CIVIL AVIATION AUTHORITY

CAA PAPER 99010

A REVIEW OF IN-FLIGHT NAPPING STRATEGIES

CIVIL AVIATION AUTHORITY, LONDON

Price £10.00

CAA PAPER 99010

A REVIEW OF IN-FLIGHT NAPPING STRATEGIES

S R Holmes
K A Robertson
A S Rogers
M B Spencer
B M Stone

CIVIL AVIATION AUTHORITY, LONDON, SEPTEMBER 1999

ISBN 0 86039 772 6

Printed and distributed by
Westward Digital Limited, 37 Windsor Street, Cheltenham, England

Executive Summary

1 TERMS OF REFERENCE

This report reviews the value of in-flight napping in civil air operations. It has been prepared for the Safety Regulation Group of the Civil Aviation Authority under contract number 7D/S/952/1, as part of a programme of research into the sleep and wakefulness of the airline pilot.

2 OVERVIEW

2.1 The increasing range of modern passenger aircraft has led to a situation in which the endurance of the aircraft may exceed that of the aircrew. As a result, on the longer flights, crews are augmented so that individual crew members are able to rest for some time during the flight. The UK requirements for the avoidance of fatigue in aircrew [14] allow for the extension of flight duty periods on the basis of the length of the in-flight rest periods and the type of rest facility available.

2.2 A considerable amount of information exists on the value of naps, both in the laboratory and in the field, including some studies of aircrew. This report reviews these studies and establishes the extent of current knowledge of the benefits and problems conferred on aircrew by napping. The issue of 'sleep inertia', a transitory deficit in mood and performance, is considered at some length, because of the implications for aircrew who return to duty soon after waking.

3 CONCLUSIONS

3.1 Naps are a beneficial countermeasure to fatigue and are most effective if they are taken prior to the onset of fatigue rather than after it has become established. Episodes of sleep as short as one hour have been shown to increase levels of alertness towards the end of a duty period. However, any relationship between the duration of a nap and the extent of subsequent benefits is unclear.

3.2 Sleep inertia is the main factor limiting the effectiveness of naps. It occurs on wakening and it may persist for between 5–35 minutes before performance returns to pre-nap levels. This appears to be influenced by the amount of sleep loss prior to the nap, the time of day that the nap is taken, and the duration of the nap. Sleep inertia has been shown to occur after in-flight naps.

3.3 This review of the literature has revealed large variations in experimental design and measurement, which has often prevented direct comparisons between studies and the provision of guidance. However, it appears that 30 minutes should elapse between awakening and the resumption of duties. This may be viable for augmented crews, where aircrew rotate through the seats. It has been reported that even when regulations forbid the use of rest on the flight deck, such as with two-man non-augmented crews, sleep does occur. Sleep inertia may occur on awakening, resulting in impaired alertness and performance.

3.4 For non-augmented crews who take the opportunity to sleep in the flight deck seat, it is likely that the quality of sleep will not be as good as that taken in a bunk. However, this has not been investigated in the field. From a laboratory study, there is evidence that the angle of the backrest is an important factor influencing the quality of sleep in aircraft seats.

3.5 For augmented crews, naps in an aircraft bunk can be as recuperative as sleep in a bed, provided that disturbances are minimised (e.g. the use of sound attenuation, air-conditioning, screening from light). Factors such as inadequate bedding, not being tired, anxieties and worries are also likely to disturb sleep in the bunk. In-flight sleep quality and quantity are likely to be optimum when the rest period follows a reasonable period of wakefulness and coincides with the phase of the circadian cycle during which sleep normally occurs.

3.6 There is currently a lack of information in the following areas:

- The influence of nap duration and timing on sleep stages, and the relationship of these factors to performance benefits and the severity and duration of sleep inertia on awakening.

- The efficacy of using multiple napping strategies in-flight.

- A comparison between the quality and duration of in-flight naps in bunks and in airline seats (on the flight deck, passenger sections).

4 RECOMMENDATIONS

4.1 Because of the effects of sleep inertia, non-augmented crews who may need to operate at short notice should not rely on napping to maintain acceptable levels of alertness. Short naps on the flight deck should only be used as an emergency measure to combat unexpectedly low levels of alertness that could not have been anticipated when the flight was scheduled. In these situations, the adoption of a multiple napping strategy consisting of 20 minute naps may minimise the severity of sleep inertia whilst maintaining performance although further studies are required to verify this.

4.2 Where augmented crews are provided, the schedule anticipates napping and this should be arranged to avoid sleep inertia: crews should not recommence duty for at least half an hour after waking from sleep. However, it is difficult to give more than general guidance on the required recovery time from sleep inertia. To maximise the beneficial effects of naps, rest periods should be scheduled to occur before excessive fatigue has set in, but after a reasonable time of wakefulness.

4.3 Careful consideration should be given to the facilities in which crews rest. It is possible that more effective rest may be achieved if augmented crews rest in crew bunks as opposed to airline seats.

4.4 The in-flight rest environment should be as conducive to sleep as possible. Where rest is taken in a bunk this may include the provision of air-conditioning, adequate bedding, sound-proofing and screening from light. For rest taken on the flight deck this will be more difficult to achieve. However, the resting crew member could be provided with ear-plugs and eyeshades in order to reduce the disturbances from random noise and light.

4.5 Generally, greater nap benefits are obtained from bunk rest if one long rest period is provided rather than two short rest periods. However, when departures occur early in the morning, it may be more beneficial to schedule two short rest periods so that some sleep can be obtained during the flight.

4.6 Aircrew should be provided with advice on strategies that may enhance their chances of sleeping during rest periods and help them avoid unintentional naps. The benefits of good sleep hygiene, relaxation techniques to aid sleep, the importance of nap placement, duration, circadian cycle and the influence of time-zone transitions on layover sleep should be highlighted.

List of Contents

1 INTRODUCTION

1.1 Terms of reference

This report reviews the value of in-flight napping in civil air operations. It has been prepared for the Safety Regulation Group of the Civil Aviation Authority under contract number 7D/S/952/1 as part of a programme of research into the sleep and wakefulness of the airline pilot.

1.2 Background

1.2.1 The increasing range of modern passenger aircraft has led to a situation in which the endurance of the aircraft may exceed that of the aircrew. As a result, on the longer flights, crews are augmented so that individual crew members are able to rest for some time during the flight. The UK requirements for the avoidance of fatigue in aircrew [14] allow for the extension of flight duty periods on the basis of the length of the in-flight rest periods and the type of rest facility available.

1.2.2 Even when special facilities are not provided, it is common for aircrew to nap during a flight when part of a heavy crew, although the conditions under which these naps can take place do not form part of the regulations.

1.2.3 Napping on the aircraft can vary between sleep periods of 4 hours or longer in a relatively comfortable bunk bed (separated and screened from the rest of the aircraft) and naps of a few minutes taken in an aircraft seat. Various claims have been made concerning the beneficial effects of naps and, in particular, the value of short naps (so-called 'power napping') has been extolled. However, because of the many factors involved, such as time of day, time into flight, the previous pattern of sleep and the number of time zone transitions, as well as the duration of the nap itself, clear guidelines for aircrew have not been established.

1.2.4 A considerable amount of information exists on the value of naps, both in the laboratory and in the field, including some studies of aircrew. The purpose of this report is to review these studies and hence to establish the extent of current knowledge of the benefits and problems conferred on aircrew by napping. The report is restricted to napping in-flight, and does not cover anticipatory naps taken prior to the start of a duty period, except where these might influence the ability of crews to sleep during the subsequent flight.

1.3 Overview of this report

1.3.1 The next section of this report consists of an introduction to sleep, including sleep structure and the various sleep stages. The following section gives an overview of the relationship between sleep, alertness and performance. These two sections provide the information necessary for an understanding of the issues specifically related to napping that are covered in the remainder of the report.

1.3.2 The literature on napping is reviewed in Section 4. Factors that influence the quality of a nap, including environmental influences and those related to the duty schedule, are discussed, as well as the associated performance benefits and possible negative effects. The issue of 'sleep inertia' is considered at some length, because of the implications for aircrew who return to duty soon after waking. All these factors and their interactions are summarised in a diagram at the end of this section.

1.3.3 Section 5 reviews the field studies carried out on aircrew. Issues relating to the scheduling of in-flight rest are also discussed.

1.3.4 Conclusions and recommendations are given in Sections 6 and 7. Areas where information is lacking are highlighted.

1.3.5 The databases used in the completion of this report include MEDLINE, Dialog Aerospace, NTIS, PsycINFO(R), Bath Information and Data Services (BIDS) and controlled-circulation literature from the databases of the Defence Research Information Centre (DRIC).

2 SLEEP

2.1 Normal sleep

2.1.1 Sleep is a fundamental requirement for humans. The amount of sleep required for the maintenance of physiological and psychological health is around 7 to 8 hours per 24 hours, although this varies between individuals.

2.1.2 The electroencephalogram (EEG) is a measure of brain activity during sleep, variations in which enable sleep to be categorised into a number of stages. Stage 1 or 'drowsy' sleep usually occurs during the transition from waking to sleep. Stage 2 sleep normally occupies up to 50% of the sleep period. The time taken to reach the first episode of stage 2 is termed 'sleep onset latency', and includes any intervening stage 1 sleep. 'Deep' sleep (stages 3 and 4), otherwise known as slow wave sleep (SWS), predominates in the early part of the night and is influenced by the length of prior wakefulness [90]. Episodes of rapid eye movement sleep (REM) occur at intervals, and are associated with dreaming.

2.1.3 A typical night's sleep pattern of a young adult is illustrated in Figure 2–1. The normal sequence of sleep stages during the night is: waking, stage 1, stage 2, stage 3, stage 4, stage 3 and then stage 2. At this point the first period of REM sleep occurs. It is followed by stages 2, 3, 4, 3 and 2 and a further REM episode. Sleep cycles recur throughout the night, with each cycle lasting around 90 minutes. As the night proceeds, the content of the sleep cycle alters, with less SWS and more REM sleep in the latter cycles.

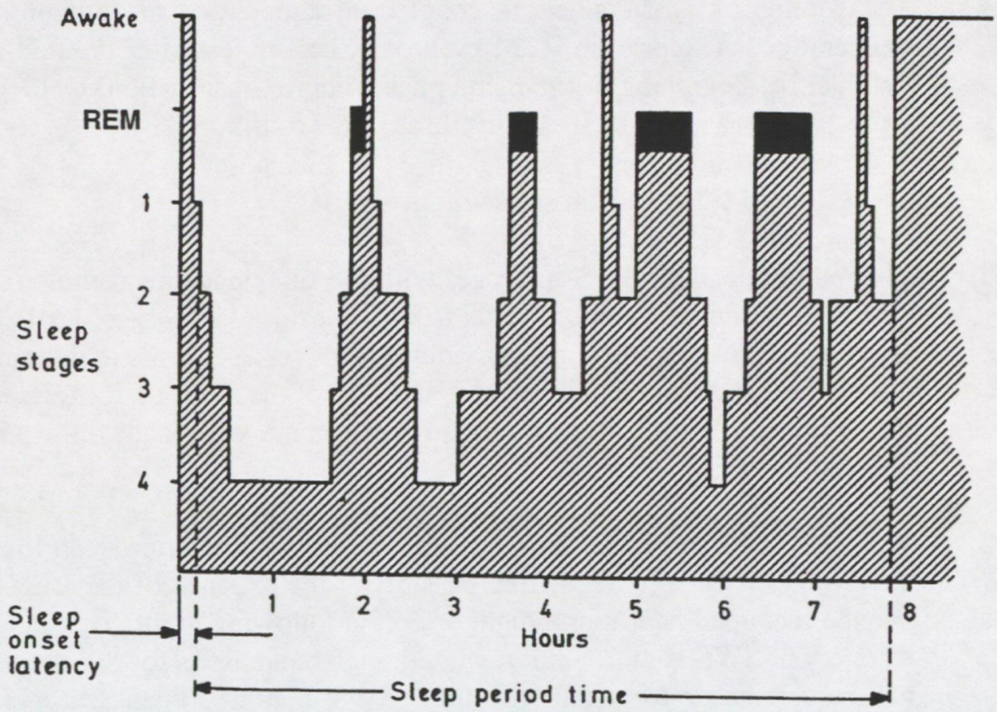

Figure 2–1 Typical nocturnal pattern of sleep in a young adult

2.2 The effect of the circadian rhythm on sleep

2.2.1 Physiological and psychological activities such as body temperature, sleep tendency and mental performance normally exhibit a 24 hour rhythm. This circadian rhythm is controlled by a biological 'clock' in the brain, and remains in phase through the influence of environmental cues. The pattern of light and dark is the most important cue, which in association with other factors, such as the timing of meals, ensures that individuals maintain their 24 hour rhythm.

2.2.2 Sleep is initiated at preferred times relative to the circadian rhythm of core body temperature [100]. In general, the longest sleep episodes are initiated several hours prior to the body temperature minimum (02:00–06:00). There is also a tendency for naps of approximately 2 hours to be taken close to the temperature maximum (14:00–17:00). Napping in the afternoon is traditional in some cultures. Generally, the duration of sleep decreases as onset times approach the temperature maximum [1], and this tendency has been confirmed in aircrew [82].

2.2.3 The two sleep phases in the circadian cycle, namely the mid-afternoon naps and nocturnal sleep, are thought to be separated by an evening period of increased alertness, known as the 'forbidden zone' for sleep [46]. During this period, which precedes the normal nocturnal sleep by approximately 2–3 hours, sleep initiation and maintenance are difficult. This phenomenon has been observed in shiftworkers who often experience difficulties in falling asleep when they retire to bed early in preparation for an early morning start [32].

2.2.4 The timing of REM sleep is coupled to the circadian rhythm of core body temperature. The peak in REM propensity occurs just after the mid-trough of this cycle, at the beginning of the rising phase (approximately 06:00, [19]). REM sleep typically increases if sleep extends through the morning [23].

2.3 The effect of sleep loss on subsequent sleep

2.3.1 The requirement for SWS increases with the time since awakening, according to a simple exponential function. This is known as the 'S process' [20]. For a normal sleep-wake pattern (where an individual sleeps for 7–8 hours at the same time every day), the S process will peak prior to the start of the sleep period, and the propensity for SWS will be high. The minimum value for S will occur on waking, when the propensity for SWS is low.

2.3.2 There will be competition to make up SWS and REM after sleep loss. Generally, the SWS will be recovered first, possibly at the expense of the REM sleep, which may be recouped later in the night or on the following night. This indicates that the recovery of SWS is more important, although the reasons for this are unclear. It will not be necessary to regain the total SWS that has been lost [11, 16] as the requirement for SWS is not a linear function of the time awake.

2.4 The interaction between sleep loss and the circadian rhythm

2.4.1 Sleep is often disrupted after travel across time zones or after a change in the work/rest schedule. This leads to a major deterioration in the quality of sleep (e.g. increased frequency of awakenings, delayed REM sleep, less SWS) and alterations in the timing of REM sleep, related to the direction of the flight or shift change [21, 58, 94].

2.4.2 Nicholson *et al.* (1986)[58] investigated the effects of east and west time zone transitions on sleep quality. Subjects flew from London to Detroit, and seven days later returned to London. They were not allowed to nap prior to or during the flights, or on the day of the return to London. There was a 5 hour delay in the first sleep period, relative to normal bedtime, following the westbound flight (23:30 EST, 04:30, GMT). Decreased latency to SWS and longer duration of SWS occurred during this sleep. This was attributed to the increased duration of prior wakefulness combined with the rest period occurring in the circadian trough.

2.4.3 During the second and third nights, REM sleep increased. This was ascribed to a lowered requirement for SWS (owing to recovery of SWS during the first night) and shifting of the sleep period into the latter part of the 'home time' morning. Subjects' sleep patterns had adapted to the new time zone by the fourth night.

2.4.4 Sleep after the return eastbound flight was more disturbed and the period of adaptation was greater than after the westbound flight. Individuals took longer to fall asleep on all of the 5 nights monitored, relative to baseline. In addition, REM sleep declined during the second and third nights. By the 5th night, the sleep pattern had not adjusted to the new time zone. This change, combined with the duration of the flight, delayed the first sleep period by 19 hours (23:30 GMT, 18:30

EST). As subjects had adapted to EST, this period (23:30 GMT) coincided with the 'forbidden zone' for sleep (18:30 EST), unlike the westbound journey, where the first rest period coincided with the circadian trough.

2.4.5 Individuals are more likely to experience problems adapting to time zone transitions when the direction of travel is eastwards, as opposed to westwards. Generally, westward travel results in a need to lengthen the day and hence delay the circadian rhythm, whereas eastbound travel results in a need to shorten the day and advance the circadian rhythm. The latter adjustment appears to be more difficult for the biological clock [97].

2.5 Environmental influences on sleep quality

2.5.1 Sleep may be disturbed by a variety of environmental factors. These can include noise, sleep facilities (chair, bunk), light and climate. Disturbance of sleep can result in increased fatigue and reduced performance during the subsequent day or duty period.

2.5.2 *Sleep facilities*

2.5.2.1 Nicholson and Stone (1987)[60] investigated the quality of sleep overnight in subjects (aged 35 to 50 years old) who slept in an armchair with a backrest angle to the vertical of 17.5°, (equivalent to a seat on the flight deck), a reclining chair with a 37.0° backrest angle and a sleeperette (equivalent to a first-class seat) with a 49.5° backrest angle, and a bed. Subjects reported significantly poorer sleep quality when they slept in an armchair than in the other chairs and bed. This was characterised by lighter sleep stages, shorter total sleep time (TST) and more awakenings compared to sleep in a reclining chair, sleeperette or bed. There were significantly more awakenings and shorter TST in the reclining chair than in the bed. Sleep in the sleeperette was not significantly different from sleep in a bed. Nicholson and Stone concluded that acceptable sleep quality in chairs may be achieved as long as the back angle to the vertical is more than 40 degrees.

2.5.2.2 The duration and quality of sleep in a bed [25] was characterised by significantly less stage 4 sleep and more stage 1 sleep. However, this may partly be explained by the fact that sleep in the armchair occurred under alerting conditions (lights on, background noises), whereas sleep in the bed occurred under conducive conditions (lights off, soundproofing). In addition, the backrest angle of the armchair was not reported.

2.5.2.3 Under laboratory conditions, nocturnal sleep quality and duration in a bunk was not significantly different from sleep in a bed [4].

2.5.3 *Noise*

2.5.3.1 Noise disturbs sleep [62, 63] and this is recognised as an environmental sleep disorder that gives rise to excessive sleepiness or insomnia [3]. In particular, difficulty in falling asleep is considered an important aspect of noise-induced sleep disturbance in man.

2.5.3.2 The sleep of aircrew is likely to be disturbed by exposure to intermittent rather than continuous noise. For intermittent noise, the upper limit has been suggested to be between 45 and 68dB(A) [37]. This wide range is related to the fact that awakening reactions are not only determined by the maximum sound level and the number of noise events but also by individual susceptibility to noise.

2.5.3.3 Peak noise levels of 45dB(A) increase the time taken to fall asleep. However, the number of events and the difference between background and peak level seem to be more important than the absolute peak level. When noise sensitive individuals were exposed to four noise events per hour at maximum noise level of 45dB(A) there was a reduction in sleep quality and with eight events sleep onset was delayed [62].

2.5.4 *Climate*

2.5.4.1 Sleep in cold environments seems to be associated with greater sleep disturbance than that experienced in the heat. However, there is a lack of consistent findings among studies particularly with respect to REM sleep suppression [12]. High environmental temperatures have been associated with difficulties initiating and maintaining sleep. SWS may be suppressed or may cease altogether if high environmental temperatures are imposed during the sleep period. However, sleep deprivation appears to be a greater stressor than temperature i.e. following a long period of wakefulness, the increased pressure for sleep will counteract the effect of the increased temperature and the suppression of SWS [12].

2.5.4.2 In a study investigating the combined effect of noise and heat on sleep, sleep was more disturbed by exposure to heat (35°C) than to traffic noise (71dB(A)). Exposure to high temperature increased the number of awakenings and the amount of stage 1 sleep and reduced total sleep time (TST). When exposed to noise at night, there was an increase in the number of stage changes and the number of episodes of stage 1 sleep. The combined effects of noise and heat were to reduce the REM sleep cycle length and TST. Increases were also seen in stage 1 sleep, number of stage changes and number of awakenings [47].

2.6 **Individual differences**

2.6.1 Individual differences in age, psychological well-being and general ability to sleep may influence the quality and duration of the sleep.

2.6.2 Individuals classed as 'flexible types' find it relatively easy to sleep at unusual times and have no preference for regular sleeping or meal times. In contrast, 'rigid types' have difficulty in getting to sleep early, or sleeping in late, even when tired. They also prefer to sleep and eat at regular times and maintain their normal sleeping habits even on holiday [18].

2.6.3 As people age, the quantity of slow wave sleep declines [7, 99]. They also become less adaptable to changes in their normal sleep pattern and are more susceptible to disturbances in subsequent sleep following a nap [53]. There is also evidence that they may find it more difficult to adapt to a new time zone. Gander *et al.* (1998)[34] reported a significant increase in the average daily percentage of sleep loss in non-augmented aircrews with increasing age over the range of 20–60 years. Inability to adapt to an unusual sleeping schedule and a new time zone could result in greater sleep loss in older pilots.

2.6.4 Anxieties are considered to be a major contributor to sleep problems [69] resulting in poor sleep quality, reduced sleep duration, and consequentially, sleep loss. Sleep loss may result in a general decline in performance and increased severity of sleep inertia following a nap (see Section 4.4).

3 PERFORMANCE

3.1 Sleep deprivation

3.1.1 Many studies have shown that mental (cognitive) performance is impaired after sleep loss [54, 98]. When nocturnal sleep is restricted to less than 4–5 hours per night, performance will deteriorate [91, 95] and even as little as 2 hours sleep loss can result in impaired performance and reduced levels of alertness [17]. The tasks most likely to be affected include those which are of long duration, machine-paced, or monotonous, and those that require sustained attention or are poorly learned [6, 39, 50].

3.1.2 In some cases, accuracy on cognitive tasks may not be impaired, but the tasks will take longer to perform. In addition, there may be lapses in attention, an inability to concentrate [6], a failure to take all relevant information into account when making decisions, an acceptance of lower performance standards, a neglect of routine or self-initiated tasks, and an increasingly erratic operation of controls [31, 38].

3.1.3 Studies of shiftworkers have indicated that individuals often take very little, if any sleep before the first night duty [45]. This means that almost 24 hours may be spent awake before retiring to bed, and consequently, individuals will feel very tired towards the end of the shift. This situation may also apply to aircrew, when individuals do not take the opportunity to nap before evening departures, although the evidence suggests that aircrew generally nap more than shiftworkers [82]. In addition, aircrew may have difficulty initiating sleep and napping during the 'forbidden zone' for sleep (see Section 2.2).

3.1.4 There is evidence that a decline in performance will be associated with extended duty periods [22, 44, 72]. Scheduling duty periods for safety-critical industries such as air transportation should include consideration of the circadian rhythm. Performance will be impaired during the circadian trough between 02:00–06:00, and this impairment will be exacerbated if an individual is near the end of their duty period [81].

3.2 Sleep inertia

3.2.1 Sleep inertia can be defined as a transient state of confusion accompanied by impairment of performance and mood following abrupt awakening from sleep. It can result in profound performance decrements on a variety of tasks, which can be worse than the impairment caused by sleep deprivation [5]. Sleep inertia can result in significant decrements in vigilance, memory, reaction times and general cognitive abilities.

3.2.2 Sleep inertia also occurs after sudden awakening from naps [24]. It is therefore an important consideration in situations where naps are used to counteract fatigue, especially if duties must be resumed immediately after waking. For this reason, the majority of research into sleep inertia has investigated performance after sudden arousal from a nap. This will be discussed further in Section 4.4.

4 NAPS

4.1 Background

The term nap is usually defined as a 'short sleep'. However, within the scientific literature, naps may vary in duration from a few microseconds to several hours, and the term has been used to describe sleep taken in the daytime, involuntary sleep, sleep not taken in bed and 'light' sleep. For the purpose of this review, a nap will be considered to be a voluntary sleep, ranging from about 10 minutes ('power naps') to 4 hours in duration, taken at any time of day or night, and either in or out of bed.

4.2 Factors influencing nap quality

4.2.1 Provided that the environmental conditions are conducive to sleep, the quality of sleep taken as a nap is unlikely to be very different from that taken during the early part of the night [70]. However, other factors such as anxiety and apprehension can influence sleep quality. Apprehension, associated with being on-call, has been shown to reduce TST, and reduce the amount of SWS and REM sleep [93]. A similar situation may sometimes be associated with the use of in-flight rest. If the operating captain finds it difficult to relinquish command this may affect the quality of his sleep during a rest period.

4.2.2 *Timing of a nap*

The timing of a nap is an important factor which will influence the structure of sleep during air operations. Therefore, when planning an in-flight napping strategy careful consideration should be given to the timing of the rest period. All the factors that influence the onset of sleep will, in a similar way, affect the ability to nap. These include the time of day at which the nap is taken, time since the last sleep period, and individual differences (e.g. age, anxiety).

4.2.3 *Duration of a nap*

4.2.3.1 When a nap is of very short duration (i.e. a power nap), it is likely to be composed of mainly stage 1 and 2 sleep. If individuals are severely sleep deprived then there is a possibility that they could reach the deeper stages of sleep within 10 minutes.

4.2.3.2 Horne and Reyner (1996)[41] asked subjects to nap for 15 minutes between two performance sessions. The average latency to stage 1 sleep was 7.4 minutes, and the TST was 10.8 minutes. The sleep stages during the nap were not reported.

4.2.3.3 Where naps are of longer duration e.g. 1–2 hours, and the conditions are conducive to sleep, the quality of sleep will be similar to that during the first part of nocturnal sleep (Section 2.1.3). Individuals are likely to experience a complete cycle of sleep stages and may obtain some SWS.

4.2.4 *Environmental influences on nap quality*

The environment in which individuals nap is likely to affect the quality of sleep. Factors such as noise, temperature, humidity, and the sleeping facilities themselves (e.g. bed, chair), have all been shown to affect the duration and quality of sleep (see Section 2.5). The influence of these factors on the quality of naps will be very similar. In general, sleep disturbances arising from environmental conditions lead to more awakenings, increased latency to sleep, reduced TST and a greater predominance of the lighter stages of sleep.

4.2.5 *Individual differences in napping ability*

4.2.5.1 It is possible to distinguish between 'nappers' who can sleep almost anywhere and 'non-nappers' who report difficulty falling asleep in various environments. Non-nappers are more likely to be disturbed and woken by alerting stimuli such as noise [24].

4.2.5.2 Generally, the same individual factors that affect sleep (e.g. age, anxiety) will influence napping ability (see Section 2.6).

4.2.6 *Effect of naps on subsequent sleep*

A nap may affect subsequent sleep by delaying its onset or disrupting the quality of later sleep periods. Following a two hour nap, reduced TST and SWS have been reported in the subsequent sleep of shiftworkers [43, 92]. This truncation of sleep after a nap is especially prevalent in older individuals who find it difficult to adapt to changes in their sleep pattern [35]. It appears that the shorter the nap, the less the truncation of subsequent sleep. A reasonable balance may be provided by naps of around 50 minutes duration. These have been shown to be effective at improving performance and mood overnight without significantly affecting subsequent sleep [77].

4.3 The beneficial effects of naps on performance

4.3.1 Naps have a beneficial effect on performance and mood [70, 88, 89] and, after careful scheduling, may be the most effective countermeasure against fatigue at work. In the aviation environment it is important to know the minimal amount of sleep required to maintain acceptable performance and, therefore when to place naps for optimal sleep. However, it appears that any performance benefits that may be gained from a nap will be dependent on several factors. These include the timing and duration of the nap and the length of the preceding period of sleep loss. These will be discussed in the following sections, and are summarised in Figure 4-2, Section 4.7.

4.3.2 *Nap timing and performance benefits*

4.3.2.1 Falling asleep may be easier at certain times of the day and night. However, some studies have found that the circadian placement of a nap may result in differential performance effects. Naitoh (1981)[54] showed that a two hour nap taken between 04:00 and 06:00 after 45 hours awake, did not improve cognitive performance to the same extent as a nap taken between 12:00 and 14:00 after 53 hours awake. A subsequent study [30] found that a 3 hour nap taken in the circadian trough also had a limited beneficial effect on performance.

4.3.2.2 On the other hand, Dinges *et al.* (1988)[28] did not observe a difference in the benefits of a 2 hour nap taken either between 15:00 and 17:00 after 30 hours awake, or after a nap taken between 03:00 and 05:00 following 42 hours awake. Performance decrements resulting from sleep inertia have been reported for 5–35 minutes following awakening from a nap (reviewed by Rosekind *et al.*, 1995[75]; see Section 4.4). These inconsistent findings may therefore be due to differences in the time elapsed between waking and performance testing, although this is not explicit. Naps placed in the circadian trough may be easy to initiate and maintain, but may result in greater performance deficits immediately following awakening than naps taken at other times.

4.3.3 *Duration of naps and performance benefits*

4.3.3.1 There is some evidence that naps as short as 10 minutes, also known as 'power naps', are restorative to performance [56]. However, this conclusion appears to be based mainly upon studies which investigated the effects of disturbed sleep over many hours, i.e. awakening subjects every 10 minutes. Hence these 10 minute 'naps' were generally taken close together and in succession.

4.3.3.2 Horne and Reyner (1996)[41] found that a 15 minute nap taken between two 1 hour sessions of monotonous simulator driving which commenced five minutes after awakening, significantly improved performance. The performance data suggest that the benefits were apparent immediately on starting the task, indicating an absence of sleep inertia. Although this short nap was beneficial to performance, two out of the ten subjects were unable to nap, and there was a high degree of variation in sleep latency and nap duration. This highlights a problem with assigning short nap periods: not all individuals will fall asleep within this time (see Section 4.2.5).

4.3.3.3 Gillberg *et al.* (1996)[36] reported significant improvements in performance on a reaction time and a vigilance task following a 30 minute nap. This nap was taken between two 4 hour testing sessions, the first of which occurred after a 4 hour sleep. To avoid sleep inertia there was a 30 minute period between awakening from the nap and commencement of the task battery. The nap returned performance to baseline levels and generally improved performance over the second four hour test battery, relative to the no nap condition.

4.3.3.4 Various studies of continuous work have demonstrated that naps of 1–2 hours duration were beneficial compared to no sleep at all [48, 96]. Generally, the longer the nap the greater the beneficial effects on mood, performance and alertness [27, 48, 49, 64].

4.3.4 *Single and multiple naps*

4.3.4.1 There remains controversy as to whether naps are more beneficial when taken as a series of short multiple naps or one long sleep period. A study of sleep loss and nap effects during 42 hours of sustained performance [52] showed that subjects who were allowed a 1 hour nap after every 6 hours did not perform as well during the last 24 hours of the study as subjects who received the same amount of sleep in a continuous block (23:00–05:00). However, operations which involve continuous, prolonged work will often not accommodate a long sleep period, and under these conditions the use of a number of short naps may be more practical. The provision of multiple short naps within a demanding schedule may help to overcome the deleterious effects of sleep loss. Indeed, this can be achieved and sustained for several days in motivated adults under both laboratory [15] and operational conditions [85].

4.3.4.2 In situations where in-flight naps are not a normal requirement, they may be needed on occasions to counteract unexpected fatigue. The development of multiple sleep schedules for use in an operational environment, is a fairly new concept. At present there is insufficient information available to predict how such a pattern may benefit individuals, as performance will be affected by other factors apart from sleep loss (such as the type of task being performed and the ability to function immediately on awakening). It is important that future studies investigate the repeated use of naps during a prolonged work period to determine the extent of their continued efficacy.

4.3.5 *The length of a preceding period of wakefulness prior to a nap*

4.3.5.1 The scheduling of naps during a duty period will depend on the operational demands. However, current data suggests that naps should be taken before an appreciable amount of sleep loss has occurred [27, 52, 70]. Dinges *et al.* (1987)[27] investigated the placement of a 2 hour nap during a 54 hour continuous operation. It was concluded that the beneficial effects of naps occurred after individuals had been awake for only 6 or 18 hours. These were substantial and remained beneficial for over 24 hours, whereas performance improvements after later naps were neither as great nor as long-lasting.

4.3.5.2 A 4 hour nap taken prior to a period of overnight work has been shown to attenuate the usual circadian decline in performance [59]. Similarly, a 2 hour nap taken in the afternoon, after only 6 hours of wakefulness, was shown to have a beneficial effect on a sustained attention task performed 10 hours later [27].

4.4 The negative effects of naps on performance: sleep inertia

4.4.1 It is generally accepted that naps are beneficial to performance. However, there are also negative effects, the most important of which is sleep inertia. As described in Section 3.2, sleep inertia is a transient state of confusion accompanied by impairment of performance and mood, following abrupt awakening from sleep (nocturnal or nap).

4.4.2 The duration of sleep inertia is usually measured as the time taken for performance to recover to pre-nap levels and has been shown to vary between 5 to 30 minutes (reviewed by Muzet *et al.*, 1995[53]). For example, Salamé *et al.* (1995)[76] reported that the effects of sleep inertia after a one hour nap overnight lasted 27 minutes before returning to pre-nap levels. These transient effects gave rise to performance levels that were significantly worse than during an overnight period without sleep control; (see Figure 4–1). As the subsequent sections will show, the severity of sleep inertia depends upon a variety of factors.

4.4.3 Sleep inertia has been reported to result in significant decrements in speed and accuracy of various tasks. These include long and short term memory tests, simple and complex reaction times, time estimation, mental arithmetic [25], vigilance and monitoring tasks [79], physical strength and co-ordination [42] all of which may be required by aircrew on duty.

4.4.4 There have been few empirical studies into the effects of sleep inertia on different tasks, although it appears that those requiring sustained attention are the most susceptible. Simons *et al.* (1994)[79] reported significantly better performance on a complex, resource management task than on a vigilance test, both of which were undertaken 15 minutes after awakening from a nap. Similar results have been reported by Naitoh (1981)[55]. As with studies of sleep deprivation, this may indicate that more interesting, complex tasks are less susceptible to sleep inertia than more mundane vigilance and monitoring tasks [78].

4.5 Factors influencing the severity of sleep inertia

4.5.1 *Depth of sleep*

4.5.1.1 The severity of sleep inertia appears to be primarily influenced by the stage of sleep on waking and the quantity of SWS during the nap [57]. Subjects woken from stage 4 sleep had significantly longer reaction times, greater memory impairments and took longer to recover than those awoken from stage 2 sleep [9, 25, 33]. Dinges *et al.* (1985)[26] reported a significant and positive relationship between the duration of stage 4 sleep and the number of incorrect responses on a mental arithmetic task.

4.5.1.2 The increase in the severity of sleep inertia following stage 4 sleep is in accord with the difficulty in awakening from deep sleep. Individuals are unlikely to be as disturbed by environmental noise such as doors slamming or a telephone ringing, during stage 4 sleep as they would be during stage 2 sleep [13].

4.5.1.3 The evidence suggests that the severity of sleep inertia increases with depth of sleep preceding awakening and the duration of SWS. However, this has not been empirically investigated. A quantifiable relationship between the severity of sleep inertia and the length of sleep stages during the nap, and sleep stages on awakening cannot be derived from the current literature.

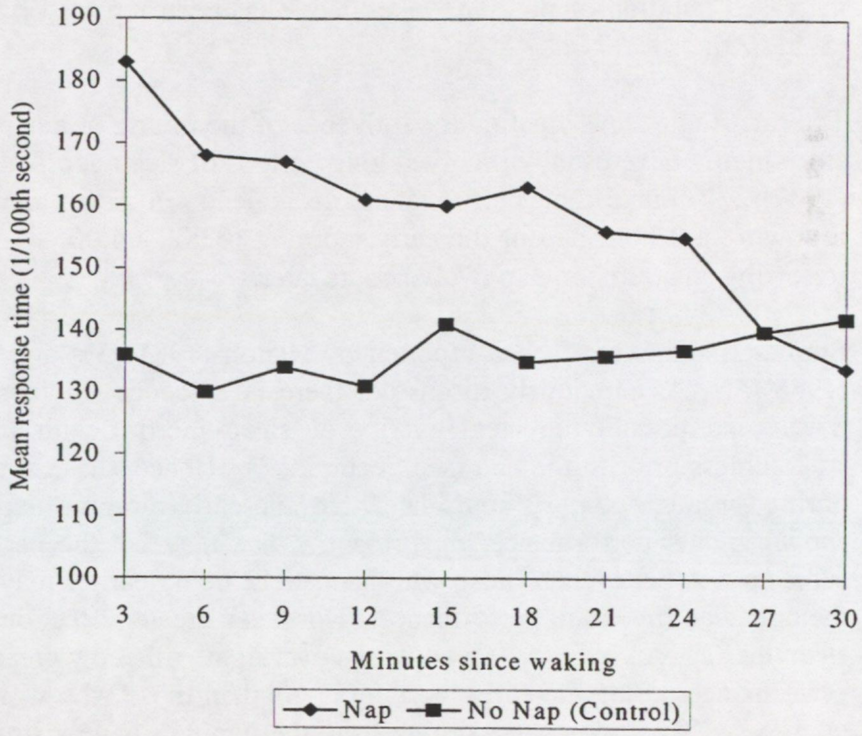

Figure 4–1 Mean reaction times for a spatial memory task following a one hour nap

(The duration of performance impairment for a nap group compared to a no-nap control group, adapted from Salamé et. al., 1995[76]).

4.5.2 *Duration, time of nap, and length of prior wakefulness*

4.5.2.1 Associations between nap duration, time of day and length of prior wakefulness (sleep loss) in relation to the severity of sleep inertia have been reported [24]. These associations may be explained by their influence on the duration and latency of SWS.

4.5.2.2 Under normal circumstances, SWS occurs mainly in the first few hours of sleep and has a latency of approximately 30 minutes [99]. Naps of two to four hours duration are likely to contain significantly more SWS than naps of an hour or less. Differences in experimental design, such as the types of tasks used, the elapsed time between awakening and starting the tasks, make it difficult to arrive at any satisfactory conclusions on the influence of nap duration on the severity of sleep inertia.

4.5.2.3 The time of prior wakefulness appears primarily to determine the amount and duration of SWS. In subjects deprived of sleep for 54 hours, with a one hour nap at 6, 18, 30, 42, or 54 hours, the latency to, and duration of, SWS increased. The duration of SWS was positively associated with an impairment in performance on a descending subtraction test on waking [26]. Increased severity of sleep inertia with increased duration of pre-nap wakefulness has been reported by other researchers [5, 53, 73].

4.5.2.4 The few studies investigating the influence of the timing of a nap on the severity of sleep inertia have usually involved long periods of sleep deprivation. Dinges *et al.* (1987)[27] found that performance decrements in sleep deprived individuals following a 2 hour nap in the early morning (02:00–04:00) were similar to those following an afternoon nap twelve hours later.

4.5.2.5 Similar findings have been reported by Naitoh (1981)[55] and Balkin and Badia (1988)[5]. As previously discussed, there is evidence for increased duration of SWS (and possibly greater severity of sleep inertia) with increasing time of wakefulness prior to the nap (see Section 2.3). Hence, those subjects who napped during the afternoon, 12 hours later than the early morning nappers, should have shown greater performance impairments. The fact that the performance of these subjects was better than those who napped 12 hours earlier may be attributable to the circadian rhythm in performance. This has a greater effect on performance than sleep inertia. An individual who works overnight will show greater impairments of performance during the early morning hours than those who work during the mid-afternoon. The time of awakening from the nap will have a stronger influence on performance after abrupt awakening than the quantity of SWS.

4.5.2.6 It is evident that unless a nap is of a very short duration (e.g. power nap), sleep inertia will occur on awakening. However, what remains unclear is how much time is required post-nap for the negative behavioural effects of sleep inertia to give way to the beneficial effects of the nap [57].

4.5.2.7 Under normal conditions, the time before performance returns to that obtained in a no-nap control appears to be approximately 30 minutes [76]. However, the duration of sleep inertia may increase to two hours or longer under conditions of severe sleep deprivation [73]. There is little consistency in the literature in terms of the timing and duration of a nap, the length of prior wakefulness, the time elapsed from awakening to commencing a task, and the type of task performed in relation to the severity of sleep inertia. This lack of empirical investigation makes it difficult to provide satisfactory recommendations for the commencement of duty following a nap.

4.6 Countermeasures to sleep inertia

4.6.1 In the context of air operations, countermeasures to sleep inertia may involve the avoidance of SWS by limiting nap duration, by preventing sleep loss and implementing effective nap schedules. Other countermeasures include the use of alerting stimuli such as loud noise and bright light to hasten recovery of performance to pre-nap levels. These factors are illustrated in Figure 4–2, Section 4.7.

4.6.2 *The prevention of sleep loss*

4.6.2.1 To aid the achievement of adequate rest prior to duty, individuals should be provided with information on optimising their sleep during rest periods. This should include advice on strategies to enhance their chances of sleeping, including: education about nap placement, duration, circadian cycle and the influence of time zone transitions on layover sleep [67, 71]. The rest environment should be as conducive to sleep as possible [68].

4.6.3 *Limiting nap duration*

4.6.3.1 It may be possible to avoid SWS by limiting the duration of the nap. As illustrated by Figure 2–1, the latency to SWS is approximately 30 minutes. A 20 minute nap may consist mainly of stage 1 and 2 sleep. However, the latency to SWS varies between individuals [99] and may also decrease with the duration of prior wakefulness (the S process, see Section 2.3). Total avoidance of SWS cannot be guaranteed. In addition, there may be reduced performance benefits with short duration naps compared to long duration naps (see Section 4.3.3), although these may be overcome by adopting a multiple napping strategy. Taking into account the performance benefits reported from multiple short naps in the laboratory (see Section 4.3.4), a multiple napping strategy consisting of 20 minute naps may minimise the severity of sleep inertia whilst maintaining performance, although further studies are required to verify this.

4.6.4 *Scheduling of naps*

It may be possible to schedule naps to avoid SWS. However, these periods are times when individuals naturally feel more able to sleep (i.e. afternoon and early morning [24]; see Section 2.2). Individuals may find it more difficult to nap at other times of day where SWS is less prevalent (e.g. in the morning following a normal night's sleep). One problem associated with scheduling naps to avoid periods of SWS is that sleep latency is likely to be increased and the quality of sleep reduced. This may affect the beneficial effects of the nap (see Section 4.3), although this has not been empirically investigated.

4.6.5 *Alerting stimuli on awakening*

4.6.5.1 There have been few investigations into the use of stimuli on awakening to aid recovery from sleep inertia. Exposure to stimuli such as loud noise and bright daylight may be alerting and therefore reduce the required recovery time. Tassi *et al.* (1992)[87] reported the abolition of sleep inertia in subjects exposed to 75 Db(A) pink noise on awakening from a one hour nap in the early part of the night. Åkerstedt and Landström (1998)[2] reviewed countermeasures to fatigue during the night shift, concluding that although exposure to noise may be alerting, the noise can be unpleasant and performance effects temporary. Exposure to daylight has also been reported as having alerting effects under conditions of fatigue [86], but this has not been studied as a countermeasure to sleep inertia.

4.6.5.2 Consumption of caffeine has been frequently reported to improve performance and increase alertness when individuals are fatigued [70]. However, caffeine can take 30 minutes from ingestion until it is effective [8]. This is approximately the same as the time required to recover unaided from sleep inertia.

4.6.5.3 Muzet *et al.* (1995)[53] suggested that high levels of motivation may be an effective countermeasure to sleep inertia, but this has not been investigated. However, the use of incentives or provision of an interesting task have been shown to improve performance during sleep deprivation studies [40, 78]. In the context of an emergency situation, it is currently unknown whether high motivation will overcome sleep inertia.

4.7 Summary of the factors influencing the effects of naps on performance

In Figure 4–2, the various factors which are influential in determining the effect of waking from a nap on performance are shown. This diagram is a representation of the relationships between influencing factors, as derived from the literature discussed in this report.

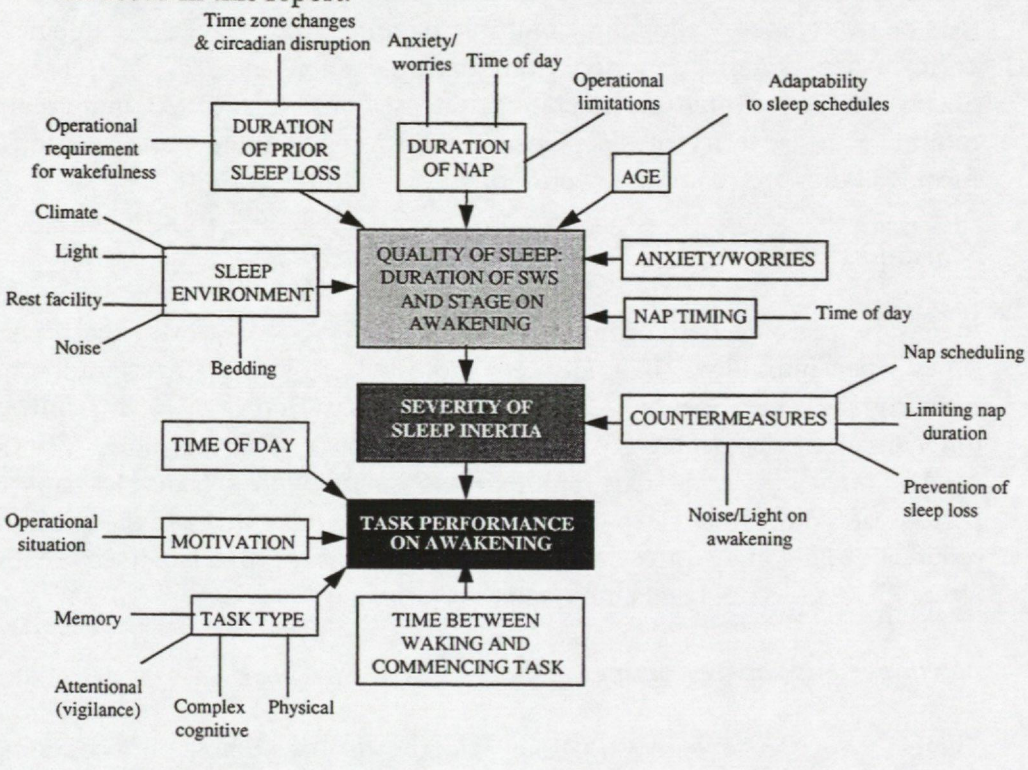

Figure 4–2 Representation of the factors influencing the quality of sleep, severity of sleep inertia and performance on awakening

5 IN-FLIGHT NAPPING

5.1 Sleeping on the aircraft

5.1.1 Information contained in the previous sections has provided a background to the issues that affect the ability to sleep, the quality of sleep during a nap, and the effects of napping on subsequent performance. This section specifically addresses napping in-flight and the factors influencing the quality of sleep in these situations.

5.1.2 In theory, rest can be taken in a number of different areas on a civil aircraft (flight deck seat, passenger seat, bunk). However, in practice, the rest facilities that are available to aircrew on a specific flight are dependent on the aircraft type, route and crew composition. Non-augmented crews who nap, do so on the flight deck in their seat. Augmented crews often have a choice of locations in which to take rest: in passenger chairs away from the flight deck (e.g. in the business or first class sections) or, where fitted, in bunk facilities situated behind the flight deck. This section reviews rest in these different situations and the benefits/limitations are highlighted.

5.2 Sleep quality in available facilities in-flight

5.2.1 Few studies have investigated the quality of rest on the flight deck and, furthermore, no studies have examined the influence of the environment on the quality of sleep on the flight deck. If a crew member were to sleep in a flight deck seat, it is likely that the quality of sleep will not be as good as that taken in a bunk (see Section 2.5.2).

5.2.2 *Napping in bunks*

5.2.2.1 Sleep in bunks during long-haul flights has been reported to be poorer than sleep in a bed [4, 65]. This has been attributed to both environmental and non-environmental factors such as noise, climate, bedding, and insomnia caused by anxiety. In a retrospective survey of long-haul pilots the most frequently cited factor that disturbed sleep in-flight was random noise (59% of respondents). When crews were asked to complete a similar questionnaire in-flight, random noise was again listed as the most disturbing factor [64].

5.2.2.2 Other factors that have been attributed to poor sleep on board aircraft are: inadequate bedding, turbulence, general background noise of the aircraft, low humidity, high temperature [4, 65, 67, 68, 79], not feeling tired and anxiety [66].

5.2.2.3 In their survey of in-flight rest, Pascoe *et al.* (1994)[66] were able to correlate some disturbing factors with subjective assessments of sleep quality and with alertness at the end of the sleep period. Turbulence and random noise both impaired sleep quality and alertness after sleep. The constant ambient noise of the aircraft was negatively related to the quality of sleep, and alertness after sleep was reduced by feeling too hot. The duration and quality of sleep, as well as alertness after sleep, were all reduced as a result of 'having thoughts on one's mind' and 'not feeling tired'.

5.2.2.4 To optimise the quality of rest in-flight it is therefore necessary to ensure that the bunk facilities are provided with good environmental control, isolation from disturbing factors, and eyeshades and earplugs [67]. However, crews will still be exposed to some factors that cannot be moderated e.g. turbulence. If rest is taken on the flight deck, it will be important to ensure that the seat is conducive to sleep, i.e. that it can be reclined and that some support is provided for the legs [60].

5.2.3 *The 'NASA nap'– napping on the flight deck*

5.2.3.1 On flights operating with augmented crews, a number of airlines have implemented the use of controlled rest on the flight deck. The use of the 'NASA nap'[74], a 40 minute sleep period whilst seated on the flight deck, has been reported to be beneficial for the maintenance of performance during the flight. Rosekind *et al.[*74] limited the nap to 40 minutes in an attempt to obtain performance benefits whilst minimising the effects of sleep inertia by reducing the possibility of entering SWS.

5.2.3.2 The NASA nap involves a rest period of just over an hour, comprising 3 minutes preparation, a 40 minute nap and a 20 minute recovery period. In the original study, three-man augmented aircrews on long-haul flights (6.7–13.8 hours) were scheduled one rest period. On average, the latency of sleep during these naps was 5.6 minutes, and the TST was 26 minutes, 61% of which was composed of stage 2 sleep. This rested group managed to maintain consistent reaction times on a vigilance test both across and within flight legs. The reaction times of a control (no-rest) group increased steadily within flight legs, and there were twice as many lapses in concentration during the vigilance task compared with the rest group.

5.2.3.3 The possible effects of sleep inertia following awakening from the nap were not fully reported in this study. In the 20 minutes immediately following awakening, the crew were given a 3 minute recovery period before commencing two tasks: an operational problem (calculation of gross-weight takeoff) lasting 7 minutes, and subsequently, a 10 minute vigilance task. For reasons which are not clearly stated, only the results of the vigilance task were reported. Rosekind *et al.* found no decrements in performance of this task which occurred 10 minutes after awakening. Therefore it is possible that any sleep inertia may have dissipated by this time, and given way to the beneficial effects of the nap. However, in practice, aircrew may be reluctant to wait 10 minutes before returning to duty.

5.2.3.4 There is little evidence to support the recommendation that naps on the flight deck should be limited to 40 minutes to minimise the possibility of entering deep sleep and hence sleep inertia. Rosekind *et al.* appear to base this choice of duration on a review by Dinges (1989)[23], but the information supplied relates to the REM sleep latency, and not latency to SWS. Normative data for the latency to various sleep stages for different age groups have been reported by Williams *et al.* (1974)[99]. For 35 to 45 year olds (similar age range to pilots), the average latency to stage 3 sleep is 35–40 minutes, ranging between 12–58 minutes. Hence, terminating the nap at 40 minutes may result in sleep inertia due to individuals awakening during SWS (see Section 2.1.3). In addition, given this range of values, it is unlikely that all individuals will not enter SWS during a 40 minute nap. Rosekind *et al.*[74] reported that pilots obtained an average of 8% SWS, showing that SWS did occur to some extent within the 40 minute nap period.

5.2.3.5 Rosekind *et al.*, (1994)[74] did not provide data on the stage of sleep on awakening, and tested pilots after they may have recovered from sleep inertia (10 minutes after waking). In addition, Sallinen *et al.* (1998)[77] reported the duration of sleep inertia to be 10–15 minutes after a 30 or 50 minute nap during an overnight shift.

5.2.3.6 Limiting the duration of the nap to 40 minutes in order to minimise the possibility of entering SWS and therefore reduce the effects of sleep inertia may be problematic. SWS may be the most recuperative of the sleep stages. The onset of SWS occurs more rapidly and for longer durations after a period of sleep deprivation [73]. For instance, sleep loss may accumulate during the layover [68, 79], and so there may be a greater requirement for sleep, and especially SWS, during the return flight (see Section 2.3). Hence variations in the requirement for SWS may influence its latency and duration within a 40 minute nap. Indeed, Rosekind *et al.*[74] reported a significantly greater percentage of SWS during naps on overnight flights than on daytime flights (11.4% and 4.3% respectively).

5.2.3.7 The avoidance of SWS may adversely affect improvements in performance. However, the relationship between nap duration, sleep stages and subsequent performance benefits has not been empirically investigated. In addition, limiting the nap period on the flight deck to 40 minutes may result in some individuals obtaining very little sleep due to the disturbing environment (i.e. noise, light etc. see Section 2.5).

5.2.3.8 Overall, Rosekind *et al.*[74] demonstrated that a 40 minute nap maintained alertness during long-haul flights. However, it is possible that sleep inertia occurred during the 10 minutes which elapsed between awakening and the onset of the vigilance task. Limiting the nap period to 40 minutes did not avoid SWS. The latency to SWS varies as a function of duration of prior wakefulness, time of day, age, and between individuals.

5.2.3.9 Subsequent to the study by Rosekind *et al.* (1994)[74], a second study into the effectiveness of flight deck napping in 3-crew (Captain, First Officer, Flight Engineer) during long-haul operations was completed by Simons and Valk (1997)[80]. Data were collected from 59 pilots flying North-Atlantic B747-300 routes. During the flights the Captain and First Officer were asked to complete a dual vigilance and tracking task on a palmtop computer and to wear an actigraph to monitor activity. In addition, crews rated alertness (Stanford sleepiness scale) and, if appropriate, sleep quality, although objective measures of sleep (EEG) were not obtained. Performance and subjective measures were taken approximately 15 minutes before and after the rest period and 30 minutes before the top of descent. However, the duration of the naps was not reported.

5.2.3.10 For both the outbound and return flights, rest on the flight deck was considered to improve alertness and tracking performance up to the top of descent. Post-rest, those crews who had rested showed improved performance on the tracking task whereas performance was impaired in those who had remained awake (the no-rest group). No differences in performance for the rest and no-rest groups could be detected using the vigilance task during both the outbound and return trips.

5.2.3.11 For the outward flight, crews who had rested were more alert at the top of descent than the no-rest group. However, there were no differences in alertness post-rest between the rest and no-rest groups. On the return flight, crews who had rested were more alert post-rest and at the top of descent than the no-rest group.

5.2.3.12 Almost half the pilots (outbound flights 48%, inbound flights 41%) who participated in the trial reported that they were unable to sleep during the scheduled rest period. Crews also commented on the shortcomings of the flight deck seat and, in particular, the absence of a headrest was considered to be detrimental to the quality of sleep.

5.2.3.13 Overall, the evidence suggests that napping on the flight deck may maintain alertness and performance on certain tasks (perceptual-motor and vigilance) throughout a long-haul flight. However, it seems that it is difficult to initiate and maintain sleep in the flight deck environment. In the cases where sleep is achieved, the extent and duration of sleep inertia on awakening is unknown.

5.3 Scheduling in-flight rest on the aircraft

5.3.1 *Two-man non-augmented aircrew*

5.3.1.1 It has been reported that even when regulations forbid the use of in-flight rest on the flight deck, such as with two-man non-augmented crews, sleep does occur [74]. Schedules should have been designed to avoid the fatigue levels which require napping, but unexpected events may lead to a requirement for a short, in-flight nap. Due to the limitations of this operational situation, the rested pilot may be required to resume duties shortly after awakening from a nap. Sleep inertia may occur during this time, resulting in impaired alertness and performance (see Section 4.4).

5.3.1.2 There are other safety implications associated with the flight deck rest of two-man non-augmented crews. It is important to ensure that the crew member who is not resting, i.e. the operating pilot, remains awake and alert. The introduction of an alarm system to monitor the status of the operating pilot may be one way of addressing this issue. Research is being currently carried out by the CHS, funded by the CAA, to develop a monitoring system based on wrist activity [51]. Other monitoring systems integral to the flight deck are also under development [84].

5.3.2 *Three-man crews: no rotation*

5.3.2.1 The majority of studies investigating the scheduling of rest onboard aircraft have involved three or four-man augmented crews resting in bunks. Crew augmentation by the provision of an additional crew member will provide flexibility in the rest schedule by allowing the aircrew to rotate through the seats (one individual rests whilst the other two remain on duty). However, in some instances three-man crews are not augmented and rotation cannot occur if the additional crew member is not fully trained. When this situation occurs, the aircrew are required to remain awake throughout the flight.

5.3.2.2 A recent study investigating the alertness of aircrew during long-haul flights showed that extensive napping did occur among non-rotating 3-man crews [83]. During the 207 flights that were monitored, 51 in-flight naps were reported. The average duration was 47 minutes, with most naps occurring during the return flight when the aircraft had no passengers. Napping during the return flight could therefore have been taken away from the flight deck in passenger seats, although no information was available regarding the location of the rest. The majority of the naps were taken between 2 and 5 hours after the start of the duty period. In addition to the naps recorded in crew diaries there was also evidence that some naps were not reported. This information was obtained from recordings of activity made via accelerometers mounted in wrist watches.

5.3.2.3 There was evidence of high fatigue levels when return flights departed in the early morning or in the evening. Despite the efforts of the crews to obtain sufficient sleep during the layover and the use of in-flight rest, it was insufficient to maintain alertness within acceptable limits. One conclusion of the study was that crews required more sleep on certain trips. It is possible that more effective rest may have been achieved if crews had the opportunity to rest in crew bunks. However, no direct comparisons have been made between the quality of rest on the flight deck and in a bunk. These findings would suggest that careful consideration should be given to the facilities in which crews rest.

5.3.3 *Augmented aircrew: one rest opportunity*

5.3.3.1 In-flight rest is taken in a bunk as a single period for many augmented crews. The aircrew bunk is usually located immediately behind the flight deck. Generally, two bunks are available and they are screened from the passengers. Augmented crews rotate from the flight deck into the bunk, with the relief crew taking the first opportunity to rest. The length of the rest period is dependent on the flight length and crew composition. For a three-man crew this means that the cruise phase of the flight is, in general, split into three equal rest periods. With a four-man crew, two individuals rest at the same time (i.e. the 2 relief or 2 operating crew) and therefore the rest period is approximately half the duration of the cruise phase.

5.3.3.2 The departure time and the timing of the rest period are important factors influencing the quality of sleep of augmented aircrew who rest in bunks [65, 67]. In-flight sleep quality and quantity are likely to be optimum when the scheduled rest follows a reasonable period of wakefulness and coincides with the phase of the circadian cycle during which sleep normally occurs. Difficulties initiating and maintaining sleep may arise if individuals attempt to sleep at other times (see Section 2.2).

5.3.3.3 The timing of the flight will also influence the quality of sleep. Sleep was less disturbed on a flight departing in the early evening with minimal time zone change, than on an eastward flight with a daytime departure. Individuals attempting to rest following a midday departure had greater difficulty sleeping than those attempting to sleep in the early evening [65].

5.3.4 *Augmented crews: two rest opportunities*

5.3.4.1 From the above sections (0–0) it is clear that the timing of rest within a flight is one important factor determining the quality of sleep. Although the prime consideration should be the scheduling of rest of the crew responsible for landing the aircraft, the relief crew should also obtain some benefit from the use of in-flight rest. Generally, the relief crew are scheduled to rest during the early part of the flight when they are more likely to experience difficulties sleeping. A study has investigated whether the use of two short rest periods may be more beneficial, in terms of the quality of sleep, than one long opportunity [68]. Two strategies were employed: strategy one involved the main and relief aircrews each taking a single long rest period; strategy two involved aircrews alternating in the rest facilities, with each member taking two shorter rest periods. The outbound flight departed at 12:00 GMT and the return departed at 12:30 local time (03:30 GMT).

5.3.4.2 During outbound flights, most aircrew who were scheduled with two rest periods chose to go into the bunk on only one occasion (4/12 during the first rest period, and 10/12 during the second). All individuals scheduled with one long rest period attempted to sleep. On average, the TST obtained by pilots who had two short opportunities to sleep was less than that obtained by crews who took one long rest period (108 minutes compared with 143.8 minutes). When comparisons were made between individuals who were scheduled with a single long nap, those who had slept during the first half of the flight were found to spend less time asleep and in bed than those who slept in the second half of the flight.

5.3.4.3 The requirement for naps on the return flight was different from the outbound flight. There were no differences in sleep duration or quality between the early or late nap periods. It was concluded that this may have been attributable to an increased need for sleep resulting from sleep loss and disruption to the circadian rhythm during the layover. This was reflected by significantly greater TST, stage 2 and REM sleep compared to the outbound flight.

5.3.4.4 These findings confirmed those of other studies that the quality of rest on long-haul flights is influenced by the time of departure and the requirement for sleep [65, 79]. It was concluded that when the requirement for sleep is high (e.g. during the second part of the flight, during a night flight or when the crews are unacclimatised) it is more beneficial for one long rest to be taken.

5.3.4.5 When the requirement for sleep is low (e.g. during the first part of a flight with a morning departure) it may be more beneficial for crews to have two opportunities to rest so that they have the chance to obtain some sleep during the flight.

5.3.5 *In-flight rest and sleep inertia*

Simons *et al.* (1994)[79] recorded the quality of sleep during a 1.5–3 hour nap in a bunk on civil aircraft. They found that those pilots who obtained less SWS performed better on a vigilance task (undertaken 15 minutes after awakening) than those whose sleep consisted of significantly more SWS. Performance benefits were reported following in-flight rest, although sleep inertia was present for a vigilance task for approximately 30 minutes after awakening. Both Simons *et al.* [79] and

Robertson *et al.* (1997b)[68] recommended allocating the final rest period to the aircrew responsible for landing to ensure they are alert during this phase of the flight.

6 CONCLUSIONS

6.1 Fatigue, resulting from prolonged periods of wakefulness and time on duty, has been shown to impair significantly the performance of subjects in the laboratory, and aircrew during long-haul flights.

6.2 Naps are a beneficial countermeasure to fatigue. Episodes of sleep as short as one hour have been shown to increase levels of alertness towards the end of a duty period. One study has shown that the use of a 40 minute nap on the flight deck was beneficial in maintaining alertness, although sleep inertia may have occurred on awakening. However, due to inconsistencies in the literature, any relationship between the duration of a nap and the extent of subsequent benefits is unclear.

6.3 Naps are most effective if they are taken prior to the onset of fatigue rather than after it has become established. The ability to nap is influenced by factors such as the time of day and the time since the last sleep. It is easiest to initiate sleep around the time of the body temperature minimum (02:00–06:00). If a nap is taken too soon after awakening from nocturnal sleep (07:00–12:00) or taken during the forbidden zone for sleep (17:00–21:00), initiation will be difficult and sleep quality will be reduced. Napping may affect the quality and onset of subsequent sleep if taken in close proximity to the next main sleep period.

6.4 Individual differences also affect the ability to nap: some individuals find it easier to nap than others. Sleep quality reduces and sleeping habits and patterns become more difficult to alter as age increases.

6.5 Environmental factors such as noise, temperature, humidity, and the sleeping facilities (i.e. bed, angle of chair backrest, inadequate bedding) have all been shown to affect the duration and quality of sleep. Factors such as not being tired and anxiety are also likely to disturb sleep. In general, sleep disturbances arising from environmental conditions lead to more awakenings, increased latency to sleep, reduced TST and a greater predominance of the lighter stages of sleep.

6.6 Due to the backrest angle and the disturbing environment, it is likely that the quality of sleep in a flight deck seat will not be as good as that taken in a bunk. However, this has not been investigated in the field. For augmented crews, naps in an aircraft bunk can be as recuperative as sleep in a bed provided that disturbances are minimised (e.g. the use of sound attenuation, air-conditioning, screening from light). In-flight sleep quality and quantity are likely to be optimum when the rest period follows a reasonable period of wakefulness and coincides with the phase of the circadian cycle during which sleep normally occurs.

6.7 Sleep inertia, a transitory deficit in mood and performance, is the main factor limiting the effectiveness of naps. It occurs on wakening and it may persist for between 5–35 minutes before performance returns to pre-nap levels. It therefore appears that 30 minutes should elapse between awakening and the resumption of duties. However, this review of the literature has revealed large variations in experimental design and measurement, and this has often prevented direct comparisons between studies.

6.8 The severity of sleep inertia appears to be associated with the stage of sleep on waking and the duration of SWS. The latter is influenced by the amount of sleep loss prior to the nap, the time of day that the nap is taken, and the duration of the nap.

6.9 Sleep inertia may be reduced by ensuring crews are not excessive ly sleep deprived before the nap, and that the duration of the nap is sufficiently short to avoid SWS (e.g. multiple 20 minute naps). However, the latter may not be feasible due to the variety of factors that influence the latency and duration of SWS. The avoidance of SWS may reduce the nap benefits, although this has not been substantiated. Other strategies such as the use of alerting stimuli on waking (e.g. pink noise or bright light) may aid recovery from sleep inertia, although they may not be practical on the flight deck.

6.10 There is currently a lack of information in the following areas:

- The influence of nap duration and timing on sleep stages, and the relationship of these factors with performance benefits and the severity and duration of sleep inertia on awakening.
- The efficacy of using multiple napping strategies in-flight.
- A comparison between the quality and duration of in-flight naps in bunks and in airline seats (on the flight deck, passenger sections).

7 RECOMMENDATIONS

7.1 Because of the effects of sleep inertia, non-augmented crews who may need to operate at short notice should not rely on napping to maintain acceptable levels of alertness. Short naps on the flight deck should only be used as an emergency measure to combat unexpectedly low levels of alertness that could not have been anticipated when the flight was scheduled. In these situations, the adoption of a multiple napping strategy consisting of 20 minute naps may minimise the severity of sleep inertia whilst maintaining performance, although further studies are required to verify this.

7.2 Where augmented crews are provided, the schedule anticipates napping and this should be arranged to avoid sleep inertia. Therefore it is recommended that crews should not recommence duty for at least half an hour after waking from sleep. However, it is difficult to give more than general guidance on the required recovery time from sleep inertia. To maximise the beneficial effects of naps, rest periods should be scheduled to occur before an appreciable amount of sleep loss, but after a reasonable time of wakefulness.

7.3 The facilities in which crews rest and the rest environment should be as conducive to sleep as possible. Where rest is taken in a bunk this should include the provision of air-conditioning, adequate bedding, sound-proofing and screening from light. For rest taken on the flight deck this will be more difficult to achieve. However, the resting crew member could be provided with ear-plugs and eyeshades in order to reduce the disturbances from random noise and light. To optimise the quality of rest in a chair, the backrest angle should be at least 40° with the vertical, and leg support should be provided.

7.4 Where the crew are unaugmented, measures should be in place to ensure that the operating pilot remains awake and alert should the other crew member require sleep.

7.5 Generally, greater nap benefits are obtained from bunk rest if one long rest period is provided rather than two short rest periods. However, when departures occur early in the morning, it may be more beneficial to schedule two short rest periods so that some sleep can be obtained during the flight.

7.6 Aircrew should be provided with advice on strategies that may enhance their chances of sleeping during rest periods and help them avoid unintentional naps. The benefits of good sleep hygiene, relaxation techniques to aid sleep, the importance of nap placement, duration, circadian cycle and the influence of time-zone transitions on layover sleep should be highlighted.

8 REFERENCES

1. Åkerstedt T, and Gillberg M. *The circadian variation of experimentally displaced sleep.* Sleep, 4:159-169, 1981.
2. Åkerstedt T, and Lanström U. *Workplace countermeasures of nightshift fatigue.* International Journal of Industrial Ergonomics, 21:322 - 327, 1998.
3. American Sleep Disorders Association. *The International Classification of Sleep Disorders Diagnostic and Coding Manual.* 77 - 80, 1990.
4. Baker B, Pascoe PA, and Rogers AS. *The quality of sleep in aircrew rest quarters: Laboratory and preliminary inflight studies.* RAF IAM Report No. 733, 1992.
5. Balkin TJ, and Badia P. *Relationship between sleep inertia and sleepiness: cumulative effects of four nights sleep deprivation/restriction on performance following abrupt nocturnal awakenings.* Biological Psychology, 27:245-258, 1988.
6. Banderet LE, Stokes JW, Francesconi R, Kowal DM, and Naitoh P. *Artillery teams in simulated sustained combat: performance and other measures.* In: Biological rhythms, sleep and shift work. Johnson LC, Tepas DI, Colquhoun WP, and Colligan MJ (eds), Advances in sleep research Vol 7, Spectrum Publications, New York. 459-479, 1981.
7. Bliwise DL. *Normal Ageing.* In: Principles and Practice of Sleep Medicine. Kryger MH, Roth T, and Dement WC (eds), 26-39, 1994.
8. Bonati M, Latin R and Galletti F. *Caffeine disposition after oral doses. Pharmacol.* Therap. 32:98-106, 1982.
9. Bonnet MH. *Memory for events occurring during arousal from sleep.* Psychophysiology, 20:81-87, 1983.
10. Bonnet MH. *Performance and sleepiness as a function of frequency and placement of sleep disruption.* Psychophysiology, 23:267-271, 1986.
11. Bonnet MH, and Rosa RR. *Sleep and performance in young adults and older insomniacs during acute sleep loss and recovery.* Biological Psychology 25:153-172, 1987.
12. Bradley CM, and Robertson KA. *Combined stressors and performance: A review.* DERA Report No. DERA/CHS/PP5/WP980083/1.0., 1998.
13. Broughton, RJ. *Chronobiological Aspects and Models of Sleep and Napping.* In: Sleep and Alertness: Chronobiological, Behavioural and Medical Aspects of Napping. Dinges DF, and Broughton RJ (eds), Raven press, New York, 1989.
14. Civil Air Publication 371. *The avoidance of excessive fatigue in aircrew - guide to requirements.* 3rd edition. Civil Aviation Authority, London, 1989.
15. Carskadon MA, and Dement WC. *Sleepiness and sleep state on a 90 minute schedule.* Psychophysiology 14:127-133, 1977.
16. Carskadon MA, and Dement WC. *Effects of total sleep loss on sleep tendency.* Perceptual and Motor Skills 48:495-506, 1979.
17. Caraskadon MA, and Roth T. *Sleep restriction.* In: Sleep, Sleepiness and Performance. Monk TH (ed), Wiley, Chichester:155-167, 1991.
18. Costa G, Lievore F, Casaletti G, Gaffuri E, and Folkard S. *Circadian characteristics influencing interindividual differences in tolerance and adjustment to shiftwork.* Ergonomics 32(4):373-385, 1989.

19. Czeisler CA, Weitzman ED, Moore-Ede MC, Zimmerman JC, and Knauer RS. *Human sleep: Its duration and organisation depend on its circadian rhythm.* Science 210:1264-1267, 1980.
20. Daan S, Beersman DGM, and Borbely AA. *Timing of human sleep: recovery process gated by a circadian pacemaker.* Am J Physiol, 246:R161-R178, 1984.
21. Dahlgren K. *Adjustment of circadian rhythms and EEG sleep functions to day and night sleep among permanent nightworkers and rotating shiftworkers.* Psychophysiology 18(4):381-391, 1981.
22. Di Milia L. *Exploring the utility of using longitudinal single subject case studies to examine the sleep of shiftworkers involved in a change from 8 to 12 hour rotating shifts.* Shiftwork Int Newsletter 12(1):12, 1995.
23. Dinges DF. *Napping Patterns and Effects in Human Adults.* In: Sleep and Alertness: Chronobiological, Behavioural and Medical Aspects of Napping. Dinges DF, and Broughton RJ (eds), Raven press, New York, 1989.
24. Dinges DF. *Adult napping and its effects on ability to function.* In: Why We Nap. Evolution, Chronobiology, and Functions of Polyphasic and Ultrashort Sleep. Stampi C(ed), Birkhauser, Boston:118-136, 1992.
25. Dinges DF, Orne EC, Evans FJ, and Orne MT. *Performance after naps in sleep conducive and alerting environments.* In: Biological Rhythms, Sleep and Shiftwork. Advances in Sleep Research, Vol. 7. Johnson IC, Tepas DI, Coloquhoun WP, and Collinghan MG, (eds) Spectrum Pub. Inc., 1981.
26. Dinges DF, Orne MT, and Orne EC. *Sleep depth and other factors associated with performance upon abrupt awakening.* Sleep Research, 14:92, 1985.
27. Dinges DF, Orne MT, Whitehouse WG, and Orne EC. *Temporal placement of a nap for alertness. Contributions of circadian phase and prior wakefulness.* Sleep, 10(4):313-329, 1987.
28. Dinges DF, Whitehouse WG, Orne EC, and Orne MT. *The benefits of a nap during prolonged work and wakefulness.* Work and Stress, 2:139-153, 1988.
29. Downey R, and Bonnet MH. *Performance during frequent sleep disruption. Sleep* 10:354-363, 1987.
30. Englund CE, Ryman DH, Naitoh P, and Hodgdon JA. *Cognitive performance during successive sustained physical work episodes.* Behavior Research Methods, Instruments and Computers, 17:75-85, 1985.
31. Flin RH, Ellis AX, Wynn VE, and Skriver J. *The effect of sleep deprivation and long duration operations on command decision making*, DERA/CHS-7381. 1998.
32. Folkard S, and Barton J. *Does the forbidden zone for sleep onset influence morning shift sleep duration*? Ergonomics, 36:85-91, 1993.
33. Fort A and Mills JN. *Influence of sleep, lack of sleep and circadian rhythm on short psychometric tests.* In Aspects of Human Efficiency, Colquhoun WP (ed). Oxford University Press, 1972.
34. Gander PH, Rosekind MR, and Gregory KB. *Flight crew fatigue VI: a synthesis.* Aviation, Space and Environmental Medicine, 69(9, Suppl.):B49-60, 1998.
35. Gander PH, Nguyen DE, Rosekind MR, and Connell LJ. *Age, circadian rhythms and sleep loss in flight crews.* Aviation, Space and Environmental Medicine, 64:189-195, 1993.

36. Gillberg M, Kecklund G, Axelsson J, and Åkerstedt T. *The effects of a short daytime nap after restricted night sleep.* Sleep 19(7):570-575, 1996.
37. Griefahn B. *Critical loads for noise exposure during the night.* In: Jonasson HG, Ed, Proceedings of Internoise '90 (Vol 2), Gotteburg, Sweden 1163-1166, 1990.
38. Harrison Y, and Horne JA. *Sleep loss and human decision making*: a review. DERA/CHS-7380. 1998.
39. Haslam DR. *Sleep loss, recovery sleep, and military performance.* Ergonomics 25(2):163-178, 1982.
40. Holmes, SR, Robertson KA, and Stone BM. *The effect of 36 hours sleep loss on cognitive function.* In preparation.
41. Horne JA, and Reyner LA. *Counteracting driver sleepiness: Effects of napping, caffeine and placebo.* Psychophysiology, 33:306-309, 1996.
42. Jeanneret PR, and *Wilse WB. Strength of grip on arousal from full nights' sleep.* Perception and Motor Skills, 17:759-761, 1963.
43. Karacan L, Williams RL, Finley WW, and Hursch CJ. *The effects of naps on nocturnal sleep: Influence of the need for stage 1 REM and stage 4 sleep.* Biological Psychiatry, 2:391-399, 1970.
44. Kelly RJ, and Schneider MF. *The 12h shift revisited: recent trends in the electric power industry.* J Hum Ergol 11(suppl):155-164, 1982.
45. Knauth P, Landau K, Droge C, Schwitteck M, Widynski M, and Rutenfranz J. *Duration of sleep depending on the type of shift work.* International Archives of Occupational and Environmental Health, 46:167-177, 1980.
46. Lavie P. *Ultrashort sleep-waking schedule III. 'Gates' and 'forbidden zones' for sleep.* Electroencephalography and Clinical Neurophysiology, 63:414-425, 1986.
47. Libert JP, Bach V, Johnson LC, Ehrhart J, Wittershiem G, and Keller D. *Relative and combined effects of heat and noise exposure on sleep in humans.* Sleep 14(1):24-31, 1991.
48. Lubin A, Hord D, Tracy ML, and Johnson LC. *Effects of exercise, bedrest and napping on performance decrement during 40 hours.* Psychophysiology, 13(4):334-339, 1976.
49. Lumley M, Roehrs T, Zorick F, Lamphere J, and Roth T. *The alerting effects of naps in sleep-deprived subjects.* Psychophysiology, 23(4):403-408, 1986.
50. May J, and Kline P. *Measuring the effects upon cognitive abilities of sleep loss during continuous operations.* British J Psych 78:443-455, 1987.
51. McGown AS, Wright NA, and Montgomery JM. *Wakefulness on the civil flight deck: An investigation of wrist activity.* CAA Paper 97001, 1997.
52. Mullaney J, Kripke DF, Fleck PA, and Johnson LC. *Sleep loss and nap effects on sustained continuous performance.* Psychophysiology, 20:643-651, 1983.
53. Muzet A, Nicolas A, Tassi P, Dewasmes G, and Bonneau A. *Implementation of napping in industry and the problem of sleep inertia.* Journal of Sleep Research 4 (S2):67-69, 1995.
54. Naitoh P. *Sleep loss and its effects on performance.* Navy Medical Neuro-Psychiatric Research Unit Technical Report. No.68-3, 1969.
55. Naitoh P. *Circadian cycles and the restorative power of naps.* In: Biological Rhythmns, Sleep and Shiftwork. Advances in Sleep Research, Vol. 7. Johnson IC, Tepas DI, Coloquhoun WP, and Collinghan MG, (eds) Spectrum Pub. Inc., 1981.

56. Naitoh P. *Minimal Sleep To Maintain Performance: The Search for Sleep Quantum in Sustained Operations.* In: Why We Nap. Evolution, Chronobiology, and Functions of Polyphasic and Ultrashort Sleep. Stampi C (ed), Birkhauser, Boston:199-216, 1992.
57. Naitoh P, and Angus RG. *Napping and Human Functioning During Prolonged Work.* In: Sleep and Alertness: Chronobiological, Behavioural and Medical Aspects of Napping. Dinges DF, and Broughton RJ, (eds), Raven press, New York, 1989.
58. Nicholson AN, Pascoe PA, Spencer MB, and Stone BM. *Sleep after transmeridian flights.* The Lancet, Nov. 22nd:1205-1208, 1986.
59. Nicholson AN, Pascoe PA, Spencer MB, Stone BM, and Green RL. *Sustained performance with short evening and morning sleeps.* Aviat Space Environ Med, 56:105-114, 1985.
60. Nicholson AN, and Stone BM. *Influence of back angle on the quality of sleep in seats.* Ergonomics, 30(7):1033-1041, 1987.
61. Ohrstrom E. *Effects of low levels of road traffic noise during the night: A laboratory study on number of events, maximum noise levels and noise sensitivity.* J Sound & Vib, 179(4):603-615, 1995.
62. Ohrstrom E. *The effects of noise on sleep.* In: Institute for Environment and Health Report on the non-auditory effects of noise. Report R10, 66-67, 1997.
63. Ohrstrom E, Bjorkman M, and Rylander R. *Effects of night time road traffic noise - an overview of laboratory and field studies on noise dose and subjective noise sensitivity.* J Sound Vib 127:441-448, 1988.
64. Opstad PK, Ekanger R, Nummestad M, and Raabe N. *Performance, mood and clinical symptoms in men exposed to prolonged physical work and sleep deprivation.* Aviat. Space Environ Med, 49:1065-1073, 1978.
65. Pascoe PA, Johnson MK, Roberstson KA, and Spencer MB. *Sleep in rest facilities onboard aircraft: field studies.* DRA Report No. DRA/CHS/A&N/CR/95/002, 1995.
66. Pascoe PA, Johnson MK, Montgomery JM, Robertson KA, and Spencer MB. *Sleep in rest facilities onboard aircraft: questionnaire studies.* RAF IAM Report No. 778, 1994.
67. Robertson KA, Rogers AS, and Stone BM. *A review of the use of on-board rest.* DERA/CHS/PP/5/CR/97136/1.0, 1997a.
68. Robertson KA, Spencer MB, Stone BM, and Johnson MK. *Scheduling the on-board rest of aircrew.* DERA Report No. DERA/CHS/PP5/CR97095/1.0, 1997b.
69. Roehrs T, Zorick F, and Roth T. *Transient and Short-Term Insomnias.* In Principles and Practice of Sleep Medicine. Kryger MH, Roth T, and Dement WC (eds), 486-493, 1994.
70. Rogers AS, Spencer MB, Stone BM, and Nicholson AN. *The influence of a 1h nap on performance overnight.* Ergonomics, 32(10):1193-1205, 1989.
71. Rogers AS, Robertson KA, and Stone BM. *A land force's guide to the management of irregular work/rest schedules.* DERA 1996.
72. Rosa R, Colligan MJ, and Lewis P. *Extended workdays: effects of 8-hour and 12-hour rotating shift schedules on performance, subjective alertness, sleep patterns, and psychosocial variables.* Work and Stress 3(1):21-32, 1989.
73. Rosa R, Bonnet MH, and Warm JS. *Recovery of performance during sleep following sleep deprivation.* Psychophysiology, 20:152-157, 1983.

74. Rosekind MR, Graeber C, Dinges DF, Connell LJ, Rountree MS, Spinweber CL, and Gillen KA. *Crew factors in flight operations IX: effects of planned cockpit rest on crew performance and alertness in long-haul operations*. NASA Technical Memorandum 108839, September 1994.
75. Rosekind MR, Smith RM, Miller DL, Co EL, Gregory KB, Webbon LL, Gander PH, and Lebacqz JV. *Alertness management: strategic naps in operational settings*. Journal of Sleep Research, 4(S2):62-66, 1995.
76. Salamé P, Otzenberger H, Ehrhart J, Dewasmes G, Nicolas A, Tassi P, Libert J, and Muzet A. *Effects of sleep inertia on cognitive performance following a 1 hour nap*. Work and Stress, 9(4):528-539, 1995.
77. Sallinen M, Härmä M, Åkerstedt T, Rosa R, and Lillqvist O. *Promoting alertness with a short nap during a night shift*. Journal of Sleep Research, 7:240-247, 1998.
78. Shariff A, Strong R, and Rich K. *The User's Guide to Work, Rest and Choice of Royal Navy Watchkeeping Schedules*. INM Technical Report, No. 97037, Portsmouth: Institute of Naval Medicine, 1997.
79. Simons RM, de Ree HJD, Valk PJL, Veldhuijeen van Zanfen BOA, and d'Huyuetter. *K. NAMC - Aircrew Alertness Programme III: onboard crew rest study: quantity and quality of onboard layover sleep: effects on aircrew performance and alertness*. Technical Memorandum RD-31-94. Netherlands Aerospace Medical Centre, 1994.
80. Simons M, Valk PJL. *Effects of controlled rest on the flight deck on crew performance and alertness*. Netherlands Aerospace Medical Centre Report No. NLRGC 1997-B3, 1997.
81. Spencer MB. *The influence of irregularity of rest and activity on performance: a model based on time since sleep and time of day*. Ergonomics, 30(9):1275-1286, 1987.
82. Spencer MB, and Montgomery JM. *Sleep patterns of aircrew on charter/air haulage routes*. DERA Report No. PLSD/CHS5/CR96/082, 1997.
83. Spencer MB, and Robertson KA. *The Haj operation: alertness of aircrew on return flights between Indonesia and Saudi Arabia*. DERA Report No. DERA/CHS/PPD/CR98207, in preparation.
84. Speyer JJ, and Elsey A. *Towards the integration of pilot guard systems for monitoring attentiveness in flight*. Airbus Industrie, 1995.
85. Stampi C. *Polyphasic and ultra short sleep and their effects on performance*. In: Why We Nap. Evolution, Chronobiology, and Functions of Polyphasic and Ultrashort Sleep. Stampi C (ed), Birkhauser, Boston:137-180, 1992.
86. Stone BM. *Personal communication*, 1998.
87. Tassi P, Nicolas A, Dewasmes G, Eschenlauer R, Ehrhart J, Salamé P, Muzet A, and Libert JP. *Effects of noise on sleep inertia as a function of circadian placement of a one-hour nap*. Perceptual and Motor Skills, 75:291-302, 1992.
88. Taub JM, Tanguay PE, and Clarkson D. *Effects of daytime naps on performance and mood in a college student population*. J Abnorm Psychol 85:210-217, 1976.
89. Taub JM. *Effects of habitual variations in napping on psychomotor performance, memory and subjective states*. Int J Neurosci 9:97-112, 1979.
90. Taub JM and Berger RJ. *Sleep stage patterns associated with acute shifts in the sleep-wakefulness cycle*. Electroencephalog Clin Neurophysiol, 35:613-619, 1973.

91. Tilley AT, and Wilkinson RT. *The effects of a restricted sleep regime on the composition of sleep and on performance*. Psychophysiology, 21:406-412, 1984.
92. Torii S, Okudaira N, and Fukuda H. *Effects of night shift on sleep patterns of nurses*. Journal of Human Ergology, 11:(Suppl.):233-244, 1982.
93. Torsvall L, and Åkerstedt T. *Disturbed sleep while being on-call: An EEG study of ships' engineers*. Sleep 11(1):35-38, 1988.
94. Torsvall L, Åkerstedt T, Gillander K, and Knuttson A. *Sleep on the night shift: 24-hour EEG monitoring of spontaneous sleep/wake behaviour*. Psychophysiology 26(3):352-358, 1989.
95. Webb WB. *Experiments on extended performance: Repetition, age and limited sleep periods*. Beh.Res. Methods Instr Computers;17:27-36, 1985.
96. Webb WB. *The proximal effects of two and four hour naps within extended performance without sleep*. Psychophysiology, 24:426-429, 1987.
97. Wever R. *The Circadian System of Man*. New York, Springer Verlag, 1979.
98. Wilkinson RT. *Sleep deprivation*. In: The physiology of human survival. Edholm OG and Bacharach AL (eds). New York: Academic Press:399-430, 1965.
99. Williams RL, Karacan I, and Hursch CJ. *Electroencephalography (EEG) of Human Sleep: Clinical Applications*. John Wiley & Sons, New York, 1974.
100. Zulley J, and Campbell S. *Napping behavior during 'spontaneous internal desynchronisation'*: Sleep remains in synchrony with body temperature. Hum Neurobiol, 4:123-126, 1985.

9 LIST OF ABBREVIATIONS

EEG	Electroencephalogram
REM	Rapid Eye Movement
SWS	Slow Wave Sleep
TST	Total Sleep Time