The Haj operation: alertness of aircrew on return flights between Indonesia and Saudi Arabia

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Executive summary

E.1 Terms of reference

E.1.1 This report describes a study carried out for the Safety Regulation Group of the Civil Aviation Authority under contract number 7D/S/952/1, as part of a programme of research into the sleep and wakefulness of the airline pilot.

E.2 Background

E.2.1 In early 1998, Britannia Airways undertook the transportation of Islamic pilgrims between Solo City in Indonesia and Jeddah in Saudi Arabia. This report relates to the first phase of the air operation, which lasted for 4 weeks, and in which the pilgrims were carried from Indonesia to Saudi Arabia.

E.2.2 Each trip involved 3 stages, a 2-hour flight from Solo to Batam, which is close to Singapore, a 10-hour flight to Jeddah, and a return flight of 10.25 hours to Solo. The layover periods in Batam and Jeddah were generally close to 30 hours, though some were 34 hours, 38 hours, or even longer. Take-off times from all 3 destinations were scheduled at 12 different times of day, each separated by 12 hours.

E.2.3 The CAA allowed a variation to CAP 371 that enabled Britannia to operate many of the flights with a crew of two. It also asked the DERA Centre for Human Sciences (CHS) to monitor the operations to determine whether levels of aircrew fatigue were within acceptable limits. This report describes the study that was carried out by the CHS in response to this request.

E.3 The study

E.3.1 Information on aircrew fatigue was collected from three sources: sleep and duty diaries that the aircrew completed throughout the operation, small hand-held computers that were kept on the flight-deck and that were used for performance testing, and wrist-mounted activity monitors (actiwatches).

E.3.2 The diaries were used to collect information on the timing and quality of every sleep period, including on days off, as well as on subjective levels of fatigue on up to 6 occasions during a duty period. These 6 occasions corresponded to one pre-flight, 4 inflight and one post-flight assessment. Information on inflight rest periods, and any naps taken while on or off duty, was also requested.

E.3.3 At approximately 3-hour intervals throughout the flights to and from Jeddah, the aircrew completed a 10-minute performance session on a Psion computer. The session consisted of a 9-minute test of sustained attention, together with subjective assessments of their workload and levels of sleepiness during the flight.

E.4 Results

E.4.1 Of the 53 aircrew who were involved in the first phase of the operation, 43 (81%) took part in the study by completing sleep and duty diaries, as well as the computer-based tasks. Of these, 26 also wore an actiwatch at some stage of the operation.

E.4.2 Sleep prior to a duty period was generally assessed as adequate, although some aircrew had trouble obtaining sufficient sleep on a 30-hour layover that included only one local night. Naps were taken on 81% of occasions prior to a start time after 17:00 local time (LT). Their mean duration was 2.0 hours prior to the outward flight and 3.1 hours prior to the return flight. Sleep had returned to normal after the second night following the return.

E.4.3 On both the outward and the return flights, subjective levels of fatigue and sleepiness varied with the time of day or night and the time into flight. The effects were most severe at the end of duty periods on the outward leg that started close to midnight, and on the return leg that started in the late evening. Similar trends were seen in the increase in response times on the computer task.

E.4.4 A total of 51 inflight naps were reported during 207 flights. The majority of these were on the return leg, and they were generally initiated between 3 and 5 hours from the start of the duty period.

E.5 Conclusions

E.5.1 Crews were struggling to stay awake during some of the flights. The most difficult times were towards the end of duty periods starting between 19:00 and 04:00 (LT) on the outward leg, and between 18:00 and 01:00 (LT) on the return leg.

E.5.2 The indications were that duties starting between 06:00 and 15:00 (LT) on the outward leg, and between 04:00 and 11:00 (LT) on return, could be managed without the need for crew augmentation.

E.6 Recommendations

E.6.1 If this operation is repeated in 1999, it is essential that crew rotation is implemented on the flights that depart at the most critical times of day, and that all 3 crew members are able to operate in either the right or left-hand seat.

E.6.2 Bunks should be installed on some flights, and levels of alertness should be monitored to determine the benefit that is conferred by sleeping in a bunk, as opposed to an aircrew seat.

E.6.3 These results support the recommendation that unaugmented flight duty periods should not exceed 10 hours overnight.

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1. Introduction

1.1 Terms of reference

1.1.1 This report describes a study carried out for the Safety Regulation Group of the Civil Aviation Authority under contract number 7D/S/952/1, as part of a programme of research into the sleep and wakefulness of the airline pilot.

1.2 The Haj

1.2.1 The Haj is the fifth Pillar of Islam which requires a pilgrimage to Mecca at least once in a lifetime for those who can afford it and whose health permits. It takes place each year and lasts for a period of 5 days, the exact timing of which is determined by the lunar calendar.

1.2.2 The transportation of pilgrims to Saudi Arabia from all parts of the world is a major undertaking involving many different airlines. In 1997, and again in 1998, Britannia Airways was involved in the air operation which carried pilgrims from Indonesia to Saudi Arabia and back again. This study is concerned with the operation that was carried out in 1998.

1.3 The Operation

1.3.1 The operation was completed by Britannia Airways in two phases. During phase I, pilgrims were flown from Solo City (Surakarta), in the centre of the island of Java, to Jeddah, with a crew change in Batam, which is off the coast of Singapore. The aircraft then returned empty to Solo. For phase II, the aircraft were flown empty from Solo to Jeddah, and the pilgrims were flown back from Jeddah to Solo via Batam.

1.3.2 The two phases were approximately four weeks long and were separated by a period of 10 days. Crews volunteered to participate in the operation and were based in Solo during phase I and Batam during phase II. Most crews completed the entire operation, although some participated for shorter periods.

1.3.3 Data were collected during both phases of the operation. However, more aircrew participated in the study during phase I, and this report is concerned only with phase I.

1.4 The Schedule

1.4.1 Britannia Airways employed three Boeing 767 aircraft to carry out the operation. The first phase involved three flights, from Solo to Batam (SOC-BTH), from Batam to Jeddah (BTH-JED) and from Jeddah to Solo (JED-SOC). Each aircraft completed the journey from Solo to Batam and Jeddah, and then back to Solo, in under 30 hours, and the operation was organised on a 30 hour cycle.

1.4.2 The 3 aircraft departed at intervals of 4 hours, repeated every 30 hours, so that the departure times were separated by 4, 4, and 22 hours throughout phase I. As a consequence, departure times over the 4 week period occurred at 12 different times of day, each separated by 2 hours.

1.4.3 The flight description, duration of the flights, flying duty periods (FDPs) and a representation of the route flown are presented in Table 1-1 and Figure 1-1. The flight descriptions are used throughout the report and to refer to the three flights as stated. The FDPs include a period of 1.25 hours from the reporting times to 'blocks off'. Any post-flight duty (normally 30 minutes) has not been included.

Flight	Description	Duration (hours)	FDP (hours)
SOC-BTH	first leg	2.00	3.25
BTH-JED	outward leg	10.00	11.25
JED-SOC	return leg	10.25	11.50

Table 1-1; Duration of flights and flying duty periods

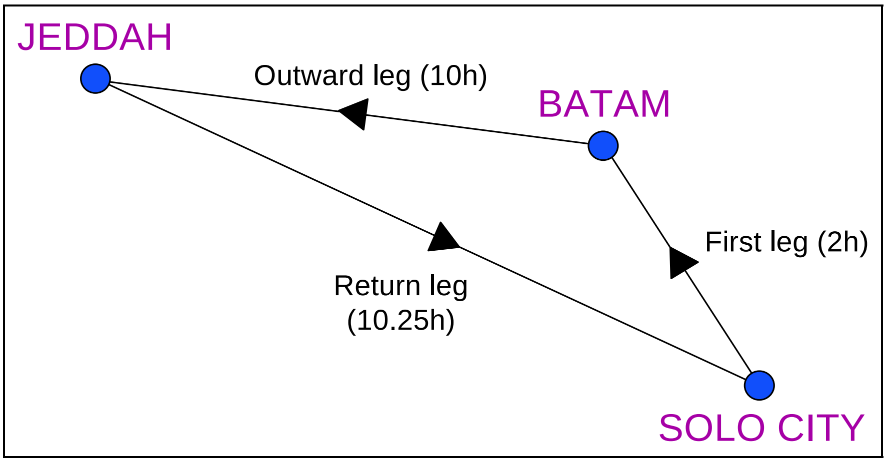

Figure 1-1; Route operated during Phase I

1.4.4 Aircrew completed up to 3 trips, with at least 3 local nights between trips. Layover times were variable, with the most frequent being 30 hours in both Batam and Jeddah. None of the layovers was less than 30 hours but some were 34 or 38 hours, and a few were longer. The time zone change from GMT was +7 hours in Solo and Batam and +3 hours in Jeddah. Prior to the first flight, crews generally spent three local nights in Solo.

1.5 The Variation

1.5.1 The current regulations for flight time limitations, detailed in CAP371 [1], restrict the maximum FDP according to the time that duty starts, whether crews are acclimatised or unacclimatised to the time zone. There are additional restrictions for 2-crew operations.

1.5.2 The Civil Aviation Authority (CAA) granted Britannia Airways a variation from CAP371, details of which are reproduced at Appendix A. If the standard criteria of CAP371 for 2-crew operations were applied to the outward and return legs they would be considered as multiple sector flights and this would reduce the length of FDPs. However, the variation allows a two-pilot crew to operate from Batam to Jeddah on a single sector and return (JED-SOC) again, on a single sector. The maximum unacclimatised FDP is 12.5 hours (JED-SOC).

1.6 The study

1.6.1 The CAA specified that the operation should be monitored by the DERA Centre for Human Sciences (CHS) to determine whether there was a potential problem with aircrew fatigue. This report describes the results of the monitoring of phase I of the operation. The investigation included three main elements:

- collection of information via a diary completed by the aircrew
- collection of performance and subjective data inflight on a Psion computer
- activity monitoring of the aircrew during their sleep and duty periods

2. Methods

2.1 Overview

2.1.1 To determine the levels of aircrew fatigue during the operation, data were collected using three different sources: a diary of sleep and duty, a Psion computer and an activity monitor. Crews volunteered to participate in one or more of these three aspects of the trial, a detailed description of which is provided at 2.2 to 2.5.

2.1.2 Subjective assessments of sleep and alertness were collected using diaries which crews completed on a daily basis. Crews rated their alertness inflight and reported any periods of sleep in the diary. In addition, a Psion computer was used over a 10-minute period inflight to complete assessments of workload, sleepiness and a performance test. The tests and assessments were completed at approximately 3 hour intervals during the long flights to and from Jeddah. Finally, an activity monitor was worn during all sleep and duty periods. The activity monitor was used to determine periods of inactivity, including any involuntary naps during the flights. It was also used to confirm the timing of other sleep periods.

2.2 Flight Crew Diary

2.2.1 The diary provided volunteers with details of the study and how to complete all the required elements of the diary. It was divided in to three sections: sleep page, duty page and duty schedule. Individuals were identified by a subject number and were asked to provide details about their position (Captain, First Officer) and age. On a daily basis, details of sleep and, if applicable, duty were requested (Appendix B). Example pages for the sleep and duty sections were included as guidance.

2.2.2 **Sleep page:** It was intended that individuals provided information about the timing and quality of their sleep. The sleep page was completed for every main sleep period, including days off. Information on naps during off-duty periods was also requested. Before sleep, subjects were asked to rate their alertness by selecting one of 7 boxes on a scale from ‘extremely alert’ to ‘extremely tired’. These data were then converted to a score from 1 (extremely tired) to 7 (extremely alert). Similarly, on waking, ratings were also made of the quality of sleep (1 = extremely poor to 7 = extremely good) and how well rested individuals felt (1 = not at all rested to 7 = well rested).

2.2.3 **Duty page:** Information was requested before, during and after all FDPs. Crews were asked to complete a 7-point fatigue assessment before and after a flight. For the short flights (SOC-BTH), assessments were also completed approximately half-way through the flight. During all other flights, a 7-point fatigue rating was completed at approximately 3-hour intervals inflight. The fatigue rating was a simplified version of the Samn-Perelli Checklist [2], which has been validated in air operations and has been used in previous studies of aircrew fatigue [3]. Aircrew were asked to choose a number from 1-7 which most closely related to their current fatigue level:

1. fully alert, wide awake
2. very lively, responsive, but not at peak

3. okay, somewhat fresh
4. a little tired, less than fresh
5. moderately tired, let down
6. extremely tired, very difficult to concentrate
7. completely exhausted, unable to function effectively.

2.2.4 The subjective assessments used in the diary are also listed at Appendix C.

2.2.5 Information was requested about the duration of any inflight rest periods or naps during the FDP. Inflight rest periods applied only to 3-man crews and were defined as any occasion when individuals were not acting as one of the operating crew. Any additional duty periods (e.g. positioning, standby) were recorded in the final section of the diary (duty schedule).

2.2.6 A single diary contained enough pages for an 11-day period, so that individuals who participated in the study throughout the operation completed more than one diary.

2.3 Psion tests

2.3.1 Crews completed a 10-minute session on a hand-held Psion (Psion Series 3a and 3c). The session included subjective assessments of workload, sleepiness and a 9-minute sustained attention task. Training for the sustained attention task was provided and subjects were encouraged to train prior to the first flight. The test sessions were completed at approximately 3-hour intervals during the long flights to and from Jeddah. During these flights, crews were asked to carry out the computer task immediately after completing the fatigue rating in the diary. If crews were interrupted for more than a few seconds in the middle of the task they were asked to abort it. Details of the individual tasks are described in paragraphs 2.3.2 to 2.3.5. Information from the Psions was not collected on the short first leg between Solo City and Batam.

2.3.2 **Subjective ratings (also listed at Appendix C):** Individuals rated their workload since the start of the duty period or since the last assessment, whichever was appropriate. The scale was as follows:

1. very high,
2. high,
3. moderate,
4. low,
5. very low.

2.3.3 Similarly, they were asked to select a statement that corresponded to their level of sleepiness since the start of the duty period or since the last assessment:

1. wide awake throughout,
2. occasionally felt a little sleepy,
3. sometimes felt rather sleepy,
4. sometimes struggling to stay awake,

5. often struggling to stay awake.

2.3.4 **Sustained attention task:** This task has previously been used in numerous laboratory experiments at DERA CHS and has been shown to be sensitive to the effects of fatigue [4]. It was adapted from a task designed by Rosvold [5] to measure sustained attention. For this particular study it has been modified further so that it runs for 9 minutes instead of the original 10 minutes. This was to ensure that the total time of Psion test and assessments did not exceed 10 minutes.

2.3.5 A random sequence of letters was presented one at a time on the Psion screen at a rate of one per second. Two letters (the critical stimulus) were displayed continuously at the top left hand corner of the screen. Subjects were required to press the space bar whenever the letters of the critical stimulus were presented consecutively during the random sequence. Response times and the nature of the responses (correct or incorrect) were recorded during the 9-minute task.

2.4 Actiwatches

2.4.1 The devices were Cambridge Neurotechnology AW4-32K actiwatches which are lightweight, wrist-worn monitors. An accelerometer within the watch records the occurrence and degree of motion and integrates this information to produce activity counts. The accelerometer is sensitive to movements of 0.01*g* in any direction. Data were integrated and recorded at 2-minute intervals.

2.4.2 A marker button is recessed in the case of the watch and, when it is depressed, the activity record is marked with the time and date. Subjects were asked to press the button every time they put on or took off the watch. This allowed periods when the watch was being worn to be identified. Data from the watches were used to confirm periods of sleep and to determine episodes of inactivity during duty.

2.5 Organisation of the study

2.5.1 The airline supervised the data collection during the study. This was achieved by the appointment of a study co-ordinator from the management of Britannia Airways who liaised between DERA CHS and the Britannia base in Indonesia. The co-ordinator was briefed about the study requirements and the operation of the equipment. Although DERA CHS supplied all the equipment and the diaries, it was the responsibility of the co-ordinator to recruit and brief subjects, to organise the distribution and collection of the equipment and diaries, and to download data between the two phases.

2.5.2 At the start of phase I, a number of aircrew positioned out to Solo and were briefed as a group about the study. They were asked to volunteer to participate in the study and to complete one or more of the three aspects of the trial. Throughout the operation other individuals joined and left the study at different times. Therefore, it was necessary for some briefings to take place on an ad hoc basis.

2.5.3 **Diaries**: Crews were randomly assigned subject identification numbers by the co-ordinator, and were issued with the diaries. Since they contained only sufficient pages to cover one return trip and the associated sleep periods, additional diaries were issued to individuals throughout the operation. A central collection/return point was established for the distribution of the diaries.

2.5.4 **Psions**: A total of 12 Psion computers were sent to Indonesia. Three Psions were installed on each of the three aircraft, with the final three being provided as backup, in the event of one of the others failing. Individuals were asked, when possible, to complete the tests on the same Psion during any one flight, so that data from any individual for a particular flight could be contained on one computer.

2.5.5 During the study it was necessary to replace two of the Psions. One computer became unusable due to problems with the screen; it was not possible to run the test session on the other.

2.5.6 **Activity monitors**: The number of individuals able to wear an activity monitor was limited by the number of available watches (24). They were issued on a 'first come' basis and were often worn by more than one subject during phase I. The limited number of watches meant that it was necessary to transfer them between individuals as subjects left and joined the study.

2.5.7 Due to the heat and humidity in Indonesia, it was considered that individuals would not have been prepared to wear the watches for the entire duration of the study. In addition, the watches were not waterproof and could not be worn whilst swimming, showering etc. The instructions given to subjects, therefore, were that they were to wear a watch during sleep and flying duty periods. However, if individuals were willing to wear the watch at other times, they were encouraged to do so.

2.5.8 The link between the three aspects of the study was achieved through the use of subject numbers and information recorded in the diary. As stated earlier (2.5.3) subjects were issued with an identification number which was recorded in the front of each diary. The same number was entered on the Psion computer at the start of each test session along with the flight number. It was therefore possible to link information from the two sources.

2.5.9 Similarly, subjects who wore a watch during the study were asked to record the final two digits of the watch serial number in the diary. All actiwatch data files were then identified by the watch serial number and hence could be associated with a subject and individual flights.

3. Statistical Methodology

3.1 Subjective fatigue

3.1.1 Levels of fatigue on the 7-point scale were analysed by unbalanced repeated measures analysis of variance (ANOVA) models, with crew member as the single random factor. The fixed effects that were considered for inclusion in the models were time of day, time within the duty period, the duration in days of the operation, the age of the crew members and the crew size. More details of these factors are given in the following paragraphs of this section. In addition, all 2- and 3-way interactions between these factors were considered. In this, and in all other analyses, post-hoc comparisons between individual means were based on the Newman-Keuls shrinking range test. Significance levels in the tables and figures refer to comparisons with the highest or lowest value and are indicated by * ($p < .05$), ** ($p < .01$) and *** ($p < .001$).

3.1.2 The analyses were generally carried out separately for the 3 legs of the operation. However, where appropriate, the two principal legs, namely the outward leg between Batam and Jeddah and the return from Jeddah to Solo, were included in the same analysis by considering leg as an additional factor. Where interactions between leg and other factors were not significant, results are presented meaned over legs.

3.1.3 Time of day was related to the time of the start of the duty period, and was assigned to one of 12 two-hour blocks, corresponding to the 12 different scheduled start times. Trends in fatigue with time of day were investigated by defining contrasts as sinusoidal functions with periods of 24 hours and 12 hours. The acrophase of the time of day effect (i.e. the time corresponding to the peak value) was calculated from the 24-hour component alone.

3.1.4 For the two main legs, time within duty period took one of 6 values corresponding to the pre-duty assessment, the 1st, 2nd, 3rd and 4th assessments during the flight and the post-flight assessment. Linear and quadratic contrasts between these 6 levels were also considered. For the short leg between Solo and Batam, there were only 3 assessments, including one during the flight.

3.1.5 The duration of the operation was considered either by including week ($n=4$) as an additional factor, or by including day as a covariate. For the purpose of the analysis, the 4 weeks of the operation were defined as starting on the 5th, 12th, 19th and 26th March.

3.1.6 The remaining two factors were crew size (either 2 or 3) and age. Age was included either as a covariate, or as a factor at two levels, corresponding to ages less than, or greater than, 50 years.

3.2 Information from the Psions

3.2.1 Subjective levels of workload and sleepiness, together with the scores from the computer task, were analysed similarly to subjective fatigue. The main difference was that the factor ‘time into duty period’ was replaced by ‘time into flight’. Each output value was assigned to one of 5 levels of this factor, according to the elapsed time from the start of the flight. The levels corresponded to 2-hour periods starting at blocks off.

3.2.2 The factor 'time of day' was defined as for subjective fatigue, with the important difference that it referred to the start of the flight rather than to the start of the duty period.

3.2.3 The single measure of performance reported here is the mean time to a correct response during the 9 minutes of the task. In order to ensure that the assumptions of ANOVA were not violated, times were transformed prior to analysis by the function $\ln(x - 0.14)$, where x was the mean response time in seconds.

3.2.4 Information was not collected from the Psions on the short leg between Solo and Batam. The analysis was therefore limited to the two main legs (BTH-JED and JED-SOC).

3.3 Sleep

3.3.1 ANOVA models were also used to analyse the subjective ratings of the last main sleep period before the start of duty on the two principal legs of the operation. Factors included in the analysis were the time of the start of duty, the duration in days of the operation, the age of the crew members and the crew size. Duty start times were assigned to 12 two-hour divisions, centred on midnight, 02:00, 04:00, etc. local time.

3.3.2 The variables included in this analysis were sleep duration, sleep quality, subjective alertness on retiring, how well rested on awaking, the time between going to bed and falling asleep, and the time between waking up and getting up (lie in time). To ensure homogeneity of variance, a square root transform was applied to the lie in time prior to analysis. An analysis was also carried out on the number and duration of naps, and the time from the end of the last sleep or nap until the start of the duty period.

3.3.3 Recovery sleep was analysed by an ANOVA model that included recovery night (1st, 2nd, 3rd or 4th) as a factor. As a result of this analysis, it was decided to use sleep on the 3rd recovery night as a 'control sleep', for comparison with sleep periods at other times during the schedule.

3.3.4 A separate analysis was carried out on sleep during 30-hour layovers. Those layover periods in Jeddah that lasted between 29 and 31 hours were identified, and the total sleep time, including naps, recorded in the diaries for this period was calculated. Regression models were then used to relate total sleep time to the time of the start of the following duty period. In addition, total sleep time was included as an additional independent variable in the analysis of subjective fatigue (see 3.1.1 above), to determine whether the amount of sleep on layover had a significant influence on subsequent levels of fatigue.

3.4 Activity

3.4.1 Each flight was divided into periods of one hour, starting at 'blocks off', and the total number of 2-minute periods with zero activity was calculated. The average number of such 2-minute periods per flight was then analysed by a fixed-effects ANOVA which included leg (outward or return), time of day (12 2-hour blocks) and hour (1 to 10) as the factors. In order to ensure that the assumptions of ANOVA were not violated, the analysis was carried out on 4th root of the number of periods per flight.

3.4.2 Counts were also made of the number of 10-minute periods of zero activity. However, these were relatively few in number and were not subjected to statistical analysis.

4. Results

4.1 The sample

4.1.1 Of the 53 crew members (26 captains and 27 first officers) who took part in phase I of the Haj operation, 43 completed at least one diary and one Psion test, and 26 also wore an actiwatch for at least some of the some the time they were on duty. The ages of the 42 who participated and gave their age ranged from 30 to 58 years, with a mean of 47.6. Twenty-two were over 50, and seven under 40.

4.1.2 There were 94 completed sleep/duty diaries returned from phase I of the operation, representing an average of over 2 per individual. They included information from a total of 807 main sleep periods and 318 duty periods, including 99 short flights from Solo to Batam, 101 flights from Batam to Jeddah and 103 return flights from Jeddah.

4.1.3 A total of 665 Psion tests were completed, 344 on 103 separate outward flights and 321 on 95 return flights.

4.1.4 Activity data were obtained from 26 subjects during 82 flights, on 42 outward and 40 return flights.

4.2 Sleep before duty

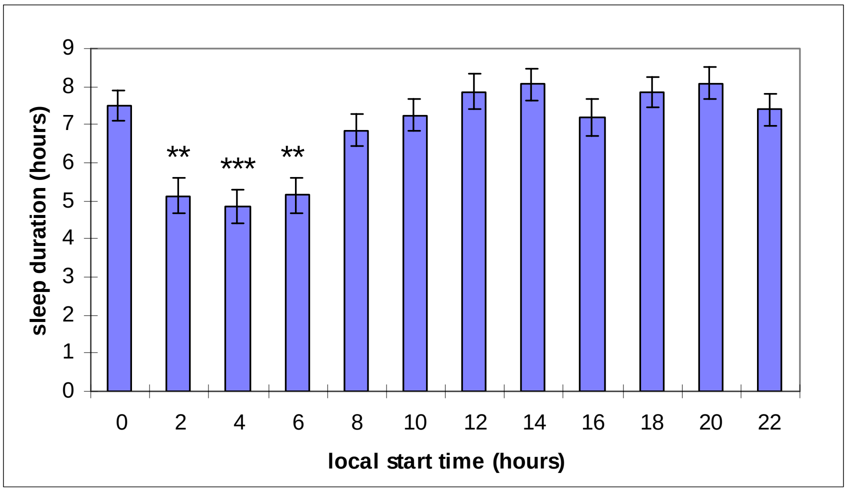

Figure 4-1; Duration of sleep prior to different duty start times

Error bars correspond to ± 1 s.e.m.

4.2.1 There were changes in the reported duration and quality of the main sleep prior to duty periods starting at different times of day. These changes are illustrated in Figures 4-1 and 4-2, which show the means and standard errors over the two legs, corresponding to the layover in Batam prior to the main outward flight and the layover in Jeddah prior to the return flight. There were no significant differences in these variables between the two legs. The duration of sleep was significantly reduced prior to start times between 01:00 and 07:00 ($p < .01$ compared with peak duration prior to midday start times), and the quality of sleep was reduced between 01:00 and 05:00 starts ($p < .05$). At other times, there were no differences from sleep on a 'control' night (for definition, see 3.3.3).

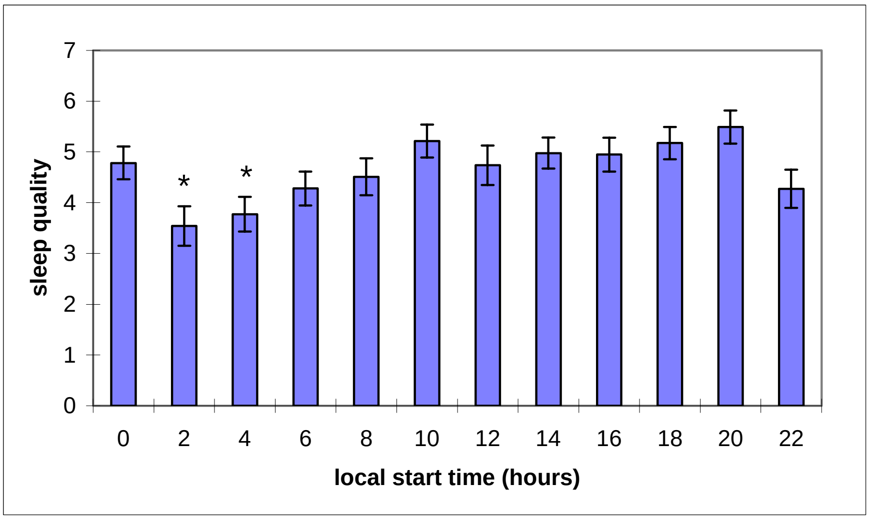

Figure 4-2; Quality of sleep prior to different duty start times

Error bars correspond to ± 1 s.e.m.

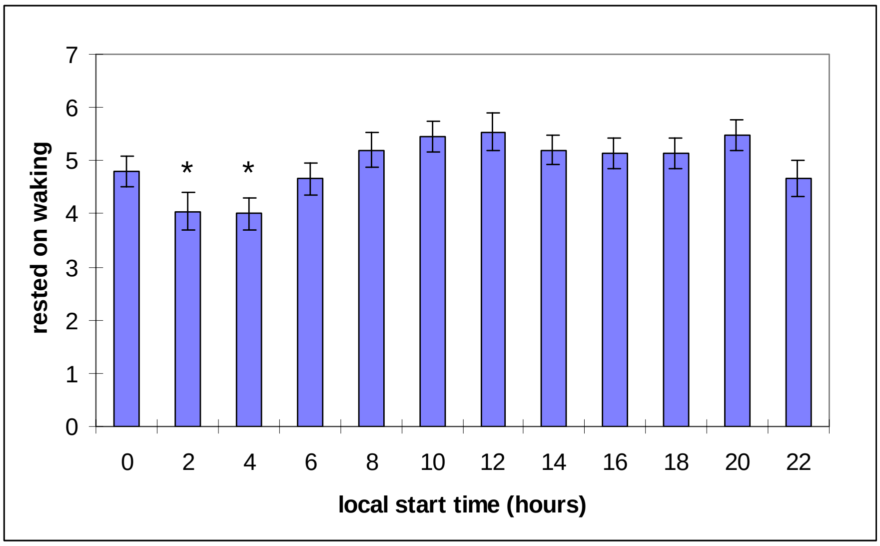

Figure 4-3; Extent to which crews were well rested on waking prior to different duty start times

Error bars correspond to ± 1 s.e.m.

4.2.2 Subjective levels of alertness on going to bed were lower prior to the return leg compared with those prior to the outward leg ($p < .05$). However, the extent to which the crews felt well-rested on waking did not differ between the legs. They generally felt less rested when waking up prior to duties starting between 01:00 and 05:00 (see Figure 4-3), than prior to start times close to midday ($p<.05$).

4.2.3 On average, the crews spent less time in bed prior to falling asleep in Jeddah (35 minutes) than in Batam (50 minutes) ($p< .05$). There was also a residual correlation with subjective alertness: shorter sleep onset times were associated with higher levels of tiredness on going to bed ($p < .05$).

4.2.4 Mean lie-in times were similar in the two locations, but the variation with time of day was quite different ($p < .05$). In Batam, the lie-in time averaged just over an hour and did not vary with start time, while in Jeddah there were large differences ($p < .001$): the mean time spent in bed after waking was 97 minutes before start times between 13:00 and 01:00, compared with only 17 minutes prior to duties starting between 03:00 and 09:00. Individuals felt less well-rested after long lie-in times ($p < .001$).

4.2.5 The frequency of napping was also dependent on the timing of duty. Naps were taken on only 7% of occasions prior to duty periods starting between 05:00 and 15:00, but on 81% of occasion prior to start times between 17:00 and 03:00. The frequency of napping was independent of location, but the duration of the sleeps classified as naps was longer in Jeddah then in Batam. Prior to start times between 17:00 and 03:00, the mean duration of a nap was 2.0 hours in Batam and 3.1 hours in Jeddah ($p < .001$), with the largest increase when the start time was after 23:00.

Duty start time	Outward leg	Return leg	Total
00:00	3	1	4
02:00	4	2	6
04:00	2	1	3
06:00	1	2	3
08:00	0	1	1
10:00	0	2	2
12:00	0	0	0
14:00	0	4	4
16:00	0	7	7
18:00	1	4	5
20:00	3	9	12
22:00	4	0	4

Table 4-1; Number of inflight naps during flights starting at different times of day

4.2.6 A total of 51 inflight naps were reported by the aircrew, of mean duration 47 minutes. There were more on the return leg than on the outward leg (33 out of 102 flights, compared with 18 out of 105, $\chi_1^2 = 6.5$, $p < .05$). The number of naps during flights at different times of day is shown in Table 4-1. A large majority (92%) of the naps were initiated between 2 and 5 hours after the start of the duty period.

4.3 Sleep on 30-hour layovers

4.3.1 The average amount of sleep, including naps, that the crews reported achieving during a 30-hour layover in Jeddah was 11.4 hours. Total sleep time followed a diurnal rhythm related to the timing of the layover ($p < .05$), with a difference of approximately 3 hours sleep between the most favourable and the least favourable times. The total amount of sleep on layover is shown in Figure 4-4, plotted against the start time of the following duty period. The trend line in the figure corresponds to the best fitting sinusoid. The peak of the rhythm occurred when the layover period started around midnight and the start of duty on the return leg was close to 08:00.

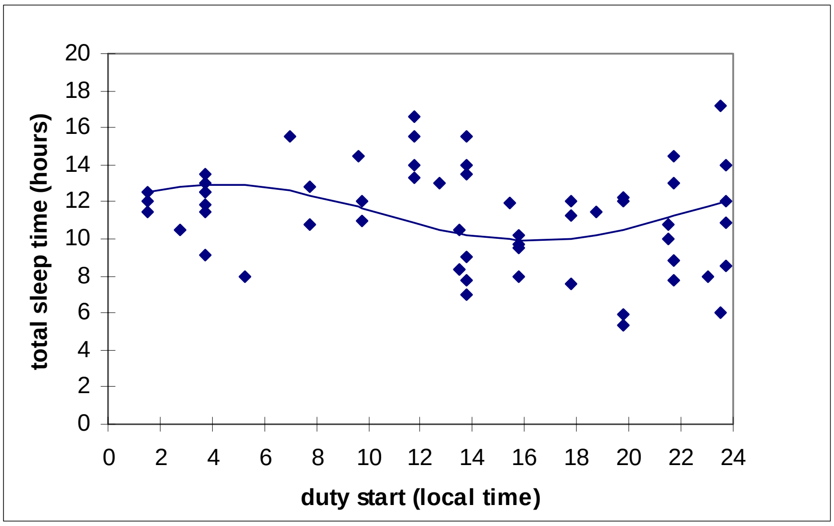

Figure 4-4; Total sleep time during 30-hour layovers at different times of day

The trend line corresponds to the best sinusoidal fit (see text)

4.3.2 There were 3 occasions when the total sleep time on layover did not exceed 6 hours. In all 3 cases, the aircrew reported lying in bed for long periods during the night without sleeping. One individual lay in bed for 4 hours before eventually getting to sleep, while another woke up in the night and lay in bed for almost a further 5 hours without getting to sleep. In both cases, the actiwatch data confirmed the poor quality of the sleep.

4.3.3 The total amount of sleep on layover had a strong effect of levels of fatigue during the following duty period ($p < .01$). The size of the effect depended on duty start time, the largest effect occurring for reporting times soon after midnight, when 5 hours extra sleep was worth an extra point on the 7-point fatigue scale.

4.4 Recovery sleep

4.4.1 The mean values for the first, second, third and fourth main sleep periods after the return to Solo are given in Table 4-2. There was no difference in the subjective quality of sleep on the 4 nights, neither were there differences in sleep length, except for the first recovery sleep. In this case, shorter sleep periods were associated entirely with flights returning to Solo in the mid to late morning, so that the first recovery sleep was displaced to a later time than usual.

	1st night	2nd night	3rd night	4th night
alertness before sleep	1.93	■2.86***	3.03***	3.31***
sleep length (hours)	6.40	7.21*	7.34*	7.04
quality	5.17	4.88	5.05	4.78
rested after sleep	4.32	4.93*	5.18**	5.17**

Significance levels: ***p<.001; **p<.01; *p<.05; comparisons with 1st night
■ p<.05 comparison with 4th night

Table 4-2; Sleep on recovery nights

4.4.2 Levels of alertness before the first recovery sleep were lower than on all subsequent nights ($p < .001$), and individuals were not as well rested afterwards as after the second, third and fourth nights ($p < .05$, $p < .01$ and $p < .01$ respectively). Alertness before the second night was still reduced ($p < .05$), but on waking, individuals were as well rested as after subsequent nights.

4.5 Subjective fatigue

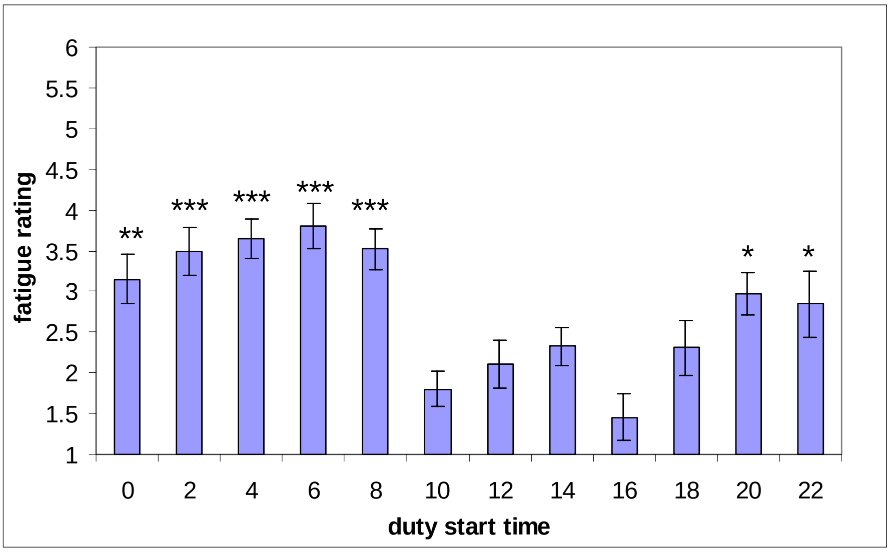

Figure 4-5; Subjective fatigue at different times of day during the first leg

Error bars correspond to ±1 s.e.m.

Results

4.5.1 On the short leg from Solo to Batam, levels of fatigue varied with two main factors, namely the time of the assessment during the duty period (pre-flight, during the flight or post-flight) and the time of day at which the duty period commenced. The effects of these two factors are illustrated in Figures 4-5 and 4-6, where significance levels refer to differences from the time at which the lowest level of fatigue was recorded. The time of day effect could be approximated by a sinusoid with an amplitude (half-range) of 0.86 and an acrophase (highest fatigue) at 02:37 local time.

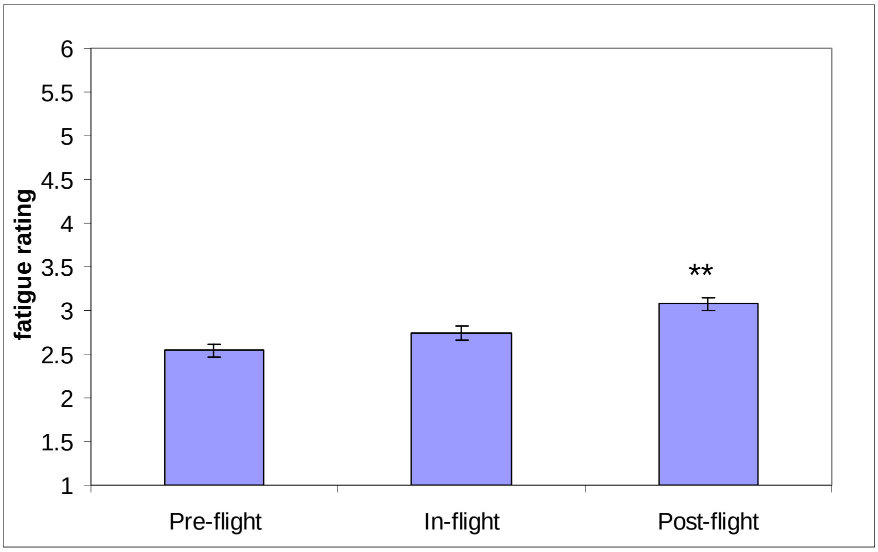

Figure 4-6; Subjective fatigue at different times during the first leg

Error bars correspond to ± 1 s.e.m.

4.5.2 Another way of illustrating the variation in fatigue during this leg of the operation is provided by the 'radar' plot in Figure 4-7. Points at the same clock time correspond to subjective levels of fatigue during duty periods starting at the same time of day. The 3 lines encircling the mid-point correspond to the pre-flight, inflight and post-flight levels. The centre of the plot corresponds to a fatigue level of 1, the perimeter to a level of 6. The time of day effect is represented by the eccentricity of the plot, while the duty period effect is shown by the increase in the area enclosed by the individual lines.

4.5.3 The radar plot showing levels of fatigue during the leg from Batam to Jeddah is given in Figure 4-8. Mean levels of 5 or more on the Samn-Perelli scale were reached during the flight for duties starting between 23:00 and 03:00, and post-flight for duties starting between 13:00 and 03:00.

4.5.4 The duty period effect was well approximated by a linear contrast in the 6 assessments made before, during and after the flight. The diurnal effect was represented by the sum of a 24-hour rhythm of amplitude 0.73 and a 12-hour rhythm of amplitude 0.24. However, the duty period and diurnal effects were not additive, and for this reason figures illustrating the main effects (corresponding to Figures 4-5 and 4-6 for the first leg) are not given here.

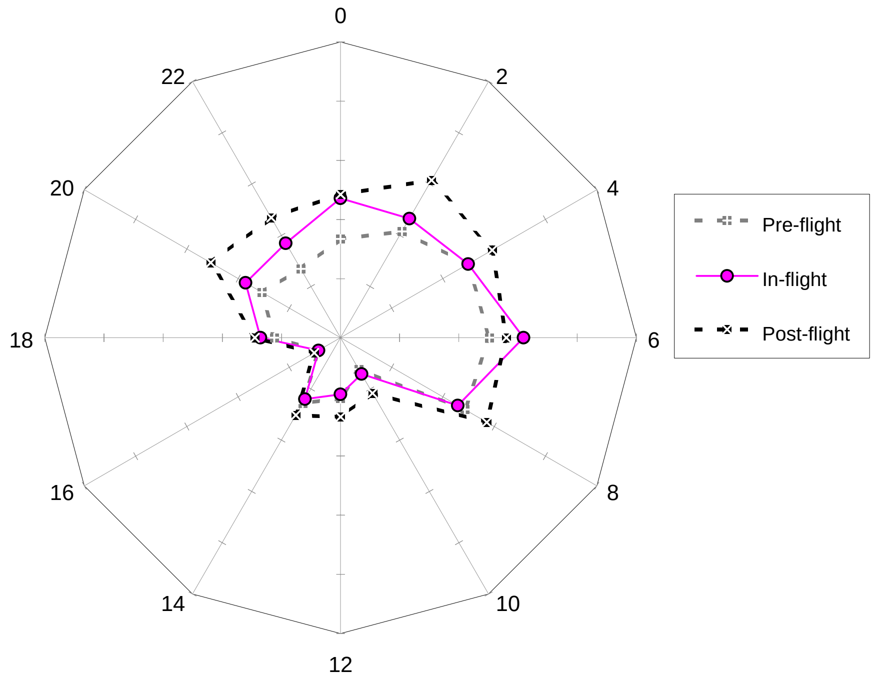

Figure 4-7; Subjective fatigue during the first leg

For explanation see 4.5.2

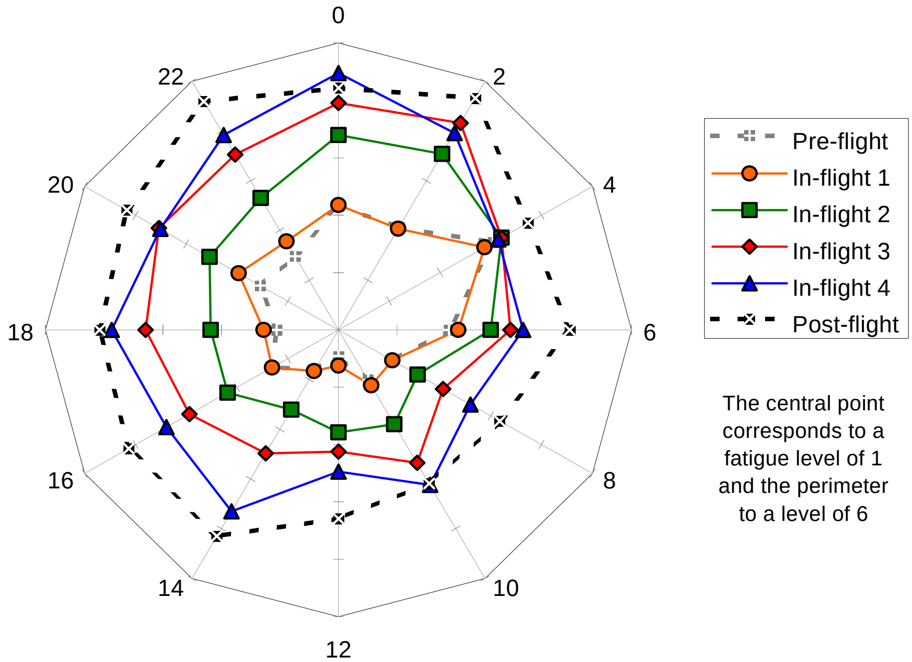

Figure 4-8; Subjective fatigue during the outward leg

4.5.5 The effect of this interaction is demonstrated by the advance of the acrophase of the 24-hour rhythm from 02:26 pre-flight to 23:06 post-flight, where both times refer to local time at the departure airport. The smoothed values given by the fitted model are shown in Figures 4-9 and 4-10.

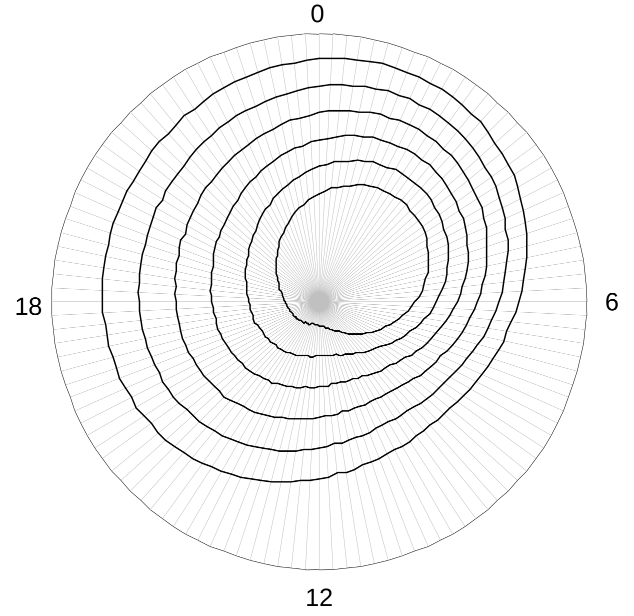

Figure 4-9; Subjective fatigue during the outward leg: fitted values

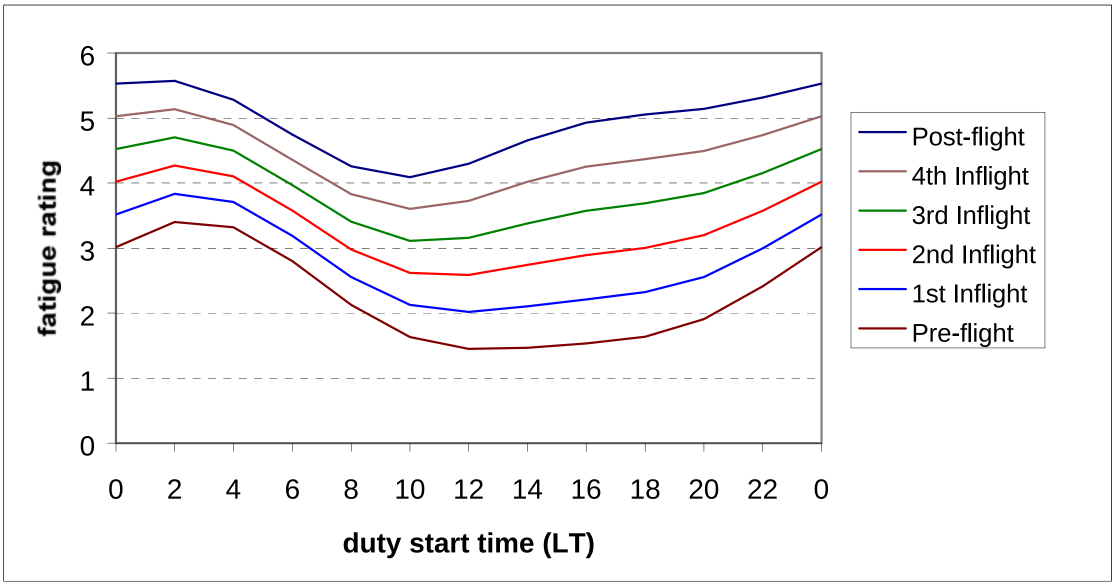

Figure 4-10; Subjective fatigue during the outward leg: fitted values (linear plot)

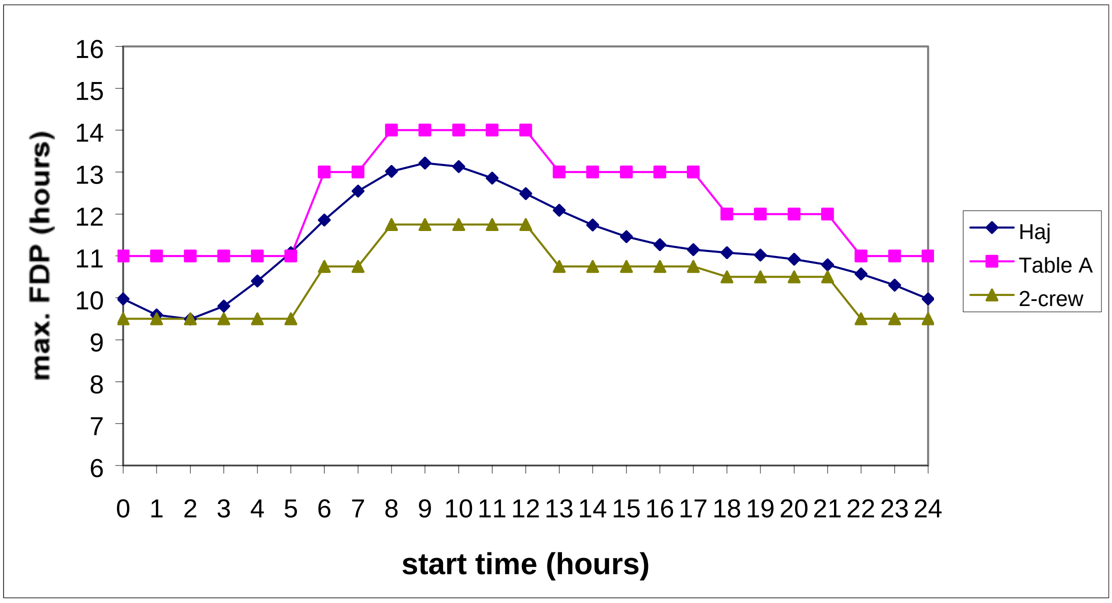

Figure 4-11; Limits on FDPs at different times of day

For explanation, see 4.5.6

4.5.6 Based on the fitted trends in fatigue on the outward leg, the flight duty times required to reach a fatigue level of 5 were calculated as a function of duty start time. These times are shown by the curved line in Figure 4-11, together with the current CAP 371 limits for single sector duty periods for three-crew and two-crew operations.

4.5.7 The radar plot showing levels of fatigue during the return leg from Jeddah to Solo is given in Figure 4-12. Mean fatigue levels of 5 were reached during the flight for duty periods starting between 17:00 and 21:00 and between 23:00 and 01:00 local time. Including the post-flight assessment, the only start times which did not reach a fatigue level of 5 were those between 05:00 and 11:00.

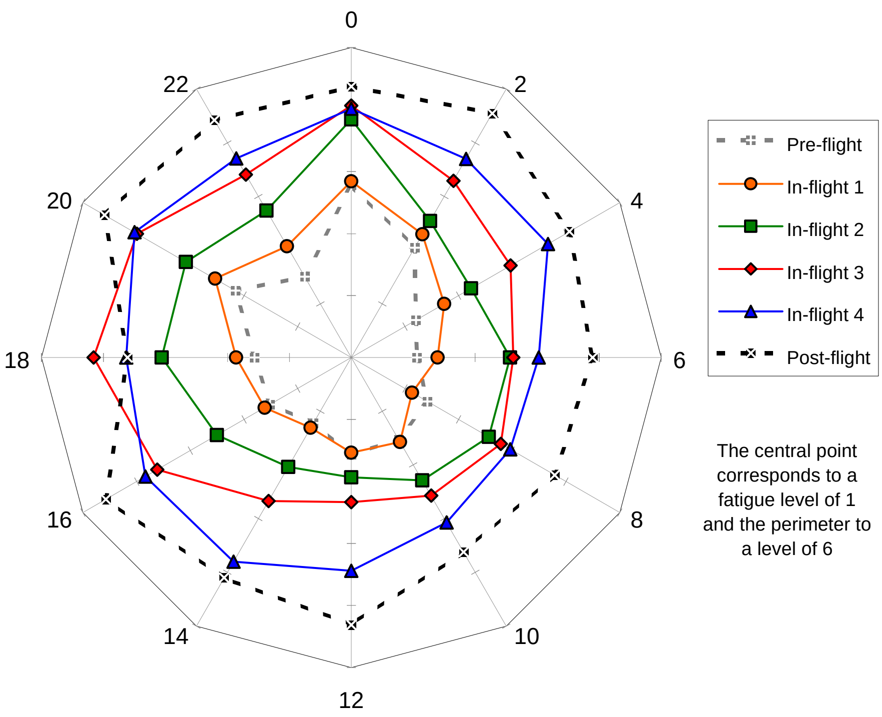

Figure 4-12; Subjective fatigue during the return leg

4.5.8 The time of day and duty period effects are illustrated in Figures 4-13 and 4-14. The effect of the duty period could be well represented by a linear increase averaging 0.54 on the Samn-Perelli scale per assessment, and the time of day effect by a 24-hour rhythm of amplitude 0.55 and acrophase 21:45 Jeddah time.

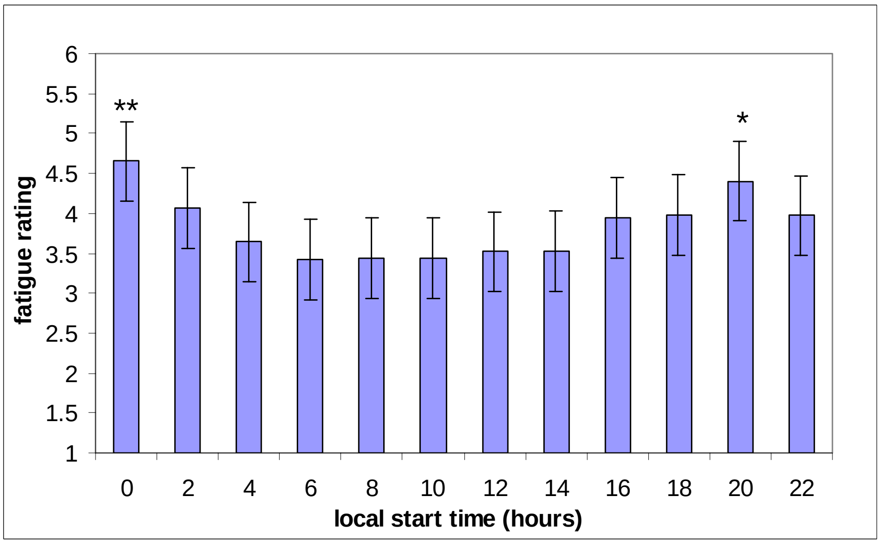

Figure 4-13; Subjective fatigue at different times of day during the return leg

Error bars correspond to ± 1 s.e.m.

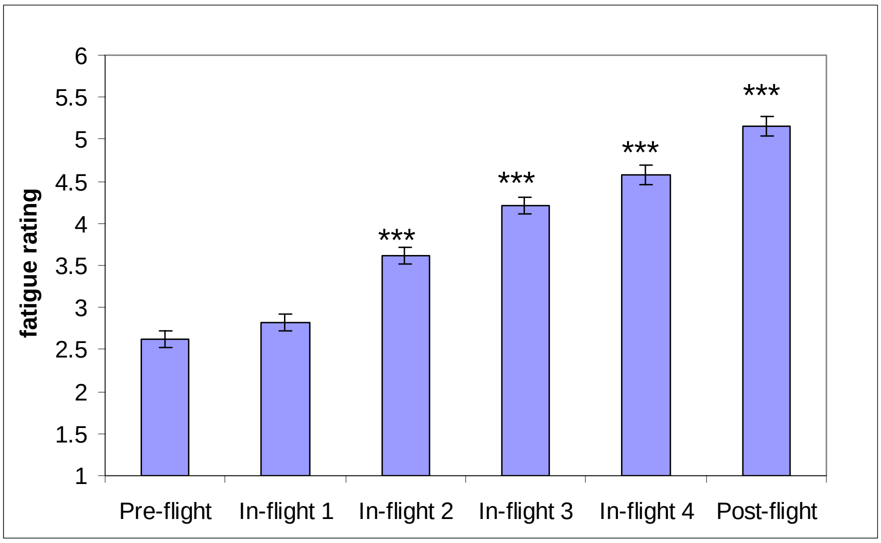

Figure 4-14; Subjective fatigue at different times during the return leg

Error bars correspond to ± 1 s.e.m.

4.5.9 The mean levels of fatigue during the 4 weeks of the operation are shown in Figure 4-15, separately for the 3 legs. The main effect of week was significant in both the first and second legs (both $p < .05$). On the short leg from Solo to Batam, fatigue increased between the 3rd and the 4th weeks ($p < .05$). On the outward leg, the trend was for fatigue to reduce after the first week and to increase on the final week. However, no individual week was associated with significantly different levels of fatigue compared with any other.

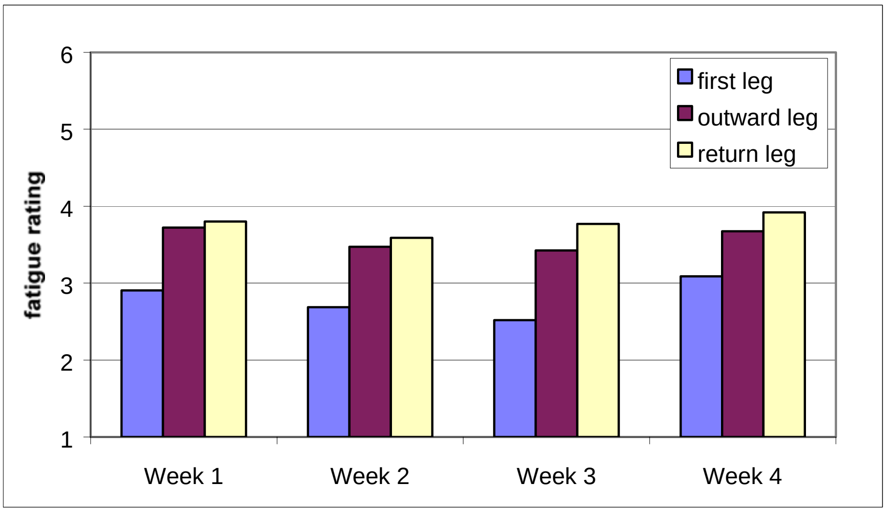

Figure 4-15; Subjective fatigue on consecutive weeks

4.5.10 On the outward leg, almost all duty periods starting between 05:00 and 17:00 were 2-crew operations, while those starting between 17:00 and 05:00 included an extra crew member. Consequently, crew size was strongly confounded with time of day and, possibly as a result, it was not possible to detect an effect of crew size on fatigue. On the return flight, there was much more overlap, and 2-crew operations were associated with an average increase of 0.34 on the fatigue scale ($p < .05$). This increase was independent of time of day or time on duty. The proportion of 2-crew operations on the outward leg (50.3%) was slightly greater than on return (47.5%).

4.5.11 There was no main effect of age on fatigue. However, the increase in fatigue during both long duty periods was much greater among those over 50, and amounted to additional increase of 0.68 on the fatigue scale between the pre-flight and post-flight assessments ($p < .001$). In addition, there was an interaction between age and week on the outward leg. Levels of fatigue were higher amongst the over 50s during the third week of the operation ($p < .05$).

4.6 The performance task

4.6.1 Mean response times on the computer task during the outward leg, as a function of duty start time and time into duty, are shown by the radar plot in Figure 4-16. The analysis indicated that the effects of these two components were additive. The effect due to time into duty (Figure 4-17) represented an increase of approximately 7% in reaction time from the first to the final two-hour period, and was approximated by a linear function of time.

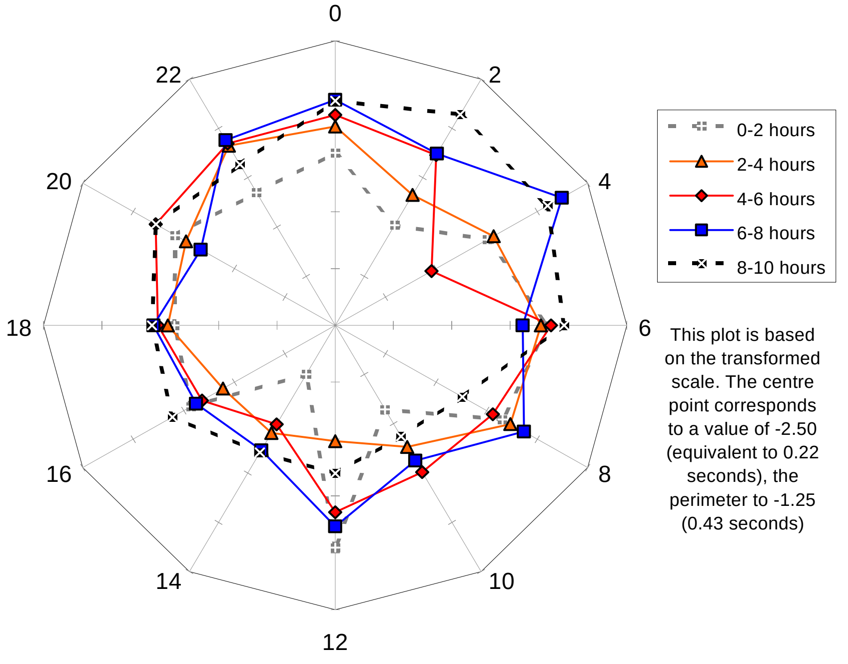

Figure 4-16; Response times on the outward leg

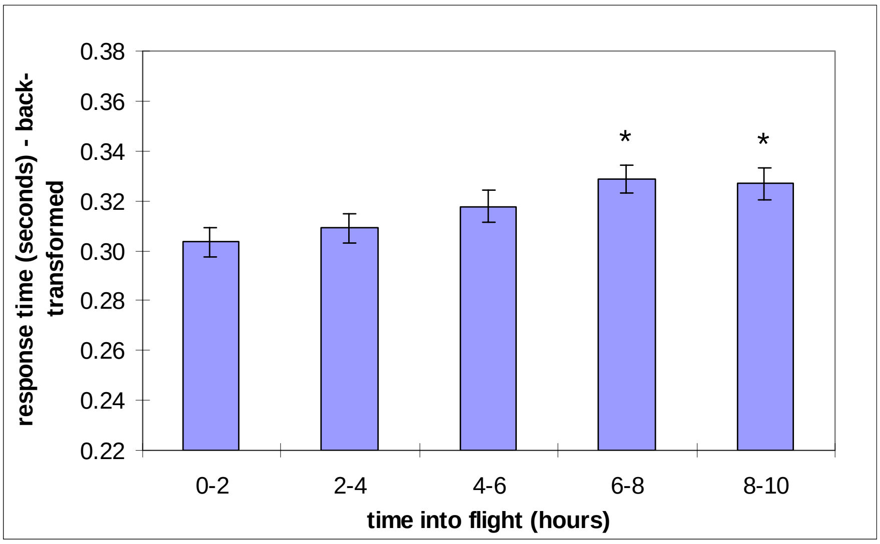

Figure 4-17; Response times at different times during the outward leg

Error bars correspond to ± 1 s.e.m.

4.6.2 The time of day component (Figure 4-18) was approximated by a 24-hour rhythm with an acrophase (longest response times) at a start time of 01:36. The amplitude of the rhythm represented an increase of approximately 14% in the response time at the least favourable, compared with the most favourable, times of day.

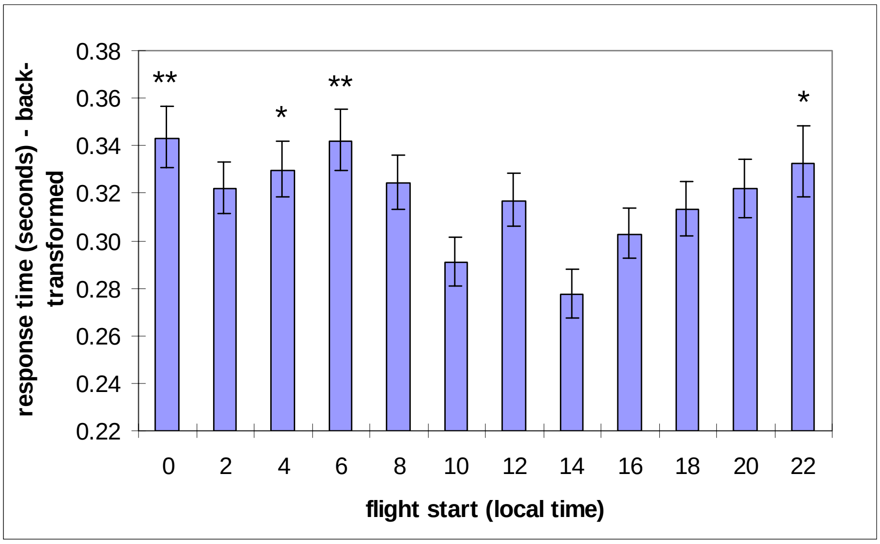

Figure 4-18; Response times at different times of day during the outward leg

Error bars correspond to ± 1 s.e.m.

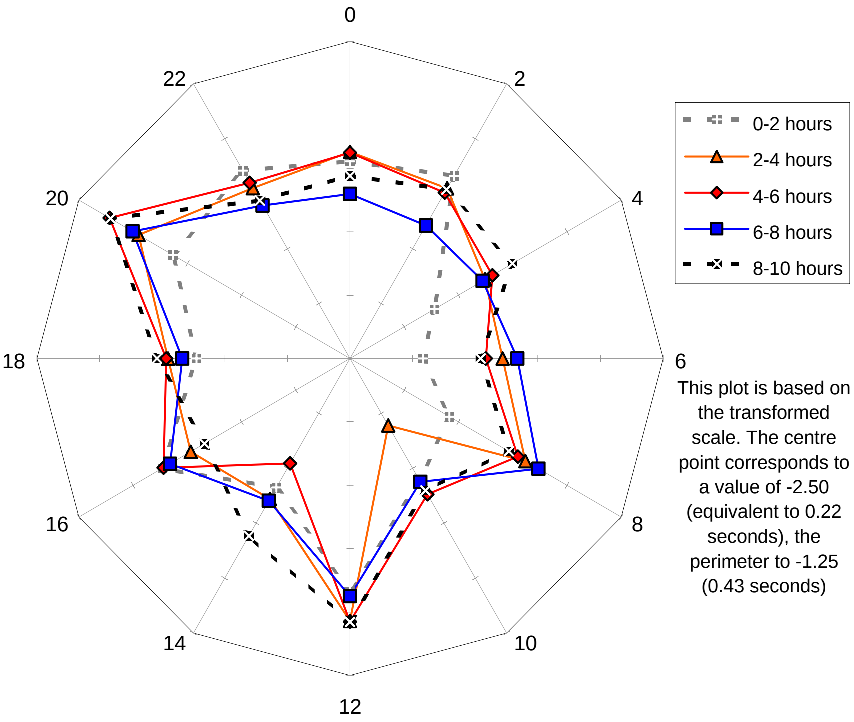

Figure 4-19; Response times on the return leg

4.6.3 Mean response times during the return leg are shown in Figure 4-19. Although there was a 24-hour rhythm ($p < .01$) with an acrophase at 19:32 local time, it was less pronounced than on the outward leg. In addition, the small increase with time on duty was significant only at the 10% level. However, performance deteriorated as the operation continued ($p < .01$), and response times at the end of the first phase were approximately 10% higher than at the start. Mean levels of performance on the return leg were similar to those on the outward leg.

4.6.4 After correcting for the other significant factors, and combining the data from the outward and the return legs, response time was strongly correlated with the subjective evaluation of sleepiness during the previous period ($p <.001$) (see 4.7.1). An increase of one point on the sleepiness scale was associated with an increase of approximately 6% in response time.

4.7 Subjective sleepiness

4.7.1 The radar plot for subjective sleepiness on the outward leg is shown in Figure 4-20. Mean levels exceeded the level 3 (‘sometimes felt rather sleepy’) during all flights taking off between 19:00 and 05:00. The time of day effect was approximated by the sum of a 24-hour rhythm of amplitude 0.50 and a 12-hour rhythm of amplitude 0.25, and the time into flight effect by a linear function of time. However, these two effects were not additive.

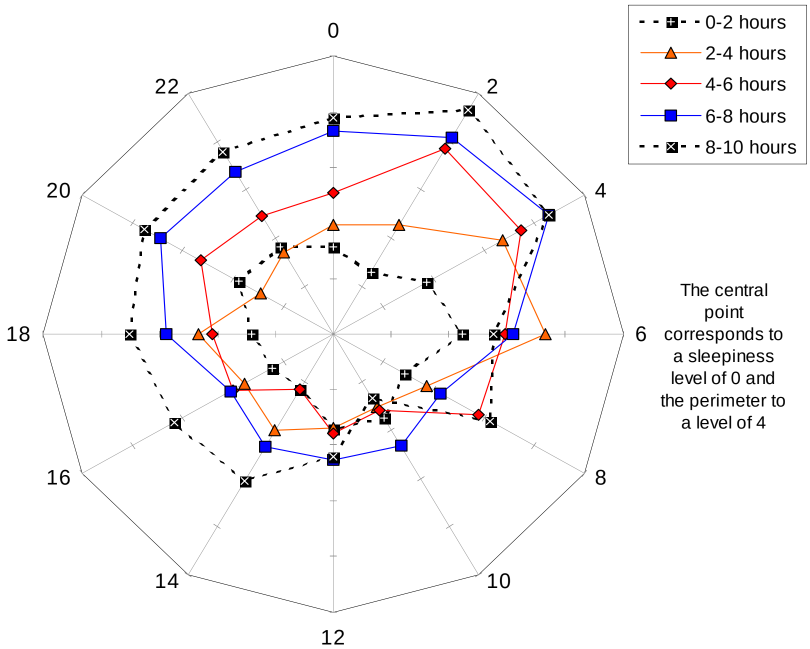

Figure 4-20; Subjective sleepiness on the outward leg

4.7.2 The best fit was constructed by including in the model smoothly changing functions of the diurnal rhythm with time into flight (Figure 4-21). This suggested that the peak levels of alertness at the start of the flight were associated with take-off times between 13:00 and 15:00, while peak levels of sleepiness were associated with take-off times between 06:00 and 08:00. At the end of the flight, highest levels of sleepiness tended to occur on flights that had started close to midnight.

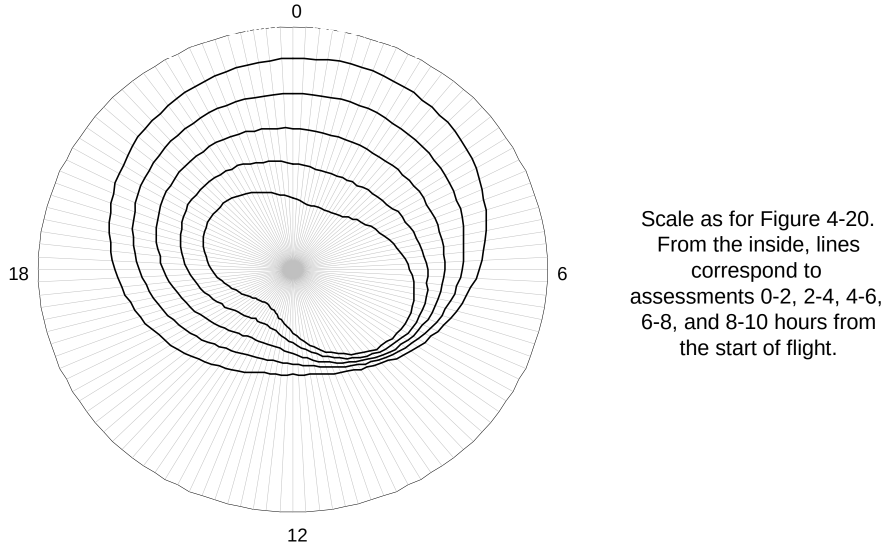

Figure 4-21; Subjective sleepiness on the outward leg: fitted values

Results

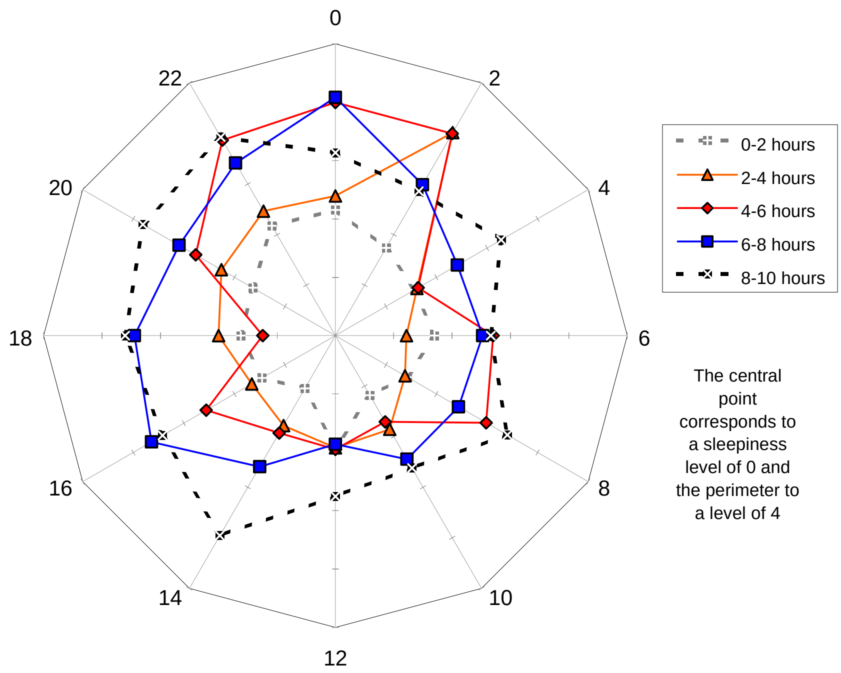

Figure 4-22; Subjective sleepiness on the return leg

4.7.3 The radar plot for the sleepiness levels on the return leg is shown in Figure 4-22. Sleepiness levels corresponding to different times into the flight and to different take-off times are shown in Figures 4-23 and 4-24. Mean levels greater than 3 (see 4.7.1) were reached at some stage during flights starting between 19:00 and 03:00. Sleepiness increased linearly throughout the flight ($p < .001$), and followed a diurnal rhythm of amplitude 0.40, with highest levels of sleepiness occurring during flights starting around 22:00 local time. These two effects were additive.

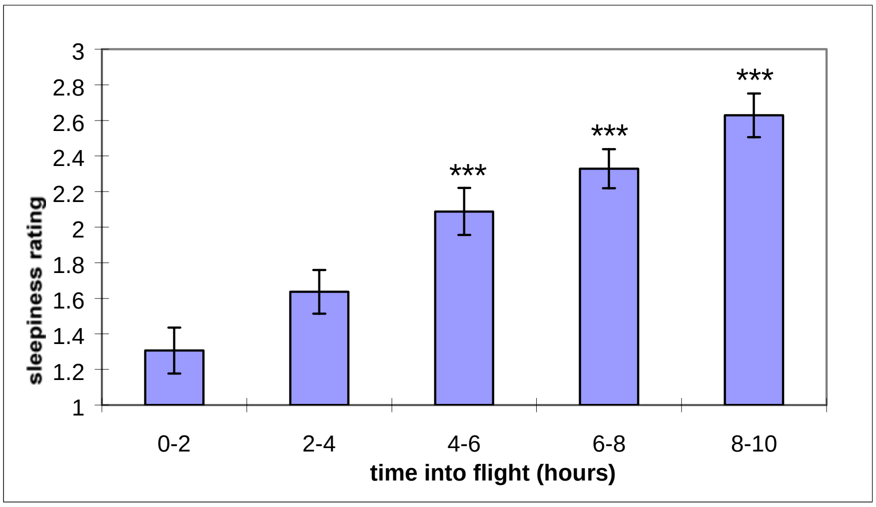

Figure 4-23; Subjective sleepiness at different times during the return leg

Error bars correspond to ± 1 s.e.m.

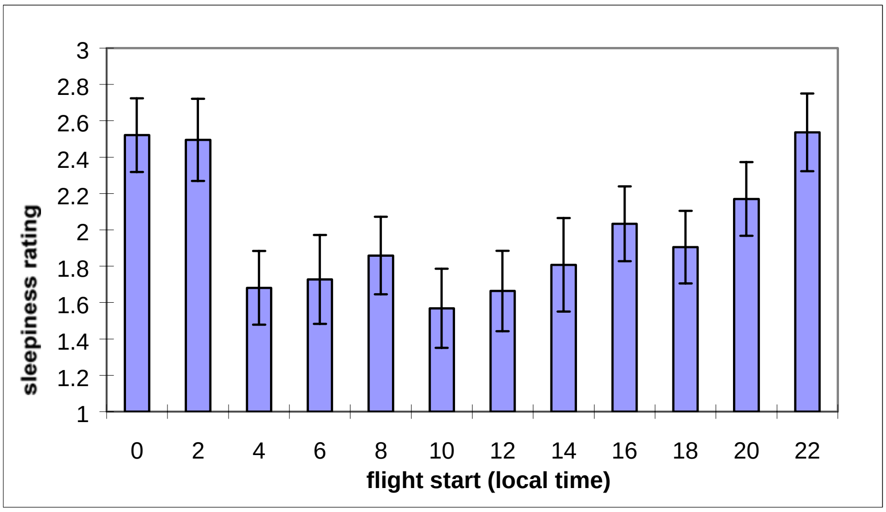

Figure 4-24; Subjective sleepiness at different times of day during the return leg

Error bars correspond to ± 1 s.e.m.

4.7.4 Throughout both the outward and the return flights, levels of sleepiness were strongly correlated with the subjective assessments of workload ($p < .001$). A reduction of one point on the workload scale was associated with an increase of 0.20 on the sleepiness scale.

4.8 Subjective workload

4.8.1 On both the outward and the return legs, the subjective level of workload reduced during the first 4 hours of the flight ($p < .001$), and then stabilised at a level of 3.6, approximately mid-way between 'moderate' and 'low'. There were small, but significant, diurnal effects ($p < .05$), with lowest levels on outward flights starting at 05:00 and on return flights starting at 14:00. However, mean levels of workload were similar on the two flights.

4.8.2 The perceived level of workload was lowest during the second half of the operation ($p < .01$).

4.9 Activity

4.9.1 The numbers of 2-minute periods of inactivity per hour, occurring at different start times, are shown in Table 4-3. The values in the table are raw means, whereas the significance levels refer to an analysis based on transformed data.

Results

Start time	Number of 2-minute periods of inactivity per hour during: Outward leg	Return leg
00:00	0.47	0.60
02:00	1.24	0.86
04:00	1.63*	0.19
06:00	0.60	0.31
08:00	0.25	2.40**
10:00	0.22	0.69
12:00	0.10	0.72
14:00	0.28	2.01*
16:00	0.83	2.81*
18:00	0.35	1.31
20:00	1.20	1.10
22:00	1.67	0.94

Table 4-3; Numbers of 2-minute periods of inactivity per hour

4.9.2 Periods of inactivity were more frequent on the return flight than on the outward flight (1.16 per hour, compared with 0.74, $p < .05$). On the outward flight, inactivity varied with time of day ($p < .01$), with a peak corresponding to flights starting at midnight local time. The time of day effect was also strong on the return flight ($p < .001$), but it was not sinusoidal.

4.9.3 On the outward flight, there were 22 periods of inactivity lasting for at least 10 minutes, of which 11 did not occur within a period identified by the crew member as a rest period or a nap. All these were on flights that started between 19:00 and 05:00 local time. There were 72 similar periods on the return flight, of which 24 did not fall in a rest period or correspond to a recorded nap. There was no obvious diurnal pattern in the timing of these periods.

5. Discussion

5.1 The outward leg

5.1.1 The alertness of the aircrew on the outward flight was strongly influenced by the circadian rhythm or ‘body clock’. This was evident both from the diurnal variation in the subjective assessments and in performance, and from the interaction between time of day and time on duty.

5.1.2 The lowest point in the circadian rhythm of alertness normally occurs around 05:00 or 06:00, which benefits those duty periods starting in mid-morning, as the increase in fatigue associated with time on task is reduced by the upward circadian trend. However, for duty periods starting in the early evening, the adverse combination of both factors can lead to a rapid reduction in alertness.

5.1.3 These trends are seen clearly in these results, especially in subjective sleepiness (Figures 4-18 and 4-19). The clear implication is that, at favourable times of day, 2-crew operations involving FDPs of 12 hours are acceptable, and this is consistent with earlier recommendations [6]. The evidence from this study is that, on the outward leg, duty periods starting between 06:00 and 15:00 can be managed by a crew of two.

5.1.4 At some other times of day, however, there were indications that fatigue had reached a level that could give cause for concern. At the worst times, subjective levels of fatigue exceeded 5 on the Samn-Perelli scale, response times on the computer task were increased by more than 15%, and mean levels of sleepiness were above the mid-point on the scale.

5.1.5 The significance of level 5 on the Samn-Perelli scale is that it corresponds to an alertness state defined by the originators of the scale as ‘Fatigue Class II’. On the basis of inflight studies, they categorised this state as ‘Moderate to severe fatigue. Some performance impairment probably occurring. Flying duty permissible but not recommended.’ Fitted trends in alertness on the outward leg exceeded the level 5 at the end of the flight during duty periods starting between 19:00 and 04:00.

5.1.6 The performance task in this study has been converted from a PC-based version of the same task, which has been used extensively in laboratory experiments at the sleep/performance laboratory in Farnborough. A recent re-analysis of a series of experiments over several years, has enabled response times on this task to be related, via the CHS Alertness Model, to effects of alcohol on performance [7]. This relationship between the effects of fatigue and alcohol on performance has been described elsewhere [8]. The results suggested that a 15% increase in response time was roughly equivalent to blood alcohol levels close to the current UK drink-drive limit. However, the extrapolation to the current study must be made with caution, in view of the different environment in which the task was carried out.

5.1.7 The mid-point of the sleepiness scale corresponds to the statement ‘sometimes felt rather sleepy’. When this level was exceeded, a substantial number of the crews were reporting sleepiness in the next category, namely ‘sometimes struggling to stay awake’.

5.1.8 The adverse combination of these three variables (fatigue, performance and sleepiness) would therefore strongly suggest that the crews were often struggling to remain alert during duty periods starting in the evening and early morning. In this context, it is surprising that the frequency of napping is relatively low. The possibility that the greater use of inflight napping might alleviate the problem is discussed below (Section 5.4).

5.2 The return leg

5.2.1 The impact of the circadian rhythm on the alertness of the crews was less obvious on the return leg. This was evident from both the lower amplitude of the diurnal effects and the absence of any interaction between the effects of time of day and time into flight.

5.2.2 The smaller diurnal rhythm may have been at least partially explained by differential adaptation of individuals to the 4-hour westward transition. The average change in the rhythm during the layover period, based on subjective alertness at the start of the two flights, was just over an hour, which is consistent with mathematical models of circadian rhythms [9]. However, it is possible that differences between individuals have contributed to a blurring of the rhythm.

5.2.3 Differences between individuals were also evident in the amount of sleep achieved during the layover period, and they contributed to differences in levels of fatigue during the return flight. Some of the crews experienced problems obtaining sufficient sleep, particularly when the layover period included only one local night. However, despite a few instances of individuals lying in bed for long periods without sleeping, and the occasional complaint of being awoken by calls to prayer, there was no evidence of any major problem with sleeping conditions in Jeddah. In addition, it is clear from the frequency and duration of napping on layover that crews made every attempt to ensure that they were fully rested prior to departure.

5.2.4 The most likely explanation for the smaller diurnal variation in alertness on the return leg is the frequency of napping during the flight, including many that were unreported, but which were detected by the actiwatches. These naps may have alleviated the build-up in fatigue, particularly at those times of day when the risk was greatest. They may also have reduced the gradual impairment in performance throughout the flight that occurred on the outward flight. The ability to nap during a flight, as part of a heavy crew, is particularly valuable when, as in this case, it has not always been possible to overcome a sleep debt before the start of the flight.

5.2.5 In spite of the increased frequency of napping, there was evidence of high levels of fatigue during flights taking off in the evening and very early morning. Subjective levels of sleepiness exceeded the mid-point of the scale during flights starting between 19:00 and 03:00, and the fitted trend in alertness reached Fatigue Class II (i.e. a value of 5 on the Samn-Perelli scale) when the duty period started between 18:00 and 01:00. In these circumstances, it must be questioned whether the arrangements for napping were adequate.

5.2.6 The acceptability of operating with a minimum crew on any of the return flights is less easy to establish than on the outward flights. However, the evidence from subjective alertness, corrected for the increase in fatigue associated with 2-crew operations, would suggest that unaugmented crews could be considered for FDPs starting between about 04:00 and 11:00 local time. These are favourable times of day on the circadian clock (allowing for a small adaptation) and they correspond to times when the crews will have benefited from two (possibly partial) local nights in Jeddah.

5.3 Rates of working

5.3.1 The rosters were designed to incorporate at least three local nights in Solo between trips. As a result, aircrew were not required to repeat the schedule more than once in 7 days, and sometimes the gap between consecutive trips was longer. Those who completed 3 trips, which was the maximum number during phase I, would therefore have worked approximately 80 hours in a period not shorter than 17 days.

5.3.2 The rates of working were always inside, and sometimes well inside, the rates defined by the Nicholson Curve, which are considered compatible with acceptable patterns of sleep in operations that disturb the circadian clock [10]. Indeed, the evidence from this study strongly suggests that the crews had recovered from the effects of a trip after the second full night back in Solo.

5.3.3 The rapid recovery of the crews was helped by the layovers in Jeddah, which were sufficiently short to limit the adjustment of the circadian rhythm to just over an hour. The most significant problems with adjustment to time-zone transitions are likely to have occurred after the initial journey from the UK to Solo. They may help to explain the somewhat elevated levels of subjective fatigue during the first week of the operation.

5.3.4 There was some evidence that the crews were experiencing greater difficulty sustaining alertness towards the end of the 4-week period, since there was an increase in subjective levels of fatigue and a small deterioration in performance on the computer task. However, it is unlikely that these long-term trends were associated with the demands of the schedule, as they were accompanied by a gradual reduction in the perceived level of workload. It is more probable that the slightly lower levels of alertness were related to a reduction in the demands of the work on successive trips, associated perhaps with an increasing familiarity with the routine of the operation.

5.4 Inflight rest

5.4.1 The role played by inflight rest in reducing the build-up of fatigue in this operation, particularly on the return leg, has already been noted. The low frequency of napping on the outward leg is surprising in view of the high levels of fatigue experienced on some of the flights, and a greater use of inflight rest would have been beneficial. However, even the increased napping on the return leg was not able to overcome the problems of fatigue.

5.4.2 An important conclusion of this study, therefore, is that the crews require more sleep on at least some of the trips. It is possible that some of this sleep could be obtained prior to the start of a flight. However, the substantial use by the crews of napping and longer periods of sleep, especially prior to the late departures, would suggest that it is unlikely that much improvement could be achieved by that approach.

5.4.3 The most promising countermeasure would be to ensure that inflight sleep was more effective. Indeed, as the NASA study showed [11], relatively short naps taken early in a flight can ensure that alertness is maintained at acceptable levels. To be most beneficial, the organisation of rest periods should be carefully planned at the start of the flight, and crews should attempt to sleep during at least part of their rest period. Strategies will be most beneficial if naps are taken in anticipation of the development of fatigue, rather than after a degree of sleepiness has already set in. It is also important to allow sufficient time between waking up and resuming duty, to avoid the effects of 'sleep inertia'.

5.4.4 The diaries have not provided very clear information on the planning and organisation of naps during this study, and some individuals may have incorrectly identified, or failed to identify, some rest periods and naps. However, it is likely, based on the activity data, that additional short unplanned naps were taken on many occasions, and that some of these were not during a rest period. Indeed, some reported naps were apparently taken on two-crew operations. There is, therefore, good reason to suppose that more effective use could be made of inflight rest, with emphasis on the careful planning of sleep on those flights, that have already been identified, where levels of alertness are most difficult to maintain.

5.4.5 It became clear, from anecdotal stories after the data collection phase of the study, that even when 3 crew members were carried, no changing of seats took place on the aircraft. In these circumstances it is difficult to see the benefit provided by the third crew member, although clearly the crews felt more able to take a nap when he was present. A sleep strategy can be effective only if the crews are able to rotate through the seats, implying that each crew member should be able to operate in both the right-hand and left-hand seats.

5.4.6 The question arises whether sufficient rest can be obtained in a seat on the flight deck. It has already been shown that the bunks fitted by British Airways on their 747-400 fleet can, in most circumstances, provide the crews with an environment in which they can obtain adequate sleep [12]. In the first phase of the Haj operation, bunks are likely to be most beneficial on the return leg, where the frequency of napping was high, but crews could not always overcome their fatigue. Indeed, it is possible that levels of fatigue could only be reduced further with the use of bunks.

5.4.7 A direct comparison between sleep in a bunk and a seat has not been carried out. If the Haj operation is repeated in 1999, we would recommend that bunks are fitted and used on many of the flights that have been identified as difficult, and that the opportunity is taken to carry out a comparison between the advantages of sleeping in a bunk, and in a seat in the cockpit. The standard of comfort provided by the third seat would need to be addressed to ensure that it is conducive to sleep of adequate quality. In particular, it is recommended that it can recline to an angle of at least 40°[13].

5.5 Implications for flight time limitations

5.5.1 The results of this study have implications beyond the Haj operation itself for the more general issues of flight time limitations. In particular, the repetition of the same pattern of duty at 12 equally spaced times of day has enabled a direct comparison to be made between the build-up in fatigue and the single-sector limits in Table A of CAP 371. This comparison has been based on the trends in fatigue on the outward trip, since it is reasonable to assume that, at that stage, the majority of the crews were adapted to local time.

5.5.2 The results of the Haj operation suggest that, with the single exception of duty periods starting between 05:00 and 05:59, the limits in Table A correspond to fatigue levels in excess of 5 on the Samn-Perelli scale. The times when differences from Table A are most prominent are in afternoon between 16:00 and 17:59 and in the early morning between 01:00 and 02:59.

5.5.3 Of course, a direct comparison with Table A is strictly valid only for operations where the same conditions apply as in the Haj, i.e. long single sectors. Moreover, the outward trip contained a mix of 2 and 3-crew operations, and the large majority of duties starting between 08:00 and 16:00 involved only a 2-man crew. However, there was considerable napping on the overnight flights, which would have helped to reduce levels of fatigue.

5.5.4 Even allowing for the extra napping on the flight deck overnight, the duty limits derived from the Haj results differ by nearly 4 hours between the most favourable start times (09:00 to 10:00) and the least favourable (01:00 to 02:00). They strongly support the view that unaugmented duty overnight should not exceed 10 hours. They also suggest that 12 hours is acceptable for 2-crew operations during the day, and perhaps even 13 hours at the most favourable times, although this would require confirmation from other studies.

5.5.5 The pattern of alertness during the return trip indicated that the crews had adapted by just over an hour during the 30-hour layover. Whereas CAP 371 would have treated these crews as unadjusted, they could more reasonably have been regarded as adjusted to a notional point one hour west of their point of departure. The duty limits that such an assumption would impose would represent much more accurately their ability to sustain levels of alertness on the return flight.

The concept of a ‘notional point of adaptation’ is one that could be considered in other situations, particularly after short layovers following a westward flight. However, problems with time-zone transitions arise not just from the shift in the body clock relative to local time, but also from the disruption of sleep, particularly, but not exclusively, after an eastward flight. Any rule based on partial adaptation would therefore need to be applied with care, and on a selected basis.

6. Conclusions

6.1 The evidence from the subjective evaluation of fatigue and sleepiness, together with the results from the computer task, suggests that the crews were struggling to remain alert during some of the flights. The most difficult times were towards the end of duty periods starting between 19:00 and 04:00 local time on the outward leg, and between 18:00 and 01:00 on the return leg.

6.2 At other times of day, the problems with fatigue were much less severe. The indications were that duties starting between 06:00 and 15:00 local time on the outward leg, and between 04:00 and 11:00 on return, could be managed by a minimum flight crew.

6.3 Crews generally slept well on the night before a flight, and they made considerable use of naps later in the day prior to an evening or an early morning departure. The main difficulty in Jeddah was obtaining sufficient sleep during a 30-hour layover that included only one local night. However, there was little evidence of problems with the hotel accommodation.

6.4 There were many instances of inflight napping, particularly on the return leg, which helped to moderate the development of fatigue. However, the amount of sleep that the crews obtained in flight was insufficient to sustain levels of alertness at the most critical times of day. Better quality rest would have been achieved if crews had been able to rotate through either the third seat or, preferably, through a bunk.

6.5 There was very little evidence of much disruption of the circadian rhythm. Individuals generally adapted by less than 1.5 hours to the 4-hour time-zone change in Jeddah, prior to their return.

6.6 Recovery from the trip was complete after the second night in Solo. Rates of working were sufficiently low to prevent the development of cumulative fatigue. However, levels of alertness reduced slightly over the four weeks of the operation, associated perhaps with an increasing familiarity with the routine of the operation.

7. Recommendations

7.1 If this operation is repeated in 1999, some action is required to ensure that the development of fatigue is kept to acceptable levels. The most promising approach would be to establish a systematic procedure for the scheduling of naps during duty periods at the most critical times of the day or night. This procedure should ensure that naps are taken in anticipation of the development of fatigue, rather than after some level of sleepiness has already become established. To achieve this, it is essential that crew rotation is implemented, and that all 3 crew members are able to operate in either the right or left-hand seat.

7.2 In addition, the quality of the conditions for sleeping needs to be addressed. The third seat should be sufficiently comfortable to provide conditions that are conducive to sleep, and should recline to at least 40°. In addition, it may be necessary to provide bunks on some of the most fatiguing flights. As a first step, therefore, we would recommend that this study is repeated during the following Haj, with the aim of investigating the additional benefit conferred by sleeping in a bunk, compared with sleeping in an aircrew seat. The results could have important implications beyond the Haj, and could help establish reasonable limits for augmented operations, where full bunk facilities are not provided.

7.3 This study has clarified some more general issues related to flight time limitations. Based on these results, supported by previous research, we would recommend that unaugmented flight duty periods overnight should not exceed 10 hours. A maximum of 12 hours is permissible for two-crew operations during the day, while the possibility of extending this by one hour at the most favourable times of day requires further verification. Flight duty limits based on a 'notional point of adaptation', should be considered on an individual basis to replace the unadjusted limits for crews on short layovers.

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