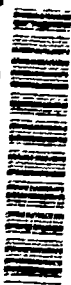


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NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY
NAVAL AIR STATION, PENSACOLA, FL 32508-5700

NAMRL-1375

**THE EFFECT OF COMBAT ON THE
WORK/REST SCHEDULES AND FATIGUE
OF A-6 AND F-14 AVIATORS DURING
OPERATION DESERT SHIELD/STORM**

David F. Neri and Scott A. Shappell

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A. J. MATECZUN, CAPT, MC USN
Commanding Officer



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13. ABSTRACT (Maximum 200 words) During Operation Desert Shield/Storm, A-6 and F-14 aviators aboard USS AMERICA completed daily activity logs and provided subjective measures of fatigue. Aviators flew frequently at night during Desert Storm, but without substantial sleep-related fatigue or problems. A likely contributing factor was the large number of naval aviation assets brought into the combat theater, allowing workload to be shared and activity and rest times to be properly managed. However, raster plots of the data suggest that there may have been an additional contributing factor. The AMERICA travelled eastward from the east coast through seven time zones and became involved in combat shortly after arrival in the Red Sea. This pattern of travel may have given AMERICA's aircrew flying at night a significant advantage over those already operating in the area. If the circadian clocks of AMERICA's aircrew had not fully adapted to local time upon arrival, local night flights were closer to being evening flights on body time. Aircrew may not have been experiencing troughs in their circadian cycles during local night flights, at least for the early part of the war. This would result in a smaller physical challenge to overcome. This situation would likely not hold for aircrew who had been in the region for longer periods, nor would it occur for future conflicts closer to the originating time zone. We recommend the incorporation into battle strategy of information about the circadian phase of combatants (as well as sleep logistics) to help prepare them to fight at suboptimal times.				
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SUMMARY PAGE

THE PROBLEM

What is the impact of combat on aircrew work/rest schedules and fatigue?

FINDINGS

For 2 weeks during Operations Desert Shield and Desert Storm, 12 A-6 aviators and 11 F-14 aviators from CARRIER AIR WING ONE (CVW-1) aboard the USS AMERICA (CV-66) completed detailed daily-activity logs while their squadrons conducted operations from the Red Sea. Subjective measures of fatigue, quality of rest, and sleep need were also collected.

Both squadrons flew frequently at night during Desert Storm without significant sleep problems or substantial fatigue from sleep loss, although the aviators generally desired more sleep. Evidently, combat did not induce serious sleep problems or associated fatigue in the sampled aircrew. A likely contributing factor was the large number of assets brought to the combat theater, which allowed workload to be shared and activity and rest times to be properly managed.

Raster plots of awake, sleep, and flying periods suggest an additional contributing factor to the relative lack of fatigue and sleep problems. The AMERICA travelled eastward from the east coast through seven time zones and became involved in combat shortly after arrival in the Red Sea. This pattern of travel may have given AMERICA's aircrew flying at night a significant advantage over other aircrew already operating in the area for a longer period. If the circadian clocks of AMERICA's aircrew had not fully adapted to local time on arrival in the Red Sea, but were operating closer to Eastern Standard Time (EST), then night flights occurring at 0300 local time (2000 EST) were closer to being evening flights on the body's internal time. These aircrew may not have been experiencing troughs in their circadian cycles during these local nighttime flights, at least for the early part of the war. This would result in less sleepiness and a significantly smaller physical challenge to overcome. This situation would likely not hold for aircrew who had been in the region for longer periods, nor would it occur for future conflicts closer to the originating time zone.

RECOMMENDATIONS

We recommend that military planners incorporate into battle strategy, when possible, information about the circadian phase of combatants. Proper sleep logistics and sleep management will better prepare combatants to fight effectively at suboptimal times. Where it is desirable to have combatants synchronized to a sleep/wake schedule different from that of the local time zone (e.g., in order to fight exclusively at night), more effective means of shifting the phase of the circadian pacemaker are required. We recommend additional applied research into the feasibility of bright light and pharmacologic treatments to phase-shift combatants.

Acknowledgments

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INTRODUCTION

The maintenance of adequate levels of human performance during wartime is a major concern of the military. Military planners realize that the inevitable stresses, fatigue, and related consequences of war may negatively affect cognitive functioning and alertness. In order to counteract the effects of stress, fatigue, and sleep deprivation, one must understand the relation between these variables and performance. Various studies and reviews of the literature (1-5) show that this relation is complex and involves factors ranging from characteristics of the individual (e.g., restedness, skill level, motivation, attention, stamina, age, temperament, personality, intelligence) to task variables (e.g., type, complexity, duration, pacing, repetitiveness) and the environment (e.g., temperature, altitude, noise, vibration, and acceleration). Unfortunately, few of these factors are modifiable under combat conditions. Of the factors over which military commanders have some control, adequate rest and sleep are acknowledged to be critically important in maintaining performance (4,6-8). Research has shown that with sleep loss both mood and performance in operational situations can degrade on a variety of tasks (9-13).

Performance degradation from inadequate sleep will express itself in different ways for different combatants because of the variety of tasks they perform. For ground troops involved in sustained or continuous operations, performance decrement would include shooting accuracy and weapons handling (14). For naval aviators, performance degradation might take the form of a reduced ability to a) detect the enemy, b) make split-second decisions correctly, c) drop bombs on target, d) fly the aircraft expertly, or e) land safely on the carrier. There have been many attempts in the laboratory and field to document aviation performance degradation as a function of stress, fatigue, and sleep deprivation. Results have been mixed. For example, Fraser (15) showed significant vigilance degradation in aircrew after long flights, while Haslam (14) also detected vigilance degradation with sleep loss. Storm (16) demonstrated that performance in a simulator was significantly degraded for transport crews given only onboard rest after flying 8-9 h missions. In a study of the sleep of carrier pilots off Vietnam, Britson, et al. (17) found that the inter-sleep interval of the pilots was more variable than that of nonflying personnel. The more variable the interval, the more likely a landing error ($R = -.762, p < .05$). Nonetheless, the magnitude of performance degradation after partial, or even total, sleep deprivation is often small (4,18). Furthermore, subjective feelings of fatigue can be inconsistent with performance (1), even exhibiting a greater sensitivity to sleep loss (14).

Several possible reasons could account for the frequently small magnitude of performance changes following sleep loss. First, compensatory efforts may serve to keep task performance high, temporarily overcoming the effects of sleep deprivation on task performance (4). Second, traditional accuracy measures (e.g., false alarm or error rate) may not be the appropriate ones for detecting performance changes. It is errors of omission that frequently increase with fatigue (3). As long ago as 1943, Bartlett (19) demonstrated how attention narrows and the variability of response latencies increases with fatigue. In other words, performance might be generally good, with interspersed periods of response lapses or failures. These lapses are not clearly reflected in accuracy rates. Third, subjects may compensate in ways that are too subtle to detect with traditional measures. For example, the Choice of Probability and Effort (COPE) model of Holding (1) predicts that fatigued subjects will make more risky choices when given the opportunity. In two recent studies in our laboratory using a simulated long-range attack scenario (20,21), fatigued subjects performed in a manner consistent with this model. That is, subjects appeared to exchange a higher failure rate for a savings in time. Regardless of the specific way in which performance degrades with sleep loss (and the difficulty in documenting the degradation), there is agreement on the importance of adequate sleep management and sleep logistics for military troops in wartime (4,6,7). Furthermore, while research on rest, sleep, and performance can be performed in both laboratory simulations and field exercises, the only way to obtain a clear and accurate picture of sleep and fatigue under combat conditions is to collect data during actual combat. For naval aviators, this means collecting data while they are involved in carrier combat operations.

The role of many naval aviators during combat is unique. They frequently spend many hours (even days) planning in detail the missions they will fly. This can lead to partial sleep deprivation before the first launch. After being "front-loaded" in this manner with fatigue, the aircrew fly high-performance aircraft

requiring periods of peak alertness and concentration. According to pilots, foremost among these periods is the carrier landing. To make matters worse, the landing may come at the end of a long, arduous flight, at night and in bad weather. The margin for error is small and the penalty extreme. Consequently, any insight into the effect of combat on fatigue and work/rest cycles is a valuable first step in the pursuit of appropriate countermeasures and strategies to aid the aviator.

Although difficulties in obtaining adequate rest are not always tightly linked to performance degradation, they are an indicator that a potentially serious problem exists. Furthermore, the time of day when aviators sleep and fly has been shown to play an important role in aviation mishaps (22). The front-loading of fatigue by involving aviators in many hours of pre-flight planning could serve to reduce their readiness and effectiveness. To examine the impact during combat of many of these variables, we examined the work/rest schedules of two carrier-based squadrons during parts of Operations Desert Shield and Storm. The purposes of the study were to provide an in-depth examination of the work/rest schedules of naval aviators in combat and to collect data on subjective fatigue and sleep problems. This report is a first step in the process of documenting fatigue-related problems before examining countermeasures. The information should be of value in adding to the growing data base (6,7) needed to make appropriate recommendations on military sleep management.

MATERIALS AND METHODS

SUBJECTS

A total of 41 respondents from CVW-1 volunteered to participate in the study. Eighteen officers participated from the A-6 Intruder squadron (VA-85 Black Falcons) and 23 from one F-14 Tomcat squadron (VF-102 Diamondbacks). The A-6 squadron was chosen because of interest expressed by the Naval Strike Warfare Center regarding the effects of mission planning on attack aircrew readiness. The F-14 squadron was added because of the anticipated heavy role of fighters in the war. All subjects received a full briefing on the purposes of the study and assurances as to the anonymity and confidentiality of the data. Initial volunteers represented between one-third and one-half of the squadrons' officer contingents.

After the study began, many subjects either chose to withdraw, failed to return sleep/activity logs, or failed to complete them properly¹. Only subjects who contributed an adequate quantity of data are included in the following analyses. The final results are therefore based on a total of 23 respondents: 12 A-6 and 11 F-14 aircrew. The six pilots and six bombardier/navigators (B/Ns) from the A-6 squadron ranged in age from 24 to 37 years ($M = 29.5$, $SD = 4.0$). The five pilots and six radar intercept officers (RIOs) from the F-14 squadron ranged in age from 25 to 39 years ($M = 29.4$, $SD = 4.4$). The distribution of officer ranks and designators for both squadrons is provided in Table 1.

MISSION TASKING

The A-6E Intruder is a carrier-based, all-weather, low-level, attack bomber that is capable of nighttime operations. It is configured with two side-by-side seats for pilot and bombardier/navigator. Its primary missions during the Persian Gulf War were long-range strikes and in-flight tanking. The F-14 Tomcat is a carrier-based, all-weather, multi-role fighter. The F-14 is also a two-seat aircraft, but with pilot and RIO seated in tandem. Its primary missions during the Gulf War were fighter escort, tactical air reconnaissance, fighter support of strikes, and combat air patrol. Additional details regarding the specific missions flown by these squadrons during this study can be found in a related report (24).

¹This is not unusual in this type of research. In a similar study with nuclear submarine crews, about one-third of the men initially volunteering for the study were not included in the data analyses for similar reasons (23).

Table 1. Rank and Designator of Study Subjects.

Rank	A-6		F-14	
	Pilot	B/N	Pilot	RIO
LTJG	0	1	0	2
LT	5	3	3	1
LCDR	1	2	1	2
CDR	0	0	0	1
Total	6	6	5	6

INSTRUMENT

We used a combination sleep log and activity-survey card (Fig. 1) after Hartman & Cantrell (25), Storm (16), and Naitoh, et al. (26) to collect data. Logs of this type can be used to predict task performance and mood (23) and have been shown to produce reliable sleep measures (26). The sleep/activity log at the top of the form enables aircrew to record their daily sleep and work activities using the key provided. One modification that we made was to customize a set of codes (Table 2) for those activities typically performed by aviators on aircraft carriers. Five additional questions on the lower part of the card pertained to sleep quality, readiness to fly another strike mission, and consumption of caffeine. The question concerning flight readiness is addressed in detail in our companion report (24).

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Table 2. Sleep Log/Activity Survey Code Definitions.

Code	Definition
Alert	Alert flight status, ready to launch in relatively short time period
Sleep	Time actually asleep
Meals	Eating
Flight	Time airborne in the aircraft
Brief	Time spent briefing for the upcoming flight
Debrief	Time spent debriefing after completion of a flight
Collateral Duties	All official duties other than flight-related activities
Strike Planning	Time spent planning the upcoming mission(s)
Recreation/Rest	Time not flying or working on other official duties
GQ/Drills	Time spent at General Quarters or duties associated with other drills
Exercise	Time spent exercising in stateroom or small workout area
Testing	Not used

PROCEDURES

Work/rest schedules and subjective sleep-related data were collected aboard USS AMERICA (CV-66) from 3 January through 4 February 1991. The ship departed Norfolk, Virginia, on 28 December 1990 and arrived in the Red Sea on 16 January 1991. Because the war began in the early morning hours of 17 January (local time), this resulted in about 2 weeks of data collection during Operation Desert Shield and 2 weeks during Desert Storm. Subjects completed a separate card for every day in which they participated in the study, for a maximum of 33 d. Subjects filled in the blocks using the 11 categories listed on the card. Given the 48 blocks per day, this provided a potentially continuous record of daily activity to a resolution of one-half hour.

In its eastward travel, the ship crossed seven time zones. Ship time was reset to local time at 0200 after crossing each meridian; 1 h was lost each time the clocks were set ahead. The seven time zones were crossed in about 2 weeks. Once on station, the USS AMERICA conducted cyclical operations in the Red Sea by generally spending several days in a row conducting air strikes followed by a day of two refuelling and resupplying.

RESULTS

The results described here pertain only to the work/rest schedules of the aviators and the subjective measures of sleep quality. For a detailed analysis of the mission and flight data and its relationship to subjective aircrew readiness see Shappell & Neri (24). The work/rest cycle and sleep quality data have been analyzed descriptively. Formal measures of statistical significance were not applied to the data because field studies of this type are inherently nonexperimental, precluding the proper use of many traditional statistical tests. Despite this limitation and the relatively small sample size, we believe that the sample was representative of the population of A-6 and F-14 aviators on the AMERICA. Moreover, the detailed nature of the data and the unusually long period over which it was collected provide a rare look at the work, rest, and sleep patterns of naval aviators during combat.

The data are presented and described separately for A-6 and F-14 aircrew. This enables the examination of differences in trends between these two communities with their different missions and tasking. Data are also broken down by Desert Shield and Storm to examine the impact of the war on the numerous measures. One of the major effects of combat on naval aviators is the flying of combat missions, particularly at night. Therefore, the various sleep- and fatigue-related measures are frequently described in this paper as a function of the type of flight that occurred that day. Day flights are defined as those occurring during the normal work day (0600-2400). This is somewhat unconventional as many flights occurred after sunset but were still considered "day" flights. Night flights are defined as those having any portion occurring between 2400 and 0600, delaying normal sleep onset.

ANALYSIS OF DAILY ACTIVITIES

Data from the sleep/activity logs are grouped by activity type and shown separately for A-6 (Fig. 2) and F-14 aircrew (Fig. 3). Both figures show the distribution for an "average" day during Desert Shield and Desert Storm. The codes that comprise the categories in the figures are given in Table 3. For some of the activities in Figs. 2 and 3 (e.g., flight, other flight) the averages include days on which some aircrew did not participate in the activity. Thus, the amount of flying in the average day does *not* equate to average flight duration, because many aircrew did not fly on any given day. On the other hand, since most aircrew slept every day, the amount of sleep in the average day will correspond more closely to average total sleep duration. Major sleep period and nap durations are discussed later in this paper; a detailed discussion of flight duration and other flight-related data may be found in our companion report (24).

Table 3. Codes Comprising the Categories Used in Figures 2 and 3.

Category	Code(s)
Sleep	Sleep time, including naps
Other rest	Rest, meals, & exercise
Flight	Flight time
Other flight	Brief, debrief, alert
Collateral duties	Collateral duty time
Other work	Planning, GQ/drills
Missing	Missing data

For the A-6 aircrew (Fig. 2), total work time (flight, other flight, collateral duties, and other work) constituted 11.6 h of the typical day during Desert Shield. Aircrew obtained a normal amount of sleep (7.3 h) while flying 1.7 h, on average. They committed 4.3 h to flight-related activities (flight and other flight) and typically worked about 5 h per day on collateral duties. During Desert Storm, total work time decreased very slightly to 11 h in the average day, although the average amount of unaccounted for (missing) time increased by over 1 h. Sleep time remained steady while rest time decreased by about a half-hour per day. The biggest changes were in flight and collateral duty time, shown as exploded pie slices. Flight time in the average day increased 71% to almost 3 h, with total flight-related activities increasing 37% to 5.9 h. Collateral duty time decreased by more than half to 2.2 h.

A-6

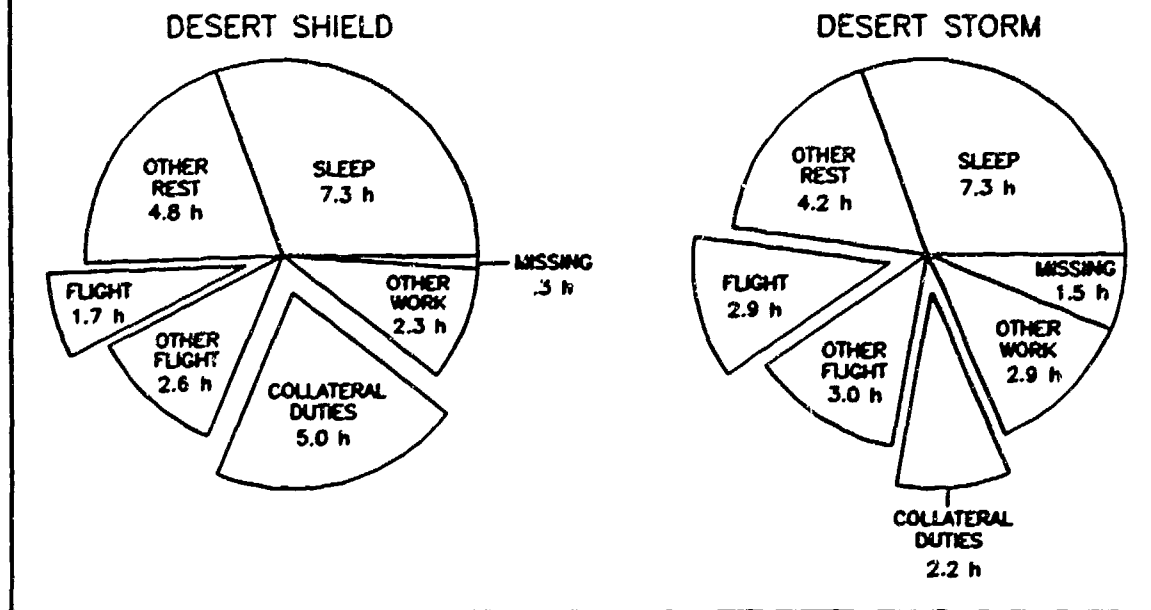


Figure 2. Distribution of sleep, rest, and work activities for A-6 aircrew during Desert Shield and Storm.

F-14

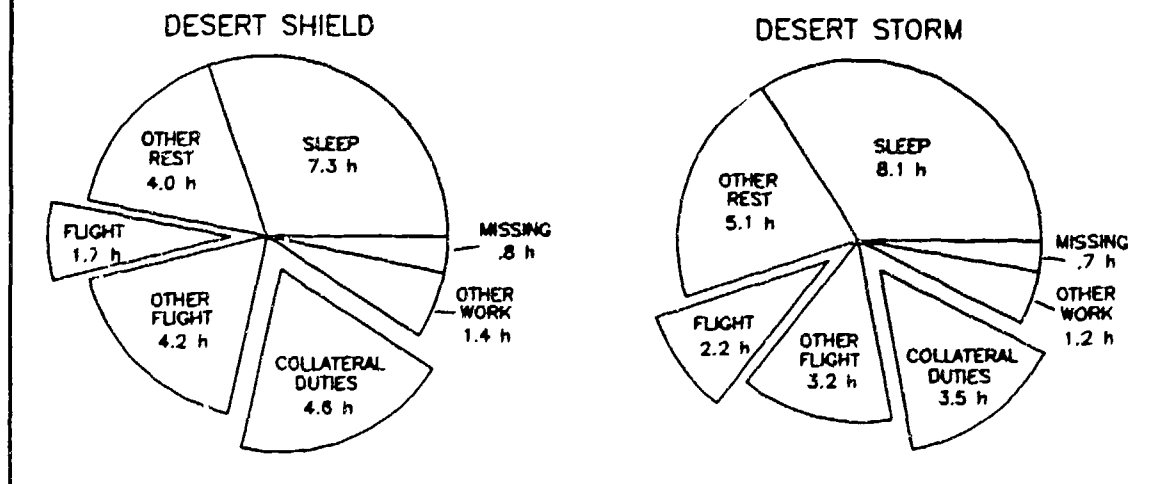


Figure 3. Distribution of sleep, rest, and work activities for F-14 aircrew during Desert Shield and Storm.

The pattern of work, rest, and sleep activities was fairly similar for F-14 aircrew (Fig. 3). Total work time averaged 11.9 h in the typical day during Desert Shield. Aircrew obtained the same amount of sleep (7.3 h) as A-6 aviators and averaged the same amount of flight time (1.7 h). (Again, this number bears no relation to duration of the average flight.) Flight-related activities were more time-consuming in the average day than for the A-6 aircrew, at 5.9 h, while collateral duty time was similar, at 4.6 h. During Desert Storm, total work time in the average day decreased almost 2 h to 10.1 h, with the amount of missing time remaining about the same. Sleep and rest time each increased by about an hour per day. Relatively large changes again occurred in flight time and collateral duties for an average day during Desert Storm. Flight time increased 35% to 2.2 h. Total flight-related activities actually decreased 8% to 5.4 h due to a decrease in the other flight activities of briefing, debriefing, and alert. Finally, collateral duty time dropped 24%, or almost an hour.

SLEEP

Sleep Patterns. One of the most basic sleep-related questions that can be asked about the aircrew in this study is "At what times were they sleeping?" A traditional way to analyze sleep data of this sort is to plot the sleep fraction (27). Sleep fraction is the percentage of aircrew reporting they were asleep at any given time of day and has been previously used to describe operational data collected with sleep logs (26). Sleep fractions for A-6 and F-14 aircrew are shown in Figs. 4 and 5, respectively.

The data in Figs. 4 and 5 are plotted separately for sleep periods *before* days with no flights and daytime flights. Sleep fraction data are plotted for periods immediately *following* nighttime flights. The latter sleep periods were delayed because of the flying. Day flights and night flights were defined above. Days without flying serve as a baseline for comparing the effects of day and night flights. Thus, any displacement in the daytime-flying and nighttime-flying curves (relative to the nonflying curves) in Figs. 4 and 5 represents a change in sleep fraction as a result of operational tasking.

Separate curves are shown for Desert Shield and Storm in Figs. 4 and 5. The figures lack night flight curves for Desert Shield because flights were too few to result in meaningful data. The notches in the two Desert Shield curves in each figure are due to time zone changes. As mentioned previously ship clocks were advanced 1 h at 0200 each time a meridian was crossed. Because sleep logs were filled out using local time, there are less data for the 0200-0300 time period. For the purposes of this data presentation, the notch is an artifact, and the curves can be considered smooth. (The impact of the changes in time zones will be further explored in the discussion.) Both local and Eastern Standard Time (EST) are shown along the abscissa for the Desert Storm data. The ship started from the EST zone. The local time scale incorporates the clock resettings. Only local time is shown for Desert Shield data because of the continually changing local time and therefore a continually changing difference between local time and EST.

For A-6 aircrew during Desert Shield, the sleep fraction before days with no flying is depicted by the solid line in the left panel of Fig. 4. Sleep fraction peaked at approximately 0400. Before days with day flights, sleep fraction followed a similar pattern, with the exception of aircrew apparently rising earlier, presumably to brief and launch. This change is indicated by the small leftward displacement after 0400 of the daytime-flying curve relative to the solid curve. During Desert Storm, A-6 aircrew showed a somewhat similar pattern for nonflying days. Day flights resulted in a shift to earlier sleep onsets the previous night as well as earlier awakenings. This is indicated by a leftward displacement of the entire daytime flying curve relative to the solid curve. Napping appeared to increase at about 1400 (evidenced by the slight bump in the daytime-flying curve). Night flights led to a predictably large shift to later sleep onset and wake times. Note that over 90% of night fliers were asleep at 0800 and about 40% were still sleeping at noon. We found no evidence of increased napping following the night flights.

A-6

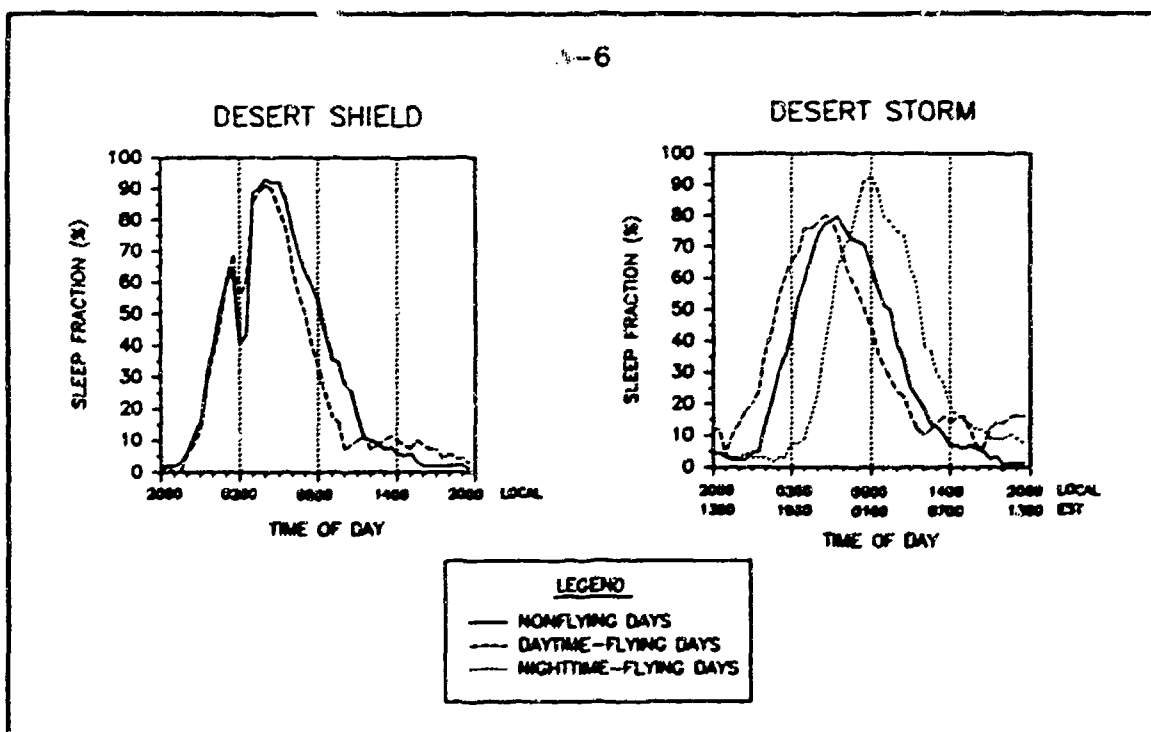


Figure 4. The sleep fraction for A-6 aircrew before nonflying and daytime-flying days, and after night flights during Desert Shield and Storm.

F-14

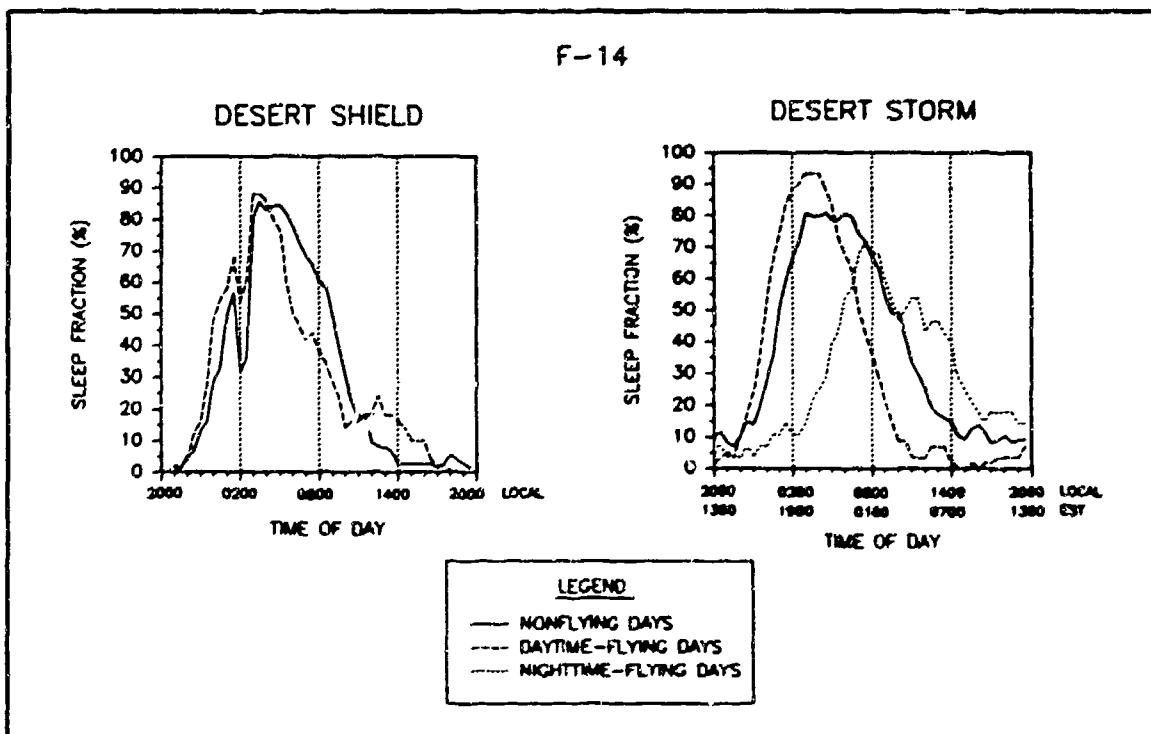


Figure 5. The sleep fraction for F-14 aircrew before nonflying and daytime-flying days, and after night flights during Desert Shield and Storm.

The sleep-fraction pattern for F-14 aircrew during Desert Shield was similar to that of A-6 aircrew before nonflying days (Fig. 5, left panel). However, sleep fraction before day flights differed in two ways from the A-6 data. First, there was a slightly greater shift toward earlier sleep onset times. Second, the bump around 1230 on daytime-flying days represents more napping than for the A-6 aircrew. During Desert Storm, sleep fraction was similar to the A-6 pattern before nonflying and daytime-flying days but differed after night flights. The increase in bandwidth indicates more variability in the sleep pattern, with a similar rate of sleep onset but 40% of the aircrew still reporting sleep as late as 1400.

These sleep fraction data can provide only hints about average sleep onset and duration times. Sleep onset for the major sleep period is further quantified in Fig. 6. Sleep episodes separated by $\frac{1}{2}$ h or more were considered different sleep periods. Naps are analyzed separately. The patterns are very similar for both squadrons. Mean sleep onset times during Desert Shield were fairly late, between about 0100 and 0130. During Desert Storm, sleep onset times on nonflying days were delayed to about 0200 for both squadrons but remained between 0030 and 0130 before days with daytime flights. Predictably, night flights during Desert Storm delayed mean sleep onset times to about 0500 local time. However, this corresponded to 2200 EST, a fact that will be considered later.

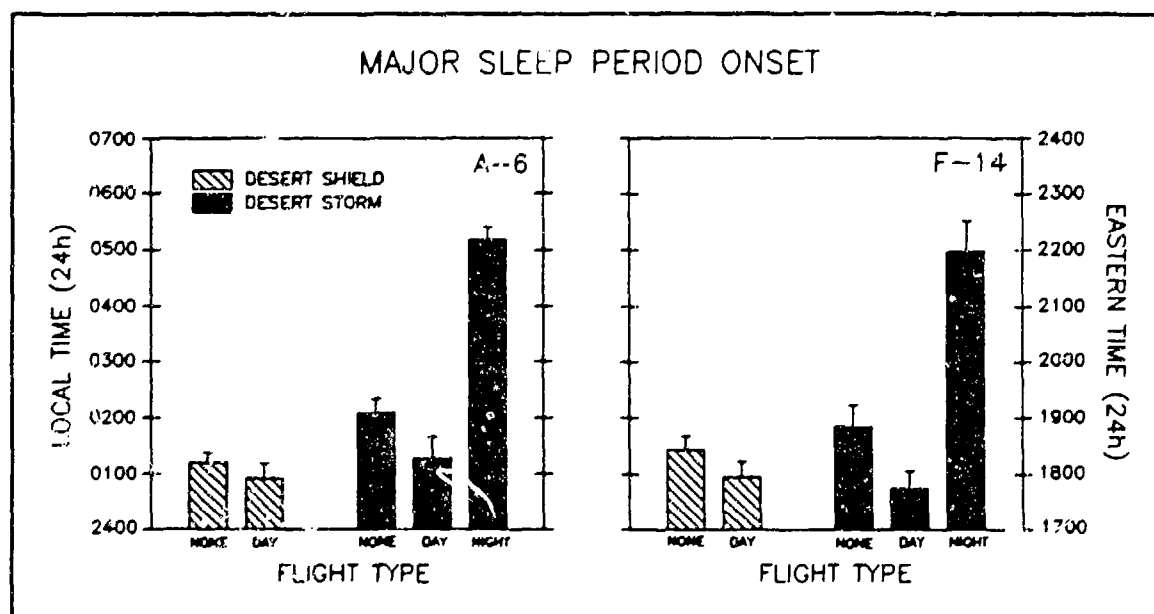


Figure 6. Mean sleep onset times (+1 SEM) for A-6 and F-14 aircrew before days with no flights and day flights, and on the days after night flights during Desert Shield and Storm.

The major sleep periods can be examined both in terms of average length and variability. Average duration provides clues as to whether subjects are obtaining adequate quantities of sleep, however, variability in sleep duration is one measure of how fragmented a sleep/wake schedule has become. Even with a stable average duration, a substantial increase in variability indicates that the major sleep period may be critically short for a sizeable portion of the sample. Sleep duration frequency histograms for the major sleep period are shown in Fig. 7 for A-6 aircrew and Fig. 8 for F-14 aircrew. The A-6 data show that, during Desert Shield, nearly all sleep periods were 4-10 h. The median durations were 6.0 h before nonflying days and 6.75 h before daytime-flying days. During Desert Storm, the frequency of major sleep period durations under 4 h before nonflying and daytime-flying days increased slightly. Relative to Desert Shield, median sleep length increased, however, to 7.5 h before nonflying days. It decreased by 1 h to 5.75 h before daytime-flying days, with no change in variability. After night flights, median sleep duration was 6.5 h.

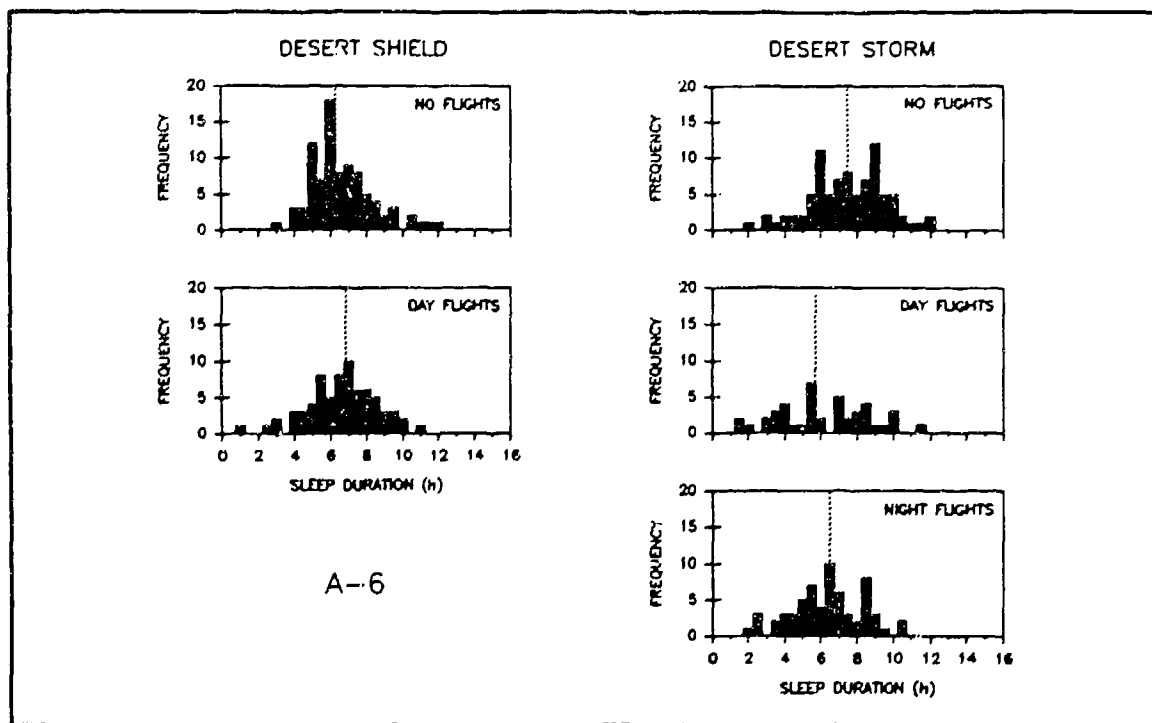


Figure 7. Sleep histograms for A-6 aircrew before days with no flights and day flights, and after night flights during Desert Shield/Storm. Median durations are indicated by the dotted lines.

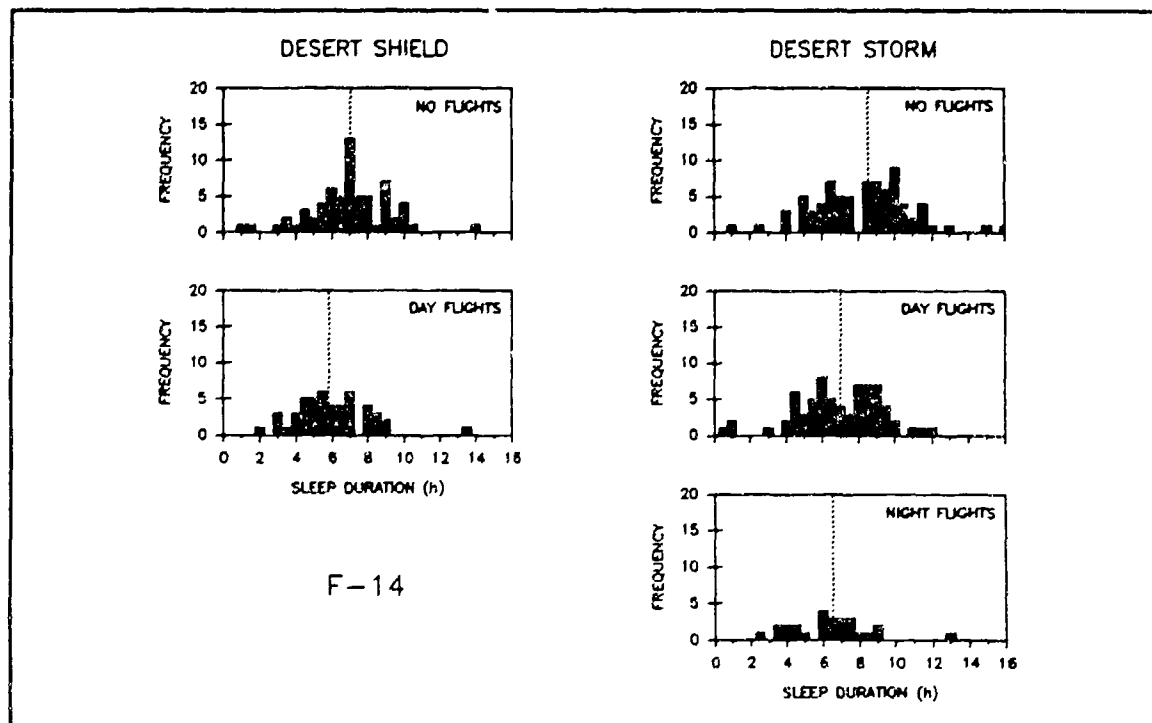


Figure 8. Sleep histograms for F-14 aircrew before days with no flights and day flights, and after night flights during Desert Shield/Storm. Median durations are indicated by the dotted lines.

A similar pattern is present for F-14 aircrew (Fig. 8). Before nonflying days during Desert Shield, median sleep length was 7 h compared to 6 h for A-6 aircrew. Unlike with A-6 aircrew, median duration decreased to 5.75 h before day flights. Again, almost all sleep periods were 4-10 h long. During Desert Storm, median sleep duration before nonflying days climbed to 8.5 h, with a substantial increase in the number of sleep periods in excess of 10 h. Median duration increased to 7.0 h before day flights and was 6.5 h after night flights.

An analysis of mean sleep duration paints much the same picture as the frequency histograms. For ease of comparison, mean values for both A-6 and F-14 aircrew were plotted together (Fig. 9). Before the war, average sleep duration typically varied between 6 and 7 h for both squadrons. During the war, both squadrons increased slightly to 7-8 h sleep on nights before nonflying days. Average sleep duration (6-7 h) before day flights and after night flights during the war did not vary substantially from sleep durations before the war.

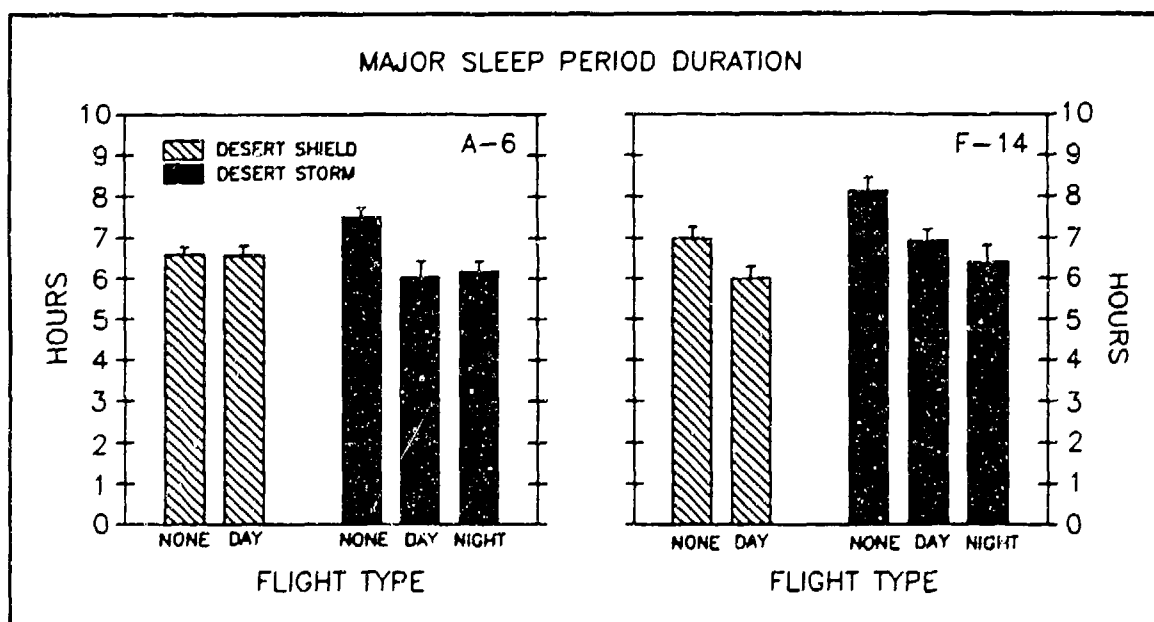


Figure 9. Mean sleep duration (+ 1 SEM) for A-6 and F-14 aircrew before days with no flights and day flights, and on the days after night flights during Desert Shield and Storm.

Sleep Problems. Given the pattern of sleep for aircrew described above, one might ask "What problems, if any, did aircrew have sleeping?" The data provide several ways of obtaining an answer. Questions 2, 3, and 4 on the sleep/activity logs (Fig. 1) relate to sleep difficulty. The responses to these subjective questions were assigned numerical values, which were averaged for the different flight conditions during Desert Shield and Storm. The results are presented in Figs. 10 and 11 for A-6 and F-14 aircrew, respectively.

Question 2 asked "How much trouble did you have sleeping during this period?" The five possible responses ranged from "none" to "did not sleep." The A-6 aircrew (Fig. 10 upper left panel) reported little difficulty sleeping both before and during the war. Average responses for all conditions were about midway between "none" and "slight." Sleep before day flights during Desert Storm was reported to be a little more difficult than under the other conditions. Question 3 asked "How rested did you feel upon awakening during this period?" Restedness followed a pattern similar to sleep trouble, with average responses fluctuating around "moderately" rested (Fig. 10 top right panel). Restedness decreased slightly before day flights during the war, consistent with the sleep trouble results. Question 4 asked "Do you feel like you could have used some more sleep?" On the average, subjects reported need for additional sleep 60-70% of the time before

the war (Fig. 10 bottom right panel). This number dropped below 50% during Desert Storm for nonflying days, but it increased to over 70% for daytime-flying days. Need for additional sleep was reported 65% of the time for sleep episodes following night flights. In sum, for the A-6 aviators, sleep before day flights during Desert Storm was the least restful and the most problematic.

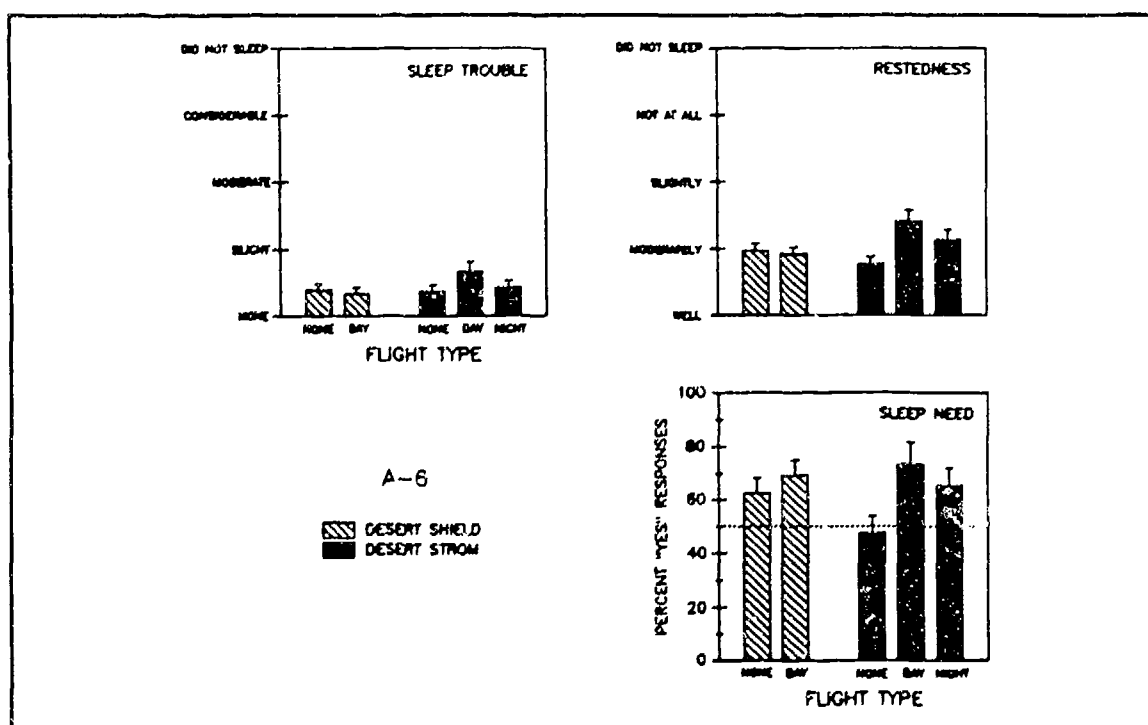


Figure 10. Mean sleep trouble, restedness, and sleep need (+ 1 SEM) for A-6 aircrew before days with no flights and day flights, and on days after night flights during Desert Shield and Storm.

The F-14 aircrew showed a tendency to report slightly more trouble sleeping than the A-6 aircrew during Desert Shield (Fig. 11, top left panel). During Desert Storm, sleep trouble remained between none and slight, with the most trouble before day flights. Like their A-6 counterparts, the F-14 aircrew generally reported being moderately rested (Fig. 11, top right panel). However, during the war, sleep after night flights was the least restful, although no worse than sleep before day flights during Desert Shield. The need for additional sleep was reported 60% of the time during Desert Shield for episodes prior to nonflying days, and about 75% of the time before day flights (Fig. 11, bottom right panel). During the war, the perceived need for more sleep dropped to about 50% of the responses for sleep periods preceding nonflying days. Desire for more sleep before day and after night flights did not exceed about 60% of responses during the war. Thus for the F-14 aviators, sleep associated with flying during Desert Shield and Storm was slightly more troublesome and less restful than sleep before nonflying days.

One result of difficulty sleeping or poor quality of sleep is the need to take naps. Nap frequency and duration are shown in Figs. 12 and 13, respectively. Naps are defined as sleep periods that are separated by at least ½ h from the major sleep period. The data shown in these figures are consistent with the data indicating naps in Figs. 4 and 5, discussed earlier. For A-6 aviators, nap frequency was about 1 nap every 3 d (3 naps per day), with the exception of days with day flights during Desert Storm (Fig. 12). Then naps occurred on an average of every other day. It should be noted that naps after night flights during the war were not as easy to take because sleep periods were already extending well into the normal workday. The F-14 aircrew also showed more frequent napping after day flights, but only during Desert Shield. During Desert Storm, the most frequent napping was on days with no flying.

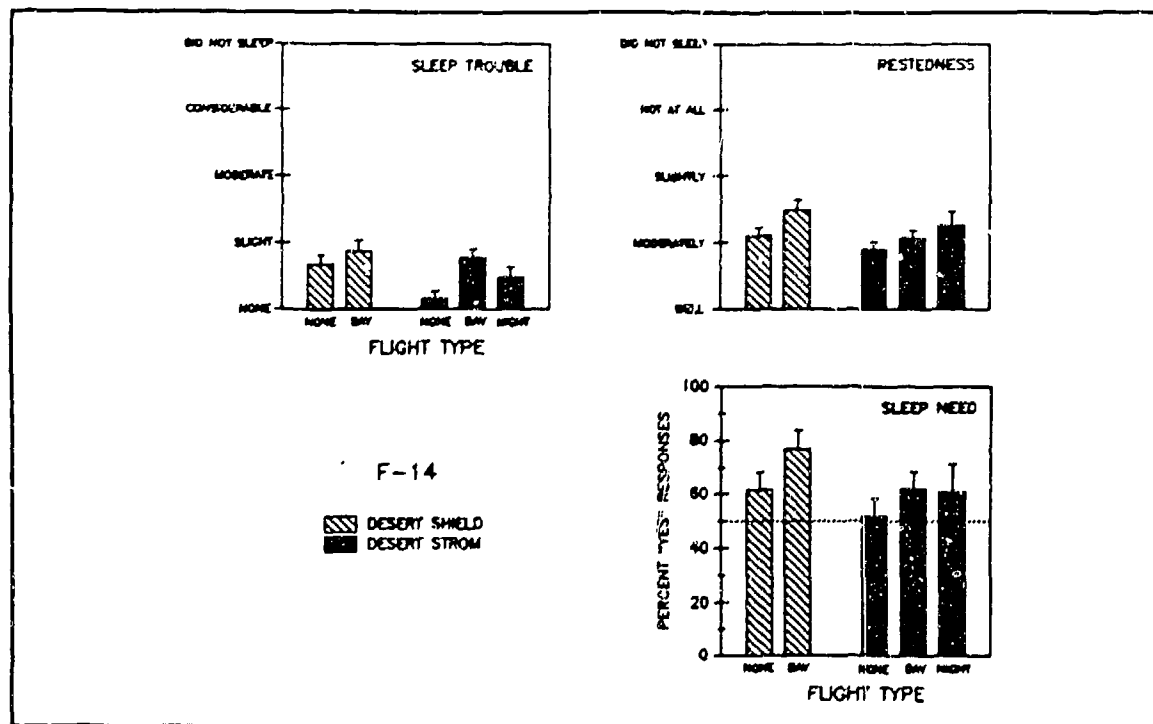


Figure 11. Mean sleep trouble, restedness, and sleep need (+ 1 SEM) for F-14 aircrew before days with no flights and day flights and on days after night flights during Desert Shield and Storm.

The nap duration pattern (Fig. 13) is remarkably similar to the nap frequency pattern for A-6 aviators. Not only were naps more frequent after day flights during Desert Storm, they were also longer, averaging about 1.3 h. Naps under other conditions averaged closer to .6-.8 h in duration. For F-14 aviators, the nap duration pattern did not follow the nap frequency pattern as closely. Naps following day flights before the war were the longest at about 1 h. Naps on nonflying days before the war and under all conditions during the war were shorter at .4-.8 h.

A less direct measure of difficulty sleeping or sleep quality is caffeine ingestion. Patterns of caffeine use are shown in Fig. 14 for both A-6 and F-14 aircrew. The data were obtained in answer to question 6: "How many cups of coffee or caffeinated soft drinks did you ingest during this period?" The average consumption for A-6 aviators was about 2 cups per day throughout Desert Shield and Storm. The F-14 aviators drank more caffeinated drinks, averaging 3-4 cups per day. Most caffeine was ingested on nonflying days during Desert Shield and on days with day flights during Desert Storm. Nap duration and caffeine use are interesting to examine together. Shorter nap durations are associated with greater caffeine use and vice versa. This relationship is particularly strong for the F-14 aircrew as seen in the complete reversal of the pattern of results in the right panels of Figs. 13 and 14. Not surprisingly, caffeine may have served to shorten or limit sleep during the day.

DISCUSSION

For the A-6 and F-14 aviators sampled by this study, the effect of combat on work/rest cycles and sleep-related fatigue was modest. Nevertheless, we emphasize that these findings are specific to these two squadrons on the AMERICA. The circumstances of the AMERICA's travel to the Red Sea are not necessarily generalizable to other aircraft carriers involved in the war, except the USS THEODORE ROOSEVELT, which left Norfolk enroute for the Persian Gulf a day earlier.

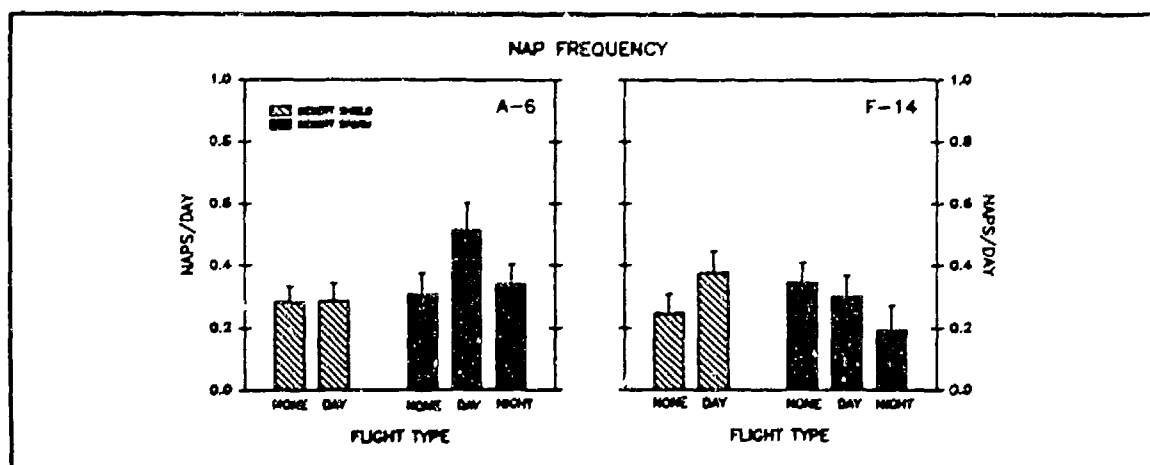


Figure 12. Mean naps per day (+ 1 SEM) for A-6 and F-14 aircrew during days with no flights and day flights, and on days after night flights during Desert Shield and Storm.

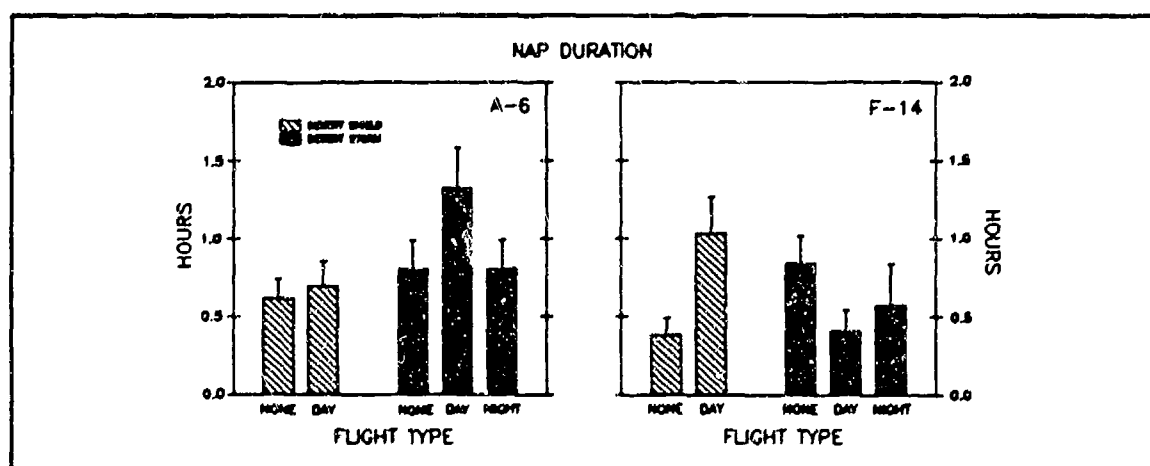


Figure 13. Mean nap duration (+ 1 SEM) for A-6 and F-14 aircrew during days with no flights and day flights, and on days after night flights during Desert Shield and Storm.

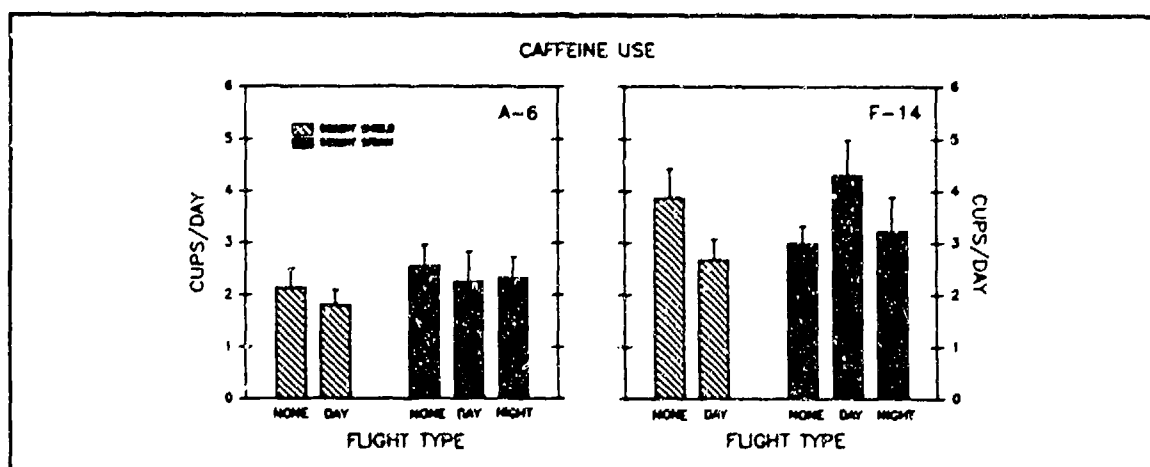


Figure 14. Mean cups caffeinated drinks consumed/day (+ 1 SEM) by A-6 and F-14 aircrew on days with no flights and day flights, and on days after night flights during Desert Shield and Storm.

The main effect of the war on the patterning of activities throughout the day was, predictably, an increase in flight time for both squadrons, and other work- and flight-related activities for the A-6 squadron (Figs. 2 & 3). At the same time, collateral duty time decreased, possibly because collateral duty tasking diminished with the onset of the war. Certainly commanding and executive officers were more heavily involved with planning, possibly leaving the more junior officers (the subjects of this study) with additional free time. Whatever the reason, the reduction in collateral duty time rather than any significant reduction in sleep time is an indicator of good sleep management. Further indication of proper sleep management is the fact that during the war the amount of sleep in the average day remained the same for the A-6 aircrew and increased by 1.9 h for the F-14 aircrew. The increase in sleep and rest for the F-14 squadron may be related to the lighter-than-anticipated role of these fighters during the war. This would probably not be the case in a different wartime scenario with the airborne threat lasting longer than it did here. The relatively large increase in missing data for the A-6 aircrew is puzzling. It may be related to war-induced stresses and demands on these attack aircrew, which resulted in the sacrifice of nonessential tasks such as completion of sleep/activity logs. The percentage of missing data did not change noticeably for the F-14 aircrew.

To examine whether the distribution of daily activities observed here is typical during armed conflict, it can be compared to similar data collected during the Vietnam War on Air Force transport aircrew (28). Tabled data from this study have been plotted in Fig. 15 for easy comparison to Figs. 2 and 3. The categories in Fig. 15 are comparable to those in Figs. 2 and 3 with the exception of "Ramp Pounding" (waiting on the flight line). Note that total work time for these transport aircrew was a little less than one-half of the typical day, which is similar to the pattern for subjects in the present study. Not surprisingly, transport aircrew spent more time flying in the average day (6.6 h). They spent 4 h in the average day on related duties (other flight, ramp pounding, squadron work), compared to about 10 h during Desert Shield and about 8 h during Desert Storm for the A-6 and F-14 aviators. The amount of time spent sleeping in the typical day for the two groups is remarkably similar at a little over 7 h. Thus, the pattern of daily activities of the aircrew in this study, both before and during the war, was similar in terms of amount of work and sleep to that for transport aircrew flying logistics missions over 20 years ago.

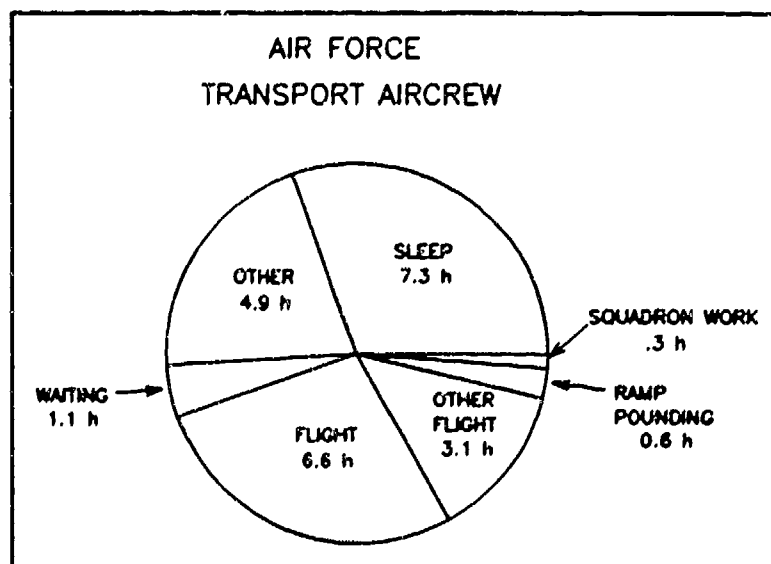


Figure 15. Average breakdown of sleep, work, and other activities for U.S. Air Force C-141 transport aircrew flying 100 logistics missions. (Adapted from data in Hartman (28)).

Sleep patterns revealed that daytime flying resulted in earlier sleep onsets the evening before for both squadrons in Desert Shield and Storm (Figs. 4-6). Evidently, knowledge of flying on the following day resulted in earlier bedtimes the night before. On the other hand, nighttime flying pushed the peak of the sleep fraction curve to 0800 (Figs. 4 & 5) and pushed mean sleep onset to about 0500 (Fig. 6) for both squadrons. This is an inevitable consequence of flying at night, but also an undesirable one. If continued, this pattern of staying awake at night and sleeping during the day can lead to circadian desynchronization--a shifting of circadian rhythms with respect to local time. Furthermore, it ordinarily means that the aircrew will be sleeping only a short time before body temperature starts to rise and sleep becomes difficult to prolong. Interestingly, the expectation of shorter sleep periods following night flights was not realized. We will return to this finding later.

Sleep duration after night flights during Desert Storm was shorter than before nonflying days but still more than 6 h (Fig. 9). It was similar to sleep durations before daytime-flying days during Desert Storm and both nonflying and daytime-flying days during Desert Shield. Average sleep duration never dipped much below 6 h and very few individual sleep periods were less than 4 h (Figs. 7 & 8). With a minimum total sleep duration of 4-5 h recommended (7,26), obtaining adequate levels of sleep was not a problem for these aircrew. In fact, a study of the sleep patterns of crew on the carrier USS KITTY HAWK almost 20 years ago showed that the median duration for uninterrupted sleep was about 4 h (29). On the other hand, the longer sleep durations during Desert Storm before days without flights may indicate the stresses of combat. Aircrew possibly took advantage of their schedules to catch up on sleep on these days, averaging about 8 h per night.

The relatively few reported sleep problems (Figs. 10 & 11), even for sleep periods after night flights, was an unexpected result. These subjective data are consistent with the major sleep period data in indicating that nighttime flying did not have a major negative impact on sleep duration, sleep need, sleep trouble, or restedness. Nap data are also consistent with these findings. The only substantial increase in nap frequency was for A-6 aircrew during the war (Fig. 12). These naps also tended to be longer (Fig. 13). We found no concomitant increase in napping after nighttime flights.

Why was there a pattern of apparently little sleep-related fatigue for these AMERICA aircrew as a result of combat? There are several possibilities. First, aircraft carrier use appeared to be well-managed. Many assets were assembled in the theater of operations with the naval air warfare load being shared by a total of six aircraft carriers. This was an unprecedented situation. The three carriers in the Red Sea rotated such that at least two were on line at any one time, flying strikes. The third could be off line, refuelling and resupplying. Thus, the burden was not as heavy as it might have been had less assets been available to military planners. For example, had the aircraft carrier USS INDEPENDENCE, which was in the area at the start of hostilities, been required to bear the combat load entirely until other ships arrived, one might expect a different result in terms of stress, fatigue, and sleep loss.

A Circadian Explanation. Other circumstances unique to the USS AMERICA and its battle group may have played a significant role in the lower-than-expected levels of sleep loss and fatigue. The experience of aviators aboard USS AMERICA was different from that of aviators assigned to other aircraft carriers in the operating area except for the aviators aboard USS THEODORE ROOSEVELT, which crossed the Atlantic at about the same time and rate. A key factor may be that the USS AMERICA traversed seven time zones and engaged in the war the day after reaching its station. Although ship clocks were reset for each time zone, and many aircrew attempted to modify their work/rest schedules accordingly, adaptation to local time by shipboard personnel was not likely to be rapid for several reasons. First, the ship's travel was eastward. The phase-advance of the circadian pacemaker required by eastward travel results in longer resynchronization times than the phase-delay required by westward travel (30). This is because the human circadian rhythm has an endogenous period of about 25 h under typical circumstances. Consequently, adjustments resulting in a shorter day (eastward travel) are more difficult than those resulting in a longer day (westward travel). Second, the seven time zones were crossed in a period of only 15 d. Although phase-shifts of the circadian rhythm are often believed to take about 1 d for every time zone traversed, conditions were not ideal for resynchronization. Exposure to the important zeitgeber ("time-giver") of sunlight appeared to be minimal for many aviators. Life onboard a Navy ship does not necessarily include copious doses of sunlight. Furthermore, recent evidence underscores the probable importance of zeitgeber strength on the timing of the circadian system (31). Third, the nighttime flights with daytime sleeping started right after arrival in the Red Sea. This served to delay work/rest schedules from becoming synchronized with local time.

If adaptation to local time was delayed, then aircrew were operating on a "body time" between local and EST. Because EST was 7 h earlier, this situation would work to the aircrew's advantage. Flying at night and sleeping during the day would be an easier schedule to follow as it would correspond (on a time schedule closer to EST) to flying during the evening and sleeping at night. To examine whether this situation was likely, a suggestion was made (C. A. Czeisler, personal communication, May, 1991) that work/rest

patterns on the trip over to the Red Sea and during the war be plotted in raster format (32). In the present context, raster plots are a means of closely examining any changes in the pattern of sleep, wake, and flying periods over many days as the ship crossed the Atlantic and became involved in the war.

Raster plots for representative subjects are shown in Figs. 16-19. The horizontal axis is EST. The vertical axis is study day. The first and last (partial) days of the study contained incomplete data so they were omitted from these plots. Note that time along the horizontal axis is double-plotted. Each day (with the exception of the first) is plotted to the right of and below the previous day. This means that the first horizontal line of data contains study days 2 and 3. The next line also shows study day 3 with study day 4 to its right. This technique exposes patterns in sleep or other activities that may bracket midnight without forcing these periods to wrap from one line to the next. Solid black bars represent sleep periods; small circles are flights. Blank space indicates activities other than sleep or flying. The jagged vertical line beginning at 2400 represents local midnight. Because the ship departed from Norfolk, Virginia, (EST), local midnight and midnight EST initially coincided. As the ship travelled eastward, crossing meridians, local midnight corresponded to earlier and earlier times EST. By study day 16, local midnight corresponded to 1700 EST, which was 7 h earlier than local midnight. The war started at approximately the beginning of study day 17, shortly after the ship's arrival in the Red Sea.

For many aviators there appear to be frequent attempts to adapt work/rest patterns to local time, as evidenced by a general phase advance of the sleep periods on the way over to the Red Sea. Subject 08 (Fig. 16) is representative of this pattern. With each clock adjustment, this subject continued to go to sleep around 2400 (local) which corresponds to earlier and earlier EST sleep onset times. It was not as difficult to adapt one's work/rest cycle to time changes before the war when operational demands were fewer. Once the war started, operational demands included increased night flights which pushed the work/rest schedule back to one more consistent with EST. For example, the night flights on days 15, 16, 18, and 20 for subject 08 pushed sleep onset to 0400-0700 local time, but only 2100-2400 EST. These flights served to act against adaptation of the work/rest schedule to local time and perhaps keep the circadian clock set to a time closer to EST.

A variant of the pattern described above can be seen in the data of subject 12 (Fig. 17). He showed initial work/rest adaptation to local time as evidenced by sleep onsets closely following the local midnight line up until the war. Once this aviator starting flying at night (study day 20), he exhibited a forced delay in sleep onset. Days 21 and 22 show a possible tendency to stick with a delayed sleep onset (several hours after local midnight) despite the presumed capability of sleeping at an earlier time. Following the night flight on days 26-27, there appeared to be a concerted effort to sleep at earlier and earlier times, thereby adapting to local time. Full adaptation was again possibly delayed by the night flight on day 30, and possibly more after the study ended.

A second pattern representative of many of the aviators is seen in the data of subject 16 (Fig. 18), who tended to stay more closely on a work/rest schedule consistent with EST (at least up until study day 9). This sleep trend may have been intentional, or perhaps he had difficulty adapting to the time zone changes. After some evidence of adaptation to local time from days 9-13, subject 16 shows a pattern of slipping back to very late sleep onset times (locally) that correspond to very typical sleep onset times for zones closer to EST. He tended to stay on a work/rest pattern closer to EST than local time despite a lack of night flights forcing the shift in sleep/wake cycle that occurred for subject 08. This might be because he wasn't tired at local midnight when it was only 1700 EST (or 1800 or 1900 in nearby time zones).

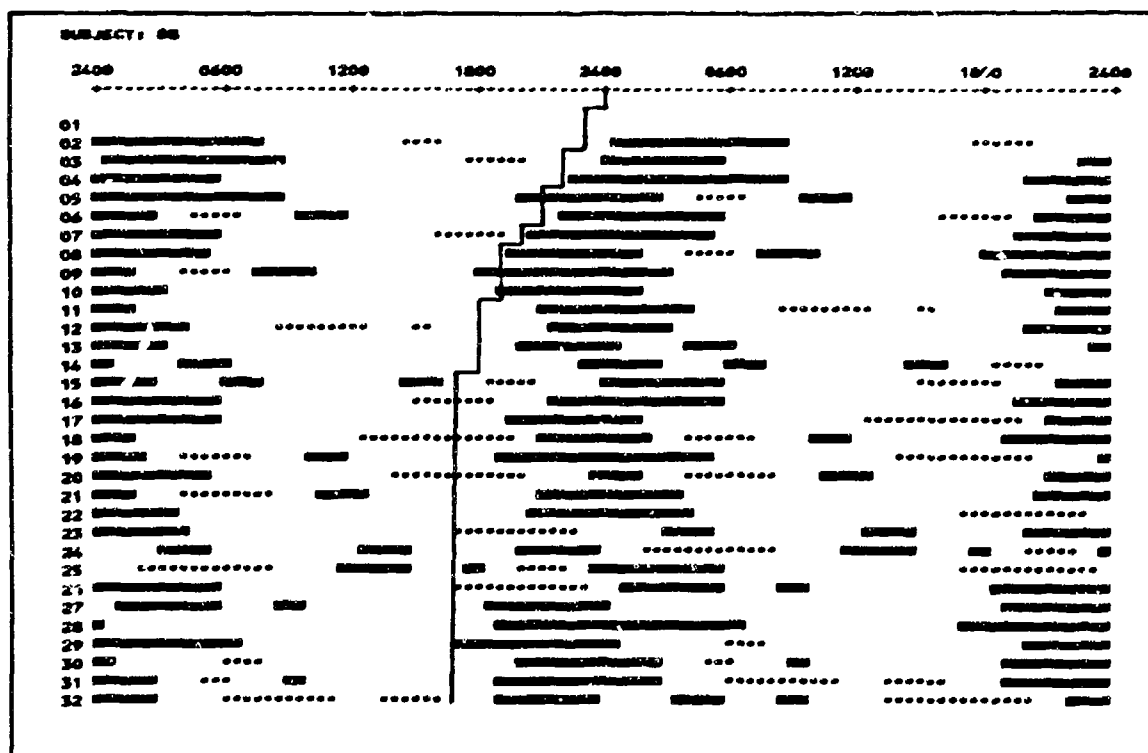


Figure 16. Raster plot of the sleep (black bar), wake (white space), and flight times (circles) of subject 08. Horizontal axis is EST, vertical axis is study day. Vertical line is local midnight.

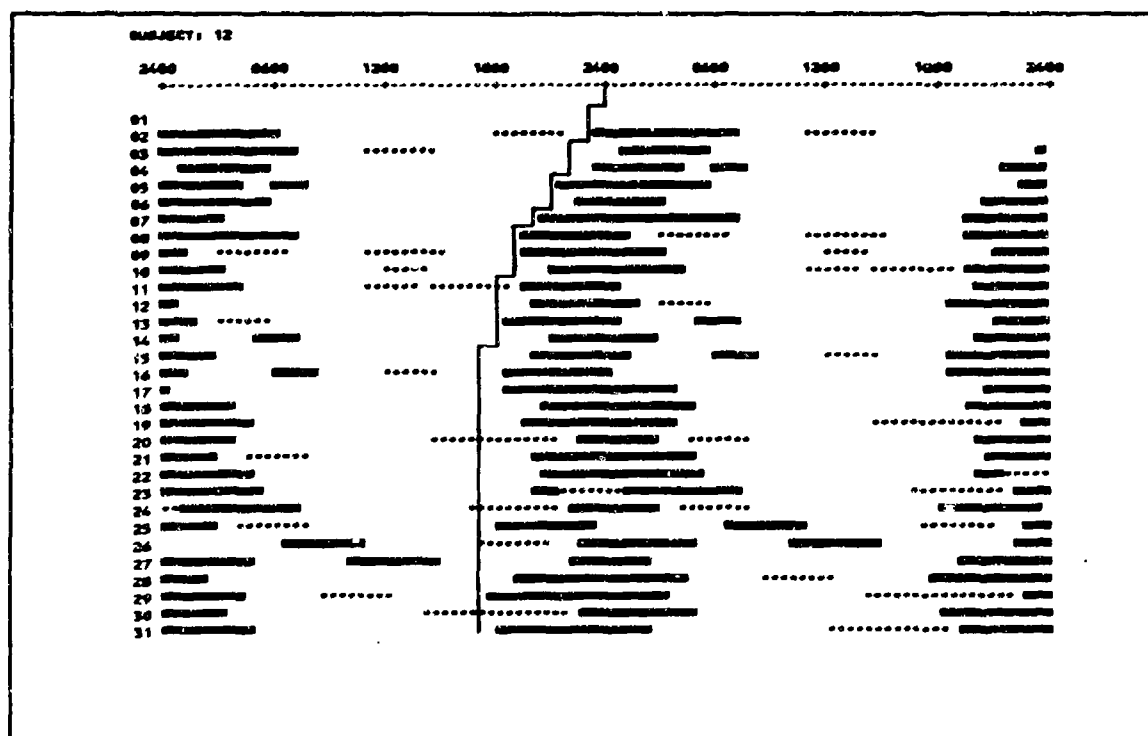


Figure 17. Raster plot of the sleep, wake, and flight times of subject 12. See Fig. 16 for additional details.

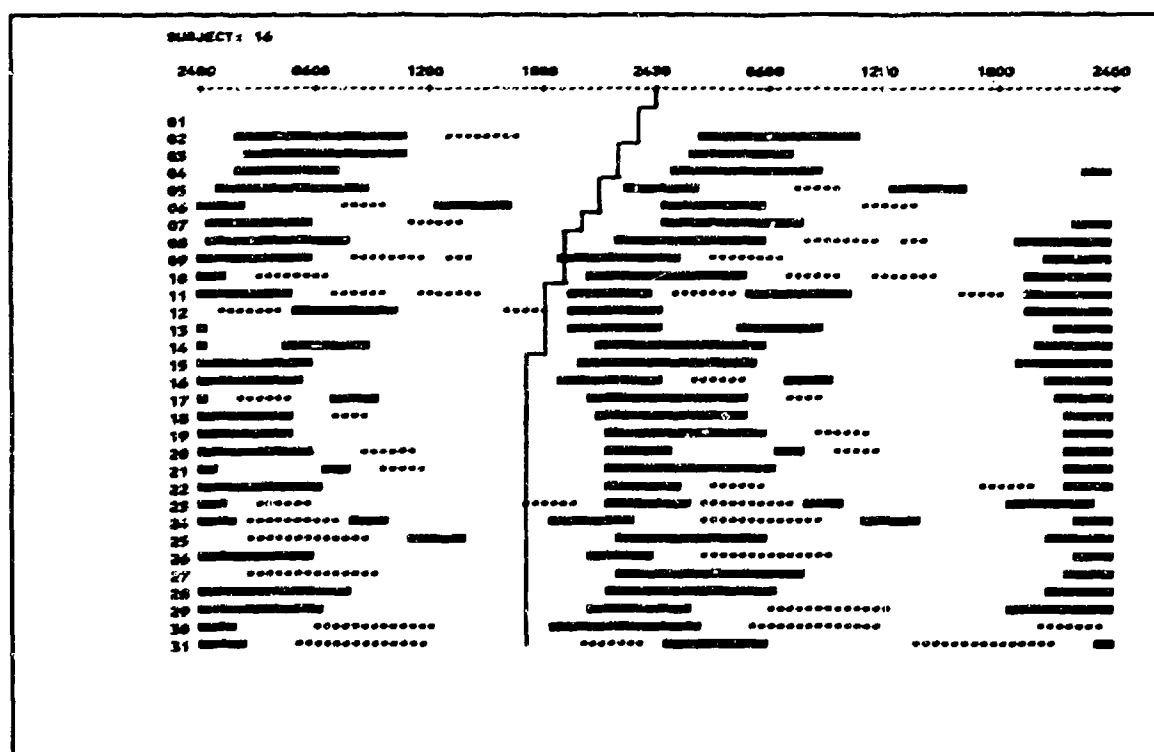


Figure 18. Raster plot of the sleep, wake, and flight times of subject 16. See Fig. 16 for additional details.

A variant of the second major pattern is exhibited by subject 17 (Fig. 19), who showed some initial variability in sleep onset time but tended to stay on a sleep schedule consistent with EST. On days 17 and 19, night flights delayed sleep onset. This subject appeared to finally establish a sleep schedule consistent with local time on days 20-22. However, three consecutive night flights (days 24-26) served to delay sleep onset and resulted in apparent difficulty in returning to a sleep schedule consistent with local time. Subject 17 continued to go to sleep well after midnight from day 27 through the end of the study.

The data to this point can be summarized as follows. The operational demands of the war meant frequent night flights for A-6 and F-14 aviators. These flights served to push sleep onset times well past local midnight. Despite this occurrence, the data described earlier show few indications of any associated increases in fatigue and sleep problems. Why was there relatively little reported fatigue and difficulty sleeping? Perhaps because the usually burdensome operational demands of nighttime flying, in addition to the other factors listed above, delayed full and complete adaptation to local time. They did so by pushing sleep onsets well beyond midnight locally, but much closer to midnight EST. This meant aviators were perhaps continuing to operate on a body time closer to EST than the time zone in the northern Red Sea. Being synchronized to a time closer to EST would have the effect of making local night flights more like evening flights according to the body's internal clock. Flights earlier in the evening are less physically demanding because body temperature has not declined as far, and aviators are less sleepy. Less-than-anticipated reports of fatigue and sleep problems, therefore, may have been both a function of the less-than-anticipated demands of this war on the aviators in this study, coupled with the fact that aviators may have been operating on a body time that gave them a decided advantage in flying and working during the local night.

An additional possible source of support for this hypothesis can be found in the data. Ordinarily, night flights would result in a reduction in duration for the immediately following sleep period. This is because the sleep period would most likely begin near the trough of the circadian cycle in body temperature. For subjects on self-selected schedules in an environment free of time cues, bedtimes near the temperature

cycle minimum were significantly shorter than those near the maximum (33). Wake times tended to occur on the rising portion of the temperature cycle. In a study of unrestricted sleep in subjects kept awake for variable periods, sleep duration was also shortest when started near the temperature minimum and occurring largely on the ascending portion of the body temperature cycle (34). As body temperature rises, sleep becomes difficult to prolong. The failure to find the expected reduction in sleep duration after night flights in the present study may be due, at least in part, to the hypothesis that the flights took place on a body time closer to EST. Figure 6 shows that sleep onset after night flights was only 2200 EST. Aviators who were adapted to a time zone about midway between EST and local time would experience onset shortly after midnight, corresponding to a typical sleep onset time before the war. Sleep fraction data also show a pattern that would not be expected to be physically demanding on an EST or similar schedule (Figs. 4 & 5). The peak in sleep fraction is at 0300-0400 after night flights for a zone in between EST and local time. Again, this is quite consistent with sleep fraction data before the war, with peaks at about 0400.

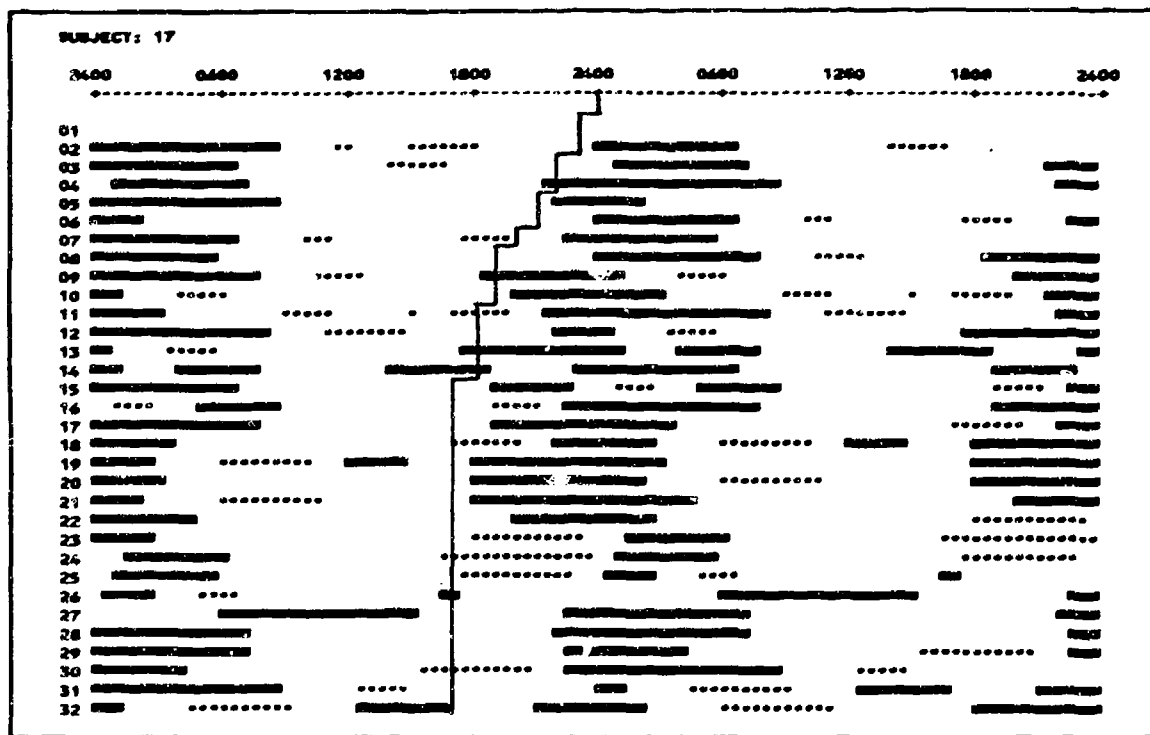


Figure 19. Raster plot of the sleep, wake, and flight times of subject 17. See Fig. 16 for additional details.

There is one piece of data that at first appears inconsistent with this explanation. Question 5 on the activity survey card asked subjects: "If you have flown during this period, how soon after your last flight could you have flown a strike?" The answers to this question are referred to as subjective strike delay (SSD) and are analyzed in our companion report (24). It is interesting that, for both aircrew, SSD was longest following night flights. However, we do not view this result as inconsistent with the hypothesis that local night flights were more akin to evening flights on body time. A possible reconciliation lies in the fact that night flights were the most difficult, dangerous, and stressful. Most combat missions were flown at night while many less stressful missions were flown during the day (e.g., tanking). It is not surprising that, after night flights, aircrew reported wanting longer delays before flying again. However, the sleep period following night flights, presumably coming at a good time in the circadian cycle, was relatively restful, restorative, and long, as seen in the data above.

The extent to which the circadian factor played a role is impossible to determine without body temperature data. Thus, the above hypothesis must be treated with caution. Even with this combination of factors acting to delay adaptation to local time, adaptation should occur before very long after the start of

the war. That is, some adaptation would be expected to occur during the 2 weeks the ship was crossing meridians. Just how much adaptation occurred can only be surmised. Nonetheless, several lines of evidence indicate that adaptation was not complete almost 2 weeks into the war and that this delay may have acted to make the schedule-related demands of the war less challenging.

What do these results mean to military planners? These data support the idea that, when possible, there may be tangible advantages to incorporating information about the circadian phase of combatants into battle strategy. It is already known that during continuous operations performance is likely to follow the diurnal cycle more than during normal work periods. As a result, low points in performance seem to coincide with troughs in the circadian cycle (4). Taking advantage of circadian factors where transmeridian travel is concerned, as on the USS AMERICA during the Gulf War, may help prepare combatants to fight at suboptimal times. This strategy is particularly important for those who can always be expected to fight and work at night (e.g., certain aviators, ground troops, and special forces). Due to the extensive amount of shiftwork performed in the Navy, circadian principles (35) and sleep logistics (4,6,7) can be used to the advantage of numerous naval personnel. The self-contained shipboard environment lends itself well to manipulations of local time and work/rest schedules that can benefit ship's crew. Further avenues worthy of exploration include the more aggressive approach of intentionally shifting the phase of the circadian pacemaker. Proper application of bright light is a proven means of phase-shifting the circadian clock (36-38), even in the very operational situation of manned space flight (39). A complete consideration of circadian factors holds the promise of minimizing the predictable performance decline in military personnel who work and fight when the body's natural tendency is to sleep.

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Other Related NAMRL Publications

Shappell, S.A. and Neri, D.F., *The Effect of Combat on Aircrew Subjective Readiness and LSO Grades During Operation Desert Shield/Storm*, NAMRL-1369, Naval Aerospace Medical Research Laboratory, Pensacola, FL, May 1992.