

CREW FATIGUE

The Development of a Computer Model of Fatigue in Civil Air Operations

by Mick Spencer, DERA Centre for Human Sciences – UK

The disruption of normal patterns of work and rest is inherent in most air operations. Short-haul operations are characterised by a mix of early start times, late finishes and, in some cases, duties that extend through the night. In long-haul operations, night flying is common, and is compounded by frequent time-zone changes. Moreover, in recent years, with the growth of the holiday market to such places as Florida and the Caribbean, some aircrew are undertaking a mix of short- and long-haul flights, and the traditional distinction between the two types of operation is becoming increasingly blurred. At the same time, aircraft are now able to operate over greater distances with reduced crew sizes, so that the protection provided by a third crew member (the flight engineer) is being lost. There is further concern that aircrew are increasingly required to operate up to the limit of existing regulations, with respect to both duty hours and rest periods. As competition grows both within Europe and world-wide, commercial pressures to extend the workload beyond reasonable limits may prove irresistible.

In these circumstances, it is essential that the best available information on the development of fatigue and the impairment of performance in air operations is available both to the regulators and to those responsible for designing the rosters. For this reason, the UK Civil Aviation Authority is sponsoring an on-going programme of research into the sleep and wakefulness of the airline pilot, which is being carried out by the DERA Centre for Human Sciences (CHS) in Farnborough. This research is leading to the development of a computer program for the assessment of fatigue in civil air operations. The aim of the program is provide an objective procedure for the evaluations of rosters, rather than the largely subjective methods that are currently used by the regulatory authorities. It is hoped that, when such a program is fully implemented and made generally available, it will provide an approach to the regulation of duty hours that will avoid the complexities and inadequacies of existing schemes.

The research background

The research programme carried out at Farnborough has involved studies of the sleep, alertness and circadian rhythms of aircrew during many different types of schedule, and has been supported by laboratory and field studies using non-aircrew volunteers. These have provided considerable insight into the effect on sleep of some of the most disruptive schedules, as well highlighting the problems associated with the disruption of the circadian rhythm or 'body clock' after long time-zone transitions. A brief résumé of the principal studies is given below:

An international collaborative study

The first major study was carried out as part of an international collaborative investigation into the sleep of aircrew after large time zone transitions [1], and involved crews from the UK, the USA, Germany and Japan. Crews flew return flights in

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He transferred to the DERA Centre for Human Sciences in 1994, with project management responsibility for a range of programmes investigating the development of fatigue associated with irregular patterns of rest and activity.

He has advised a number of private and public sector organisations on the scheduling of shift work, including those responsible for the management of train drivers, air traffic controllers, airport security staff and nuclear power workers.

Mick Spencer's particular interest is the development of models to predict the alertness and performance of shift workers and of others who are exposed to irregular schedules of work and rest. He has developed a computer program to predict levels of alertness of the civil airline pilot, and has undertaken, on behalf of the HSE, the development of a Fatigue Index for the assessment of the risks associated with fatigue in different patterns of shift work.

either a west-east or an east-west direction across seven, eight or nine time zones. Clear differences emerged in the patterns of sleep following eastward and westward flights. After a westward flight, crews tended to delay their sleep time until nearly the normal local time of day [2]. The resultant sleep deficit led to shorter sleep onset times and good quality sleep in the first part of the night. However, there was increased wakefulness in the second half of the night as the crews tried to sustain their sleep beyond the normal waking time according to their body clock. Sleep patterns were much more variable and fragmented after the eastward flights, as individuals attempted to shorten their day, and this was reflected in increased levels of daytime drowsiness.

The polar route

The sleep and circadian rhythms of aircrew were studied immediately before, during and after a



seven-day tour of duty between London and Tokyo [3]. This was a more complex schedule than the single flights studied previously, since the eight-hour eastward transition was accomplished by two westward flights, with a 24-hour layover in Anchorage, Alaska. Sleep throughout the schedule was fragmented, with naps before duty and short sleeps after arrival at a new location. Changes in the electrical activity of the brain during sleep reflected both the sleep deficit built up at the start of the schedule, and the displacement of the circadian rhythm later in the schedule. Realignment of the circadian rhythm on return was achieved by a phase advance in eight aircrew and by a phase delay in 3, with resynchronisation taking up to six days.

In ultra long-haul flights, crews are augmented, and rest facilities are provided in the form of bunks to enable the crew members that have been relieved to achieve some sleep. Extensions to maximum flight duty limits are provided on the basis of the rest that these facilities allow. It is important, therefore, that the bunks are conducive to adequate sleep, and several studies have been carried out to investigate the quality of sleep that the crews are able to achieve. Both environmental (noise, turbulence, dry atmosphere, inadequate bedding) and non-environmental factors (lack of tiredness, thoughts on mind) have been identified as causes of sleep disturbance on board the aircraft [4]. Sleep recordings on-board flights between London and Johannesburg, Tokyo and Seoul have shown that the quality and quantity of in-flight sleep is influenced by the timing of the flight itself and also by the scheduling of rest periods within the flight [5,6]. Often it is the relief crew, who take their rest period early in the flight, who have the greatest problems. Their sleep is characterised by long sleep onset times, frequent awakenings and poor sleep quality, whereas, later in the flight, good quality sleep lasting for three or more hours is often achievable.

Two major sleep log studies were carried out to investigate the impact of duty schedules on the timing and subjective quality of sleep. In the first of these, which investigated long haul operations, completed diaries were received from 241 aircrew, covering a total of 2201 separate flying duty periods [7]. The information collected revealed major differences in the sleep of crews after westward and eastward trips. Patterns of sleep were much less regular after long eastward trips. Some aircrew attempted to sleep on local time, while many sleep periods were delayed closer to home time. However, the greatest disruption of the sleep-wake pattern occurred on the UK-Australia trip, with frequent napping, as well as short, and some exceptionally long, periods of sleep. The second study concentrated on short-haul, includ-

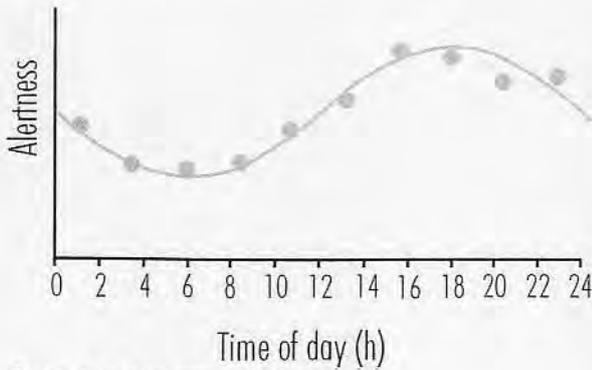
ing some air-freight operations [8]. Fourteen companies participated and a total of 175 diaries were returned. This study highlighted the problems associated with schedules involving consecutive early starts and consecutive night operations. Factors influencing either the duration or the quality of sleep included the time of day, the previous sleep timing, the duration of the rest period, the previous rate of working and the amount of time to the start of the next duty period.

In an initial study, the sleep, performance and circadian rhythms of 6 subjects were monitored before, during and after the five-hour time zone transition between London and Detroit [9,10]. The results confirmed that the rate of adaptation was dependent on the direction of travel, and changes in both sleep and the rhythm of body temperature were more persistent after the eastward flight. Subsequent studies have focused on long eastward transitions, including London to Hong Kong (7 hours) [11] and London to Sydney (10 hours) [12]. In both studies, some subjects adapted by a phase advance and some by a phase delay. The rate of adaptation to the 10 hour transition varied considerably, with some individuals, requiring more than seven days to synchronise their rhythms to Sydney time. In the group as a whole, the recovery of sleep and performance took at least six days.

The field studies of aircrew have been underpinned by laboratory investigations into the regulation of sleep and wakefulness during irregular patterns of work and rest. These experiments have led to the development of an alertness model, known as the CHS Alertness Model, that forms the basis for the computer model of fatigue. This model predicts levels of alertness and fatigue as a function of two components, one related to the time of day, the other related to the pattern of sleep and wakefulness. (Figure 1).

The time of day component is associated with the endogenous circadian rhythm or 'body clock'. This rhythm runs in isolation with a period that is slightly longer than 24 hours, but is normally entrained by time-cues (e.g. the pattern of light exposure) to the 24-hour day. In its entrained state, peak levels of alertness tend to occur in the late afternoon, with a corresponding dip in the early hours of the morning. The component related to the pattern of sleep contains two separate elements, the first of which is the recovery of alertness immediately on waking: the so-called 'sleep inertia' effect. The second element is an exponential reduction in alertness associated with increasing time since sleep. This element recovers exponentially during sleep, and is related to a homeostatic sleep-regulating process [13]. When the sleep period is disturbed or is not sufficiently





Change in alertness with time of day



Change in alertness with time since sleep

Figure 1 The two components of alertness

long to effect a full recovery, then levels of alertness are lower than those shown in Figure 1.

Trends in alertness, as predicted by the model, are a combination of these two components. Figure 2 illustrates the changes in alertness for different wake-up times (along the horizontal axis) and different durations of wakefulness (along the vertical axis). The rating of 4 corresponds to the highest levels of alertness and 0 to the lowest levels. Thus, after waking at 06:00 and overcoming the initial brief period of sleep inertia, alertness remains at level three until almost 18:00, corresponding to 12 hours of wakefulness. In contrast, after waking at 20:00, level 1 is reached after only eight hours. This demonstrates the problem inherent in overnight duties, where it is not possible to maintain alertness at the same levels as during the day, even when, as is assumed in Figure 2, an individual is fully rested at the start of duty.

Based on the results of a series of laboratory experiments, which have established the relationship between alertness and performance on a variety of tasks, the alertness model has been extended to predict changes in performance associated with different patterns of work and rest [14]. For example, after 16 hours of continuous wakefulness starting at 07:00, response times are degraded by between 5% and 7% on vigilance and sustained attention tasks, and the number of missed responses is more than doubled. After 24 hours awake, the increase in response time is between 12% and 15% and the number of missed

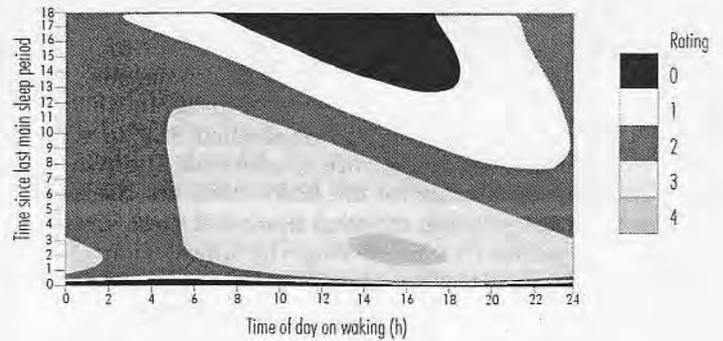


Figure 2 Alertness after sleep at different times of day

responses is quadrupled. A recent study of the influence of alcohol intoxication on performance [15] has enabled these degradations to be compared with the effect of different levels of blood alcohol concentration (BAC). The effects of 16 hour wakefulness starting at 07:00 are roughly equivalent to a BAC level of 0.028%, while the effect of remaining awake for 24 hours is similar to that of a BAC level of 0.083%. This is close to the drink-drive limit in the UK, and in excess of that in many EU countries.

Computer implementation

The information from the studies outlined above is now being used to develop a computer program which could be used as the first step in the assessment of the impact on fatigue of any current or proposed schedule. An initial version of the program has been written as a proof-of-concept prototype, and a schematic representation of its structure is given in Figure 3. The input to the program is a duty schedule, specified by the user and defined by the start and end times and locations of individual duty periods; the output consists of predicted levels of alertness throughout each duty period.

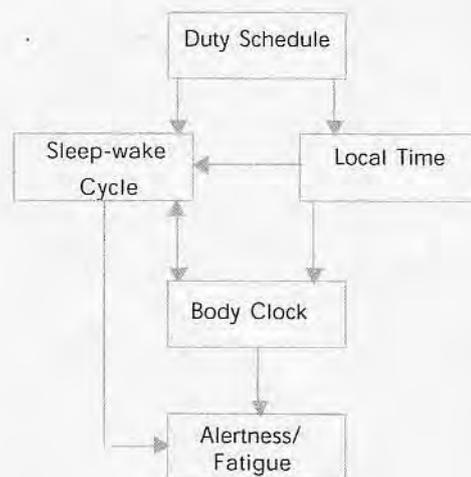


Figure 3: Structure of the computer model



FATIGUE – the development of a computer model

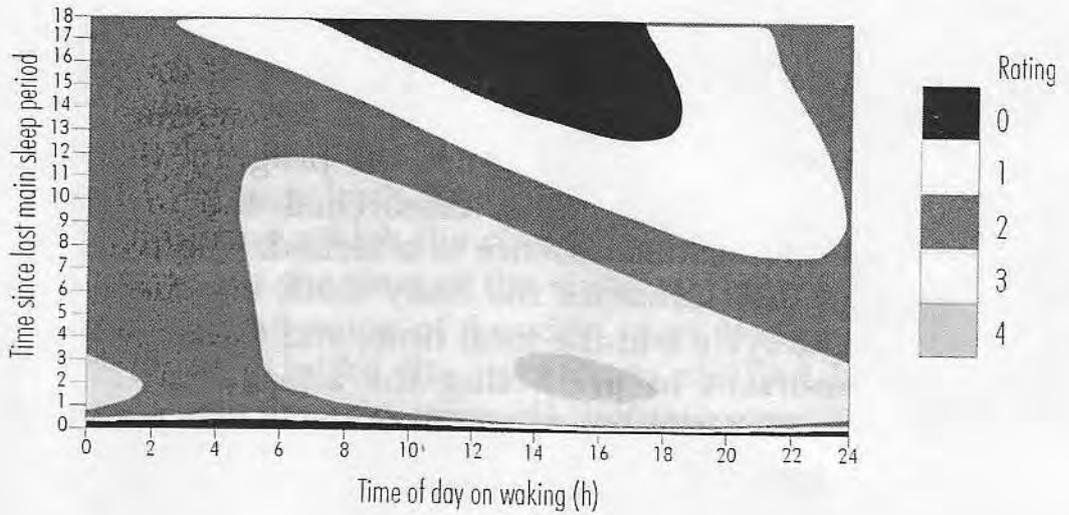
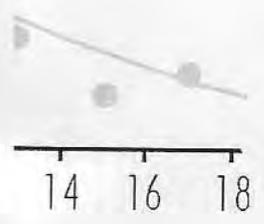


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