Sleep patterns of aircrew on charter / air haulage routes

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Executive Summary

E.1 Introduction

E.1.1 This report has been prepared for the Safety Regulation Group of the Civil Aviation Authority (CAA) under contracts 7D/S/952 and 7D/S/952/1.

E.1.2 The majority of recent work on the sleep and wakefulness of civil aircrew has concentrated on long haul crews who are subject to disruptions associated with repeated time zone transitions. However, short haul schedules, and particularly those operated by the charter companies, can be equally disruptive. Commercial pressures are increasing the load on the crews, and the charter companies are now undertaking a greater amount of long haul work. The fatigue implications of current schedules that include a mix of long and short haul trips have given some cause for concern.

E.1.3 This sleep log study has been carried out to obtain an overall assessment of the impact of the schedules currently being operated by the charter companies in the UK, including those with a mix of long and short haul, on the sleep and wakefulness of the aircrew. It was extended, at the request of the CAA, to include companies involved in air freight operations.

E.2 Methodology

E.2.1 The design of the logs was similar to that used in a previous study of the sleep patterns of long haul crews. The main part of the log consisted of a sleep diary which the crews were asked to complete before and after each sleep period. The questions asked related to the timing and quality of sleep and to levels of alertness before and after sleep and throughout the previous day. Information on the timing and type of the duty undertaken was also requested.

E.2.2 A total of 580 logs were sent to 18 charter and air haulage companies for distribution to the aircrew. Individual companies received 20, 40 or 60 logs, depending on their size. Two companies received the logs in June 1994, the remainder in June 1995. The completed logs were returned anonymously to the Centre for Human Sciences (CHS).

E.2.3 A three stage approach to the analysis of the logs was adopted. The first stage involved a simple analysis of sleep associated with duty periods at different times of day, irrespective of the previous duty history. The second stage considered the most common patterns of duty, namely those involving consecutive periods of duty at similar times of day, either during the day, overnight, or starting early in the morning ('early starts'). The third stage used an approach based on unbalanced analysis of variance (ANOVA) and regression models to estimate the effect on sleep of such factors as the time of day and the length of the rest period, after correcting for all the other significant factors.

E.3 Results

E.3.1 A total of 175 logs were returned, representing a response rate of 30.2%. The majority of passenger operations involved daytime schedules with a large number of early starts (defined as earlier than 07:00) and some night-time flights. The majority of freight operations involved night work, with frequent periods of two or three consecutive night duties.

E.3.2 When a duty period started before 09:00, the duration of the preceding sleep period was reduced, as the crews did not advance their bedtime to compensate for the early start. The sleep loss amounted to approximately 30 minutes for every hour that the duty period advanced between 09:00 and 05:00. The subjective quality of sleep was reduced for duty periods starting before 07:00. During schedules involving consecutive early starts, the sleep deficit accumulated and levels of alertness tended to deteriorate.

E.3.3 During schedules involving consecutive night duties, the sleep patterns were similar to those of shift workers on the night shift. The duration of daytime sleep was over 2.5 hours less than normal, and crews frequently napped later in the day in preparation for the following duty period. The majority of aircrew took a daytime nap after their final night-time duty. Levels of alertness both before and after this nap were very low, and they remained lower than normal after the first and second recovery nights.

E.3.4 Most of the long haul schedules were passenger flights between the UK and the eastern USA or the Caribbean and did not involve a rapid switch between long and short haul. Levels of alertness on return from a long haul trip did not recover until after the third night.

E.3.5 The factors that affected either the duration or the quality of sleep during these operations included:

a) the time of day,
b) the amount of sleep recently obtained,
c) the duration of the rest period,
d) the amount of time before the start of the next duty period,
e) the previous rate of working,
f) the number of consecutive night duties,
g) the type of the next duty period (flying, standby, etc.).

E.3.6 The factor that had by far the greatest effect on the duration of sleep was the time of day. The mean duration of sleep starting between 21:00 and 01:00 was greater than 7 hours. As the start of sleep was progressively delayed, its duration reduced to a value of 2.46 hours between 17:00 and 18:00. However, there was some evidence of a small secondary peak close to midday. Changes in the quality of sleep with time of day followed a similar pattern.

E.4 Conclusions

E.4.1 Rates of working on some schedules are higher than levels recommended for irregular duty patterns, and give rise to a reduction in the subjective quality of sleep.

E.4.2 The time of day at which sleep is taken is by far the most important influence on the duration and quality of sleep. The best and the longest sleep periods start in the late evening. There is a progressive deterioration from midnight until the early evening, except for a small secondary peak at midday.

E.4.3 Sleep is poor throughout a period of three duties on consecutive nights, with little evidence of adaptation. At least 48 hours are required to complete a full recovery from a period of night flying.

E.4.4 Schedules involving consecutive early starts lead to an accumulating sleep deficit, since aircrew do not advance their bedtime sufficiently to compensate for the early start.

E.4.5 Sleep becomes progressively impaired when the length of time available before the start of duty is less than 10 hours and when the rest period is less than 14 hours. This effect is most severe for daytime sleep.

E.4.6 Two full days and three nights are required to complete the recovery from the trips to the American continent.

E.5 Recommendations

E.5.1 Guidelines for good rostering practice suggested by the results from this study include:

a) limiting the number of consecutive early starts, bearing in mind that sleep becomes progressively impaired when duty starts before 09:00,
b) making provision for recovery sleep after no more than 3 consecutive early starts,
c) limiting the number of consecutive night duties,
d) providing more than the minimum allowable rest period between consecutive night duties,
e) providing sufficient time at the end of a period of consecutive night duties.

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1 Introduction

1.1 Background

1.1.1 Concerns related to aircrew fatigue have tended in recent years to focus on long haul operations, especially with the extended range of modern aircraft and the requirement for augmented crews. The difficulties faced by crews operating mainly short haul, and particularly those on charter operations, are quite different from those of long haul crews. Nevertheless, the increasingly competitive environment is now placing considerable pressure on those operating short as well as long haul.

1.1.2 Short haul operations often involve a mixture of early starts, late night finishes and overnight duties, combined with high rates of working. A more recent development has been the movement of the charter companies into the long haul market, with many flights particularly between the UK and Florida or the Caribbean islands. As a consequence, a number of charter operations now involve a mix of both long and short haul.

1.1.3 While the implications for safety with air haulage are somewhat different from passenger carrying operations, they do include significant amounts of overnight flying. The schedules followed by air haulage operators, therefore, may have potentially serious implications for the development of fatigue.

1.2 Previous studies

1.2.1 In a major study of short haul operations in the US[1], subjective ratings of fatigue increased during schedules lasting for 3 or 4 days. These operations involved early start times with some disruption of the normal pattern of sleep and wakefulness. However, these results may not be directly applicable to operations in the UK, where patterns of working are different.

1.2.2 In 1991, a questionnaire study was conducted into the work, sleep and well being of British charter pilots[2]. The main factors affecting the acceptability of a duty period were the length of the duty period, the cease duty time, and the extent to which the crews were fully rested at the start of the duty period.

1.2.3 A brief analysis of duty rosters from 6 charter companies was carried out in the summer of 1993[3]. The schedules were analysed to determine the extent of any likely disruption and to provide an overall assessment of their implications for aircrew fatigue.

1.2.4 This analysis highlighted potential problems with duty periods overnight that extended frequently beyond 10 hours and sometimes beyond 12 hours. Also, the preceding rest period was often close to, and sometimes below, the 12 hours minimum. There was additional concern expressed at the possible development of short term fatigue during many of the long haul trips that were included in some of the duty schedules.

1.3 Current study

1.3.1 The main recommendation arising from the analysis of the duty rosters was that more information was required on the disruption of sleep associated with the duty patterns. Accordingly we have conducted a sleep log study of aircrew on charter operations, and this study was extended, at the request of the CAA, to include air haulage operations.

1.3.2 The principal aim of the study was to obtain an overall assessment of the impact of different duty schedules on the sleep and wakefulness of aircrew during these types of operation. It was also intended to identify any current operations that may be associated with particular problems.

2 Methods

2.1 Design of the sleep log

2.1.1 The design of the log was similar to that used in a previous study of the sleep patterns of long haul crews[4]. The main pages of the questionnaire are reproduced at Annex A. The principal change from the logs used previously was the inclusion in the duty log of a request for information on the type of duty (whether flying duty, standby, positioning or other duty). In addition, a question relating specifically to jet lag was omitted.

2.1.2 Each log contained a page of brief personal information, a duty schedule report form and approximately 100 pages in the form of a sleep diary. Several blank pages were provided at the end for the aircrew to add any further comments that they considered relevant. The log was ring bound, and of a suitable size (15 cm x 11 cm) to fit inside a pocket.

2.1.3 The main part of the log was the sleep diary, and this consisted of two separate pages of questions which were repeated throughout the book. The first page was designed to be completed before each sleep period, and the second after each sleep period. Sufficient pages were provided to cover a 28 day period, allowing for many naps, and crews were encouraged to continue the diary for as long as possible, including during periods of leave.

2.1.4 The questions in the pre-sleep section related to levels of tiredness experienced during the day and at the end of duty, the overall workload for any duty undertaken and the reasons for retiring at that particular time. The second section was concerned mainly with the timing and quality of the sleep period and levels of alertness on rising.

2.1.5 Crews were instructed to enter details of each planned sleep period, no matter how short or where it was taken. They were also asked to enter unplanned naps retrospectively.

2.1.6 Many of the subjective assessments in the log required the crews to respond by marking a 5 cm line at a point between two extremes, such as 'extremely tired' and 'extremely alert'. For subsequent analysis the distance of the mark along the line was converted to a scale ranging from 0 to 100, and the mean values quoted in this report relate to this scale. The high end of the scale was generally a positive assessment: feeling very alert, very good sleep quality, etc. However, the extreme responses to the question "did you want more or less sleep than you did?" were 0 (much more) and 100 (much less).

2.2 Distribution of the logs

2.2.1 A total of 580 logs were sent to 18 charter and air haulage companies for distribution to the aircrew. Individual companies received 20, 40 or 60 logs, depending on their size. Two companies received the logs in June 1994, the remainder in June 1995.

2.2.2 Arrangements were made for the completed logs to be returned anonymously directly to the CHS.

2.3 Initial processing

2.3.1 As in the long haul study, a considerable amount of time was spent resolving ambiguities and uncertainties in the returned logs. Many of these became apparent through conflicts in the timing of the duty and the sleep periods. In most cases the problem was resolved satisfactorily, but, where difficulties were irreconcilable, the books were excluded from the subsequent analysis.

2.3.2 Another problem arose from the different ways in which some of the aircrew specified multiple sector operations on the duty page. Again, it was usually possible to restore the data to the correct form, but in some cases insufficient information was available.

2.3.3 The aim of the pre-processing was to establish, for each individual log, continuous periods during which all the information appeared to be reliable. This information was then input to the Centre's CRAY YMP-EL computer for subsequent statistical analysis.

2.4 Classification of duty periods

2.4.1 Duty periods were classified into one of four types according to the response of the individual to the relevant question on the duty page. If any part of a duty period was identified as 'flying' then, for the purposes of the analysis, the entire duty period was classified as a flight duty period.

2.4.2 Flight duties were classified as long haul, as opposed to short haul, if the time zone difference between the initial and the destination airport was greater than two hours.

2.4.3 On the basis of an initial analysis of the effect of duty time on sleep, flight duties were further categorized as follows:

- daytime flights (starting after 07:00 and ending before midnight)
- early starts (starting between 05:00 and 07:00)
- night flights (having at least four hours of duty between midnight and 08:00)

This characterization included over 90% of the total short haul flying duty periods.

2.5 Control nights

2.5.1 Where possible, one sleep period was selected as a control for each individual. This control sleep was chosen on a day when the individual was sleeping at home, on the penultimate night before the next duty period. It was chosen as long after the previous duty period as possible and, in all cases, was preceded by 36 hours free of duty.

2.6 Sleep propensity

2.6.1 Following the procedure used previously in the analysis of the long haul logs, sleep propensity throughout the schedules was estimated by the S process[5]. This is a homeostatic process which increases according to a negative exponential rule during periods of wakefulness and reduces under a similar rule during sleep. It was chosen instead of a variable representing sleep balance since it represents more realistically the recuperative value of sleep periods of different length. Throughout a normal sleep-wake pattern, S oscillates between its lowest value on waking and its highest value on falling asleep.

2.6.2 Process S was calculated throughout each period for which the information on sleep was complete, and values corresponding to the start and end of duty, and to the start and end of sleep, were used in the subsequent analysis.

3 Statistical Methodology

3.1 Descriptive statistics

3.1.1 Simple descriptive statistics were obtained for the timing, duration and distribution of the individual flight duty periods. In addition, mean weekly work rates were calculated for each log. All types of duty were included in this calculation.

3.1.2 An initial analysis was carried out of the timing and quality of the last main sleep period prior to flight duty periods starting at different times of day, irrespective of the preceding pattern of sleep and duty. For the purpose of this analysis, the duty start times were divided into 24 separate one hour periods. Changes in sleep prior to different start times were tested against the control sleep using Dunnett's multiple comparison procedure[6].

3.1.3 For the analysis of sleep, it was convenient to distinguish between the main sleep periods and naps. To some extent, the definition of a nap depended on the timing of past and future duty, and on the timing of other sleep taken on the same day. In general a short sleep (less than 3 hours in duration) taken during the day (09:00 - 21:00) was considered to be a nap, although this definition had to be modified during periods of night duty, or during the recovery from a long haul flight.

3.2 Sleep on consecutive days

3.2.1 An analysis was carried out of consecutive sleep periods during a schedule. The schedules included in this analysis were those involving consecutive periods of duty that were either all during the day, all early starts, or all during the night, using the categorization of duty periods described in Section 2.4. In all cases, the consecutive period of duty was preceded by at least one day off, including a normal overnight sleep.

3.2.2 An unbalanced analysis of variance (ANOVA) model was used for the analysis of the sleep variables, in which the factors were subject and sleep period (including the control sleep). Differences between individual sleep periods (first, second, third, etc. in sequence) and the control sleep were tested using Dunnett's method with a pooled error term, and differences among the individual periods themselves were tested using the Newman-Keuls shrinking range procedure[7].

3.2.3 In addition to the analysis of sleep during the schedules themselves, similar analyses were carried out of recovery sleep during the first three nights after a night-time schedule and during the first night after a series of early starts. All schedules involving one or more consecutive nights, or one or more consecutive early starts, were included in this analysis.

3.2.4 An analysis was also carried out of the first three recovery nights following the return flight from America. In this analysis, all flights to the east coast of North America and the Caribbean were included in which the duration of the layover was between 1 and 4 days.

Since a detailed study of sleep patterns during a layover on long haul trips has already been undertaken[8], no similar analysis has been carried out on these schedules.

3.3 ANOVA and regression models

3.3.1 Unbalanced ANOVA models were used to investigate the factors related to the schedules that had a significant influence on subjective measures of sleep and alertness. In these models, subject and any subject interactions were represented as random effects, while the other factors were fixed effects.

3.3.2 The factors that were tested for inclusion in the models were :

a) Time of day at the start of sleep in intervals of either 1 or 2 hours.

b) Sleep propensity as represented by process S, (see Section 2.6), in 8 intervals with divisions at .45, .55, .60, .65, .7, .75 and .8.

c) The length of time until the next period of duty (the time from the start of sleep to the start of the next duty) in 7 categories, with divisions at 4, 6, 8, 10 and 12 hours and one category to cover the case when there was no succeeding duty recorded.

d) Total duration of the rest period (the length of time from the end of the previous duty to the start of the next duty) in 9 categories with divisions at 10, 11, 12, 14, 16, 20, and 30 hours, and one category to cover the case when the rest period was undefined due to the absence in the log of a previous or succeeding duty.

e) The recent disruption to sleep, as measured either by the number (1 - 6) of consecutive duties whose timing would have involved some sleep disruption (i.e. early starts, night duties), or simply by the number of consecutive night duties (0, 1 or more than 1).

f) Work rate, related to the maximum acceptable limits for irregular schedules as defined by the Nicholson Curve[9,10]. This factor was divided into 7 categories according to the difference between the cumulative duty hours at the end of the last duty period and the maximum acceptable limit, with divisions at -10, -5, 0, 5 and 10 hours and one category to cover the case where no previous duty was recorded.

g) The type of the previous duty, in five categories according to whether the next duty was predominantly a flying duty, a stand-by, positioning, or another type of duty, as well as one category for the case when no previous duty was recorded.

3.3.3 Other factors, such as the duration of the next duty, the number of previous consecutive duties and the number of previous consecutive early starts were also considered, but did not contribute significantly to changes in sleep and alertness.

3.3.4 Informal stepwise procedures were used to search for the best fit. Where the organization of the data permitted, interactions between factors were also investigated.

3.3.5 This analysis enabled the effects of the various factors to be calculated in the presence of other significant factors. The mean values for these effects presented in this report have therefore been corrected for the influence of the other effects.

3.3.6 When the factors that contributed significantly to changes in the sleep variables had been identified by this procedure, the next stage was to derive simple representations of the individual contributions of these factors. This was achieved by reducing the degrees of freedom for the various terms using a contrast analysis. For example, changes due to time of day were represented by sine and cosine functions (both first and second harmonics). The resulting models, constituting 'best fits' to the data, are presented here in the form of regression equations.

3.3.7 This method of analysis was applied to all the main sleep variables. For the sake of brevity, we only report here the results relating to sleep length and subjective sleep quality.

3.3.8 The analysis was restricted to the short haul schedules by excluding all logs that included any long haul work.

4 Results : statistical analysis

4.1 General information

4.1.1 Of the 580 logs that were distributed, a total of 175 were returned, representing a response rate of 30.2%. However, no returns were received from 4 of the 18 companies, presumably because they were not distributed to the aircrew by the companies or because the aircrew themselves decided against participation. The response rate from the companies who participated was 39.8%.

4.1.2 The respondents included 100 captains (57.1%) and 70 first officers (40%): the remaining 5 did not identify their position. A total of 45 (25.7%) were involved in air haulage operations.

4.1.3 The sample varied in age between 22 and 61, with a mean of 42.3 ± 8.5 (s.d.). There were 2732 duty periods recorded, of which 2035 (74.5%) were flying duties, representing an average of 15.6 per individual. The aircrew recorded a total of 6780 sleep episodes (mean 38.7) over an average of 35 days.

4.2 Control sleeps

4.2.1 Using the criteria described in Section 2.5, a control sleep was selected from 166 of the 175 completed logs. On average, crew went to bed on the control night at 23:23, fell asleep at 23:49, woke up at 07:53 and got up at 08:27. The mean sleep time was 7.88 hours. They reported that 77% of these sleep periods were undisturbed, while 8% included more than two awakenings. There were no occasions when an individual napped during the day that followed the control sleep.

4.2.2 Subjective levels of alertness increased from 37.2 on going to bed to 56.5 on rising (see Section 2.1.6 for an explanation of the scale of measurement). The mean assessment of sleep quality was 61.2. The mean value of Process S (see Section 2.6) on going to sleep was 0.650, and on waking was 0.110.

4.2.3 The sleep distribution on the control day is shown in Figure 1. The dark shading represents time asleep, while the light shading represents time in bed before, during or after the sleep period.

4.3 Duty schedules

4.3.1 The distribution of the flying duty hours over the 24 hour clock for crews on passenger and freight operations is shown in Figure 2. In order to avoid any ambiguity resulting from time zone transitions, long haul flights were excluded from this analysis. The majority of passenger operations were during the day (only 18% between 22:00 and 06:00), while the majority of air haulage operations were overnight (63% between 22:00 and 06:00).

4.3.2 The distribution of duty start times for the two different types of operation is shown in Figure 3, and the distribution of duty period length in Figure 4. Most cargo duties started in the evening, between 19:00 and 23:00, and the duration of the duty period was bimodal, with peaks at 3 and 10 hours. The majority of passenger operations started in the morning, between 05:00 and 09:00 hours, although there were smaller peaks in the afternoon, between 13:00 and 15:00, and later in the evening. The duration was usually between 6 and 12 hours, with a peak around 8 hours.

4.3.3 The average work rate for aircrew on passenger operations was 34 duty hours per week, compared with 27.5 hours per week for cargo operations (Figure 5). In only two cases was the work rate greater than 45 hours per week. One of these corresponded to a log that was only completed for 6 days and involved approximately 49 hours duty. However, the other individual accumulated almost 105 hours in 16 days, although all the duty periods were during the day.

4.3.4 The distributions of the duration of the rest period prior to each duty period are shown in Figure 6. In passenger operations, over 56% of rest periods were between 12 and 20 hours, with a peak between 17 and 18 hours. For cargo operations, 60% of the rest periods were between 10 and 17 hours, with a peak between 14 and 15 hours.

4.3.5 Of the 175 log books returned, the vast majority were completed by aircrew who flew short haul operations exclusively. However, there were 30 aircrew that were also involved in long haul operations.

4.3.6 Most of the long haul schedules were passenger flights between the UK and the east coast of North America. Apart from a small number of flights within the US, these did not involve a mix of long and short haul operations. Nine logs were completed by aircrew flying long haul cargo operations. Although these operations involved a mix of long and short haul, they usually included at least four days rest during the change-over period.

4.3.7 Night duties tended to be organized in groups of 2, 3 and occasionally 4 duties, separated by at least 2 or 3 days off. There was some mix of day and night duties, but this was relatively rare.

4.3.8 There were frequent examples of groups of consecutive duties that were all early starts, or that were a mixture of early starts and early daytime duties. The majority of early starts occurred singly or in groups of 2 or 3.

4.4 Sleep prior to different start times

4.4.1 In Figure 7, the duration of the last main sleep period is plotted as a function of the duty start time. There was no difference in the duration of sleep prior to duty periods starting between 09:00 and 01:00, nor were there differences compared with sleep on the control night. However, as the start time advanced from 09:00 to 05:00, the duration of sleep reduced by approximately 30 minutes per hour. Over this 4 hour period, the time of rising advanced by 3.37 hours, while bedtime advanced by only 1.57 hours.

4.4.2 The proportion of naps prior to duty periods starting at different times of day is shown in Figure 8. There were no instances of napping prior to duties starting between 04:00 and 14:00. The highest proportion (over 1 in 3 duties) occurred before duties between 21:00 and 01:00.

4.4.3 The quality of sleep prior to a duty period was lower than on the control night when the following duty period started between 02:00 and 07:00 (02:00-03:00 and 04:00-05:00 $p<.001$; 03:00-04:00, $p<.01$; 05:00-06:00 and 06:00-07:00 $p<.05$).

4.5 Consecutive sleep periods on daytime schedules

4.5.1 The means for the main sleep variables during the first 4 days of a consecutive period of daytime duties are given in Table 1. On the first night, bedtime was 19 minutes earlier than on the control night ($p<.01$). Sleep length was significantly shorter prior to daytime duties than it was on the control night ($p<.001$). Also sleep quality was poorer on the first, second and fourth nights ($p<.01$, $p<.01$ and $p<.001$ respectively) than on the control night. Nevertheless, there were no significant differences between the first, second, third or fourth nights, nor evidence of a trend in any of the sleep variables during this period.

4.6 Consecutive sleep periods on night-time schedules

4.6.1 The means for the main sleep variables during the first 3 days of a consecutive period of night-time duties are given in Table 2.

4.6.2 The main sleep period prior to the first night duty was similar to that on the control night. However, 44% of aircrew took a further nap of mean duration 1.72 hours before going on duty.

4.6.3 After the first night duty, the mean bedtime was from 08:16 to 14:42, and sleep was over 2.5 hours shorter than control ($p<.001$). This sleep period was also of poorer quality and post-sleep alertness was lower than the control sleep (both $p<.001$). On 24% of occasions, aircrew took a further nap of mean duration 1.75 hours before their second night duty.

4.6.4 Aircrew reported lower levels of alertness during the day prior to the third night duty than during the previous day ($p<.05$). Sleep prior to the third night was nearly one hour longer than sleep prior to the second night duty. Less than 8% of aircrew took an extra sleep period (mean duration 4.1 hours) before the third night duty.

4.7 Recovery from night-time schedules

4.7.1 The means for the main sleep variables during the recovery from a period of night-time duties are given in Table 3.

4.7.2 At the end of their final night duty, the majority (65%) of aircrew took a daytime nap, starting on average 2 hours after the end of the duty period. The typical bedtime was between 08:05 and 13:03, and the mean duration of the reported sleep period was 4.2 hours. The levels of alertness both before and after this nap were very low, and the quality of sleep was significantly worse than on the control night.

4.7.3 With the single exception of a short sleep onset time on the second night ($p<.05$), sleep on the 3 nights following a night-time schedule was not significantly different from the control night. However, levels of alertness on going to bed were low on both the first ($p<.001$) and second ($p<.01$) nights, and levels of alertness on rising were low after the first and second recovery nights (both $p<.05$ - all comparisons with the control night).

4.7.4 During the recovery period only 2% of aircrew took additional naps.

4.8 Sleep associated with early starts

4.8.1 Means for the various sleep variables for sleep periods preceding 4 consecutive early starts are given in Table 4. The incidence of napping during this period was relatively low, varying between 6.2% before the first duty period and 2.6% before the second.

4.8.2 Sleep prior to the first early start was over 2 hours shorter than on the control night ($p<.001$). The wake up time was advanced by nearly 3 hours ($p<.001$), while the time of going to bed was less than an hour earlier ($p<.01$). On waking, levels of alertness were much reduced compared with the control night ($p<.01$), and the desire for more sleep was much greater ($p<.001$).

4.8.3 Sleep prior to the second and third consecutive early starts was similar to the first night, except for the longer sleep time on the third night ($p<.01$). Nevertheless, sleep on the third night was still over 1.5 hours shorter than on the control night ($p<.001$).

4.8.4 There were only 6 reported instances of 4 consecutive early starts. Levels of alertness on going to bed on the fourth night were lower than on the first night ($p<.05$), and bedtime was later than on all the 3 previous nights ($p<.01$). Despite the shorter duration of sleep compared with the previous night ($p<.05$), the quality of sleep was rated more highly than on nights 2 and 3 ($p<.05$). However, there was no change in the level of alertness and in the desire for more sleep on rising compared with any of the 3 previous nights.

4.9 Recovery from early starts

4.9.1 The mean values for the main sleep variables during the recovery from a schedule involving different numbers of consecutive early starts are given in Table 5. One individual who did not sleep at all on the recovery night after 3 consecutive early starts has been excluded from this analysis.

4.9.2 While the timing of sleep was slightly earlier during the recovery period, this was only significant after a single early start ($p<0.05$). Levels of alertness during the day and on going to bed on the recovery night were lower than on the control night ($p<.001$). On waking the desire for more sleep was greater than control ($p<0.05$, 1 and 3 consecutive early starts).

4.10 Long haul schedules

4.10.1 Of the 153 duty periods classified as long haul (see Paragraph 2.4.2), a large majority (83%) involved flights between the UK and Eastern America or the Caribbean. For most of the flights from the UK to America, duty started between 08:00 and 10:00 local time and ended between 14:00 and 16:00 local time. For the return flights, most duty periods started between 14:00 and 17:00 local time and finished between 05:00 and 08:00.

4.10.2 The duration of the layover for 23% of the trips was between 12 and 20 hours and included one local night. A further 23% involved two local nights, 34% three local nights, while the remaining 20% involved from 4 to 7 local nights. In this analysis we considered only those trips involving short layovers (3 or fewer local nights).

4.10.3 Means for the various sleep variables after the return from America are given in Table 6. Only those flights with a layover of less than 4 days were included in the analysis (80% of all American flights).

4.10.4 Approximately 50% of the aircrew slept during the day, soon after the return flight. The mean duration of this sleep period was just under 4 hours, but levels of alertness both before and after the nap were much lower than on the control night (both $p<.001$).

4.10.5 The reported timing, duration and quality of sleep on the three nights after the return were similar to the control night. However, levels of alertness on waking on the first and second night were lower than control ($p<.01$ and $p<.05$ respectively), and did not recover until after the third night. Levels of alertness on going to bed on the third night were higher than control ($p<.01$).

5 ANOVA and regression models

5.1 Sleep duration : ANOVA model

5.1.1 The results of the analysis of variance of sleep duration are given in Table 7. The effects on sleep duration due to time of day, the S process, the length of time to the start of the next duty, the duration of the rest period, and the number of proceeding consecutive night duties were all highly significant ($p<.001$), as were several of the interaction terms.

5.1.2 The main effect of time of day is shown in Figure 9. The duration of sleep starting between 21:00 and 01:00 was greater than 7 hours. As the start of sleep was progressively delayed, its duration reduced to a value of 2.46 hours between 17:00 and 18:00.

5.1.3 The main effect of sleep history on sleep duration is shown in Figure 10. Values of S below 0.60 were associated with sleep of progressively shorter duration.

5.1.4 The main effect of the length of time to the start of the next duty period on sleep duration is shown in Figure 11. When this time was less than 10 hours, sleep was progressively curtailed. Sleep was similarly curtailed when the duration of the rest period was less than 14 hours (Figure 12).

5.1.5 Sleep duration was influenced by the number of consecutive night duties prior to the sleep period. A single night duty was associated with an increase in sleep length of 0.31 hours, and two or more nights with an increase of 0.77 hours.

5.1.6 In addition to these main effects, there were three significant interactions. These terms were investigated further by a regression model and are described in the next section.

5.2 Sleep duration : regression model

5.2.1 A regression equation was derived for the sleep duration in hours as a function of time of day, sleep history, the length of time to the start of the next duty, the number of previous night duties and the duration of the rest period. The full details of the model are given in Annex B.

5.2.2 The pattern by which sleep duration altered throughout the day is represented in the model by a pair of cosine functions. One has a period of 24 hours while the other has a period of 12 hours. The two cosine terms combine to produce a large peak in sleep duration overnight with a smaller peak around midday.

5.2.3 The effect of sleep history on sleep duration is represented in the model by a linear function, which increases as the value of S increases.

5.2.4 Sleep was curtailed whenever there were less than 10 hours before the start of the next duty period (Section 5.1.4). This shortening of sleep is represented in the model by a linear function of the time to the start of the next duty.

5.2.5 Table 8 shows the interaction between the number of consecutive night duties and the duration of the rest period. The increase in the number of consecutive night duties from 0 to 1 to more than 1 was associated with an increase in sleep duration (after correcting for other factors), except when the duration of the next period was less than 14 hours.

5.2.6 The two remaining significant interactions both involved the time of day and are represented in the model by changes in the time of day profiles as a function of the S process and the time to the next duty. These effects are illustrated by the plots in Figure 13. When values of the S process are low, there is a clear peak in sleep duration close to midday which is less evident when S is high. The effect of a reduced amount of time to the next duty period was to truncate sleep beyond a certain point.

5.3 Sleep quality : ANOVA model

5.3.1 The results of the analysis of variance for sleep quality are given in Table 9. The effects on the quality of sleep due to time of day, the S process, the length of time to the start of the next duty, and work rate were all significant ($p<.001$, $p<.01$, $p<.001$ and $p<.01$ respectively), as were three of the interaction terms.

5.3.2 The main effect of time of day on sleep quality is shown in Figure 14. The quality of sleep was generally best during the late evening, with a second peak, slightly less well defined, close to midday.

5.3.3 The influence of sleep history (the S process) is shown in Figure 15. The quality of sleep improved with increasing values of S, from 51.6 for S less than 0.45, to 60.9 for S greater than 0.8.

5.3.4 The effect of work rate is shown in Figure 16. This effect was explained by the poor subjective sleep quality, involving a reduction of 10 points, on those occasions when the cumulative duty hours exceeded the level of the Nicholson Curve by more than 10 hours.

5.3.5 Figure 17 shows the main effect of rest period duration on sleep quality. The quality of sleep improved as the length of the rest period increased up to 14 hours, beyond which there was no further improvement.

5.3.6 The influence of the timing of the next duty period on sleep quality is shown in Figure 18. Sleep quality was poorest when the amount of time to the start of the next duty period fell between 6 and 8 hours ($p<.001$), but improved as the time interval increased to over 12 hours. Sleep quality was also better for short (4 to 6 hours) or very short (less than 4 hours) periods before the start of the next duty period.

5.3.7 Sleep quality was influenced by the nature of the subsequent duty period. When the duty was a standby, sleep was of a better quality that when it was a flying duty period ($p<0.05$), or when it was positioning duty ($p<0.05$). Sleep was best of all when it was not followed by any duty period ($p<0.01$). The association of sleep quality with type of duty varied according to the level of the S process (see paragraph 5.4.4)

5.3.8 The three significant interactions terms were investigated further in the regression model (see next section).

5.4 Sleep quality : regression model

5.4.1 A regression equation was derived for subjective sleep quality as a function of time of day, sleep history, work rate, the length of time to the start of the next duty period, the duration of the rest period, and the nature of the following duty. The full details of the model are given in Annex C.

5.4.2 One purpose for the development of a regression model was to clarify the nature of the three significant interactions in the analysis of variance. One of these interactions, between sleep history and the duration of the rest period, did not contribute significantly to the regression analysis and is therefore not considered here.

5.4.3 As with the model of sleep duration, the pattern by which sleep quality altered throughout the day was represented by two sinusoidal functions, with periods of 24 and 12 hours respectively. The resultant was a bimodal function of time of day with a large peak overnight and a much smaller peak during the day.

5.4.4 While sleep quality always improved as the value of the S process increased, the rate of this improvement depended upon the nature of the following duty. The value of the S process had the largest effect on sleep quality before a flying duty or positioning, a lesser effect before standby and hardly any effect before a time free from duty.

5.4.5 The interaction between sleep history (the S process) and the length of time to the start of the next duty period is illustrated in Figure 19. When the requirement for sleep was low, as measured by S, the subjective quality of sleep was poorer if it was followed by a duty of any type rather by than a day off. When the propensity for sleep was high, sleep quality was best prior to a flying duty period or one that involved positioning.

5.4.6 There was a significant interaction between the time of day and the time to the start of the next duty period. The effect of time of day was most pronounced when there were approximately 7 hours before the start of the next duty. It was less pronounced when short naps were taken immediately prior to duty or when the period before the next duty was much longer than 7 hours.

6 Discussion

6.1 Overview of the methodology

6.1.1 As in the previous sleep log study of long haul operations[4], it is important to stress that all the information collected in this study is subjective and must, therefore, be interpreted with some caution. In particular, subjective estimates of the quality of sleep are unlikely to reflect subtle changes in the structure of sleep that could have important consequences for the development of fatigue. Even estimates of sleep onset and total sleep length may be biased[11].

6.1.2 The main purpose of this study was to investigate the impact on patterns of sleep and wakefulness of the duty schedules, and particularly of those schedules that involve irregular patterns of duty. For this reason, the questions were concerned with the quality and timing of sleep and with levels of alertness at the start and end of sleep, rather than with estimates of alertness and performance during the duty periods themselves. An understanding of the relationship between the timing of duty periods and sleep is required for the further development of computer models of fatigue in air operations.

6.1.3 These sleep logs contain a considerable quantity of information concerning the sleep experience of aircrew on charter and air haulage operations. The analysis that has been carried out so far, and which is reported here, presents a broad overview of the main issues. No attempt has been made to provide a detailed analysis of individual schedules or to identify specific cases where high levels of fatigue have been reported. Rather, schedules at similar times of day have been combined so that general conclusions can be drawn about the most common types of duty pattern. As the requirement arises in the future, further more detailed analyses of specific schedules can be carried out, based on the information in this database.

6.1.4 A three stage approach to the analysis has been adopted, involving increasing levels of sophistication. The first stage comprised a simple analysis of sleep associated with duty periods at different times of day, irrespective of the previous duty history. The second stage considered the most common patterns of duty, namely those involving consecutive periods of duty at similar times of day, either during the day, overnight or early starts. The selection of these three groups was made on the basis of their impact on sleep patterns.

6.1.5 The weakness of both these first two approaches was that they did not incorporate all the factors that are known to influence the duration and quality of sleep. For example, all early starts were classified together, irrespective of whether the start time was 05:00, 06:00 or 06:59, and irrespective of the duty schedule that preceded the early starts.

6.1.6 To rectify this, the third stage considered all these factors simultaneously, using an approach based on unbalanced ANOVA and regression models. In this way, it was possible to estimate the effect on sleep of such factors as the time of day and the length of the rest period, after correcting for all the other significant factors. The properties of the database were such that it was also possible to examine the interactions or, in other words, to determine whether the influence of a given factor was stronger at certain levels of another factor. The software used in this analysis enabled full account to be taken of both within and between subject comparisons.

6.1.7 While the regression formulae quoted in Section 5 may appear rather cumbersome, this approach has the advantage of providing estimates of the quality and the duration of sleep taken at any point during a duty schedule. The formulae themselves would, of course, require validation against other data. However, they already provide a means of assessing the consequences for sleep of short haul schedules other than those considered here. They also form an essential ingredient for the development of the computer models mentioned above (6.1.2).

6.2 Overview of the schedules

6.2.1 The increase in the amount of long haul work undertaken by the charter crews has led to the development of schedules that include a mix of long and short haul flights. There is certainly a risk that high levels of fatigue could develop if the normal short haul work undertaken by the charter companies were closely interspersed with long haul operations. The work patterns in this study, however, did not give great cause for concern as, with the exception of one or two freight schedules, the long haul trips were always followed by several days off. It is possible that, in this respect, these schedules may not have been fully representative of those being operated at the time of the study.

6.2.2 The distribution of duty periods over the 24 hour clock was different between the freight and passenger operations. Most freight operations started in the evening between 19:00 and 23:00 and continued to early or mid morning. Frequently, these duties were performed on three successive nights with intervening rest periods of between 12 and 15 hours.

6.2.3 The majority of passenger flights were during the day, with a significant minority overnight. The proportion of overnight duties from these logs is less than the proportion calculated earlier from the reported rosters of 5 charter companies[3]. This is partly explained by a certain amount of daytime non-flying duty that has been included in the present data. However, there is little evidence from the logs of an evening peak in the start of duty time that was evident in the previous study.

6.2.4 A large majority of the duty periods in this study started in the morning between 06:00 and 10:00, with a small secondary peak in mid afternoon. Consequently, most patterns of work involved consecutive early starts, consecutive daytime duties, or a mixture of the two. Schedules which switched rapidly between day and night-time work were relatively uncommon.

6.2.5 While the mean rates of working for the passenger crews, which were generally between 30 and 40 hours per week, may not seem severe, they represent rates over 4 weeks or more that are well above the level of the Nicholson Curve. The implications of this are discussed below (see Section 6.8). Work rates for the freight crews, most of whose duty was overnight, were significantly lower.

6.3 Control sleeps

6.3.1 As in the previous long haul study, the aircrew were encouraged to complete the sleep logs continuously and to record sleep periods during their time off. It was possible, therefore, to identify, in all but 9 cases, a sleep period at some point in the log that could be considered as 'normal' using the criteria described in Section 2.5. The aim was to select a night when sleep was least likely to have been influenced by the duty schedule.

6.3.2 These control sleeps were then included in the analysis of sleep periods during various schedules to identify differences associated with the schedules. The means for sleep on the control nights quoted in this report vary slightly according to the schedules that are being compared, since different individuals were included in the different analyses.

6.3.3 Although formal comparisons between these control sleep periods and those from the long haul logs have not been carried out, there are some apparent differences. Mean reported time in bed and time asleep were about 20 minutes longer in the short haul logs and, while the quality of sleep was similar, levels of alertness on waking were higher (56.5 compared with 50.5). In the earlier study there were difficulties in selecting control nights that were free from the residual effects of time zone transitions. The control sleep periods in this study, therefore, are more likely to be representative of the normal sleep of the crews.

6.4 Daytime schedules

6.4.1 There was little evidence to suggest that schedules involving mostly daytime work were leading to problems with sleep. Levels of alertness and the quality of sleep after 4 consecutive days were unchanged from the first day, and the length of the schedule did not contribute significantly to either sleep quality or sleep duration.

6.4.2 The dividing line between a daytime duty schedule and an early start in this analysis was a duty start time of 07:00. Since there was a reduction in both sleep duration and sleep quality when duty periods started before 09:00, the average values of these variables across all daytime sleep periods were consistently lower than on the control night. When the duty period began after 09:00 there was no indication of any effect on sleep.

6.5 Early starts

6.5.1 There is much evidence from studies of shift workers that early start times (usually defined as before 06:00 rather than 07:00) are associated with difficulty in obtaining adequate sleep prior to the start of duty[12,13]. Moreover, even the relatively mild sleep disturbances associated with early start times have been shown to affect alertness on the following day[14,15]. Both the loss of sleep and the reduction in alertness were evident in a recent study of air traffic controllers where start times were relatively late and the dividing line was chosen as 07:30[16].

6.5.2 The results from the sleep logs confirm that early starts are also associated with sleep impairments in aircrew, as well as with low levels of alertness on waking. Reductions in the amount of sleep were evident when the duty start time was earlier than 09:00, and averaged between one and two hours for start times between 05:00 and 07:00.

6.5.3 The reduction in sleep arose because the crews did not advance their bedtime sufficiently to compensate for the early starts. This pattern of sleeping, which has also been found in shift workers, may not be entirely due to social and environmental factors. It may reflect the influence of the so-called 'forbidden zone' for sleep[17], which is a period, lasting for about 4 hours, during which the propensity for sleep is greatly reduced.

6.5.4 The extent to which individuals can adapt to a schedule involving consecutive early start is uncertain. The air traffic controllers[16] showed some improvement in sleep after the first night, although they did not report feeling better rested on waking. The aircrew in this study did increase the duration of sleep on the third night, but this improvement was not maintained on the fourth night when levels of alertness on going to bed were particularly low.

6.5.5 After a period of consecutive early starts, the sleep debt accumulates, amounting perhaps to as much as two hours per night, and it is only rarely alleviated by extra naps taken at the end of the duty periods. A strong case can, therefore, be made for limiting the number of consecutive early starts, through the provision of a recovery night. Based on the evidence from this study, sufficient sleep could be achieved if the subsequent duty started after 10:00. This would allow for a normal sleep consistent with a 09:00 start time, with an extra hour for additional recovery.

6.6 Consecutive nights

6.6.1 Many of the operations covered by the logs involved periods of one, two or three consecutive night duties. The sleep patterns during these night-time schedules were similar to those reported elsewhere[16]. The daytime sleep period following the night duty was generally between 2 and 3 hours shorter than a normal night-time sleep, and it was sometimes followed by a nap of between 1 and 2 hours. The mean sleep deficit after two night shifts was over 3 hours.

6.6.2 While environmental and social factors may contribute, the patterns of poor daytime sleep are an inevitable consequence of the circadian rhythm or body clock. This helps to maintain individuals on a normal diurnal cycle so that they can remain alert most easily during the day and sleep most easily at night. Low levels of alertness during night flights can arise as a combination of the normal circadian rhythm of alertness and the poor quality of the preceding sleep.

6.6.3 Problems with night work are likely to continue, and may indeed get worse, until the circadian rhythm can adjust to the night-time orientation. This may take several days, or even longer. It is unlikely, therefore, that the periods of consecutive night work in these schedules would have been sufficiently long to generate any significant adaptation.

6.6.4 Nevertheless, there is some evidence of an improvement in sleep after the first night-time duty period. Both time in bed and time asleep were longer after the second night duty. In addition, after correcting for other factors in the regression model, sleep on consecutive nights was approximately 20 minutes longer than expected after the first night and 45 minutes longer after the second and subsequent nights. However, there was no similar improvement in sleep quality, and levels of alertness during the second night were lower than on the first.

6.6.5 On balance, therefore, these results confirm the case for severely limiting the number of consecutive night duties. The alternative would be to permit long periods of consecutive nights so that advantage could be taken of the reorientation of the circadian rhythm.

6.6.6 Evidence from the literature would suggest that at least two days are required to recover from a short period of continuous night work[18]. The low levels of alertness reported by the crews in this study during the 48 hours following the end of a period of night work strongly support this conclusion.

6.7 Long haul operations

6.7.1 In the absence of much information on the mix of long and short haul operations, the analysis in this study has been restricted to single long haul operations. This, in turn, was limited to an analysis of the recovery from the most common east coast of North America or Caribbean trip, in view of the extensive analysis of long haul operations carried out in the previous sleep log study of British Airways' crews[4].

6.7.2 The pattern of sleep on the first three nights after the return was similar to that of the British Airways' crews, with levels of alertness remaining low after both the first and second night. This would support the conclusion drawn from the earlier study that the recovery from the trip was not complete until after the third night.

6.8 Rates of working

6.8.1 The rates of working in the majority of these schedules exceeded, at some point, the maximum acceptable rate as defined by the Nicholson Curve[10]. However, this curve, which limits flight duty hours over periods of 7, 14 and 28 days to 50, 73 and 120 hours respectively, is only strictly applicable to irregular duty schedules in which the normal pattern of sleep and wakefulness is continually disturbed. The rules for resetting the curve when normal daytime working is resumed have yet to be determined. Indeed, a more detailed analysis of the current data may help to resolve this issue.

6.8.2 Nevertheless, there was some evidence from this study that the quality of sleep was reduced when rates of working exceeded the Nicholson Curve by more than 10 hours. The extent of this reduction was considerable, representing over a 10 point shift on the 100 point alertness scale.

6.8.3 This provides a clear indication that high work rates may lead to sleep disturbance on short haul schedules. The fact that the reduction in quality appeared after an extra 10 hours can partly be explained by the inclusion in the calculation of some non-flying duties. It may also reflect the limited degree of disruption in these schedules compared with the long haul schedules from which the curve was originally derived.

6.9 The influence of time of day

6.9.1 The single most important factor affecting the sleep quality, and particularly the duration of the sleep periods logged by the aircrew, was the time of day at the start of the sleep period. There was a difference of almost 5 hours between the longest sleeps starting in the late evening and the shortest which started just a few hours earlier in the early evening. Since the sleep durations on which this is based have been corrected for the influence of all other factors, including the timing of duty, they should represent the influence on sleep of the time of day, or the circadian rhythm, alone.

6.9.2 In the time of day profile of both sleep duration and sleep quality, there was evidence of a small secondary peak close to midday. Sleep periods starting at this time would normally continue past the normal time of the so-called 'post-lunch dip'. Consequently, there are two periods during the day when sleep, if initiated at that time, may be curtailed significantly. The first one of these is between 16:00 and 18:00, while the second is between 05:00 and 07:00. However, the second period is only present at low levels of S or, in other words, when the requirement for sleep is low.

6.9.3 The implications of these results for night operations have already been noted. Daytime sleep tends to be shorter and less restful than overnight sleep, and aircrew frequently take an additional nap in an attempt to prepare themselves for an overnight flight. Nevertheless, they rarely manage to achieve the level of rest provided by a normal sleep period.

6.9.4 This sleep deficit, which accumulates on successive nights, will accentuate the reduction in alertness associated with the circadian rhythm. Previous advice concerning maximum duty times for overnight operations[19] has been based on the assumption that the crews are fully rested before the start of the duty period. It must be recognized that, in practice, this will be very difficult for the crews to achieve.

6.10 Rest period duration

6.10.1 The regression models developed for the duration and quality of sleep provided some indication of the relationship between sleep and the duration of the rest period. Sleep was progressively curtailed when the time between the start of sleep and the start of duty was less than 10 hours, and it was further reduced when the rest period was less than 14 hours. Moreover, the effect of a short rest period was most marked after two or more successive nights.

6.10.2 Reductions in the quality of sleep were greatest when sleep was initiated between 4 and 10 hours before the start of the next duty period, and they were particularly dependent on the time of day. Taken together, these results support the case for longer rest periods during the day prior to an overnight duty.

7 Conclusions

7.1 The majority of the passenger-carrying operations reported in these sleep logs involve schedules consisting of daytime duty periods with frequent early start times, as well as a few overnight flights. Consecutive early starts are common. The freight operations are mainly overnight and often involve three consecutive night-time duty periods.

7.2 Rates of working on some schedules are higher than levels recommended for irregular duty patterns, and give rise to a reduction in the subjective quality of sleep.

7.3 The time of day at which sleep is taken is by far the most important influence of the duration and quality of sleep. The best and the longest sleep periods start in the late evening. There is a progressive deterioration from midnight until the early evening, except for a small secondary peak at midday.

7.4 Sleep is poor throughout a period of three duties on consecutive nights, with little evidence of adaptation. At least 48 hours are required to complete a full recovery from a period of night flying.

7.5 Schedules involving consecutive early starts lead to an accumulating sleep deficit, since aircrew do not advance their bedtime sufficiently to compensate for the early start.

7.6 Sleep becomes progressively impaired when the length of time available before the start of duty is less than 10 hours and when the rest period is less than 14 hours. This effect is most severe for daytime sleep.

7.7 Two full days and three nights are required to complete the recovery from the trips to the American continent.

8 Recommendations

8.1 Early start times and overnight duty periods, that are a common feature of the operations in this study, inevitably involve some sleep disturbance which may, in turn, have consequences for alertness levels in the cockpit. It is important, therefore, that the schedules are managed so that the risks associated with fatigue are minimised. To achieve this, and to encourage good rostering practice, we offer the following guidelines.

8.2 The number of consecutive duties that involve early start times should be limited as much as possible. The definition of an early start in CAP 371, namely before 07:00, is a good guide, but start times a lot earlier than this will have a greater disruptive effect, and even duties that start as late as 08:00 are not free from adverse effects on sleep.

8.3 In schedules with many early starts, the opportunity for a recovery sleep should be provided as frequently as possible, and preferably after no more than 3 consecutive early starts. To achieve this, it would be sufficient if the duty period on the following day began no earlier than 10:00.

8.4 The number of consecutive night time duties should be kept to a minimum. When crews are rostered for 2 or 3 consecutive nights, careful consideration should be given to the duration of the rest period between successive night duties. Periods of at least 13 and preferably 14 hours should be provided whenever possible.

8.5 Periods of consecutive night duties should be followed by sufficient time off to allow for the recovery of sleep. To achieve a complete recovery, the rest period should cover at least two local nights.

8.6 A variation to CAP 371 for night freight operations, that may be implemented on a trial basis by the CAA, allows 10 night duties to be scheduled in two groups of 5 on 11 consecutive nights. In contrast to current operations, which are generally limited to 3 consecutive nights, this would encourage the adaptation of the circadian rhythm to a nocturnal orientation. This change requires careful monitoring for, if the crews are unable to adjust to any great extent, high levels of fatigue could be generated. The pattern of duty on successive nights should delay, rather than advance, to assist the process of adaptation, and minimum rest periods should be avoided as much as possible.

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	Control	before 1st duty	before 2nd duty	before 3rd duty	before 4th duty
Bedtime (h:min)	23:23	23:04 **	23:17	23:29	23:29
Sleep onset time (h:min)	23:49	23:39	23:45	23:55	23:55
Time of awakening (h:min)	07:53	06:56 ***	07:00 ***	07:08 ***	06:58 ***
Time of rising (h:min)	08:27	07:18 ***	07:29 ***	07:35 ***	07:32 ***
Length of time in bed (h)	9.07	8.23 ***	8.19 ***	8.09 ***	8.05 ***
Length of time asleep (h)	7.88	7.10 ***	7.12 ***	7.06 ***	6.90 ***
Sleep onset latency (min)	26.6	29.4	27.2	26.0	26.2
Alertness on going to bed	37.2	36.1	34.0 *	30.0 ***	33.5 **
Alertness during previous day	54.5	50.7 **	51.2 **	49.4 ***	49.5 ***
Quality of sleep	61.2	56.0 **	55.2 **	57.9	53.1 ***
Desire for less sleep	45.0	38.1 ***	37.1 ***	37.3 ***	37.6 ***
Post sleep alertness	56.5	49.6 ***	48.0 ***	46.9 ***	47.6 ***

Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from the control day.

Table 1
Sleep prior to consecutive daytime duties

	Control	before 1st night	before 2nd night	before 3rd night
Bedtime (h:min)	23:23	23:53	08:16 ***	07:58 ***
Sleep onset time (h:min)	23:49	00:16	08:32 ***	08:18 ***
Time of awakening (h:min)	07:53	08:19	13:57 *** ++	15:06 ***
Time of rising (h:min)	08:27	08:53	14:42 *** ++	15:41 ***
Length of time in bed (h)	9.07	9.01	6.43 *** ++	7.72 ***
Length of time asleep (h)	7.88	7.83	5.16 *** ++	6.10 ***
Sleep onset latency (min)	26.6	22.8	15.8 *	20.7
Alertness on going to bed	37.2	35.1	18.0 ***	19.4 ***
Alertness during previous day	54.5	51.1	37.8 *** +	31.7 ***
Quality of sleep	61.2	59.3	46.7 ***	56.1
Desire for less sleep	45.0	42.1	30.3 ***	36.8 **
Post sleep alertness	56.5	53.3	39.2 ***	43.3 ***

Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from the control day.
Significance levels (+ p< .05, ++ p<.01, +++ p<.001) refer to differences from the 3rd night.

Table 2
Sleep prior to consecutive night-time duties

	Control	1st main sleep	2nd main sleep	3rd main sleep	4th main sleep
Bedtime (h:min)	23:23	08:05 ***	23:15 +++	23:22 +++	23:18 +++
Sleep onset time (h:min)	23:49	08:24 ***	23:39 +++	23:41 +++	23:41 +++
Time of awakening (h:min)	07:53	12:38 ***	07:57 +++	07:31 +++	07:42 +++
Time of rising (h:min)	08:27	13:03 ***	08:38 +++	08:23 +++	08:15 +++
Length of time in bed (h)	9.07	4.96 ***	9.38 +++	9.01 +++	8.95 +++
Length of time asleep (h)	7.88	4.18 ***	8.05 +++	7.65 +++	7.86 +++
Sleep onset latency (min)	26.6	18.1 *	24.0	18.7 *	22.6
Time since last duty (h)	-	1.93	19.14	43.82	67.54
Alertness on going to bed	37.2	17.0 ***	28.0 *** +++	40.8 +++ xxx	43.3 ** +++ xxx
Alertness during previous day	54.5	35.8 ***	38.5 ***	53.0 ++ xx	53.8 ++ xx
Quality of sleep	61.2	46.7 ***	61.1 +++	60.3 +++	59.4 +++
Desire for less sleep	45.0	27.9 ***	40.7 * +++	41.9 +++	44.9 +++
Post sleep alertness	56.5	34.2 ***	52.3 * +++	51.6 * +++	55.2 +++

Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from the control day.
Significance levels (+ p< .05, ++ p<.01, +++ p<.001) refer to differences from the 1st main sleep.
Significance levels (x p< .05, xx p<.01, xxx p<.001) refer to differences from the 2nd main sleep.

Table 3
Recovery sleep after a period of night-time duties

	Control	before 1st early start	before 2nd early start	before 3rd early start	before 4th early start
Bedtime (h:min)	23:23	22:33 ** ++	22:34 ** ++	22:14 *** ++	23:07
Sleep onset time (h:min)	23:49	23:14	23:11 *	22:33 *** +	23:23
Time of awakening (h:min)	07:53	04:54 ***	04:40 ***	04:56 ***	04:52 ***
Time of rising (h:min)	08:27	05:00 ***	04:46 ***	04:59 ***	04:52 ***
Length of time in bed (h)	9.07	6.43 ***	6.19 ***	6.75 *** ++	5.86 ***
Length of time asleep (h)	7.88	5.52 *** x	5.51 *** x	6.36 *** +	5.44 *** x
Sleep onset latency (min)	26.6	35.1	27.0	18.3	22.5
Alertness on going to bed	37.2	39.1 +	34.3	31.5	27.3 *
Alertness during previous day	54.5	52.9	49.2	45.6	48.8
Quality of sleep	61.2	50.6 +	51.1 +	56.4	65.3
Desire for less sleep	45.0	28.5 ***	27.8 ***	31.3 ***	28.5 ***
Post sleep alertness	56.5	41.0 **	39.1 ***	44.5 *	45.3 *

Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from the control sleep.
Significance levels (+ p< .05, ++ p<.01, +++ p<.001) refer to differences from the 4th sleep.
Significance levels (x p< .05, xx p<.01, xxx p<.001) refer to differences from the 3rd sleep.

Table 4
Sleep prior to consecutive duties with early starts

	Control	after one early start	after two early starts	after three early starts
Bedtime (h:min)	23:23	22:58	23:09	23:09
Sleep onset time (h:min)	23:49	23:22	23:29	23:54
Time of awakening (h:min)	07:53	07:13 *	07:31	07:48
Time of rising (h:min)	08:27	07:48 *	07:58	08:26
Length of time in bed (h)	9.07	8.83	8.83	9.26
Length of time asleep (h)	7.88	7.60	7.85	7.86
Sleep onset latency (min)	26.6	23.7	20.8	17.9
Alertness on going to bed	37.2	27.0 ***	26.4 ***	28.3 **
Alertness during previous day	54.5	43.4 ***	41.1 ***	43.2 ***
Quality of sleep	61.2	59.0	60.7	61.2
Desire for less sleep	45.0	39.2 *	40.2	39.0 *
Post sleep alertness	56.5	49.9	50.5	50.8

Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from the control day.

Table 5
Recovery sleep after a period of duties with early starts

	Control	Post duty nap	1st main sleep	2nd main sleep	3rd main sleep
Bebtime (h:min)	23:23	10:51 ***	23:29	00:10	23:22
Sleep onset time (h:min)	23:49	11:04 ***	23:59	00:41	00:02
Time of awakening (h:min)	07:53	15:08 ***	08:46	08:49	08:14
Time of rising (h:min)	08:27	15:25 ***	09:25	09:20	08:36
Length of time in bed (h)	9.07	4.58 ***	9.93	9.16	9.24
Length of time asleep (h)	7.88	3.96 ***	8.49	7.77	7.87
Sleep onset latency (min)	26.6	13.87	29.38	30.42	40.77
Alertness on going to bed	37.2	18.3 ***	27.2 **	43.3 +++	49.0 ** +++
Alertness during previous day	54.5	40.2 ***	33.9 ***	47.8 +++	51.6 +++
Quality of sleep	61.2	53.1	64.1	61.9	57.5
Desire for less sleep	45.0	23.1 ***	38.7	42.8	45.3
Post sleep alertnes	56.5	29.6 ***	47.1 **	48.2 *	50.9

Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from the control day.
Significance levels (+ p< .05, ++ p<.01, +++ p<.001) refer to differences from the 1st main sleep.

Table 6
Recovery sleep after the flight from Eastern America

Factor	Degrees of freedom	F-ratio	Probability
Time of day	11	222.68	<.001
S process	7	5.56	<.001
Time to start of next duty (h)	6	63.76	<.001
Length of rest period (h)	7	4.07	<.001
Number of preceding consecutive night duties	3	5.87	<.001
Interaction between Time of day and S process	71	1.97	<.001
Interaction between Time of day and time to next duty	56	5.94	<.001
Interaction between Rest period and no. of night duties	14	2.96	<.001

Table 7
Significant factors in the ANOVA for sleep duration
(tested against a pooled error term with 101 degrees of freedom)

		Duration of rest period (h)			
		<14	14-16	16-30	>30
Number of consecutive nights	0	6.2	6.4	6.5	6.4
	1	7.3	7.6	6.5	6.4
	more than 1	6.7	8.2	10.1	6.8

Table 8
Sleep duration (h) as a function of rest period and consecutive night duties (see Annex B)

Factor	Degrees of freedom	F-ratio	Probability
Time of day	11	8.20	<.001
S process	7	3.32	.004
Time to start of next duty (h)	5	5.52	<.001
Length of rest period (h)	7	1.99	.064
Duty history	6	3.23	.007
Type of duty	3	2.10	.110
Interaction between time of day and time to next duty	57	1.79	.006
Interaction between S process and rest period duration	39	1.64	.026
Interaction between S process and type of duty	20	2.27	.041

Table 9
Significant factors in the ANOVA for quality of sleep
(tested against a pooled error term with 104 degrees of freedom).

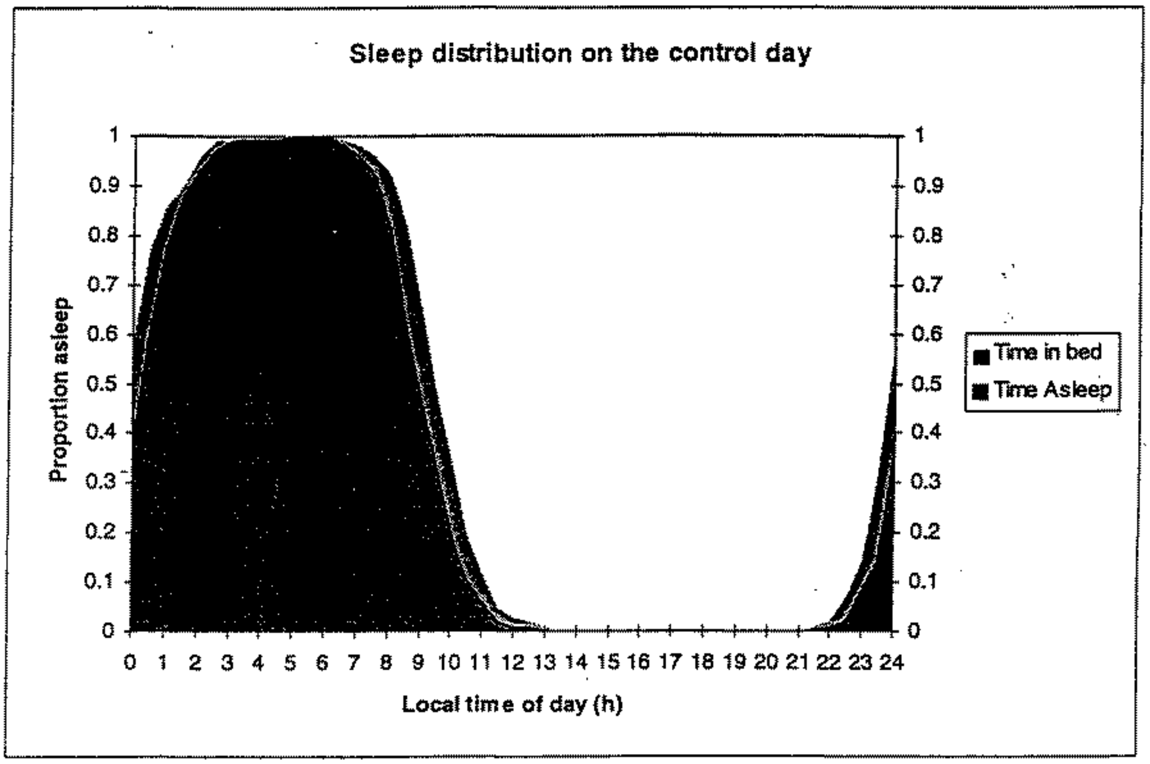


Figure 1
Sleep distribution on the control day

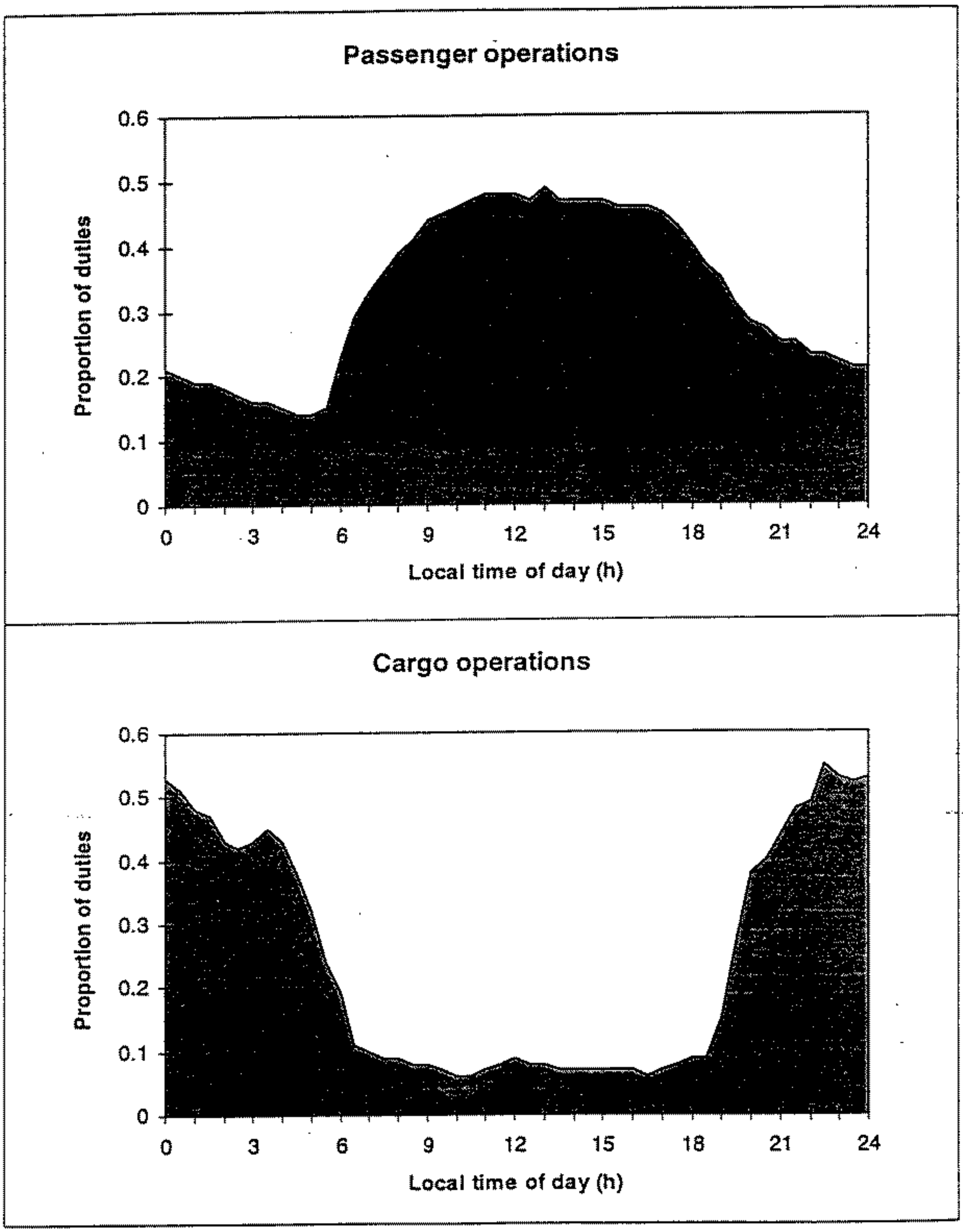


Figure 2
Distribution of duty hours over the 24h clock

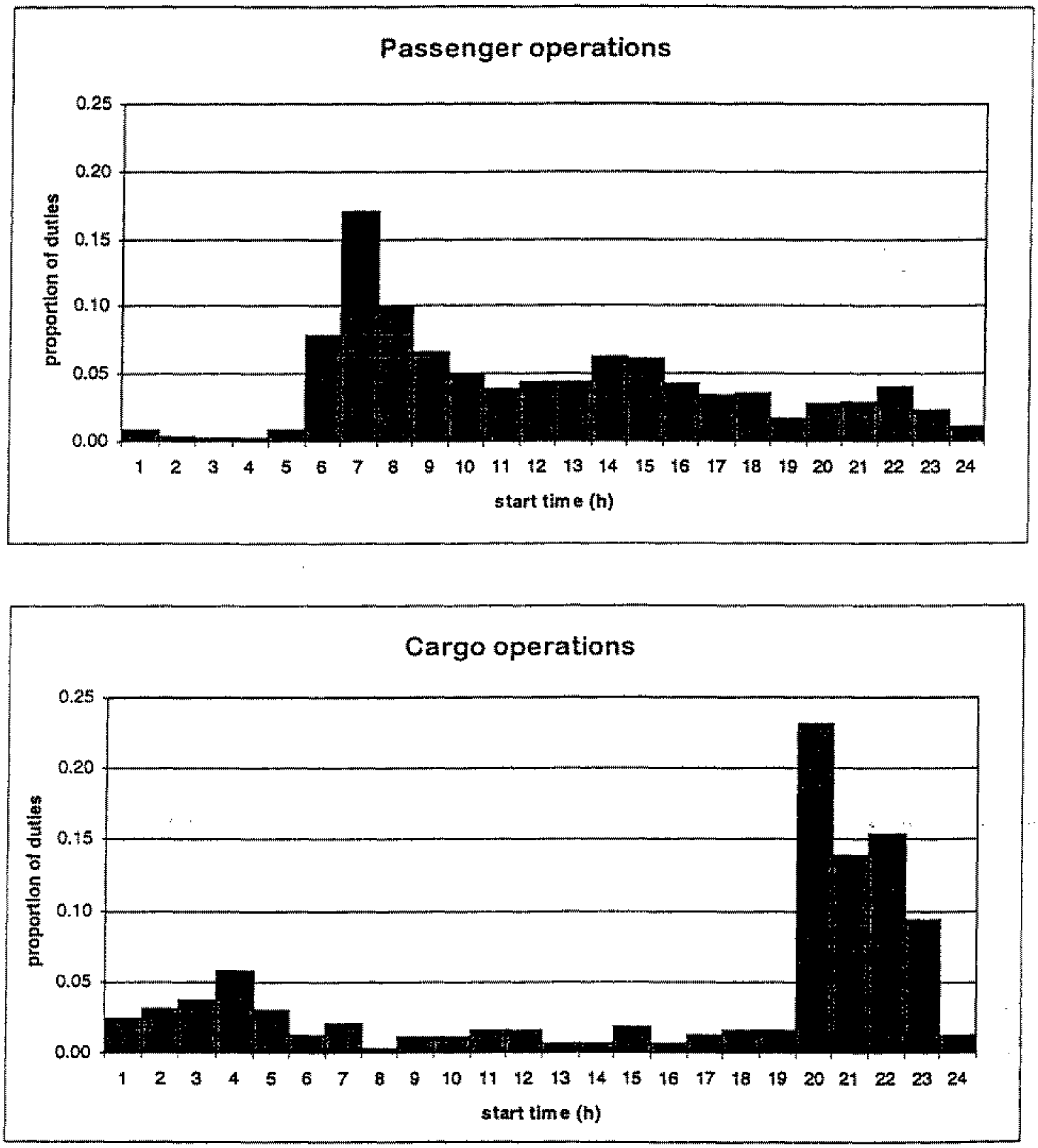


Figure 3
Distribution of duty start times

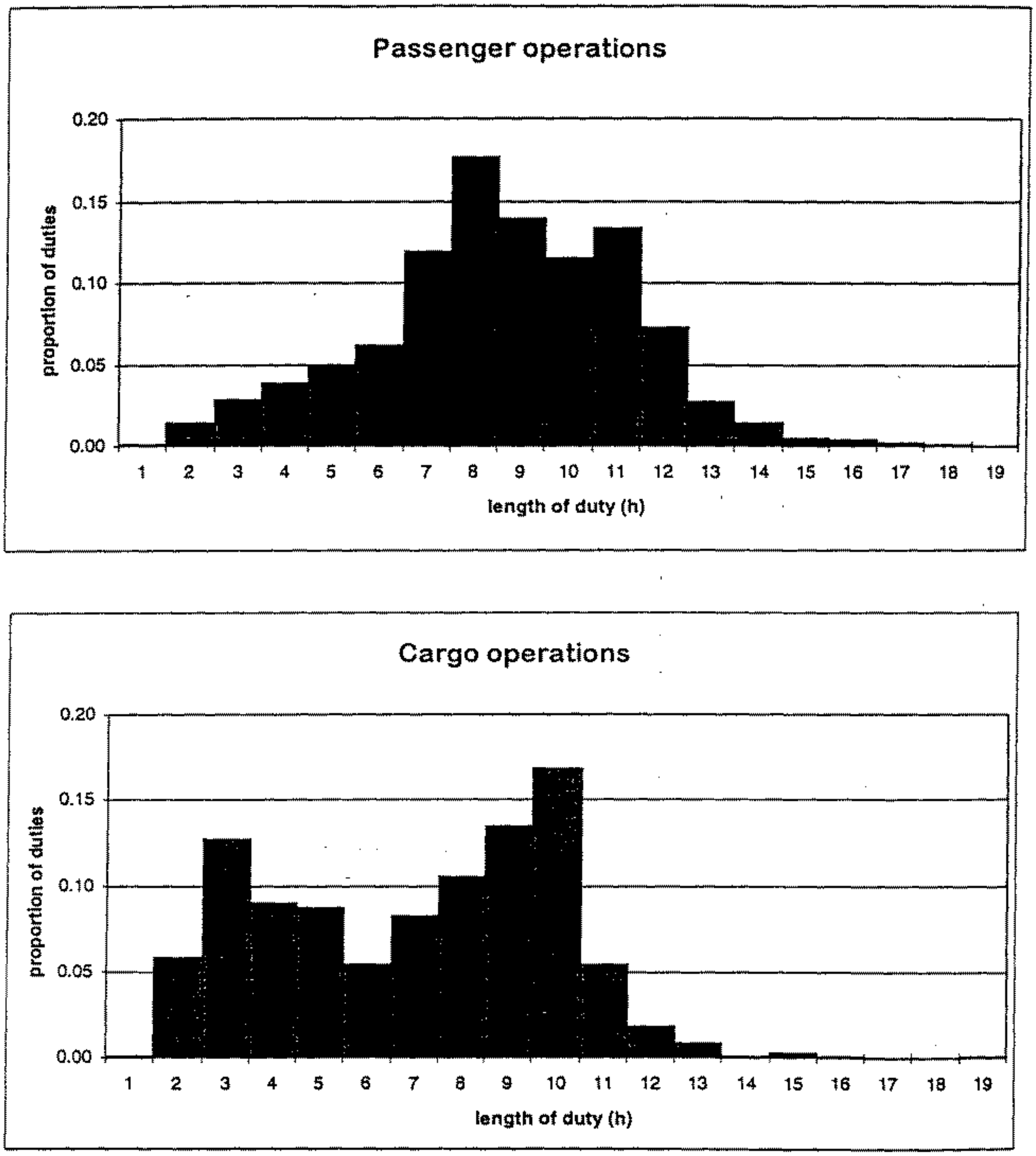
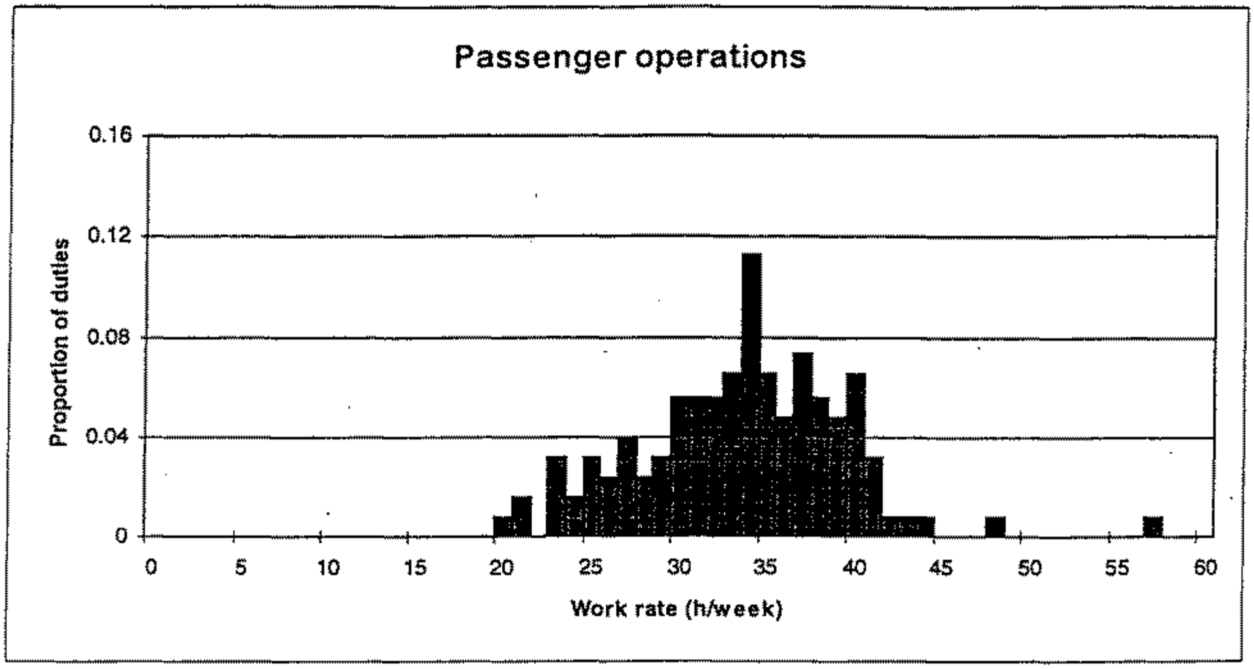


Figure 4
Distribution of duty period length



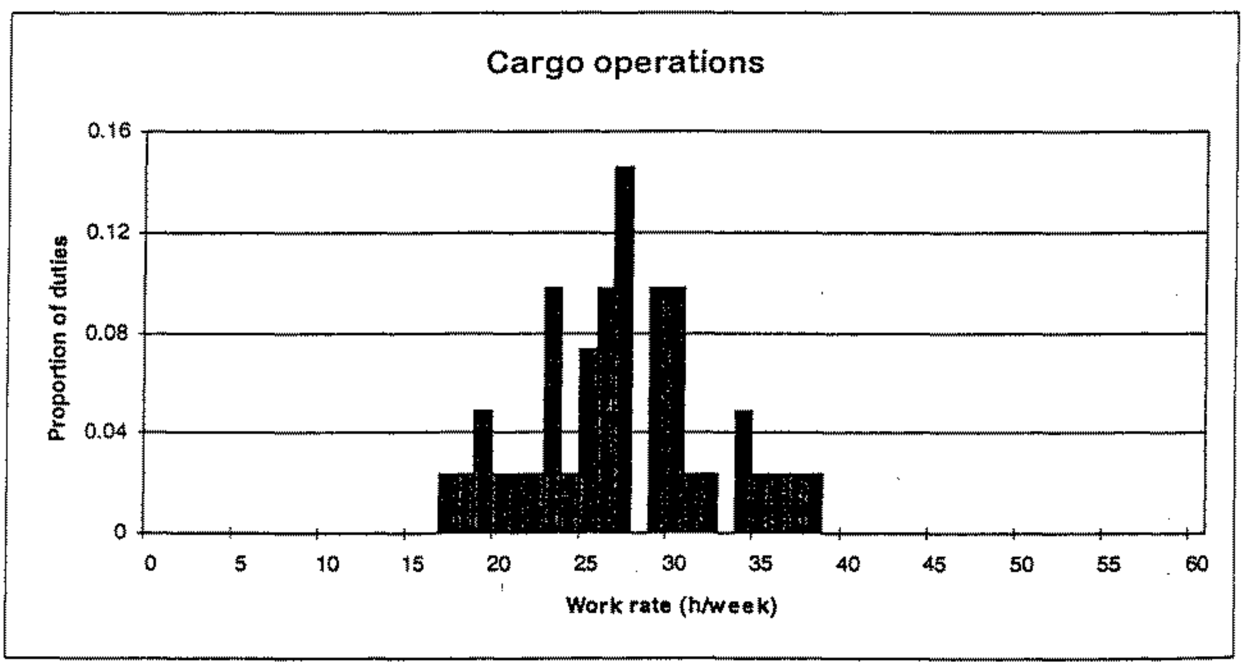


Figure 5
Distribution of mean duty hours per week

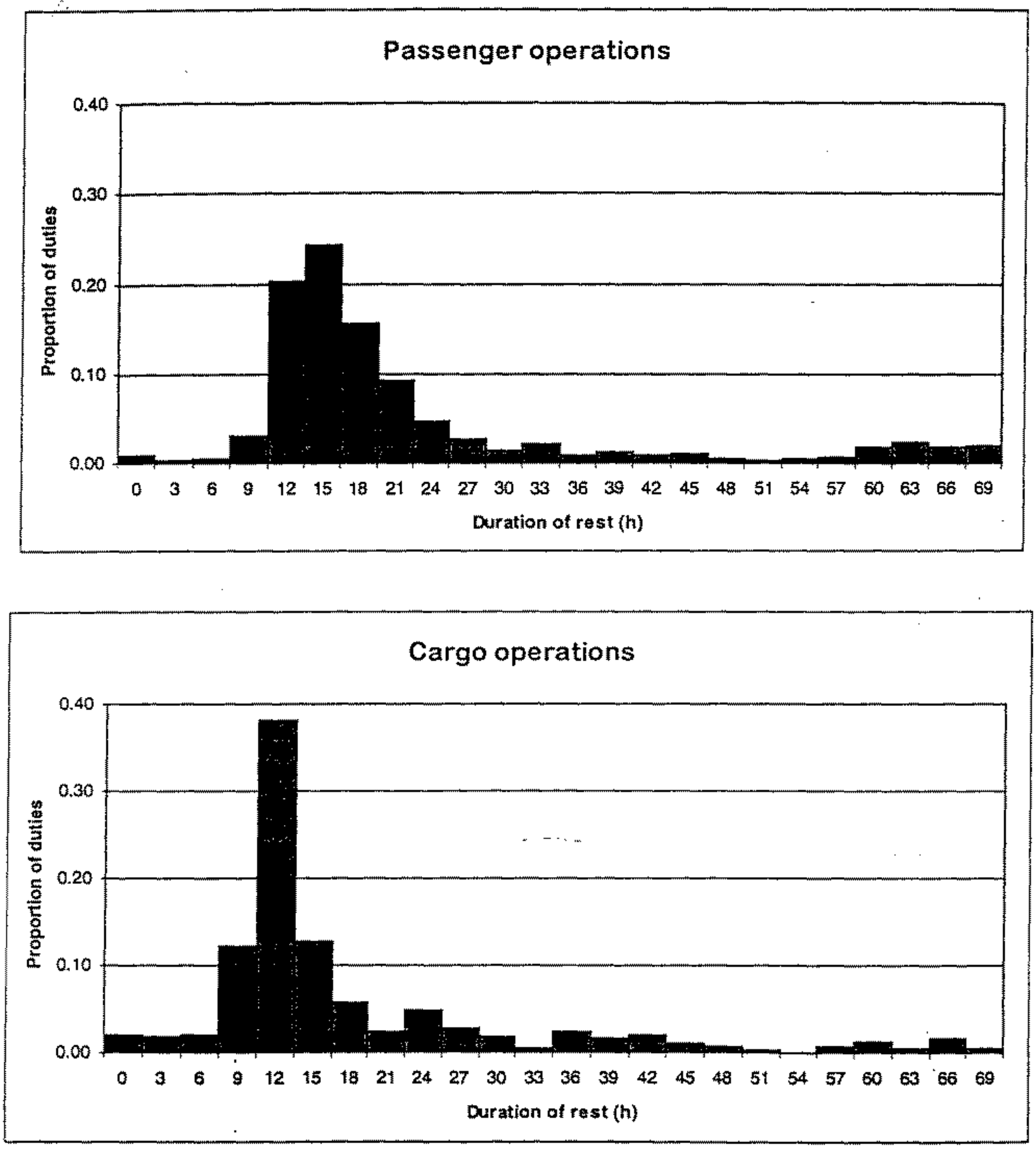
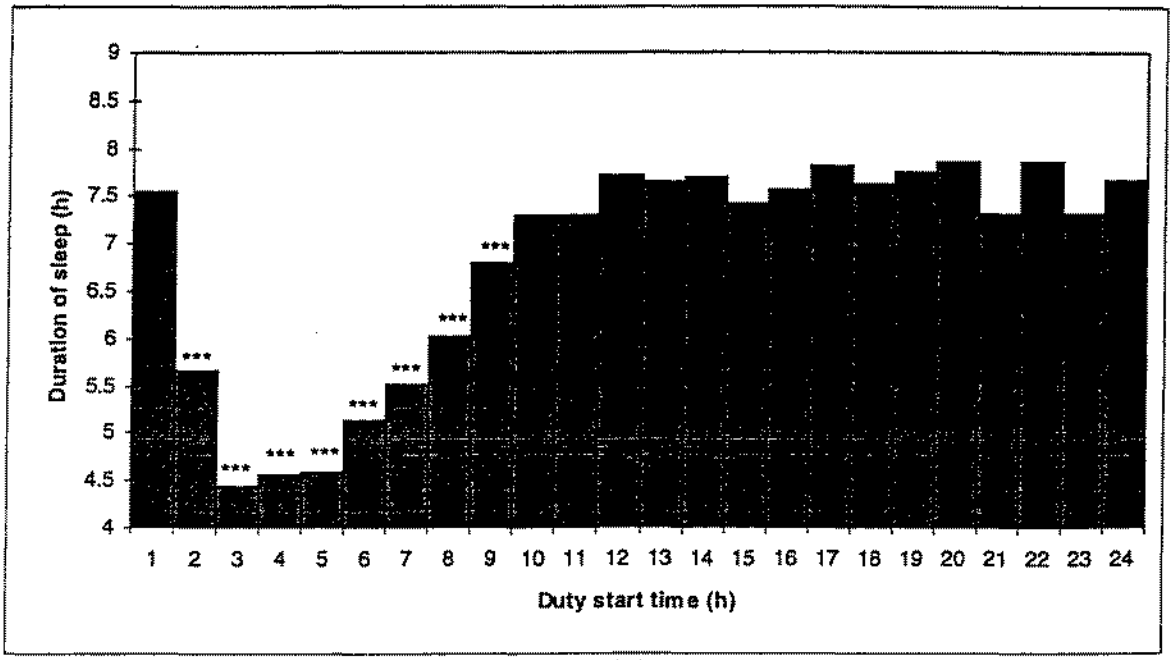


Figure 6
Distribution of rest period duration



Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from the control day.

Figure 7
Sleep duration prior to duties starting at different times of day

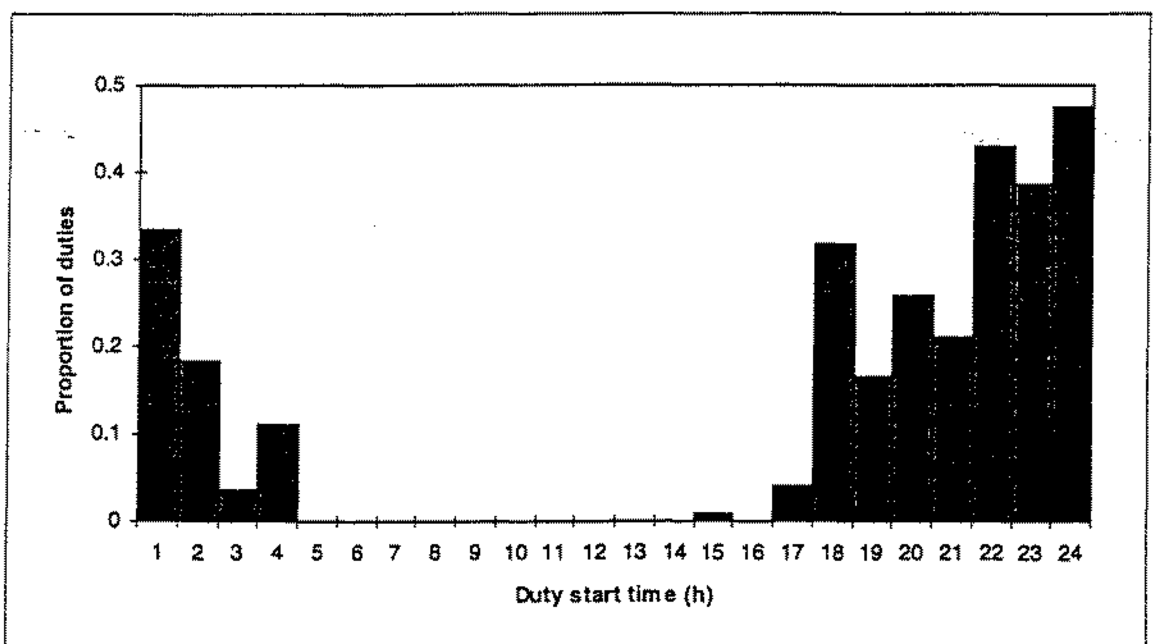
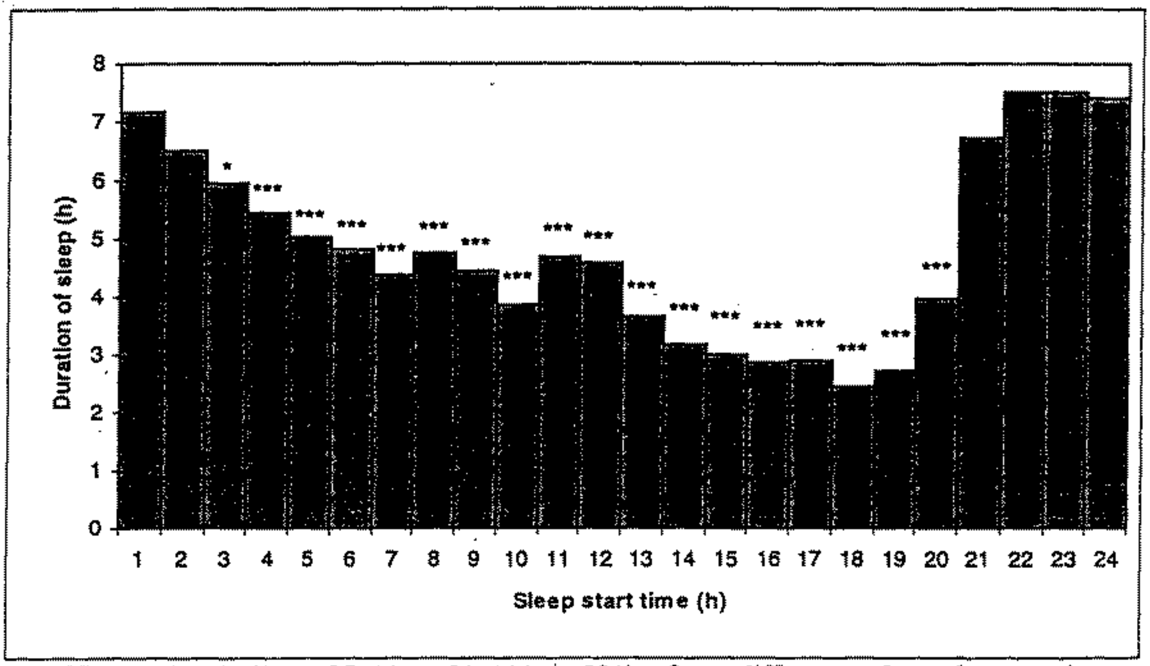
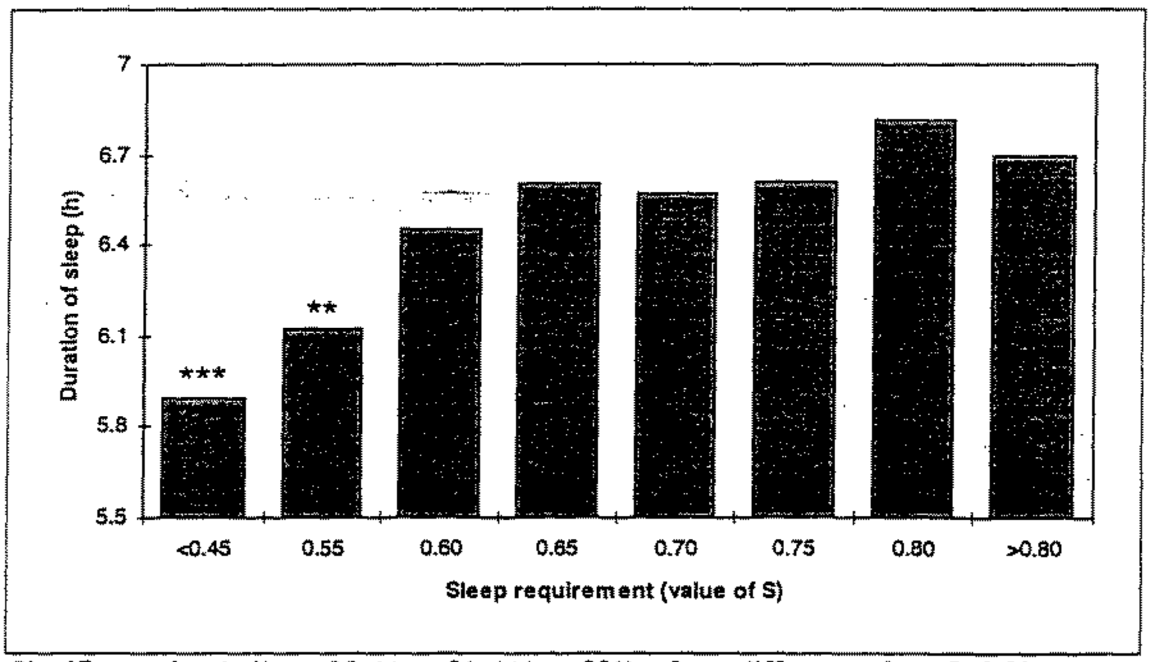


Figure 8
Proportion of duties preceded by a nap



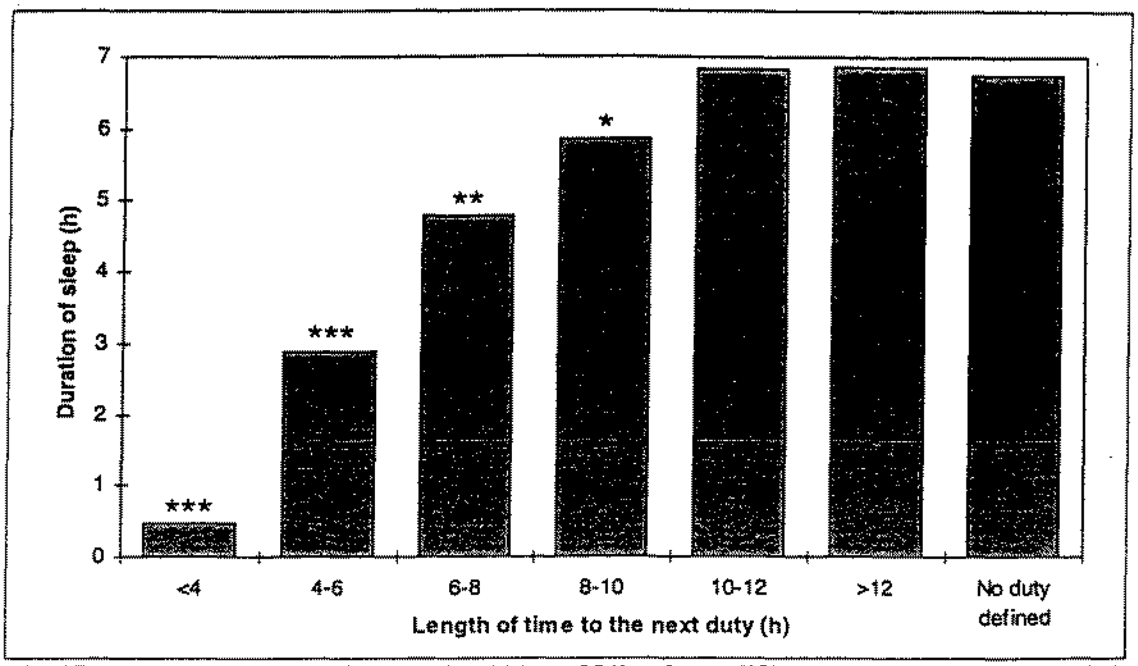
Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from sleep starting between 22:00 and 01:00.

Figure 9
Changes in duration of sleep with time of day



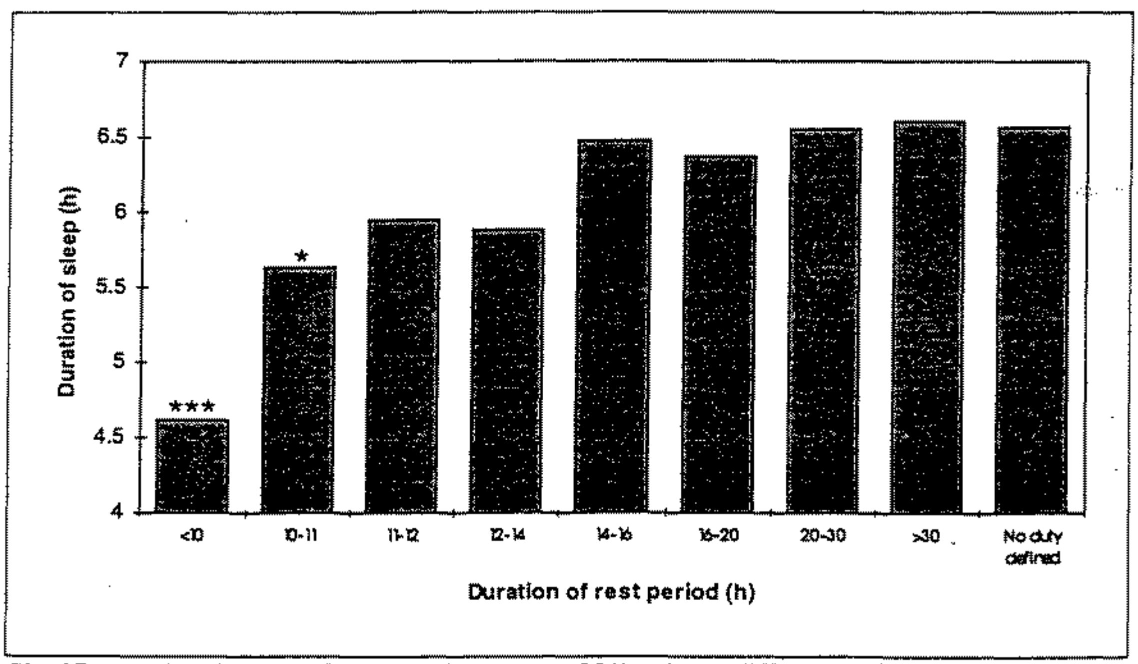
Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from S>0.80.

Figure 10
Changes in duration of sleep with sleep requirement



Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from sleep with >12h to the start of the next duty.

Figure 11
Sleep duration as a function of the time to the start of the next duty



Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from sleep during rest periods >30h.

Figure 12
Sleep duration as a function of rest period duration

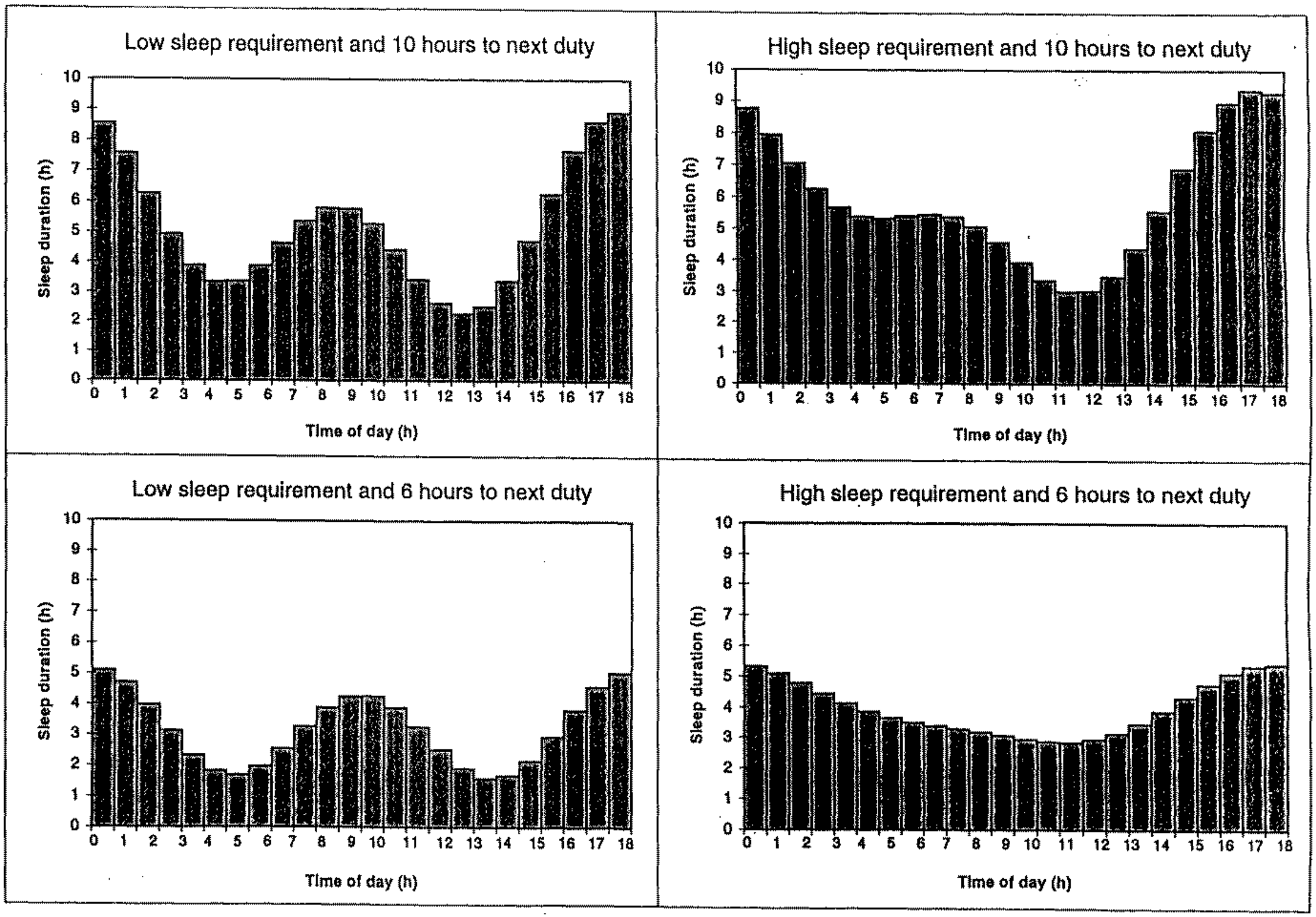
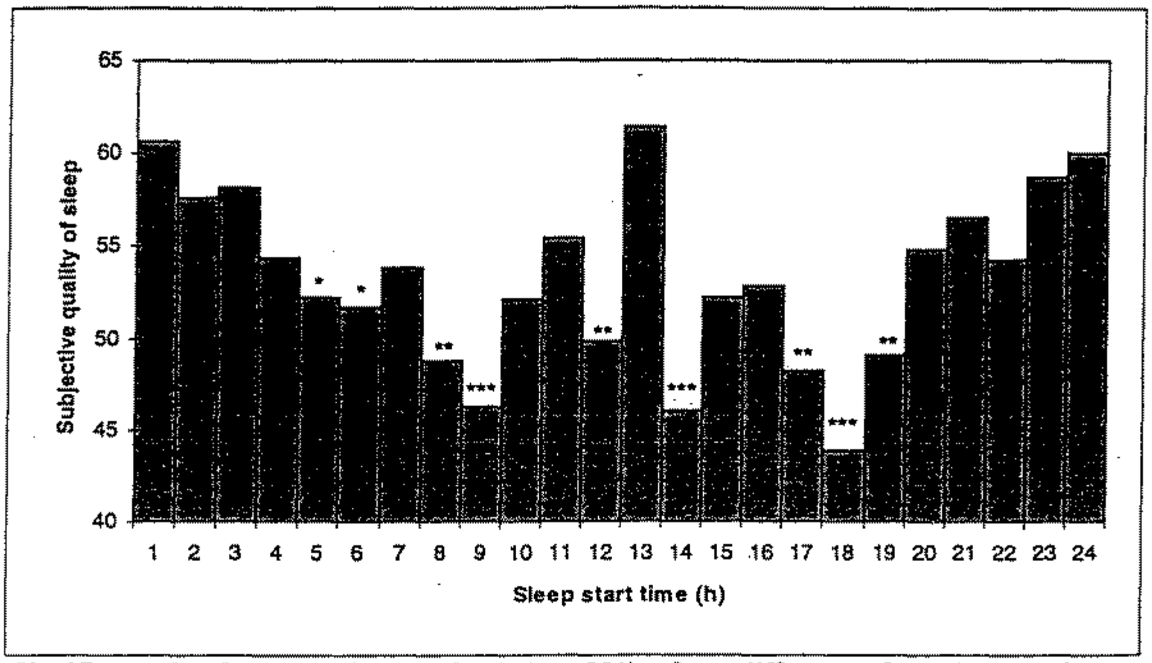
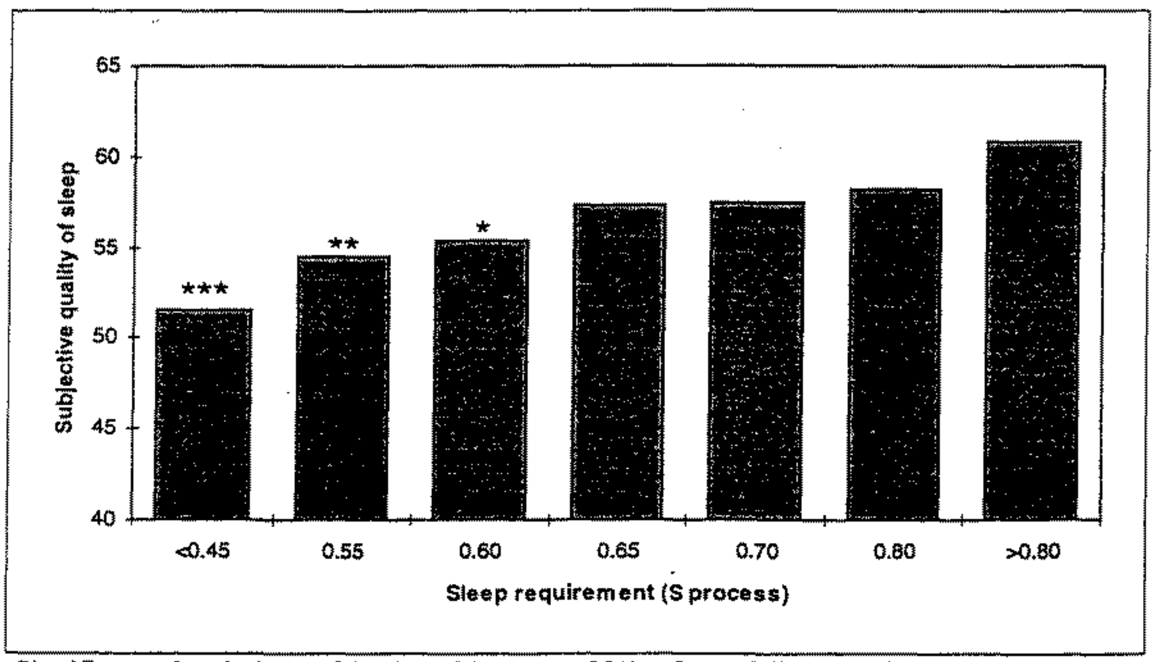


Figure 13
Sleep duration as a function of time of day
(based on the regression model)



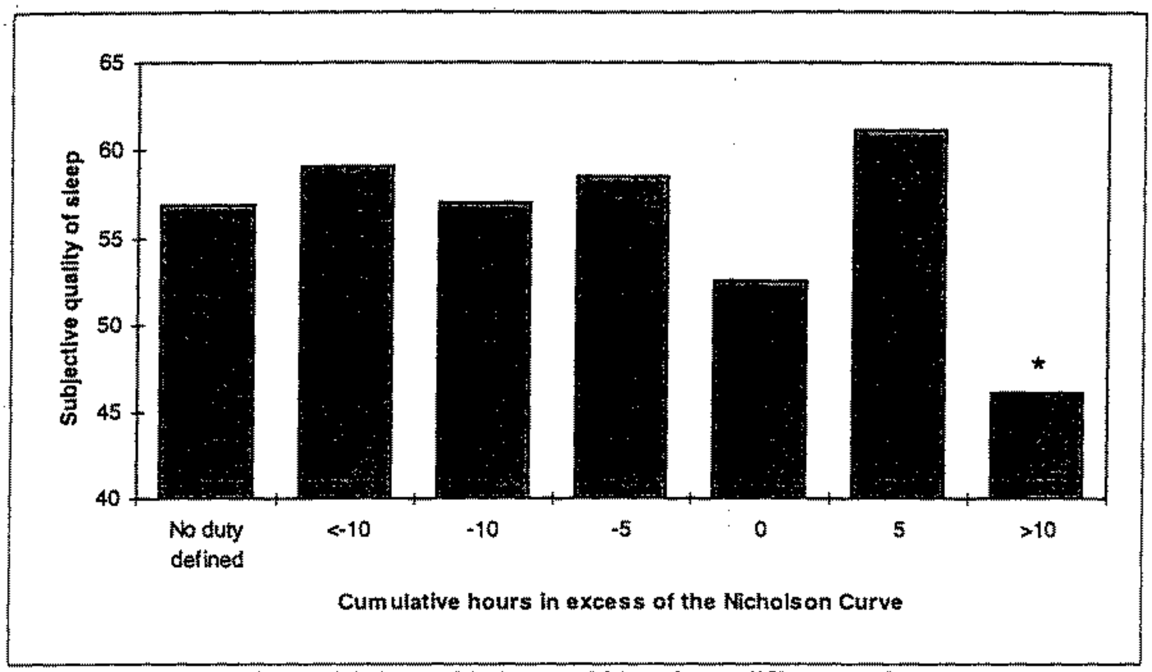
Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from sleep starting between 22:00 and 01:00.

Figure 14
Sleep quality as a function of time of day



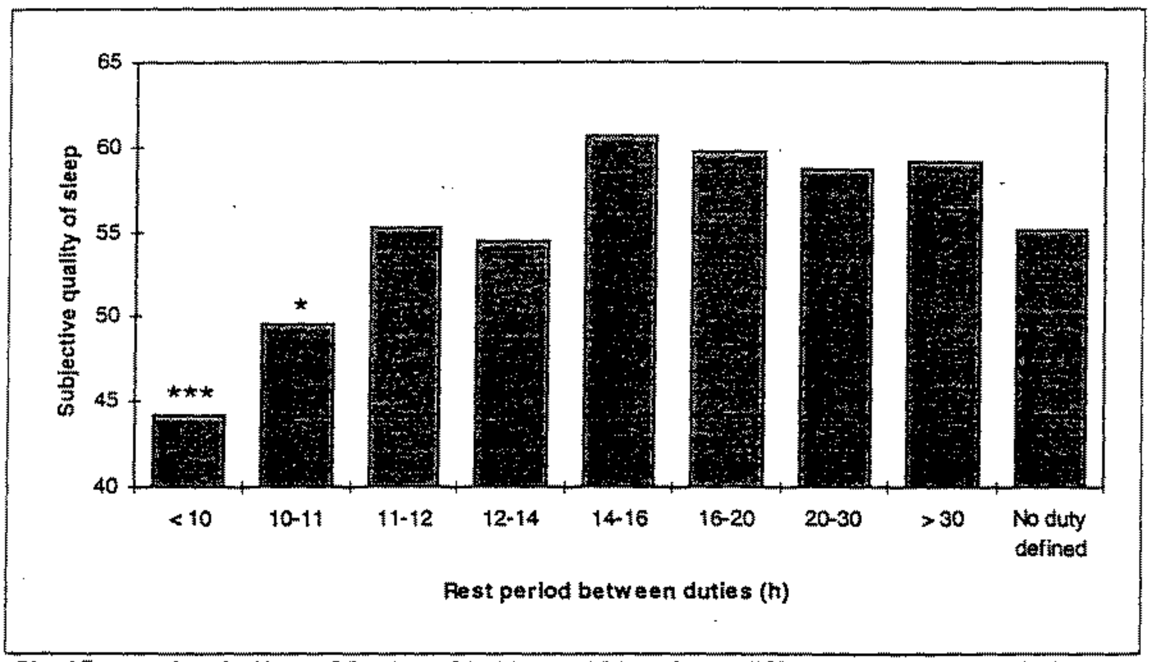
Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from S>0.80.

Figure 15
Sleep quality as a function of sleep requirement



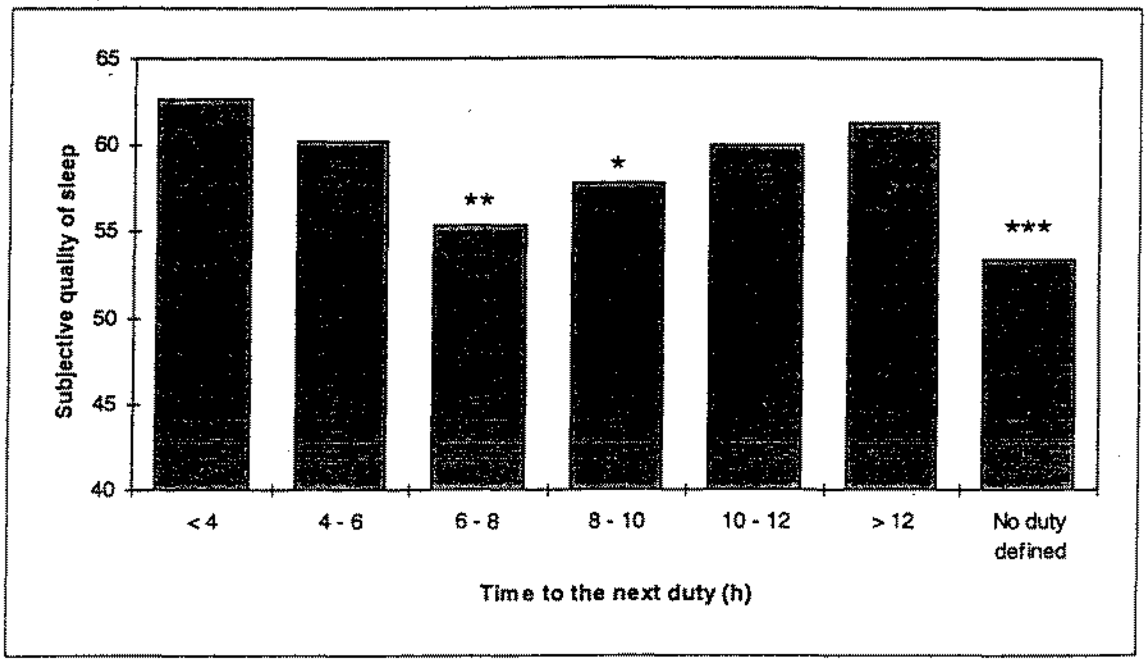
Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from sleep with work rates >10h below Nicholson Curve.

Figure 16
Sleep quality as a function of work rate



Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from sleep during rest periods >30h.

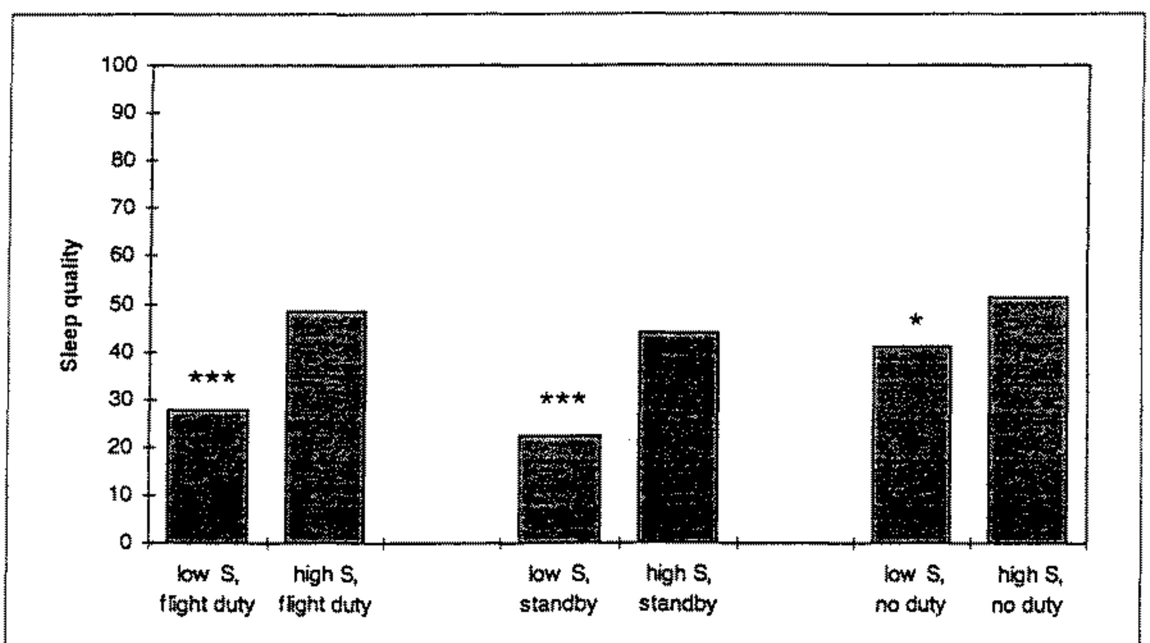
Figure 17
Sleep quality as a function of the duration of the rest period



Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from sleep with >12h to the start of the next duty.

Figure 18

Sleep quality as a function of the amount of time to the start of the next duty



Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences between low and high S within type of duty.

Figure 19

Sleep quality as a function of sleep requirement and the type of the next duty

Annex A

POSITION : CP [redacted] FO [redacted]

AGE : [redacted] Years

AIRCRAFT TYPE : [redacted]

OPERATOR : [redacted]

ANNEX A
to PLSD/CHS5/CR96/082

SECTION 1 - TO BE COMPLETED BEFORE EACH SLEEP

DATE
day mnth yr

TIME
hrs min
Local time

Airport code
LOCATION

HOW DO YOU FEEL NOW?
Extremely tired — Extremely alert

ON AVERAGE, SINCE YOU LAST SLEPT, HAVE YOU FELT?
Extremely tired — Extremely alert

WERE YOU ON DUTY TODAY? No Yes

Please fill in details of the Flight/Duty times on the back page, if appropriate

WHAT WAS THE OVERALL WORKLOAD FOR THIS DUTY?
Extremely low — Extremely high

HOW DID YOU FEEL AT THE END OF THE DUTY PERIOD?
Extremely tired — Extremely alert

WHA T THIS TIME?
Tiredness
Flight schedule
Local bedtime
Other reason

COMMENTS

SECTION 2 - TO BE COMPLETED AFTER EACH SLEEP

	day	mnth	yr
DATE (on getting up)			

	hrs	mins	
IN BED AT :			Local time
ASLEEP AT :			
WAKE UP AT :			
GET UP AT :			

HOW WOULD YOU RATE THE OVERALL QUALITY OF YOUR SLEEP?

Extremely poor ——— Extremely good

DID YOU WANT T N YOU DID?

Much more ——— Much less

HOW DID YOU FEEL AFTER YOU WOKE UP?

Extremely tired ——— Extremely alert

WHAT WAS THE REASON FOR YOUR AWAKENING?

Natural awakening ☐ Planned awakening ☐ Disturbance ☐ Other reason ☐

DID YOU WAK NT TIME?

No ☐ Yes ☐

If your answer is y e the following

Awakening	Approx. time hrs	Approx. time mins	Approx. duration hrs	Approx. duration mins
Longest				
2nd longest				
3rd longest				

COMMENTS

ANNEX A
to PLSD/CHS5/CR96/082

TYPE OF DUTY F/S/P/O Flying Standby Positioning Other	DATE		FLIGHT		REPORTING TIME (GMT) (or start of non-flying duty)		PUSH BACK (GMT)		ENGINES OFF (GMT) (or end of non-flying duty)	
	Day	Month	From	To	Hrs	Mins	Hrs	Mins	Hrs	Mins

Annex B

Regression model for sleep duration

A regression equation was derived for the sleep duration in hours (y) as a function of time of day (t), sleep history (s), the length of time to the start of the next duty (d), the number of previous night duties (n) and the duration of the rest period (r), as follows:

$$y = \alpha_0 + A_1(s,d)\cos(\frac{\pi t}{12} - \Phi_1(s,d)) + A_2(s,d)\cos(\frac{\pi t}{6} - \Phi_2(s,d)) + \alpha_1 s + \alpha_2 d + C_m$$

where:
t is the time of day in hours at the start of the sleep,
s is the value of the S process,
d is the amount of time in hours from the start of sleep to the next duty, or 10 hours, whichever is the smaller,
C_m takes a value dependent on the duration of the rest period and the number of previous duties, as shown in Table 8.

The values of the constants α_0, α_1 and α_2 are -7.605, 0.489 and 1.883 respectively.

The amplitude and phase of the sinusoidal functions relating time of day to sleep duration are dependent on both sleep history (s) and the length of time to the start of the next duty period (d). These four functions $A_1(s,d)$, $A_2(s,d)$, $\Phi_1(s,d)$ and $\Phi_2(s,d)$ are given by:

$$A_1^2(s,d) = [\,(0.128 - 0.300s - 0.004d)^2 + (-2.008 + 1.939s + 0.306d)^2\,]$$

$$A_2^2(s,d) = [\,(1.077 + 0.265s - 0.253d)^2 + (2.098 - 3.295s + 0.066d)^2\,]$$

$$\tan(\Phi_1(s,d)) = [\,(0.128 - 0.300s - 0.004d) / (-2.008 + 1.939s + 0.306d)\,]$$

$$\tan(\Phi_2(s,d)) = [\,(1.077 + 0.265s - 0.253d) / (2.098 - 3.295s + 0.066d)\,]$$

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Annex C

Regression model of sleep quality

A regression equation was derived for subjective sleep quality (y) as a function of time of day (t), sleep history (s), duty history (n), the length of time to the start of the next duty period (d), the duration of the rest period (r) and the type of the following duty (f), as follows:

$$y = \alpha_0 + \alpha_1(f) + \alpha_2(n) + \alpha_3 r + \alpha_4 F(d) + A_1(d)\cos(\frac{\pi t}{12} - \Phi_1(d)) + A_2(d)\cos(\frac{\pi t}{6} - \Phi_2(d)) + B(f)s$$

where:
t is the time of day in hours at the start of sleep,
s is the value of the S process,
r is the duration of the rest period in hours, or 16 hours, whichever is the smaller,
d is the time in hours to the start of sleep to the start of the next duty period, or 14 hours, whichever is the smaller,
f is a variable which takes a value of 1 when the following duty is a flight or positioning, a value of 2 if it is stand-by or another type of duty and a value of 3 if there is no recorded duty after sleep,
n is a variable which takes a value of 1 if the cumulative duty hours exceeds the level of the Nicholson Curve by more than 10 hours, and 2 otherwise.

The function F(d), relating to the time to the start of the next duty (d) takes one of three forms, depending on the value of d:

$$F(d) = 7 - d \ (d \leq 7 \text{ hours})$$
$$F(d) = d - 7 \ (d > 7 \text{ and } d \leq 14 \text{ hours})$$
$$F(d) = 7 \ (d > 14 \text{ hours})$$

The values of the constants α_0, α_3 and α_4 are -91.2, -.0384 and 1.259 respectively. The constant $\alpha_2(n)$ is 46.7 when n equals 1 and 57.2 when n is 2. The constant $\alpha_1(f)$ is 53.3 when f is 1 (flight duty or positioning), 60.2 when f is 2 (standby) and 81.1 when f is 3 (no duty).

B(f) is a function which takes the value 46.1 when f is 1, 29.5 when f is 2 and 2.39 when f is 3.

The amplitude and phase of the sinusoidal functions relating time of day to sleep quality are dependent on the length of time to the start of the next duty period (d). These four functions $A_1(d)$, $A_2(d)$, $\Phi_1(d)$ and $\Phi_2(d)$ are given by:

$$A_1^2(d) = [\,(0.008 + 0.022\,F(d))^2 + (3.746 - 0.021\,F(d))^2\,]$$
$$A_2^2(d) = [\,(2.162 - 0.354\,F(d))^2 + (5.447 - 0.399\,F(d))^2\,]$$
$$\tan(\Phi_1(d)) = [(0.008 + 0.022\,F(d)) \,/\, (3.746 - 0.021\,F(d))]$$
$$\tan(\Phi_2(d)) = [(2.162 + 0.354\,F(d)) \,/\, (5.447 - 0.399\,F(d))]$$

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REPORT DOCUMENTATION PAGE

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1. DRIC Reference (to be added by DRIC)	2. Originators Reference PLSD/CHS5/CR96/082	3. Agency Reference -	4. Report Security Classification/Marking UNCLASSIFIED
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5a. Sponsoring Agency's Code S/952/1	6a. Sponsoring Agency (Contract Authority) Name and Location Civil Aviation Authority, Aviation House, Gatwick Airport, West Sussex.		
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16. Descriptors (Keywords) (Descriptors marked * are selected from TEST)

Sleep Patterns, Aircrew, Workload.

17. Abstract Tick here ...... if summary from title page is to be inserted.

Sleep log questionnaires were completed by 175 aircrew on charter/air haulage operations. Details of sleep and duty were obtained typically over a period of 4 weeks. The timing, duration and subjective quality of each sleep period were recorded, as well as subjective assessments of alertness both before and after sleep. Duration and quality of sleep were affected by the timing of the next duty period. Periods of duty involving consecutive early starts led to an accumulation of sleep deficit. In addition to the time of day, other factors affecting sleep duration and quality included the requirement for sleep as measured by Process S, the duration of the rest period and the number of preceding consecutive night duties.

NOTES ON COMPLETION OF DRA REPORT DOCUMENTATION PAGE

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