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

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LIST OF ACRONYMS

ECG	electrocardiogram
EDT	Eastern daylight time
EEG	electroencephalogram
EST	Eastern standard time
FARs	Federal Aviation Regulations
GMT	Greenwich mean time
ILS	instrument landing system
IMC	instrument meteorological conditions
REM	rapid eye movement
S.D.	standard deviation
VMC	visual meteorological conditions

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SUMMARY

Seventy-four pilots were monitored before, during, and after 3- or 4-day commercial short-haul trip patterns. The trips studied averaged 10.6 hr of duty per day with 4.5 hr of flight time and 5.5 flight segments. The mean rest period lasted 12.5 hr and occurred progressively earlier across successive days. On trip nights, subjects took longer to fall asleep, slept less, woke earlier, and reported lighter, poorer sleep with more awakenings than on pretrip nights. During layovers, subjective fatigue and negative affect were higher, and positive affect and activation lower, than during pretrip, in-flight, or posttrip. Pilots consumed more caffeine, alcohol, and snacks on trip days than either pretrip or posttrip. Increases in heart rate over mid-cruise were observed during descent and landing, and were greater for the pilot flying. Heart-rate increases were greater during takeoff and descent under instrument meteorological conditions (IMC) than under visual meteorological conditions (VMC). The following would be expected to reduce fatigue in short-haul operations: regulating duty hours, as well as flight hours; scheduling rest periods to begin at the same time of day, or progressively later, across the days of a trip; and educating pilots about alternatives to alcohol as a means of relaxing before sleep.

1.0 OPERATIONAL OVERVIEW

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

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

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

The trips studied were selected to provide information on the upper range of fatigue experienced by pilots in predominantly daytime and evening operations. Common features were early report times and long duty days with multiple flight segments (average 5.5 per day). Daily duty durations averaged 10.6 hr which included, on average, 4.5 hr of flight time. One third of all duty periods studied were longer than 12 hr. The mean rest-period duration, as defined by the

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pilots in their daily logs, was 12.5 hr. The mean rest-period duration calculated from the last wheels-on of one duty day to the first wheels-off of the next duty day was significantly longer (14.0 hr). Overnight layovers after successive duty days occurred progressively earlier across most trips.

On trip nights, subjects reported taking about 12 min longer to fall asleep, sleeping about 1.2 hr less, and waking about 1.4 hr earlier than on pretrip nights. They also rated their sleep on trips as lighter and poorer overall, and reported significantly more awakenings. In contrast, in the laboratory, sleep restriction results in more rapid sleep onset and more consolidated sleep (refs. 1–4). The longer sleep latencies and more frequent awakenings reported by pilots on trips may reflect the commonly reported need to "spin down" after coming off duty and the disruptive effects of sleeping in unfamiliar environments. The fact that sleep during trips was reported not only as shorter but also as more disturbed, suggests that the effects of this sleep restriction on subsequent daytime sleepiness, performance, and mood may be greater than those reported in laboratory studies with similar levels of sleep restriction.

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

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

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

Heart rates during takeoff, descent, and landing were compared with values during mid-cruise for 72 pilots during 589 flight segments. Increases in heart rate were greater during descent and landing for the pilot flying. The difference between flying and not flying during descent was greater for first officers than for captains. Heart-rate increases were greater during takeoff and descent under instrument flight conditions than under visual flight conditions. On the basis of similar findings, Ruffell-Smith proposed that the number of segments flown per day should be regulated (ref. 5).

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

2.0 INTRODUCTION

This report is the second in a series on the physiological and psychological effects of flight operations on flight crews, and on the operational significance of these effects. These studies were conducted in response to a congressional request. The original response to this request was a workshop held at NASA Ames Research Center in August 1980, which included representatives from the scientific community, airline pilots, and airline management (ref. 6). This group concluded that "...there is a safety problem, of uncertain magnitude, due to transmeridian flying and a potential problem due to fatigue in association with various factors found in air transport operations."

This consensus was supported by the results of an initial review of reports to NASA's Aviation Safety Reporting System (ref. 7). Of 2,006 air transport crewmember error reports received between 1976 and 1980, 426 reports (i.e., 21.2%) mentioned factors related, directly or indirectly, to fatigue. Those incidents that explicitly cited fatigue as a factor (4%) tended to occur more frequently between 0000 and 0600, and during the descent, approach, and landing phases. Subsequent to this survey, from July 1980 to August 1984, an additional 261 incidents were reported that were directly related to fatigue. These incidents occurred during flight schedules involving multiple time-zone shifts (long-haul operations) and during trips without time-zone changes (short-haul operations) but with long duty days, numerous flight segments per day, and night operations (ref. 8).

A survey of the literature (1972–1980) was also conducted to examine the psychophysiological effects of altered circadian-rhythm phase relationships and their possible effects on pilot performance (ref. 9). This updated a previous review of literature on human performance in the aviation environment (ref. 10). From these preliminary reports, two points requiring further action became apparent. First, although there was a considerable body of potentially applicable data available from laboratory studies, the necessary complementary studies in the operational environment were lacking. This undermined the credibility of any recommendations made on the basis of existing information. Second, it was evident that most of the existing information was not readily accessible to the aviation community, regulatory authorities, or the flying public.

Consequently, the Flight Human Factors Branch at Ames Research Center has undertaken extensive field studies of both short-haul and long-haul flight operations, with the following goals:

1. Document physiological and psychological responses of pilots before, during, and after duty cycles, (with particular attention to circadian physiology, sleep quantity and quality, and subjective fatigue and mood)
2. Identify operational factors that have significant effects on the psychophysiological responses to trips
3. Identify pilot attributes that might determine an individual's responses to the operational requirements of air transport flying
4. Identify adaptive strategies that enable individuals to cope successfully with operational requirements

In addition to these observational field studies, full-mission simulation studies are being conducted, in which it is possible to combine greater experimental control with high fidelity to real flight operations. The simulator studies are designed to address the following issues:

1. Determine if behavioral and crew-performance changes are associated with certain types of duty cycles
2. Determine the operational significance of any changes, with regard to flight safety and operational efficiency
3. Identify adaptive strategies used on the flight deck that enable crews to cope more successfully with the requirements of various duty cycles
4. Determine whether individual pilot attributes contribute to crew coordination and performance

The scope of the entire program is summarized in figure 1.

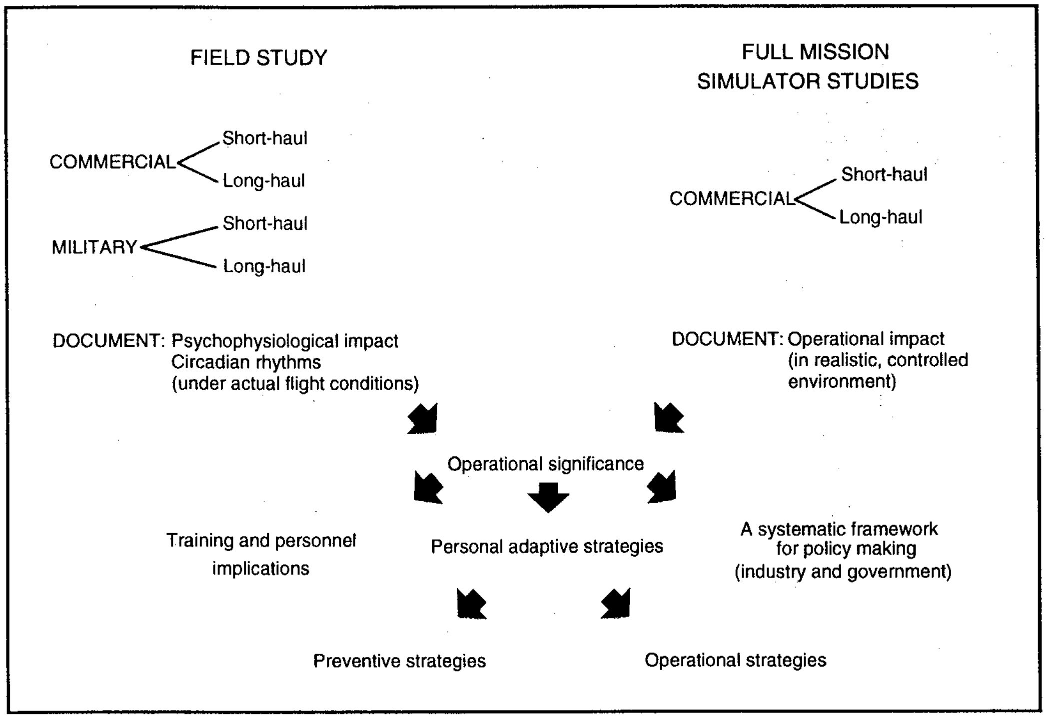


Figure 1. Overview of studies designed to examine issues of crew factors in flight operations.

The applicability of previous studies pertaining to the physiological and psychological effects of flight operations on cockpit crews is restricted for a variety of reasons (ref. 11). From a scientific point of view, laboratory studies are advantageous because they permit systematic manipulation of the variables of interest, and control of extraneous factors. However, extrapolation of laboratory findings to the operational setting has often met with reasonable skepticism from airline flight-operations personnel. The relevance of subtle behavioral phenomena, as opposed to straightforward biomedical effects, is particularly contentious, especially if increased operating costs are involved. Consequently, the advantages of laboratory research must be balanced against the real problem of its generalizability.

From an operational point of view, the most credible data are those collected from crew-members actually flying aircraft. However, cockpit access during line-flying operations is, by necessity, highly restricted, and field studies are logistically difficult. Most in-flight research (with the exception of military studies) has concentrated on the effects of acute stress on the autonomic nervous system during high workload situations (e.g., refs. 5, 12–22).

A key element of commercial short-haul operations—multiple daily flight segments—was examined in controlled in-flight experiments by Howitt et al. (ref. 14). The effects of fatigue on the electroencephalogram (EEG) and electrocardiogram (ECG) during flight were examined under different workload conditions. A single pilot flew repetitions of the same three-part flight plan: (1) an instrument approach flown with and without the use of the autopilot and flight director, (2) a coupled instrument landing system (ILS) approach followed either by an overshoot or visual landing, and (3) a simulated engine failure upon takeoff. All flights originated and terminated at the same airport. The fatigue condition consisted of flights that followed either 30 hr of sleep deprivation or prior iterations of the same flight earlier in the day.

The physiological recordings substantiated the subjective feelings of fatigue; that is, increased workload produced a significantly smaller increase in EEG activity during fatigue flights. However, the combined statistical treatment of both fatigue conditions makes it impossible to determine if the fatigue induced by sleep loss affected the EEG differently than the fatigue associated with time-on-task. Behavioral observations by the pilot and the training captain occupying the right seat indicated that only the sleep-deprived condition produced a marked narrowing of attention and a tendency to commit gross errors caused by short-term memory losses whenever attention was diverted. Fatigue produced by repeated flights on the same day was characterized by boredom and a lack of concern about maintaining precision on the instruments. Although less compelling than quantitative data, these observations are the only behavioral data in the open literature on actual flying proficiency as a function of fatigue.

Ruffell-Smith reported increases in heart rate during takeoff, approach, and landing of captains flying commercial Trident aircraft on selected short-haul flights (ref. 5). On the basis of these findings, he made the recommendation that the number of daily flight segments should be included as a factor in the design of flight-crew schedules.

To date, only one study has examined the psychophysiological responses of commercial flight crews flying typical short-haul trips with multiple takeoffs and landings for several days. Klein et al. monitored physiological indices of acute stress in 11 B-737 crews across two different 3-day trips involving either a 0600–1400 or a 1200–2300 schedule (ref. 17). Flight-related increases (15%–20% above rest values) were found in pulse and respiration rate, comparable to those reported for other moderate workload activities (e.g., intense administrative work or driving a car a long distance). The amount of increase did not change with successive days on the trip, suggesting that there was no accumulation of stress. Concentrations of urinary catecholamines and 17-OCHS generally increased substantially during flight and across each trip day, relative to control values. An observed increase in concentration from day 1 to day 2 was probably a result of the lower workload on day 1. Despite the apparent lack of cumulative effects, hormone levels remained high during nighttime sleep. This may indicate that the effects of flying short-haul trips dissipated only slowly, or that the hormone response continued during the night. It should be noted that the subjects in this study were relatively young males (mean for pilots = 32.2 yr; for copilots = 26.8 yr).

All previous in-flight research on the psychophysiological effects of flight operations has focused on the individual pilot. This ignores the critical dimensions of integrated crew performance in multi-pilot crews (ref. 11). Very few incidents or accidents are the result of a single gross error by one individual (ref. 23). Full-mission simulation studies can provide the necessary realism for studies of group process and performance (refs. 24, 25). In addition, in full-mission simulations, it is possible to make considerably more-detailed performance measurements than in line-flying operations. Such data are essential for assessing the operational significance of the psychophysiological changes induced by flight operations. Full-mission simulation studies (ref. 26) were therefore conducted in parallel to the short-haul field study reported here (fig. 1). Our conceptualization of the various factors influencing individual and crew performance is summarized in figure 2.

Fatigue has been defined in a variety of ways by different researchers. A major problem has been the failure of many studies to demonstrate a relationship between subjective fatigue and measurable changes in performance. The problems include identifying fatigue-inducing factors and quantifying the resulting fatigue; the task characteristics of the performance measures used; and effects of boredom and motivation on performance. Two interrelated lines of research, which focus more narrowly, are of interest because they provide a more cohesive picture, and because they have relevance to aviation operations: the effects of prolonged work or duty and the effects of reductions in sleep quantity or quality on subsequent alertness and performance. In commercial air transport operations, regulation of the number of flight hours per day attests to the perceived importance of the fatiguing effects of prolonged work, and regulation of the duration of rest times reflects the perceived importance of adequate sleep.

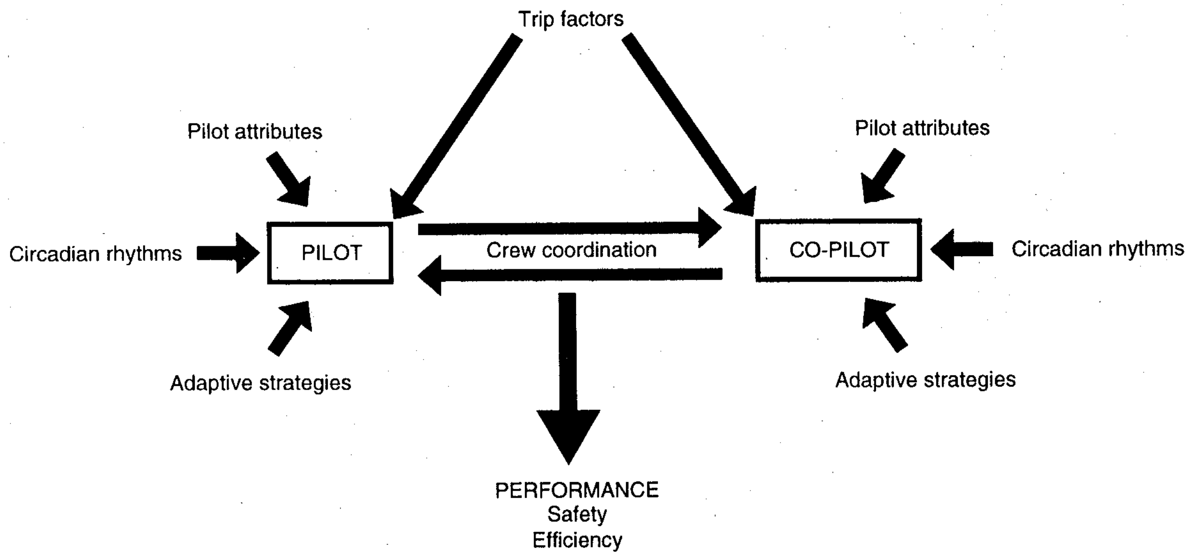


Figure 2. Conceptual model of factors influencing crew performance in multi-pilot cockpits.

There are well-established empirical data indicating perceptual and motor deterioration, and disintegration of skill on complex tasks during prolonged performance (reviewed in ref. 27). Deterioration is most readily demonstrated on simple, repetitive tasks. For more skilled tasks, a progressive disorganization in performance is observed, together with increasing variability of response and probably a change in strategy as the task continues. Lowering of performance standards and an increased willingness to take risks have also been observed during prolonged performance. There is evidence, however, that motivation can reduce these effects, especially in real-life situations but also in the laboratory.

Prolonged performance is often accompanied by sleep loss. In laboratory studies (reviewed in ref. 28), sleep loss has been found to be associated with increasingly variable performance (more lapses), cognitive slowing, and impaired immediate and delayed recall of information acquired when sleep deprived. The longer the duration of the task, the less sleep deprivation is required before performance decrements become evident; that is, sleep loss and prolonged performance may have synergistic effects in degrading performance.

Experimental manipulations usually involve greater acute sleep loss (one or more nights of total sleep deprivation) than would normally be expected in commercial short-haul flight operations. However, flight crews potentially could accumulate a significant sleep debt over several nights of shortened or disturbed sleep. The effects of such cumulative sleep loss on performance are not well documented, although the level of physiological sleepiness (measured by the speed of falling asleep in a soporific environment) has been shown to increase with as little as 1 hr per night of sleep restriction (ref. 29).

Since fatigue is ill-defined, and its effects sometimes elusive to measure, we took the approach of monitoring many variables in order to assess the effect of flying commercial short-haul air transport operations. In view of the potential for performance decrements with increasing time-on-task, particular attention was given to flight and duty durations. In view of the performance decrements associated with sleep loss, changes in sleep and the effects of layover duration and timing were also of special concern.

We are indebted to the management and pilot associations of the participating airlines and to Mike Baetge and Kathy Craig for invaluable services as cockpit observers; to Carol Carrington and Mary Lally for field equipment support and data entry; Bill Carson, Kevin Gregory, Donna Miller, De Nguyen, and Herb Schreiber for data processing and programming support; and to Drs. Roger Remington, Charles Billings, and Donald Hudson for valuable discussion and comment. This study would not have been possible without the substantial commitment and enthusiastic cooperation of the pilot volunteers.

3.0 METHODS

3.1 Subject Recruitment

Once agreement had been obtained from both pilot unions and airline management, all of the pilots at the selected domiciles (i.e., airports at which the pilots were based) were sent a copy of a NASA brochure explaining the purposes of the study and outlining what would be involved if they decided to participate. In both of the airlines studied, pilots bid for monthly trip schedules, which were then awarded on the basis of seniority. NASA received copies of the monthly schedules in advance. Three- or 4-day trips were selected that appeared the most challenging in terms of one or more of the following factors: number of segments flown in a day, duration of enroute layovers, duration and timing of the duty day, and short nighttime layovers. The crew-scheduling office for each airline then provided NASA with the names of pilots who had been awarded the selected trips for the following month. These pilots were initially contacted by telephone and briefed on the details of the study. Participation was completely voluntary and there was no disclosure by NASA of the names of individuals who did or did not participate. This method of subject recruitment minimized the problem of sample bias, since the subjects were not volunteers responding to an open request for participation.

Protecting the confidentiality of the volunteers was a major consideration in the design of the study and of the corresponding database, both to safeguard the individuals involved and to encourage honesty in reporting. Subjects were first met by a NASA representative (one of the cockpit observers) either in their own homes or at their assigned domicile. During the introduction phase, they were given a card with their subject identification (ID) number for the study. All data and other information pertaining to their participation in the study were identified only by this number, and no record was kept of which ID was issued to which pilot. In addition, trips were identified only by month, not by date or trip number. This ensured that data could never be traced to a particular individual. The only way to contact a subject subsequently, with regard to his participation in the study, was to broadcast a request for the subject with that particular ID number to contact the NASA investigators; in other words, subsequent contact was entirely voluntary. (This was done rarely, e.g., to obtain information omitted in the background questionnaire—discussed later in this section.) These protective measures were evidently satisfactory to the pilots since the overall rate of refusal to participate was only 15%, and confidentiality was never cited as a concern. The only incentives offered for participation were passes to observe space shuttle launchings at Kennedy Space Center, a NASA certificate of appreciation, and the opportunity to view and discuss personal physiological data.

3.2 Data Collected

Volunteers undertook the participation schedule described in table 1.

It was not always possible to meet subjects before they reported for duty on the first day of the trip. In such cases, the introductory phase took place just before the start of duty, and every effort was made to obtain additional days of recording posttrip, in order to ensure adequate baseline data for comparison with trip data.

Table 1. Subject Participation Schedule

	Introduction	Baseline	Trip	Recovery
Location	Base/home	Home	In-flight and layover	Home
Duration	2 hr	1–2 days	Line of flying	Up to 3 days
Activity	•Briefing •Background Questionnaire	•Vitalog PMS-8 •Daily log •Fatigue and mood	•Vitalog PMS-8 •Daily log •Fatigue and mood •NASA cockpit observer	•Vitalog PMS-8 •Daily log •Fatigue and mood

3.2.1 Background Questionnaire

At some time during the study, preferably during the introductory phase, subjects completed a background questionnaire compiled to obtain information on life-style variables, sleep and nutritional habits, and personality profiles.

The Personal Attributes Questionnaire (ref. 30) was included because it has received particular attention in the group performance context. People who score high on the "Instrumentality" (I) or "goal orientation" scale in this questionnaire tend to be very performance-oriented, decisive, capable of getting the job done, and so on. People who score high on the "Expressiveness" (E) or "group orientation" scale tend to be sensitive to the feelings of others, warm in interpersonal relationships, and communicative. Both Instrumentality and Expressiveness have been found to be positively related to check-airman ratings of flight-crew performance (ref. 31). Individuals who score high in both Instrumentality and Expressiveness (i.e., the combined (I+E) scale of this questionnaire) are effective in group problem-solving situations because they are able to both initiate contributions and to defer to allow the participation of others (ref. 32). There are indications that these instrumental-expressive people also have the capacity to adapt when the situation calls for flexibility.

The Work and Family Orientation Questionnaire was designed to measure achievement, motivation, and attitudes toward family and career (ref. 33). The three scales included in the background questionnaire—Work, Mastery, and Competitiveness—deal respectively with desire to work hard, desire for intellectual challenge, and desire to succeed in competitive interpersonal situations. High Work and Mastery needs, coupled with low Competitiveness, have been found to be associated with highest attainment in groups of scientists, students, and businessmen (ref. 34).

People who score high on the Extroversion scale of the Eysenck Personality Inventory (ref. 35) tend to be outgoing, uninhibited, impulsive, and sociable. The Neuroticism scale refers to general emotional over responsiveness and tendency to neurotic breakdown under stress. The Lie scale is intended to detect attempts to falsify responses. It has been suggested that extroversion and neuroticism scores may be related to individual differences in circadian rhythms in several types of performance and body temperature, and that neurotic extroverts may adjust more rapidly than other personality types to time-zone and schedule changes (ref. 36). Not all studies have been able to confirm these findings (ref. 37). In a group of Norwegian Air Force flight crewmembers, subjects who scored higher on the extroversion scale also showed larger phase delays in their rectal temperature rhythms 5 days after a 9 hr westward time-zone transition (ref. 38).

The Morningness-Eveningness Questionnaire (ref. 39) was designed to distinguish between "morning types" and "evening types." The extreme groups identified by the questionnaire apparently differ in sleep timing and in the time of day of the circadian temperature maximum. Several European studies have suggested that evening types adapt better to shift work (refs. 37, 40–42). Colquhoun has also reported that subjects with late-peaking temperature rhythms adjusted more rapidly to an 8 hr eastward transmeridian flight than subjects with early-peaking temperature rhythms (ref. 43). In our study of nine Norwegian Air Force flight crewmembers experiencing a 9 hr westward transmeridian flight, no significant correlations were found between the phase of the temperature rhythm before the trip, the magnitude of the phase delay by the fifth day postflight, and scores on the Morning/Eveningness Questionnaire (ref. 38); however, the small sample size in this study may have been a factor.

The background questionnaire also included 46 assorted questions on sleep quality and timing. Of these, 31 were asked twice, first with respect to home sleep and second with respect to sleep on layovers. These questions, as well as those relating to changes in nutrition and exercise on trips relative to home, represent self-assessments of the effects of short-haul operations.

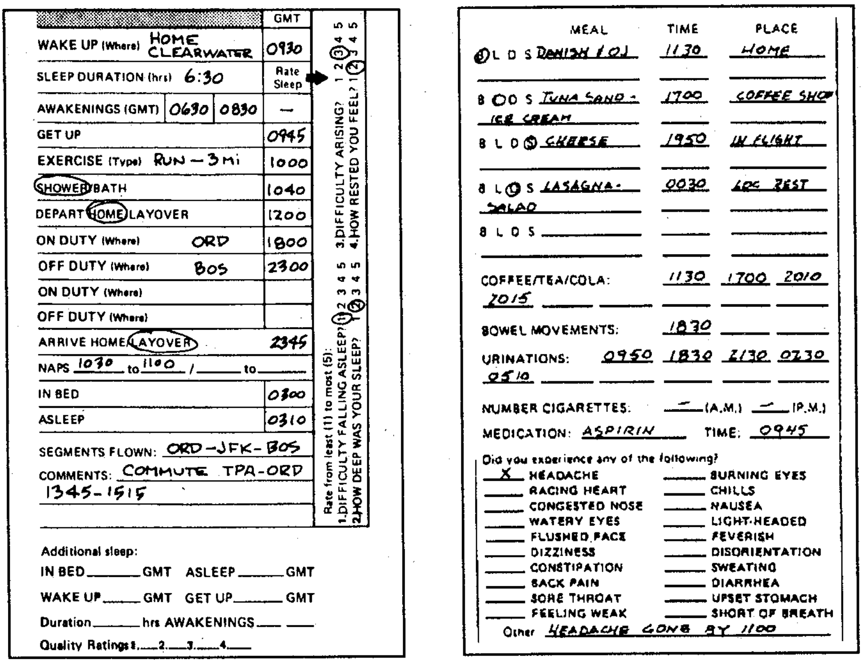
3.2.2 Physiological Data

Throughout the baseline, trip, and recovery phases of the study (table 1), subjects wore a Vitalog PMS-8 biomedical monitor (except while showering or bathing). This 8K solid-state device, weighing 12 oz and measuring 6.0 by 3.4 by 1.3 inches, was worn in a pouch on the belt. Rectal temperature (Yellow Springs Instrument, Series 400 thermistor), heart rate (r-wave detector), and activity of the nondominant wrist (watch-sized array of omnidirectional mercury tilt switches) were recorded every 2 min. Rectal temperature is the standard rhythm used to monitor the circadian system. Heart rate was monitored as a physiological indicator of the demands of different phases of flight and also to give a measure, along with wrist activity, of activation during sleep. Because the activity sensors could not be cross-calibrated, care was taken to ensure that each subject wore the same sensor throughout his participation in the study.

3.2.3 Daily Logbooks

Throughout the study, subjects kept a daily log of sleep timing and quality, naps, showers or baths, exercise, duty times, food and caffeine consumption, bowel movements, urinations, cigarettes, medications, and medical symptoms (fig. 3). Daily alcohol consumption was also noted, with each glass of beer or wine or one measure of spirits counting as one drink or unit of consumption.

Every 2 hr during the waking day, subjects also completed a 26-adjective mood checklist and estimated their fatigue by placing a mark on a 10 cm line signifying a continuum from most alert to most drowsy (fig. 4). A number of subjective fatigue measurements were considered for use in this study. Two of these, the Stanford Sleepiness Scale (ref. 44) and the Fatigue Checklist (ref. 45) would have required considerable space in the logbook for repeated testing. The latter has also been found to produce inconsistent response patterns. Consequently, the visual analog scale (10 cm line) was selected. Responses to this scale have been shown to exhibit circadian rhythmicity in the presence or absence of environmental synchronizers (refs. 46, 47). Changes in mood were assessed by the Naval Health Research Center's adjective checklist mood scale (ref. 48). Previous research has demonstrated that responses to this scale exhibit circadian rhythmicity and are sensitive to sleep loss (refs. 49, 50).



			GMT
WAKE UP (Where)	HOME CLEARWATER		0930
SLEEP DURATION (hrs)	6:30		Rate Sleep
AWAKENINGS (GMT)	0630	0830	—
GET UP			0945
EXERCISE (Type)	RUN — 3 mi		1000
[✓ SHOWER]/BATH			1040
DEPART [✓ HOME]/LAYOVER			1200
ON DUTY (Where)	ORD		1800
OFF DUTY (Where)	BOS		2300
ON DUTY (Where)			
OFF DUTY (Where)			
ARRIVE HOME/[✓ LAYOVER]			2345
NAPS 1030 to 1100 / ____ to ____			
IN BED			0300
ASLEEP			0310

SEGMENTS FLOWN: ORD-JFK-BOS

COMMENTS: COMMUTE TPA-ORD 1345-1515

Rate from least (1) to most (5):

1.DIFFICULTY FALLING ASLEEP? [✓ 1] 2 3 4 5
2.HOW DEEP WAS YOUR SLEEP? 1 [✓ 2] 3 4 5
3.DIFFICULTY ARISING? 1 2 [✓ 3] 4 5
4.HOW RESTED YOU FEEL? 1 [✓ 2] 3 4 5

Additional sleep:
IN BED ______ GMT ASLEEP ______ GMT
WAKE UP ______ GMT GET UP ______ GMT
Duration ______ hrs AWAKENINGS ____ ____
Quality Ratings 1.___ 2.___ 3.___ 4.___

MEAL	TIME	PLACE
[✓ B] L D S DANISH & OJ	1130	HOME
B [✓ L] D S TUNA SAND - ICE CREAM	1700	COFFEE SHOP
B L D [✓ S] CHEESE	1950	IN FLIGHT
B L [✓ D] S LASAGNA - SALAD	0030	LOC REST
B L D S		

COFFEE/TEA/COLA: 1130 1700 2010 2015

BOWEL MOVEMENTS: 1830

URINATIONS: 0950 1830 2130 0230 0510

NUMBER CIGARETTES: — (A.M.) — (P.M.)

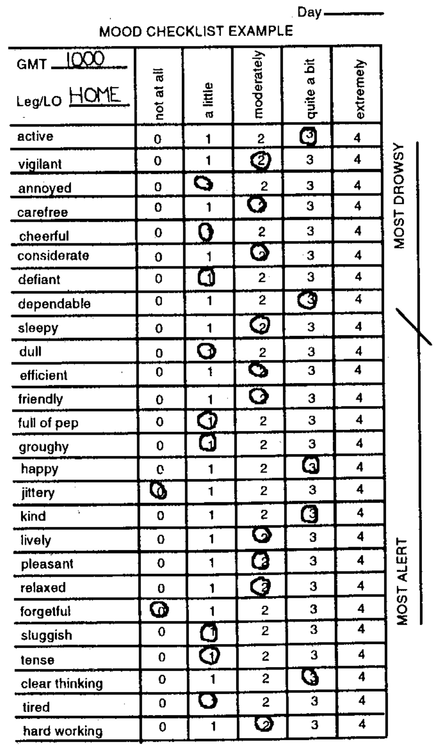
MEDICATION: ASPIRIN TIME: 0945

Did you experience any of the following?

X	HEADACHE		BURNING EYES
	RACING HEART		CHILLS
	CONGESTED NOSE		NAUSEA
	WATERY EYES		LIGHT-HEADED
	FLUSHED FACE		FEVERISH
	DIZZINESS		DISORIENTATION
	CONSTIPATION		SWEATING
	BACK PAIN		DIARRHEA
	SORE THROAT		UPSET STOMACH
	FEELING WEAK		SHORT OF BREATH

Other HEADACHE GONE BY 1100

Figure 3. Example of logbook pages recording a subject's daily activities. One set was completed by the subject for each day that he participated in the study.



Day ______

MOOD CHECKLIST EXAMPLE

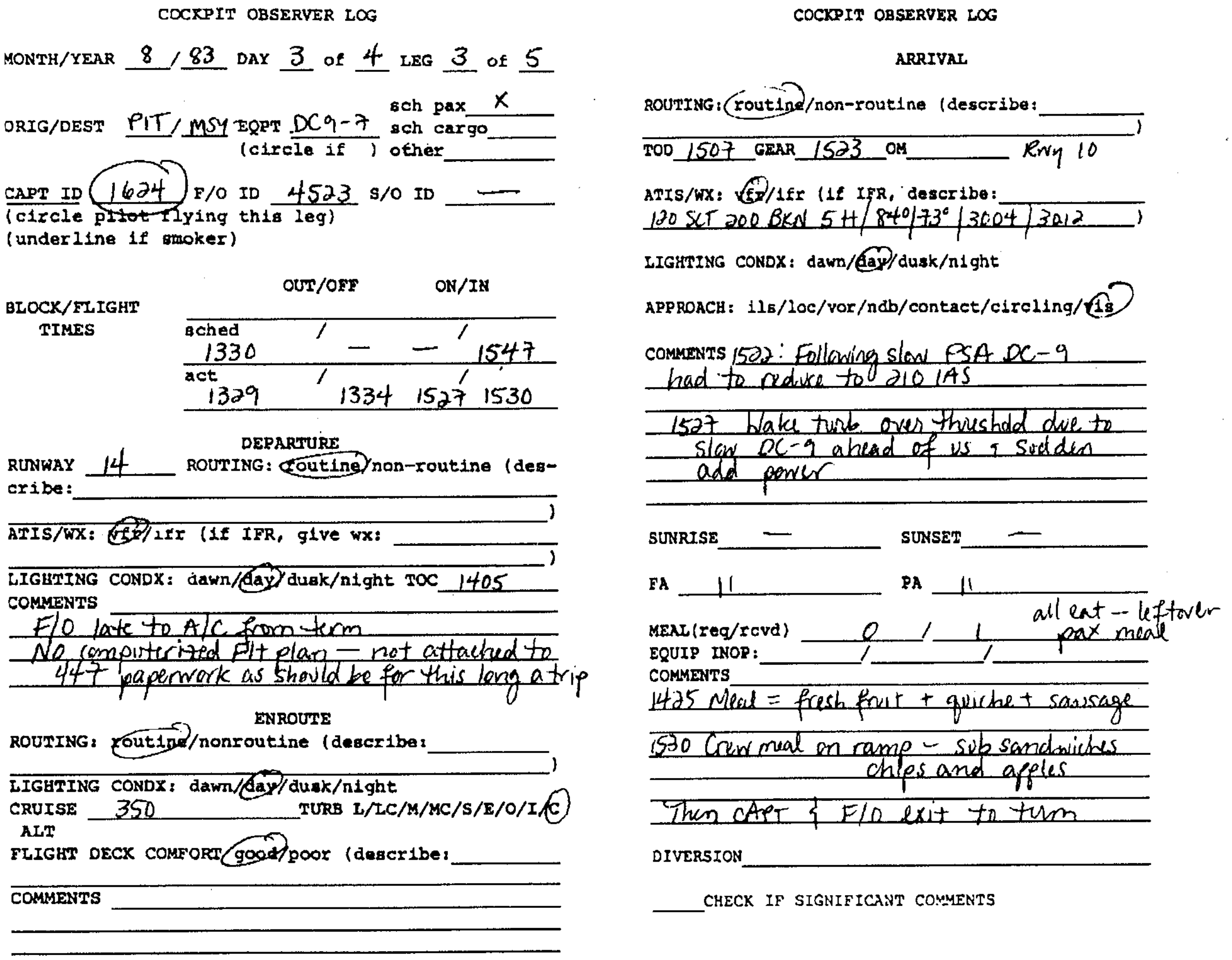
GMT 1000
Leg/LO HOME

	not at all	a little	moderately	quite a bit	extremely
active	0	1	2	[✓ 3]	4
vigilant	0	1	[✓ 2]	3	4
annoyed	0	[✓ 1]	2	3	4
carefree	0	1	[✓ 2]	3	4
cheerful	0	[✓ 1]	2	3	4
considerate	0	1	[✓ 2]	3	4
defiant	0	[✓ 1]	2	3	4
dependable	0	1	2	[✓ 3]	4
sleepy	0	1	[✓ 2]	3	4
dull	0	[✓ 1]	2	3	4
efficient	0	1	[✓ 2]	3	4
friendly	0	1	[✓ 2]	3	4
full of pep	0	[✓ 1]	2	3	4
groughy	0	[✓ 1]	2	3	4
happy	0	1	2	[✓ 3]	4
jittery	[✓ 0]	1	2	3	4
kind	0	1	2	[✓ 3]	4
lively	0	1	[✓ 2]	3	4
pleasant	0	1	[✓ 2]	3	4
relaxed	0	1	[✓ 2]	3	4
forgetful	[✓ 0]	1	2	3	4
sluggish	0	[✓ 1]	2	3	4
tense	0	[✓ 1]	2	3	4
clear thinking	0	1	2	[✓ 3]	4
tired	0	[✓ 1]	2	3	4
hard working	0	1	[✓ 2]	3	4

Figure 4. Example of mood-checklist/fatigue-rating page from logbook. One page was completed every 2 hr during waking day for each day subject participated in study.

3.2.4 Cockpit Observer Logs

Subjects were accompanied throughout the trip by a NASA cockpit observer, who held at least a private pilot's license and was familiar with air transport operations. The observers completed a log of operationally significant events (fig. 5) for each trip segment flown. They also met subjects in the introductory phase, instructed them in the use and care of the Vitalog PMS-8, and showed them how to complete the background questionnaire and daily logs. At the end of the trip, the observers transferred to and displayed each subject's physiological data on an Apple II Plus microcomputer, so that each subject had an opportunity to examine his own physiological data.



COCKPIT OBSERVER LOG

MONTH/YEAR 8 / 83 DAY 3 of 4 LEG 3 of 5

ORIG/DEST PIT / MSY EQPT DC9-7 sch pax X
sch cargo ____
(circle if) other ____

CAPT ID [✓ 1624] F/O ID 4523 S/O ID —
(circle pilot flying this leg)
(underline if smoker)

BLOCK/FLIGHT TIMES	OUT/OFF		ON/IN	
sched	1330	—	—	1547
act	1329	1334	1527	1530

DEPARTURE

RUNWAY 14 ROUTING: [✓ routine]/non-routine (describe: ____)

ATIS/WX: [✓ vfr]/ifr (if IFR, give wx: ____)

LIGHTING CONDX: dawn/[✓ day]/dusk/night TOC 1405

COMMENTS
F/O late to A/C from term
No computerized Flt plan — not attached to
447 paperwork as should be for this long a trip

ENROUTE

ROUTING: [✓ routine]/nonroutine (describe: ____)

LIGHTING CONDX: dawn/[✓ day]/dusk/night

CRUISE ALT 350 TURB L/LC/M/MC/S/E/O/I/[✓ C]

FLIGHT DECK COMFORT [✓ good]/poor (describe: ____)

COMMENTS ____

COCKPIT OBSERVER LOG

ARRIVAL

ROUTING: [✓ routine]/non-routine (describe: ____)

TOD 1507 GEAR 1523 OM ____ Rwy 10

ATIS/WX: [✓ vfr]/ifr (if IFR, describe:
120 SCT 200 BKN 5H / 84°/73° / 3004 / 3012)

LIGHTING CONDX: dawn/[✓ day]/dusk/night

APPROACH: ils/loc/vor/ndb/contact/circling/[✓ vis]

COMMENTS 1522: Following slow PSA DC-9
had to reduce to 210 IAS

1527 Wake turb. over threshold due to
slow DC-9 ahead of us c̄ sudden
add power

SUNRISE — SUNSET —

FA 11 PA 11

MEAL(req/rcvd) 0 / 1 all eat -- leftover pax meal

EQUIP INOP: ____/____/____

COMMENTS
1425 Meal = fresh fruit + quiche + sausage
1530 Crew meal on ramp – sub sandwiches
chips and apples
Then CAPT & F/O exit to term

DIVERSION ____

____ CHECK IF SIGNIFICANT COMMENTS

Figure 5. Example of a cockpit observer log sheet. One sheet was completed for every flight segment studied.

3.3 Data Management and Analysis

Background questionnaire, daily log, and observer log data were coded and entered into a specially modified Relational Information (RIM) database on a VAX 11/750 computer running 4.2 BSD UNIX. The Vitalog data were initially read out to an Apple II Plus computer and stored on diskettes. The original binary files were converted to text files and transferred to the VAX. After editing, the physiological data were entered into the same database as the questionnaire, daily log, and observer log data.

In view of the large number of variables collected and the number of subjects who completed the study (n = 74), an initial analysis plan was formulated based on the following key questions:

1. What measurable effects did the selected trips have on the physiology and psychology (measured by the Vitalog and daily log data) of pilots?
2. Were the observed changes in physiology and psychology on trips related to specific scheduling parameters (as recorded in the daily and observer logs)?
3. Were the observed changes in physiology and psychology on trips associated with particular pilot attributes (as measured by the personality inventories and questions in the background questionnaire)?
4. Could specific phases of flight (takeoff, descent, and landing) and flight conditions (e.g., instrument meteorological conditions [IMC] versus visual meteorological conditions [VMC]) be identified as "stressful" based on consistent increases in heart rate?

All analyses were carried out using BMDP Statistical Software on the VAX 11/750. Details of specific analyses are presented in the following sections.

4.0 RESULTS

4.1 Pilot Statistics

Thirty-seven male captains and 37 male first officers from two airlines participated in this study (table 2). The distributions of their ages and airline experience are shown in figure 6, and the distributions of their heights and weights are shown in figure 7.

Table 2. Summary Statistics for Participating Pilots

Variable	Mean	Standard deviation (S.D.)	Figure number
Age, yr	41.25	7.65	6
Airline experience, yr	14.64	7.52	6
Monthly flying, hr*	68.64	9.78	7
Height, inches	70.65	2.20	7
Weight, lb.	176.62	20.94	7

* Includes flying hours in all categories of aviation.

The age distribution was bimodal (fig. 6) owing to the difference in ages of captains (mean 46.6 yr) and first officers (mean 36.6 yr, $F = 43.07$, $p < 0.01$). This bimodality was suppressed somewhat because a number of first officers in one airline were furloughed captains from another airline.

The distributions for the various personality scales are shown in figures 8–11. On the Personal Attributes Questionnaire (fig. 8), the group tended to score higher on Instrumentality (I) than on Expressiveness (E), but relatively high on both scales and, therefore, in the upper two quartiles of (I + E). This is the profile associated with higher check-airman ratings of crew performance (ref. 31).

On the Work and Family Orientation Questionnaire (fig. 9), the average scores were high for Mastery and Work and relatively low for Competitiveness, conforming to the pattern found for high achievers in other occupations (ref. 33).

On the Eysenck Personality Inventory (fig. 10), subjects tended to score high on Extroversion and low on the Neuroticism index. There is some evidence to suggest that extroverts, particularly neurotic extroverts, adapt more rapidly to shift work and time-zone shifts (refs. 36, 38).

On the Morningness-Eveningness Questionnaire (fig. 11), the population tended to be more morning-type. Generally, evening types have been reported to adapt more rapidly to shiftwork (refs. 37, 40–42, 51). There may be significant cultural differences in the timing of the daily routine between these American subjects and the European groups previously studied. Comparative studies of morningness-eveningness in students, soldiers, and shift-workers showed different frequency distributions of the raw scores for the three groups; that is, this type of questionnaire may also need to be adapted for different subject groups (refs. 37, 51). In the present study, extroversion and morningness-eveningness scores were not significantly correlated (r = -0.05).

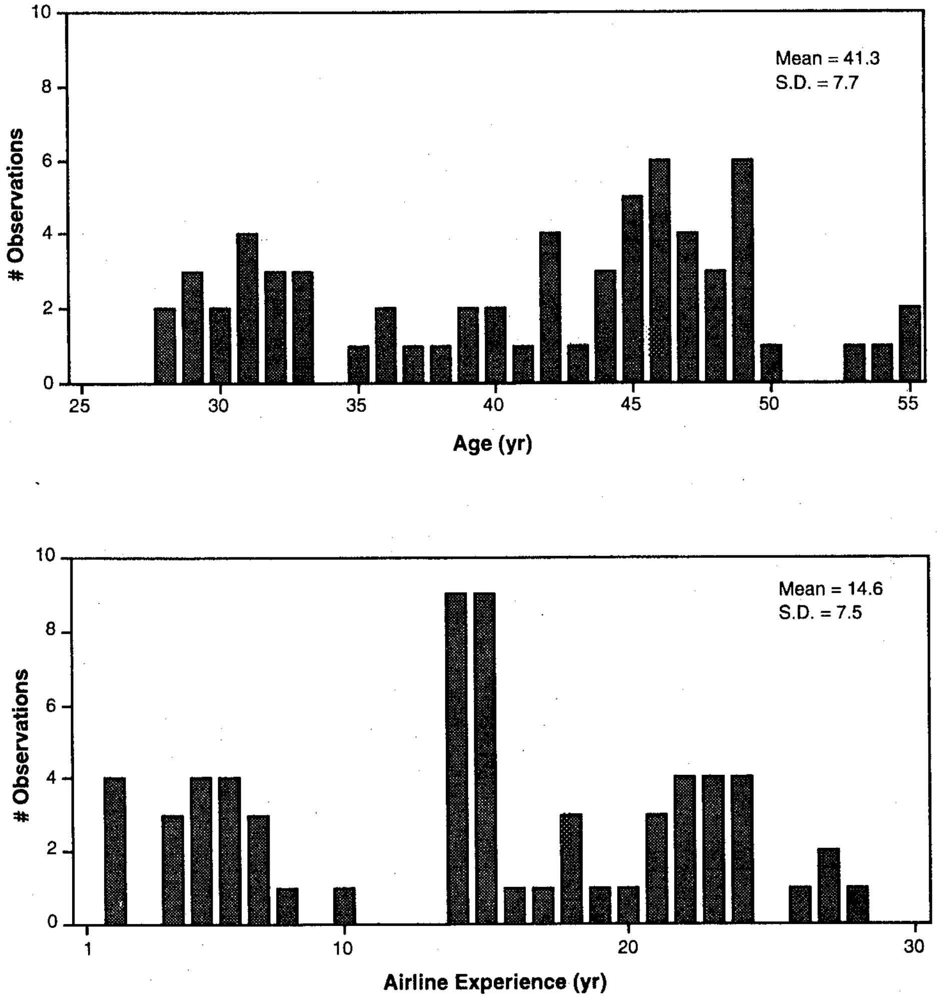


Figure 6. Age and airline experience of the 74 participating pilots.

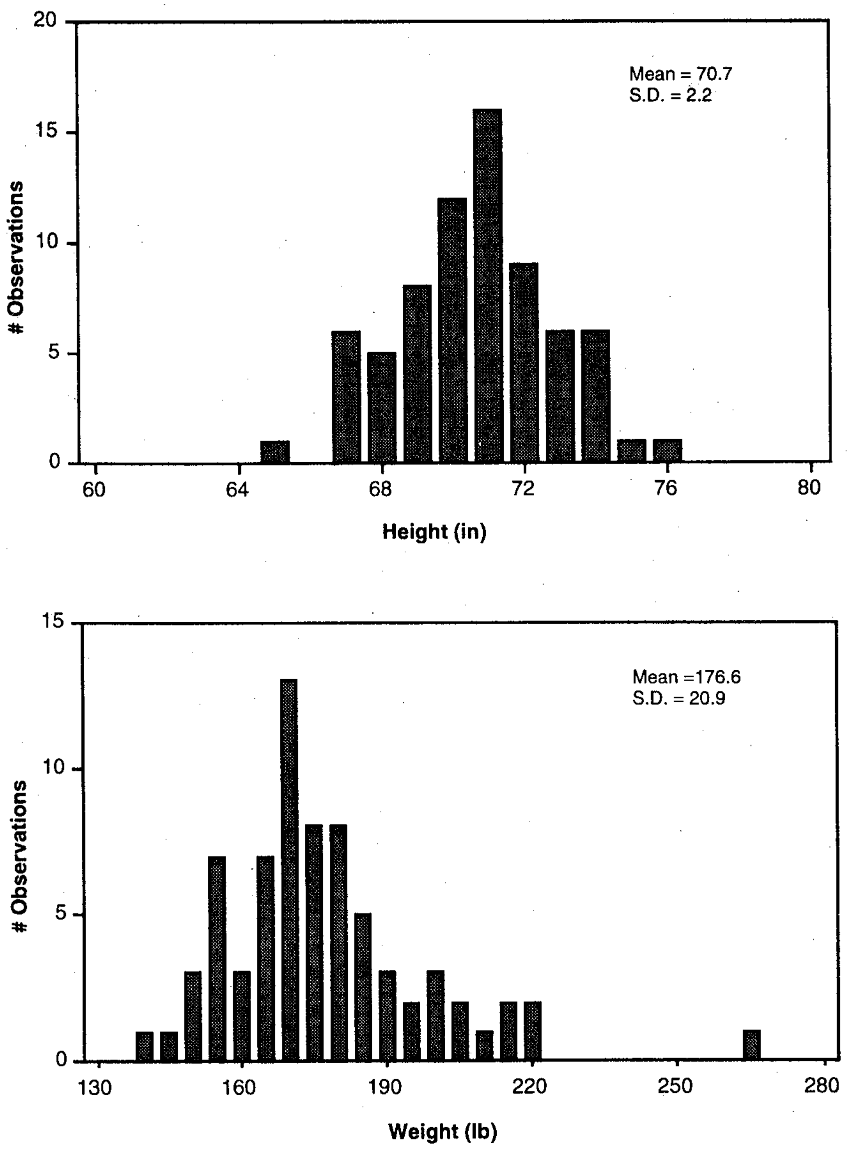


Figure 7. Height and weight of the 74 participating pilots.

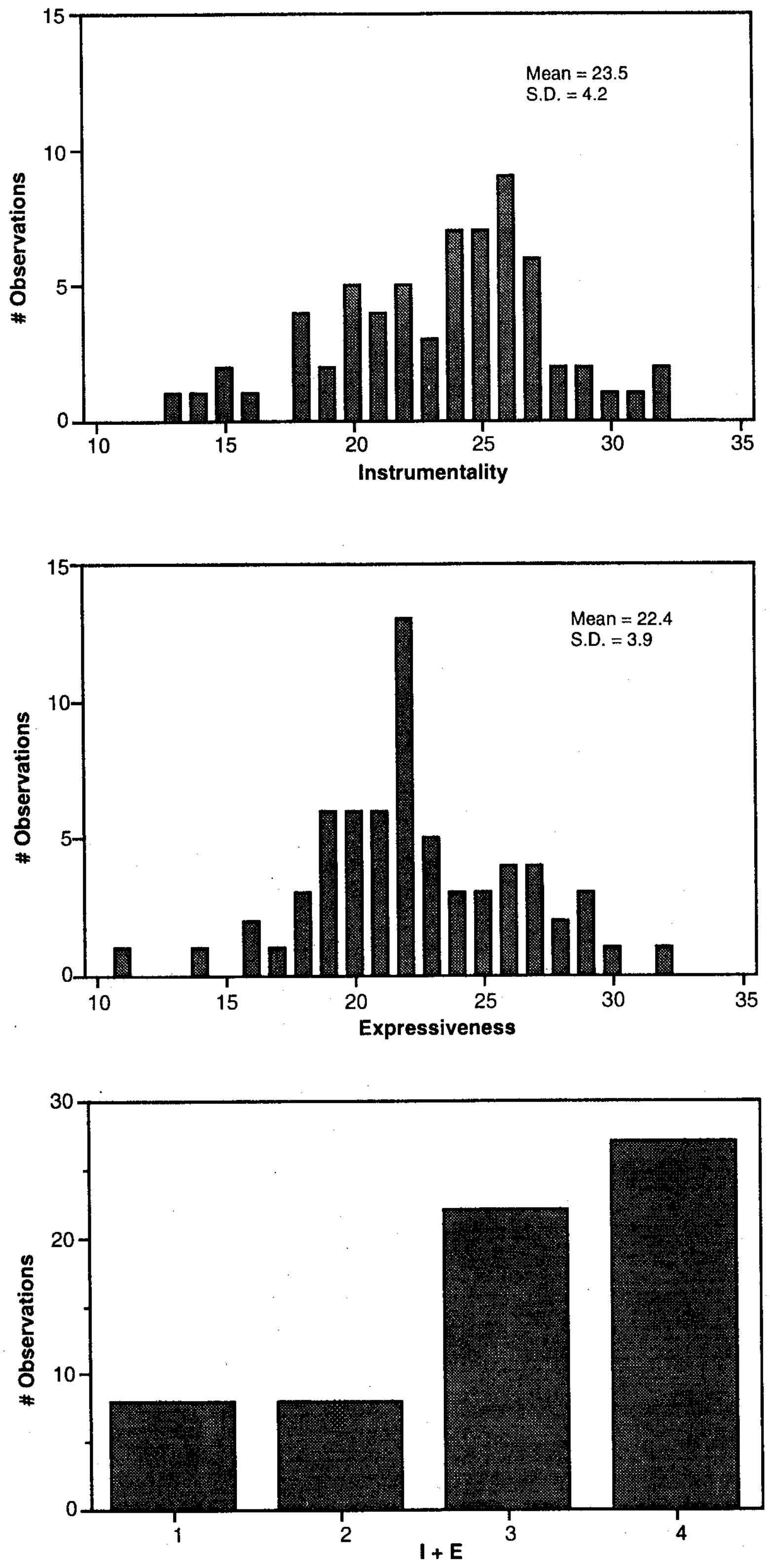


Figure 8. *Scores on the three scales of the Personal Attributes Questionnaire.*

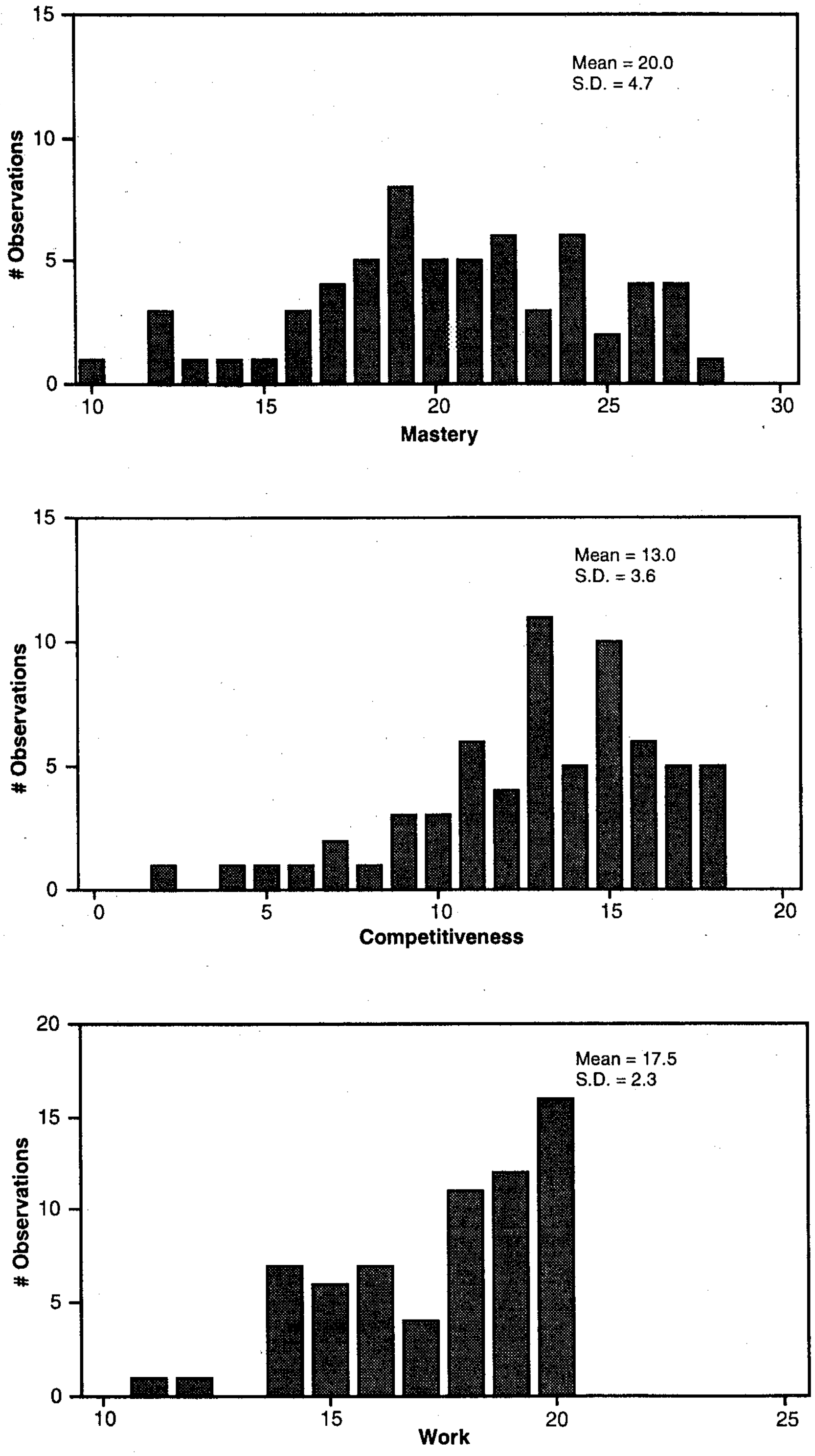


Figure 9. *Scores on the three scales of the Work and Family Orientation Questionnaire.*

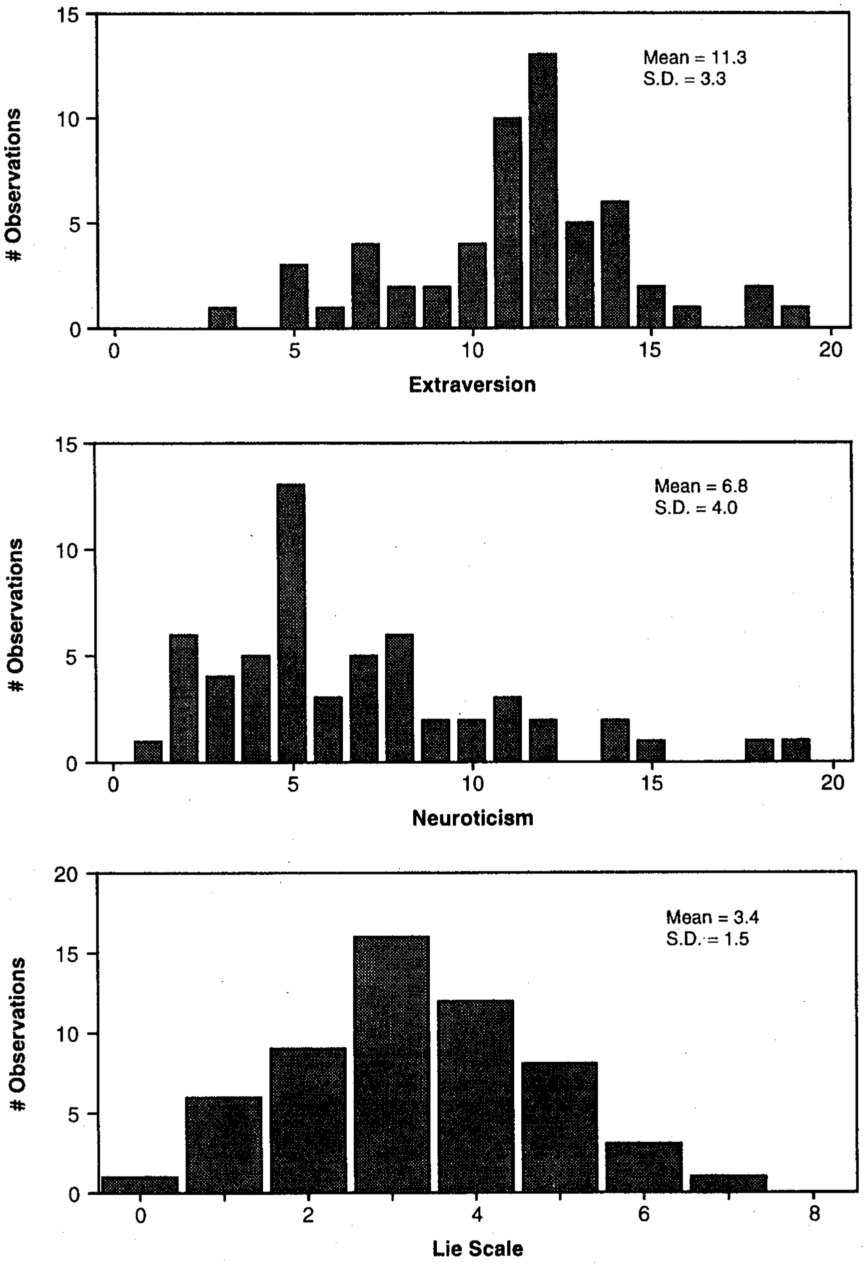


Figure 10. Scores on the three scales of the Eysenck Personality Inventory.

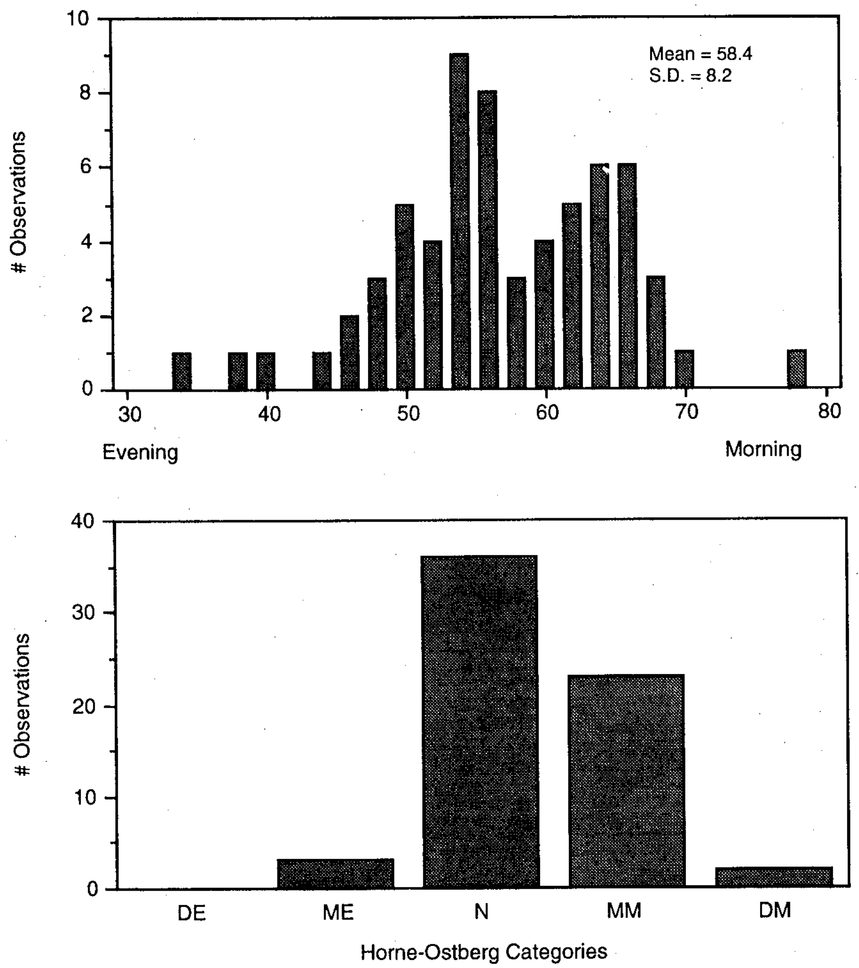


Figure 11. Scores for Morningness-Eveningness Questionnaire. Higher score indicates more morningness. (Categories determined by Horne and Ostberg, ref. 39.)

4.2 Trip Statistics

The trips studied are summarized in table 3. All trips originated in the eastern United States and involved a maximum daily time-zone change of 1 hr. Data were collected through all seasons of the year and were recorded on Greenwich mean time (GMT). Thus some data were collected on Eastern standard time (EST) (GMT minus 5 hr) and some on Eastern daylight time (EDT) (GMT minus 4 hr); however, no data spanned the change from daylight to standard time, or vice versa. Where appropriate, data were converted to local time, since duty times were also on local time.

Figure 12 illustrates all of the trip patterns studied and distinguishes day and night landings. The preliminary 2-day trip shown was not included in the analyses. From figure 12 it is clear that a significant proportion of the daily duty time is spent on the ground between flight segments. The plot of on-duty time versus duty hours (fig. 13) illustrates the predominance of early on-duty times combined with long duty days. Descriptive statistics of the trips studied are presented in table 4.

Table 3. Summary of Trips Studies					
Aircraft	Trips	Days	Segments	Flight hours	Pilots
DC-9	26	100	509	537.00	48
B-737	13	39	206	225.78	26
Total	39	139	715	762.78	74

Note: Both aircraft studied have two-person flight crews.

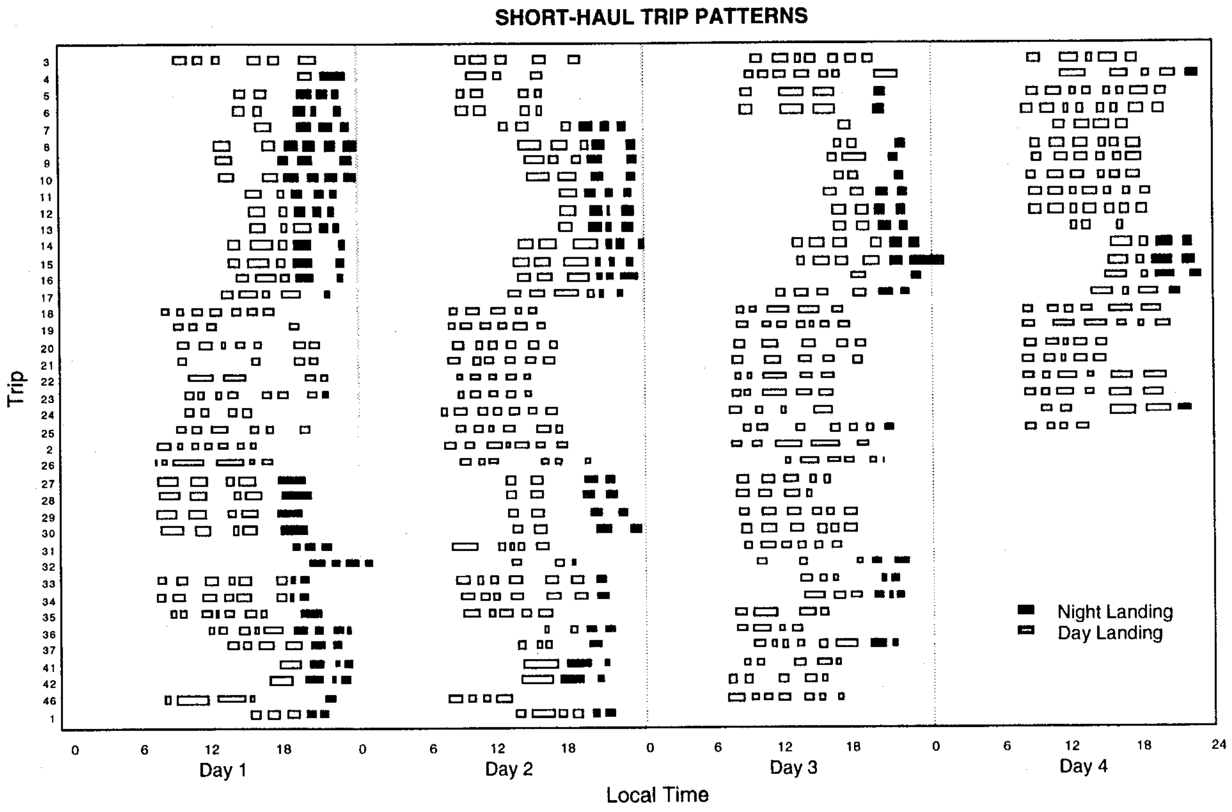


Figure 12. Sequence of flight segments for each of the trips studied (twenty-three 4-day trips; sixteen 3-day trips; one preliminary 2-day trip). Trip numbers indicate the order in which trips were studied. Times are in hours (local time). Open boxes: segments landing in daylight; black boxes: segments landing at night.

Currently, Federal Aviation Regulations (FARs) govern flight hours and rest hours. The difference between flight hours (the daily sum of wheels-off to wheels-on for each flight segment, as recorded by the NASA cockpit observer) and duty hours (as recorded by the pilots in their daily logs) is clearly illustrated in figure 14 (matched pairs t-test, $t = -58.46$, $p < 0.0001$). The mean flight time per day was 4.5 hr and the mean daily duty duration was 10.6 hr. None of these trips exceeded the legal maximum of 8 hr of flight time per day; however, approximately one third (32%) of the duty periods were longer than 12 hr. The current FARs are also imprecise concerning the definitions of rest time. In figure 15, the nighttime layover durations recorded by the pilots are compared with the most extreme possible definition of rest-period duration, that is, from last wheels-on in one duty period to first wheels-off in the next duty period. The mean rest-period duration calculated from last wheels-on to first wheels-off (14.0 hr) is significantly longer ($t = -17.52$, $p < 0.0001$) than the mean recorded by the pilots in this study in their daily logs (12.5 hr).

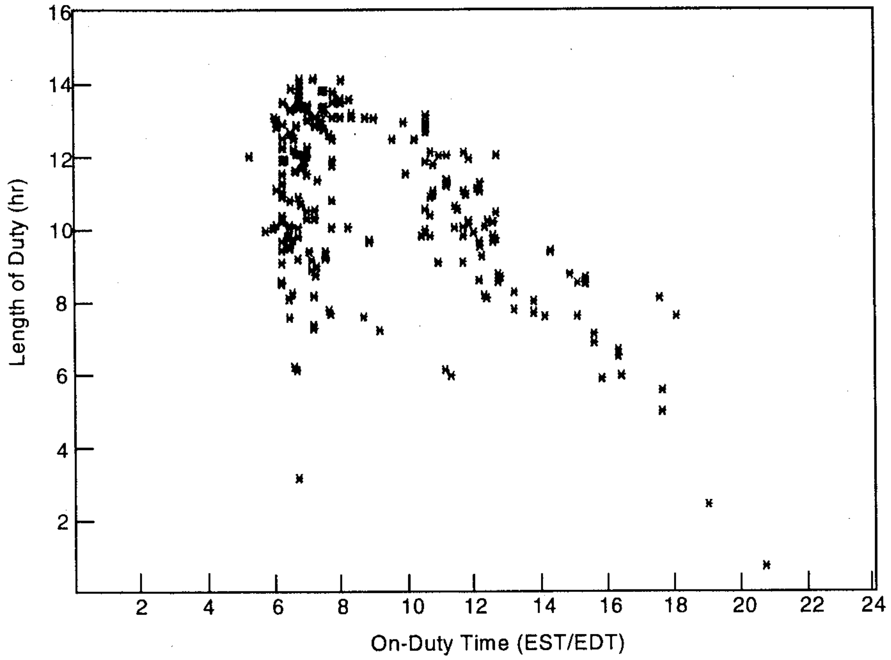


Figure 13. On-duty time vs. duration of the duty day for the 3-day and 4-day trips studied.

Table 4. Trip Statistics

Variable	Mean	S.D.	Minimum	Maximum
On-duty (local time)	09:43	4.19	05:00	21:15
Off-duty (local time)	19:30	2.86	09:35	01:30
Duty hours	10.63	2.24	2.23	15.83
Flight hours	4.51	1.35	0.83	7.48
(Duty) - (flight) hours	6.13	1.68	0.29	10.72
Number of segments	5.51	1.37	1.00	8.00
Segment duration, hr	1.07	0.46	0.22	2.97
Night layover hours	12.45	2.66	7.17	20.02

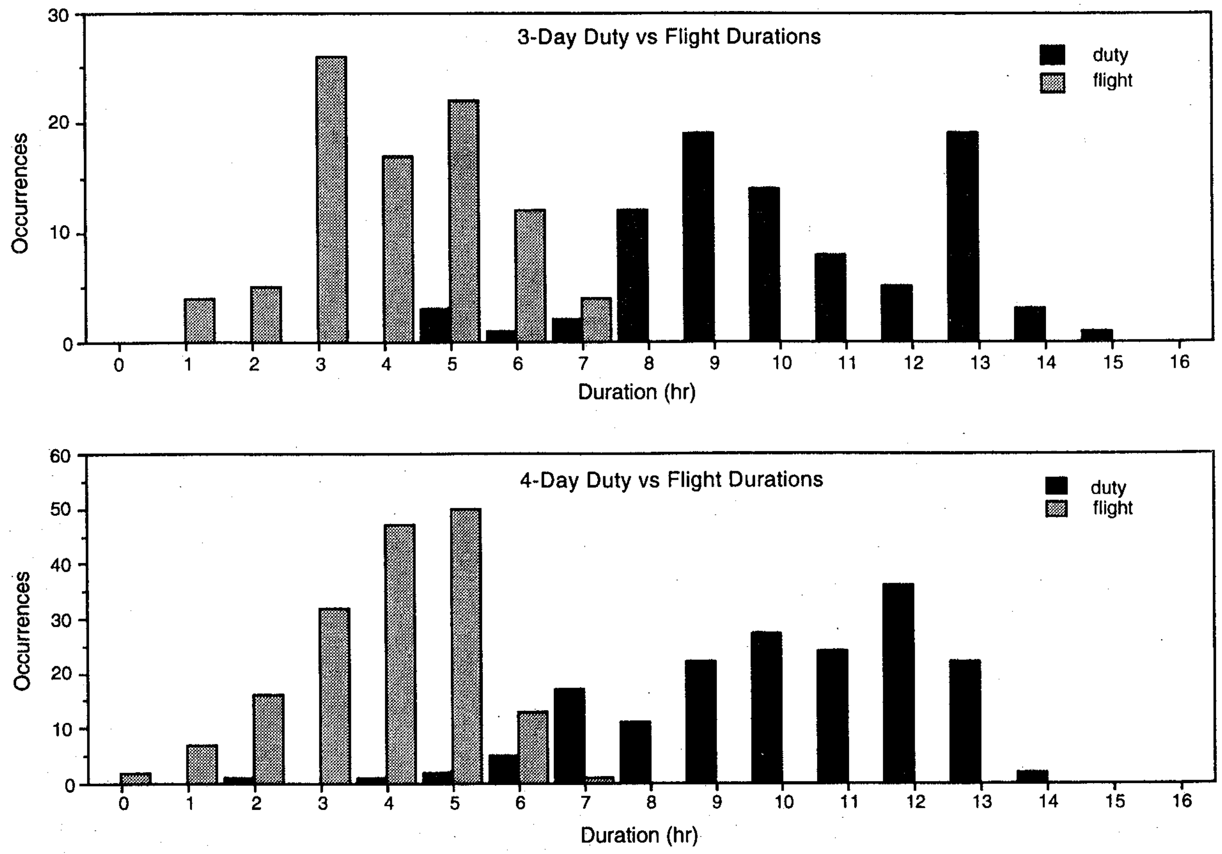


Figure 14. Daily duty durations vs flight durations for 3-day and 4-day trips; duty durations were significantly longer (mean = 10.6 hr) than flight durations (mean = 4.5 hr).

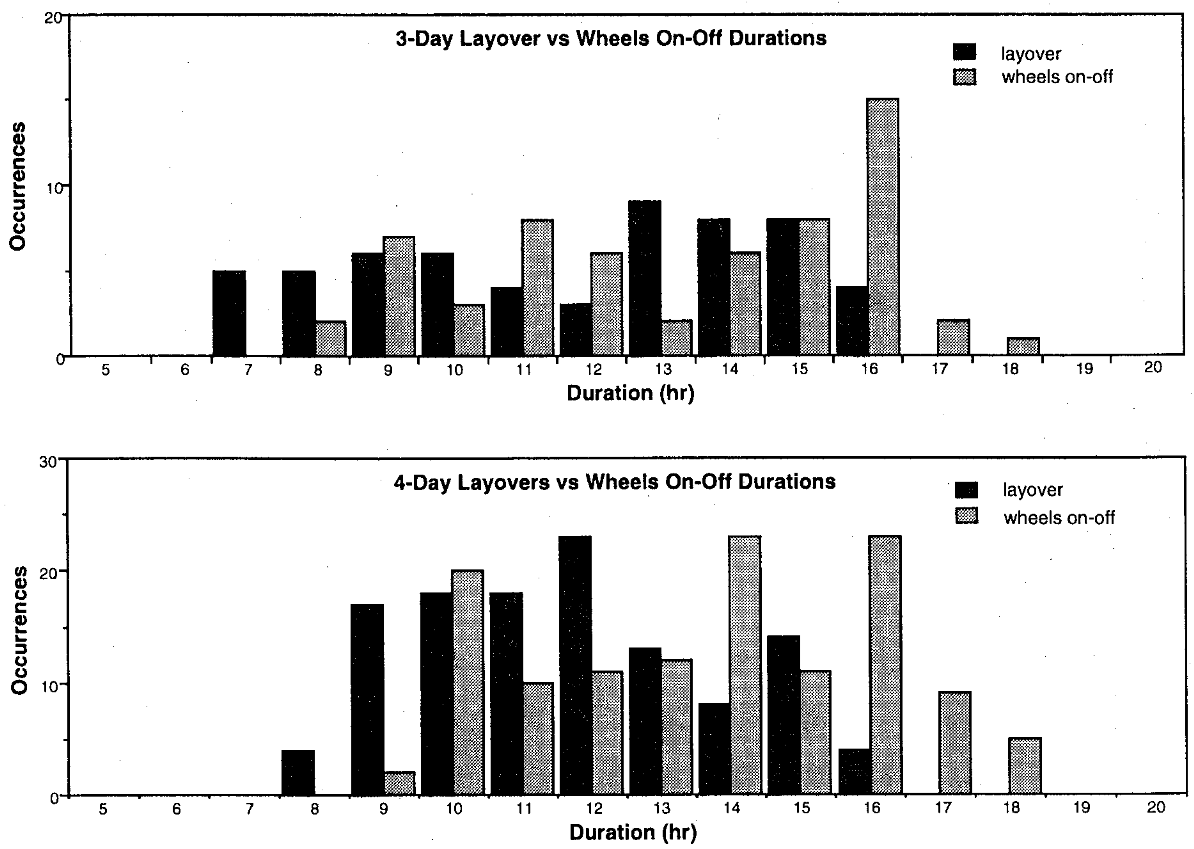


Figure 15. Layover durations (as defined by the pilots in their daily logs) vs the time from last wheels-on on one duty day to first wheels-off on next duty day (from the observer logs), for 3-day and 4-day trips. Layover durations from the pilot logs were significantly shorter (mean = 12.5 hr) than the longest possible definition of layovers (wheels-on to wheels-off, mean = 14.0 hr).

4.3 Effects of Trips on Physiological and Psychological Variables

4.3.1 Sleep

Only subjects who provided data for at least one pretrip sleep episode, all trip sleep episodes, and at least one posttrip sleep episode, were included in the analyses of sleep. This included 44 subjects (59%) for the subjective sleep-quality measures and 25 subjects (30%) for physiological measures during sleep. To extract the data for activity and heart rate during sleep, sleep was defined as beginning 20 min after the reported sleep onset time and ending 10 min before the reported wake-up time. This definition was adopted, after careful examination of many activity and heart-rate records, to overcome the inaccuracies of subjective estimates of sleep timing. The aim was to minimize the contamination of estimates of mean levels during sleep by the comparatively high values that occurred immediately before and after sleep. Variability in heart rate and activity during sleep was estimated as the standard deviation of the raw scores for each sleep episode for each subject.

Mean values for each of the sleep-related variables on pretrip, trip, and posttrip days are given in table 5. Note that sleep episodes occurred at the beginning of the GMT day (local time plus 4 or 5 hr). Thus the two sleep episodes that occurred away from home on 3-day trips occurred on the second and third (GMT) trip days (days 2 and 3 in fig. 16), and the three sleep episodes that occurred away from home on 4-day trips occurred on the second, third, and fourth (GMT) trip days (days 2, 3, and 4 in fig. 16). Sleep ratings have been converted so that higher values indicate better sleep.

With the single exception of ratings on the question "Difficulty rising?," the subjective sleep measures consistently indicate poorer sleep on trips. Subjects took longer to fall asleep, slept for a shorter time, woke earlier, rated their sleep as lighter and poorer overall, and reported significantly more awakenings. However, they reported the greatest difficulty in rising after the trip. Significant changes in activity and heart rate during sleep may have been obscured because of the small number of subjects for whom complete physiological data were available (25) and the large intersubject variability (see below).

Table 5. Sleep Measures: Pretrip, Trip, and Posttrip

	Pre-trip	Trip	Post-trip	p(f)
Time of sleep onset, GMT	4.24	4.24	4.58	
Time of wake-up, GMT	11.29	11.05	12.21	****
Sleep latency, hr	0.25	0.45	0.36	**
Sleep duration, hr	7.06	6.69	7.36	*
Difficulty falling asleep? (1–5)	4.09	4.02	4.25	
How deep was your sleep? (1–5)	3.51	3.23	3.74	****
Difficulty rising? (1–5)	4.27	4.03	3.85	*
How rested do you feel? (1–5)	3.37	3.14	3.40	
Sleep rating (4–20)	15.23	14.42	15.24	**
Number of awakenings	0.76	1.22	1.18	****
Mean heart rate during sleep, beats/min	61.50	62.83	61.20	
Standard deviation of heart rate during sleep, beats/min	5.90	6.19	6.09	
Mean activity during sleep, counts/min	1.14	1.40	1.49	
Standard deviation of activity during sleep, counts/min	3.78	4.72	5.43	

* 0.05 > p(f) > 0.01; ** 0.01 > p(f) > 0.001; *** 0.001 > p(f) > 0.0001; **** p(f) < 0.0001.

Notes: p(f) from 2-way ANOVA (subjects by pretrip/trip/posttrip).
Local time = GMT minus 4 hr or 5 hr.

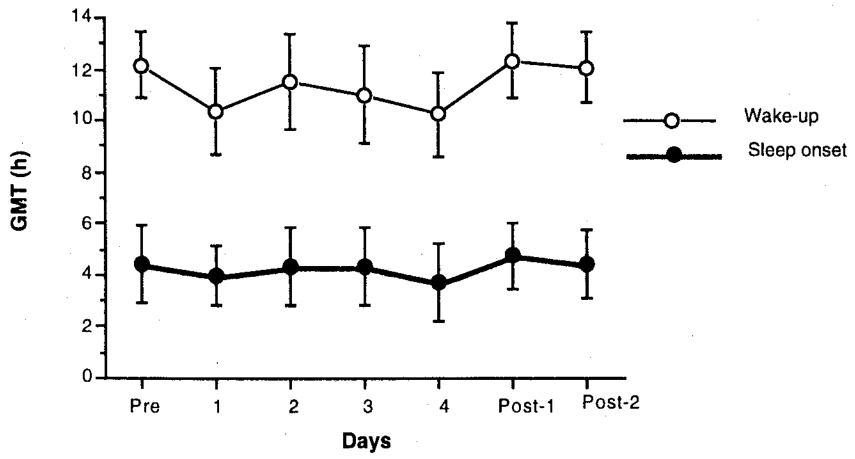


Figure 16. *Average times of sleep onset and wake-up; vertical bars indicate standard errors. All pretrip sleep episodes for each subject have been averaged together, and data for 3-day and 4-day trips have been combined. Because the data are on GMT, the sleep episodes on days 1–4 preceded the duty periods on those days.*

To test if sleep differed significantly on pretrip, trip, and posttrip days, two-way ANOVAs were performed (subjects by pre/trip/post). These analyses are summarized in table 6, and are the source of the significance levels indicated in table 5.

Table 6. Intersubject Differences and Sleep Quality: Pretrip, Trip, and Posttrip (two-way ANOVA)

	F Subjects	F Pre/trip/post	F Interaction
Time of sleep onset, GMT	4.31****	2.87	1.21
Time of wake-up, GMT	3.81****	13.70****	0.94
Sleep latency, hr	3.40****	6.72**	1.17
Sleep duration, hr	1.47*	3.97*	0.62
Difficulty falling asleep? (1–5)	2.79***	2.56	1.54*
How deep was your sleep? (1–5)	4.01***	12.70***	2.05***
Difficulty rising? (1–5)	4.54***	3.08*	1.69**
How rested do you feel? (1–5)	2.75***	2.03	1.37*
Sleep rating (4–20)	5.19***	4.85**	1.96***
Number of awakenings	4.78***	10.80***	1.01
Mean heart rate during sleep, beats/min	7.39***	1.94	0.41
Standard deviation of heart rate during sleep, beats/min	3.23***	0.43	1.74*
Mean activity during sleep, counts/min	2.07*	0.70	0.66
Standard deviation of activity during sleep, counts/min	1.42	1.36	0.79

* 0.05 > p > 0.01; ** 0.01 > p > 0.001; *** 0.001 > p > 0.0001; **** p < 0.0001.

It should be noted that the sleep episode that occurred at home immediately preceding the trip was counted as a pretrip sleep in these analyses. It was, however, curtailed by the early wake-up required by the early duty report time. This effect is seen more clearly in figure 16. This would be expected to have contaminated other baseline sleep measures, particularly sleep duration (fig. 17). When the sleep immediately before the trip was included as a trip sleep, the time of wake-up was significantly earlier on trips (means: pretrip 12.16 hr, trip 10.77 hr, posttrip 12.19 hr; $F = 41.50$, $p < 0.0000$), and sleep duration was significantly shorter on trips (means: pretrip 7.76 hr, trip 6.54 hr, posttrip 7.48 hr; $F = 20.72$, $p < 0.0000$).

There was significant variability among subjects for all the sleep measures. The significant interactions for the ratings on the four sleep questions and the overall sleep ratings indicate that not all subjects reported themselves as "worst" on these measures during trips. These effects are examined further in table 7.

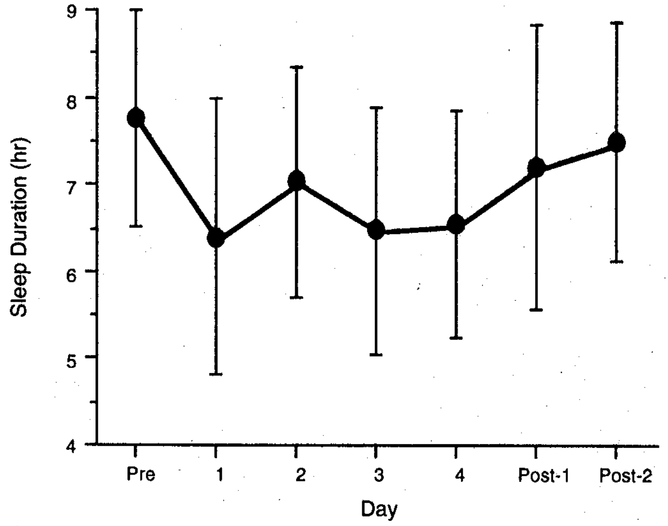


Figure 17. Durations of pretrip, trip, and posttrip sleep episodes. Vertical bars indicate standard errors. Sleep was significantly shorter on trip days (1–4).

Table 7. Subjects Rating Their Sleep as Worst Pretrip, Trip, and Posttrip

	Worst pretrip, %	Worst trip, %	Worst, posttrip, %	Other %
Difficulty falling asleep? (1–5)	32	32	23	14
How deep was your sleep? (1–5)	25	39	9	27
Difficulty rising? (1–5)	9	23	36	32
How rested do you feel? (1–5)	25	32	25	18
Sleep rating (4–20)	23	43	27	7

These analyses underscore the high level of interindividual variability inherent in the subjective sleep ratings, which clouds the pretrip/trip/posttrip comparisons. Nevertheless, for the group overall, the only subjective sleep rating that did not follow the general pattern of being worst on trips was the question "Difficulty rising?"

The significant interaction for the heart-rate variability during sleep likewise indicates that not all subjects showed the same pattern of response during pretrip, trip, and posttrip sleep episodes. Heart-rate variability during sleep was highest pretrip for 28%, highest during trips for 36%, and highest posttrip for 36% of subjects.

Since no subjects flew both 3-day and 4-day trips, two-group t-tests were performed to test whether 3-day and 4-day pilots differed significantly in any of the sleep measures during baseline. On average, pilots flying 3-day trips reported deeper sleep ($t = 2.08$, $p < 0.05$) and more difficulty rising ($t = 2.06$, $p < 0.05$) pretrip than did pilots flying 4-day trips. There were no other significant differences between baseline sleep measures for 3-day and 4-day pilots. The effects of 3-day and 4-day trips on sleep were then compared (two-way ANOVAs) in two ways. First, the two trip types were compared across pretrip sleeps, all trips sleeps, and posttrip sleeps. Second, they were compared across pretrip sleeps, the last trip sleep, and posttrip sleeps. The latter analyses were intended to highlight any differences in the cumulative effects of duty days. Significant interactions in these analyses (tables 8 and 9) indicate differences between 3-day and 4-day trips.

Table 8. Sleep Measures on 3-Day vs. 4-Day Trips: Pretrip, Posttrip, and All Trip Sleeps (two-way ANOVA)

	F Trip Type	F Pre/trip/post	F Interaction
Time of sleep onset, GMT	0.80	1.58	0.27
Time of wake-up, GMT	0.58	10.37****	1.45
Sleep latency, hr	0.22	4.02*	1.62
Sleep duration, hr	0.31	4.41*	0.19
Difficulty falling asleep? (1–5)	0.00	0.59	3.50*
How deep was your sleep? (1–5)	0.41	5.94**	1.43
Difficulty rising? (1–5)	0.63	4.08*	0.85
How rested do you feel? (1–5)	0.00	1.71	0.14
Sleep rating (4–20)	0.23	2.32	0.88
Number of awakenings	1.24	7.57***	1.55
Mean heart rate during sleep, beats/min	4.83*	1.12	0.17
Standard deviation of heart rate during sleep, beats/min	1.12	0.20	2.56
Mean activity during sleep, counts/min	0.23	0.22	0.25
Standard deviation of activity during sleep, counts/min	0.21	0.80	0.31

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

Table 9. Sleep Measures on 3-Day vs. 4-Day Trips: Pretrip, Posttrip, and Last Sleep of Trip (two-way ANOVA)

	F Trip type	F Pre/trip/post	F Interaction
Time of sleep onset, GMT	1.92	2.35	0.85
Time of wake-up, GMT	0.54	16.56****	0.96
Sleep latency, hr	0.34	2.25	1.68
Sleep duration, hr	0.00	5.85**	0.03
Difficulty falling asleep? (1–5)	0.02	0.38	1.85
How deep was your sleep? (1–5)	0.59	2.31	3.56*
Difficulty rising? (1–5)	0.77	4.19*	0.80
How rested do you feel? (1–5)	0.01	1.00	0.07
Sleep rating (4–20)	0.00	0.92	0.77
Number of awakenings	1.17	5.11**	1.37
Mean heart rate during sleep, beats/min	0.98	2.78	1.70
Standard deviation of heart rate during sleep, beats/min	4.58*	0.43	1.43
Mean activity during sleep, counts/min	0.97	1.64	0.60
Standard deviation of activity during sleep, counts/min	0.29	0.75	0.11

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

There is a significant interaction in table 8 for the question “Difficulty falling asleep?” because pilots flying 3-day trips reported least difficulty falling asleep on trip nights, whereas pilots flying 4-day trips reported most difficulty falling asleep on trip nights, by comparison with pretrip and posttrip nights. Since the two groups were not significantly different on this measure for baseline sleeps, this may represent a differential effect of 3-day versus 4-day trips. The significant interaction in table 9 for the question “How deep was your sleep?” reflects the fact that pilots flying 3-day trips reported their final trip sleep as less deep than either pretrip or posttrip, whereas pilots flying 4-day trips reported their final trip sleep as deeper than pretrip but less deep than posttrip. The meaning of this interaction is unclear, however, because pilots flying 3-day trips reported significantly deeper sleep pretrip than pilots flying 4-day trips.

The fact that sleep durations averaged 1.2 hr shorter than baseline for the sleep episode immediately preceding trips and for the sleeps during trips suggests that pilots accumulated a sleep debt across the trips. However, this calculation does not include the sleep accrued as naps. The overall sleep loss (including both naps and sleeps) associated with 3-day and 4-day trips is illustrated in figure 18. This figure and the following analyses include only 32 subjects who provided data for at least two nights of sleep before the trip, and whose baseline sleep durations per 24 hr (sleeps plus naps) averaged between 7 hr and 10 hr. These criteria were adopted because abnormal baseline sleep durations confound subsequent calculations of sleep loss. To test if day-by-day sleep loss differed among subjects and between 3-day and 4-day trips, two-way ANOVAs were performed. These analyses are summarized in table 10.

The significant difference in the amount of sleep lost on different study days is trivial since, by definition, no sleep was lost on the first baseline sleep. There were also significant differences between subjects, and between trip types, in the amount of sleep lost during trips. Table 11 summarizes these differences.

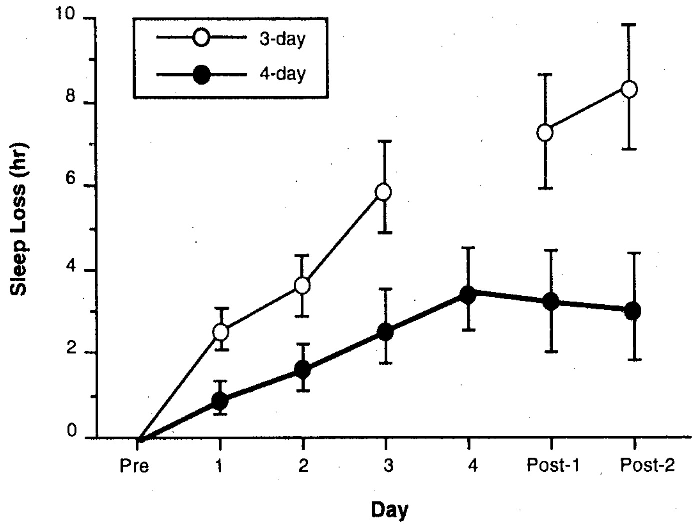


Figure 18. *Averaged cumulative sleep loss on 3-day and 4-day trips. For each subject, cumulative sleep loss was calculated as the number of hours of sleep (including naps) lost per 24 hr period, by comparison with the average pretrip sleep (plus nap) duration.*

Table 10. Day-by-Day Sleep Loss Between Subjects and for 3-Day Trips vs. 4-Day Trips (two-way ANOVA)

	Subject	Days	
Sleep loss, %	6.55****	9.61****	
Cumulative hours lost	10.62****	25.70****	
	F Trip type	F Days	F Interaction
Sleep loss, %	23.14****	5.64****	1.11
Cumulative hours lost	26.67****	12.08****	2.17

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

Note: The sleep episodes included in these analyses were two pretrip sleeps (Pre and day 1), two trip sleeps (days 2, 3), and two posttrip sleeps (Post-1 and -2). Since there is only one value for the total sleep duration (sleeps plus naps) for each subject on each day, there is no interaction term for the subject/days analysis.

Table 11. Percentages of Subjects Accumulating Different Levels of Sleep Debt After the Final Trip Sleep: 3-Day vs. 4-Day Trips

Trip	Sleep loss					Sleep gain		
	>8 hr	6–8 hr	4–6 hr	2–4 hr	0–2 hr	0–2 hr	2–4 hr	4–6 hr
3-day	36%	7%	14%	29%	7%	7%		
4-day	16%	11%	11%	26%	16%	11%	5%	5%

Cumulative sleep loss was significantly greater on 3-day trips than on 4-day trips. Since the duration of sleep episodes (as opposed to naps) was not significantly different between the trip types (tables 8, 9), this difference in cumulative sleep loss must be attributable to differences in napping behavior. The percentage of subjects reporting naps on 3-day and 4-day trips is shown in figure 19. Napping during pretrip baseline was three times more common among 3-day-trip pilots than 4-day-trip pilots. The question then arises whether 3-day-trip pilots habitually napped more than the 4-day-trip pilots, or whether this pretrip difference might reflect some kind of pretrip sleep strategy. To test if the pretrip baseline sleep durations (sleeps plus naps) reported in the daily logbooks were representative of normal home sleep durations, they were compared, for each subject, with his usual home sleep duration reported in the background questionnaire. The results of these matched-pairs t-tests are summarized in table 12.

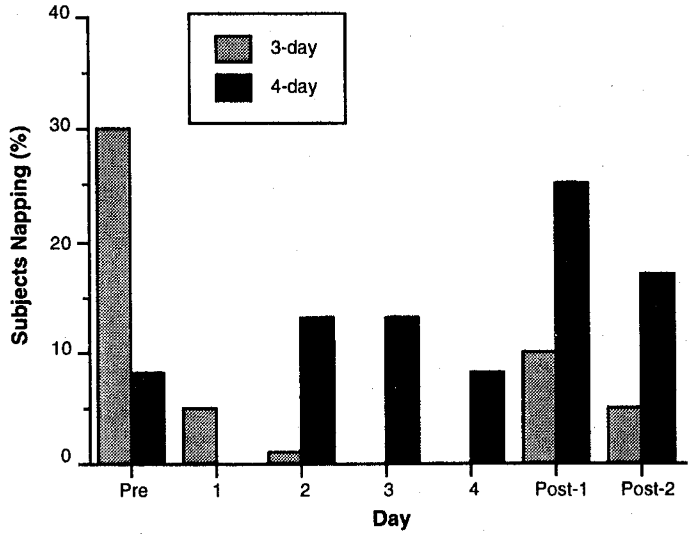


Figure 19. Percentages of subjects reporting naps on each study day. Pretrip napping was more common among pilots flying 3-day trips, whereas napping during trips and posttrip was more common among pilots flying 4-day trips.

Table 12. Comparisons of Usual Home Sleep Durations and Pretrip Sleep Durations (matched pairs t-test)

	t 3-day trips	t 4-day trips
Usual home/pretrip (nap + sleep)	2.41*	0.70
Usual home/pretrip (sleep only)	0.70	0.82

* $p < 0.05$.

The total daily pretrip sleep durations (sleep plus nap) reported in the logbooks by pilots flying 3-day trips were significantly longer than their reported usual home sleep durations (8.53 hr versus 7.98 hr). However, the durations of pretrip sleep episodes alone (i.e., excluding naps) were not significantly different from the usual home sleep durations. Two-group t-tests showed no significant differences between 3-day and 4-day-trip pilots in their usual sleep durations at home, or in their frequency of napping at home. The latter was rated from 1 (never) to 5 (frequently) on the question in the background questionnaire: "How often do you take naps (actually fall asleep for 5 min or more)?" Taken together, these analyses suggest that the high number of 3-day-trip pilots reporting naps before a trip may represent a strategy for coping with anticipated sleep loss. This strategy was not used, however, by pilots on 4-day trips. Duty timing and duration were therefore compared between 3-day and 4-day trips in an attempt to explain this difference.

The times of going on duty on the first day of the trip were not significantly different between 3-day and 4-day trips (two-group test, $t = -0.10$, $p = 0.92$); that is, 3-day-trip pilots were not forced to wake up earlier on the first trip day. As noted above, 4-day-trip pilots napped more frequently during trips. To test if this may have been a result of differences in the timing, duration, or intensity of duty days between 3-day trips ($n = 20$) and 4-day trips ($n = 24$), two-way ANOVAs were carried out comparing trip type by days of trip (days 1–3). There were no significant differences in the times of duty onset and duty end, duty duration, or the number of segments flown (table 13). However, the subjects on the 3-day trips had significantly more flight hours per day than the subjects on 4-day trips (fig. 20); that is, there was less time available for napping between flight segments on 3-day trips.

Table 13. Day-Day Comparison of Duty Variables on 3-Day vs. 4-Day Trips (two-way ANOVA)

Duty variable	F Trip type	F Days	F Interaction
Duty onset time	0.12	3.24*	0.22
Duty off time	0.97	7.75***	0.29
Duty duration	1.05	7.16**	0.01
Number of flight segments/day	0.10	2.42	6.82**
Flight hours/day	7.40**	5.35**	2.10

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

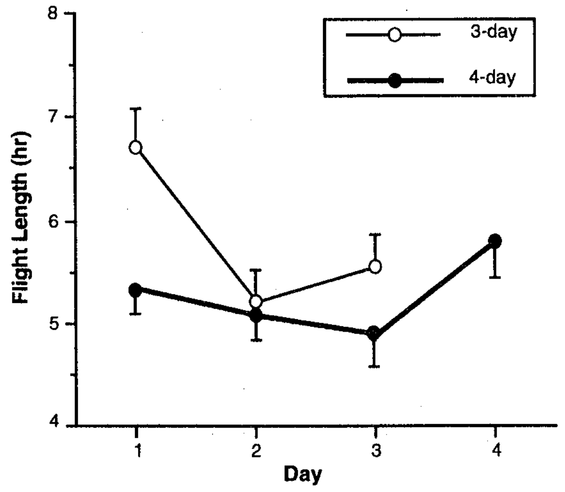


Figure 20. Average flight hours per trip day for 3-day trips vs. 4-day trips; vertical bars indicate standard errors.

In summary, more 3-day-trip pilots had naps included in their baseline sleep durations against which subsequent sleep loss or gain was calculated, and fewer pilots on 3-day trips found time to nap during trips. These two factors combined contributed to a significantly greater average sleep loss by pilots on 3-day trips than by pilots on 4-day trips. The hours of sleep lost during the trips were not regained after two nights of posttrip sleep. However, this is not unexpected since sleep loss is normally compensated by deeper rather than proportionally longer sleep. In the subjective sleep ratings, sleep was reported as being deepest posttrip (table 6).

The analyses in table 13 also revealed another aspect of the timing of duty which would be expected to affect the amount of sleep obtained on layovers. The times of duty-onset and duty-end were progressively earlier across the days of the trip. This was significant across the first 3 days of the trip for 3-day and 4-day trips (table 13), and continued on the fourth day of 4-day trips (fig. 21).

The reliability of subjective ratings of sleep quality and the number of awakenings is a matter of concern. Analyses were therefore carried out to see if any of these subjective measures were correlated with the physiological measures of mean heart rate and activity during sleep. It should be noted that these analyses do not allow for the significant interindividual variability that exists in all the sleep measures. None of the sleep-quality ratings or the number of awakenings was significantly correlated with the average heart rate during sleep. However, the higher the average activity during sleep, the greater the difficulty subjects reported rising (multiple $r^2 = 0.03$, $n = 116$, $F = 4.07$, $0.05 > p > 0.01$). The difficulty that subjects reported in falling asleep was positively correlated with the sleep latency calculated from the reported times of going to bed and falling asleep (multiple $r^2 = 0.21$, $n = 290$, $F = 77.98$, $p < 0.01$). Longer sleep latencies were associated with shorter sleep durations (multiple $r^2 = 0.04$, $n = 289$, $F = 12.10$, $p < 0.01$). Longer sleep durations were associated with less difficulty falling asleep (multiple $r^2 = 0.05$, $n = 290$, $F = 15.80$, $p < 0.01$); deeper sleep (multiple $r^2 = 0.02$, $n = 290$, $F = 6.28$, $0.05 > p > 0.01$); feeling more rested on awakening (multiple $r^2 = 0.05$, $n = 291$, $F = 15.32$, $p < 0.01$), and higher scores on the combined sleep rating (multiple $r^2 = 0.07$, $n = 289$, $F = 20.81$, $p < 0.01$). Although they account for only a very small amount of the variability in each case, these relationships suggest at least some internal consistency among the sleep-quality ratings and the subjective estimates of sleep timing and duration.

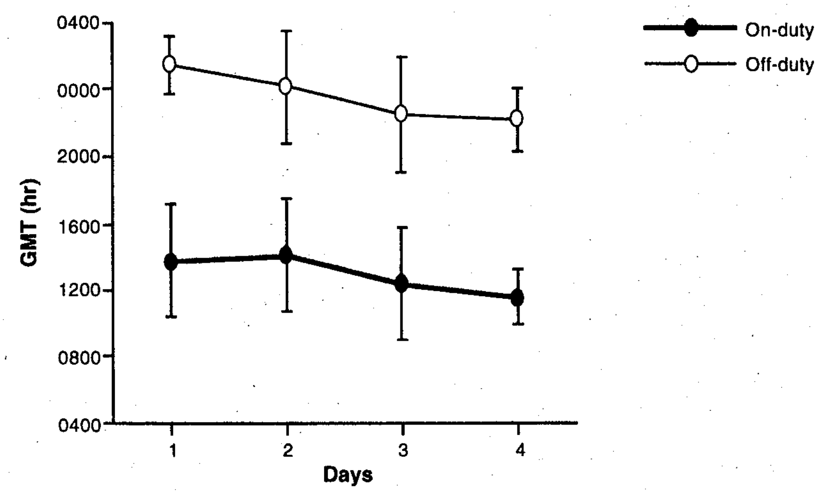


Figure 21. Average times of going on-duty and coming off-duty for each duty day (vertical bars indicate standard errors). On average, layovers began and ended progressively earlier across the trip; however, physiological constraints make it difficult for pilots to fall asleep progressively earlier.

4.3.2 Subjective Fatigue and Mood

Subjective fatigue and mood were rated every 2 hr during the waking day. Subjects also noted their location, and this information was divided into four categories: pretrip, during flights, during layovers (including layovers between flight segments and layovers between duty days), and posttrip. Fatigue was rated on a 10 cm line from "drowsy" to "alert." Moods were rated from 1 ("not at all") to 4 ("extremely") on 26 adjectives. The average ratings for each subject on each adjective were fed into a factor analysis which revealed that ratings on the 26 adjectives loaded on three orthogonal factors, designated positive affect, negative affect, and activation, which accounted, respectively, for 25.0%, 22.2%, and 19.4% of the variance. The loadings for each item on each factor are listed in table 14.

Table 14. Factor Analysis of Mood Adjective Checklist

Positive affect	Negative affect	Activation
Friendly	Grouchy	Efficient
Pleasant	Sluggish	Clear thinking
Cheerful	Dull	Vigilant
Happy	Tired	Lively
Kind	Sleepy	Full of pep
Relaxed	Forgetful	Hard working
Carefree	Annoyed	Dependable
Defiant	Active	
Tense		

Rotated factor loadings

	Positive affect	Negative affect	Activation
Friendly	0.885*	-0.050	0.255
Pleasant	0.870*	-0.070	0.346
Cheerful	0.851*	-0.144	0.328
Happy	0.834*	-0.180	0.275
Kind	0.831*	-0.015	0.276
Considerate	0.800*	-0.069	0.331
Relaxed	0.597*	-0.298	0.377
Carefree	0.572*	0.135	0.115
Grouchy	-0.259	0.834*	-0.016
Sluggish	0.066	0.795*	-0.234
Dull	0.011	0.778*	-0.340
Tense	-0.119	0.769*	0.003
Tired	0.125	0.751*	-0.253
Sleepy	0.134	-0.725*	-0.399
Jittery	-0.130	0.705*	0.004
Forgetful	0.128	0.703*	-0.348
Annoyed	-0.291	0.684*	0.231
Defiant	-0.185	0.574*	0.256
Efficient	0.361	-0.205	0.808*
Clear thinking	0.381	0.278	0.770*
Vigilant	0.353	-0.214	0.692*
Lively	0.502	-0.067	0.680*
Full of pep	0.473	-0.069	0.663*
Hard working	0.248	0.103	0.647*
Dependable	0.504	-0.099	0.602*
Active	0.254	-0.096	0.551*

* Indicates highest factor loading for each variable.

To compare the relative importance of intersubject differences, time-of-day, and location where the ratings were made, a three-way ANOVA was planned. However, only nine subjects (12%) completed sufficient ratings across a pretrip day for this comparison, and it was further necessary to combine the ratings in 4-hr time-bins. The results of the three-way ANOVAs were therefore compared with two-way ANOVAs (subjects/time-of-day; location by time-of-day) using data from the 44 subjects who provided complete sleep data, and combining the data in 2 hr time bins. These analyses are summarized in tables 15–17.

Table 15. Fatigue and Mood Ratings, three-way ANOVA (subject/time-of-day/location where rating was made, n = 9)

	F Fatigue	F Positive affect	F Negative affect	F Activation
Subject	22.18****	30.48****	20.08****	37.64****
Time-of-day	27.20****	5.05**	7.26***	11.72****
Location	3.10*	2.61*	1.44	5.11**
Subject/time	2.43**	1.17	0.78	1.35
Subject/location	2.21**	1.64*	1.86*	1.48
Time/location	3.95***	0.55	1.14	3.51**
sub/time/loc	1.42	0.74	0.81	1.14

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

Table 16. Intersubject Differences in Fatigue and Mood Ratings at Different Times of Day (two-way ANOVA, n = 44)

	F Fatigue	F Positive affect	F Negative affect	F Activation
Subject	11.15****	26.74****	17.49****	17.74****
Time-of-day	30.92****	4.13***	18.70****	17.75****
Interaction	1.77****	0.99	1.11	1.25*

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

Table 17. Fatigue and Mood, Comparing Time-of-Day, Ratings Were Made with Location (two-way ANOVA, n = 44)

	F Fatigue	F Positive affect	F Negative affect	F Activation
Time-of-day	11.79****	1.15	7.06****	7.43****
Location	8.90****	7.14***	3.68*	13.70****
Interaction	1.09	1.05	0.93	1.14

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

Ratings on the fatigue scale and the three mood factors all varied significantly among subjects, and according to the location at which they were made (fig. 22). Fatigue was rated lowest pretrip and posttrip, higher on segments, and highest on layovers. Positive affect was highest on segments and lowest on layovers. Negative affect was highest on layovers and lowest posttrip, whereas activation was highest posttrip and lowest on layovers. Thus, the greatest subjective fatigue and worst mood ratings were recorded during layovers. Positive affect was rated as highest during flight segments, even though fatigue was rated as higher than on either pretrip or posttrip (but lower than on layovers). Posttrip recovery was indicated by the return of fatigue to baseline levels, the lowest negative affect ratings, and the highest activation ratings. The significant subject/location interactions for fatigue, positive affect, and negative affect in the three-way ANOVA indicate that not all subjects conformed to this pattern.

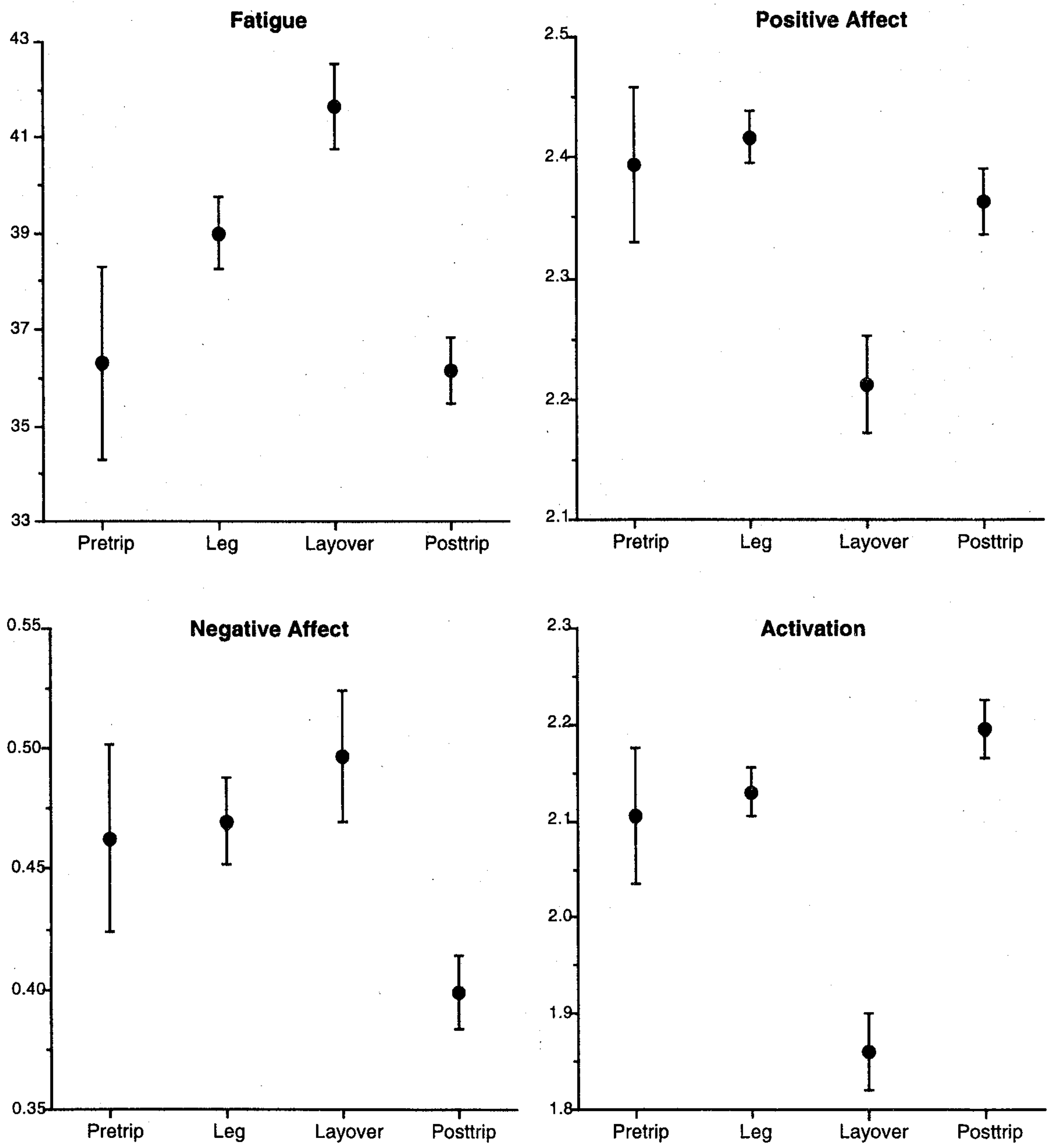


Figure 22. Average fatigue and mood ratings separated according to where the ratings were made. "Leg" indicates ratings made during flight segments. "Layover" includes ratings made on the ground between flight segments, and ratings made during nighttime layovers. Vertical bars indicate standard errors. Fatigue was rated on a 100 mm line from 0 ("alert") to 100 ("drowsy"). Mood adjectives were rated on a scale from 1 to 5.

The three-way ANOVA (n = 9) and the two-way ANOVA comparing subjects and time-of-day (n = 44) both suggest that fatigue and all three mood factors showed significant time-of-day variation (fig. 23). However, the two-way ANOVA comparing location and time-of-day did not indicate a significant variation in positive affect with time-of-day. The one-way ANOVA for positive affect by time-of-day was also not significant (F = 1.77, p = 0.102). There were also no significant interactions for positive affect between time-of-day and either subjects or location. These results suggest that the time-of-day variation in positive affect is, at best, less robust than the time-of-day variations in fatigue, negative affect, and activation.

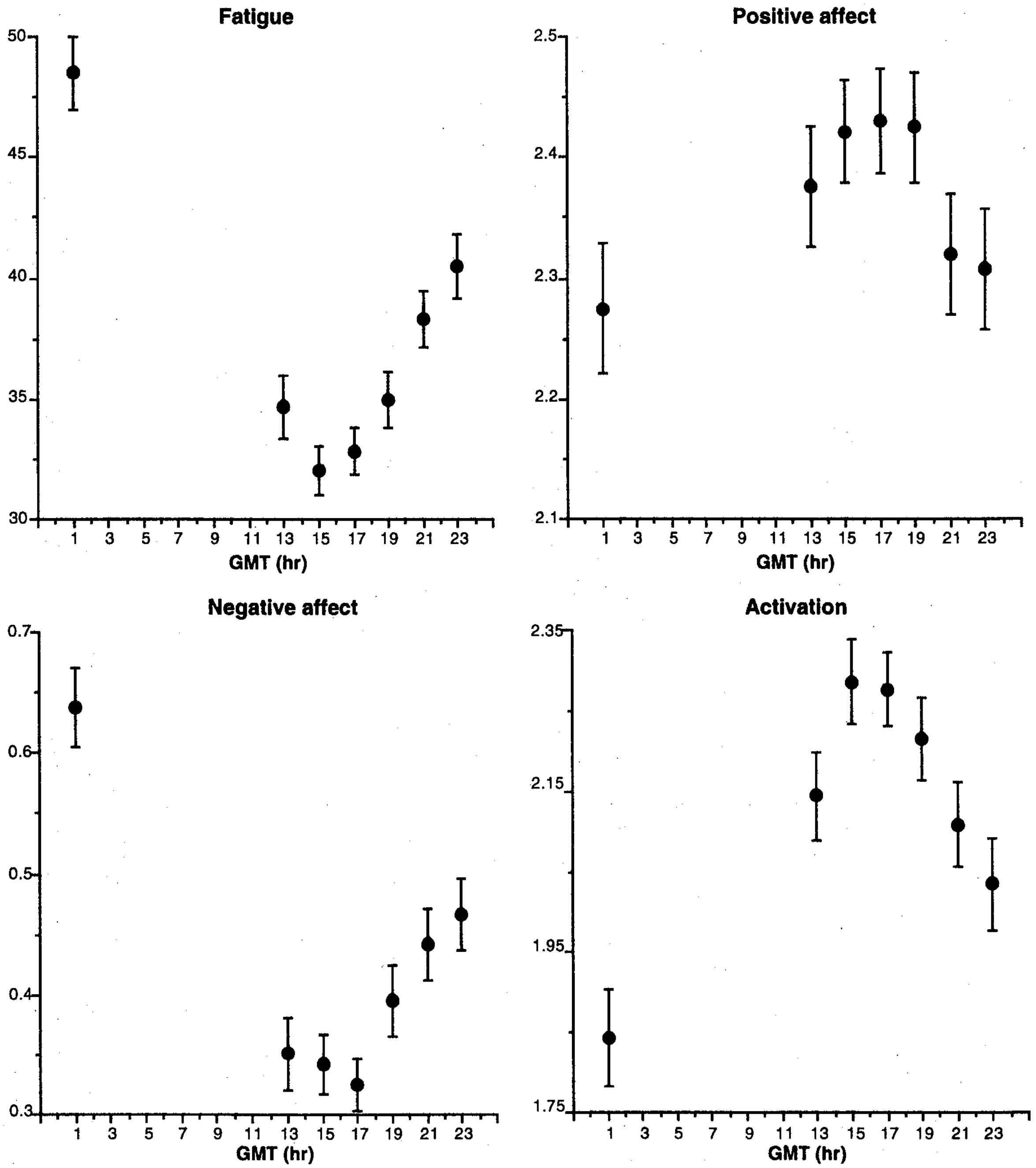


Figure 23. Time-of-day variations in fatigue and mood ratings (vertical bars indicate standard errors). The variations in fatigue, negative affect, and activation are significant. As expected, the daily cycles in fatigue and negative affect are mirror images of the variation in activation. Ordinates as in figure 22.

The significant subject/time-of-day interactions for fatigue and activation indicate that all subjects did not show the same daily pattern of variation in these measures. The lack of significant time-of-day/location interactions in the two-way ANOVA may have been a result of these analyses not taking into account this intersubject variability, since both fatigue and activation showed time-of-day/location interactions in the three-way ANOVAs. This implies that the daily pattern of variation in fatigue and activation was also different at different locations. The significant interaction subject/time-of-day/location for fatigue in the three-way ANOVA supports this interpretation. It is interesting to note that the strongest correlation in fatigue and mood ratings is the negative relationship between fatigue and activation ($r = 0.55$, $p < 0.05$).

Since no subjects flew both 3-day and 4-day trips, two-way ANOVAs (trip type by time-of-day) were performed to test whether 3-day and 4-day pilots differed significantly in their fatigue and mood ratings during baseline. It should be noted that only twenty-three 3-day pilots and two 4-day pilots gave complete pretrip baseline data. Thus the second and third days of posttrip data were also included as baseline days. As a group, pilots flying 4-day trips reported greater fatigue ($F = 4.33$, $p < 0.05$), less positive affect ($F = 7.29$, $p < 0.01$), and lower activation ($F = 8.89$, $p < 0.01$) during baseline; however, this may be misleading because of the definition of baseline in these analyses. To test if the fatigue and mood ratings varied significantly between 3-day and 4-day trips, two-way ANOVAs were performed (trip type by location). These analyses are summarized in table 18.

Table 18. Fatigue and Mood on 3-Day vs. 4-Day Trips: Comparing Values Pretrip, In-Flight, During Layovers, and Posttrip (two-way ANOVA, n = 44)

	F Fatigue	F Positive affect	F Negative affect	F Activation
Trip type	1.73	39.96****	1.07	26.76****
Location	5.03**	9.47****	3.97**	15.09****
Interaction	1.70	3.36*	2.01	3.95**

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

Since intersubject variability was significant for all the fatigue and mood ratings, the possibility that the significant differences in positive affect and activation found between 3-day and 4-day trips is attributable to the different subject pools cannot be excluded. The significant trip type/location interactions for these two measures are examined in figure 24. Pilots who flew 3-day trips rated their positive affect as lowest pretrip, whereas pilots who flew 4-day trips rated it as highest pretrip. The pilots who flew 3-day trips consistently rated themselves higher on the activation scale than the pilots who flew 4-day trips. Both groups rated their activation as lowest on layovers; however, 3-day pilots rated their activation as highest in-flight, and 4-day pilots showed their highest ratings posttrip.

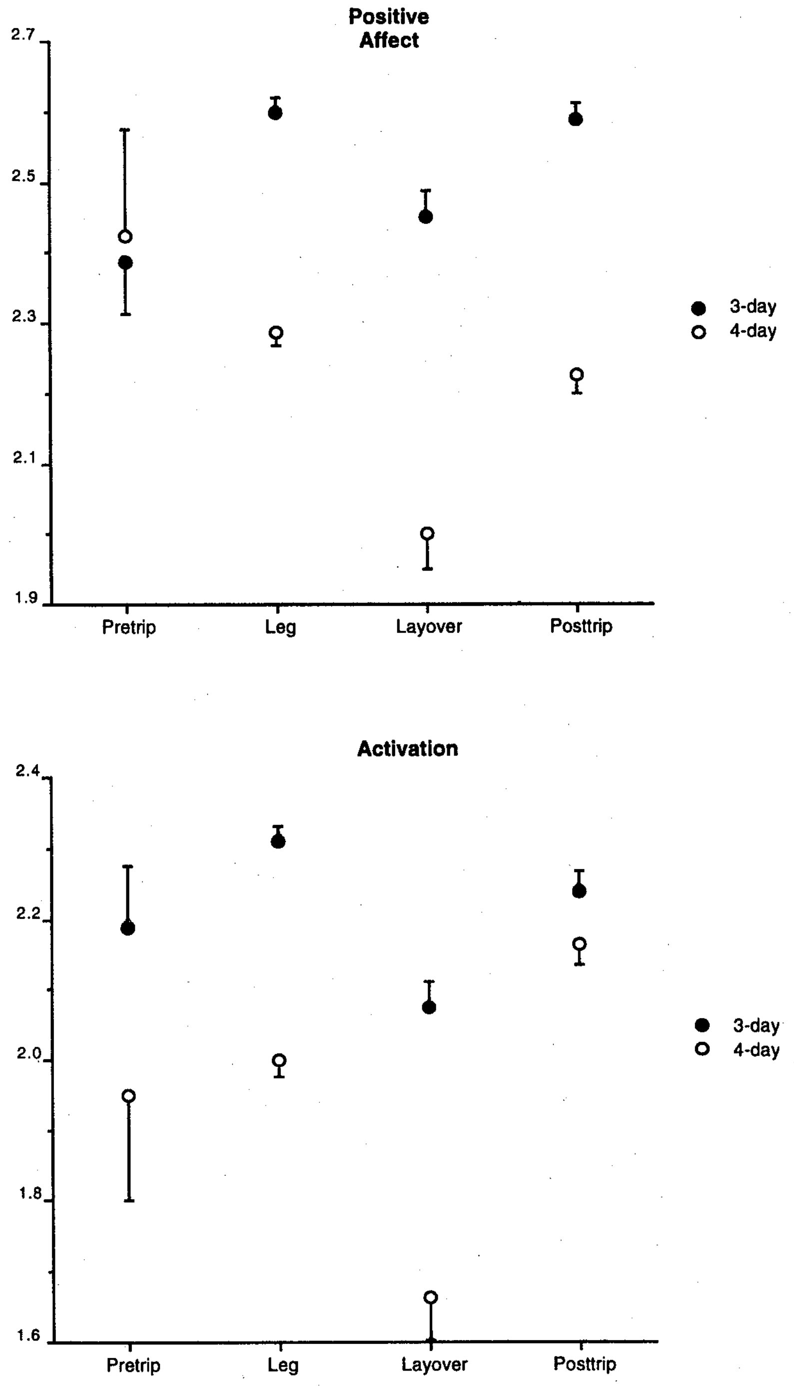


Figure 24. *Comparison of 3-day and 4-day trips for positive affect and activation at different locations. "Leg" indicates ratings made during flight segments. "Layover" includes ratings made on the ground between flight segments, and ratings made during nighttime layovers. Vertical bars indicate standard errors. Ordinates as in figure 22.*

4.3.3 Drug Intake, Medical Symptoms, and Exercise

The percentages of subjects reporting the use of tobacco, caffeine, alcohol, and medications, and the occurrence of medical symptoms and exercise at some time during the study are shown in table 19.

Table 19. Percentage of Subjects Reporting Drug Intake, Medical Symptoms, and Exercise

	Subjects, %			
	Home only	Trip only	Home + Trip	None
Tobacco	1.5	3.0	12.1	83.3
Caffeine	3.1	7.7	83.1	6.2
Alcohol	0.0	39.1	40.6	20.3
Medication	10.6	12.1	12.1	65.2
Medical symptoms	12.3	20.0	27.7	40.0
Exercise	22.7	9.1	33.3	34.8

Because of the reduced number of subjects in these data sets, no comparisons between 3-day and 4-day trips were attempted.

Seventeen percent of all subjects reported smoking tobacco at some time during the study (table 19). The time of day at which smoking occurred was recorded in the logbook only as A.M. or P.M. Of the 44 subjects who provided logbook data for at least 1 day pretrip and 2 days posttrip, 10 (23%) were smokers, and nine of these provided complete data on smoking. To test if the number of cigarettes smoked per day varied before, during, and after trips, two-way ANOVAs (subject by pre/trip/post) were performed using the data from these nine subjects (table 20).

Table 20. Intersubject Differences and Cigarette Smoking Before, During, and After Trips (two-way ANOVA, $n = 9$)

Cigarettes	F Subjects	F Pre/trip/post	F Interaction
A.M.	10.75****	0.77	1.29
P.M.	8.71****	0.19	0.83
Daily total	27.15****	0.44	1.44

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

There were significant differences between smokers in the number of cigarettes smoked per day; however, individual smokers did not change the number of cigarettes smoked on trip days from that of pretrip or posttrip days.

Caffeine was consumed by 93.8% of the subjects at some time during the study (table 19). The time of day at which caffeine consumption occurred was also recorded in the logbook. Of the 44 subjects who provided logbook data for at least 1 day pretrip and 2 days posttrip, 39 (89%) drank caffeinated beverages, and 35 of these provided complete data on consumption of caffeinated beverages. To test if the number of caffeinated beverages consumed per day varied before, during, and after trips, two-way ANOVAs (subject by pre/trip/post) were performed using the data from these 35 subjects (table 21).

Table 21. Intersubject Differences and Caffeine Consumption Before, During, and After Trips (two-way ANOVA, n = 35)

Caffeine	F Subjects	F Pre/trip/post	F Interaction
Servings	4.64****	18.38****	1.09
Time of consumption	2.54****	1.93	0.98

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

Overall, subjects who drank caffeinated beverages consumed more caffeine on trip days (mean = 3.4 servings) than on either pretrip days (mean = 1.9 servings) or posttrip (mean = 2.7 servings) (fig. 25). There were also significant differences between caffeine drinkers in the number of cups of beverages containing caffeine that were consumed daily, and in the times at which they were consumed.

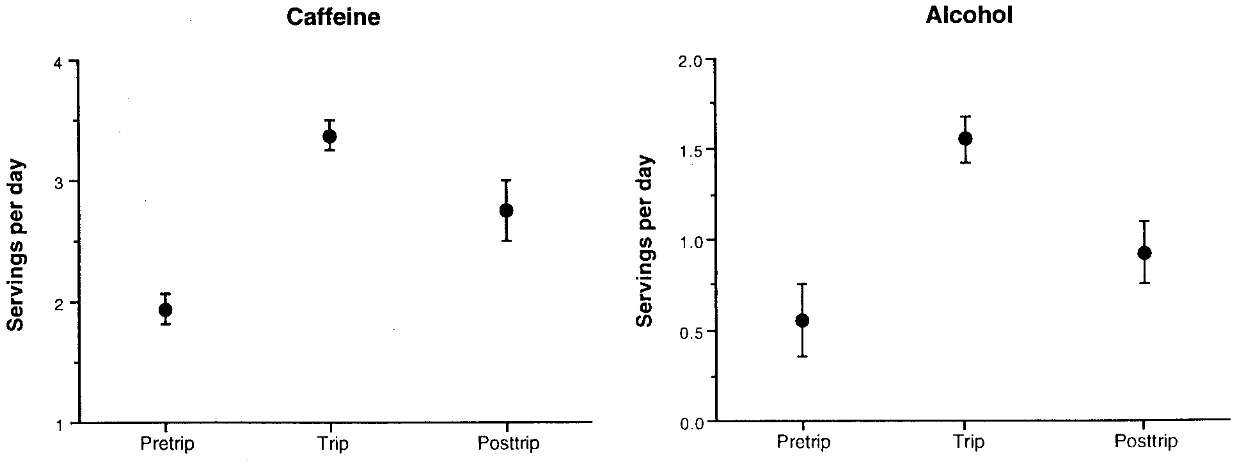


Figure 25. Average caffeine and alcohol consumption on pretrip, trip, and posttrip days (vertical bars indicate standard errors). One glass of beer or wine or one measure of spirits was counted as one serving of alcohol.

Although the timing of caffeine consumption did not vary significantly among pretrip, trip, and posttrip days (table 21), figure 26 indicates that much of the additional caffeine consumption on trips occurred shortly after waking up, in association with the significantly earlier wake-up times on trip days, and during the afternoon.

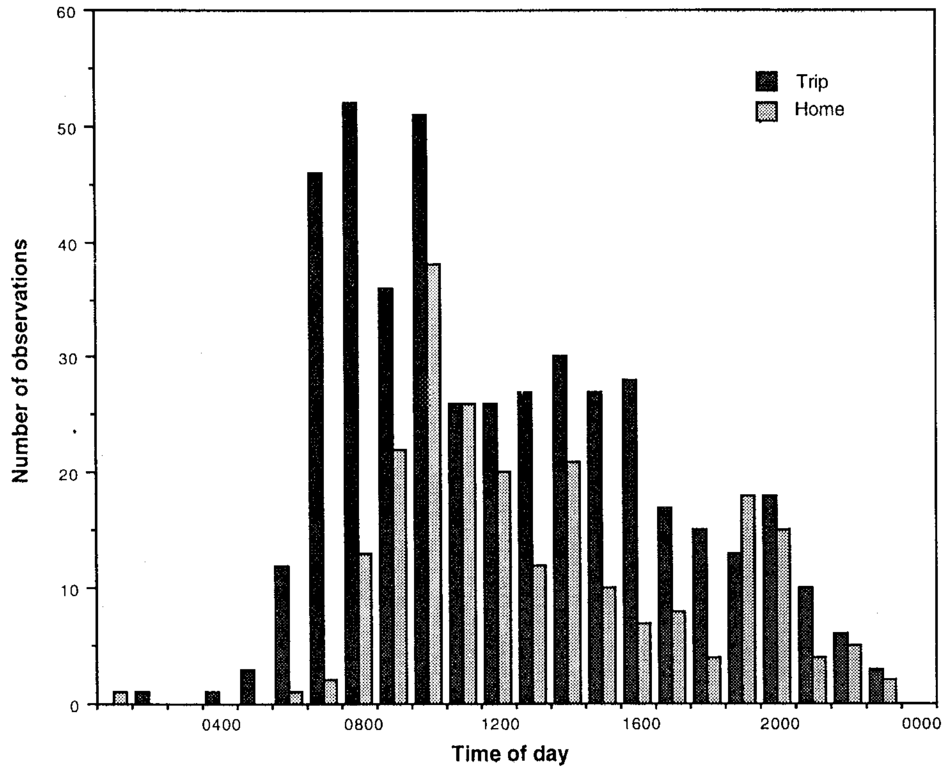


Figure 26. Histogram of the number of cups of caffeinated beverages consumed at different times of day at home and on trips. Most of the increased consumption on trips occurred in the early morning and mid-afternoon.

Alcohol was consumed by 79.7% of subjects during trips (table 19). The time of alcohol consumption was not recorded in the logbook. Of the 44 subjects who provided logbook data for at least 1 day pretrip and 2 days posttrip, 29 (66%) consumed alcohol at some time during the study, and 27 of these provided complete data on alcohol consumption. To test if the number of servings of alcohol per day varied before, during, and after trips, two-way ANOVAs (subject by pre/trip/post) were performed using the data from these 27 subjects (table 22). Note that a glass of beer or wine or one measure of liquor was counted as one serving of alcohol.

Subjects who consumed alcohol during the study consumed more on trip days (mean 1.6 servings) than on either pretrip days (0.5 servings) or posttrip days (1.0 servings) (fig. 26).

Table 22. Intersubject Differences and Alcohol Consumption Before, During, and After Trips (two-way ANOVA, n = 27)

Alcohol	F Subjects	F Pre/trip/post	F Interaction
Servings	1.41	4.82**	0.51

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

Medications of various kinds were used by 34.8% of the subjects at some time during the study (table 19). These were classified into the categories: cold remedies (2 subjects); analgesics (18 subjects); anti-acids (2 subjects); prescription medication (1 subject); and topical medications

(3 subjects). Of the 44 subjects who provided logbook data for at least 1 day pretrip and 2 days posttrip, 16 (36%) reported using medications at some time during the study, and 14 of these provided complete data on the use of medications. To test if the daily use of medications varied before, during, and after trips, two-way ANOVAs (subject by pre/trip/post) were performed using the data from these 14 subjects (table 23). Analgesic use was also examined in this way for the 9 (of the 14) subjects who used analgesics at some time during the study (table 23).

Table 23. Intersubject Differences and Use of Medications Before, During, and After Trips (two-way ANOVA)

Medication	F Subjects	F Pre/trip/post	F Interaction
Number of medications/day (n = 27)	2.94**	0.44	1.75*
Number of analgesics/day (n = 9)	1.44	1.38	0.82

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

Among subjects who reported using medications, there were significant differences in the number of medications used per day. However, there was no significant difference between the number of medications used on trip days and the number used on pretrip or posttrip days. The significant interaction indicates that subjects varied in their patterns of medication intake before, during, and after trips. The highest percentage of subjects (43%) reported greatest medication use posttrip; 21% reported greatest use pretrip; and 21% reported greatest use during trips. The remaining 14% reported other patterns. Analgesic use did not change significantly between pretrip, trip , and posttrip days.

Medical symptoms in one or more of the categories listed in table 24 were reported by 60% of the subjects at some time during the study.

Table 24. Percentage of Subjects Reporting Symptoms

Symptom	Pretrip	Trip	Posttrip	Symptom	Pretrip	Trip	Posttrip
Headache	5	9	10	Burning eyes	0	2	0
Racing heart	0	1	0	Chills	0	0	0
Congested nose	6	8	6	Nausea	0	1	0
Watery eyes	0	1	1	Light-headed	2	1	0
Flushed face	0	1	0	Feverish	0	0	0
Dizziness	0	1	0	Disorientation	0	0	0
Constipation	0	2	1	Sweating	6	1	0
Back pain	2	4	3	Diarrhea	2	1	1
Sore throat	2	2	1	Upset stomach	0	2	0
Feeling weak	0	1	1	Short of breath	0	0	0

Of the 44 subjects who provided logbook data for at least 1 day pretrip and 2 days posttrip, 22 (50%) reported medical symptoms in the above categories at some time during the study, and 19 of these provided complete data on the occurrence of symptoms. To test if the daily reporting of symptoms (in all categories) varied before, during, and after trips, two-way ANOVAs (subject by pre/trip/post) were performed using the data from these 19 subjects (table 25). The three most commonly reported symptoms (headache, congested nose, and back pain) were also analyzed separately. Twenty-five percent (11/44) of the subjects reported having headaches at some time during the study, 16% (7/44) reported having a congested nose, and 7% (3/44) reported back pain.

Table 25. Intersubject Differences and Symptom Reporting Before, During, and After Trips (two-way ANOVA)

Symptom	F Subjects	F Pre/trip/post	F Interaction
Number of reported (n = 19)	1.78*	1.00	0.91
Number of headaches (n = 10)	0.38	1.77	0.99
Number of congested nose (n = 5)	4.02*	0.28	1.59
Number of back pain (n = 3)	0.41	1.69	4.50*

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

There were significant differences between subjects in the total number of symptoms reported per day and in the number of reports of congested noses. However, there were no significant differences in the total number of symptoms reported on trip, pretrip, or posttrip days. Similarly, there was no evidence for increased reports of headaches, congested noses, or back pain on trips. One subject reported back pain at home and on the trip, one reported back pain only during the trip, and the third reported back pain during the trip and posttrip.

Because of the small number of subjects in the above analyses, these data were also examined in a different way. The percentages of subjects reporting headache, congested nose, and back pain were calculated with respect to the number of subjects completing logbook data for each day of the study (fig. 27). One-way ANOVA confirmed that none of these symptoms differed significantly on trip days from either pretrip or posttrip days (for headache, $F = 0.02$, $p = 0.90$; for congested nose $F = 4.99$, $p = 0.12$; for back pain, $F = 1.61$, $p = 0.26$.)

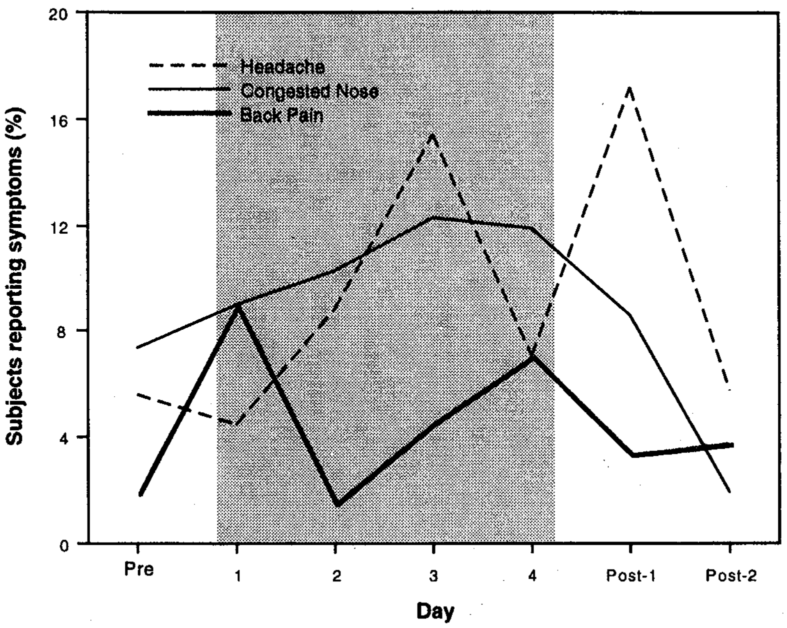


Figure 27. Percentages of subjects reporting the 3 most common symptoms on each of the study days. Shading indicates trip days.

Exercise was reported by 65.1% of subjects at some time during the study (table 19). Of the 44 subjects who provided logbook data for at least 1 day pretrip and 2 days posttrip, 31 (70%) reported exercising at some time during the study, and 27 of these provided complete data on exercise. To test if the daily number of exercise sessions varied before, during, and after trips, two-way ANOVAs (subject by pre/trip/post) were performed using the data from these 27 subjects (table 26). Note that exercise was not categorized by type or duration in these analyses.

Table 26. Intersubject Differences and Exercise Before, During, and After Trips (two-way ANOVA, n-27)

	F Subjects	F Pre/trip/post	F Interaction
Number of exercise sessions/day	1.84*	2.55	1.27

* 0.05 > p > 0.01; ** 0.01 > p > 0.001; *** 0.001 > p > 0.0001; **** p < 0.0001.

Among subjects who reported exercising at some time during the study, there were significant differences in the number of daily exercise sessions. However, there was no significant difference in the average amount of exercise performed on trip days (0.34 sessions per day) by comparison with either pretrip (0.52 sessions per day) or posttrip days (0.48 sessions per day).

4.3.4 Meals

Of the 44 subjects who provided logbook data for at least 1 day pretrip and 2 days posttrip, 34 (77%) provided complete data on meals. To test if the daily number of meals or snacks varied before, during, and after trips, two-way ANOVAs (subject by pre/trip/post) were performed using the data from these 34 subjects (table 27).

The only significant finding in these analyses was that more snacks were eaten on trip days than on pretrip and posttrip days (fig. 28).

Table 27. Intersubject Differences and Meal Patterns Before, During, and After Trips (two-way ANOVA, n = 34)

	F Subjects	F Pre/trip/post	F Interaction
Meals (B+L+D)	0.51	1.65	0.24
Snacks	0.87	16.05****	0.41

* 0.05 > p > 0.01; ** 0.01 > p > 0.001; *** 0.001 > p > 0.0001; **** p < 0.0001.

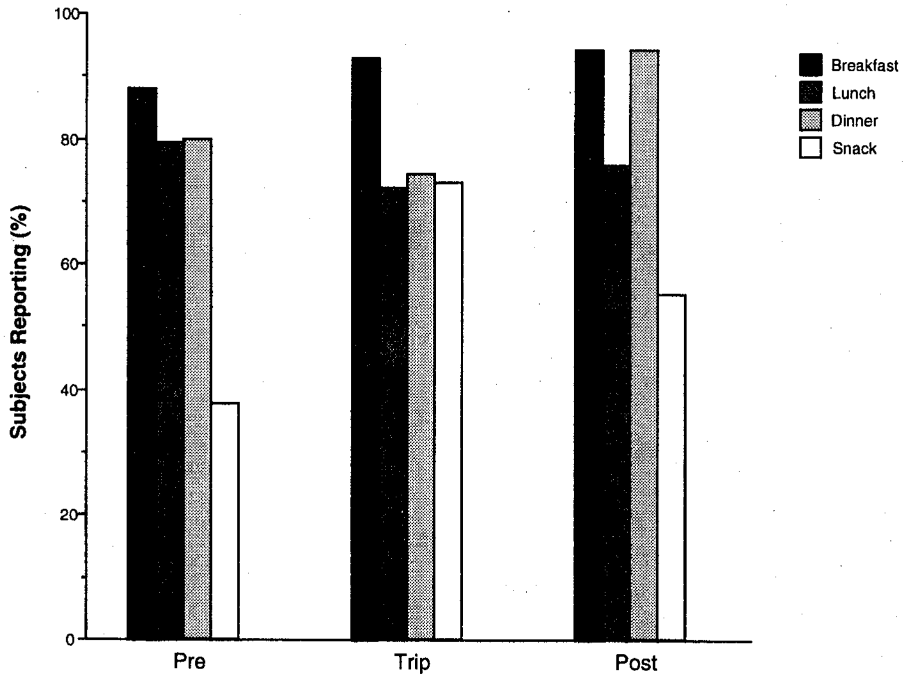


Figure 28. Percentages of subjects reporting meals and snacks on pretrip, trip, and posttrip days. Significantly more snacks were reported on trip days.

The pilots in this study were from two different commercial carriers, one of which provided crew meals, and one that did not. To test if the provision by the company of crew meals affected the numbers of meals and snacks eaten, two-way ANOVAs (company by pre/trip/post) were performed (table 28).

Table 28. Meals Before, During, and After Trips, With and Without Crew Meals (two-way ANOVA)

	F Crew meals	F Pre/trip/post	F Interaction
Meals (B+L+D)	0.65	2.03	0.13
Snacks	1.54	15.14****	0.11

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

The lack of significant interactions in these analyses suggests that the provision of crew meals did not change the patterns of meal consumption. Table 28 also confirms that more snacks were consumed on trip days than on pretrip and posttrip days.

The effects of 3-day versus 4-day trips on the numbers of meals and snacks eaten were also compared by two-way ANOVA (table 29).

Table 29. Meals Before, During, and After Trips, Comparing 3-Day and 4-Day Trips (two-way ANOVA)

	F Subjects	F Pre/trip/post	F Interaction
Meals (B+L+D)	0.25	2.09	0.27
Snacks	0.60	15.52****	0.29

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

These analyses suggest that the patterns of meal consumption were not significantly different on 3-day and 4-day trips. They also confirm that more snacks were consumed on trip days than on pretrip and posttrip days.

The (local) times at which meals and snacks were eaten were examined for the 34 subjects who gave complete data on meals. Meal times on pretrip, trip, and posttrip days were compared between pilots from the two companies and on 3-day versus 4-day trips, by two-way ANOVA (tables 30 and 31).

Table 30. Meal Timing Before, During, and After Trips, With and Without Meals (two-way ANOVA)

Meal	F Crew meals	F Pre/trip/post	F Interaction
Breakfast	0.31	1.19	0.22
Lunch	0.01	0.70	1.99
Dinner	0.07	2.14	0.38
Snacks	0.29	8.26***	2.62

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

Table 31. Meal Timing Before, During, and After Trips, Comparing 3-Day and 4-Day Trips (two-way ANOVA)

Meal	F Crew meals	F Pre/trip/post	F Interaction
Breakfast	0.01	1.14	0.61
Lunch	0.01	0.92	3.27*
Dinner	0.08	2.01	0.10
Snacks	0.31	7.50***	2.42

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

These analyses indicate that meal timing did not differ significantly on trip days by comparison with either pretrip or posttrip days. However, snacks were eaten earlier on trips than either pretrip or posttrip (fig. 29).

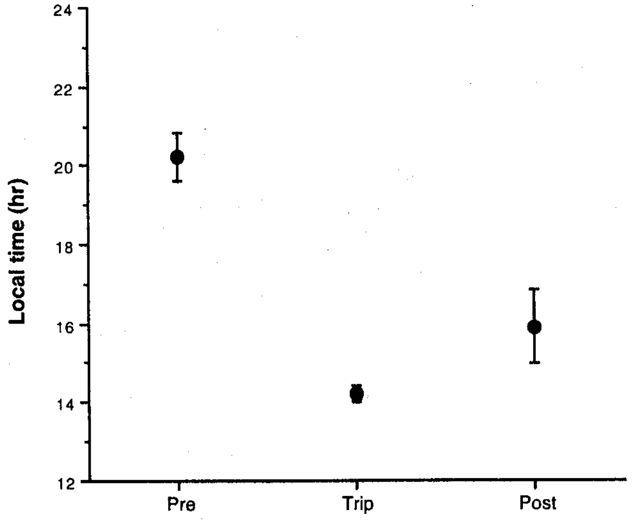


Figure 29. Local times of snack consumption on pretrip, trip, and posttrip days. Vertical bars indicate standard errors.

The significant interaction term for the timing of lunch reflects the fact that subjects on 3-day trips ate lunch latest during trips, whereas subjects on 4-day trips ate lunch latest posttrip.

4.3.5 Summary

On trips, subjects took longer to fall asleep, slept for a shorter time, awoke earlier, and reported lighter and poorer sleep overall, with more awakenings. The effect of duty days was also seen in the subjective fatigue and mood ratings. During layovers, subjective fatigue was higher and mood ratings were poorer (lowest activation and positive affect, highest negative affect) than during either pretrip or posttrip, or during flight segments. More caffeine and alcohol were consumed on trips, and snacking increased.

There were no significant differences between trip days and either pretrip or posttrip days in the use of tobacco or medications, in the incidence of reports of medical symptoms, or in the number of exercise sessions reported.

4.4 Duty Factors and Changes in Behavior on Trips

Multiple regression analyses were carried out to examine which aspects of duty schedules contributed most to the changes in behavior observed on trips. Each duty day for each of the 44 subjects with complete pretrip, trip, and posttrip data was included in these analyses. It should be noted that differences between individuals are not taken into account in these analyses.

4.4.1 Sleep

The following dependent variables were examined for their contributions to the variance in sleep measures: preceding duty duration, preceding flight hours, preceding number of flight segments, preceding off-duty time, layover duration, and the following on-duty time (table 32). The sleep episode after the final trip day occurred at home and therefore could not be included in these analyses, which are based on 112 nights of trip sleep. The analyses concerning the number of awakenings include only 96 nights of trip sleep because not all subjects reported awakenings, and only those who did were included.

The most important contribution to the variability in wake-up times was the time of the next on-duty, with later wake-ups being associated with later duty report times. Later times of coming off-duty the night before were also associated with later wake-up times the following morning. The most important contribution to the variability in sleep duration was the duration of the layover, followed by the time of the next on-duty. The duration of the preceding duty period was also positively correlated with the sleep duration. Fewer awakenings were reported following longer duty days and later off-duty times. Conversely, more awakenings were reported after duty days containing more flight hours and when the next duty period began later.

Table 32. Multiple Regression Analyses of the Duty Factors Affecting Sleep on Trips

Wake-up time[a]				
Variable	Unstandardized reg. coeff.	Standardized reg. coeff.	p	* Contribution to r^2
Next on-duty time	0.267	0.457	0.000	0.121
Off-duty time	0.222	0.445	0.000	0.106
Layover duration	0.131	0.196	0.003	0.027
Duty duration	-0.186	-0.235	0.008	0.022
Flight hours	0.279	0.227	0.008	0.021
Sleep latency[b]				
Variable	Unstandardized reg. coeff.	Standardized reg. coeff.	p	Contribution to r^2
Number of segments	-0.037	-0.107	0.262	0.011
Sleep duration[c]				
Variable	Unstandardized reg. coeff.	Standardized reg. coeff.	p	Contribution to r^2
Layover duration	0.176	0.357	0.000	0.115
Next on-duty time	0.119	0.278	0.001	0.071
Duty duration	0.155	0.267	0.001	0.069
Overall sleep rating[d]				
Variable	Unstandardized reg. coeff.	Standardized reg. coeff.	p	Contribution to r^2
Flight hours	0.362	0.213	0.024	0.046
How deep was your sleep[e]				
Variable	Unstandardized reg. coeff.	Standardized reg. coeff.	p	Contribution to r^2
Duty duration	0.033	0.082	0.390	0.007
Number of awakenings (n = 96)[f]				
Variable	Unstandardized reg. coeff.	Standardized reg. coeff.	p	Contribution to r^2
Off-duty time	-0.242	-0.330	0.002	0.091
Flight hours	0.622	0.335	0.019	0.052
Next on-duty time	0.436	0.148	0.142	0.020
Duty hours	-0.255	-0.210	0.145	0.020

* Indicates the amount by which r^2 would be reduced if the variable were removed from the regression equation.

a. For the best subset: $r^2 = 0.693$, $F = 47.82$, $p = 0.0000$.

b. For the best subset: $r^2 = 0.011$, $F = 1.27$, $p = 0.2523$.

c. For the best subset: $r^2 = 0.309$, $F = 16.14$, $p = 0.0000$.

d. For the best subset: $r^2 = 0.046$, $F = 5.20$, $p = 0.0245$.

e. For the best subset: $r^2 = 0.007$, $F = 0.74$, $p = 0.3902$.

f. For the best subset: $r^2 = 0.167$, $F = 4.56$, $p = 0.0021$.

4.4.2 Layover Fatigue and Mood Ratings

The following dependent variables were examined for their contributions to the variance in layover fatigue and mood ratings: on-duty time, off-duty time, duty duration, flight hours, and the number of segments flown (table 33). Fatigue and mood ratings were available for 149/156 duty days.

These analyses suggest that duty-related factors did not contribute significantly to the variance in fatigue and mood ratings during layovers. However, they do not take into account individual variability, which was highly significant for the fatigue and mood ratings.

Table 33. Multiple Regression Analyses of Duty Factors Affecting Layover Fatigue and Mood Ratings

Layover fatigue[a]				
Variable	Unstandardized reg. coeff.	Standardized reg. coeff.	p	* Contribution to r^2
Duty duration	-0.544	-0.086	0.299	0.007
Layover positive affect[b]				
Variable	Unstandardized reg. coeff.	Standardized reg. coeff.	p	Contribution to r^2
Flight hours	0.040	0.113	0.170	0.013
Layover negative affect[c]				
Variable	Unstandardized reg. coeff.	Standardized reg. coeff.	p	Contribution to r^2
On-duty time	0.013	0.127	0.121	0.016
Layover activation[d]				
Variable	Unstandardized reg. coeff.	Standardized reg. coeff.	p	Contribution to r^2
Flight hours	0.059	0.150	0.068	0.023

* Indicates the amount by which r^2 would be reduced if the variable were removed from the regression equation.

a. For the best subset: $r^2 = 0.007$, $F = 1.08$, $p = 0.2994$.

b. For the best subset: $r^2 = 0.013$, $F = 1.90$, $p = 0.1705$.

c. For the best subset: $r^2 = 0.016$, $F = 2.43$, $p = 0.1214$.

d. For the best subset: $r^2 = 0.023$, $F = 3.39$, $p = 0.0675$.

4.4.3 Caffeine, Alcohol, and Snack Consumption

The following dependent variables were examined for their contributions to the variance in daily caffeine, alcohol, and snack consumption during trips: on-duty time, off-duty time, duty duration, flight duration, and the number of segments flown (table 34). Subjects who consumed no caffeine, alcohol, or snacks on trips were excluded from the respective analyses.

The longer pilots were on duty, the more caffeine they consumed. Conversely, the shorter the duty duration and the later the duty day began, the more alcohol they drank in a day.

Table 34. Multiple Regression Analyses of Duty Factors Affecting Daily Caffeine, Alcohol, and Snack Consumption

Caffeine^a (n = 124)				
Variable	Unstandardized reg. coeff.	Standardized reg. coeff.	p	* Contribution to r^2
Duty duration	0.176	0.200	0.028	0.038
On-duty time	-0.085	-0.131	0.147	0.016
Alcohol^b (n = 103)				
Variable	Unstandardized reg. coeff.	Standardized reg. coeff.	p	Contribution to r^2
Duty duration	-0.309	-0.402	0.000	0.159
On-duty time	0.095	0.176	0.053	0.030
Snacks^c (n = 112)				
Variable	Unstandardized reg. coeff.	Standardized reg. coeff.	p	Contribution to r^2
Flight hours	-0.029	-0.042	0.661	0.002

* Indicates the amount by which r^2 would be reduced if the variable were removed from the regression equation.

a. For the best subset: $r^2 = 0.068$, $F = 4.40$, $p = 0.0143$.

b. For the best subset: $r^2 = 0.212$, $F = 13.43$, $p = 0.0000$.

c. For the best subset: $r^2 = 0.002$, $F = 0.19$, $p = 0.6614$.

4.5 Heart Rate Changes During Different Phases of Flight

In these analyses, changes in heart rate during different phases of flight were examined as one possible measure of the "stress" associated with regular operational events. The heart-rate data were recorded as 2 min averages of the r-wave intervals, so it was not possible to examine beat-by-beat variability in these data. The heart rate during takeoff was taken as the average of three consecutive 2 min intervals, with actual takeoff occurring in the first 2 min interval. The heart rate during mid-cruise was taken as the average of five consecutive 2 min intervals centered between top-of-climb and top-of-descent. The heart rate during descent was taken as the average of five consecutive 2 min intervals, with touchdown occurring in the 2 min interval immediately following the 10 min defined as descent. The average heart rate during landing was taken as the average of three consecutive 2 min intervals, with touchdown occurring in the last interval. Complete heart-rate data were available for 589 flight segments.

4.5.1 Heart Rate Changes During Takeoff, Descent, and Landing

For each subject, for each flight segment, the difference between the heart rate during takeoff and during mid-cruise was converted to a percentage of the heart rate during mid-cruise. Similarly, percentage changes in heart rate were calculated for descent and landing with respect to the heart rate during mid-cruise. The percentage change in heart rate was chosen as a metric to minimize intersubject and time-of-day variability. Significant increases in heart rate over mid-cruise were found for descent (paired t-test, $t = -5.48$, $p < 0.0001$) and for landing (paired t-test, $t = -5.64$, $p < 0.0001$), but not for takeoff (paired t-test, $t = 1.91$, $p > 0.05$). Two-way ANOVAs (table 35) were performed to test for possible differences between captains and first officers, and between flying and not-flying conditions, since most crews alternated responsibility for control of the aircraft between successive flight segments.

These analyses indicate that heart-rate changes during different changes of flight were not significantly different for captains and first officers. However, during both descent and landing, the pilot flying showed much greater increases in heart rate than the pilot not flying. During descent, the flying pilots showed an average increase in heart rate over mid-cruise of 5.8%, whereas the non-flying pilots showed a 1.9% decrease. The significant interaction is a result of first officers showing a bigger difference between flying and non-flying conditions (9.6%) than captains (5.9%). During landing, the flying pilots showed an average increase in heart rate over mid-cruise of 4.2%, and the non-flying pilots showed a 0.1% decrease.

Table 35. Heart Rate During Takeoff, Descent, and Landing: Captains vs. First Officers, Flying and Not-Flying (two-way ANOVA)

Flight phase	F Crew position	F Flying/not flying	F Interaction
Takeoff	0.23	0.01	0.01
Descent	2.50	172.07****	9.61**
Landing	0.40	41.72****	0.71

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

4.5.2 Heart Rate Changes Under Visual Conditions Versus Instrument Conditions

Possible differences between visual meteorological conditions (VMC) and instrument meteorological conditions (IMC) in their effects on heart-rate changes were also examined (table 36).

Heart rate increases during takeoff were greater under IMC conditions (mean increase over mid cruise 1.2%) than under VMC conditions (mean decrease over mid-cruise 0.6%). Similarly, heart -rate increases were greater during descent under IMC conditions (mean increase over mid-cruise 4.3%) than under VMC conditions (mean increase over mid-cruise 1.6%). The significant interaction indicates that the difference between flying and not-flying conditions was much greater under IMC conditions (11.0%) than under VMC conditions (7.2%). Heart-rate changes during landing were not significantly different between IMC and VMC conditions.

Table 36. Heart Rate During Takeoff, Descent, and Landing: VMC vs. IMC, Flying and Not-Flying (two-way ANOVA)

Flight phase	F VMC/IMC	F Flying/not flying	F Interaction
Takeoff	4.29*	0.16	0.31
Descent	8.22**	92.28****	3.94*
Landing	1.17	14.79****	0.07

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $0.001 > p > 0.0001$; **** $p < 0.0001$.

5.0 DISCUSSION

These studies represent the most comprehensive documentation, in a large group of pilots, of some of the physiological and psychological effects of flying short-haul air transport operations. A preliminary investigation has also been made into the roles of duty requirements in the observed psychophysiological changes. The interpretation and application of these findings must take into account the kind of schedules studied. From the monthly schedules, 3-day and 4-day trip patterns were selected that were perceived by the investigators, pilots, and management groups as the most challenging in terms of duty timing, intensity, and duration. All trips took place on the east coast of the United States and involved considerable flying in high-density airspace. Data collection covered all seasons of the year. The effects observed are thus expected to represent the upper range of fatigue experienced by pilots in predominantly daytime and evening, short-haul air transport operations in FAR Part 121 operations. The pilot population studied was experienced (average age 41.25 yr, average airline experience 14.64 yr) and averaged 68.64 hr of flying per month in all categories of aviation.

5.1 Flight and Duty Time Regulations in Practice

Currently, Federal Aviation Regulations govern flight hours and rest hours. Because commercial short-haul air transport operations can include up to eight flight segments per day, a considerable portion of the duty day is spent on the ground between segments. In the schedules studied, daily duty durations averaged more than twice as long as flight times (10.6 hr versus 4.5 hr). About one third of all duty periods studied were longer than 12 hr. Longer duty periods were not followed by longer rest periods (multiple $r^2 = 0.02$, $F = 2.22$, $p > 0.05$). As noted in the Introduction, the most consistent findings concerning fatigue are that performance decrements increase with time on task and as a result of sleep loss. Thus, at least in the short-haul environment, it may be appropriate to limit duty times as well as flight times. The definition of rest time may also need to be more precise. The mean rest-period duration in the trips studied, as defined by the pilots in their daily logs, was 12.5 hr. The mean rest-period duration calculated from the last wheels-on of one duty day to the first wheels-off of the next duty day was significantly longer (14.0 hr). The actual definition of rest time is currently decided by negotiation between pilots and management in each company.

At least in a subset (59%) of the trips studied, the duty periods began and ended progressively earlier on successive trip days. Evidence from laboratory, shift-work, and jet lag studies indicates that it is more difficult to progressively advance sleep than to delay it, because the "biological day" generated by the circadian system tends to be longer than 24 hr. Thus, it is unlikely that pilots would be able to fall asleep earlier on each successive overnight layover, except after major sleep loss (refs. 52, 53). The effect of a schedule with progressively earlier layover times is thus to progressively restrict the time available for sleep within each successive layover.

5.2 Changes in Sleep on Trips

On trips nights, subjects reported taking about 12 min longer to fall asleep, sleeping about 1.2 hr less, and waking about 1.4 hr earlier than at home. They also rated their sleep on trips as lighter and poorer overall, and reported significantly more awakenings. These changes in subjective sleep measures were not reflected in the heart-rate levels during sleep. This finding is consistent with the reported lack of correlation between heart rate during sleep and sleep quality as determined by polysomnography (ref. 54). Higher average activity during sleep was correlated with greater difficulty rising the following morning. There was a high level of internal consistency among the subjective measures of sleep timing, duration, and quality. Longer sleep latencies were correlated with reports of greater difficulty falling asleep and shorter sleep durations. Longer sleep durations were correlated with less difficulty falling asleep, deeper sleep, feeling more rested on awakening, and better overall sleep-quality ratings. There was significant variability between subjects for all of the sleep measures, and not all subjects rated their sleep quality as worst on trips.

There were no significant differences between 3-day and 4-day trips in their effect on nighttime sleep timing, duration, or subjective quality. However, when total sleep per 24 hr (i.e., including naps) was taken into account, pilots flying 3-day trips accumulated a significantly greater sleep debt by the end of 3 days than did pilots flying 4-day trips after an additional duty day. One reason for this difference is that napping on the day before a trip was three times more common among pilots flying 3-day trips than among pilots flying 4-day trips, although the two groups did not differ significantly in their habitual napping at home or in their normal nighttime sleep durations at home. This suggests that the napping on the day before a 3-day trip may have been a strategy to cope with the anticipated sleep loss. Napping on trip days was also reported less frequently on 3-day trips than on 4-day trips. There were no differences between the two trip types in daily duty timing, duration, or the number of segments flown. However, the total number of flight hours per day was significantly greater on 3-day trips, which would have reduced the time available for napping during the duty day. This finding supports the value of the current practice of regulating flight hours.

Multiple regression analyses indicated that duty-related factors significantly affected the timing of wake-up, the duration of sleep, and the number of awakenings during sleep. The timing of wake-up was primarily determined by the time of reporting for the next duty period, and by the time of coming off-duty before the sleep period. The amount of sleep that pilots were able to obtain was primarily determined by the duration of the layover, by the next on-duty time, and by the duration of the prior duty day. These findings confirm that duty timing was curtailing sleep in some instances. Pilots also reported fewer awakenings in sleep episodes after later off-duty times and longer duty periods. This may reflect more consolidated sleep after longer periods of wakefulness. On the other hand, they also reported more awakenings during sleep episodes that followed duty days with more flight hours. The finding that more awakenings were recalled when layovers ended later in the morning could be attributable to the increasing tendency to wake up as the circadian temperature rhythm rises in the morning (ref. 53).

In summary, the flight schedules studied imposed a sleep restriction of about 1.2 hr per night during trips. Laboratory studies have reported consistent effects of sleep restriction on sleep quality, that is, reductions in stage 2 and rapid eye movement (REM) sleep, minimal reductions in slow-wave (stages 3 and 4) sleep, shorter sleep latencies, and fewer awakenings (refs. 1, 3, 4). In contrast, the pilots in the present study reported longer sleep latencies and more awakenings in association with restricted sleep durations on trip nights. Subjective reports of sleep latencies and nocturnal awakenings are clearly less reliable than polygraphically documented events. However, the longer sleep latencies and more frequent awakenings reported on trips are also consistent with the commonly reported need to "spin down" after coming off duty, and with the well-documented effects of sleeping in unfamiliar settings. The fact that sleep during trips was reported not only as shorter but also as more disturbed, suggests that the effects of this sleep restriction on subsequent daytime sleepiness, performance, and mood are probably greater than those reported in laboratory studies with similar levels of sleep restriction. Sleep fragmentation (including nocturnal awakenings) is consistently associated with increased physiological sleepiness the following day (refs. 29, 55, 56). In the laboratory, one hour per night of sleep restriction has been shown to accumulate to progressively increased daytime sleepiness (ref. 3).

Although the results are not always consistent, studies on the effects of acute or chronic sleep reduction have usually found adverse effects on psychological performance and subjective or objective measures of daytime sleepiness when sleep was restricted to less than about 6 hr per day (refs. 3, 4, 57, 58). Performance on prolonged vigilance tasks seems to be more adversely affected by sleep reduction than other types of performance (refs. 1, 56). Changes in affect have been reported in some studies (ref. 59), but not others (refs. 1, 57). It should be noted that the subjects in all these experiments were young adults (on average, in their early twenties), by comparison with the average age of 41.25 in the present study. It is not clear whether the tolerance for sleep restriction declines with age.

Sleep restriction caused by early on-duty times, as documented in the present study in commercial short-haul flight operations, has also been reported in a study of U.S. Air Force pilot instructors and students (ref. 60). The Air Force crews worked alternating weeks of early (0530 report time) and late (1030–1230 report time) schedules during flight training. On the early schedule, the forced early rising was associated with shorter average sleep durations (6.8 hr per night) and subjective reports of need for more sleep and of higher fatigue. The subjects were not able to fall asleep earlier to obtain normal amounts of sleep. Interestingly, however, on the late schedule, the same subjects averaged 8.6 hr of sleep per night, awoke feeling rested, and reported fatigue levels comparable to those observed after a full night of sleep. This study clearly indicates the effect of duty timing, independently of duty duration, in producing sleep loss and fatigue.

5.3 Changes in Subjective Fatigue and Mood on Trips

The effects of trips on subjective fatigue and mood are most clearly seen in the comparisons of ratings made pretrip, during flight segments, during layovers, and posttrip. During layovers, fatigue and negative affect were rated as highest and positive affect and activation as lowest. Positive affect was rated as highest during flight segments, even though fatigue was higher than during either pretrip or posttrip. Posttrip recovery was indicated by return of fatigue levels to baseline, the lowest negative affect ratings, and the highest levels of activation.

Significant time-of-day variations were found in fatigue, negative affect, and activation. Fatigue and negative affect were low in the first three ratings after awakening, and rose thereafter to reach their highest daily values in the final rating before sleep. Subjective fatigue has been reported to exhibit a circadian rhythm in subjects living in time-free environments, such that fatigue is lowest around subjective noon (ref. 46). As expected, activation showed the opposite time-of-day variation, being highest after awakening and declining to its lowest daily value in the final rating before sleep.

Multiple regression analyses were carried out to see if aspects of the duty day were significant predictors of subjective fatigue and mood ratings during the layovers (between flight segments on that day and the subsequent nighttime layover). No significant relationships were found, possibly because of the high levels of individual variability in the fatigue and mood ratings.

5.4 Changes in Drug Intake, Medical Symptoms, and Exercise on Trips

Only 17% of the subjects reported using tobacco at any time during their participation in the study, and there was no evidence of changes in tobacco use during trips relative to pretrip or posttrip.

In contrast, caffeine was consumed by 94% of subjects at some time during their participation in the study, and there was a 48% increase in average daily caffeine consumption on trips over the average daily consumption pretrip and posttrip. Much of this additional consumption occurred shortly after wake-up, probably in response to the earlier wake-up times dictated by early on-duty times. Caffeine consumption in the mid-afternoon was also greater on trips, around the time of the mid-afternoon peak in physiological sleepiness. The urge to fall asleep at this peak would increase progressively with the accumulating sleep debt across trip days (ref. 3). Multiple regression analyses of the duty factors contributing to the variability in caffeine consumption on trips indicated that the earlier pilots went on duty, and the longer they remained on duty, the more caffeine they consumed.

Alcohol was consumed by 80% of the subjects at some time during their participation in the study. There was a 113% increase in the average daily alcohol consumption on trips, over the average daily consumption pretrip and posttrip. The time of alcohol consumption was not recorded in the logbook. However, since alcohol consumption is prohibited by Federal Aviation Regulations within 8 hr of duty, most of the additional alcohol consumption on trips is assumed to have occurred post-duty, that is, close to sleep time. This assumption is consistent with the results of the multiple regression analyses on the duty factors influencing alcohol consumption on trips. More alcohol was consumed after shorter duty days. Alcohol causes dose-dependent changes in sleep, increasing slow-wave sleep, shortening the non-REM/REM cycle, and reducing and fragmenting REM sleep (ref. 61). Indeed, evening consumption of alcohol has been reported to cause greater sleep disruption than evening consumption of caffeine, and may therefore adversely affect subsequent waking alertness and performance.

Medications were used by 35% of subjects at some time during their participation in the study, with analgesics being the most common (used by 16%). However, there was no evidence of increased medication use in general, or of increased use of analgesics, during trips relative to pretrip or posttrip use.

Medical symptoms were reported by 60% of subjects at some time during their participation in the study, with headaches, congested noses, and back pains being the three most common complaints. However, there was no evidence of increased reporting of medical symptoms in general, or of the three most common symptoms, during trips over those reported pretrip or posttrip.

Exercise was reported by 65% of subjects at some time during their participation in the study, although the duration and kind of exercise were not consistently specified. There was no evidence of changes in the daily number of exercise sessions on trips by comparison with either pretrip or posttrip.

5.5 Changes in the Types and Timing of Meals Eaten on Trips

There was no evidence of changes in the number or timing of meals (breakfast, lunch, dinner) eaten during trips from pretrip or posttrip timing. However, the average number of snacks consumed daily on trips was 130% greater on trips than pretrip and posttrip. Snacks were also eaten earlier on trips than pretrip or posttrip. Multiple regression analyses failed to reveal any duty factors that contributed significantly to the variability in snack consumption on trips.

These findings must be interpreted with caution, because the analyses addressed only the subjective categorization of meals as breakfast, lunch, dinner, or snacks. They did not consider the quantity or type of food consumed. The increased consumption of snacks on trip days suggests that the meals consumed on trip days may have been smaller or less filling than those consumed pretrip and posttrip.

The number of meals and snacks eaten daily by pilots from the company that provided crew meals was not significantly different from the number eaten daily by pilots from the company that did not provide crew meals. Similarly, there were no significant differences in the times of meal or snack consumption. However, because meal content was not considered, it would be extremely premature to conclude on this basis that the provision of crew meals did not affect nutrition during trips. There were also no significant differences between pilots flying 3-day trips and pilots flying 4-day trips in the number or timing of meals or snacks consumed daily.

5.6 Heart-Rate Changes During Different Phases of Flight

Significant increases in heart rate over the value during mid-cruise were found for descents and landings, but not for takeoffs. The increases were greater during descent and landing for the pilot flying than for the pilot not flying. The difference between flying and not flying during descent was greater for first officers than for captains. Heart-rate increases were greater during takeoff and descent under instrument flight conditions than under visual flight conditions.

These results are in general agreement with those from many previous studies showing increases in heart rate on takeoff, greater increases on landing, and greater increases in the pilot flying for all phases of flight (refs. 5, 12–15, 19, 20, 22, 24). These effects have been observed in a wide variety of aircraft types, and are evidently similar in line-flying, line-training, and simulator situations. The magnitude of the heart-rate changes seen has been shown to depend on prevailing conditions. In the present data, we looked at visual versus instrument conditions, and confirmed the expectation that instrument conditions produced greater heart-rate increases for takeoffs and descents. It has been argued that these heart-rate responses in experienced pilots are influenced primarily by work-related factors, rather than emotional stressors such as risk and anxiety (refs. 19–21).

5.7 Effects of Fatigue on Simulator Performance

The operational significance of the levels of fatigue accumulated during 3-day commercial short-haul trips was addressed in a short-haul simulation study (ref. 26). In this study, fully qualified, twin-engine transport crews flew a full-mission simulation segment, either as the first segment of a 3-day trip pattern (pre-duty condition), or as the final segment of a 3-day trip pattern (post-duty condition). Post-duty crews scored significantly better on all operational measures of performance. This was shown to be a consequence of the fact that crews who had recently flown together performed significantly better than crews who had not flown their last trip together. Thus, the levels of fatigue accumulated during the 3-day trip were more than compensated by improved crew coordination. It should be noted, however, that the measures of fatigue used in the simulation study were not comprehensive and did not reveal major differences between the post-duty and pre-duty crews. All comparisons were based on a single rating made after the simulator segment. Post-duty captains reported less sleep on the night before the simulator segment. However, there were no differences between post-duty and pre-duty first officers in their sleep durations on the previous night. In contrast, in the present study, sleep was significantly shorter on trip nights.

For flight crews in the simulator study, there were also no significant differences between any groups in their sleep ratings. However, on the same measures, pilots in the present study reported lighter sleep and poorer sleep overall on trip nights. In the simulator study, there were also no significant ($p < 0.05$) differences between groups in their fatigue and mood ratings. Given the marked circadian variation in these measures, as shown in the present study, the value of a single measurement is questionable. Post-duty crews in the simulator study did report greater tiredness on a seven-point bi-polar scale for fresh versus tired. The discrepancies between the two studies may be attributable to the fact that subjects in the present study were asked to record sleep information immediately on awakening, and rated their fatigue and mood repeatedly (at 3-hourly intervals over a minimum of 5 days). On the other hand, it may be that the trips flown by the post-duty crews in the simulator study were less fatiguing, on average, than the trips flown by crews in the present study. Nevertheless, the suggestion that improved crew coordination may be an effective countermeasure for the effects of fatigue on performance merits additional research.

6.0 Conclusions

The short-haul trips studied were characterized by early report times and long duty days. This produced an average reduction in sleep duration of 1.2 hr on trip nights. In the laboratory, sleep restriction results in more rapid sleep onset and more consolidated sleep. However, the pilots in the present study reported longer sleep latencies, more awakenings, and lighter sleep on trip nights, than on pretrip and posttrip nights. Thus the sleep restriction experienced by the pilots in the present study might be expected to have greater effects on subsequent daytime sleepiness, performance, and mood than comparable sleep restriction in the laboratory. Subjective fatigue was rated as higher during flight segments and on layovers than either pretrip or posttrip. Positive affect and activation were lowest, and negative affect highest on layovers. Caffeine appears to have been used as a fatigue countermeasure during trips, with greater consumption on days with early report times and long duty periods. Alcohol appears to have been used as an aid for relaxing after the duty day; however, this practice is not recommended since alcohol disrupts sleep. Increased consumption of snacks on trips suggests that meals eaten on trips were smaller or less filling than meals eaten pretrip or posttrip.

Several potential means for reducing fatigue during short-haul air transport operations are suggested by this study. First, since daily duty durations were more than twice as long as daily flight durations, and about one third of all duty periods were longer than 12 hr, it would seem reasonable to regulate duty hours, at least in short-haul operations. On the other hand, the cumulative sleep-loss data support the idea of also regulating flight hours. There may also be some advantage to defining the rest period more precisely, since significant variability is possible within the present system of definition by contract negotiation.

Second, the practice of requiring early report times makes it more difficult for pilots to obtain adequate sleep, even during relatively long layovers. This is because circadian rhythms impede falling sleep earlier than usual, except after major sleep loss.

Third, in the trips studied, duty began progressively earlier across the days of the trip. Because of the difficulty of falling asleep earlier, this has the effect of progressively shortening the time available for sleep across the days of the trip. In addition, because the innate "physiological day" determined by the circadian system is longer than 24 hr, it adapts more readily to schedule delays than to advances. Thus, where possible, successive duty days should begin progressively later.

Fourth, the widespread use of alcohol as a means of relaxing before going to sleep is ill-advised. Although alcohol may facilitate falling asleep, it has well-documented disruptive effects on sleep which can adversely affect subsequent waking alertness and performance. It seems likely that sleep on trips could be improved in many cases by providing pilots with information on alternative relaxation techniques that have been well-tested in the treatment of sleep disorders.

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13. ABSTRACT ***(Maximum 200 words)***

Seventy-four pilots were monitored before, during, and after 3- or 4-day commercial short-haul trip patterns. The trips studied averaged 10.6 hr of duty per day with 4.5 hr of flight time and 5.5 flight segments. The mean rest period lasted 12.5 hr and occurred progressively earlier across successive days. On trip nights, subjects took longer to fall asleep, slept less, woke earlier, and reported lighter, poorer sleep with more awakenings than on pretrip nights. During layovers, subjective fatigue and negative affect were higher, and positive affect and activation lower, than during pretrip, in-flight, or posttrip. Pilots consumed more caffeine, alcohol, and snacks on trip days than either pretrip or posttrip. Increases in heart rate over mid-cruise were observed during descent and landing, and were greater for the pilot flying. Heart-rate increases were greater during takeoff and descent under instrument meteorological conditions (IMC) than under visual meteorological conditions (VMC). The following would be expected to reduce fatigue in short-haul operations: regulating duty hours, as well as flight hours; scheduling rest periods to begin at the same time of day, or progressively later, across the days of a trip; and educating pilots about alternatives to alcohol as a means of relaxing before sleep.

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