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

Mitsuo Sasaki, Yuko Kurosaki, Atsuyoshi Mori*, and Shiro Endo**

Flight Crew Medical Service Department, Japan Air Lines, Haneda, Tokyo, Japan; *Department of Neurology and Psychiatry, Jikei University School of Medicine, Tokyo, Japan; and **Psychiatric Research Institute of Tokyo, Tokyo, Japan

## ABSTRACT

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

## INTRODUCTION

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

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

## SUBJECTS AND METHODS

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

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

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

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

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

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

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

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

## RESULTS

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

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

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

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

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

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

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

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

sleep is within the normative range.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

*$p<0.05$; **$p<0.01$

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

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

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

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

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

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

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

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

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

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

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

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

## DISCUSSION

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

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

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

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

## ACKNOWLEDGMENTS

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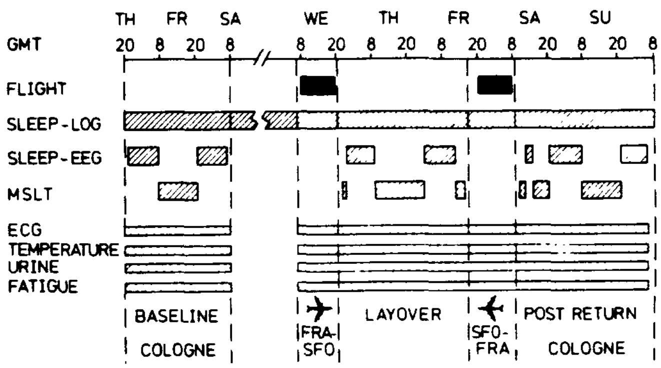


**Figure 1.- Overview of time lines for the data collection of the flight schedule Frankfurt-San Francisco.**

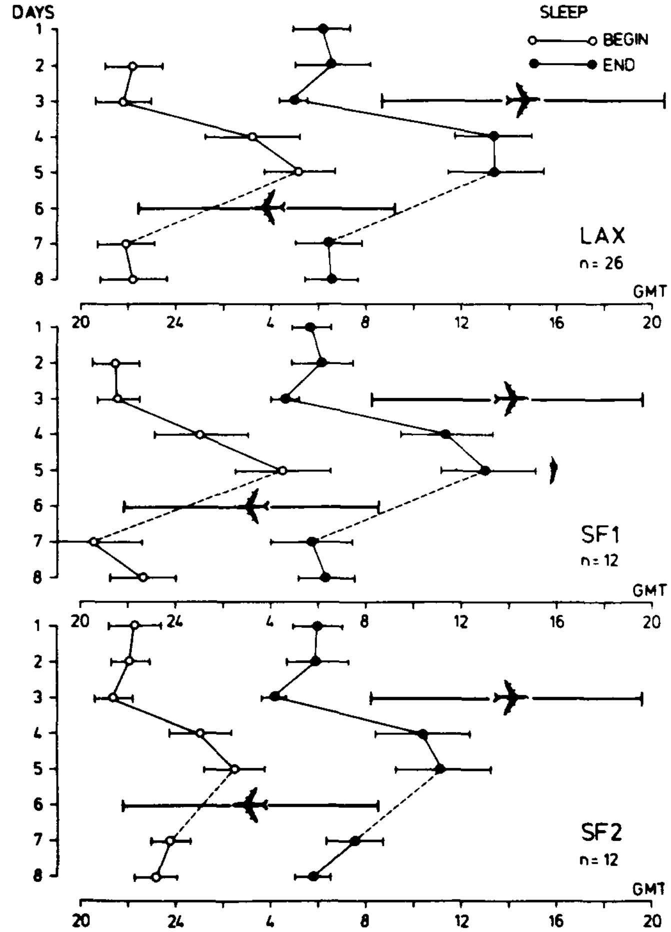


**Figure 2. Subjective ratings of beginning and end of sleep during control, layover and post-return nights. Presented are means (±S.D.) of the three different groups. (Numbers of days at the vertical axis refer to days beginning at 2400 GMT.)**

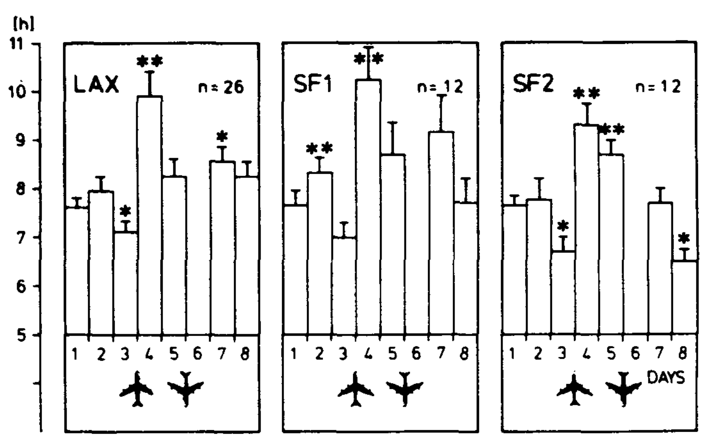


**Figure 3. Subjective ratings of sleep duration during control, layover, and post-return nights (means +/- S.E.). * p<=0.05; ** p<=0.01 for differences from sleep period of day 1.**

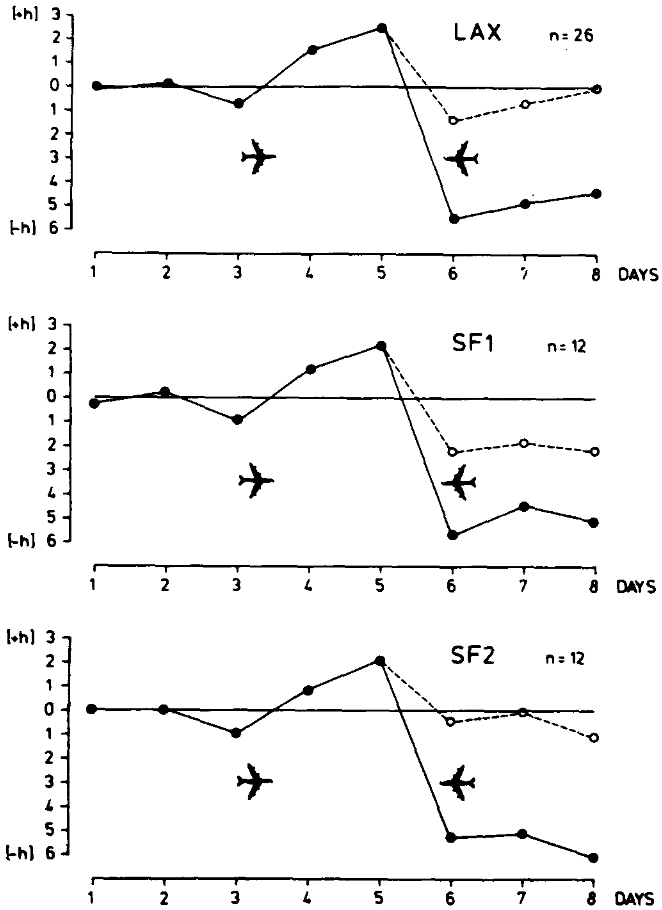


Figure 4. Sleep balance: accumulated deviations of subjectively rated sleep duration from control nights (day 1 and day 2). Values do not include short extra sleep periods (naps). Open circles and dashed lines represent sleep balance including sleep in the afternoon following return flight.

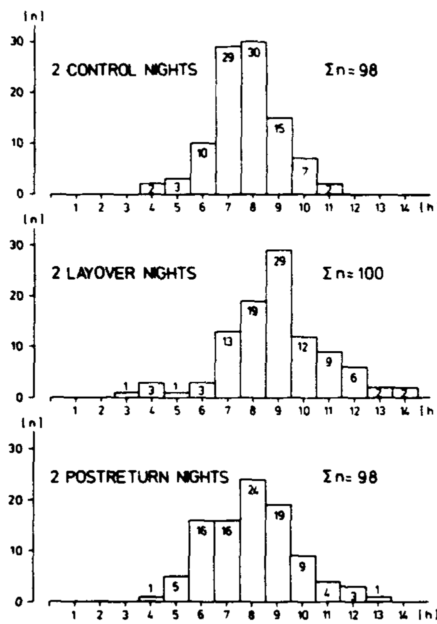


Figure 5. Histogram of subjectively rated sleep duration of all three groups together. Combined are two nights each from the control, layover and post-return period. (Note: sleep period immediately preceding flight schedule not included).

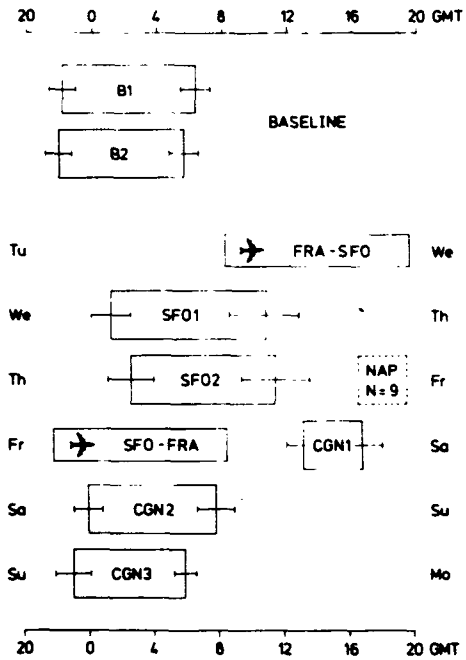


Figure 6. Time schedule of sleep periods and flights. Time axis is chosen from 2000 to 2000 GMT. Bars for sleep periods show standard deviation for light off and on. Baseline recordings were taken several days before flight to SFO.

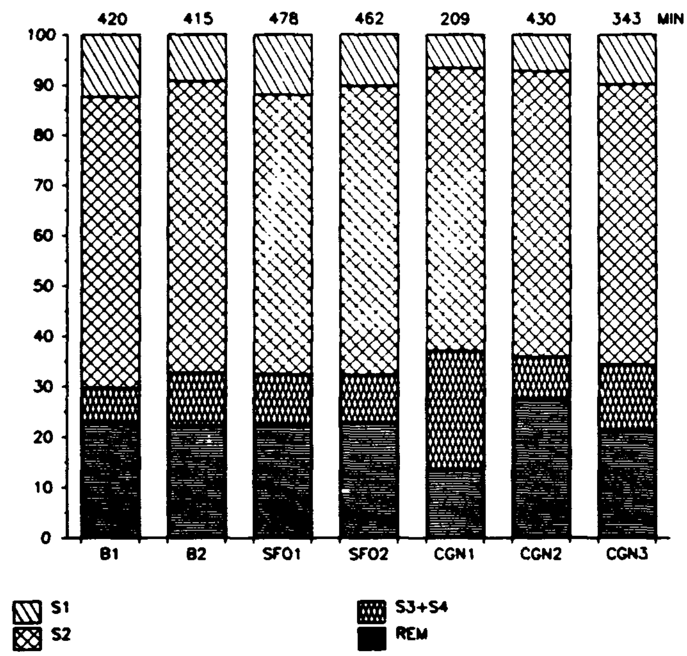


Figure 7. Mean percentage of total sleep time (TST) for sleep stages. Means (N = 12) are shown for seven sleep periods. Absolute TST values (min) are given on top of the bars.

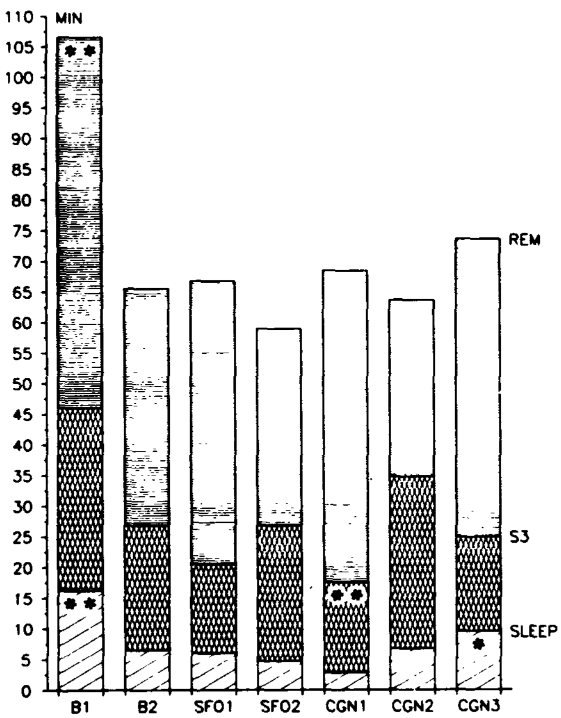


Figure 8. Median (N=12) latencies to the first ten minutes of persistent sleep, to slow-wave sleep (S3), and to REM sleep. Significant differences from baseline values (B2) are indicated (*p<0.05, **p<=0.01, Wilcoxon-matched-pairs-signed-rank test).

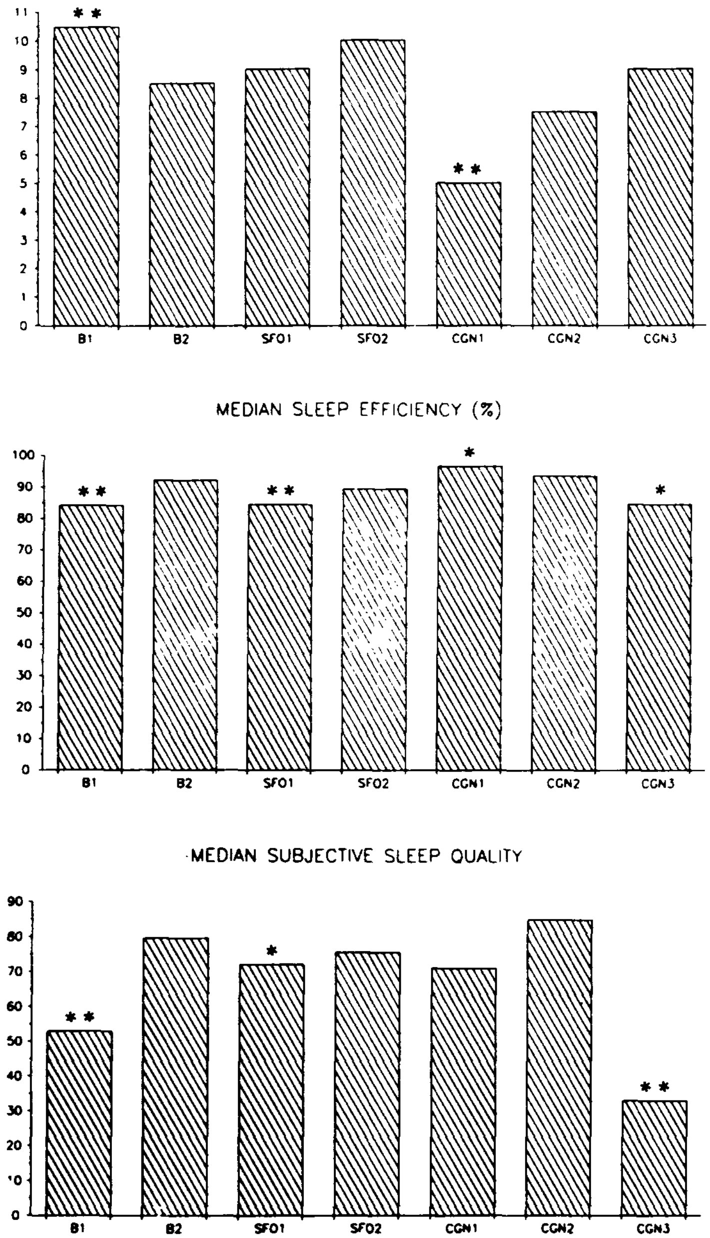


Figure 9. Sleep efficiency, number of awakenings, and subjective ratings of sleep quality for seven sleep periods. Significant differences from baseline (B2) are indicated (* p<=0.05, ** p<=0.01).

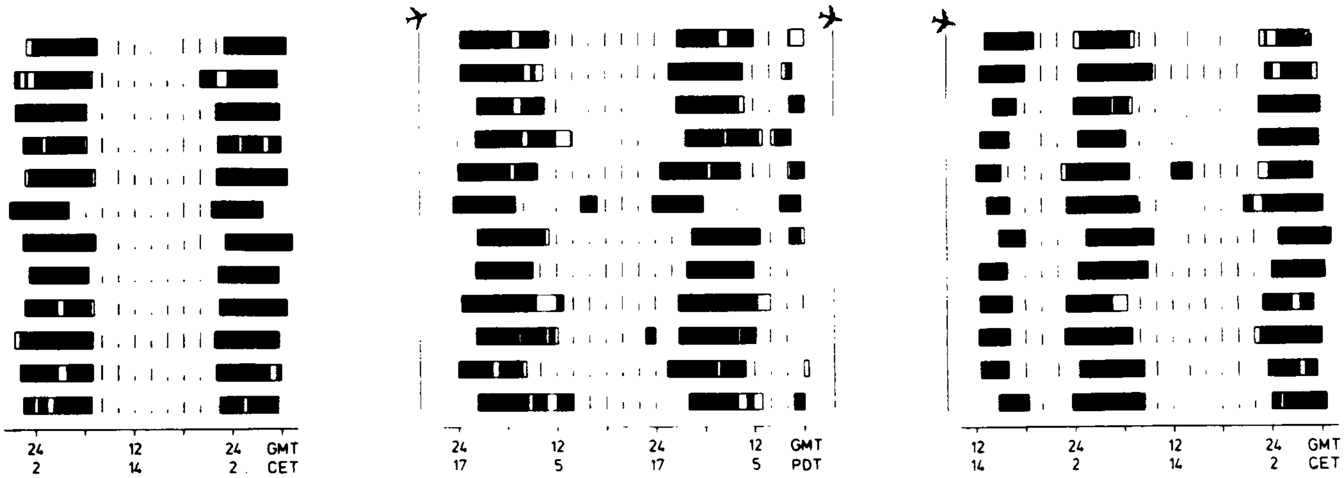


**Figure 10.** Sleep pattern and multiple sleep latency test (MSLT). Sleep periods in black, wake times in white. Vertical lines between sleep periods represent MSLT; their height is sleep latency in minutes.

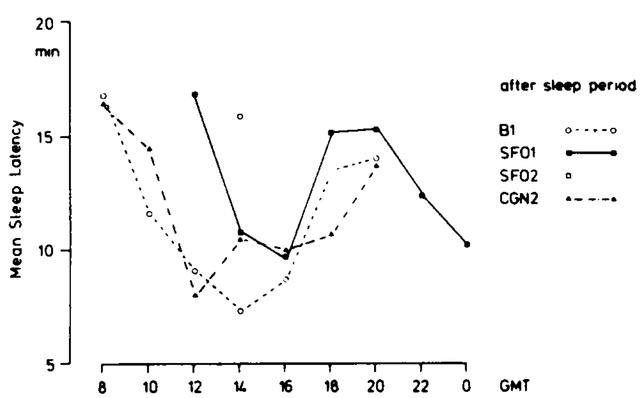


**Figure 11.** Mean MSLT after sleep periods B1, SFO1, SFO2, CGN2.

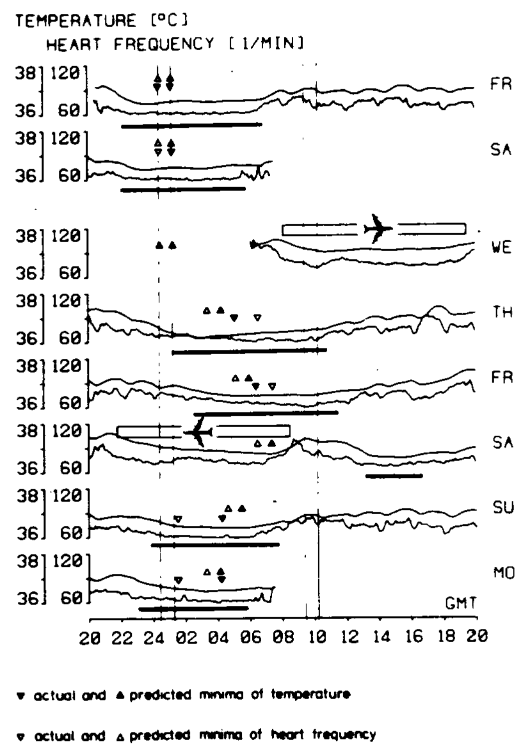


**Figure 12.** Means for temperature (upper curves) and heart rate (lower curves) before, during and after flights. Vertical lines indicate position of minima during baseline and after complete shift by 9h (solid lines: temperture; dashed lines: heart rate).

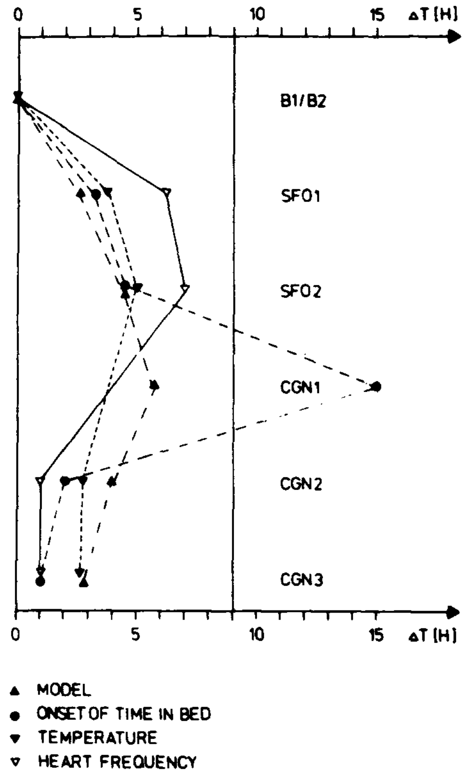


**Figure 13. Shifts in acrophases relative to baseline position.**