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Aircrew alertness during short-haul operations, including the impact of early starts

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Executive summary

Terms of reference

This study of the short-haul operations of bmi British Midland (bmi) has been carried out for the Civil Aviation Authority (CAA) by QinetiQ (formerly DERA) Centre for Human Sciences (CHS) under contract number 7D/S/952/4.

Background

The computer program SAFE (System for Aircrew Fatigue Evaluation) is currently being developed by the CHS to predict the levels of fatigue in civil air operations. The most recent version has recently been distributed as a beta copy to the airline industry for evaluation. As part of a programme of work to validate the model that forms the basis of SAFE, the CHS is undertaking a series of studies of aircrew fatigue in current operations. Two studies have been carried out of short-haul operations, one with KLM UK, the other with bmi British Midland. This report describes the second of these studies.

Methodology

Diaries were sent to a total of 476 British Midland pilots, based at either London Heathrow or East Midlands airport. They were asked to complete them over a period of 28 days. This involved the crews providing details of their sleep (timing and quality) on a daily basis, and of each flight duty period (FDP) that they undertook. Information was requested on each flight within the FDP, including the timing (blocks off and blocks on), the level of 'hassle'[1] associated with the flight and the level of fatigue (on a modified 7-point Samn-Perelli scale), at the end of the flight.

The analysis of the information from the diaries concentrated on the identification of those factors that contributed to a build up in fatigue. Special attention was given to early starts, as these feature in a large proportion of bmi operations. The statistical methodology enabled the effect of each factor to be estimated after correcting for the influence of all other significant factors.

The sample

A total of 157 diaries were returned, 124 from Heathrow and 33 from East Midlands, a response rate of 33%. The responses included 2629 FDPs and 6413 individual flights, giving an average of 2.4 sectors per duty. The average length of each FDP was 8.0 hours and the average length of each flight was 1.6 hours.

Early starts

The duration of sleep prior to an early start was reduced, the reduction amounting to almost an hour for report times between 07:00 and 08:00 and to almost two hours for report times between 05:00 and 06:00. This was because the advance in wake-up times was not matched by an equivalent advance in the timing of sleep onset.

Duties starting before 09:00 were associated with an increase in fatigue throughout the following duty period. Fatigue also increased during schedules that included several consecutive duties that started at 08:00 or earlier. This was in addition to a cumulative effect that applied, particularly

[1] Hassle was chosen as a term used and understood by aircrew to represent the unanticipated problems associated with the flight that contribute to increased workload.

among the captains, to a sequence of duties on consecutive days, irrespective of the duty start time. Among the First Officers there was a tendency for fatigue levels to reduce when the start time occurred before 06:00.

Duties starting at 07:00 (local European time) or earlier were associated with higher levels of fatigue when they occurred after an overnight stop on the mainland of Europe.

Other factors influencing fatigue

The factor that was most highly correlated with fatigue was the amount of hassle that the aircrew reported during the flight. Other factors included the time of day, with aircrew reporting their highest levels close to 07:00, time since sleep and time on duty. The time since sleep effect was linear, but the effect of time on duty was a quadratic function of the duration of the duty period. The combined effect of time since sleep and time on duty represented an average increase of 0.14 per hour on the 7-point fatigue scale during the first 5 hours of a duty period, and of 0.20 per hour during the second 10 hours.

Fatigue also increased with the number of sectors flown. The increase from a one to a 4-sector duty was equivalent to the effect of an additional 2.77 hours duty, or approximately 55 minutes duty per sector.

There were no differences in overall levels of fatigue among aircrew at the two bases. However, those at Heathrow tended to report more tiredness when the duty period started late in the day and less for departures between 09:00 and 14:00.

Conclusions

The fatiguing effect of early starts is less strong than previously estimated. However, it becomes more pronounced when several early starts are operated without an intervening rest day. The current version of SAFE will be amended to take into account these findings. However, the unexpected reduction in fatigue with very early starts (those before 06:00) will not be incorporated until it is independently corroborated.

The main factor influencing fatigue in multi-sector short-haul operations was hassle. Currently, this is not included in the SAFE program. The influence of other factors, such as time of day, time on duty and the number of sectors is broadly similar to the results of the previous study. The confirmation of the effects of these factors will give greater credibility to the computer model, which will now incorporate the results from two independent short-haul operators.

Information from consecutive night duties is required to complete the validation of the model with respect to short-haul operations.

Recommendations

This study has provided further evidence to support the previous recommendation that early starts should be defined with respect to home time rather than local time during a night stop on the mainland of Europe.

While the main purpose of this work has been to validate the computer model, the results provide information to guide the definition of future flight time limitations. In particular, they support the provision of a reduction in the FDP according to the number of sectors flown, and suggest that the 45 minutes per sector provided by CAP371 (Table A) should not be reduced.

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1 Introduction

1.1 Terms of reference

1.1.1 This study of aircrew fatigue in short-haul operations was carried out on behalf the Safety Regulation Group of the Civil Aviation Authority (CAA) under contract number 7D/S/952/. It is part of an on-going programme of work into the sleep and wakefulness of the airline pilot.

1.2 Background

1.2.1 The main purpose of this study was to provide information to validate the computer program SAFE (System for Aircrew Fatigue Evaluation), which is currently being developed for the CAA by the Centre for Human Sciences (CHS). This program predicts the average levels of fatigue that are likely to be experienced by crews during different types of operation. It has been designed both to guide operators in the planning of acceptable duty rosters and to enable the regulator to evaluate the fatigue implications of proposed duty schedules.

1.2.2 An initial version of SAFE was developed as a proof-of-concept prototype, based on the CHS Alertness Model [1]. It was recognized, however, that there were many areas where knowledge was lacking and, accordingly, a strategy was drawn up for the further development of the program [2]. The main requirement was to obtain information on the alertness of aircrew in flight, to validate the model which, up until that time, had been based primarily on the results of laboratory investigations.

1.2.3 One area where the initial version of the program was deficient was in the modelling of short-haul operations, particularly those involving multiple sectors. To rectify this, a study was carried out of the short-haul operations of one major UK carrier, KLM UK [3]. This carrier was chosen because of the large number of operations involving duties with 4 or more sectors. The results of this study enabled the computer model to be adapted to incorporate the effects of multiple sectors, as well as the effects of other factors that were a feature of these operations, such as consecutive early starts. These changes have been included in the latest version of SAFE, version 2.09, a beta copy of which has now been distributed within the airline industry.

1.2.4 Although the KLM UK data included many examples of duty periods with early report times (i.e. before 07:00), there was some concern that the conclusions drawn from that study may not have been fully representative of the general experience of aircrew with respect to early starts. This was mainly due to the unexpected nature of some of the findings, which are briefly described below (section 1.3). It was therefore considered unwise to base this aspect of the program entirely on the results from one operator.

1.2.5 Since the operations of British Midland were known to involve a large number of start times before 06:00, possibly with more examples of consecutive early starts than KLM UK, it was decided to approach this operator to carry out a similar study of their operations. The management and aircrew of British Midland kindly agreed to participate. While this study would provide additional information on other factors, including multiple sectors, that are a feature of short-haul operations, the main purpose was to establish the impact of early start times on fatigue.

2 Methods

2.1 Background

2.1.1 The methodology adopted was similar to that of the previous KLM UK study [3]. All the BM crews based at LHR and EMA were asked to complete a diary of their sleep and alertness over a period of 28 days.

2.2 The diary

2.2.1 The first page of the diary included general information on age, position (captain, co-pilot), gender, airport base, type of aircraft flown and number of years on type. The rest of the diary consisted of alternating sleep and duty pages. Participants were requested to complete a sleep page each day throughout the 28-day period. For the days that they were on duty, they were asked to complete the corresponding duty page. As a result of experience gained from the previous study, some minor changes to the diary were made, but the information requested and the diary layout were broadly comparable. The sleep and duty pages are reproduced at Appendix A.

2.2.2 The duty section included details of the report time, duration of the journey to the airport, the airport code and a pre-flight fatigue assessment. Throughout the diary the same fatigue assessment was used, namely the modified Samn-Perelli 7-point scale [12]. For each sector during the duty period, crews were asked to provide information on the timing (blocks off and on), their post-flight fatigue and an evaluation of the level of hassle they had experienced during the flight. The term 'hassle' was chosen, as in the previous study, to represent the unanticipated problems associated with the flight that contribute to an increased level of workload. Other questions related to the period between the end of one flight and the start of the next. Space was provided on the duty page for a maximum number of 6 sectors.

2.2.3 For the sleep section crews were asked to rate their level of fatigue before retiring to bed and to indicate whether they were sleeping in an hotel or at home. After waking, they provided details of the timing and quality of sleep, and rated their level of fatigue. All times in this section were reported in UK local time (GMT +1 at the time of the study) even if crews were spending the night in Europe. The duration of any naps were recorded in the sleep section. A small area for comments was provided on the sleep page and further pages were provided at the back of the diary for any additional comments.

2.3 Distribution

2.3.1 Initial details of the study were publicised in the company newsletter. This was followed by a letter to all crews from the Pilot Medical Officer, describing the study and encouraging all pilots to participate. DERA CHS then sent a pack of information to the home address of all pilots based at either Heathrow (387) or East Midlands (89). The pack contained the diary, an explanatory letter detailing the background to the study, an overview of the study, and a return envelope addressed to CHS.

2.3.2 The crews completed the diaries anonymously, and all the information received was treated in the strictest confidence.

1.3 Early starts

1.3.1 It has been shown that shiftworkers starting work at 06:00 have difficulty in obtaining adequate sleep at the start of duty [4]. This is not entirely due to environmental factors and social pressures, but may also reflect the influence of the 'forbidden zone' for sleep [5], which is a period in the evening, lasting for about 4 hours, when the ability to fall asleep is considerably reduced. The loss of sleep is accompanied by increased levels of tiredness at the end of a shift [6,7], and subjective levels of fatigue may accumulate over consecutive early starts [8].

1.3.2 Evidence from aircrew, though sparse, tends to show similar effects. There are indications that early start times, particularly those before 06:00, impair levels of performance and that this impairment persists at least until the top of descent [9]. The KLM UK study suggested that duties before 09:00 were associated with reduced sleep and increased levels of fatigue and that, when the report time is before 07:00, the increase in fatigue is similar to the effect of an extra 3 hours of duty.

1.3.3 There is also some evidence that levels of sleepiness on waking increase over consecutive early starts [10], though it has not been established whether this is reflected in reduced levels of alertness during the duty periods themselves. There was no evidence from the KLM UK study of any cumulative effect of early starts, other than that associated with consecutive duties starting at any time of day. This is in contrast to anecdotal reports from aircrew, which suggest that consecutive early starts are often associated with increasing levels of fatigue. This may have arisen because of an increasing sleep debt over successive days, if crews are unable to adjust their sleep to the advanced time [3]. In the previous study there was a small adjustment before the 2nd early start, but little evidence of any subsequent adjustment. This pattern is supported by studies of shiftworkers [11]. The present study has been designed to establish the significance of any such cumulative effect.

1.4 British Midland (BM) operations

1.4.1 British Midland crews were asked to participate in the study because BM operates predominantly short-haul routes between the UK and mainland Europe, with a high proportion of early starts (before 07:00). Whilst the airline operates out of a number of UK bases, including London, Heathrow, East Midlands, Manchester and Edinburgh only two bases were selected for inclusion in the study. These were London Heathrow (LHR) and East Midlands airport (EMA). Heathrow was chosen because the largest number of aircrew were based there and the schedules included a high proportion of early starts. EMA was selected as an alternative base that was representative of a regional airport.

1.4.2 The study was carried out during the summer of 2000 with the help and co-operation of both BM and the British Airline Pilots Association.

2.4 Analysis

2.4.1 As is normally the case in field trials, where it is not possible to control the circumstances in which the data are collected, special procedures are required for the data analysis. One approach is to analyze subsets of the data which are homogeneous. However, this has the disadvantage that those data that cannot easily be categorized are not included in the analysis. The approach adopted here, as in several previous studies of aircrew fatigue, was to use methods that are applicable to unbalanced designs and which permit all the data that have been collected to be included.

2.4.2 The principal analysis described in this report was of the levels of fatigue reported by the crews at the end of each flight. The methodology used was based on unbalanced repeated measures analysis of variance (ANOVA) models. These models were valid for all analyses carried out, despite the unequal cell sizes and the discrete nature of the measurement of fatigue. Ordered data with large samples have been shown to behave as an approximate normal distribution, so that the F-test derived from the ANOVA model is appropriate as the most powerful test.

2.4.3 The purpose of using these models was to enable the effects of different factors to be estimated, after correcting for the influence of all other significant factors. The mean values from this analysis that are quoted in this report have, unless otherwise stated, had this correction applied to them, and are different from the raw means. The error bars in the figures refer to standard errors that have been obtained from the ANOVA.

2.4.4 The main factors that were considered for inclusion in the analysis were the following:

i the time of day, in one-hour intervals;

ii the length of the duty period in one-hour intervals (i.e. the time that had elapsed between the start of duty and the time of the fatigue assessment);

iii the total amount of flying up until that point (in one-hour intervals);

iv the number of sectors that had been flown up until that time;

v the level of hassle associated with the last sector, on a scale from 1 to 5;

vi the time that had elapsed since the end of that individual's last main sleep period (in one hour intervals);

vii report time, in one-hour intervals;

viii the number of consecutive duty days;

ix the number of consecutive early starts (i.e. before 07:00). Consecutive duties starting a) before 08:00 and b) before 09:00 were also investigated.

2.4.5 Not all factors could be included in the same analysis. For example, the three factors of time of day, length of duty and report time are confounded. There is also a strong relationship between length of duty and time since sleep which explains why time since sleep was not considered for inclusion in the analysis of the KLM UK data.

2.4.6 The approach adopted here was to attempt to simplify the contribution of the individual factors once their significance had been established. To achieve this, the individual factor levels were replaced by 'contrasts' representing smooth functions of the factors. For example, a sinusoidal function was used for the time of day effect and a polynomial function for the time since sleep effect. The investigation of the effect of report time concentrated on early report times (those before 09:00) as the effect of early starts was one of the main subjects of the study.

2.4.7 Informal stepwise procedures were used to derive the function of the various factors that best explained changes in levels of fatigue. The effect of each individual factor was then estimated in the presence of the other factors that were included in this 'best' fit, and these are the estimates that are plotted in the following section, together with their standard errors. These plots, therefore, illustrate the effect of each factor after it has been corrected for the influence of all other significant factors.

2.4.8 Once the best fit for the main factors was established, the influence of other factors was investigated. These included the duration of travel to the airport, and inter-individual factors such as age, position, aircraft type and base location. Where the data permitted, interactions between the various factors were also considered.

2.4.9 One factor that was investigated was the effect of a time-zone transition, together with the interaction between a time-zone transition and an early start. This was to establish whether the effect of an early start was exacerbated, for example, immediately after the one-hour advance from the UK to the continent of Europe.

3 Results

3.1 The sample

3.1.1 Of the 476 diaries that were distributed, 157 were returned, representing a response rate of 33%. A total of 78 captains and 79 co-pilots participated in the study, of whom 151 were male and 6 female. Ages ranged between 23 and 59 years, with a mean of 37.6 years. The average age of the captains was 42.6 years and for the first officers it was 32.7 years. There were 124 returns from pilots based at LHR (120 men, 4 women) and 33 from EMA (31 men, 2 women).

3.1.2 Most pilots (53%) were flying the B737 aircraft, compared with 29% flying the A320/321 and 18% the Fokker 100/70. On average, crews had 3.6 years experience on type, with a maximum of 12 years.

3.2 The schedules

3.2.1 Data were collected from a total of 4613 days, which included 2629 flight duty periods (FDPs) and 6413 individual flights. On average, therefore, individual pilots completed the diary for a total of 29 days, which included 17 FDPs, with a mean of 2.4 flights per duty period.

3.2.2 The large majority of flights were between locations in North-West Europe. The airports from which at least 10 departures were reported are listed in Table 3-1.

Airport	Number of departures	Airport	Number of departures
London Heathrow	2342	Munich	72
East Midlands (Derby)	378	Cologne	71
Edinburgh	349	Hanover	70
Manchester	288	Stuttgart	61
Glasgow	261	Birmingham	60
Paris(Charles de Gaulle)	234	Jersey	54
Amsterdam	225	Leeds/Bradford	51
Dublin	192	Luton	47
Belfast	166	Budapest	32
London Stansted	156	Copenhagen	25
Brussels	137	Malaga	18
Milan	114	Corfu	18
Frankfurt	114	Faro	14
Rome	113	Larnaca	12
Madrid	108	Naples	11
Hamburg	101	Gerona	11
Dusseldorf	88	Cagliari	11
Teesside	87	Santa Cruz de Tenerife	10
Palma de Mallorca	77	Menorca	10
Nice	72	Gran Canaria	10

Table 3-1 Number of departures (≥10) from different airports

3.2.3 The distribution of reporting times over the 24-hour day is shown in Figure 3-1. Approximately 33% of FDPs started in the two hours leading up to 07:00. There are two smaller peaks, one just after mid-day, and the other in the late afternoon. There were just 86 night duties, where a night duty was defined as one starting before midnight and ending after 02:00.

3.2.4 The majority (54%) of FDPs were between 6 and 10 hours, with a mean of 8.0 hours (Figure 3-2). The average length of each individual flight was 1.6 hours (Figure 3-3).

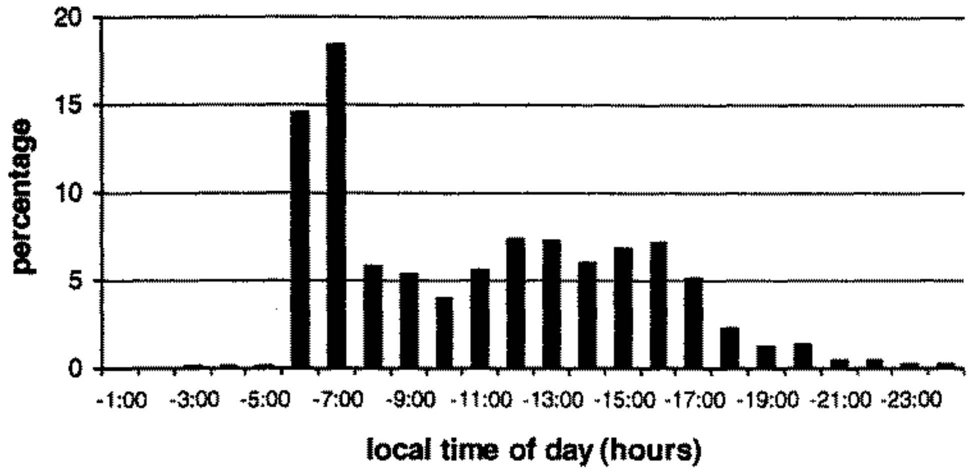

Figure 3-1 Distribution of reporting times

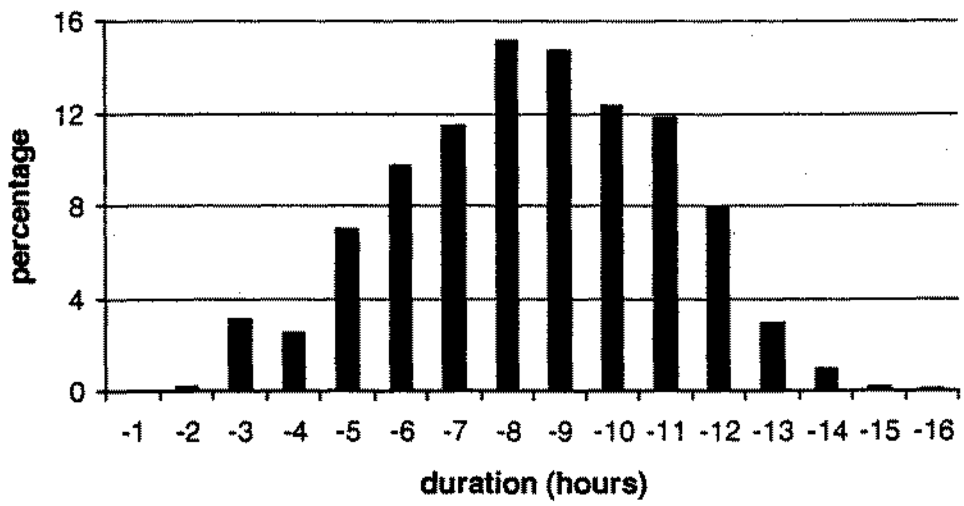

Figure 3-2 Distribution of the duration of the FDPs

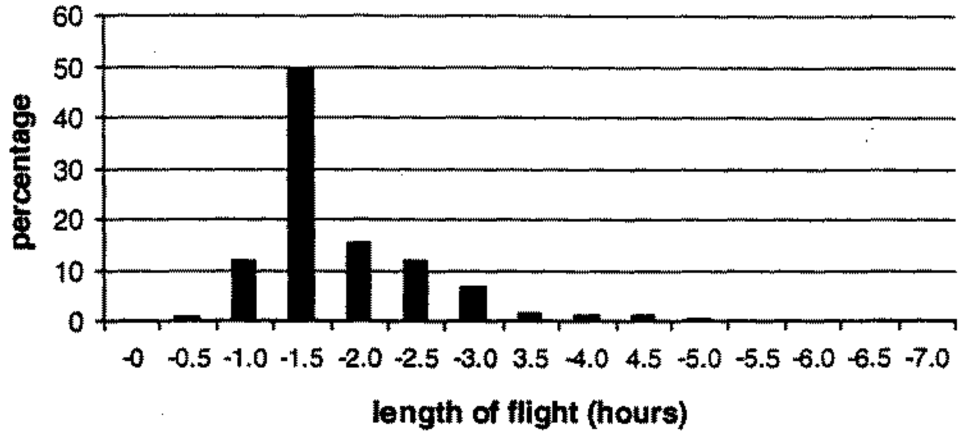

Figure 3-3 Distribution of the length of individual flights

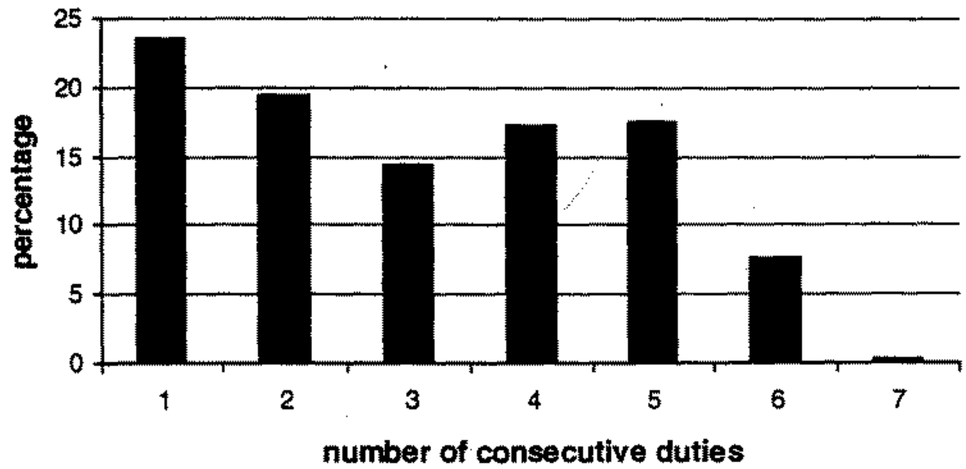

Figure 3-4 Distribution of the number of consecutive flying duty days

3.2.5 The number of consecutive duties without a rest day varied between one and (in just 2 cases) 7 (Figure 3-4).

3.3 Sleep

3.3.1 The average sleep times prior to report times at different times of day are shown in Figure 3-5. When the report time was later than mid-day, the average time of awakening was after 08:00 whereas, when it was before mid-day, crews tended to wake up before 08:00. As the report time advanced from between 10:00 and 11:00 to between 05:00 and 06:00, the wake-up time advanced by approximately 3 hours from 07:27 to 04:26. Over the same range, bed-time advanced by 71 minutes, and sleep onset by just 64 minutes. As a consequence, average sleep time, as defined by sleep onset to final wake-up, increased from 5.88 hours for duties starting between 05:00 and 06:00, to 6.90 hours for duties starting between 07:00 and 08:00, and to 7.83 hours for duties starting between 10:00 and 11:00.

3.3.2 The means in Figure 3-5 were calculated after excluding those duties that immediately followed a night duty.

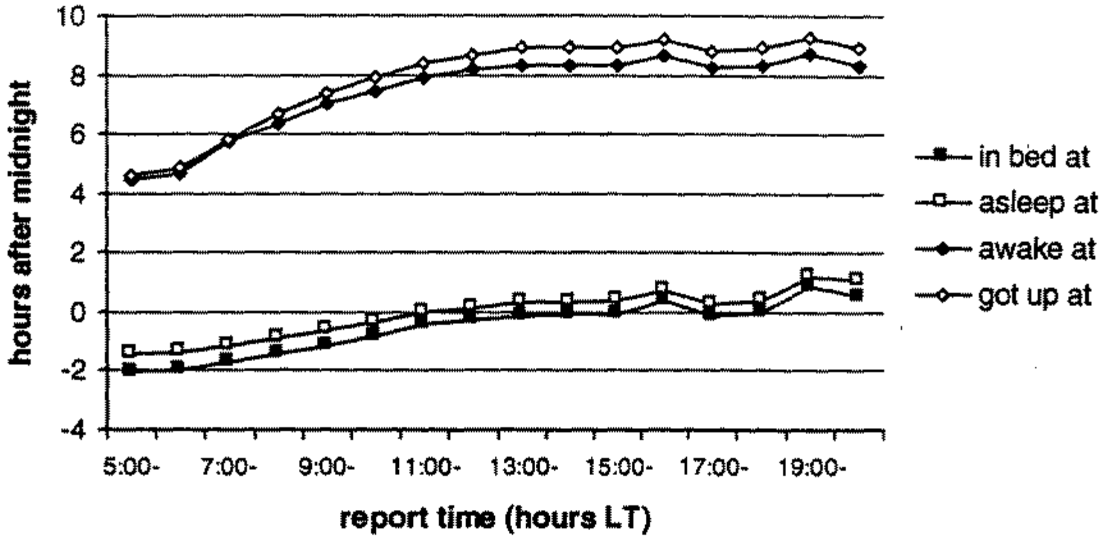

Figure 3-5 The timing of sleep prior to duty starting at different times of day

3.4 Fatigue

3.4.1 The various factors that were found to influence levels of subjective fatigue at the end of a flight are described below.

3.4.2 **The amount of hassle.** The level of hassle associated with a flight had a significant effect on fatigue (F=62.68, n=4/5489, p<0.001). Fatigue levels increased as the level of hassle increased from 1 to 5 (Figure 3-6).

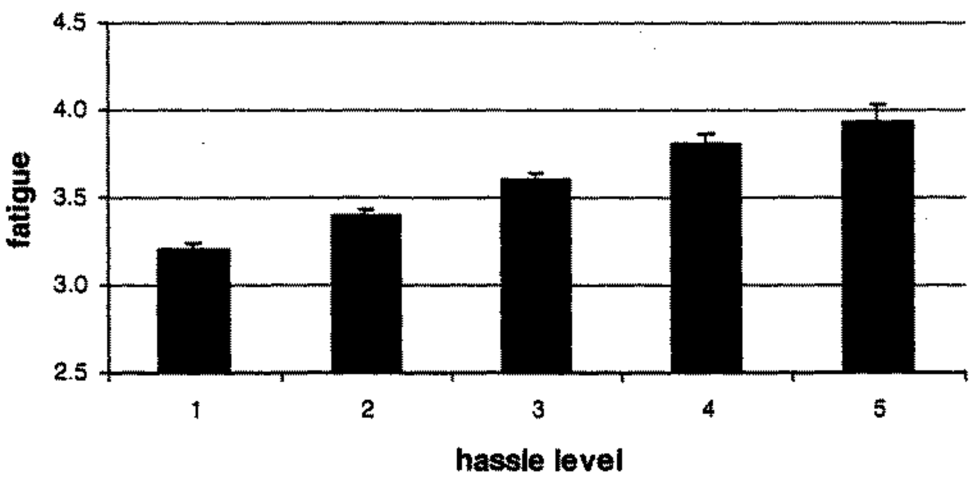

Figure 3-6 The effect of hassle level on fatigue

3.4.3 **The time of day.** The effect of time of day on fatigue (Figure 3-7) was explained by a sinusoidal function with an amplitude of 0.318 and a peak at 06:52 ($F=54.66$, $n=2/5489$, $p<0.001$). However, in the raw data the peak occurred between 05:00 and 06:00.

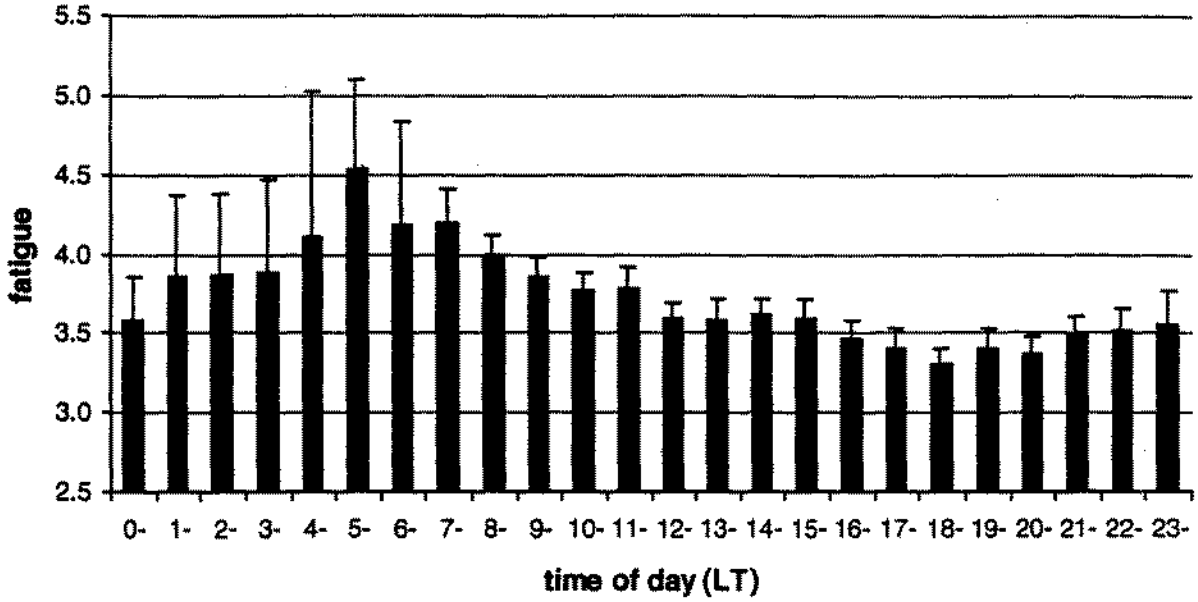

Figure 3-7 The effect of time of day on fatigue

3.4.4 **Time since sleep.** The effect of time since sleep on fatigue (Figure 3-8) was explained by a linear function of the time that had elapsed since the end of the last main sleep period ($F=45.09$, $n=1/152$, $p<0.001$). The linear function represented an increase of 0.06 on the fatigue scale for each additional hour of wakefulness.

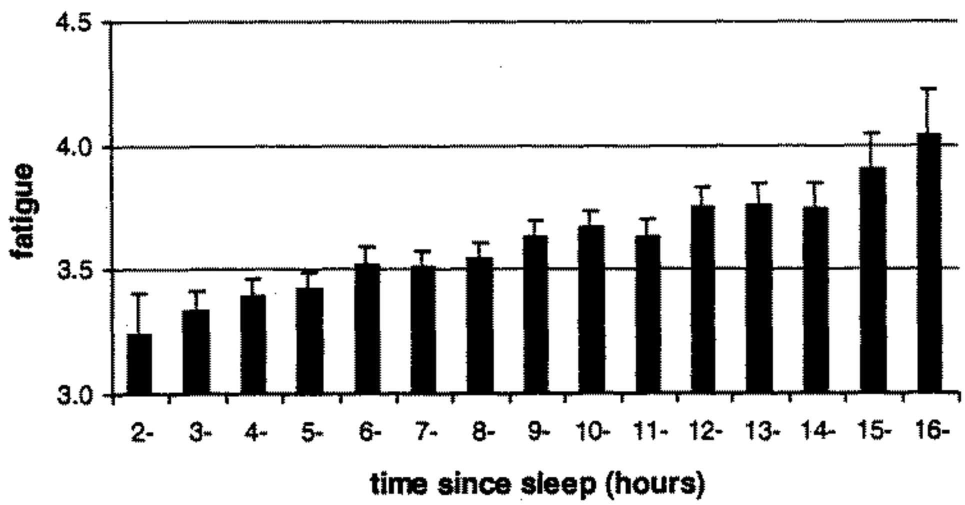

Figure 3-8 The effect of time since sleep on fatigue

3.4.5 **The length of time on duty.** The effect of time on duty (Figure 3-9) was explained by a quadratic function of the length of the duty period ($F=7.12$, $n=1/5489$, $p<0.001$). This represented an increase on the 7-point fatigue scale of $0.045d + .0064d^2$ after a duty of length d hours. Therefore, during the first 5 hours of a duty period, fatigue increased by an average of 0.08 per hour, and during the second 5 hours by an average of 0.14 per hour. This was in addition to the increase associated with time since sleep.

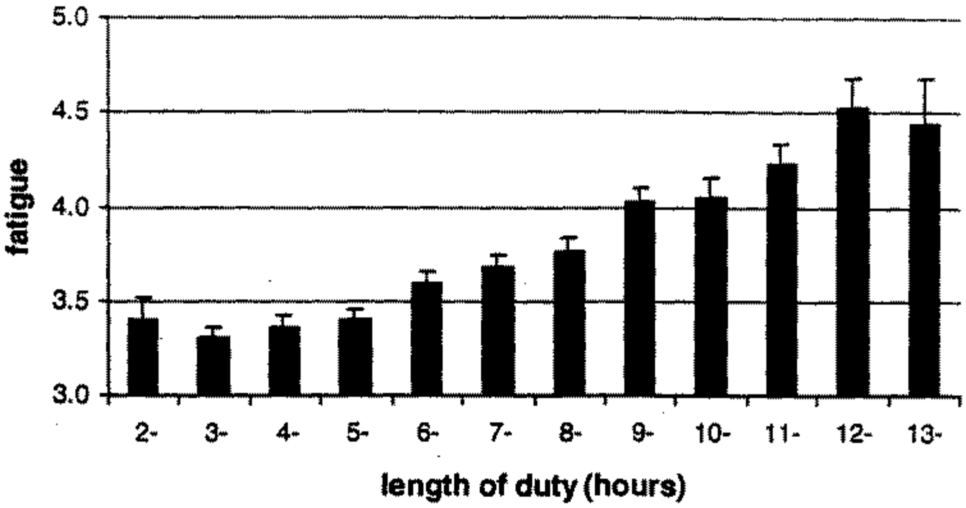

Figure 3-9 The effect of length of duty on fatigue

3.4.6 **The number of sectors.** Levels of fatigue increased with the number of sectors flown ($F=11.95$, $n=5/5489$, $p<0.001$; Figure 3-10).

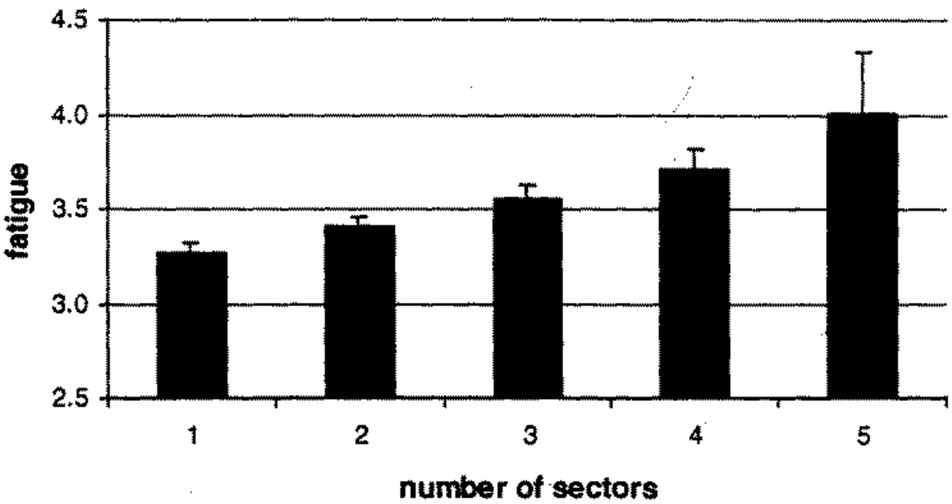

Figure 3-10 The effect of the number of sectors on fatigue

3.4.7 **Duty start time.** Duty start time had an influence on fatigue that was entirely associated with start times before 09:00 ($F=3.98$, $n=5/152$, $p<0.01$; Figure 3-11). Duties starting between 06:00 and 07:00 were associated with an increase in fatigue throughout the entire duty period of 0.22 compared with duties starting later in the day ($p<0.05$). However, the trends in duty start time were slightly different between captains and first officers (see Section 3.4.11).

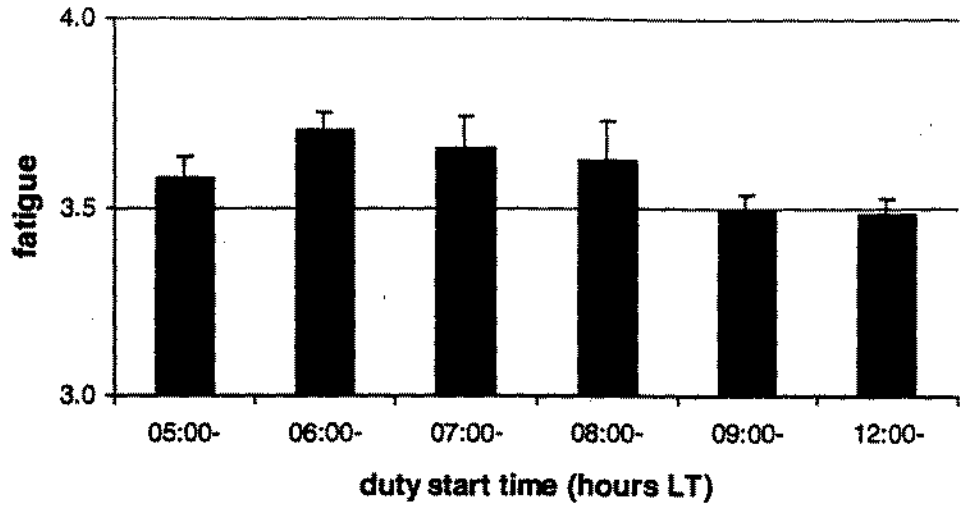

Figure 3-11 The effect of duty start time on fatigue

3.4.8 **The number of consecutive duty days.** There were changes in fatigue associated with the number of consecutive days of duty without a rest day ($F=12.36$, $n=6/152$, $p<0.001$; Figure 3-12).

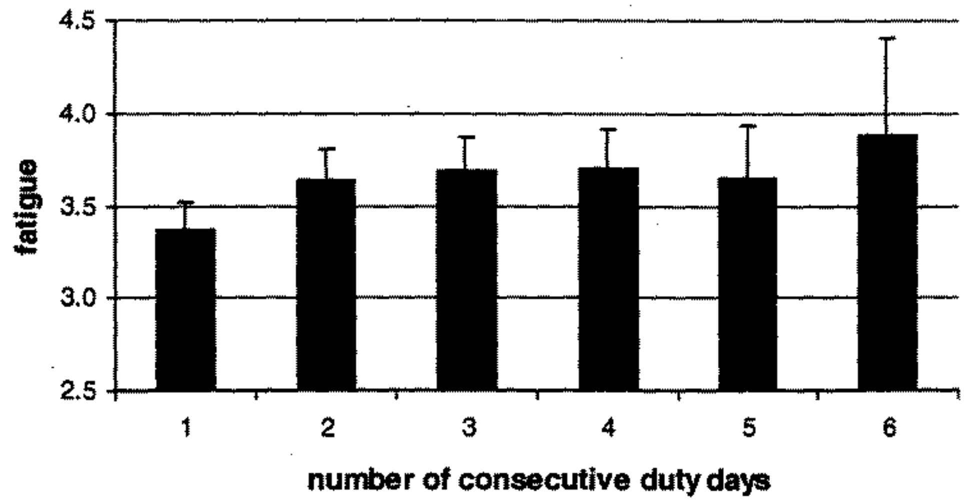

Figure 3-12 The effect of duties on consecutive days on fatigue

3.4.9 **The number of consecutive early starts.** The only significant effect that could be established for consecutive early starts, in addition to the effect of consecutive duties at any time of day, was related to duties at 08:00 or earlier. The main effect of consecutive duties at these times was not itself significant, but there was an increasing trend as the number of consecutive duties increased ($F=3.93$, $n=1/5489$, $p<0.05$; Figure 3-13). This corresponded to an increase of 0.04 on the fatigue scale for each additional duty day.

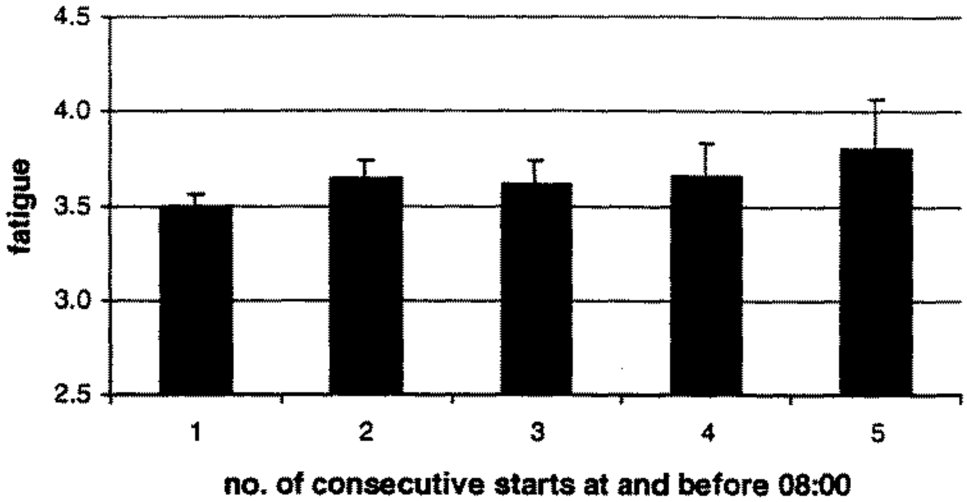

Figure 3-13 The effect of consecutive early starts on fatigue

3.4.10 **Interaction between consecutive duty days and crew position.** The linear increase in fatigue associated with working on consecutive days varied with the seniority of the individual pilot (F=5.89, n=1/5489, $p<0.05$; Figure 3-14). The mean increase was 0.088 per day for captains and 0.044 per day for first officers.

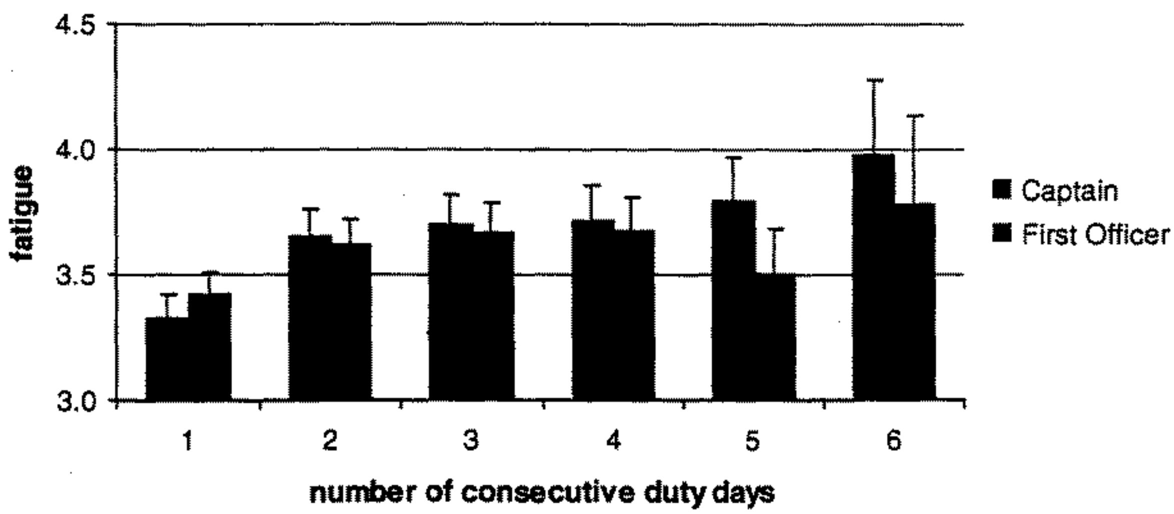

Figure 3-14 The effect of consecutive duty days and crew position on fatigue

3.4.11 **Interaction between report time and crew position.** There was a difference in fatigue associated with early start times according to the seniority of the pilot (F=2.38, n=5/152, $p<0.05$; Figure 3-15). This was explained by the fatigue levels of the first officers during duties starting before 06:00, which were similar to those during duties starting after 09:00.

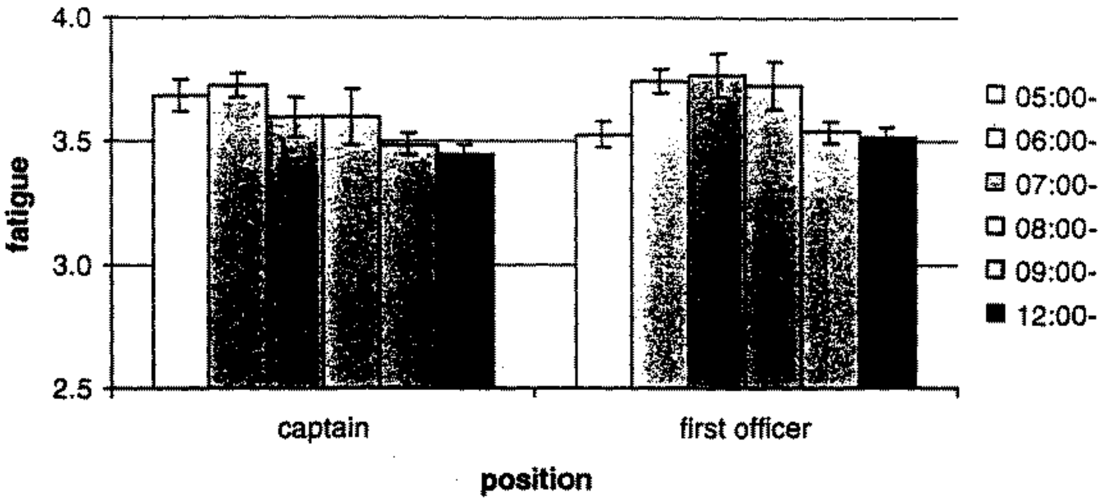

Figure 3-15 The effect of report time and crew position on fatigue

3.4.12 **Interaction between report time and base.** The effect of report time on fatigue varied according to the base location. This interaction was best explained by dividing the duties into three categories, those that started before 09:00, those that started between 09:00 and 14:00, and those that started after 14:00 (F=8.64, n=2/152, p<0.001; Figure 3-16).

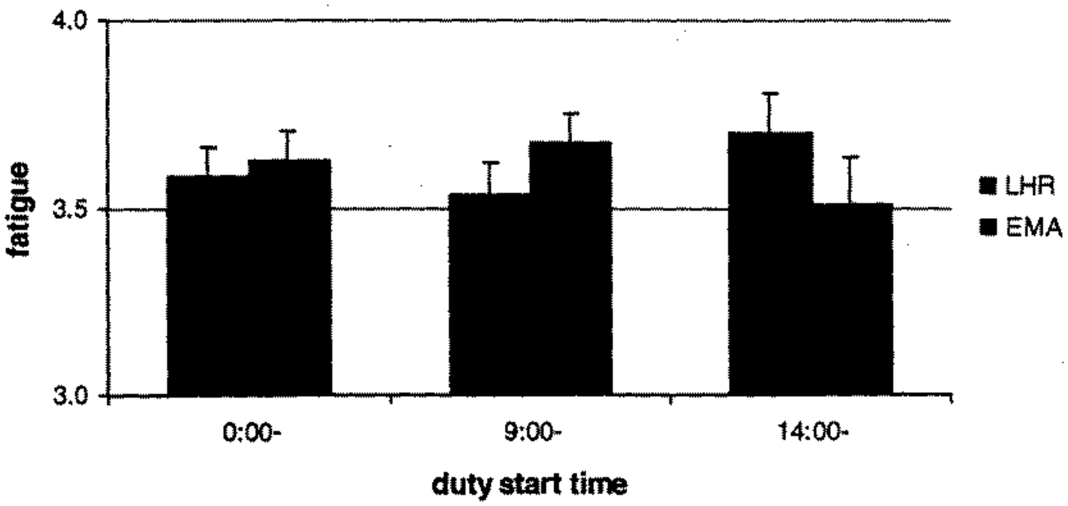

Figure 3-16 The effect of report time and base on fatigue

3.4.13 **Interaction between time-zone changes and early starts.** There were changes in the impact of early starts on fatigue when the pilot had experience of a time-zone change on the previous day. The greatest effect was seen when the start time was 07:00 or earlier (F=3.94, n=1/5488). A time-zone advance of one hour was associated with an increase in fatigue of 0.16 throughout the following duty period.

4 Discussion

4.1 Overview

4.1.1 In the majority of cases, this study has confirmed the results of the previous investigation of the short-haul operations of KLM UK. The flying duties were broadly similar, with a high proportion of report times before 07:00, although there was a larger percentage of very early starts (those before 06:00). The bmi operations also involved more night duties, but these were still a small percentage of the overall total. The workload, in terms of mean sector length and mean duration of FDP, was slightly greater, which may help to explain the somewhat higher levels of subjective fatigue than in the earlier study.

4.1.2 The importance of the level of 'hassle' experienced by the crews in determining the level of fatigue at the end of a sector has again been established. However, while the elimination of the factors that increase the amount of hassle would undoubtedly help to reduce fatigue, they are not directly related to the patterns of duty and are therefore outside the scope of the present study. Nevertheless, it is important to recognize that many short-haul operations are subject to various problems that serve to increase the workload of the crews to a considerable extent, and that this will have an impact on fatigue.

4.1.3 Of the other factors that correlate with fatigue, it is not surprising that the two most significant are the time of day and the time that has elapsed since the end of the last main sleep period (time since sleep). These two factors are the main components of the CHS Alertness Model [13] which forms the basis for SAFE. Indeed, the trend in fatigue as a function of time of day, with lowest levels in the late afternoon, confirms the pattern observed in laboratory studies [14] and adds credibility to the integrity of the subjective data.

4.1.4 In this study it has been possible to separate the effects of time since sleep and time on duty. The results must be treated with some caution since these two factors are partially confounded. However, it is important for an understanding of the basic principles, and therefore for the development of the model, that the effect of increased duty time can be distinguished from the increase that would have occurred during any period of continuous wakefulness. The combined effect of time since sleep and time on duty represents an increase of 0.16 on the 7-point fatigue scale during the 5th hour of duty. This is close to the value of 0.17 per hour of duty derived as a result of the previous KLM UK study. However, the bmi data suggest that this rate increases after the 5th hour. On the basis of this study, therefore, the fatiguing effects of long duty periods may be slightly greater than previously estimated.

4.2 Early starts

4.2.1 The main purpose of carrying out this study was to establish the impact of early duty start times on fatigue. Early starts are defined in CAP 371 as those duties that begin before 07:00. However, the previous KLM UK study suggested that a substantial increase in fatigue is associated with duties starting before 09:00. More unexpectedly, in view of the sleep loss that accumulates over consecutive early starts, no cumulative effect was observed on fatigue, other than that associated with consecutive duties at any time of day.

4.2.2 The results from this study do not entirely support these conclusions. While start times earlier than 09:00 were again identified as a factor contributing to fatigue, the size of the effect was less than before. The tendency for fatigue to reduce when the start time is earlier than 06:00 is difficult to explain particularly as the effect has been corrected for circadian influences. It is possible that some of the effect may have been absorbed by the time of day effect, since some of the flights associated with these very early starts will have ended between 06:00 and 08:00, when the highest levels of fatigue are reported. This is unlikely, however, to provide a complete explanation.

4.2.3 The tendency for reduced levels of fatigue with very early starts applied to the first officers, but not to the captains. Since no such trend was observed with increasing age, in spite of the relationship between age and position, it may be related to the increased level of responsibility. Whatever the cause, it would be unwise to assume that this reduction is a general phenomenon when it is not replicated in an important subset of the data.

4.2.4 Another issue related to early starts is the number that are operated from a continental location on the day after a one-hour time-zone advance. Since early starts are defined with respect to local time, crews may effectively be operating an hour earlier according to their own body clock and sleep propensity. This study has confirmed the additional fatigue associated with such duties, and has reinforced the previous recommendation that, for an overnight stop on the mainland of Europe, early starts should be defined with respect to home time.

4.3 Duties on consecutive days

4.3.1 This study has confirmed the tendency for fatigue to increase over consecutive duty days that has been previously reported both among both shiftworkers [8] and aircrew [3]. However, it remains to be established whether this trend in fatigue extends to performance. It is more clearly identified among the captains than the first officers and, since it correlates more strongly with crew position than age, may again be related to the level of responsibility.

4.3.2 A major finding is that, in contrast to the conclusions of the previous KLM UK study, the cumulative effect of working on consecutive days is more pronounced when the duties involve early starts. The identification of this effect has undoubtedly been assisted by the tendency of the bmi operations to include slightly longer sequences of early starts than those of KLM UK. This effect is in addition to that associated with consecutive duties at any time of day. The combined effect would amount to an average increase of approximately 0.11 per day, which is equivalent, in terms of fatigue, to an extra 40 minutes of duty per day.

4.4 Multiple sectors

4.4.1 The increase in fatigue associated with multiple sectors is in broad agreement with the results of the KLM UK study. However, whereas there was previously no difference between the effect of one and two sectors, the trend here is much closer to linear. The increase in fatigue from one to four sectors, when compared to the effect of duty time, was equivalent to an additional 2.77 hours duty, compared with the value of 2.67 hours from the KLM UK study. The findings from the two studies are therefore in good agreement.

4.4.2 It should be emphasized that this increase in fatigue with multiple sectors is in addition to the increase that is associated with the length of duty and time since sleep. Although these three factors are highly correlated, the statistical methodology has enabled them to be estimated separately. To predict the overall impact of a multi-sector operation, all three components should be estimated and their effects combined.

4.5 Differences between the two bases

4.5.1 The base location was included as a factor in the analysis as it was considered that there may have been consistent differences in the levels of fatigue experienced by the crews operating from Heathrow and East Midlands. In the event, the only significant finding was an interaction between base location and duty start time. This effect was not associated with early starts, but with the different trends in fatigue later in the day. The reason for these trends (higher fatigue at Heathrow late in the day, compared with higher fatigue at East Midlands in the morning) is unclear. Since they were of marginal significance and unlikely to be relevant to the main objectives of the study, they were not considered further.

4.6 Implications for modelling

4.6.1 The results from the previous study of multi-sector operations have already been incorporated into the latest version of the System for Aircrew Fatigue Evaluation (SAFE) computer program. Since many of the results from the two studies are in reasonable agreement, it should not be necessary to make many changes. Indeed, where there is good agreement, the model and the program will gain credibility from having been derived from independent studies of two different operations.

4.6.2 However, one area that will be re-examined is the impact of early start times. It appears that the present model may have overestimated the level of fatigue associated with a single early start, and the next version will be amended to represent a compromise between the two sets of results. For reasons outlined above, the improvement that may be associated with very early starts will not be incorporated unless and until it can be corroborated from an independent source.

4.6.3 The model will also be amended to include a cumulative effect of consecutive early starts. The overall effect of this, together with the previous change, will mean that the level of fatigue for the first in a sequence of early starts will be reduced compared with the previous prediction, but that, at the end of a sequence of three or four, it would be increased.

4.6.4 With these changes, the model should provide reasonable estimates of levels of fatigue in short-haul operations. Moreover, it should be possible to extrapolate with a reasonable degree of confidence to operations which are just beyond the bounds of those studied with respect to factors such as duty length, number of sectors and consecutive duties. This will enable predictions to be made for operations outside the current experience for which data cannot be collected. However, one area of uncertainty is night operations, particularly the effect of consecutive night duties. These are a feature of the operations of several charter companies, and it will be important to ensure that the model is validated with respect to them.

5 Conclusions

5.1.1 The schedules operated by bmi were broadly similar to those of KLM UK. The main exceptions were that bmi rosters had a higher proportion of duties starting before 06:00, slightly longer sequences of consecutive early starts and the duty periods were on average slightly longer.

5.1.2 The main factor influencing fatigue in multi-sector short-haul operations was hassle. Currently, this is not included in the SAFE program. Other factors of almost equal importance were time of day, duty length and the number of sectors.

5.1.3 The effect of early starts may be less severe than previously estimated. However, the tendency for fatigue to reduce when the start time is before 06:00 in first officers requires independent confirmation.

5.1.4 There is a cumulative effect associated with consecutive early starts. Each successive day is associated with an increase in fatigue, which is equivalent to an extra 40 minutes duty per day.

5.1.5 The increase in fatigue from one to four sectors was equivalent to an additional 2.77 hours on duty.

5.1.6 The only aspect of short-haul operations for which further data are required in support of the SAFE computer program, is that of consecutive night duties.

6 Recommendations

6.1.1 The purpose of the current study was to validate the computer program, SAFE, rather than to provide specific recommendations for the regulation of current operations. Nevertheless, this study has provided further evidence to support the previous recommendation that an early start during an overnight stop on the mainland of Europe should be defined with respect to home time rather than local time.

6.1.2 When future regulations for flight time limitations are being debated, it is clear from this study that factors such as time of day, early starts and the number of sectors need to be included. In particular, these results indicate that the current reduction in duty time of 0.75 of an hour for each additional sector should not be reduced.

7 Acknowledgements

7.1.1 This study could not have been carried out without the whole-hearted support and co-operation of the management of bmi British Midland and of the British Airline Pilot's Association (BALPA), for which the authors are most grateful. In particular, we would like to thank the crews for their effort and commitment in the completion of the diaries and Dr Graham Cresswell for his assistance in the organisation and preparation of the trial.

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A Appendix

A.1 Sleep and duty diary

SLEEP section (use UK local time even if n/s in Europe)

NAPS

If you have napped/ slept since your last main sleep please record start and end times here:

	Start (hrs mins)	End (hrs mins)
1	:	:
2	:	:

AFTER SLEEP

DATE ON WAKING: day mon

IN BED AT (UK Local) hrs mins	ASLEEP AT (UK Local) hrs mins	AWOKE AT (UK Local) hrs mins	GOT UP AT (UK Local) hrs mins
:	:	:	:

BEFORE SLEEP

LOCATION (✓): Hotel ☐ Home ☐

DURATION OF SLEEP: (excluding awakenings) hrs : mins

I FEEL: (please circle as appropriate) *fully alert* 1 2 3 4 5 6 7 *completely exhausted*

SLEEP QUALITY: *extremely good* 1 2 3 4 5 6 7 *extremely poor*

NOW I FEEL: *fully alert* 1 2 3 4 5 6 7 *completely exhausted*

COMMENTS

RATINGS

Fatigue : *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.*

DUTY section (use Zulu as per flight report)

DATE: day mon

DURATION OF JOURNEY TO AIRPORT: hrs : mins

OFF-DUTY TIME: ROSTERED hrs : mins ACTUAL hrs : mins

REPORT TIME: hrs : mins

THREE LETTER AIRPORT CODE:

PRE- FLIGHT FATIGUE: *fully alert* 1 2 3 4 5 6 7 *completely exhausted*

START OF FLIGHT — *END OF FLIGHT* — *TURNROUND AFTER SECTOR*

If NO then please complete this section at the end of the break between flights.

Sector	Off Blocks (Z)	On Blocks (Z)	Airport Code	Post-flight fatigue	Hassle level	Was the entire period spent ON the aircraft?	How restful was the break?	Fatigue at end of break
1	:	:		1 2 3 4 5 6 7	1 2 3 4 5	YES NO	1 2 3 4 5	1 2 3 4 5 6 7
2	:	:		1 2 3 4 5 6 7	1 2 3 4 5	YES NO	1 2 3 4 5	1 2 3 4 5 6 7
3	:	:		1 2 3 4 5 6 7	1 2 3 4 5	YES NO	1 2 3 4 5	1 2 3 4 5 6 7
4	:	:		1 2 3 4 5 6 7	1 2 3 4 5	YES NO	1 2 3 4 5	1 2 3 4 5 6 7
5	:	:		1 2 3 4 5 6 7	1 2 3 4 5	YES NO	1 2 3 4 5	1 2 3 4 5 6 7
6	:	:		1 2 3 4 5 6 7	1 2 3 4 5	*Please record any naps over the page*		

RATINGS

Fatigue : *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.*
Hassle Level : *1=hassle-free* thro' to *5=extremely annoying.*
Restfulness of break : *1=extremely restful* thro' to *5=not at all restful.*

9 Distribution list

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8. Authors:	Spencer MB, Robertson KA
9. Descriptors / Key words:	**AIRCREW, SHORT-HAUL, FATIGUE, MULTIPLE SECTORS**

10a. Abstract. (An abstract should aim to give an informative and concise summary of the report in up to 300 words).

A diary study of bmi British Midland short-haul operations was completed by crews based at either London Heathrow or East Midlands airport. This involved the crews providing details of their sleep (timing and quality) on a daily basis, and of each flight duty period (FDP) that they undertook. Information was requested on each flight within the FDP, including the timing (blocks off and blocks on), the level of 'hassle' associated with the flight and the level of fatigue (on a modified 7-point Samn-Perelli scale), at the end of the flight. The analysis of the information from the diaries concentrated on the identification of those factors that contributed to the build up in fatigue. Special attention was given to early starts, as these feature in a large proportion of bmi operations. The duration of sleep prior to an early start was reduced, the reduction amounting to almost an hour for report times between 07:00 and 08:00 and to almost two hours for report times between 05:00 and 06:00. This was because the advance in wake-up times was not matched by an equivalent advance in the timing of sleep onset. Duties starting before 09:00 were associated with an increase in fatigue throughout the following duty period. Fatigue also increased during schedules that included several consecutive duties that started at 08:00 or earlier. This was in addition to a cumulative effect that applied, particularly among the captains, to a sequence of duties on consecutive days, irrespective of the duty start time. Duties starting at 07:00 (local European time) or earlier were associated with higher levels of fatigue when they occurred after an overnight stop on the mainland of Europe. Other factors that influenced fatigue were the time of day, time since sleep, time on duty and the number of sectors flown.

10b. Abstract classification: Unclassified	FORM MEETS DRIC 1000 ISSUE 5

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