nap of around 1h duration in the afternoon preceding the return flight. These naps would have been encouraged by the drowsiness at this time and facilitated by the departure of the aircraft being scheduled during the early evening. An early evening departure had the further advantage that the circadian increase in vigilance expected during the early part of the day would occur during the latter part of the return flight.

INTRODUCTION

Long range transport aircrew operating world-wide routes have to cope with time zone changes and duty periods of varying durations which commence at virtually all times of the day and night. Such a pattern of work leads to irregularity of sleep (9), and the ability of crews to create an acceptable sleep pattern probably depends on the relationship between duty hours and the number of days on route remaining within certain limits (10).

Although, a satisfactory sleep pattern is the crucial factor in determining the acceptability of flight schedules to aircrew, it is the level of alertness during the duty period which is directly relevant to the safety of the operation, and this will also depend on the duration of duty and the circadian rhythm of vigilance (6, 7 & 15). The situation may be complicated further by partial adaptation to a new time zone (16), when the rhythms of the individual are not in synchrony with the environment.

It is in the context of these considerations and in attempting to understand the factors which influence vigilance during duty periods that we have carried out the present study on the nocturnal sleep and daytime alertness of aircrew operating a transmeridian flight between London and San Francisco.

MATERIALS AND METHODS

Subjects. The subjects were 13 healthy males (7 Captains, 2 First Officers, and 4 Flight Engineers) between 31 and 54 (mean 42.1) years old. They weighed between 68 and 91 (mean 81) kg, and their heights were between 173 and 191 (mean 182) cm. They were engaged in active flying duty and were scheduled to make at least one return flight between London and San Francisco during the study. Subjects were recruited from normally scheduled crews, and between one and three members of each crew participated. At the time of the study the United Kingdom was on British Summer Time (BST) and the time zone change with San Francisco (PDT) was 8h. The flight from London to San Francisco departed at 1245h (local time) and was about 10.5h in duration. On arrival at San Francisco (1525h - local time) the subjects were taken to the Stanford Sleep Research Center.

Procedures. Adaptation to a sleep laboratory and the control recordings of sleep and daytime sleep latencies were carried out at the Royal Air Force Institute of Aviation Medicine, Farnborough. During the control period each subject slept in the laboratory overnight and the sleep latency test (3) was carried out at 2h intervals (even GMT hours) during the next day. The individual bedrooms were light-proofed and sound attenuated, and temperature (20$\pm$2^{O}C) and humidity (55$\pm$2%) were controlled. Each subject was adapted to the laboratory for one night prior to any control or layover (L/O) recordings. Where possible, the control was recorded within the 3 weeks before or after the flight, although with some subjects this period had to be extended to comply with the additional requirement that at least 3 days at home preceded the recording.

During the L/O at Stanford subjects chose their own pattern of rest and activity. In practice, they all adopted a similar strategy and this involved two overnight sleep periods (S1 and S2) and, in all but one case, a short sleep or nap before the return flight at 1745 h (Fig 1). During the L/O all sleeps were recorded and sleep latency tests were carried out every 2h (even GMT hours) when subjects were not sleeping. During the control and L/O periods, alcohol and caffeine intake were restricted. Subjects were allowed 2 measures of alcohol prior to a major sleep period. They were requested to abstain from alcohol and caffeine-containing beverages between sleep latency tests, and meals were avoided during the 30 min preceding each test.

At Farnborough, electroencephalographic (EEG) activity from the C3-A2 (or C4-A1) positions, submental electromyographic (EMG), and bilateral electro-oculographic (EOG) activity were recorded, and EEG activity from the 01-A2 (or 02-A1) positions was also monitored until sleep onset. Recordings were made with silver-silver chloride electrodes filled with electrode jelly applied to the skin with collodion, and resistances of less than 10 Kohms were maintained. During the multiple sleep latency test (MSLT), two channels of EEG activity (C3-A2 or C4-A1, O1-A2 or O2-A1) and bilateral EOG activity were recorded. A Grass 8-10 EEG machine sited in an adjoining room was used, and a paper speed of 10mm/sec was maintained throughout each recording session. The half-amplitiude frequency response was 0.3-35 Hz for the EEG and EOG and 5-70 Hz for the EMG with a selective 50 Hz notch filter in each channel. In addition, respiratory activity was monitored during sleep using nasal thermistors and abdominal strain gauges, and bipolar anterior tibialis EMG was recorded; these data will be presented elsewhere. The sleep records were scored into 30 sec epochs according to conventional criteria (13), and all records from each subject were scored by the same analyst. The latency to the first epoch of stage 1 (drowsy) sleep was determined for each of the sleep latency tests. Similar techniques were used at Stanford.

Subjective assessments of sleep and well-being were completed before and after each overnight sleep and before each MSLT. Assessments included the Stanford Sleepiness Scale, visual analogue scales related to sleep quality and quantity, alertness and tenseness, and estimations of sleep onset latency and sleep duration.

Statistical Analysis. The sleep variables, together with the subjective assessments of sleep and well-being completed immediately before and after the sleep periods, were analyzed by analysis of variance (ANOVA). Differences between the means for the three overnight sleeps (control, S1 and S2) were compared using the Newman-Keuls shrinking range test (5). Analyses were carried out on both the whole sleep and the first 4h of sleep and on awake activity in the two halves of time in bed. Data from the short sleep period prior to the return flight were included in the analysis of sleep onset latency and of latencies to slow wave and rapid eye movement sleep. The assumptions of ANOVA - homogeneity of variance, normality and additivity - were studied by considering transformations of the raw measures using the maximum likelihood method of Box and Cox (2). The residuals from an ANOVA applied to data using the selected transformation were then examined after the method of Anscombe (1), and, if appropriate, this transformation was applied. However, the means presented in the tables have been calculated from the raw data. Changes in sleep with age were tested by calculating the Kendall rank correlation between age and the sleep variables both from the control alone and from the mean of the three overnight sleeps.

A linear regression model was used to relate the assessments of sleep to the sleep variables. Differences between the slopes and intercepts for individual subjects were tested; and, if possible, a pooled relationship was obtained, and the appropriate correlation coefficients calculated. A similar method was used to relate estimated sleep onset latency and sleep duration to their true values.

Sleep latencies between 1100h and 1900h (local time) on the control day and between 0900h and 1900h during the first day at Stanford were analyzed in separate two-factor ANOVAs where the factors were time-of-day (at five and six levels respectively) and subject. The mean for individual times of day were estimated by the method of Maximum Likelihood to allow for the censoring of data at 20 min. A logarithmic transformation was applied prior to analysis and back-transformed means are presented. Differences between the means were tested using the Newman-Keuls procedure. The sleep latency measured on arrival at Stanford (1900h) was compared with those of the next day and the control day by the Sign test, with the size of the test adjusted to allow for multiple comparisons. A similar procedure was used to compare the sleep latency at 0900h on the control day (when only 4 values under 20 min were recorded) with latencies at later times on the same day.

The subjective assessments obtained immediately before each MSLT were analyzed by a two-factor ANOVA with 13 subjects and 15 times, corresponding to six times on the control day (0900-1900h), one on arrival (1900h), six on the first full day (0900-1900h) and two on the second day (0900 and 1100h). Separate error terms were calculated for within day and between day comparisons by splitting the degrees of freedom for time. Differences between means during the same day were tested by Newman-Keuls, while differences between the value on arrival and those on the next day and the control day were tested according to Dunn (4). Relationships between the assessments and the sleep latencies were examined by testing the correlation coefficients of the residuals from the respective ANOVAs.

The subjective and objective measures of total sleep time and onset latency were compared by fitting the estimated to the actual values using linear regression. A 95% confidence band for the regression line was obtained by Scheffe's S-method, so that for any objective value x, a 95% confidence interval (y1, y2) for the equivalent subjective measure could be calculated. This provided a test of the hypothesis that the subjective measures were biased, the true values being underestimated when $x>y2$ and overestimated when $x<y1$.

RESULTS

The individual patterns of sleep and MSLT results are displayed in Fig. 2. Following the control sleep period, six sleep latency tests were carried out. During the layover at Stanford all subjects had two overnight sleep periods and, with the exception of one subject, a short sleep before the return flight. Sleep latencies were recorded on arrival at Stanford and between sleep periods.

Changes in sleep with age. The duration of slow wave sleep (stages 3+4) decreased as age increased ($p<0.05$), and this relationship was maintained ($p<0.01$) when the data from the overnight sleeps at Stanford (S1 & S2) were included in the analysis. Total sleep time decreased with increasing age ($p<0.01$), and although it was not possible to show that the amount of awake activity was age-related, there was an indication that the older subjects had more stage 1 (drowsy) sleep, particularly in the early part of the night.

Analysis of sleep. The frequency distribution of total sleep time for the three overnight sleeps (Fig. 3) showed that there were five periods of less than 300 min. Two of these were controls which were curtailed by the subjects for social reasons, and a third was a subject who slept very poorly during the control night. These three subjects were excluded from the analysis of the sleep data, and so results are presented for 10 subjects (Tables I, II, and III). Differences in total sleep time, the sleep efficiency index, or time in bed could not be established, but sleep onset latencies were shorter ($p<0.001$) at Stanford than at Farnborough (Fig. 4). Awake activity and stage 1 sleep in the first 4 h were reduced during S2 compared with control ($p<0.05$), and over the whole night there was a decrease in the duration of stage 1 sleep and there were fewer awakenings ($p<0.05$). However, the duration of awake activity was increased ($p<0.05$) in the second half of time in bed during S1 (60.8 min) and S2 (74.4 min) compared with control (27.5 min).

In general, the analysis of slow wave sleep (SWS) revealed a change in the temporal distribution and an increase in the amount of SWS during the L/O as compared to baseline (Fig. 5). Latencies to SWS (stage 3) were shorter (S1, $p<0.05$; S2, $p<0.01$) at Stanford than at Farnborough (Fig. 4), and the duration of SWS was increased in the first 4h of sleep (S1, $p<0.05$; S2, $p<0.001$) and over the whole night (S1, $p<0.01$; S2, $p<0.001$). During the control night SWS occurred mainly in the early part of sleep, whereas at Stanford there was a greater tendency for it to be distributed throughout the night. During the first 2h of sleep the duration of SWS was increased from 23.0 min in control to 41.1 min in S2 ($p<0.05$) and, excluding the first 2h of sleep, total SWS was greater in S1 (45.2 min, $p<0.01$) and S2 (38.6 min, $p<0.05$) than control (24.9 min). The duration of stage 2 sleep was less in the

TABLE I. CHANGES IN VARIOUS SLEEP MEASURES OVER THE WHOLE NIGHT ($n = 10$).

Measure	Transformation	Control Sleep	S1	S2
Total sleep time (min)		445.40	455.10	416.50
Sleep efficiency index[+]		0.90	0.86	0.84
Sleep onset latency (min)	$\log_x$	15.00	5.00***	5.00***
Latency (min) to stage 3	$\log_x$	24.20	18.20*	12.90**
Latency (min) to REM sleep	$\log_x$	87.20	73.00	54.60*
REM/NREM ratio		0.26	0.29	0.31
Number of awakenings	$\sqrt{x}$	10.90	9.70 ——— * ———	6.00*

*$p<0.05$; **$p<0.01$; ***$p<0.001$.
[+]Sleep Efficiency index = Total sleep time/Time in bed.

TABLE II. CHANGES IN THE DURATION (min) OF SLEEP STAGES OVER THE WHOLE NIGHT ($n = 10$).

Sleep Stages	Transformation	Control Sleep	S1	S2
Awake	$\sqrt{x}$	21.5	50.5	28.7
1		50.0	40.7	29.7*
Awake + 1	$\sqrt{x}$	71.5	91.2	58.4
2		255.8	234.0	210.1*
3		39.8	51.3	54.3
3+4	$\sqrt{x}$	47.9	74.6**	79.7***
REM		91.8	105.0	96.5

*$p<0.05$; ***$p<0.001$.

TABLE III. CHANGES IN THE DURATION (min) OF SLEEP STAGES IN THE FIRST 4H ($n = 10$).

Sleep Stage	Transformation	Control Sleep	S1	S2
Awake	$\log_x$	8.9	7.4 ——— * ———	5.1
1	$\log_x$	20.4	12.6	9.9*
Awake + 1	$\log_x$	29.3	20.0	15.0*
2		139.6	117.1**	105.3***
3		28.6	36.6	41.7
3+4	$\sqrt{x}$	36.3	52.7*	63.3***
REM		33.0	47.8*	53.9**

*$p<0.05$; **$p<0.01$; ***$p<0.001$.

first 4h of sleep in S1 ($p<0.01$) and S2 ($p<0.001$) than in the corresponding period of the control night, but over the whole night this reduction was seen only in S2 ($p<0.05$).

As shown in Fig. 4, the latency to rapid eye movement (REM) sleep was shorter during S2 than control ($p<0.05$). Although REM sleep duration was increased during the first 4h of sleep at Stanford (S1, $p<0.05$; S2, $p<0.01$), there was no change over the whole night.

There were only minor differences between the overnight sleeps at Stanford. There was less awake activity in the first 4h of sleep ($p<0.05$) and fewer awakenings ($p<0.05$) during S2 compared with S1. The hypnograms (Fig. 6) show the three sleep patterns (control, S1 and S2) from a single subject, and illustrate the changes in sleep that were observed at Stanford.

The mean total sleep time of the short sleep taken before the return flight by 12 of the 13 subjects was 69.2 min. Latencies to sleep onset (15.0 min), stage 3 sleep (25.7 min) and REM sleep (74.9 min) were not different from those of the control sleep.

Multiple sleep latency test. During the control day (0900-1900h) at Farnborough, sleep latencies exhibited the usual pattern (Fig. 7) with an increase in the tendency to sleep from 0900-1300h ($p<0.05$) and a decrease from 1500-1900h ($p<0.05$). However, after the first overnight sleep at Stanford the sleep latencies (0900-1900h) showed increasing drowsiness over the day (Fig. 8). The sleep latency at 1900h was shorter than at 1700h ($p<0.05$), 1100-1500h ($p<0.01$) and 0900h ($p<0.001$). After the second overnight sleep there were fewer latency tests but, including the latency to stage 1 sleep of the nap as an additional value, there was a similar increase in sleep tendency from 0900-1300h, though it was not possible to establish a significant effect.

Subjective assessments. The assessments obtained before and after the three overnight sleep periods (control, S1, and S2) are given in Table IV. Subjects reported on the Stanford Sleepiness Scale (SSS) that they felt more sleepy before S1 and S2 ($p<0.001$) than before the control sleep. After S1 and S2, their sleepiness rating decreased ($p<0.01$) to a level consistent with that after the control night. As shown in Fig. 9, quality of sleep was assessed as better at Stanford than at Farnborough (S1, $p<0.05$; S2 $p<0.01$), and this correlated with shorter latencies to stage 3 and REM sleep ($p<0.05$). Subjects also felt that they had obtained a satisfactory amount of sleep on S1 and S2, and this correlated with the increase in the duration of stage 3 sleep ($p<0.01$) and the reduction in the number of awakenings ($p<0.05$).

There was a positive correlation between estimated and actual sleep onset latencies ($p<0.01$) with a fitted relationship $\log y = 1.8 + 0.46 \log x$ where y (min) is the estimated and x (min) is the actual value. The corresponding relationship for total sleep time ($p<0.001$) was $y = 102.7 + 0.691\ x$. Subjects overestimated their short (<12 min) sleep onset latencies ($p<0.05$), and underestimated their long (>410 min) sleep periods ($p<0.05$).

During the control day at Farnborough there were no differences in assessments of tenseness, alertness or sleepiness completed before sleep latency tests, but on arrival at Stanford subjects reported increased sleepiness before the 1900 h test: SSS scores were higher and alertness ratings were lower than those observed on the control day and from 0900-1500h on the first day at Stanford. After S1 subjects felt more sleepy and less alert at 1500h and at all later times than at 1100h ($p<0.05$). There was a residual negative correlation between the SSS score and sleep latency ($r = -0.16$, $n=168$, $p<0.05$), shorter sleep latencies tending to be associated with increased subjective sleepiness. The large residual correlation ($r = -0.68$, $n=168$, $p<0.001$) between the SSS score and assessment of alertness indicated the close agreement between these two similar subjective measures.

DISCUSSION

The age-related differences in total sleep time and SWS observed in this study were consistent with the age range of the subjects, and were present in the control observations at

TABLE IV. CHANGES IN SUBJECTIVE ASSESSMENTS OF SLEEP AND WELL-BEING BEFORE AND AFTER MAJOR SLEEP PERIODS (n = 13).

Assessment	Control Sleep	S1		S2	
SSS before sleep	3.54	5.00***	**	4.85***	**
SSS after sleep	3.08	2.85		2.77	
Sleep quality	43.0	59.2*		64.9**	
Sleep quantity	61.8	58.5		56.2	

*p<0.05; **p<0.01; ***p<0.001.

Farnborough and in the sleeps at Stanford. There was no evidence that the older subjects had more difficulty sleeping in the new time zone, and alterations in sleep after the outward flight were similar in all age groups. These changes may be attributed to various factors such as the previous pattern of sleep and wakefulness, the length of prior wakefulness, and the time of day at which sleep occurred.

Although sleep during the nights before the outward flight was not recorded, subjects reported durations of 7h or less on some occasions in the preceding 3 or 4 nights, and, of course, subjects were awake for more than 20h before the first sleep in the new time zone. The increased duration of SWS observed in the two overnight sleeps at Stanford (S1 and S2) is likely to be due to this extended period of wakefulness (14) and, possibly, to some sleep loss during the days before the flight. Sleep onset was faster and this change was also probably related to the preceding sleep deprivation. During the first 4 h of the night, which would coincide with part of the sleep period at home, sleep continuity was similar during S1 and control, and there was evidence of improved sleep during S2. However, the less restful sleep during the second half of each night was likely to be due to difficulty in sleeping at a time of day when the individuals would normally be awake.

The appearance and distribution of REM sleep during L/O were primarily influenced by the time at which the sleep occurred. The shorter latencies to REM sleep were consistent with subjects retiring in the 'early morning' of their circadian rhythm at home. It is likely that by the second night subjects may have adapted by about 2h, and so their circadian rhythm would have been displaced by about 6h from the new time zone. Bedtime in the new time zone around 2200h would correspond to 0300-0400h of their circadian rhythm, and previous studies have indicated that this bedtime is associated with a short latency to REM sleep and the highest propensity for REM activity (11, 14).

The latencies to sleep data recorded during MSLT's on the control day showed the characteristic pattern. Sleep tendency increased over the first few hours after wakening, but reversed later in the day. However, after both the first and second nights in the new time zone, sleep latencies decreased with time awake, and the subjects reported that they felt more sleepy. This pattern of sleep tendency revealed by the multiple sleep latency test arises from the changed relationship between the circadian rhythm of alertness and the new environment. The increase in drowsiness with time awake would normally be reversed by the rising phase of the circadian rhythm during the latter half of the day, but the rising phase would have occurred much earlier in the day in California, and so drowsiness would persist during the afternoon.

Concerning the operational significance of these findings, the studies suggest that overall sleep was not unduly altered in the new time zone, although the second halves of the night were more interrupted by wakefulness. Further, sleep latencies during the day suggest that drowsiness would have persisted up to the time of the return flight even with the progressive adaptation of the circadian rhythm of alertness. However, on the day of the return flight all but one of the 13 subjects took a short sleep of around 1h duration during the afternoon, and such sleeps improve alertness in sleep deprived subjects over the next 8h (8,12). In addition, although the increase in alertness related to the circadian rhythm of the individual was displaced, it would still have influenced vigilance during the latter part of the flight which terminated about midday local time.

The most advantageous time for the return flight from San Francisco would therefore appear to be in the early evening. However, the tendency to sleep in the afternoon would become less insistent with successive days in the new time zone as the rhythm of alertness adapts to local time, and so a L/O of limited duration may be appropriate. Whereas, a departure during the early afternoon may not allow a nap beforehand, and the flight may terminate without the benefit of the rising phase of the circadian rhythm of vigilance.

ACKNOWLEDGEMENTS

The authors are indebted to the staff of the Stanford Sleep Research Center who carried out the sleep and daytime latency recordings when the crews were in the United States. We also wish to thank the volunteer flight crews for their cooperation as subjects. The study was supported by the National Aeronautics and Space Administration (NASA Cooperative Agreement NCC 2-302 with Stanford University School of Medicine), United States, and the Civil Aviation Authority, United Kingdom.

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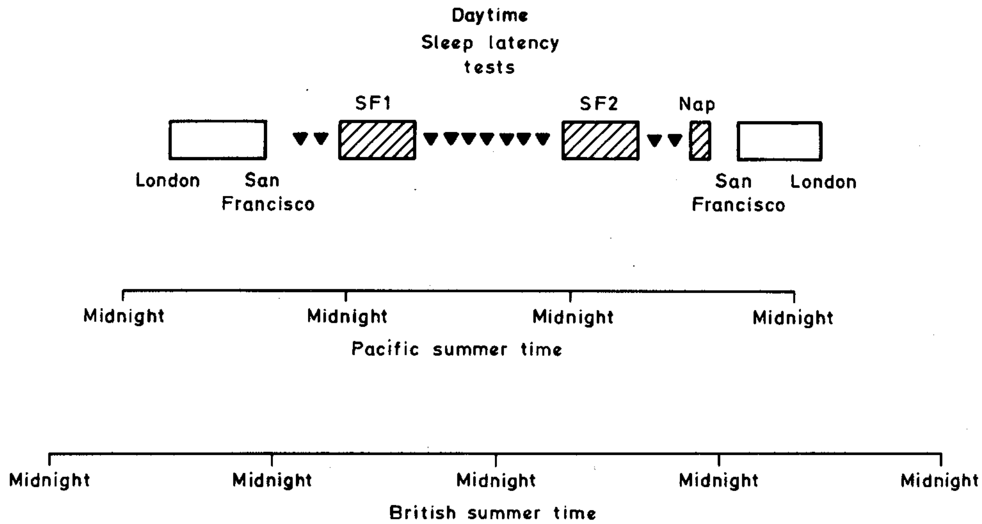

Fig 1. Flights, sleeps and recordings of sleep latency during the schedule. The crews departed from London at 1245 h and arrived in San Francisco at 1525 h. The latencies to stage 1 (drowsy) sleep were recorded during the remaining part of the first day, during the whole of the second day and before the nap on the third day. The return flight commenced at 1745 h and the crews arrived in London at 1145 h (local times).

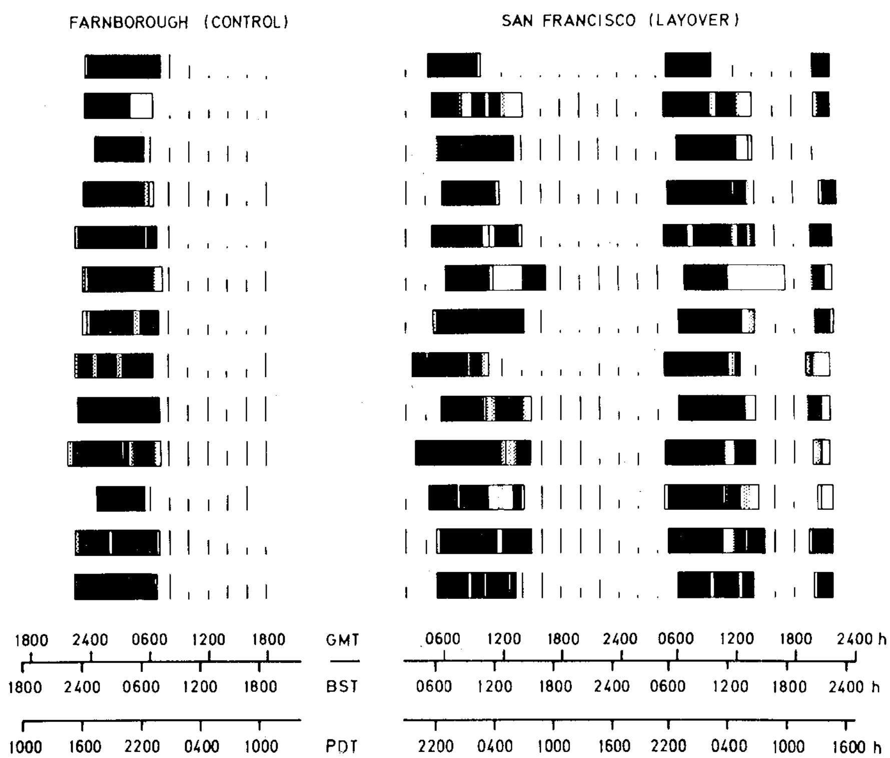

Fig 2. Sleeps and recordings of daytime sleep latencies of the 13 individuals. Within sleep periods, wakefulness is denoted by white areas and stage 1 (drowsy) sleep by stippled area. Sleep latencies are represented by bars (maximum 20 min).

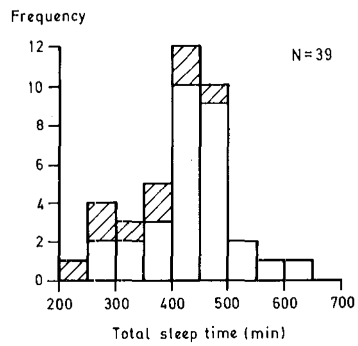

Fig 3. Frequency distribution of total sleep time for the three overnight sleeps (control at Farnborough, and two nights at Stanford). Shaded portions indicate sleeps not included in the analysis because the controls were less than 300 min.

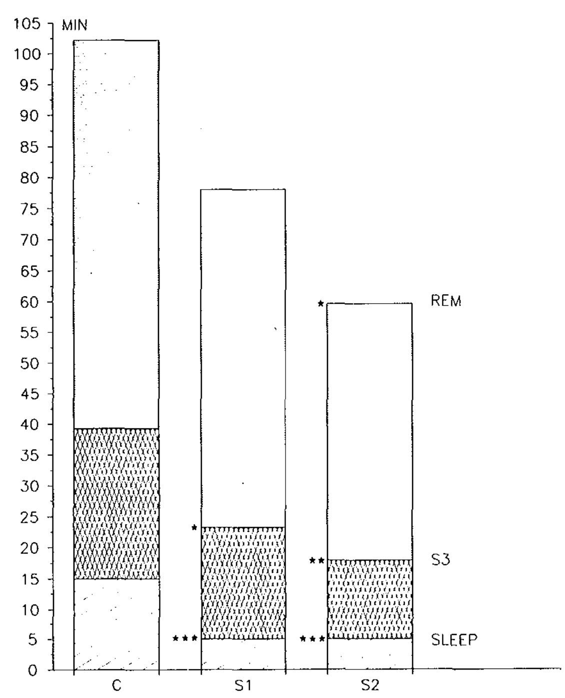

Fig 4. Mean (N=10) onset latencies to the first ten min. of persistent sleep, to slow wave sleep (stage 3), and to REM sleep for the three overnight sleeps. Significant differences from baseline values indicated by * ($p<0.05$) or ** ($p<0.01$) or *** ($p<0.001$), see Table I.

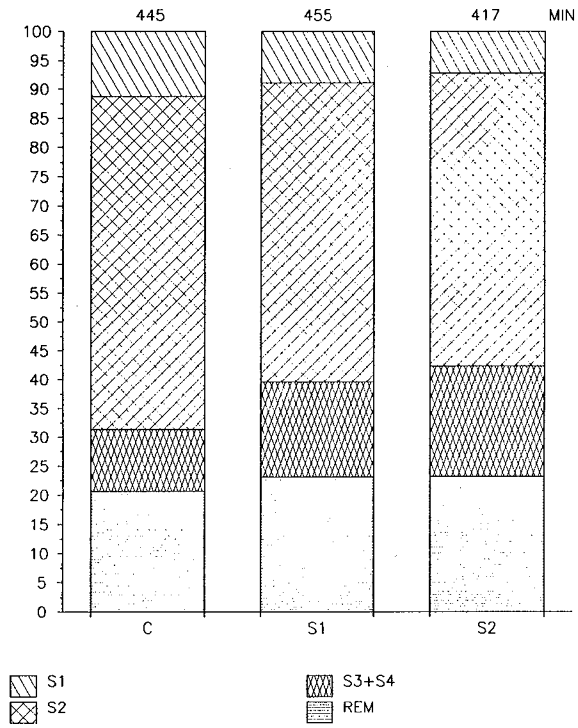

Fig 5. Mean percentage of total sleep time (TST) for sleep stages during the three overnight sleeps. Absolute TST values (min.) are given on top of the bars.

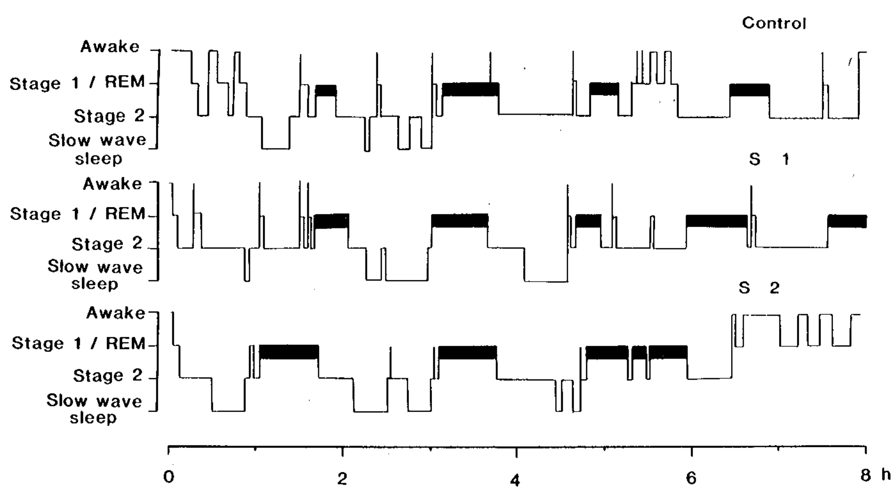

Fig 6. Hypnograms of a pilot. Control is the recording at Farnborough, and S1 and S2 refer to consecutive night recordings after arrival in San Francisco.

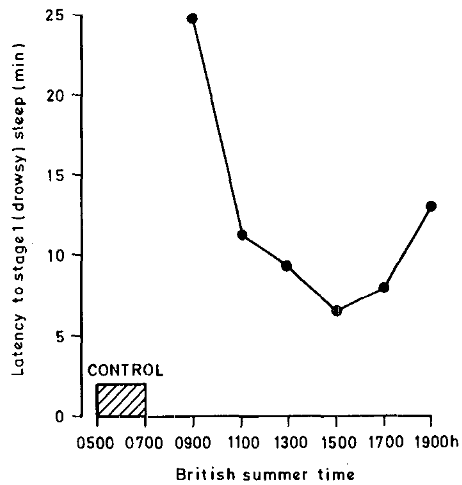

Fig 7. Control multiple sleep latency test at Farnborough. Latencies to drowsy (stage 1) sleep during the day (means for 13 individuals).

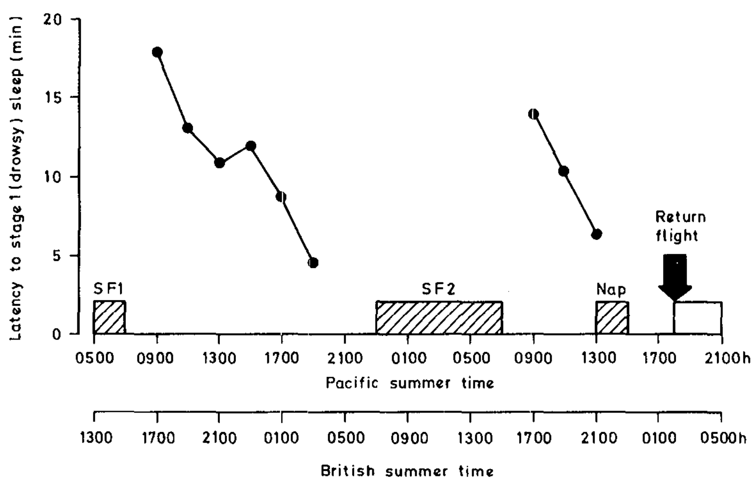

Fig 8. Mean sleep latencies for MSLTs during the layover in San Francisco.

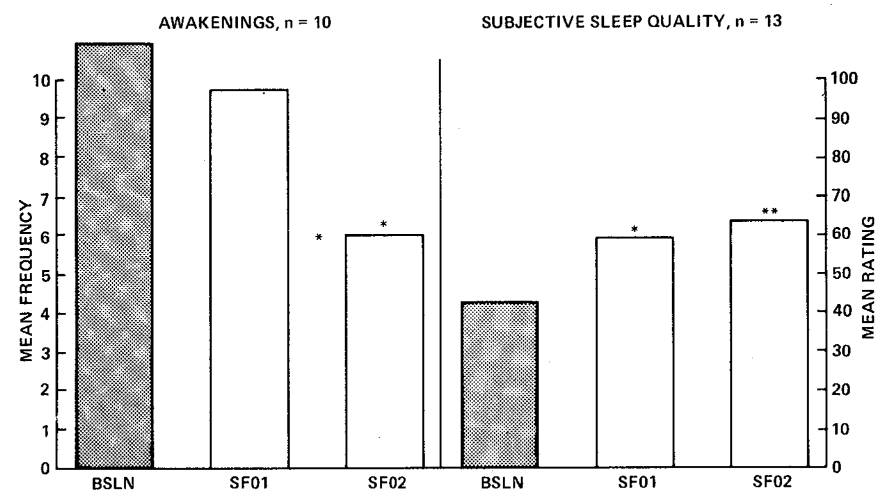

Fig 9. Mean number of awakenings and subjective sleep quality for the three overnight sleeps. Significant L/O sleep differences are indicated between bars and differences from baseline are indicated at tops of bars (*$p<0.05$, **$p<0.01$).

Sleep, Sleepiness, and Circadian Rhythmicity in Aircrews Operating on Transatlantic Routes

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ABSTRACT

This study was performed on B-747 aircrews operating on regular passenger flights between Frankfurt and the U.S. west coast (9h time difference). In an initial phase, sleep behavior was surveyed by daily logs in 38 crew members. The results for the layover period indicate congruent sleep patterns with shifts in sleep onset distinctly less than 9h. In comparison with preflight control data, sleep duration was significantly prolonged and, on average, no sleep deficits were experienced before commencing the return flight. The main part of the study consisted of polygraphic sleep recordings and multiple sleep latency tests (MSLT) applied to four complete cockpit crews (12 members total) in a baseline period, during layover, and after return to homebase. In addition, body temperature and ECG were continuously recorded. During layover, mean bed times were shifted by 4.5h at maximum. Sleep was disturbed by early and prolonged awakenings which led to a reduction of sleep efficiency. In contrast, no sleep deficits nor increases in daytime sleepiness occurred. Night duty associated with the return flight caused sleep deprivation which conversely resulted in good sleep during the first night back in Germany. However, during the second night after return, impaired sleep was observed, at least in part caused by rhythm disturbances. As predicted by our resynchronization model, ECG and rectal temperature recordings gave evidence for a desynchronization of the circadian system and an internal dissociation of different body functions.

INTRODUCTION

In principle, our investigations were performed in two major phases. In a first step (Phase I) sleep-log surveys were obtained from crews operating on the FRA-SFO and FRA-LAX routes. The latter route was included since the flight schedules of both routes are almost identical. The primary purpose of this phase was to obtain a better understanding of individual daily habits and strategies. As it subsequently turned out, these sleep surveys also provided valuable information about the quantity of sleep and its deviation from "normal".

The second phase (Phase II) served as the main part of our investigation and consisted of a battery of tests and measurements applied to a group of twelve volunteers operating as B-747 crews on scheduled passenger flights between FRA and SFO. Like the other participating research groups, our central purpose was to study sleep in aircrews exposed to a time zone considerably different from their home base. However, since multiple time zone transitions are known to affect sleep by circadian rhythm disturbances, additional efforts were aimed at defining changes in the 24h fluctuations of selected variables. Therefore, besides studying sleep-EEG and daytime sleep latency (MSLT) in the laboratory, we continuously recorded body temperature and ECG and collected continuous urine samples. The additional measurements were conducted not only during pre-duty and layover (L/O) periods, but also during flight. Furthermore, we attempted to learn more about flight crew readjustment to home time by continuing all measurements in the laboratory for approximately two more days after return to FRA.

Fig. 1 illustrates time lines and the general experimental design. At present time, the results are limited to sleep-EEG, MSLTs, body temperature and ECG records. The chemical analysis of urinary hormones and electrolytes is still in process.

MATERIALS AND METHODS

During Phase I, 26 sleep logs were completed on the FRA-LAX route and 12 on the FRA-SFO route. The two groups were labeled "LAX" and "SF1" respectively. In Phase II, 12 additional logs were obtained from the experimental group, "SF2".

The Phase I sleep surveys extended from two days before flight duty until two days after return to home base, whereas Phase II logs extended up to 6 days before duty commenced. To obtain better comparability between Phases, the additional 4 days were omitted from the analysis. Another difference was that Phase I crew members stayed in a hotel during their L/O and at home after the return flight. The experimental, Phase II group spent both periods in sleep laboratories.

Phase II subjects were four complete cockpit crews (1 Capt, 1 F/O, 1 F/E) for a total of 12 subjects who were assembled from a group of volunteer crew members. The age for captains and flight engineers ranged from 44 to 53y and for flight officers from 32 to 40y. As Fig. 1 shows, measurements were conducted over a baseline period of 36h in our Cologne sleep laboratory, in most cases during the week before the flight. All measurements were carried out in September 1984, with each crew leaving for SFO on Wednesday and returning to FRA on Saturday. Scheduled flight times were (in GMT) FRA:0810 SFO:1935 for the outgoing and SFO:2145 FRA:0830 for the home-going flight. After arriving at SFO the crews stayed together in separate rooms at the Stanford sleep laboratory for the 48h L/O period. After returning to FRA they were transported by helicopter to the Cologne laboratory where they remained for an additional 44h (post-return).

Table I summarizes all variables and methods included in our investigations. Sleep EEG recordings were performed as described in detail in the introductory paper (Graeber, et al.). Contrary to the other research groups, respiration and leg movements were not recorded in this study, and the pretrip measurements were conducted in the sequence: adaptation night, MSLTs, baseline night, i.e., the MSLTs did not follow the baseline sleep period. Seven baseline MSLTs were administered instead of six. ECG and rectal temperature were continuously recorded by means of Oxford Medilog tape recorders. Frequency analysis for the first harmonic was carried out on the heart rate and temperature data, according to Bliss (1), by shifting a 24h window by 1h intervals over the entire experiment. The results from this analysis were compared with values predicted by a model for the estimation of resynchronization after time-zone flights (13). Urine samples were collected in approximately 2-h intervals and frozen for later chemical analysis. Subjective

TABLE I. OVERVIEW OF VARIABLES AND MEASURES.

VARIABLES				
Mood	Sleepiness	Sleep	Rhythmicity (24h)	Workload
Pre-Sleep Scales	MSLT (EEG, EOG)	EEG	Temperature	ECG
	SSS	EOG	ECG	Catecholamines
	Fatigue Card	EMG	Urine Constituents	17-OHCS
	10cm Scale	Sleep Log		
		Self-Ratings		

SSS = Stanford Sleepiness Scale

fatigue ratings (10) were obtained from the subjects at regular intervals during the awake periods.

RESULTS

Sleep log surveys. Figs. 2 to 5 present those results from the sleep log surveys which relate to the self-ratings of time and duration of sleep. Quality of sleep was also assessed by five different rating categories. These data will be published elsewhere.

The means of sleep-onset and -end shown in Fig. 2 demonstrate that sleep timing under control conditions (days 1 and 2) can be considered quite normal. Thus, it can be concluded that these aircrews, when at home, go to bed at about 2200 GMT and get up at about 0600 GMT. This is true for all three groups with only minor differences in the mean values. The sleep-end preceding flight duty on day 3 is earlier by 1-2h, again in all three groups. As shown more clearly in the next figure, this results in a reduction of sleep duration, since sleep-onset on the prior evening is not adjusted correspondingly. During L/O, sleep timing is considerably shifted towards later hours, as would be expected by the time difference of -9h between FRA and SFO/LAX. However, crew members do not shift their sleep periods completely, i.e., on the average groups LAX and SF1 delayed their sleep by not more than 7 to 7.5h (onset and end of sleep respectively). Shifts of the experimental group are distinctly less ($p<0.01$), averaging a 5h delay at the most. Thus, the experimental crews went to bed, fell asleep and got up earlier than the crews staying at the hotel. After the return flight, sleep timing was immediately shifted back towards the habitual hours of sleep at home base. The experimental group (SF2) again differs from the others in that its mean times exhibit a slower readjustment, especially sleep onset ($p<0.001$).

In summary, Fig. 2 demonstrates similar sleep behavior patterns of the three groups before, during and after the duty period. During L/O, shifts in sleep times on average were distinctly less than the difference in local time between FRA and SFO/LAX.

Fig. 3 presents the results from the self-reports of sleep duration for the different groups. The similarity of the patterns is evident. Compared with the sleep period on day 1 (control night), there is consistently a significant reduction in sleep duration during the night immediately preceding flight duty. As demonstrated previously, these shorter sleep periods resulted primarily from the earlier wakeup times in preparation for the relatively early commencement of duty. Sleep duration is significantly extended in all groups during the first L/O, but only for the experimental group during the second night. After the return-flight, significant changes appear only twice: longer sleep on the first night for the LAX group and shorter sleep on the second night for the SF2 group. The pronounced reduction in the latter was, at least in part, caused by earlier arising at the end of the experiment due to an early pick-up time. As in the LAX group, a longer sleep duration occurred on the first post-return night for the SF1 group; however, this duration is not significantly different from control levels due to increased variance, probably caused by some substantially delayed return flights in this group. To summarize the findings of Fig. 3, it can be concluded that aircrews on the average slept less than "normal" on the night before commencing duty, but considerably more during the L/O period.

Fig. 4 illustrates what we call "sleep balance", i.e., the sum of the deviations in sleep duration from control nights. Thus, the curves reflect sleep deficit or surplus accumulated each consecutive day over the entire experimental period. Again, the three groups exhibit almost identical patterns with a moderate sleep deficit on day 3, substantial surpluses during the L/O period, and dramatic deficits after the return flight. Obviously, these deficits result from the preceding night duty when normal sleep was not possible; however, if we take into account the afternoon sleep after arrival in CGN, the sleep balance approaches zero. Although the practical implication of computing sleep balance curves may be debatable, they nevertheless demonstrate that aircrews usually attempt to get enough sleep and that they succeed.

Finally, Fig. 5 combines the three groups' sleep duration data during the three major stages of the sleep log survey. From the distribution of sleep durations it can be concluded that under control conditions about 90% of sleep episodes were between 6 and 10h. Sleep duration was 5h or less in only 5 out of 98 cases, indicating that severe sleep deficits do occur, although very rarely. This number of extremely short sleep periods remains the same throughout duty and post-duty days. In addition, for the two L/O nights the histogram clearly shows a shift to longer sleep durations with maxima of 13 and 14h in 4 cases. During the two post-return days, sleep periods show a tendency to normal length. The higher incidence in the 6-h class mainly reflects the enforced early termination of sleep during group SF2's last test night in Cologne.

Sleep recording and MSLTs. In preparing to compare sleep parameters with baseline (B2) values, we first had to check the latter for outliers. Any value deviating by more than two standard deviations (2-sigma-limit) from the group mean was defined as an outlier. Indeed, one subject exhibited REM sleep lower than this limit and wake time and time in bed (TIB) longer than this limit. In addition, his subjective sleep quality rating was below the 2-sigma-limit. He complained about a headache during the baseline night and took two aspirin. As an apparent outlier, this subject was excluded when comparisons with baseline data were made.

The beginning and end of sleep periods were calculated as mean times (N=12) of lights-off and lights-on and summarized in Fig.6. Compared with baselines B1 and B2 when crew members went to bed at about 2200 GMT, their mean bed times shifted by 3.2h on the first L/O night (SFO1) and by 4.5h on the second (SFO2). These values generally ageree with those obtained from the sleep logs for the same period. For both sleep periods the average TIB was longer than during baseline or post-return. Get-up times showed considerable interindividual variability, with a standard deviation about twice that for baseline and post-return sleep. Before leaving Stanford for the return flight, nine subjects tried to nap, seven of them fell asleep. After the return flight, which was a complete night flight according to FRA time, all crew members went to bed in the afternoon (CGN1). On the following two nights, sleep was delayed by 1.9h (CGN2) and 1.0h (CGN3) compared to baseline.

Fig. 7 shows the total sleep time (TST) as well as the percentages for different sleep stages. While TST was about 7.0h for all night-sleep periods in Cologne (except for CGN3, as explained above), it increased to almost 8.0h during L/O. The afternoon sleep following the return flight (CGN1) had a mean TST of 3.5h. REM sleep (%) was nearly constant for all sleep periods, except for a decrease during CGN1 and an increase in CGN2. While stage 2 sleep (%) was also fairly constant, slow wave sleep (stages 3+4, SWS) displayed a greater variability between sleep periods and a strikingly higher portion in CGN1. Large differences were also observed for stage 1.

Table II compares the baseline (B2) sleep parameters of our group with data reported by Williams et al. (14) for a group of males (n=10) ranging in age from 40-49y. TIB, TST as well as sleep stage percentages do not differ significantly. In addition, this table compares all sleep periods with baseline sleep B2. As might be expected, the adaptation night (B1) produced a longer mean TIB ($p<0.05$) and more stage 1 sleep. During L/O nights, TIB and TST were significantly longer with more stage 1 sleep (%) in SFO1. The afternoon sleep CGN1 had more SWS(%) and less REM sleep (%), while the following night

TABLE II. COMPARISON OF BASELINE (B2) SLEEP PARAMETERS (n=11) WITH THOSE FROM 40-49 YEAR OLD MALES (Williams) AND FROM ADAPTATION (B1), LAYOVER, AND POST-TRIP RECORDINGS.

Source	Minutes		Percentage			
	TIB	TST	S1	S2	S3+S4	REM
B2	460.20	414.60	9.24	57.98	10.48	22.30
Williams	429.10	389.10	8.07[a]	58.41[a]	9.13[a]	24.39[a]
B1	494.50*	420.40	12.38*	57.86	6.90	22.85
SFO1	572.30**	477.50**	11.93*	55.59	10.13	22.35
SFO2	529.80**	461.90**	10.19	57.48	9.38	22.96
CGN1	219.10**	208.70**	6.67	56.23	23.47**	13.63**
CGN2	469.80	429.90	7.22	56.84	8.32	27.61**
CGN3	409.40	342.90	9.86	55.75	13.12	21.27

*$p<0.05$; **$p<0.01$
[a] % SPT values given by Williams were transformed to % TST

(CGN2) showed enhanced REM sleep.

Median latencies to sleep onset, slow-wave sleep (S3), and REM sleep are shown in Fig. 8. Though the interindividual variability was rather high, the following comparisons to baseline were statistically significant: longer latencies to sleep onset and REM during adaptation, reduced latency to S3 for the CGN1 day sleep, and delayed sleep onset on the second post-return night (CGN3).

Fig. 9 presents median values of several sleep quality parameters. The number of awakenings varied between 5 (CGN1) and 11.5 (B1). In comparison with B2, sleep was less efficient during B1, SFO1, and CGN3, but more efficient during CGN1. Subjective sleep quality ratings also suggest poorer sleep during B1, SFO1, and CGN3. Computations of correlations between sleep quality parameters and age revealed significant negative coefficients ($r=-0.63$, $p<0.05$) for sleep efficiency during each L/O night, but not for total sleep time.

Individual sleep patterns and MSLT results for baseline, L/O, and post-return are presented in Fig. 10. Most of the crew members underwent one SLT after arrival at Stanford and 5-9 MSLTs between the major sleep periods. For sleep SFO1, subjects went to bed at very different times, and this rank order remained almost the same for SFO2. One subject (row 6) had relatively long naps in addition to his short sleep periods and seemed to stay on home-base time. Shifts of sleep periods were more obvious for other subjects who exhibited longer TIB. As this figure clearly indicates, reduced sleep efficiency resulted from long waking times (a) in the second half of SFO1 sleep and (b) in the beginning of CGN3 sleep.

Mean SLT values were calculated only if at least seven subjects performed the SLT at the corresponding time. In the home time zone, these mean values revealed a general pattern of long latencies immediately after sleep, short latencies in the afternoon, and longer again in the early evening (Fig. 11). During L/O, when measurements were extended until late evening, the MSLT showed the typical biphasic contour. The longest onset latencies were always found after the main sleep periods (B1, SFO1, SFO2, CGN2), regardless of how far they were shifted. Comparison of MSLT latencies revealed the following significant differences (Wilcoxon test): (a) increase between 1600 and 1800 GMT for baseline ($p<0.05$) and L/O ($p<0.10$); (b) increase between 1600 and 2000 GMT for baseline ($p<0.05$), L/O ($p<0.01$), and post-return ($p<0.05$); and a decrease between 2000 and 2400 GMT for L/O ($p<0.05$). In addition, latencies of the MSLTs at 1800 GMT were significantly different ($p<0.05$) between L/O and post-return.

Temperature and ECG. As compared with baseline data, temperature and heart rate curves revealed distinct phase shifts during L/O and after return to FRA. The curves in Fig. 12 represent mean values from all experimental subjects. Computed minima (Bliss [1]), as well as minima predicted by our model (13), are marked differently in the figure. Vertical lines illustrate where the minima would be expected if subjects had completely adapted to SFO time.

The temperature rhythm was shifted by 3.75h on the first and by 5h on the second day of the L/O period (both relative to baseline), while after return to home base the shift was 3.25h relative to the last day in SFO (or 2.75h relative to baseline). The rhythm of heart rate was shifted even more: 6.25h on the first day in SFO and 7.0h on the second;

after return to FRA a shift of 6.0h relative to SFO2 occurred, which corresponds to a time difference of 1h relative to the baseline rhythm.

As a consequence of the different adjustment speeds, internal dissociation can be observed. The phase difference between heart rate and temperature rhythms was -1h during baseline periods and changed to +1.5h during the first and +1.0h during the second day in SFO. Due to the faster readaptation of the heart rate, the phase difference became -2.75h after return to home base. No actual minima from harmonic analysis are given for the return-flight day, because of the irregularities in the sleep-wake cycle. According to FRA time this flight was a total night flight. Even if related to the shifted circadian rhythm (delay by 5h), it must still be considered as night duty, at least in part. Inspection of the curves demonstrates that, though the first circadian trough occurred in the second part of the duty period, heart rate and temperature already increased again about 2h before landing.

The periodical decrease of heart rate and temperature every 2h during awake time in Fig. 12 was most likely caused by the reduction of activity during MSLTs. Compared with the heart rate oscillations, the temperature fluctuations were delayed by 20-30 min.

While the 24-h means of the circadian rhythms show only minor variation, the amplitudes are considerably higher during L/O as compared with baseline and post-return periods (Table III). In our view, this is mainly caused by a masking effect. From the longer sleep durations one could expect an increase in amplitude since longer periods of inactivity result in longer sections of lower values in heart rate and temperature rhythms. At the same time this would also lead to a decrease in the 24-h mean, but in our case such an effect is compensated by the higher physical activity of most subjects during the day at Stanford (e.g., bicycling and jogging). Of course, these activities enhance the rhythm amplitudes even more by adding sections of values higher than normal to the rhythm curves.

In order to interpret the circadian results in more detail, shifts in acrophases of temperature and heart rate as well as those predicted by our model are presented in Fig. 13, along with the subjects' mean daily bedtimes. All parameters indicate a clear shift towards the corresponding hours of the new time-zone (by a delay during L/O and by an advance after return to CGN). However, heart rate adapts faster, mainly due to the simultaneous shift of the rest-activity cycle. Temperature acrophases shift more slowly, and their

TABLE III. ESTIMATED 24H MEANS AND AMPLITUDES OF HEART RATE AND TEMPERATURE COMPUTED FROM AVERAGE CURVES (After Bliss (1))

SOURCE	HEART RATE (1/min)		TEMPERATURE (^{o}C)	
	Mean	Amplitude	Mean	Amplitude
B1/B2	68.5	13.0	36.8	0.55
SF01	71.5	19.5	36.75	1.00
SF02	72.5	17.5	36.8	0.60

adjustment pattern corresponds well with the bedtimes, except for day CGN3. Fig. 13 also demonstrates that changes in temperature rhythm acrophase, after either westward or eastward flight, can be correctly predicted by our model of resynchronization.

DISCUSSION

Our experimental design was based initially on the following hypothesis: Due to the considerable time difference between FRA and SFO, aircrews performing duty on this route would suffer from rhythm disturbance of their circadian system. As a direct consequence, they would also experience sleep difficulties, a problem which has repeatedly been a matter of serious concern among aircrews and safety researchers (5,7,8). Furthermore, sleep difficulties would be manifested by sleep loss and reduced sleep quality, both in terms of subjective ratings and objective EEG recordings.

Sleep log analysis. Clearly, the results from our sleep-log surveys do not support the above hypothesis. In contrast, there is convincing evidence that our pilots slept significantly more during the L/O period and did not suffer at all from sleep loss, as compared with their normal sleep habits at home base. It is not possible to determine whether this was achieved by conscious attempts or by efforts and conditions beyond the subjects' direct control. From personal communications, however, we are inclined to conclude that the majority of the pilot population is well aware of this problem and takes serious measures to get enough sleep. No doubt, the results from the sleep-log surveys demonstrate that they succeed; however, the findings presented in this paper do not rule out the possibility that sleep deficits may occur in individual cases. The presented results deal only with computed means and thus merely reflect average behavior. There are already indications that severe sleep deficits may be experienced by some crew members. In at least five cases, sleep was 5h or less during L/O as well as during control and post-return periods (with a 3h minimum in one case). A more detailed analysis is planned to settle this question of individual problems.

There is another, more general, but also quite unexpected result that the sleep-log surveys are disclosing. Initially, all participating research groups were concerned about whether the sleep laboratory would be an adequate setting to obtain realistic information about "true" L/O behavior in the hotel environment. Comparison of the three sleep-log groups reveals strong evidence that we were well "on the safe side", in essence for two reasons: (a) The patterns of sleep timing and duration were almost identical; in fact, statistical analysis (Kruksal-Wallis test) did not detect any general difference when the data sets (entities of 8 days) as a whole were compared. (b) During the first L/O, night sleep duration in the laboratory was significantly shorter than in the hotel environment (U-test); again, this was in contrast to what had been expected. Despite the quiet, isolated surroundings of the sleep facility, our subject group did not sleep longer than aircrew staying in the commercial atmosphere of the city hotel. In addition, during both post-return nights the laboratory group reported distinctly shorter sleep durations than the other groups sleeping at home. Thus, the data clearly refute the argument that sleep deficits could be anticipated in the realistic world even though they had not been observed in the laboratory.

Of course, conclusions drawn from subjective ratings may give cause for criticism. However, subjective estimates of sleep duration, i.e., time between onset and end, correlate well with objective measurements. This is not necessarily true for the amount of sleep, since number and time of awakenings are frequently misjudged thus leading to major discrepancies between subjective and objective assessments of total sleep time. Theoretically, our sleep-log data could have indicated longer sleep periods despite a decrease in the amount of sleep, if our subjects had suffered from longer awakenings than accounted for by the surplus in sleep duration. In fact, the sleep-EEG recordings in our experimental group disclosed considerably prolonged awake periods during L/O sleep. Nevertheless, total sleep time was distinctly longer than under baseline conditions. To us, there appears to be not much evidence that this should be different in the two other groups. In particular, the impressive and consistent similarities between the three groups in almost all sleep-log results support this view.

Sleep recording and MSLT analysis. As a prerequisite for discussing details of the sleep-EEG and MSLT results it is important to know whether there are any differences between crew members' usual habits and their behavior in the laboratory, and how such differences may influence final conclusions about the study.

Each time subjects left the sleep laboratories, questionnaires were administered asking for general sleep quality and a comparison between their usual sleeping conditions and those of the laboratory. In general, the answers to each question were equivalent after the baseline, L/O, and post-return periods. On a 5-point-scale from "very poor" to "very good" the subjects consistently rated their sleep quality as being good. Quantity of sleep, daytime drowsiness, and quantity of meals were judged as comparable with the usual conditions. Upon leaving the Cologne laboratory after the post-return phase, all crew members were interviewed. Six claimed that their sleep was better than at home, and six reported no difference. The improved sleep was attributed to the darkness and silence of the laboratory and to the absence of family disturbances. In contrast to what we inferred from the sleep-log surveys, these findings could mean that conclusions regarding sleep quality drawn from the experimental results should be rather conservative with regard to sleep in the usual world where flight crews are sometimes faced with a more disturbing environment.

The experimental part of the sleep investigations revealed a clear pattern of sleep periods with only minor individual differences. During L/O, the onset of the two main sleep periods was shifted ahead by 3.2 and 4.5h, respectively, as compared with baseline data. Our results cannot distinguish whether these shifts were due to a phase shift of an autonomous circadian sleep rhythm, or whether they reflect a conscious compromise between increased fatigue and an adjustment to the social environment of the new time zone. If the crew members delayed sleep completely by 9h, they would be much more tired during the pre-sleep hours. Even with only a partial sleep delay, Stanford Sleepiness Scale (SSS) ratings and MSLT results indicate that the subjects were more tired before L/O sleep than before baseline or post-return sleep.

After the return flight, which according to FRA local time was a complete night flight, crew members retired in the afternoon for a recovery sleep of several hours. For the night-sleep periods, they went to bed more than 1h later than during baseline. As there was no social need, this behavior may be explained by a circadian phase delay resulting from the preceding adjustment to the SFO time zone. However, another reason is also conceivable: it might be assumed that recovery sleep in the afternoon leads to delayed tiredness in the evening and consequently to a later sleep time.

Objective sleep quality may be conceived as a matter of the amount and continuity of sleep. Accordingly, the typical disturbance of sleep during the adaptation night was manifested by decreased sleep efficiency, a higher number of awakenings, a longer sleep-onset latency, and a longer latency to REM sleep. Despite this impaired sleep quality, there was no increase of overall sleepiness during the day. In fact, the MSLT results provided no indication of an abnormal increase in sleep tendency during any phase of the study.

On the first L/O night subjects slept less efficiently and rated their sleep subjectively worse. The efficiency was reduced by relatively long awakenings during the second half of the night. Probably, the circadian system forced them to awake too early, e.g., because they felt hungry or had to use the bathroom. Possibly due to training or experience, they were able to fall asleep again and to compensate somewhat for the effects of shifted sleep by staying in bed longer. Thus, at the end they got even more total sleep than during the baseline night. The sleep disturbances seen during SFO1 were not as pronounced for SFO2.

However, from correlational analysis, we found that difficulties in sleep continuity during L/O increased with age, so that older crew members had to stay in bed longer than younger ones in order to get enough sleep.

The majority of the crew members took a nap before the return flight home. This short extra sleep most likely improved alertness for the following night shift (6,9). During the return flight the subjects incurred a sleep loss which may account for the good sleep experienced during the afternoon and first night after arrival in Germany. The afternoon sleep was characterized by a rebound of SWS, i.e., a short latency to stage 3 sleep and more SWS(%) than observed during baseline. During the following night a rebound of REM sleep was observed. These effects are well known as consequences of sleep deprivation. During the second night, objective as well as subjective sleep quality was reduced, very likely due to rhythm disturbances, some of which were detected in MSLT and body temperature.

The MSLT results closely reflect the 24-h profiles reported by Richardson et al (11). Nevertheless, the interpretation of MSLT results turned out to be more complicated. At least two factors seem to influence daytime sleepiness. The first is related to the time since the preceding sleep. Thus, long sleep latencies were observed whenever subjects had recently awakened from a major sleep regardless of time of day. After pilots awoke, they were unlikely to fall asleep during the following SLT. A second factor reflects a circadian influence on sleep tendency. It is characterized by relatively high sleepiness around midday and an increase in sleep latency in the late afternoon. The increase occurred at the same time (GMT) during the baseline and L/O periods. Consequently, we conclude that the underlying sleepiness rhythm might have shifted too slowly to be disclosed after the westbound flight. The observation of an SLT-rhythm delay after the return flight supports the view that the delayed nocturnal sleep in Cologne is related to the observed delay in the circadian rhythmicity of other physiological functions.

Rhythm disturbances. As expected, our results provided evidence that the time-zone transition associated with flight duty on the FRA-SFO route leads to (a) desynchronization of internal body time from the external timing system and (b) to an internal dissociation between the circadian rhythms of different body functions. Both effects influence sleep behavior. This was most clearly shown by the early and prolonged awakenings of the first L/O sleep period. Most likely these awakenings were triggered by the circadian system, which was out of phase with the new local time by an advance of more than 5h (according to the acrophase of the temperature rhythm). Due to progressive synchronization, awakenings occurred at later hours and became shorter or disappeared during the second nocturnal sleep period. In contrast to awakenings, sleep-onset time is influenced by other factors in addition to circadian rhythmicity, e.g., activation, conscious efforts, and in particular the duration of the preceding awake period. Therefore, the advance of sleep onset during L/O may not reflect the "true" shift of the underlying rhythm, but more probably is the result of several influences. This could also explain our findings from the sleep surveys that sleep-onset time in the laboratory was earlier than in the hotel.

For the post-return period we were also able to demonstrate a desynchronization of circadian rhythms from local time. In contrast to the SFO L/O, however, it was a delay and the extent was less pronounced (ca. 2h). Theoretically, this again should affect sleep; but awakenings would be expected at the beginning of the sleep period, or a delayed onset of sleep should occur. As already mentioned, our EEG data confirmed this assumption for the second night, whereas the findings for the first nocturnal sleep were confounded by the effects of sleep deprivation and the preceding afternoon sleep.

Our rhythm results reveal one other important operationally relevant fact. Due to the relatively short L/O period, synchronization with SFO time was not completed. In fact, the circadian system had only shifted by about 5h before the return flight commenced. Thus, readaptation to home-base time would be comparable to conditions after the transition of five time zones. As a result, desynchronization on the second post-return day was not more than about 2.5h, which is below the limit (3h) that is accepted as critical in terms of operational significance (13,15).

CONCLUSIONS

We were able to show that the time zone transition associated with FRA-SFO flight duty leads to a desynchronization of the circadian system. According to our hypothesis, rhythm disturbances would cause major difficulties for sleep quality and quantity. However, from our subjective and objective sleep data we must conclude that the observed desynchronization produced only moderate effects upon sleep. During L/O, early and extended awakenings led to a reduction of sleep efficiency, but did not cause sleep deficits. Sleepiness during the diurnal phase was not elevated, but quite normal. Night duty during the return flight caused sleep deprivation which in turn resulted in good sleep during the first night at homebase; however, impaired sleep occurred on the second night, at least in part caused by desynchronization. Nevertheless, resynchronization to homebase time appears fast enough that pilots can achieve a reasonable re-adjustment before commencing flight duty again.

Obviously, these conclusions cannot be generalized. In the present form, our results consider only mean values and do not address individual cases where the situation may be far less favorable than on the average. Finally, our conclusions apply only to a duty schedule that is relatively short and not especially complex. There are other duty patterns that require operations with much more complex schedules involvi.g many more days away from home base and more transit stops in different time zones. From these we may anticipate a quite different picture as to sleep problems and rhythm disturbances. Finally, it should be mentioned that the present results fit well into the line of our previous studies in aircrews and complement the results that have been obtained from short-haul (4) as well as from long-haul flight schedules (2,3,12).

ACKNOWLEDGEMENTS

The authors are very much obliged to the staff of the Stanford University Sleep Research Center who carried out the sleep and MSLT recordings during the L/O period in the U.S. We wish to express our sincere gratitude to the participating crew members for their exceptional motivation and outstanding cooperation. Special thanks go to Ute Brandl, Gabriele Kraus, and Paul Esser for their valuable assistance. This research was supported by the U.S. National Aeronautics and Space Administration (NASA Cooperative Agreement NCC2-302 with Stanford University School of Medicine) and the German Ministry of Transport.

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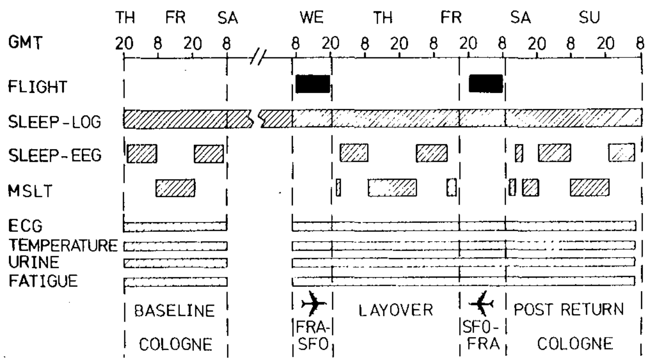

Figure 1.- Overview of time lines for the data collection of the flight schedule Frankfurt-San Francisco.

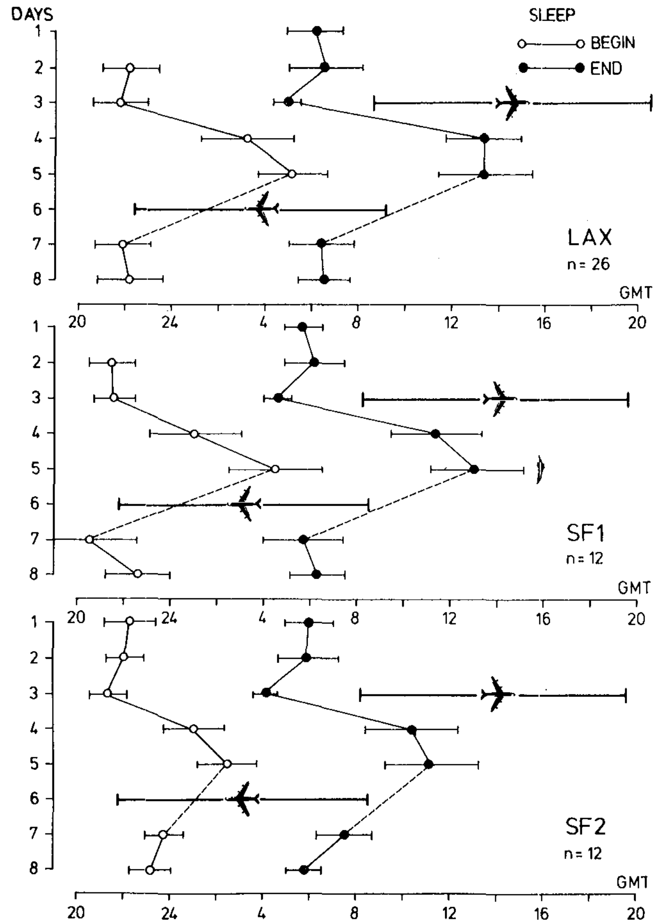

Figure 2. Subjective ratings of beginning and end of sleep during control, layover and post-return nights. Presented are means (±S.D.) of the three different groups. (Numbers of days at the vertical axis refer to days beginning at 2400 GMT.)

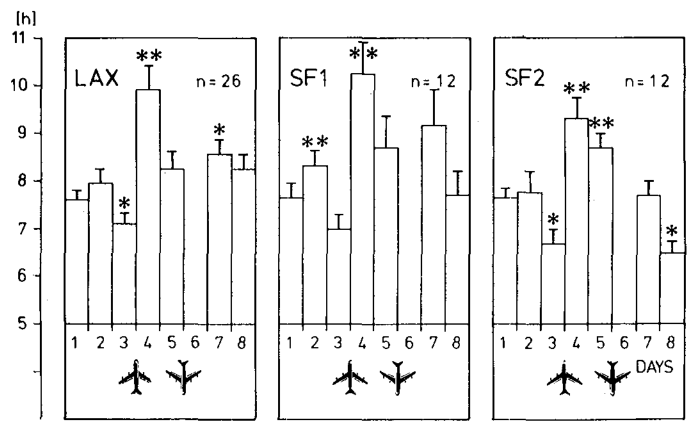

Figure 3. Subjective ratings of sleep duration during control, layover, and post-return nights (means +/- S.E.). * p<=0.05; ** p<=0.01 for differences from sleep period of day 1.

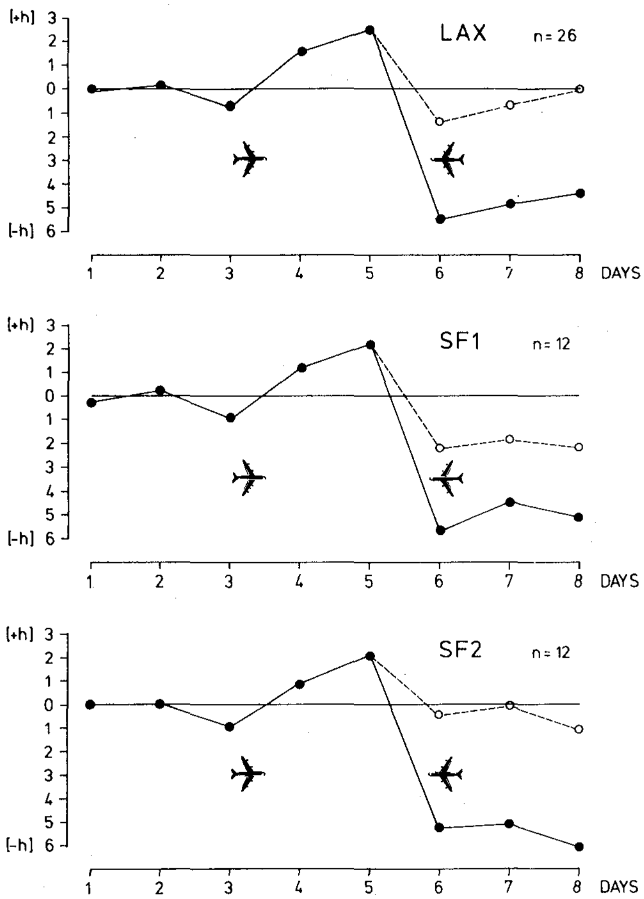

Figure 4. Sleep balance: accumulated deviations of subjectively rated sleep duration from control nights (day 1 and day 2). Values do not include short extra sleep periods (naps). Open circles and dashed lines represent sleep balance including sleep in the afternoon following return flight.

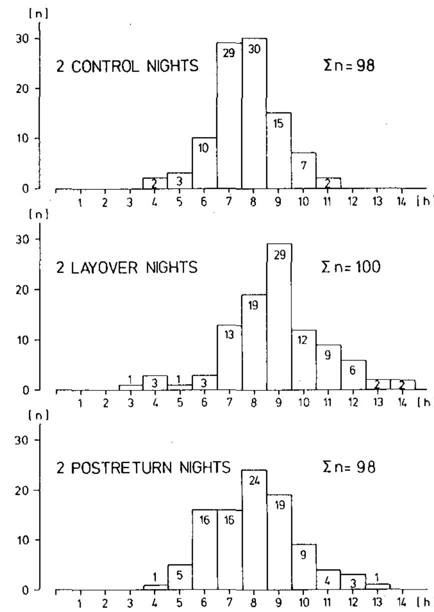

Figure 5. Histogram of subjectively rated sleep duration of all three groups together. Combined are two nights each from the control, layover and post-return period. (Note: sleep period immediately preceding flight schedule not included).

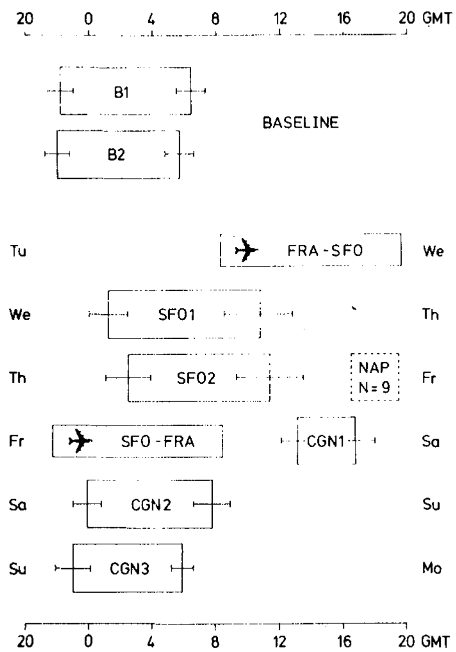

Figure 6. Time schedule of sleep periods and flights. Time axis is chosen from 2000 to 2000 GMT. Bars for sleep periods show standard deviation for light off and on. Baseline recordings were taken several days before flight to SFO.

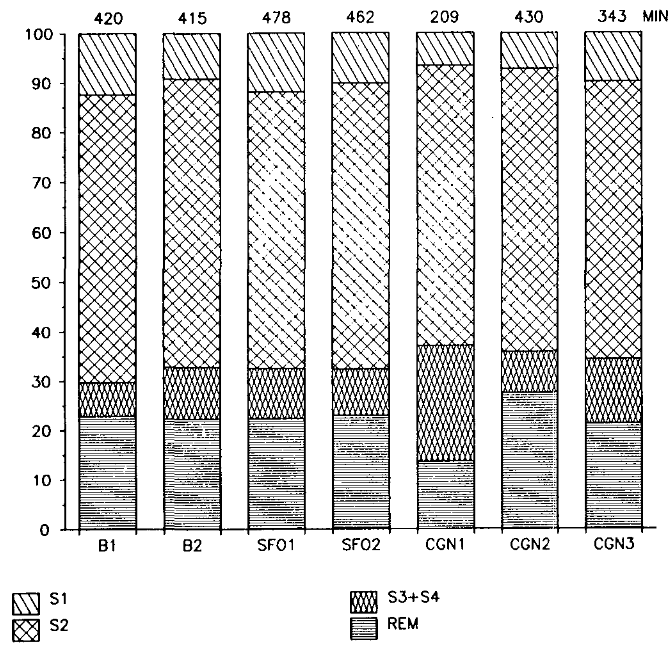

Figure 7. Mean percentage of total sleep time (TST) for sleep stages. Means (N = 12) are shown for seven sleep periods. Absolute TST values (min) are given on top of the bars.

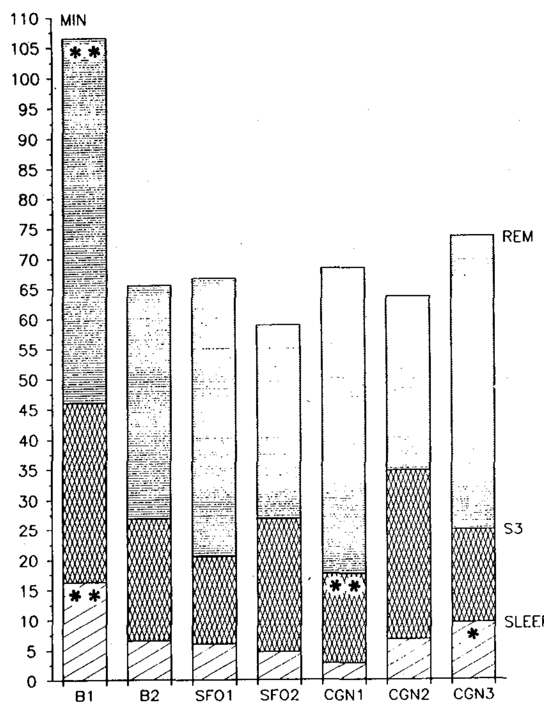

Figure 8. Median (N=12) latencies to the first ten minutes of persistent sleep, to slow-wave sleep (S3), and to REM sleep. Significant differences from baseline values (B2) are indicated (*p<0.05, **p<=0.01, Wilcoxon-matched-pairs-signed-rank test).

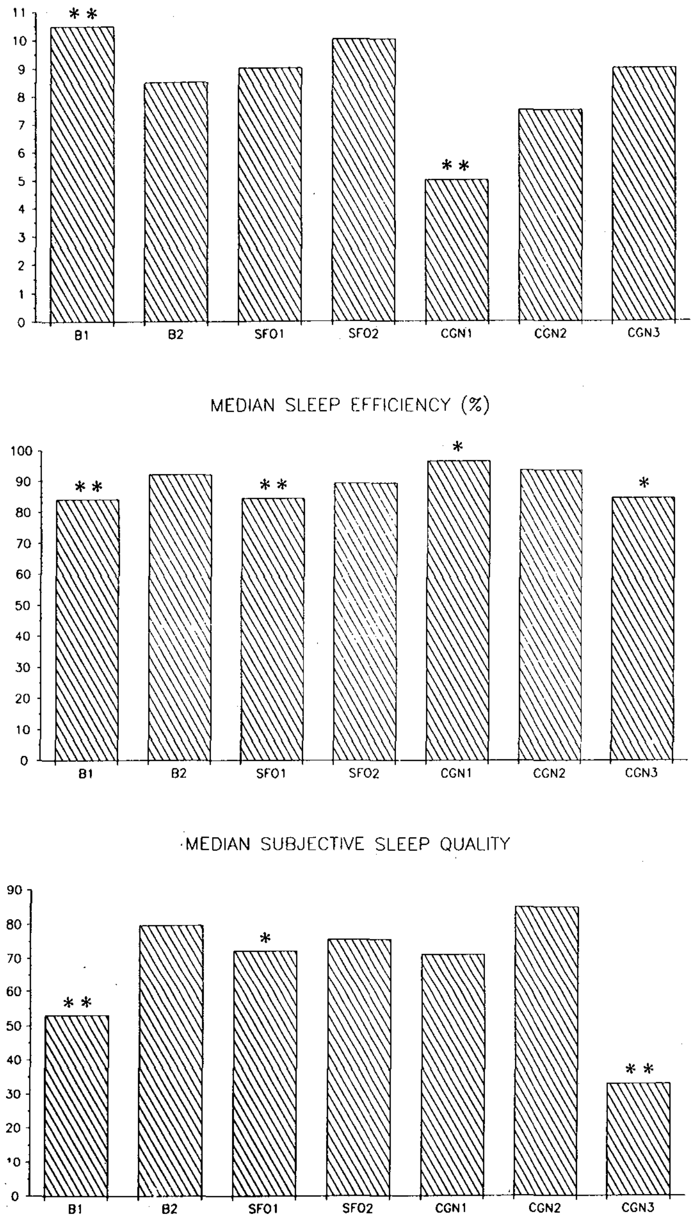

Figure 9. Sleep efficiency, number of awakenings, and subjective ratings of sleep quality for seven sleep periods. Significant differences from baseline (B2) are indicated (* p<=0.05, ** p <= 0.01).

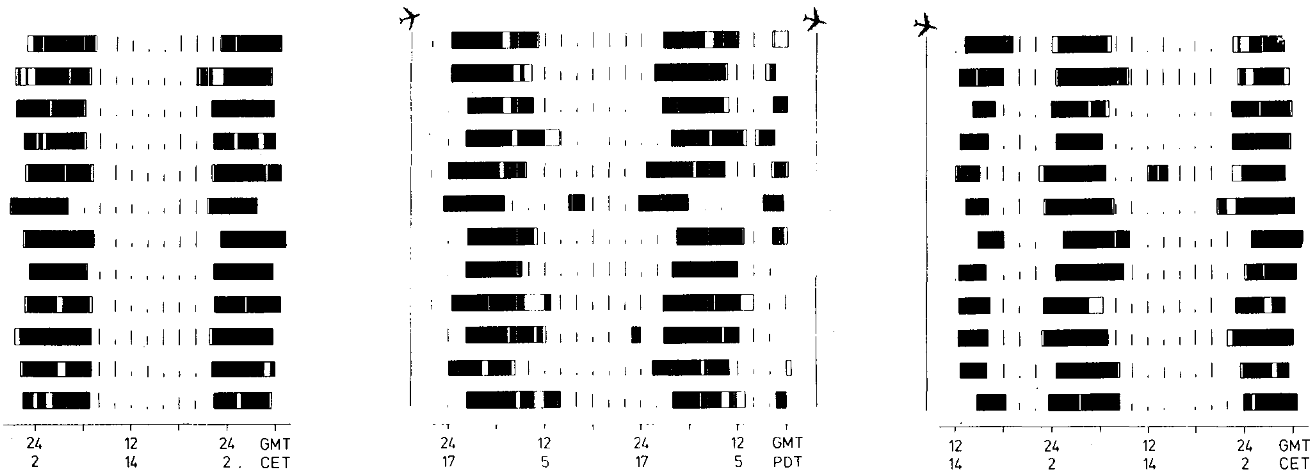

Figure 10. Sleep pattern and multiple sleep latency test (MSLT). Sleep periods in black, wake times in white. Vertical lines between sleep periods represent MSLT; their height is sleep latency in minutes.

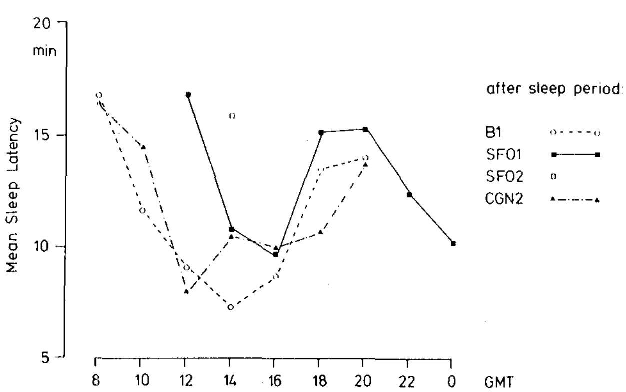

Figure 11. Mean MSLT after sleep periods B1, SFO1, SFO2, CGN2.

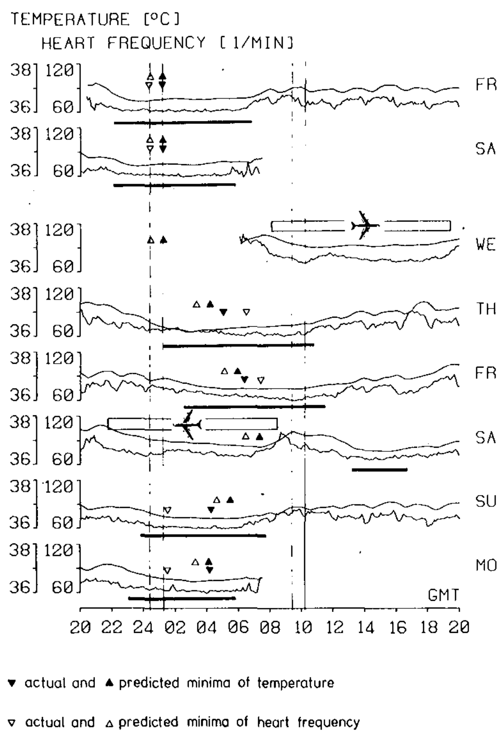

Figure 12. Means for temperature (upper curves) and heart rate (lower curves) before, during and after flights. Vertical lines indicate position of minima during baseline and after complete shift by 9h (solid lines: temperture; dashed lines: heart rate).

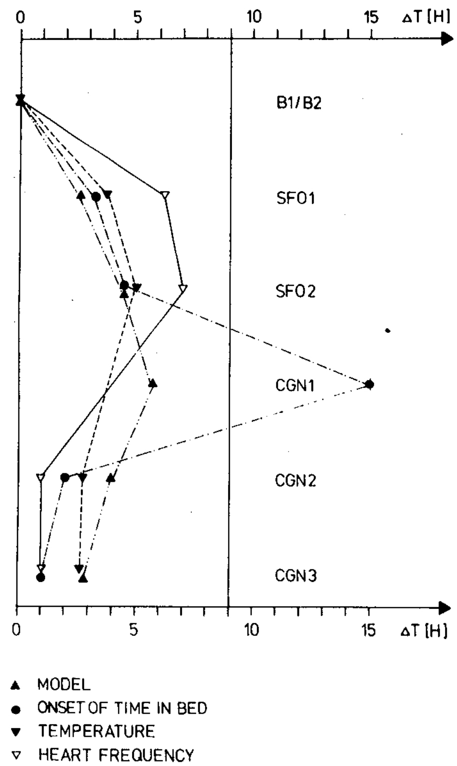

Figure 13. Shifts in acrophases relative to baseline position.

1. Report No. NASA TM-88231	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle CREW FACTORS IN FLIGHT OPERATIONS: IV. SLEEP AND WAKEFULNESS IN INTERNATIONAL AIRCREWS		5. Report Date February 1986
		6. Performing Organization Code
7. XXXXXX Editor: R. Curtis Graeber		8. Performing Organization Report No. A-86182
9. Performing Organization Name and Address Ames Research Center Moffett Field, Calif. 94035		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code 505-67-01
15. Supplementary Notes Point of Contact: R. Curtis Graeber, Ames Research Center, MS 239-21, Moffett Field, CA 94035 (415) 694-5792 or FTS 464-5792		

16. Abstract

The research reported here represents the first attempt to obtain physiological recordings of sleep and wakefulness in operating international (B-747) flight crews. It is the result of a joint cooperative effort among researchers from four countries (Japan, the United Kingdom, the United States, and West Germany) and four international air carriers. Crews spent their first layover (48 h) of a trip in a sleep laboratory where standardized EEG, EOG, and EMG sleep recordings were carried out whenever the volunteers chose to sleep. During periods of wakefulness they underwent multiple sleep latency tests every 2 h in order to assess daytime drowsiness. The same standardized recordings were carried out at a home-base laboratory before departure. Approximately four crews each participated in flights over 7-9 time zones on five routes: SFO-NRT, NRT-SFO, SFO-LHR, LHR-SFO, FRA-SFO. All participants were encouraged to use whatever sleep-wake strategies they thought would provide them with the most satisfactory crew rest. Overall, layover sleep quality was not seriously disturbed, but eastward flights produced greater sleep disruption. The contributors of individual factors and the usefulness of various sleep strategies are discussed in the individual laboratory reports and in an operational summary.

17. Key Words (Suggested by Author(s))		18. Distribution Statement	
sleep, circadian rhythms, fatigue, EEG, human factors, desynchronization, jet lag, pilots, flight crews, crew rest, flight operations, airlines polysomnography		Unlimited Subject category: 52	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 114	22. Price* A06

*For sale by the National Technical Information Service, Springfield, Virginia 22161

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