In-Flight Sleep as a Pilot Fatigue Mitigation on Long Range and Ultra-Long Range Flights

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ABSTRACT

Objectives: Long range flights operate around the clock with long duty periods for pilots. To mitigate the effects of fatigue, these flights are operated by augmented crews, providing each pilot with the opportunity for sleep in on-board rest facilities. This thesis used a mixed methods approach to investigate the use of in-flight sleep and the factors that influence it.

Methods: Retrospective survey data (291 pilots, five studies) were analysed to provide an overview of pilots' sleep at home and investigate potential relationships with in-flight sleep. A second project monitored the sleep, fatigue and performance of 35 pilots operating a B767 flight route between Atlanta and Lagos. These projects were supplemented by thematic analysis of pilots' logbook comments on in-flight sleep (N=123) and on the way they manage their fatigue (N=629).

Results: Pilots viewed in-flight sleep as an important fatigue management strategy and actigraphic sleep monitoring confirmed that the B767 pilots made good use of their in-flight breaks for obtaining sleep. Self-ratings of in-flight sleep quality reflected ratings at home, but were usually poorer. Pilots indicated that the type, location and design of rest facilities affected sleep quality and duration, and identified strategies for minimizing sleep disturbances and improving alertness. Comments indicated that prior knowledge of in-flight break allocations can influence the planning of pre-trip sleep, use of naps, and in-flight sleep. Actigraphic measures of sleep indicated that the B767 pilots obtained more sleep in the 24 hours prior to departure than during baseline days regardless of their subsequent pattern of in-flight breaks, but it is unclear when they were advised about their break pattern. Ratings of sleepiness and fatigue increased across the B767 flights, but psychomotor vigilance task performance at the start of duty and at top of descent was not associated with prior wakefulness, prior sleep duration or in-flight sleep duration.

Conclusions: In-flight sleep is a well-utilized and effective fatigue mitigation strategy that may be supplemented by other strategies such as flight preparation techniques. To further reduce pilot fatigue risk on long range flights, additional research is warranted into the effects of flight preparation techniques and in-flight break patterns.

(350 words)

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ABBREVIATIONS AND TECHNICAL TERMS

actigraphy	method of monitoring rest/activity rhythms over a period of days or weeks using a wrist worn device containing an accelerometer
AIC	Aike's Information Criterion
ANCOVA	analysis of covariance
ANOVA	analysis of variance
ANTE(1)	first-order ante-dependence
AR(1)	first-order auto-regressive
ATL	Atlanta, USA
augmented flight crew	a flight crew that comprises more than the minimum number required to operate the aeroplane and in which each flight crew member can leave his or her assigned post and be replaced by another appropriately qualified flight crew member for the purpose of in-flight rest (definition from ICAO, 2010, Attachment 4, section 4.2.1)
AW-64	model of actigraphy device
awakenings	term used in reference to recalled periods of wakefulness during the sleep period
baseline	24 hour period (beginning at 1600 UTC) that is free of duty and does not overlap with the last 24 hours prior to duty or the first 24 hours after duty
BIC	Bayesian Information Criterion
blocks off	moment when the aircraft first moves out of the gate at the start of the flight
blocks on	time at the end of the flight when the aircraft finally comes to rest at the gate
c-statistic	also termed concordance index, is a measure used to compare the goodness of fit of logistic regression models. It is a measure of the probability that the prediction of the outcome is better than chance

	alone. A value of 0.5 indicates that the model prediction is no better than chance while a value of 1 indicates the model prediction is correct 100% of the time. Typically values above 0.7 are interpreted as the model being a reasonable fit while values above 0.8 indicate a strong model. (definition derived from documentation available in University of Manitoba, 2011)
CAAS	Civil Aviation Authority of Singapore
class 1	type of on-board rest facility; bunk or other lie-flat sleeping surface in an area separate from the flight deck and passenger cabin, where pilots can control a number of environmental factors (definition from Federal Aviation Administration, 2012b)
class 2	type of on-board rest facility; seat (in passenger cabin) that reclines to a flat or near-flat position and is separated from passengers by at least a curtain (definition from Federal Aviation Administration, 2012b)
class 3	type of on-board rest facility; seat (on flight deck or in passenger cabin) that reclines at least 40° providing leg and foot support (definition from Federal Aviation Administration, 2012b)
crew rest seat	refers to a class 2 or 3 facility located in the passenger cabin
cruise	low workload phase of flight between TOC and TOD during which pilots may have to opportunity for in-flight sleep
CS	compound symmetry
dB(A)	unit of measure of the loudness of sounds (decibels) adjusted for the way sounds are perceived by the human ear
domicile time	refers to time (in terms of time zone) at pilot's home base (i.e., departure airport of the outbound flight)
duty end	time when a pilot signs off duty after a flight (typically 1 hour after arrival)
duty start	time when a pilot reports for duty (signs on) prior to a flight (typically 2 hours prior to an international departure)
EEG	electroencephalography
EDT	Eastern Daylight Time
EMG	electromyogram

EOG	electroocculogram
EST	Eastern Standard Time
FAA	US Federal Aviation Administration
fatigue mitigation	a strategy, attitude or action used to minimise the effects of fatigue and/or the likelihood of fatigue occurring (also termed 'fatigue mitigation strategy' or 'mitigation')
FDP	flight duty period
flight segment	term used to refer to a single flight (i.e., flight without stopovers) between two points
flying crew	refers to the two pilots flying the aircraft during take-off and landing in an augmented crew
FRM	fatigue risk management
FRMS	fatigue risk management system
hypnogram	graphical representation of sleep architecture derived from the sleep stages identified from a polysomnographic recording
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IFALPA	International Federation of Airline Pilots' Associations
IGT	Iowa Gambling Task
JFK	New York city, USA
JNB	Johannesburg, South Africa
KSS	Karolinska Sleepiness Scale
landing	high-workload phase of flight between TOD and blocks on
landing crew	refers to the two pilots flying the aircraft during landing in an augmented crew
lapse	lapse in attention (typically a reaction time longer than 500ms)
LAX	Los Angeles, USA
LOS	Lagos, Nigeria

LR	long-range flight
mitigation	see '*fatigue mitigation'*
N1	NREM stage 1 sleep; stage 1 sleep
N2	NREM stage 2 sleep; stage 2 sleep
N3	NREM stage 3 sleep; also termed slow wave sleep
NIH	US National Institutes of Health
NREM	non-rapid eye movement sleep
OR	odds ratio
PAX	passengers
PF	pilot flying
PM	pilot monitoring
polysomnography	method of monitoring sleep using physiological measures; typically conducted in in a laboratory setting
post break 1	end of pilots' first in-flight rest period; time at which PVT test and post-sleep subjective ratings are completed
post break 2	end of pilots' second in-flight rest period; time at which PVT test and post-sleep subjective ratings are completed
post-flight	phase of flight between blocks on and duty end
pre-break 1	start of pilots' first in-flight rest period; time at which pre-sleep subjective ratings are completed
pre-break 2	start of pilots' first in-flight rest period; time at which pre-sleep subjective ratings are completed
pre-flight	phase of flight between duty start and blocks off
prospective	term used in reference to research designed to investigate situations and experiences occurring at the time of the study (e.g., in this thesis the data from the duty/sleep diary is prospective as participants are asked to record events of the study as they occur)
PSG	polysomnography
PVT	psychomotor vigilance task

relief crew	refers to the two additional pilots in a 4-person augmented crew
relief pilot	refers to the additional (third) pilot in a 3-person crew
REM	rapid eye movement sleep
rest break	refers to the in-flight rest opportunities of augmented crews
rest break pattern	refers to the specific rest breaks (1st break, 2nd break, 3rd break,…) taken on a given flight
rest period	refers to a pilot's in-flight sleep opportunity (i.e., rest period 1 or 2)
rest facility	facility on-board the aircraft provided for augmented crews to use during their rest breaks
retrospective	term used in reference to research designed to investigate situations and experiences that occurred prior to the study (e.g., in this thesis the survey data is retrospective as it requires participants to reflect on their past experiences of in-flight sleep)
RT	reaction time
SCN	suprachiasmatic nuclei
SD	standard deviation
SE	sleep efficiency
SIN	Singapore, Singapore
SOL	sleep onset latency
SP	Samn-Perelli Crew Status Check
SPI	safety performance indicator
SWS	slow wave sleep
take-off	high workload phase of flight between blocks off and TOC
TIFST	total in-flight sleep time
TOC	top of climb
TOD	top of descent
TOL	tolerance statistics

TST	total sleep time
ULR	ultra-long range; flight with a planned duration of more than 16 hours (definition from Flight Safety Foundation, 2003a)
UTC	Coordinated Universal Time; common time standard used around the world to keep the time scales of the world's timing centres synchronised (definition from www.timeanddate.com)
VIF	variance inflation factor
wake maintenance zone	period in the early evening during which wake drive is high and it is difficult to initiate sleep; performance during this period it typically maintained
WAT	West Africa Time Zone
window of circadian low	WOCL, period in the early morning during which sleep drive and sleepiness are high and performance is lower is impaired; fatigue-related errors are more likely during this time
WOCL	window of circadian low

Il est peu et de réussites faciles,
et d'échecs définitifs.
~Marcel Proust

CHAPTER 1 INTRODUCTION

Sleep is integral to human health and functioning. Early animal models of sleep deprivation have shown that the life expectancy of sleep deprived rats is drastically reduced (reviewed by Rechtschaffen & Bergmann, 1995), while large scale population studies have found that atypical sleep duration and shift work negatively impact on the risk of cancer (Hurley, Goldberg, Bernstein, & Reynolds, 2015; Parent, El-Zein, Rousseau, Pintos, & Siemiatycki, 2012), obesity (Logue, Scott, Palmieri, & Dudley, 2014; Lucassen, Rother, & Cizza, 2012), diabetes (Ferrie et al., 2015; Reutrakul & Van Cauter, 2014), heart disease (Gottlieb et al., 2006) and mortality in general (Grandner, Hale, Moore, & Patel, 2010; Kronholm, Laatikainen, Peltonen, Sippola, & Partonen, 2011; Xiao, Keadle, Hollenbeck, & Matthews, 2014). Daily life is also affected by sleep disruption through changes in mood (Pilcher, Callan, & Posey, 2015; van der Helm & Walker, 2012), appetite (Chaput, 2014; Pejovic et al., 2010; Schmid, Hallschmid, Jauch-Chara, Born, & Schultes, 2008) and cognitive functioning (reviewed in Killgore & Weber, 2014).

In our increasingly 24-hour society, obtaining sufficient sleep of good quality can be challenging. Work and social constraints can result in a shortening of sleep opportunities and/or a shift in sleep timing, particularly in industries that operate around the clock like aviation. In turn this disrupted sleep impacts on individuals' waking function and can affect the way operations are run.

This chapter provides an overview of the processes that regulate sleep and waking function and summarizes the effects of disrupting these processes. It also provides an overview of how this is managed in the commercial aviation industry.

1.1 Fundamentals of sleep

1.1.1 Normal sleep

1.1.1.1 Sleep architecture

Sleep can be divided into two distinct states: non-rapid eye movement (NREM) and rapid-eye movement (REM), that alternate across the sleep period. This can be visualised using recordings of brain activity, eye movements and muscle tone, a technique known as polysomnography (PSG) (see section 1.1.4 for more detail).

Using the sleep scoring criteria developed by the American Academy of Sleep Medicine, NREM sleep, characterised by reduced brain activity and normal muscle tone, can be further sub-divided into N1, N2 and N3 sleep. These stages form a continuum of depth of sleep and are differentiated primarily through changes in brain activity visualised using electroencephalography (EEG) in PSG (Carskadon & Rechtschaffen, 2005).

N1 sleep (also known as stage 1 NREM) is characterised by slow rolling eye movements and a relatively low voltage, mixed frequency EEG signal (which reflects concurrent activity rhythms). The predominant frequency in N1 is a theta rhythm occurring within the 4-7Hz range (i.e., occurring at a rate of 4-7 times per second). In some individuals, an alpha rhythm (8-13Hz), typically seen during quiet wakefulness, may also be present during N1 in attenuated form (Iber, Ancoli-Israel, Chesson, & Quan, 2007).

N2 (stage 2 sleep) also presents a low voltage, mixed frequency EEG signal but is characterised by the occurrence of K-complexes and sleep spindles. In the EEG signal, a K-complex is visualised as a sharp negative (upwards) deflection followed by a sharp positive (downwards) deflection[1] (Iber, et al., 2007). K-complexes generally occur at a rate of 1-3

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[1] In PSG, the 'negative up' convention is frequently used meaning that a negative potential is visualised as an upward deflection on the EEG signal (Carskadon & Rechtschaffen, 2005).

per minute and may also be present in slow wave sleep. The other characteristic EEG phenomenon of N2, sleep spindles, presents as short bursts of higher frequency waves (12-14Hz) that last at least 0.5 seconds (Iber, et al., 2007). The occurrence of sleep spindles varies significantly between individuals but these generally occur at a rate of 3-8 per minute.

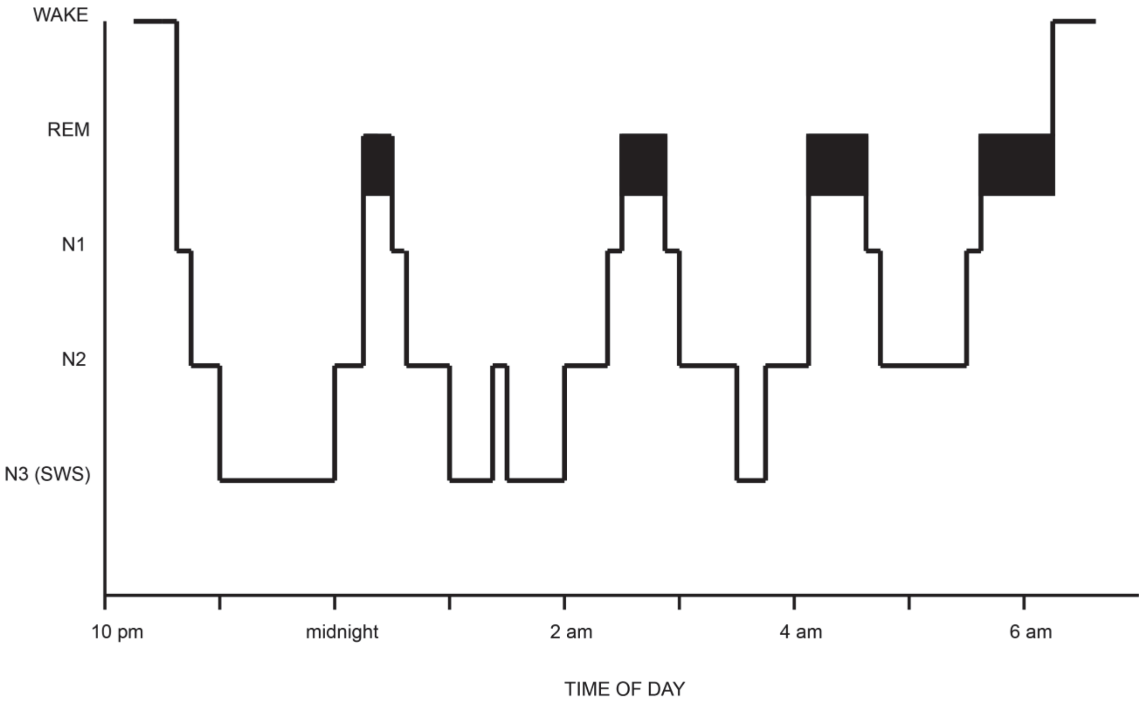
In N3 sleep (also known as Slow Wave Sleep or SWS), the deepest stage of sleep, the EEG signal is characterised by high amplitude (>75µV), slow wave activity in the range of 0.5-2Hz. This slow wave activity reflects a greater amount of synchronised neuronal activity. During this sleep stage eye movements are typically absent and muscle tone is often lower than in stage N2 sleep (Iber, et al., 2007).

In contrast, REM sleep is characterised by mixed frequency, low voltage EEG and muscle atonia. The EEG in REM sleep may at times resemble the EEG signal seen during wakefulness and doesn't present any dominant wave forms. Instead, REM sleep is identified by low muscle tone in the electromyogram (EMG), the presence of bursts of rapid eye movements in the electrooculogram (EOG) and the absence of K-complexes and sleep spindles in the EEG. Despite the characteristic low muscle tone, muscle twitches may still be observed in this stage (Iber, et al., 2007). REM sleep is also typically associated with dreaming.

Across a normal night, healthy young adults alternate between NREM and REM sleep in cycles of approximately 90 to 110 minutes. Sleep is typically entered through light sleep (N1 closely followed by N2) then a gradual progression into SWS. Individuals may progress directly from SWS to REM sleep or may briefly transition back to N2 before progressing into REM sleep (Carskadon & Dement, 2005). The distribution of sleep stages varies across the night with the first third being dominated by SWS while the last third is dominated by REM sleep. In healthy young adults, the NREM stage typically occupies 75-80% of sleep while the REM stage (which occurs as 4-6 distinct periods) occupies the remaining 20-25%

(Carskadon & Dement, 2005). All sleep stages are important and an example of their distribution across the night is presented in Figure 1.1 below.

Figure 1.1 Hypnogram of a healthy young adult



The figure depicts the different sleep stages and their distribution across the night in a normal healthy adult. Time of day is presented on the x-axis, sleep stages are on the y-axis. The shaded black boxes represent episodes of REM sleep. Arousals and awakenings during the night are not depicted in this figure.

The hypnogram above doesn't depict any awakenings or arousals (brief periods of waking during the sleep period) but these are a common and normal part of sleep (Bonnet & Arand, 2007). In the EEG signal, arousals are visualised as an abrupt shift to an alpha or theta rhythm or to a frequency greater than 16Hz that lasts at minimum 3 seconds (Iber, et al., 2007). Arousals are typically brief transitions to a lighter stage of sleep but may include a transition to wake whereas awakenings are defined as a transition from sleep to wake for more than 15 seconds (Iber, et al., 2007). As an individual moves from light sleep (N1 and N2) towards deep sleep (N3), arousal and awakening thresholds increase with a more intense stimulus being required to wake the individual (Carskadon & Dement, 2005). Both arousals and awakenings are relatively frequent across the night, but arousals occur more frequently than awakenings.

Although relatively frequent, awakenings and arousals are generally too brief to be remembered in the morning. However, an increased frequency of arousals and awakenings (recalled or not) can lead to sleep fragmentation and reduces the recuperative value of sleep (Levine, Roehrs, Stepanski, Zorick, & Roth, 1987; E. J. Stepanski, 2002) which in turn can result in increased daytime sleepiness and impaired cognitive performance (Bonnet & Arand, 2003; Martin, Engleman, Deary, & Douglas, 1996; E. Stepanski, Lamphere, Badia, Zorick, & Roth, 1984). In this thesis, the term 'awakenings' is used in reference to recalled periods of nocturnal waking and does not include unrecalled arousals or unrecalled awakenings.

1.1.1.2 Sleep duration

Based on the findings of longitudinal and experimental studies investigating associations between sleep, health and performance, the healthy range of self-reported normal sleep duration for adults aged 18-64 years is considered to be 7 to 9 hours (Hirshkowitz et al., 2015; Watson et al., 2015). Analyses of the baseline sleep in a multi-airline sample of long haul pilots indicated that, on days when their sleep is not affected by flight duties, pilots' home sleep duration falls within the normal sleep duration range with a mean self-reported sleep duration of 7.6 hours and an average actigraphic sleep duration of 6.8 hours (Wu, Gander, van den Berg, & Signal, 2016).

Short sleep (less than 7 hours sleep per night) is associated with increased mortality risk and adverse health consequences (Ferrie, et al., 2015; Grandner, Hale, et al., 2010; Grandner, Patel, Gehrman, Perlis, & Pack, 2010; Jean-Louis et al., 2014; Martinez et al., 2014; Verkasalo et al., 2005). In some habitual short sleepers, sleep is more consolidated, with shorter onset latencies and increased sleep efficiency compared to long sleepers (Grandner, Patel, et al., 2010). These characteristics of short sleep architecture can be induced by sleep restriction in the laboratory, suggesting that habitual short sleepers may be chronically sleep restricted. A large scale survey study of a representative sample of 1004 adults in the United States indicated that short sleepers (self-reported nightly sleep duration of 4-6 hours) were more likely to report difficulties falling asleep, frequent nocturnal awakenings, daytime sleepiness and waking early from sleep compared to respondents who reported sleeping 7-8 hours per night (Grandner & Kripke, 2004). Another recent study found that short sleep duration may also have a genetic component with links being found between self-reported sleep duration and a single nucleotide polymorphism that affects the dopamine D2 receptor (Cade et al., 2016).

Sleep also changes as a normal part of development and aging. Sleep is often shorter in older adults, although their need for sleep is generally not different to that of younger adults (Hirshkowitz, et al., 2015; Ohayon, Carskadon, Guilleminault, & Vitiello, 2004). Across adulthood, sleep efficiency decreases, the amount of SWS and REM sleep declines and the amount of stage 1 (light sleep) increases. The changes in SWS and stage 1 sleep are particularly pronounced in men (Bliwise, 2011) and are hypothesised to be a result of changes in hormone and neurotransmitter secretion (Bliwise, 2005). The more frequent arousals in older adults may also result from a reduction in the homeostatic drive for continuous sleep (the use of naps to alleviate daytime sleepiness is more common with age) and can be exacerbated by other comorbidities (e.g., pain, sleep disordered breathing, nocturia) (Bliwise, 2011). However, it is not clear whether the increased fragmentation of sleep seen with aging degrades waking function to the same extent as induced experimental sleep fragmentation in younger adults (Gander & Signal, 2008).

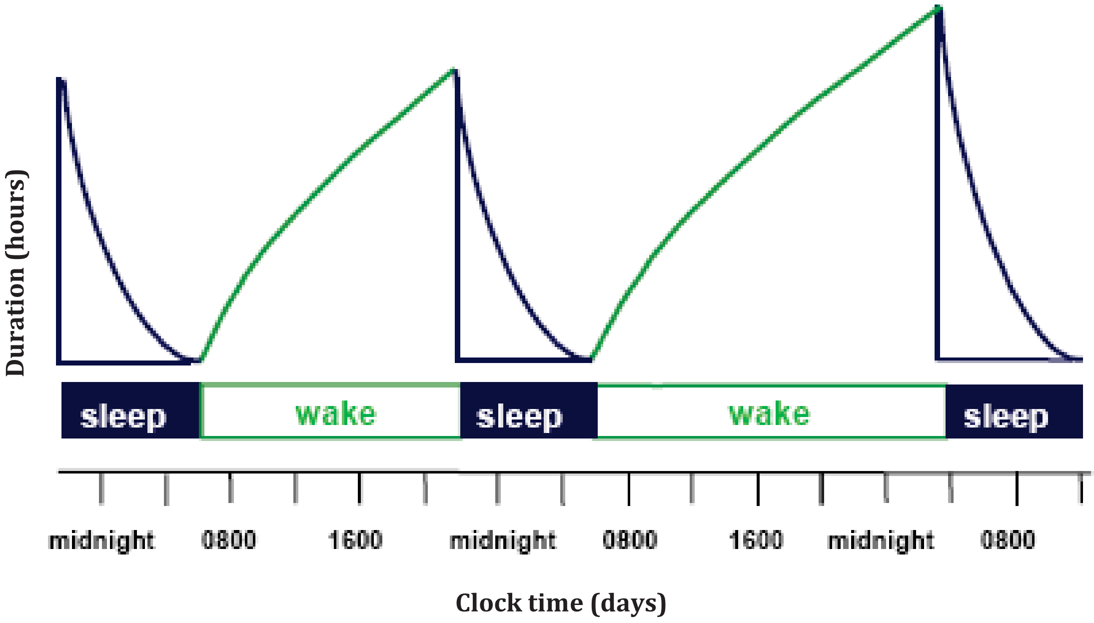
Previous studies of sleep and ageing in airline pilots have shown that increasing age is associated with greater sleep loss and poorer sleep quality across long haul trip patterns (Gander, Nguyen, Rosekind, & Connell, 1993; Signal, Gander, van den Berg, & Graeber, 2013). In the airline industry pilots have a mandatory retirement age meaning the population doesn't face the same challenges as other sectors may do in terms of ageing of the workforce. However, long haul and ultra-long haul flight routes are staffed on the basis of seniority resulting in these routes frequently being operated by older more senior pilots.

1.1.2 The sleep/wake cycle

The regulation of sleep timing is typically envisaged in terms of two main processes, as first posited by Borbély (1982): the sleep homeostat (process S) and a process (process C) driven by endogenous circadian pacemaker located in the suprachiasmatic nuclei (SCN) of the hypothalamus (Edgar, Dement, & Fuller, 1993).

The sleep homeostatic process is described as a pressure for sleep which grows as the duration of prior wakefulness increases and dissipates across each sleep period (Borbély & Achermann, 1999) (Figure 1.2). When a sleep opportunity is cut short, the accumulated pressure for sleep is not fully dissipated and the individual begins the next wake period with residual pressure for sleep. Analysis of polysomnographic sleep data from studies of both partial sleep restriction and total sleep deprivation, has shown that the amount of N3 sleep increases as a function of the duration of prior wake, resulting in N3 sleep being considered a surrogate marker for the sleep homeostatic process (Achermann, Dijk, Brunner, & Borbély, 1993; Borbély, Baumann, Brandeis, Strauch, & Lehmann, 1981; Plante et al., 2016). This is further supported by the observation that N3 sleep dominates the first part of the night and progressively decreases as the sleep period progresses (Borbély, et al., 1981).

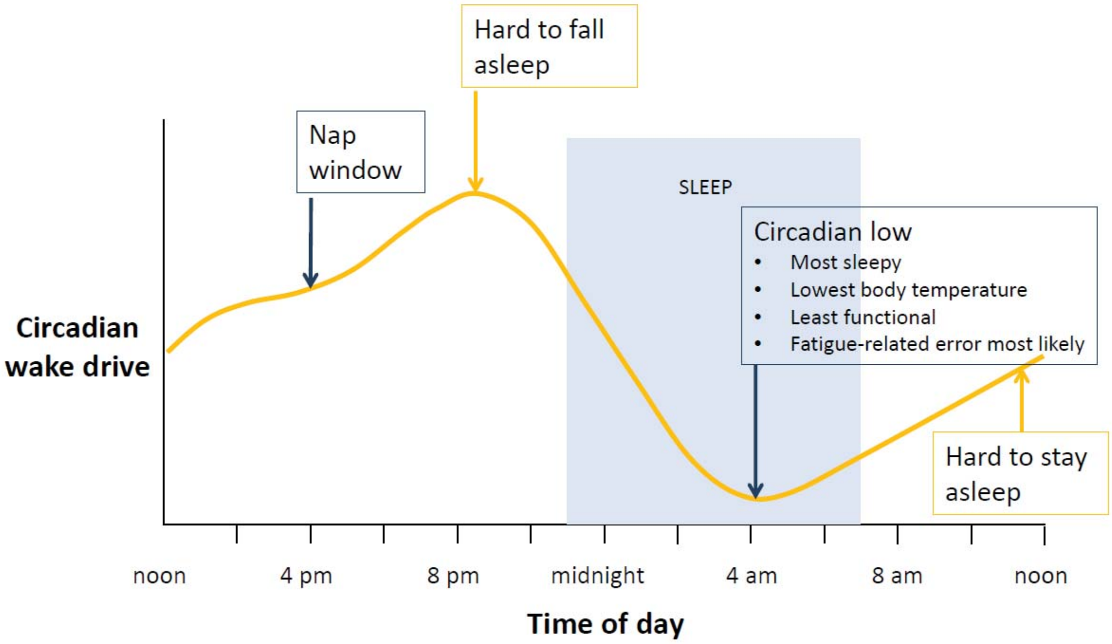
Figure 1.2 Schematic of the sleep homeostat (process S) (from Gander, 2003, with permission)



In this figure the shaded boxes represent periods of sleep, while the white boxes represent periods of wakefulness. The dark blue lines represent the dissipation of homeostatic sleep pressure during sleep, while the increasing green lines represent the growth of the pressure for sleep with the increasing duration of the period of wake.

The circadian process is visualised as a pressure for wakefulness that varies across the 24-hour day (Edgar, et al., 1993). In healthy individuals, the circadian process provides the greatest pressure for wake during the early evening in a period referred to as the evening wake maintenance zone, and provides the least pressure for wake in the early morning in a period sometimes referred to as the window of circadian low (WOCL) (Figure 1.3). Circadian rhythms in alertness and sleepiness are influenced by the waxing and waning of this circadian wake drive, as are circadian rhythms in cognitive performance, with better performance during periods with a high wake drive and decreased performance during the periods with low wake drive (Goel, Van Dongen, & Dinges, 2011). Although it is not possible to directly measure the circadian rhythm of the SCN, other biological measures such as core body temperature and plasma melatonin levels can be used as surrogate markers of circadian phase since their rhythms closely reflect (or in the case of melatonin mirror) the variation in the circadian rhythm of the SCN (Czeisler, Buxton, & Khalsa, 2005).

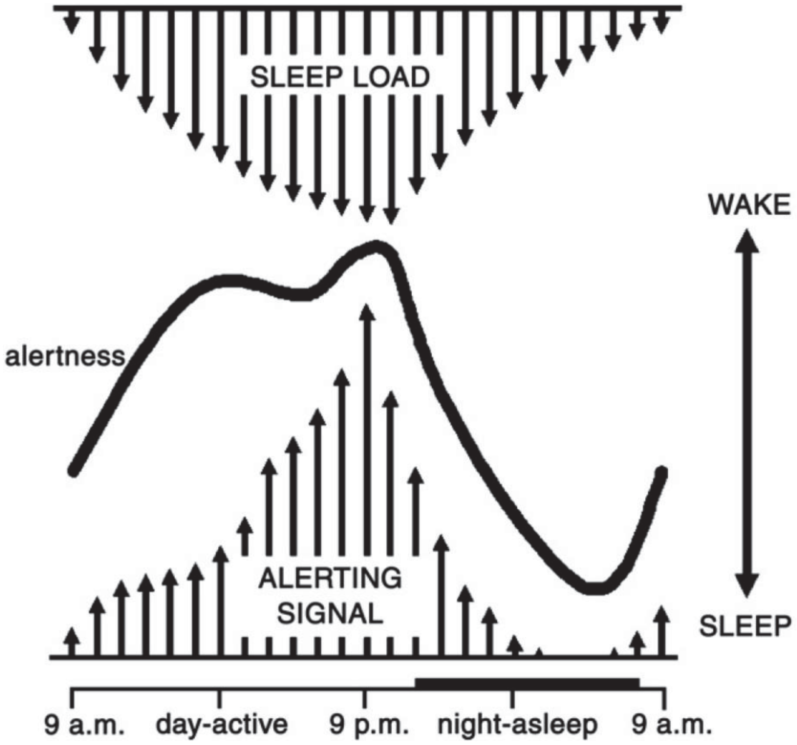
Figure 1.3 Schematic of the daily variation in circadian wake drive



In most individuals, the period of the endogenous circadian pacemaker is slightly longer than 24 hours, with an estimated average of 24.2 hours (Czeisler, et al., 2005). However, exposure to environmental time cues (known as “zeitgebers”) serves to keep the SCN pacemaker synchronised with the day/night cycle through small, daily adjustments to the timing of the SCN pacemaker cycle. The most potent zeitgeber is light and exposure to bright light (natural or artificial) can be used to shift the SCN pacemaker cycle earlier or later depending on the timing, duration, intensity and wavelength of the light exposure (Jewett, Kronauer, & Czeisler, 1994; Jewett et al., 1997; Khalsa, Jewett, Cajochen, & Czeisler, 2003; Skene, Lockley, Thapan, & Arendt, 1999; Warman, Dijk, Warman, Arendt, & Skene, 2003). The SCN receives light intensity information via a direct pathway from retinal melanopsin cells that are most sensitive to blue light. Other environmental time cues such as social interaction, meal timing, and physical activity can phase shift circadian rhythms earlier or later, but these environmental cues generally have weaker phase shifting effects than light (Czeisler, et al., 2005).

In healthy individuals, over the course of a normal day, the sleep homeostat and the circadian wake drive interact in opposing fashion to provide continuous pressure for wake during the daytime (low homeostatic sleep pressure, high wake drive) and a consolidated period of sleep during the night (high homeostatic sleep pressure, low wake drive) (Dijk & Czeisler, 1994). At the start of the nighttime period, the high homeostatic sleep pressure helps initiate sleep, then as this pressure dissipates, the interacting low wake drive helps to maintain sleep (Figure 1.4).

Figure 1.4 The opponent process model of sleep-wake regulation (from Dijk & Edgar, 1999)



1.1.3 Disruptions to the sleep/wake cycle

Extended periods of wake and/or shortened periods of sleep as well as a misalignment of the SCN pacemaker cycle with external time cues can cause increased sleep pressure and sleepiness during wake. For instance, long work shifts can lead to extended periods of wake and the circadian timing system can be disrupted by shift work (which requires sleeping at inappropriate times in the SCN pacemaker cycle) or by trans-meridian travel (which exposes the SCN pacemaker to abrupt shifts in the day/night cycle). In long haul flight operations the rapid crossing of multiple time zones on such flights disrupts the circadian timing system as the external light/dark cycle of the destination is different to that of the place the flight originated from and to which the SCN pacemaker cycle of the crew member is synchronised. Similarly, long flights often involve long periods of wakefulness and little sleep thus disrupting (increasing) the sleep drive of the crew member.

Long flight duty periods can result in periods of extended wakefulness and sleep loss, while the timing of duty periods relative to the circadian body clock cycle can also result in sleep restriction by affecting sleep prior to and during the flight (Bourgeois-Bougrine, Cabon, Gounelle, Mollard, & Coblentz, 2003; Gander, Mulrine, et al., 2014; Pascoe, Johnson, Roberston, & Spencer, 1995; Roach, Darwent, & Dawson, 2010; Signal, Gander, et al., 2013). For example, early duty start times are associated with higher levels of fatigue and shortened sleep opportunities pre-flight compared to flights that depart later in the day (Bourgeois-Bougrine, Cabon, Mollard, Coblentz, & Speyer, 2003; Roach, Sargent, Darwent, & Dawson, 2012) as pilots are not necessarily able to shift their sleep earlier because of the evening wake maintenance zone.

During layovers, misalignment between the circadian pacemaker and local time may reduce sleep duration and quality and can lead to incomplete recovery prior to the inbound flight (Lamond, Petrilli, Dawson, & Roach, 2006; Roach, Petrilli, Dawson, & Lamond, 2012; Samel et al., 1997). Local time cues (e.g., local light/dark cycle, periods of greater social activity,…) may also influence pilots' choices about when to sleep during layovers (Gander, van den Berg, Mulrine, Signal, & Mangie, 2013; Roach, Rodgers, & Dawson, 2002; Signal et al., 2014), even when they are advised by the airline to time their sleep and other activities to remain on their home time zone (Holmes, Al-Bayat, Hilditch, & Bourgeois-Bougrine, 2012).

Other operational factors including commute times, airport transfers, and delays can also cut into the time available for sleep, particularly during layovers; while the characteristics of the available rest facilities (in flight and on layover) can further increase sleep loss across the trip pattern if the facilities do not provide conditions conducive to good quality sleep (Pascoe, Johnson, Montgomery, Roberston, & Spencer, 1994; Rosekind, Gregory, Co, Miller, & Dinges, 2000; Samel, Wegmann, Vejvoda, et al., 1997).

1.1.4 Measuring sleep

Sleep is often measured objectively using polysomnography (PSG), a method which involves, at minimum, the monitoring of brain activity, eye movements, and muscle tone, and is regarded as the gold standard for staging human sleep. PSG can be used to identify different sleep stages and the cycling between theses stages throughout the recording period (reviewed in Bloch, 1997; Vaughn & Giallanza, 2008). This makes PSG particularly suited to situations where sleep architecture is of interest and allows the distinction between sleep and periods of quiet wake during which an individual may be physically inactive but remains awake.

However, PSG currently involves the application of multiple electrodes, which can be invasive for the participant and is impractical for long term monitoring (PSG is typically used overnight in the laboratory). Setting up the recording equipment and analysis of the data requires a trained technician, which is time consuming and costly (Bloch, 1997). In addition, the recording conditions do not necessarily reflect a normal night's sleep and can result in changes in sleep quality often termed 'first night effect' (reduced sleep quality and longer sleep onset latency) and 'reverse first night effect' (improved sleep quality and shorter sleep onset latency) (Agnew, Webb, & Williams, 1966; Hauri & Olmstead, 1989; Mendels & Hawkins, 1967; Riedel, Winfield, & Lichstein, 2001; Toussaint et al., 1995).

An alternative method of objectively monitoring sleep is actigraphy, which involves the continuous monitoring of activity and use of specific scoring algorithms to infer sleep and wake patterns. In actigraphy, activity is measured using a small, typically wrist-worn device that contains an accelerometer, making it less invasive and uncomfortable for the participant than PSG. Actigraphy is also more practical for the field environment as it does not involve a complicated set-up and activity can be monitored over several days or weeks. However, since actigraphy doesn't include neurophysiological recordings, sleep staging and sleep architecture can't be determined and measures of sleep quality are less reliable (Sadeh, 2011). Nonetheless, the use of actigraphy is well accepted in sleep medicine and sleep research (Ancoli-Israel et al., 2003; de Souza et al., 2003; Hauri & Wisbey, 1992; Jean-Louis, Kripke, Cole, Assmus, & Langer, 2001; Sadeh, 2011; Sadeh, Hauri, Kripke, & Lavie, 1995). Actigraphy (specifically the Actiwatch AW-64 device[2]) has also been validated against PSG for measuring the in-flight and layover sleep of pilots and is most reliable when estimating average sleep duration for groups of pilots (Signal, Gale, & Gander, 2005).

Since actigraphic measures of sleep quality are less reliable than PSG measures, the primary measure derived from actigraphy is sleep duration. Despite this, sleep efficiency is also frequently reported as an indicator of sleep quality. Sleep efficiency (SE) is calculated as a percentage and represents the amount of time an individual was actually asleep compared to the amount of time the individual spent trying to sleep (i.e., $SE = \frac{Duration\ of\ Actual\ Sleep}{Duration\ of\ Attempted\ Sleep} * 100$). Based on the sleep efficiencies observed in populations with documented sleep disorders, a sleep efficiency above 90% is generally

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[2] Respironics Mini Mitter, Bend, Oregon, USA

considered to indicate good quality sleep while a lower sleep efficiency is usually associated with disrupted sleep (Lavigne, McMillan, & Zucconi, 2005).

1.2 Sleep and behaviour

In broad terms, behaviour can be conceptualised into three interacting functions: 'cognition' which relates to how information is handled by the individual, 'emotionality' which relates to the individual's feelings and motivation, and the 'executive functions' which relate to the expression of behaviours (Lezak, Howieson, & Loring, 2004). Different aspects of these three functions are affected differently by sleep loss and periods of extended wakefulness (reviewed by Killgore & Weber, 2014). This section provides an overview of some of these effects with particular focus on psychomotor vigilance performance as the measure of interest in this thesis research.

1.2.1 Psychomotor vigilance

One method of reliably assessing aspects of cognitive performance is the psychomotor vigilance task (PVT), which is a quick and simple reaction-time test (Dinges & Powell, 1985; Dorrian, Rogers, & Dinges, 2005). The test involves the presentation of a stimulus (auditory or visual) at repeated random short time intervals and may vary in length (3-minute, 5-minute and 10-minute versions of the test exist) (Basner, Mollicone, & Dinges, 2011; Dinges & Powell, 1985; Roach, Dawson, & Lamond, 2006; Thorne et al., 2005). Performance on the PVT is measured as reaction time (RT, in ms), with reaction times greater than 500ms attributed to lapses in attention. In the 3-minute version of the PVT, the shorter duration of the test has resulted in two definitions of lapses being used: the standard 500ms threshold and an adjusted 355ms threshold (adjusted to ensure that under comparable conditions the lapse frequency on the 3-minute PVT is similar to that on the 10-minute PVT) (Basner, et al., 2011).

In healthy individuals, performance deficits on the PVT have been shown to accumulate with increasing sleep loss in a dose-dependent manner (Belenky et al., 2003; Van Dongen, Maislin, Mullington, & Dinges, 2003). The accumulation of these deficits over prolonged periods of chronic sleep restriction (14 days of ≤6hrs sleep per night) results in levels of performance impairments comparable to those observed in conditions of one to two days of total sleep deprivation (Van Dongen, et al., 2003). Even relatively mild chronic sleep restriction (to 5 or 7 hours time-in-bed) over a week produces performance deficits, although performance appears to stabilise at a lower-than-baseline level (Belenky, et al., 2003). Additionally, in conditions of chronic sleep restriction, individuals are unreliable at estimating their own level of impairment (Van Dongen, et al., 2003) and recovery from chronic sleep restriction appears to be slower than recovery from acute total sleep deprivation (Belenky, et al., 2003).

Performance deficits as measured by the PVT are also amplified during the part of the circadian cycle when sleep would normally occur (so-called 'biological night') and by time on task, with individuals being unable to maintain stable performance (Doran, Van Dongen, & Dinges, 2001; Goel, et al., 2011). In a study of sustained attention on the PVT during 88 hours of total sleep deprivation, Doran and colleagues (2001) found that the number of PVT lapses increased, the average fastest response time slowed, and performance was consistently worse during the nighttime test bouts compared to the daytime test bouts.

In addition to the circadian effects, as the duration of wakefulness increases (beyond 16 hours of continuous wake), performance becomes increasingly variable, a phenomenon known as 'wake-state-instability'. As the individual's sleep drive increases, their ability to maintain alertness is challenged by the intrusion of sleep initiating mechanisms, resulting in rapidly varying levels of alertness and inconsistent performance, as seen on the PVT by Doran and colleagues (2001). The performance impairments resulting from such extended periods of wake have been equated with those due to alcohol intoxication. In a within-subjects study by Dawson and Reid (1997), participants' performance impairments on a hand-eye coordination test after 17 hours of continuous wakefulness were found to be equivalent to a blood alcohol concentration of 0.05%, while impairments after 24 hours of wakefulness were similar to a blood alcohol concentration of 0.10%. By means of comparison, the current legal blood alcohol concentration drink driving limits in many countries (including New Zealand, Australia and most of Europe) is 0.05%.

There is large inter-individual variability in performance decrements in response to sleep loss which appears to be trait-like. Both in conditions of total sleep deprivation and partial sleep restriction, the effects of sleep loss on an individual's performance are largely reproducible from one bout of sleep loss to another (Rupp, Wesensten, & Balkin, 2012; Van Dongen, Baynard, Maislin, & Dinges, 2004). In a study of US Air Force fighter pilots' performance in a high-fidelity flight simulator after acute sleep deprivation, Van Dongen and colleagues (2006) found that, even in this highly-selected population, the performance impairments varied between individuals and across different tasks. Recent studies have also identified genetic polymorphisms that appear to be associated with greater resilience to PVT performance impairments following sleep restriction (Rupp, Wesensten, Newman, & Balkin, 2013; Satterfield, Wisor, Field, Schmidt, & Van Dongen, 2015).

Although the PVT is practical for use in the field (it is portable and the task is relatively short), it measures only simple reaction time and vigilance. This limits the translation of PVT impairments to specific real-world tasks as these typically involve more complex executive functions. For instance, pilots must make decisions, switch between tasks, multi-task and work as part of a crew. It is unclear to what extent impairments on the PVT reflect impairments on such tasks and how an individual pilot's impairments affect a crew's ability to operate an aircraft. However, the PVT is currently the most widely-used method of assessing cognitive function in field studies involving the monitoring of pilots during their flight duties.

1.2.2 Visual performance and spatial orientation

Following sleep loss, visual perception and performance on related tasks is degraded and the activation of the associated areas of the brain is reduced (reviewed in Killgore & Weber, 2014). Simulator studies of military pilots on a variety of flight profiles have investigated the effects of fatigue on different aspects of visual perception and have documented degradation of flight performance that is not always attributable to changes in the visual system. The occurrence of visual neglect (defined as the inability to recognize or acknowledge visual information despite a structurally intact visual system) was observed in all areas of the field of vision during periods of wakefulness extending beyond 19 hours in two groups of 8 military pilots (LeDuc et al., 1999; Russo et al., 2005; Russo et al., 2004). However, basic eye movement measures and instrument scanning (a highly trained skill) appeared to be resilient to sleep loss with no degradation across the 32-hour sleep deprivation period in a study of 10 US Air Force Pilots (Previc et al., 2009). This suggests that the impaired flight performance may be a result of impaired decision-making and information processing rather than an impaired visual system (Previc, et al., 2009).

The results of simulator studies investigating the effects of sleep loss on events of induced spatial disorientation are more varied. In aviation, occurrences of spatial disorientation are termed ‘spatial disorientation conflicts’ as these manifest as a discrepancy between pilots’ senses and flight instruments in relation to aircraft position (Benson & Stott, 2006). While an early study of US Army helicopter pilots documented slower recovery from spatial disorientation events in fatigued aviators across a single night of sleep deprivation (LeDuc, et al., 1999), a later study of 10 US Air Force fixed-wing pilots found that sleep loss did not affect the recognition of spatial disorientation conflicts (Previc et al., 2007). These differing results may be linked to the fact that recognition of spatial disorientation conflicts was measured differently: in helicopter pilots this was measured in terms of time elapsed between onset of the conflict and recovery of the aircraft while in fixed-wing pilots this was measured in terms of effect on flight parameters (conflict was recognised or not). Helicopters and fixed-wing aircraft also have different operational capabilities and there are differences in the performance skills required to fly them. Since different flight skills were tested and affected in these studies, this may have contributed to the different results. However, there was some evidence from both studies that maintaining a constant altitude may be more consistently affected by fatigue (LeDuc, et al., 1999; Previc, et al., 2009).

1.2.3 Risk-taking, decision-making and teamwork

Risk-taking and decision-making are also affected by sleep loss, but this is complicated by the way in which a situation is viewed by the individual (reviewed in Killgore & Weber, 2014). Studies of varying lengths of sleep deprivation have shown that when sleep deprived, individuals demonstrate increased risk-taking on the Iowa Gambling Task (IGT), a computer-based task that simulates a gambling situation using two decks of cards (one which leads to small gains and equally small losses and one which allows large gains and equally large losses) (Killgore, Balkin, & Wesensten, 2006; Killgore, Grugle, & Balkin, 2012; Killgore et al., 2007; Killgore, Lipizzi, Kamimori, & Balkin, 2007). However, it appears that the framing of the outcome modulates risk-taking behaviours (McKenna, Dickinson, Orff, & Drummond, 2007). Indeed, sleep-deprived individuals tend to be more risk averse when the outcome is framed in terms of a potential loss (McKenna, et al., 2007). This may in part explain the increased risk-taking observed in studies using the IGT, as the IGT frames the outcome in terms of potential gains (participants are trying to win money).

Related to the framing of an outcome is the manner in which individuals judge the situation. Compared to well-rested individuals, sleep-deprived individuals were observed to judge neutral images in a more negative way (Tempesta et al., 2010). This is an important consideration in aviation, as pilots' assessment of a safety risk and the associated choice of action in ambiguous situations appears to be related to whether they focused on the negative or positive cues. Those who view the situation in a more negative way take a more cautious (risk-averse) approach (Orasanu, Fischer, & Davison, 2004).

If fatigued individuals judge uncertain or ambiguous situations in a more negative way, they are more likely to be risk averse in their decision making. This is reflected in the results of a B747 simulator study of flight crews faced with a critical decision event where fatigued crews reported that they preferred to stay within their 'comfort zone' and were more conservative in their decision making than their well-rested counterparts (Petrilli, Thomas, Dawson, & Roach, 2006). These fatigued crews were also observed using performance protection strategies such as increased cross checking (Petrilli, et al., 2006), which allowed them detect more of their errors but did not reduce the occurrence of errors or the mismanagement of threats (Roach, Petrilli, Dawson, & Thomas, 2006).

Decision-making, task-switching and multi-tasking performance are all also impaired by sleep loss and periods of extended wakefulness (Couyoumdjian et al., 2010; Haavisto et al., 2010; J. Horne, 2012). Rapidly switching between tasks incurs a 'switching cost' which manifests as a decrease in performance as the cognitive system re-configures for the next task (Meiran, Chorev, & Sapir, 2000). In a study of 108 university students, Couyoumdjian and colleagues (2010) found that task-switching costs increased significantly after one night of total sleep deprivation. Students in the sleep deprivation group switched more slowly between tasks and made more errors than those who had a normal night's sleep. Similarly, multi-tasking, which involves frequent and rapid switches between tasks, is degraded under conditions of sleep restriction. Haavisto and colleagues (2010) found that performance on a long (50 min) computer-based multi-task (comprised of 4 sub-tasks) progressively degraded across five days of restriction to 4 hours time-in-bed. Multi-tasking performance was also negatively affected by time on task and was highly variable between participants, with the majority of individuals showing only moderate impairment while two individuals appeared particularly affected by sleep restriction, presenting with an 80% decrease in performance compared to their baseline performance. In safety-critical operational environments like aviation, this is of particular concern as decision-making in these settings is complex and typically involves multiple skills or subtasks that must be monitored or completed simultaneously, while requiring individuals to be able to adjust their behaviour in the face of a changing environment.

Divergent and flexible thinking has previously been shown to be impaired by sleep deprivation. Sleep-restricted individuals are more likely to persevere with an unsuccessful strategy and less likely to learn from their mistakes to adapt to a changing situation (Killgore & Weber, 2014). In a study of 24 students, those subjected to 32 hours of total sleep loss scored more poorly on all aspects of a divergent and creative thinking test than their rested counterparts. They were less successful at adapting to changing problems and persevered with unsuccessful strategies in the tested verbal tasks, repeatedly writing down the same word before crossing it out (J. A. Horne, 1988). Similarly, in a study of the effects of 36 hours of sleep deprivation on performance on a computer-based marketing simulation game, sleep deprivation resulted in participants failing to adapt their strategy to the changing situation within the game, ultimately resulting in their failure (Harrison & Horne, 1999).

In such situations, working as a team may help to mitigate the effects of sleep loss, as it appears that team performance on interdependent tasks is better than individual performance on the same tasks (Baranski et al., 2007). However, the individual deficits remain and overall task performance is still affected albeit to a lesser extent (Pilcher, Vander Wood, & O'Connell, 2011). In the previously mentioned B747 simulator study, despite applying performance protection strategies, fatigued crews took 34-42% longer to finalise their decisions than the well-rested crews (Petrilli, et al., 2006). Although this delay in decision-making did not significantly impact on flight performance in the simulator study, in certain real flight situations it could be detrimental to safety.

1.3 Managing fatigue in aviation

1.3.1 Defining fatigue

The International Civil Aviation Organisation (ICAO) defines fatigue as ‘a physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a crewmember’s alertness and ability to safely operate an aircraft or perform safety related duties’ (International Civil Aviation Organisation, 2012).

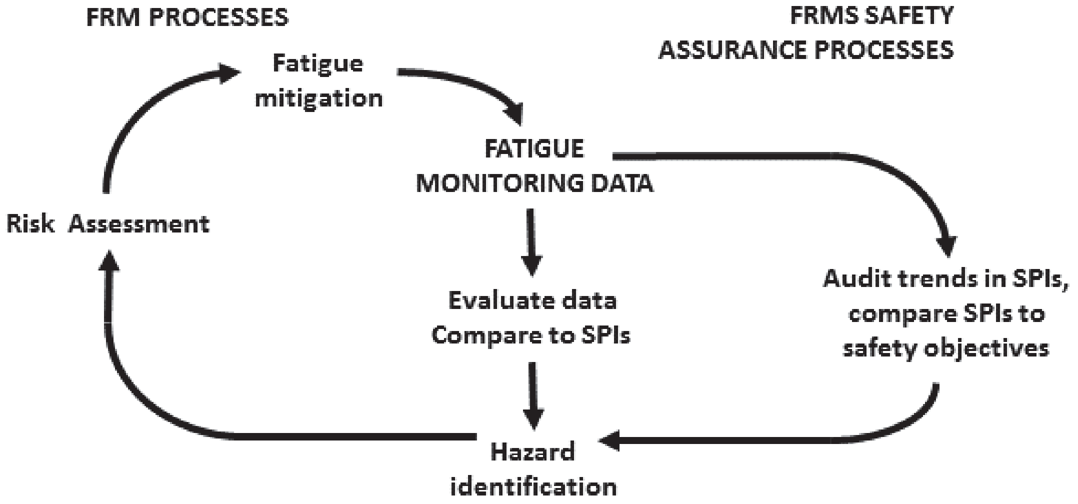
In a high-risk environment like aviation, the detrimental effects of fatigue on pilot performance can have serious consequences, as is evidenced by accidents in which fatigue was identified as a causal or contributing factor (NTSB, 1994, 2000, 2010, 2014; RNF, 2009; TSB, 2006). Consequently, different strategies and safeguards have been put in place to help minimize the risks associated with pilot fatigue. An overview of these approaches is provided in the sections that follow.

1.3.2 Fatigue Risk Management Systems

The traditional approach to managing pilot fatigue has been to prescribe regulatory limits on maximum duty and flight times and minimum rest periods. A recent alternative approach, Fatigue Risk Management Systems (FRMSs), combines advances in fatigue and safety science with established practices of risk assessment and management. Many regulatory agencies have recently amended their flight and duty time regulations and are developing regulations that permit FRMSs as an alternative. FRMSs are designed to include multiple defensive strategies (mitigations), making them more robust than the traditional single strategy of flight and duty time limits, and more resilient in the face of gaps in current scientific knowledge (Gander, Wu, et al., 2015). FRMSs are typically designed as closed feedback loops that take into account changes in the environment by continuously monitoring and assessing the situation.

FRMSs are data-driven, which requires monitoring fatigue in the operation(s) of interest (Gander, Wu, et al., 2015). This can include routinely-collected data (e.g., information about scheduled and actual flight durations, which airlines are required to keep records of) and, where appropriate, targeted data collection (e.g., monitoring studies of pilots). Other important sources of fatigue data are non-punitive fatigue hazard reports by pilots and analysis of the role of fatigue in safety incidents and accidents. These data sources are used to identify fatigue hazards, which are then subject to a formal risk assessment process (usually by a specialised safety team) to determine the likely impact of the hazard on safety. The risk assessment determines whether additional mitigations are needed, and the effectiveness of these is evaluated through ongoing monitoring. These FRM processes are illustrated on the left-hand loop of Figure 1.5.

Figure 1.5 Required processes in a Fatigue Risk Management System



An example of such successful monitoring and management of fatigue risks is found in a study by Houston and colleagues (2012) who analysed fatigue reports submitted by flight and cabin crew over a 12 month period at a UK airline. Review of fatigue reports by month revealed that 10 of the 12 fatigue reports submitted in December of the study related to operational disruption due to heavy unexpected snowfall in the UK during that period. The fatigue reports in this study also helped identify a layover location where a change in the hotel used by crews resulted in increased fatigue reporting due to noise disturbances (Houston, et al., 2012).

The effectiveness of the FRM processes is evaluated regularly via safety assurance processes (the right-hand loop in Figure 1.5), which compare specific measures of fatigue in the collected monitoring data with agreed acceptable thresholds (Safety Performance Indicators, SPIs). The safety assurance processes track SPIs across time, allowing the identification of emerging hazards. In addition, they track changes in the company (for example, introduction of a new route), in the operational environment (for example, changes to routes or airport approach paths), or regulatory changes that could impact on fatigue management.

The International Air Transport Association (IATA), ICAO and International Federation of Airline Pilots' Associations (IFALPA) have jointly developed FRMS implementation guidance manuals for airlines and regulators (IATA, ICAO, & IFALPA, 2011; ICAO, 2012). The design of FRMSs means that they may vary from one organisation to another but also makes them a more flexible approach to regulating the diverse types of operations encountered in the aviation industry. FRMSs also shift the responsibility for safety away from regulators towards employers and employees, making safety a shared responsibility in this environment (Gander, Wu, et al., 2015). This is essential, given that fatigue is influenced by all waking activities, not just work demands, and by crew members' choices about their allocation of time off duty for sleep.

1.3.3 Recommended Fatigue Safety Performance Indicators

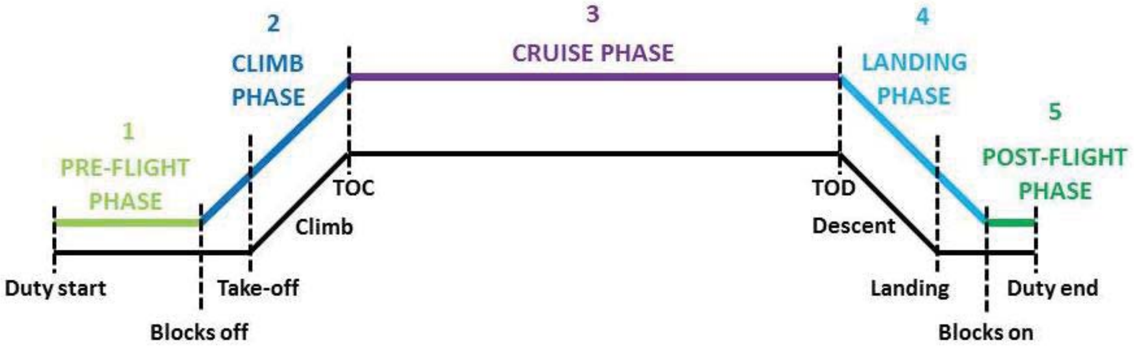
In the context of FRMS, SPIs can relate both to the causes of fatigue and the actual measured levels of crew member fatigue (Gander, Wu, et al., 2015). SPIs relating to the causes of fatigue make use of data collected as part of routine operations (e.g. frequencies of duty periods ending later than scheduled), while SPIs relating to crew member fatigue levels require the monitoring and measuring of fatigue (e.g., using surveys or studies monitoring pilots' sleep and fatigue during trips) at key times during an operation (e.g. pre-flight to determine readiness for duty and top of descent to determine functionality at a critical phase of flight). The SPIs commonly recommended for the monitoring of pilot fatigue on long range commercial flights are measures of pilot performance on the PVT, sleep (i.e., total sleep time in the last 24hrs, duration of wakefulness at the time of measurement, and total in-flight sleep) as well as subjective measures of pilot fatigue status, in particular the Karolinska Sleepiness Scale and Samn-Perelli Crew Status Check (a fatigue rating scale) (Gander, Mangie, et al., 2014; IATA, et al., 2011; ICAO, 2012).

1.3.4 In-fight sleep as a fatigue mitigation in long range and ultra-long range flight operations

Technological advances have progressively extended the length of non-stop flights for commercial passenger aircraft. Precise definitions of long range flights differ between airlines and countries but in this thesis the term is used to refer to flights with flight durations of 8 hours or longer. Ultra-long range flights have been defined as flights which have a planned flight duration of more than 16 hours (Flight Safety Foundation, 2003b).

Figure 1.6 identifies the key phases of flight that are relevant to this thesis and is based on a simplified version of phases of flight identified by the ICAO Common Taxonomy Team (2013). The definition of flight duration used here is the time between blocks off (when the aircraft first moves out of the gate) and blocks on (when it finally comes to rest at the gate at the end of the flight).

Figure 1.6 Phases of flight defined in this thesis



The ‘pre-flight’ phase begins when pilots sign-on for duty (duty start) and ends when the aircraft leaves the gate (blocks off). During this phase pilots prepare for duty and complete pre-flight checks.

The ‘take-off’ phase begins at blocks off and ends at top of climb (TOC) when the aircraft levels off at its initial cruising altitude. This is a high workload phase of flight during which pilots need to taxi down the runway, configure the aircraft for take-off, take-off, and climb to cruising altitude all the while maintaining communication with air traffic control. A large number of the associated tasks during this phase are time critical adding to the workload. This is also a time during which the aircraft is closer to the ground and therefore in a more vulnerable position should anything go wrong. For these reasons, take-off is considered a critical phase of flight.

The ‘cruise’ phase begins at TOC and ends at top of descent (TOD), when the aircraft begins its descent and final approach. Cruise is normally a lower workload phase of flight during which the autopilot is typically engaged and pilots are primarily monitoring instruments, and making planned adjustments to the aircraft's track and altitude. On flights where pilots have in-flight rest breaks, these occur during the cruise phase.

The 'landing' phase beings at TOD and ends when the aircraft comes to a complete stop at the gate (blocks on). This includes the descent, approach, and landing, and is another high workload phase during which the pilots need to configure the aircraft for landing, prepare and execute the approach while maintaining communication with air traffic control. As with the take-off phase, the aircraft is closer to the ground and pilots must complete a large number of time critical tasks making it another critical phase of flight.

The 'post-flight' phase begins at blocks on and ends when pilots sign off duty. During this time, pilots shut down the aircraft and complete their post-flight check lists.

Aircraft used in long range and ultra-long range operations are typically operated by a crew of two pilots who have designated roles with specific tasks. At any given time, one pilot is flying (pilot flying, PF) and one pilot is monitoring the instruments (pilot monitoring, PM). When flight durations exceed 8-9 hours, regulations typically require the use of augmented flight crews (Federal Aviation Administration, 2012a, Table A to Part 117). An augmented flight crew is defined in ICAO regulations as "a flight crew that comprises more than the minimum number required to operate the aeroplane and in which each flight crew member can leave his or her assigned post and be replaced by another appropriately qualified flight crew member for the purpose of in-flight rest" (ICAO, 2010, attachment A section 4.2.1). In crews augmented by a single extra pilot (3-pilot crew), the third pilot is referred to as the 'relief pilot' and the others are referred to as the 'flying crew'. In crews augmented by two pilots (4-pilot crew), the crew is split into two 2-pilot crews referred to as the 'flying crew' and the 'relief crew'. In augmented crews, all pilots are present on the flight deck for take-off and landing and take turns taking their in-flight rest during the cruise phase.

For flights with augmented crews, aircraft are fitted with crew rest facilities, which vary by aircraft and airline in their layout, location and type. Regulatory authorities define the requirements for rest facilities which are typically of three types (Federal Aviation Administration, 2012b; M. Simons & Spencer, 2007). For example, in the US Federal Aviation Administration regulations, class 1 rest facilities require a bunk or other lie-flat sleeping surface in an area separate from the flight deck and passenger cabin, where crew members can control a number of environmental factors. Class 2 facilities require a seat in the passenger cabin that reclines to a flat or near-flat position and is separated from passengers at minimum by a curtain. Class 3 facilities require a seat in the passenger cabin or flight deck that reclines at least 40 degrees providing leg and foot support (Federal Aviation Administration, 2012b). Similar categorisations of rest facilities also exist in other countries (M. Simons & Spencer, 2007). The maximum allowable flight duty period is dependent on the type of rest facility available to pilots and the number of crew members in the augmented crew. In general, for the same crew complement, a longer duty period is allowed for operations where a class 1 facility is provided than for operations where a class 2 or a class 3 facility is used (Federal Aviation Administration, 2012a; M. Simons & Spencer, 2007).

1.3.4.1 Factors affecting in-flight sleep

In-flight sleep is generally well accepted as a method of maintaining appropriate levels of pilot performance and alertness on long range and ultra-long range flights (Caldwell et al., 2009; Gander, Mangie, et al., 2014). The duration of the in-flight sleep opportunities is dependent on flight duration, with longer flights providing a longer sleep opportunity for all crew members. However, in-flight sleep duration and quality is also linked to the timing of the sleep opportunities within the flight and to the flight departure and arrival times (Gander, Mulrine, et al., 2014; Pascoe, et al., 1995; R. M. Simons, Valk, de Ree, Veldhuijzen van Zanten, & d'Huyvetter, 1994). For instance, reduced sleep quality and duration are reported during rest breaks occurring at a time when pilots' wake drive is high and/or during passenger meal times. In-flight sleep quality and duration are also reduced compared to ground sleep (Roach, et al., 2010; Signal, et al., 2005; Signal, Gander, et al., 2013), but this does not seem to be an effect of altitude (Muhm et al., 2009). In a laboratory study comparing different split sleep schedules to consolidated sleep, Mollicone and colleagues (2008) found that changes in waking function were associated with sleep duration rather than sleep schedule. However, in this study all the split sleep schedules included an anchor sleep during the biological night which is not necessarily the case in international flight operations.

The patterns of in-flight rest used by pilots often vary by fleet, route and airline. The total time available for rest in flight (i.e., the time spent at cruise) may be split evenly between the crew members to ensure each is allocated the same amount of break time, however in some cases relief crew members (i.e., the crew members not responsible for flying the approach and landing) may be allocated a slightly shorter amount of break time. In three person crews, the available rest time is typically split into three (one break per crew member) but in four person crews the available rest time may be split into 2 long breaks (one break per person) or into 4 or 5 shorter breaks (2-3 breaks per person).

When crew members have multiple in-flight rest periods, the in-flight breaks are commonly referred to by their order of appearance (i.e., '1st break, '2nd break', '3rd break'…). In this thesis, the term 'in-flight break pattern' is used to describe the in-flight breaks taken by individual crew members. For instance, when the available rest time is split into four breaks, one potential in-flight break pattern would be for a crew member to take the 1st and 3rd breaks.

To date, only one study has compared the effects of a single long break or two shorter breaks on flight crew sleep and subjective fatigue (Roberston, Spencer, Stone, & Johnson, 1997). In this study, which used polysomnography to monitor the sleep of 28 pilots operating a B747-400 between London and Seoul, pilots obtained significantly more sleep when taking a single long rest period than when taking two shorter breaks (difference 36min). Subjective ratings of alertness upon awakening did not significantly differ by break pattern, however the increase in alertness was greater after a long rest period, possibly as a result of lower alertness prior to the break (Roberston, et al., 1997). It is not clear from the study methods if pilots were allocated to a specific rest break pattern or if they chose their rest break pattern. The generalizability of this study's findings is limited, as departure time is likely to affect which pattern of in-flight rest is better suited to a given operation. Indeed, pilots' comments in this study indicated that their preferred break system depended on the flight departure time (Roberston, et al., 1997). The lack of objective measures of performance also limits the generalizability of results as individuals are known to be unreliable at estimating their own sleepiness (Van Dongen, et al., 2003).

Although the organisation of in-flight breaks can be very different from one operation to the next, it is usually done in a way that favours the crew members who will be flying the aircraft during approach and landing (i.e., the landing crew). As a result, relief pilots are often allocated the least favourable or least desirable rest breaks (Pascoe, et al., 1994). Some airlines provide training and recommendations regarding the optimal allocation of in-flight breaks on a given flight, to help pilots manage their fatigue and to maximise the alertness of the landing crew during the critical phases of flight. In the United States, a recent amendment to section 17 of the flight duty time regulations now requires the landing crew to be allocated two consecutive hours of rest time in the second half of the flight duty period (Federal Aviation Administration, 2012a), which precludes certain in-flight break patterns. This amendment occurred after the completion of data collection for this thesis and as a result a wide range of in-flight break patterns were observed in the data reported here.

Previous studies of in-flight sleep have documented a number of factors which disturb sleep in the on-board facilities, primarily noise, temperature, humidity, turbulence and comfort. In the two retrospective survey studies conducted to date (Pascoe, et al., 1994; Rosekind, et al., 2000), participants were given a list of factors with the potential to influence in-flight sleep and were asked to rate them. In the study by Pascoe and colleagues (1994), these factors could be rated as 'mildly disturbing,' 'disturbing' or 'extremely disturbing', while in the study by Rosekind and colleagues (2000) the listed factors were rated on a scale of 1 to 5 (where 1=interfere, 3=no effect, 5=promotes).

In these studies as well as a later prospective study, pilots reported that noise negatively impacted on their sleep, with random noise being particularly disruptive (Pascoe, et al., 1994; Rosekind, et al., 2000; Spencer & Robertson, 2000). Noise disturbance is known to affect sleep architecture and lead to arousals and a lightening of sleep (reviewed in Muzet, 2007), with meaningful sounds being more likely to result in an awakening than other sounds (Oswald, Taylor, & Treisman, 1960). Intermittent noise and constant background noise are more likely to affect SWS and REM sleep respectively, with disturbances documented for noise levels above 45 dB(A) (Eberhardt, Stråle, & Berlin, 1987). The emergence of noise peaks above constant background noise can also be particularly disruptive (Eberhardt, et al., 1987; Muzet, 2007). Noise levels measured in different aircraft types have shown that noise within the aircraft cabin and bunk can range between 60 dB(A) and 80dB(A) (Ozcan & Nemlioglu, 2006; Pascoe, et al., 1995; Roberston, et al., 1997; R. M. Simons, de Ree, Valk, Veldhuijzen van Zanten, & d'Huyvetter, 1994), which makes reports of noise disturbances unsurprising.

In-flight sleep disturbances linked to temperature, humidity and turbulence have also been reported (Pascoe, et al., 1994; Rosekind, et al., 2000; Spencer & Robertson, 2000). Ambient temperatures within the thermo-neutral range (13°C - 23°C) do not affect sleep architecture, however warmer ambient temperatures can lead to difficulties initiating sleep as the decrease in core body temperature usually associated with sleep onset is suppressed by the high ambient temperature (heat loss through the skin is reduced when ambient temperature is high) (Okamoto-Mizuno & Mizuno, 2012). In studies where temperature in the crew rest facility was measured, temperature varied by flight route, ranging from 22°C-29°C with pilots reporting that 'heat' and feeling 'too hot' negatively affected their in-flight sleep (Pascoe, et al., 1994; Pascoe, et al., 1995; Roberston, et al., 1997; Rosekind, et al., 2000; R. M. Simons, de Ree, et al., 1994).

Similarly, in these studies pilots reported that the low humidity and dry air in the crew rest facilities led to dry eyes, nose and throat affecting their sleep. In light of the recorded relative humidity in these facilities ranging between 6-26%, well below the recommended 40-60% for comfort and health, these complaints are understandable (Arundel, Sterling, Biggin, & Sterling, 1986; Pascoe, et al., 1994; Pascoe, et al., 1995; Roberston, et al., 1997; Rosekind, et al., 2000; R. M. Simons, de Ree, et al., 1994). Although no studies have formally investigated the effects of atmospheric turbulence on in-flight sleep, anecdotal evidence and pilots' comments suggests that turbulence can significantly disrupt in-flight sleep (Pascoe, et al., 1994; Rosekind, et al., 2000; Spencer & Robertson, 2000).

Pilots also report that inadequate or uncomfortable bedding and the general discomfort of the rest facilities disturbs their sleep (Pascoe, et al., 1994; Rosekind, et al., 2000; Spencer & Robertson, 2000). Anecdotal evidence indicates that pilots prefer crew bunks (class 1 rest facilities) over crew rest seats (class 2 or 3 rest facilities). In the only study to date which has directly compared sleep in a bunk to sleep in a seat, pilots obtained more sleep in the bunk compared to the seat and were more alert following rest in the bunk rest facility (Spencer & Robertson, 2000). This aligns with the findings of a previous study which used polysomnography to investigate sleep in bed and in seats which reclined to different angles from vertical (49.5° sleeperette, 37.0° reclining seat, and 17.5° armchair) of 9 male subjects (Nicholson & Stone, 1987). Although sleep in the sleeperette did not differ from sleep in the bed, sleep in the armchair displayed marked disruptions with more awakenings, reduced sleep efficiency and a reduction in REM sleep (Nicholson & Stone, 1987). In the study by Spencer and Robertson (2000), pilots reported being more frequently disturbed by other people and being generally more uncomfortable in the seat with the lack of leg support being an additional sleep disturbance. These disturbances are partly addressed in current requirements for crew rest facilities (Federal Aviation Administration, 2012b; M. Simons & Spencer, 2007) but anecdotal evidence suggests that such disturbances are not completely eliminated.

Flight deck napping is legal in some countries and can be a useful fatigue mitigation, particularly in non-augmented operations where there are no other in-flight sleep opportunities. Previous studies of controlled flight deck napping have demonstrated the beneficial effects of a 40-min planned flight deck nap on pilots' alertness and PVT performance (Rosekind et al., 1994; M. Simons & Valk, 1997). Rosekind and colleagues (Rosekind, et al., 1994) used polysomnography to monitor pilots' sleep during the flight deck nap, while Simons and Valk (1997) relied on actigraphy and subjective ratings of sleep. Both studies were conducted with three-person crews composed of a Captain, First Officer and Flight Engineer, a crew complement that is no longer current. During the studied flights, one pilot was given a flight deck nap and the other was used as a control (no nap). At TOD, pilots who took a flight deck nap displayed improved alertness and performance compared to their no-nap counterparts (Rosekind, et al., 1994; M. Simons & Valk, 1997). However, to maintain flight safety it is important to establish controlled flight deck napping procedures in order to minimise the likelihood of the crew member who is meant to be awake inadvertently falling asleep, and although sleep inertia is less likely following a short nap, it is necessary for pilots to be aware of the potential performance impairment immediately upon awakening (Rosekind, et al., 1994; M. Simons & Valk, 1997). Such procedures already exist where flight deck napping is legal and survey data from one such airline supports flight deck napping as a useful fatigue mitigation strategy (Petrie, Powell, & Broadbent, 2004).

1.3.5 Other fatigue measures and mitigations

Bio-mathematical modelling is increasingly being used to help identify schedules and operations likely to result in fatigue, and a range of different models are available to airlines (CASA, 2014). While these models may help identify situations with increased likelihood of fatigue, they cannot yet predict the safety risk associated with having an individual crew member impaired by fatigue operating in a two-person flight deck crew. The reliability of their predictions is also limited by the complexity of the processes affecting fatigue and the large inter-individual differences in susceptibility to the effects of fatigue (Anund, Fors, Kecklund, Van Leeuwen, & Åkerstedt, 2015; Belenky, Lamp, Hemp, & Zaslona, 2014; Dawson, Noy, Härmä, Åkerstedt, & Belenky, 2011).

A number of other fatigue mitigations are used that provide temporary reduction in fatigue symptoms, but do not address the underlying causes, namely sleep loss, extended wakefulness, and circadian disruption. Although alertness enhancing substances (e.g., modafinil) are legal in certain military operations (Caldwell, et al., 2009), their use is prohibited in commercial aviation and their complex pharmacokinetics can be associated with significant side effects, including a potential for substance abuse (reviewed in Nishino & Mignot, 2005). Similarly, hypnotics can improve sleep prior to or after a duty period (by increasing sleep duration), but the differing half-lives of the active ingredients can result in residual decremental effects on performance and alertness, particularly if they are taken at the wrong time, and the long term use of these substances is not advised (reviewed in Anund, et al., 2015; Caldwell, et al., 2009).

Other non-pharmacological fatigue mitigation strategies aimed at promoting wakefulness, such as the use of caffeine, bright light and exercise/activity, provide only temporary relief of symptoms. Although bright light leads to an increase in subjective alertness, improved mood and improved performance, these effects are dependent on the illumination level, wavelength and duration and timing of light exposure (Cajochen, 2007). The use of bright light may also impact on pilots' sleep during the next rest period by shifting pilots' circadian body clock earlier or later depending on the timing of the light exposure (Cajochen, 2007). Similarly, the use of regular brief activity breaks during the flight can temporarily improve subjective sleepiness and alertness by reducing the monotony of the flight monitoring task, but these improvements are short-lasting (15-25min) and do not appear to extend to objective performance on the PVT (reviewed in Caldwell, et al., 2009).

Caffeine has also been shown to improve alertness, subjective sleepiness, mood and PVT performance during periods of sleep loss and extended wakefulness. However large inter-individual differences exist in the effects and metabolism of caffeine (half-life ranges from 3-7 hours, average 4-5 hours in normal healthy individuals) leading to variability in the duration of effectiveness (reviewed in Alameddine, Klerman, & Bianchi, 2014; Roehrs & Roth, 2008). Although both single (200-400mg dose) and repeated (150-300mg at 2-6 hour intervals) doses of caffeine have positive effects on vigilance and arousal (Bonnet, Gomez, Wirth, & Arand, 1995; Kamimori et al., 2015; Lieberman, Tharion, Shukitt-Hale, Speckman, & Tulley, 2002), studies of military personnel have found that caffeine does not improve or affect fine motor coordination as assessed by marksmanship (Kamimori, et al., 2015; Lieberman, et al., 2002). A recent study has also demonstrated that evening caffeine consumption may delay the human circadian clock (Burke et al., 2015), a finding that is significant as the stimulant effects of evening caffeine consumption can disrupt subsequent sleep by impacting on sleep onset latency, sleep duration and architecture (Drake, Roehrs, Shambroom, & Roth, 2013; Paterson, Nutt, Ivarsson, Hutson, & Wilson, 2009).

Anecdotally, pilots report using a variety of fatigue mitigation strategies in addition to in-flight sleep. These reports include the use of flight preparation routines, changes to pre-flight sleep timing and the use of caffeine. However, to date, no study has investigated what fatigue mitigation strategies pilots are actually using on their flights and pilots' perceptions of in-flight sleep have seldom been sought.

1.4 Thesis organisation and rationale

1.4.1 Aims of this thesis research

This thesis research is structured around the investigation of the in-flight sleep of long haul pilots (primarily 4-person crews) operating a variety of aircraft and flight routes. It integrates four projects which each investigate different aspects of in-flight sleep, the factors that influence it, and its use as a fatigue mitigation. An overview of the structure of this thesis and the research questions that lead to each of the projects included is provided in Figure 1.7.

Project A (detailed in chapter 2) collated retrospective survey data from five previous studies to investigate the sleep of pilots at home and its potential relationship to sleep in flight. It was hypothesised that differences in pilots' perceptions of the quality and restorative value of their sleep at home might be a source of variability in their perceptions of the quality and restorative value of their in-flight sleep.

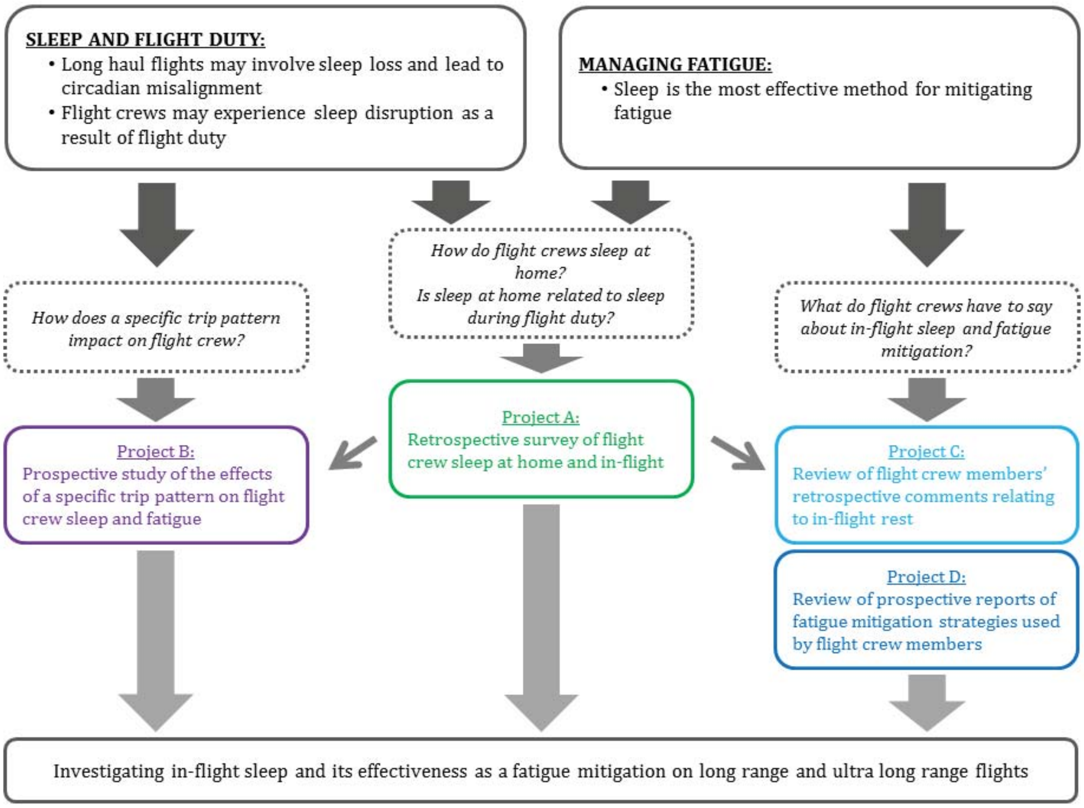
Project B (detailed in chapter 3) monitored the sleep and fatigue of pilots across a particular out-and-back long haul trip pattern, adding to the limited number of published studies that have looked at the effects of specific trips and different in-flight rest break patterns on pilot sleep and performance on long haul flights (Gander, van den Berg, Jay, & Signal, 2011; Holmes, et al., 2012; Signal, Gander, et al., 2013; Signal, et al., 2014; Signal, van den Berg, Travier, & Gander, 2004; Spencer & Robertson, 1999).

Previous studies indicate that rest break patterns vary by flight route and airline, and anecdotal evidence suggests that rest break patterns may influence pilots' preparation for trips and their in-flight sleep. Project B was designed to add to existing knowledge by using standard measures to evaluate the influence of rest break patterns on the use of naps as a flight preparation technique and on in-flight sleep duration, and sleepiness, fatigue and PVT performance at top of descent.

Project C (presented in chapter 4) used prospective log book data collected during flights from the pilots in Study A to investigate their perspectives on in-flight sleep and on-board rest facilities. An increasing number of studies that have objectively measured the amount of in-flight sleep obtained on a variety of flights have highlighted that the quality of in-flight sleep is poorer than sleep at home (Roach, et al., 2010; Roach, Darwent, Sletten, & Dawson, 2011; Signal, et al., 2005; Signal, Gander, et al., 2013). Regulatory specifications for in-flight rest facilities (e.g., type, volume) are intended to ensure that they are conducive to in-flight sleep. However, facilities that meet the regulatory requirements vary considerably in design and location, depending on the aircraft and airline. Limited information is available regarding the factors that pilots themselves consider important in rest facilities. Previous survey studies (Pascoe, et al., 1994; Rosekind, et al., 2000) used closed answer questions and were conducted prior to the introduction of the newer ultra-long range aircraft flown by 4-pilot crews.

Finally, Project D (chapter 5) examined the fatigue mitigations that the pilots in Study C reported using on long haul flights. In-flight sleep is the primary recommended fatigue mitigation strategy for long haul pilots, but anecdotal evidence suggests that they also use other strategies (such as napping and strategic caffeine consumption). Pilots' operational experience is valuable in developing strategies to manage fatigue on specific routes and it was hypothesised that these analyses would provide new insights into how they manage fatigue and into the operational realities that they face.

Figure 1.7 Schematic of the organisation of the projects and research questions of this thesis research



1.4.2 Mixed methods research and pragmatism

The nature of the data and research questions of interest in this study required different analytical approaches and resulted in the choice of a mixed methods research methodology. Mixed methods research integrates quantitative and qualitative methodology as it recognises that these research methods have different strengths and contribute differently to the same research question (Morgan, 2014).

Quantitative research is typically deductive, objective, and findings can be applied in a variety of settings (Morgan, 2014). This makes quantitative research particularly useful when the aim is to make comparisons but this generality also makes it less suited to capturing the texture or richness of the data (Pistrang & Barker, 2012). Qualitative research on the other hand is typically inductive, subjective, and findings are limited to a specific setting or context (Morgan, 2014). Qualitative research is used to describe and interpret the experiences of the research participants but cannot be used to investigate relationships between variables (Willig, 2012).

Quantitative and qualitative research methods are typically underpinned by different epistemological positions (specific assumptions regarding the acquisition and validity of knowledge). These different epistemological positions form a continuum and the researcher's own position on this continuum will influence the chosen research methods (Willig, 2012). Quantitative research often relies on a realist position in which the researcher assumes that there is a single reality that can be measured objectively and their aim is to accurately reflect this reality (Willig, 2012). In contrast, qualitative research is usually situated further along the continuum and centred around a relativist position which posits that there is no objective reality, instead each individual has their own reality shaped by their own experiences and thoughts (Pistrang & Barker, 2012).

These epistemological positions are quite different and approaching the quantitative and qualitative research components from a purely realist or relativist position can compromise the quality of the data and analysis (Bishop, 2015) as the chosen data collection or analysis methods may not be suited to answering the question of interest. Therefore mixed methods research often uses a pragmatist approach which can be viewed as a middle road (Morgan, 2014). The pragmatist approach posits that although each individual's knowledge is unique and shaped by their experiences (relativist view), much of that knowledge comes from socially shared experiences in a shared reality (realist view) (Bishop, 2015; Morgan, 2014). When using a pragmatist approach, the choice of methods is determined by the research questions and what is most suited to answering those questions, making this approach particularly useful in mixed methods research (Creswell & Plano Clark, 2011). Additionally, the pragmatist approach shifts the focus away from how knowledge is acquired and viewed and concentrates instead on the usefulness of the knowledge and on finding a solution to the research question(s) (Creswell & Plano Clark, 2011; Morgan, 2014). For these reasons, this thesis research was conducted using a pragmatist approach.

1.4.3 Structure of this thesis

The variety of the research projects included has resulted in this thesis combining the traditional thesis structure with the thesis by publication structure. Projects A and B are written in the form of traditional thesis chapters. Projects C and D are presented as research papers which will be submitted for peer-review. These manuscripts have been re-formatted to reflect the style used throughout the rest of the document and the references have been incorporated into the full bibliography.

CHAPTER 2 RETROSPECTIVE QUESTIONNARE ANALYSES (PROJECT A)

This project used retrospective survey data from five previous studies to investigate the sleep of pilots at home and its potential relationship to sleep in flight. It was hypothesised that differences in pilots' perceptions of the quality and restorative value of their sleep at home might be a source of variability in their perceptions of the quality and restorative value of their in-flight sleep. Combined demographic information for the pilots from the five studies was also derived, which is relevant to Studies C and D which used log book data from the same pilots.

The data used in this project were collected as part of studies conducted with four different airlines, namely Delta Air Lines, United Airlines, South African Airways and Singapore Airlines. Each study was undertaken and completed with a different research team prior to the start of this project and all four airlines gave permission for the use of their data for these analyses and to be identified in this research. The five studies were:

- the Delta Air Lines B767 bunk study (described in chapter 3);
- a study (completed in 2012) comparing the sleep and performance of United Airlines B777 pilots between ultra-long range (ULR) and long range (LR) flights [henceforth referred to as the 'United Airlines study'] (Wu, 2012);
- a study (completed in 2011) comparing the sleep and performance of Delta Air Lines B777 pilots between ULR and LR flights [henceforth referred to as the 'Delta Air Lines B777 study'] (Gander, et al., 2011);

- a study (completed in 2013) evaluating the effects of a specific ULR route on sleep and performance in South African Airways A330/A340 pilots [henceforth referred to as the 'South African Airways study'] (Signal, Mulrine, van den Berg, Smith, & Gander, 2013); and
- a study (completed in 2004) investigating the sleep and alertness of Singapore Airlines A340 pilots on a specific ULR route [henceforth referred to as the 'Singapore Airlines study'] (Signal, et al., 2004).

In all five studies, participants were asked to complete a pre-study questionnaire at the beginning of their study period, which provided the data used in this project. The data made it possible to investigate pilots' self-reported sleep at home and in flight across a number of different flight routes and different fleets. All pilots had access to class 1 rest facilities on their studied flights (see glossary and section 1.3.4 for definition), however information about their home sleep environment was not provided. Based on previous research findings, it was hypothesised that pilots would report lower sleep quality in flight than at home (Signal, et al., 2005; Signal, Gander, et al., 2013) and that pilots' sleep at home would fall within accepted population norms (Wu, et al., 2016). A better understanding of pilots' usual sleep at home is important as unusual sleep durations and/or poor sleep quality at home could negatively impact on pilots' sleep in flight and would need to be managed appropriately to reduce fatigue risk.

2.1 Methods

These methods refer to the combined analyses of data from the five studies. Details of the methods used in the Delta Air Lines B767 bunk study are provided in chapter 3, while an overview of the methods from the four previously completed studies is provided in appendix 2A.

The common database and analyses in this chapter were completed primarily by the author with technical and statistical assistance provided when required.

2.1.1 Ethics

Ethics approval was obtained for each individual study. These original ethics approvals included a clause stating that the data would be stored in a de-identified form and that the de-identified data may be combined with data from other studies in further analyses. The analyses of the pre-study questionnaire data undertaken here were therefore covered by these original ethics approvals. The owners of the data sets also gave permission for their use in these analyses: for the Delta Air Lines studies, the United Airlines study, and the South African Airways study, the owners of the data were the airlines; for the Singapore Airlines study, the owners were the Civil Aviation Authority of Singapore.

2.1.2 Questionnaire

The questionnaire was composed of three sections and provided space for participants to comment at the end of the questionnaire. The questionnaires were very similar between studies, with the only differences being in questions relating to specific operational factors.

The questions in the first section related to pilots' experience, namely:

- crew position (Captain or First Officer);
- length of time operating the study specific aircraft;
- length of time operating long-haul flights;
- length of time operating ultra-long range flights;
- total flight hours;
- age; and
- commute time.

In this first section, differences between studies were:

- the addition (in the South African Airways study) of the option “In-flight Relief Officer” to the question relating to crew position;
- the addition (in the South African Airways study) of a question relating to experience operating aircraft of different fleet as a sub-section of the question relating to experience on the study specific aircraft type;
- the addition (in the South African Airways study) of a question asking how long pilots had been continuously flying long-haul;
- the removal (in the Delta Air Lines B767 bunk study) of the question relating to experience of flying ultra-long range;

The second section of the questionnaire concerned habitual sleep at home and was identical between all five studies. The questions in this section related to:

- habitual bed and rise times on days off;
- average sleep onset latency;
- frequency and causes of difficulty falling asleep;
- average number and causes of nighttime awakenings;
- difficulty resuming sleep following a nighttime awakening;
- average nighttime sleep duration;
- frequency of daytime napping;
- use of sleep aids;
- type of sleeper (rated from ‘very poor’ to ‘very good’); and
- sleep problems.

The third section of the questionnaire addressed in-flight sleep with questions about:

- the use of the crew rest facilities in the past 12 months: total bunk and crew rest seat use, bunk and crew rest seat use on the study specific aircraft type, and bunk and crew rest seat use on other aircraft types;
- average sleep onset latency in the bunk and in the crew rest seat;
- average sleep duration in the bunk and in the crew rest seat;
- number of times the bunk and crew rest seat were used for rest not sleep;
- percentage of rest break spent sleeping in the bunk or crew rest seat;
- sleep quality in the bunk and in the crew rest seat; and
- effects of sleep in the bunk and crew rest seat on alertness and performance.

In the final section, differences between studies were:

- the removal (in the United Airlines and Delta Air Lines B777 studies) of all questions relating to the use of a cabin seat for in-flight rest;
- the removal (in the Singapore Airlines study) of all questions relating to the use of a cabin seat for in-flight rest, except for the question relating to the percentage of a rest break spent sleeping in either the bunk or cabin seat;
- in the question about use of the bunk (and cabin seat), the removal (for the South African Airways study) of the break down by specific aircraft type (pilots were only asked about their total use of the rest facilities).

The questionnaires used in each of the five studies can be found in appendices 2B – 2D.

2.1.3 Creating a common database

As data were collected by different research teams and with different airlines, they were entered into five distinct databases in SPSS (version 21.0, IBM SPSS Statistics for Windows) and MS Access (2010, Microsoft Corporation). A common database for the five studies was created by merging data from the individual databases using two separate steps. In the first instance, the data from the four SPSS databases (United Airlines, Delta Air Lines B777, South African Airways, and Singapore Airlines studies) were merged into a combined database in SPSS. Subsequently, this combined database and the data that were stored in MS Access (Delta Air Lines B767 bunk study) were imported into SAS (version 9.2, SAS Institute Inc., Cary, NC, USA) where they were merged to create the final five study common database.

There were minor differences in the way data were entered and coded in the individual study databases. Therefore, when creating the common database for this study, coding for some variables had to be edited. For instance, in the United Airlines and Delta Air Lines B767 bunk studies, commute time was recorded in hours, but in the other three studies, commute time was recorded in minutes. Similar conversions of units were required for variables such as length of time operating LR and ULR flights and sleep duration both at home and in-flight.

When combining the databases, data were also checked for anomalies. Where anomalies were identified, these were dealt with on a case-by-case basis according to rules detailed in appendix 2E.

2.1.4 Data analysis

Data were analysed using the SAS statistics program (version 9.3). No data were excluded from the descriptive analyses, except in cases where a participant's answer to a question made the ensuing questions not applicable (e.g., a participant answered the question "when sleeping at home, do you have problems getting to sleep at night?" with "never", making the following question "if you do experience problems falling asleep what is it that usually keeps you awake?" not applicable).

Unless otherwise specified, the α-level for significance that was used was 0.05 for all analyses. For analyses where the sample size was greater than 40, the Kolmogorov-Smirnov test for normality was used (normally distributed if $p \geq 0.05$). For samples smaller than, or equal to 40, the Shapiro-Wilk test for normality was used (normally distributed if $p \geq 0.05$) (Field & Miles, 2010).

In all analyses, outliers were identified as part of the SAS 'proc univariate' procedure using the Tukey method. Using this method, values greater than the value of the 75th percentile plus 1.5 times interquartile range or smaller than the value of the 25th percentile minus 1.5 times the interquartile range are flagged as outliers. This method is robust to different distributions making it a reliable method for all samples regardless of whether or not they are normally distributed (Shoemaker, 1999).

Analyses were also undertaken to test whether the general quality of pilots' sleep at home predicted the quality of their sleep in flight, and to identify factors associated with the quality and duration of pilots' sleep at home. These analyses, and the procedures involved in preparing the data for further analysis, are described in the following sub-sections and were all completed using SAS version 9.3.

2.1.4.1 Grouping and re-categorization of responses

In order to provide more meaningful categories, responses for certain questions were grouped or re-categorized at the time of analysis. For instance, since the range of responses for reported total sleep duration per night was relatively large, participant responses were grouped into three categories:

- sleep <7 hours per night (short sleepers);
- sleep that was >7 hours and ≤9 hours (normal sleepers); and
- sleep >9 hours per night (long sleepers).

These categories were defined by taking into account findings from experimental and longitudinal studies of habitual sleep and its effects on health and performance (Grandner & Drummond, 2007; Grandner, Hale, et al., 2010; Grandner, Patel, et al., 2010; Hirshkowitz, et al., 2015; Kripke, Garfinkel, Wingard, Klauber, & Marler, 2002; Kronholm et al., 2011; Kronholm et al., 2009; Lucassen, et al., 2012; Patel et al., 2004; Tamakoshi & Ohno, 2004).

Responses relating to the type of sleep aid used were also re-grouped. The initial categorization into: "medication (prescribed or over the counter)", "herbal or homeopathic remedy", "food/beverage", "radio/music", "reading", "answer was unclear" and "missing" did not allow a clear distinction between the types of sleep aids used, as over 70% of pilots who reported using a sleep aid fell into the "medication" category. The categorization of sleep aids was therefore altered to reflect drug class. Where a participant used the trade name for a sleep aid, the active ingredient was looked up and its drug class was used to classify the compound into one of the following categories:

- "sedative hypnotics" (such as zolpidem, zopiclone, and eszopiclone);
- "melatonin";
- "antihistamines" (such as diphenhydramine hydrochloride or diphenhydramine citrate);
- "analgesics" (such as ibuprofen, acetaminophen/paracetamol, and aspirin);
- a "combination" of analgesic and antihistamine (such as over the counter cold and flu remedies);
- "other" sleep aids (such as beverages, reading, radio,…);
- "multiple" sleep aids (for instance a sedative hypnotic and a cold and flu remedy);
- "answer was unclear" (e.g., participant answer was "nighttime sleep aid"); and
- "missing".

2.1.4.2 Spearman's correlation: investigating possible correlations

Spearman's correlation was used to compare responses to questions where data were ordinal or non-normally distributed (Field & Miles, 2010; McDonald, 2014b). If data were missing for one or both of the compared variables, the pilot in question was excluded from the analysis.

2.1.4.3 The Wilcoxon signed-rank test: comparing sleep quality ratings

The relationship between the type of sleeper that participants' report themselves to be at home and their self-reported sleep quality in the bunk was examined using the Wilcoxon signed-rank test. This test was selected because the data for these questions were ordinal and not normally distributed (Field & Miles, 2010; McDonald, 2014c). In this comparison, if data were missing for one or both of the variables, the pilot in question was excluded from the analysis.

2.1.4.4 The Wilcoxon-Mann-Whitney test: investigating the use of sleep aids

The Wilcoxon-Mann-Whitney test was used to examine the relationship between age and reported frequencies of use of a sleep aid ("seldom, sometimes, often, or always" vs. "never"). The Wilcoxon-Mann-Whitney test is the non-parametric equivalent of the independent t-test and uses ranked data to determine whether or not the measurement variable (in this case age) significantly differs between the two tested groups (Field & Miles, 2010).

2.1.4.5 The Kruskal-Wallis test: investigating difficulties falling asleep

The Kruskal-Wallis test is the non-parametric equivalent of the one-way independent analysis of variance (ANOVA). It is used to compare three or more samples and is based on the use of ranked data (Field & Miles, 2010; McDonald, 2014a).

In these analyses, the Kruskal-Wallis test was used to examine the relationship between self-reported sleep onset latency (SOL) and the frequency of problems falling asleep[3], as the data for these variables were not normally distributed. The Kruskal-Wallis test was also used to examine the relationship between age and the frequency of problems falling asleep.

2.1.4.6 Binary logistic regression: factors related to sleep at home

Binary logistic regression was used to identify factors that were independently associated with self-reported “better than average sleep” at home. Likely predictor variables were selected based on a priori knowledge of factors that influence sleep quality and included both categorical and continuous variables. A table describing the variables included in the logistic regression model can be found in the corresponding section of the results (section 2.2.4).

Prior to running the logistic regression model, the recommended multi-collinearity checks were run to ensure that the predictors included in the model were not strongly correlated amongst themselves. Spearman’s correlation was used to test for relationships between the predictors, as were the collinearity diagnostics provided in the SAS version 9.3 statistics program. For these tests, it was considered that there was a potential issue with multi-collinearity if:

- correlation coefficients were greater than ±0.7;
- the tolerance statistics (TOL) were less than 0.1;
- the statistics for the variance inflation factor (VIF) were greater than 10;
- the values for the condition indexes were greater than 10; or

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[3] The categories of problems falling asleep used here were: “never”, “seldom”, “sometimes”, and “often or always”.

- the proportion of variance values were greater than 0.5 for more than one predictor in any given dimension of the cross-product matrix.

The goodness of fit of the binary logistic regression model was checked using the Pearson Chi-Square test and the concordance index[4] (Hosmer, Taber, & Lemeshow, 1991; LaValley, 2008), while the amount of variance explained by the logistic regression model was checked using the coefficient of determination[5] (Field & Miles, 2010).

The contribution of predictors to the model was measured using the Wald statistic. A predictor was identified as being a significant contributor if the p-value for its Wald statistic was less than 0.05. Odds ratios were also reported for each of the included predictors, as the Wald statistic may be underestimated when the regression coefficient is large (Menard, 1995).

2.1.4.7 Analysis of covariance: investigating nightly home sleep duration

Analysis of covariance (ANCOVA)[6] was used to identify factors related to self-reported nightly sleep duration at home. A table describing the predictor variables included in the model can be found in the corresponding section of the results (section 2.2.5).

As with the binary logistic regression, the recommended multi-collinearity checks were undertaken prior to running the ANCOVA. In addition, the goodness of fit of the model was

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[4] Values for the concordance index or C-statistic range from 0.5 to 1; a model is typically regarded as a reasonably good fit when values for the C-statistic are greater than 0.7 and is considered a very good fit when values exceed 0.8 (University of Manitoba, 2011).

[5] In this analysis, both Cox & Snell's R^2 (R^2_{CS}) and Nagelkerke's R^2 (R^2_N) were reviewed, as R^2_{CS} is known to never reach its maximum value (1), a problem that is somewhat resolved when using R^2_N.

[6] An ANCOVA tests the overall fit of a linear model while controlling for the effects of one or more covariates on the outcome variable (in this case nightly sleep duration at home).

assessed using the F-statistic (including its associated p-value)[7] and the R^2 which is a measure of how much variance is explained by the model.

For categorical variables that were significant in the model, least squares mean post-hoc tests with Bonferroni correction (to adjust for multiple comparisons) were conducted.

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[7] The F-statistic is calculated as the ratio of the average variability in the data that the model can explain compared to the amount of variability in the data that the model does not explain; as such it is the ratio of the model to its error. A significant F-statistic implies that the model is explaining more variance in the outcome than would be explained by chance alone. (Field & Miles, 2010)

2.2 Results

2.2.1 Participant demographics

In total there were 291 pilots included in these analyses:

- 74 from the United Airlines study;
- 70 from the Delta Air Lines B777 study;
- 54 from the Delta Air Lines B767 bunk study;
- 52 from the South African Airways study; and
- 41 from the Singapore Airlines study.

Demographic information for these pilots is summarized by study in Table 2.1.

Captains, First Officers and In-flight Relief Officers differed in age (Kruskal-Wallis p<0.0001). Post-hoc comparisons (using the Wilcoxon-Mann-Whitney test) with Bonferroni correction showed that Captains were significantly older than First Officers (p<0.0001, median ages 56 and 47 years respectively) and significantly older than In-flight Relief Officers (p<0.0001, median ages 56 and 29 years respectively). First Officers were also significantly older than In-Flight Relief Officers (p<0.0001, median ages 47 and 29 years respectively).

Table 2.1 Pilot demographics by study

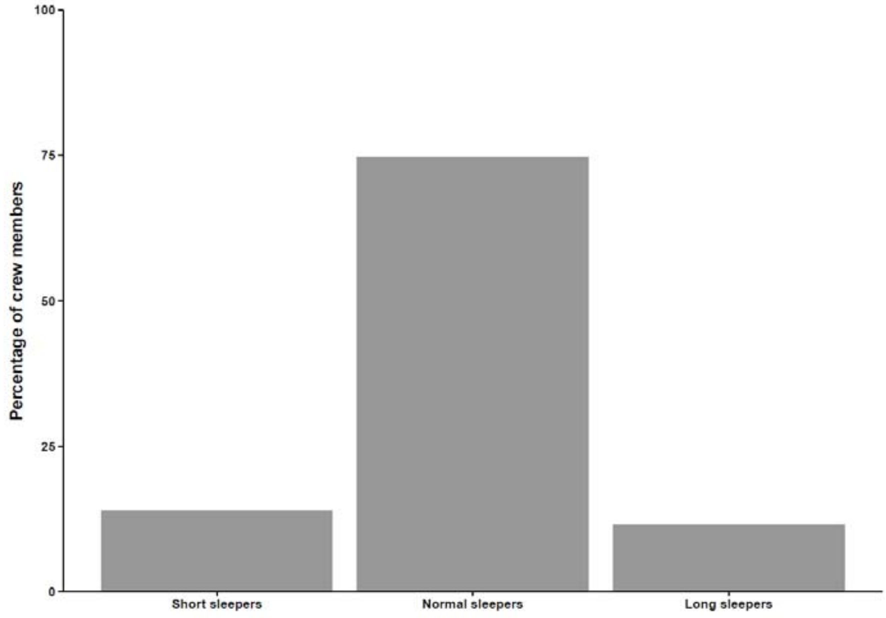
	United Airlines	Delta Air Lines B777	Delta Air Lines B767 bunk	South African Airways	Singapore Airlines	Combined
Captains (%)	34%	43%	55%	37%	56%	43%
First Officers (%)	66%	57%	45%	48%	44%	54%
In-flight Relief (%)	N/A	N/A	N/A	15%	N/A	3%
Age (yrs) (median, range)	51.0 (38.0-63.0)$^{a, 1}$	51.5 (43.0-60.0)	54.0 (40.0-62.0)^{a}	44.0 (27.0-62.0)	47.0 (29.0-58.0)^{a}	50.5 (27.0-63.0)$^{a, 1, 2}$
Total flight hours (median, range)	18750 (9000-33000) ^{3}	13548 (5400-30000) $^{4, 5}$	15000 (6000-24000) ^{6}	13584 (2420-25000) ^{1}	11500 (800-20000)^{a}	15000 (800-33000) $^{7, 8}$
Long range experience (yrs) (median, range)	8.3 (0.3-33.1)$^{a, 6, 9}$	7.0 (0.8-28.0)$^{a, 1, 10}$	7.2 (0.3-22.0)$^{a, 1, 11}$	11.0 (0.1-31.0)$^{a, 1}$	6.0 (0.0-32.0)$^{a, 9}$	7.6 (0.0-33.1)$^{a, 12, 13}$
Ultra-long range experience (yrs) (median, range)	0.8 (0.0-9.0)$^{a, 14, 15}$	1.0 (0.0-5.0)$^{a, 3}$	N/A	0.5 (0.0-3.0)$^{a, 1, 11}$	0.2 (0.0-0.4)$^{b, 1}$	0.5 (0.0-9.0)$^{a, 16, 17}$
Experience of specific aircraft type (yrs) (median, range)^{a}	B777 series 3.8 (0.1-12.0)$^{a, 3}$	B777 series 2.5 (0.1-9.1)$^{a, 9}$	B767-300 8.0 (0.1-15.8) ^{1}	A330/A340 series 4.1 (0.1-9.7)^{a}	A340 series 2.5 (0.1-11.3)$^{a, 9}$	3.6 (0.1-15.8)$^{a, 18, 15}$

[a] Data not normally distributed (i.e., Kolmogorov-Smirnov p-value <0.05); [b] Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05, as N≤40)
[1] 1 missing value; [2] Includes 13 outliers; [3] 2 missing values, [4] 6 missing values; [5] Includes 3 outliers; [6] 4 missing values; [7] 13 missing values; [8] Includes 5 outliers;
[9] Includes 1 outlier; [10] Includes 7 outliers; [11] Includes 2 outliers; [12] 7 missing values; [13] Includes 16 outliers; [14] 5 missing values; [15] Includes 4 outliers; [16] 9 missing values;
[17] Includes 18 outliers; [18] 3 missing values

Information about pilots usual sleep at home and their usual sleep habits are summarised in Table 2.2 and Table 2.3.

The range of self-reported nightly sleep duration at home was relatively large, therefore responses were grouped into three categories: short sleepers (TST<7hrs), normal sleepers (7hrs≤TST<9hrs), and long sleepers (TST≥9hrs) (Figure 2.1).

Figure 2.1 Total sleep duration per night categorized into short, normal or long sleepers



Note: Data missing for 2 pilots.

The range for sleep onset latency (SOL) for sleep at home was quite large (0 to 105 minutes) as it included three outliers with recorded SOL times of 90, 90 and 105 minutes respectively but 90% of pilots reported a SOL of 30 minutes or less.

Table 2.2 Usual sleep at home by study

	United Airlines	Delta Air Lines B777	Delta Air Lines B767 bunk	South African Airways	Singapore Airlines	Combined
Sleep onset latency (min) (median, range)[a]	15 (3-105)[1, 2]	15 (1-45)	15 (5-90)[2]	15 (5-90)[2]	30 (0-60)[3]	15 (0-105)[1, 3]
Nighttime awakenings (median, range)	1.0 (0.0-10.0)[a, 1, 4]	1.0 (0.0-5.0)[a, 4]	1.0 (0.0-3.5)[a]	1.0 (0.0-4.0)[a, 5, 2]	1.8 (0.0-4.0)[b, 1, 6]	1.0 (0.0-10.0)[a, 7, 8]
Total sleep per night (hrs) (median, range)[a]	8.0 (5.0-10.5)[1]	7.5 (5.0-9.0)[1, 2]	7.5 (5.5-10.0)[2]	8.0 (5.0-10.0)[9]	8.0 (5.5-9.3)	7.8 (5.0-10.5)[5, 10]

[a] Data not normally distributed (i.e., Kolmogorov-Smirnov p-value <0.05); [b] Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05, as N≤40);

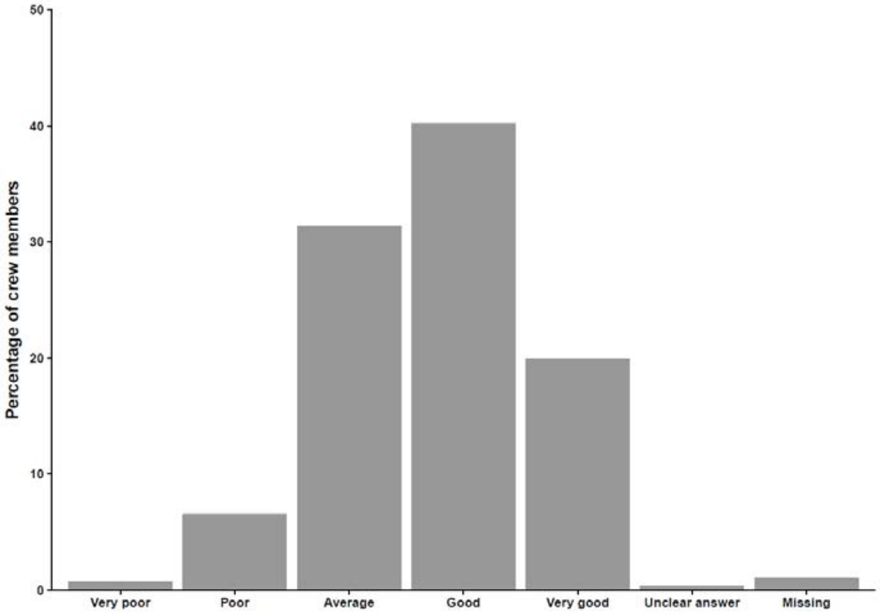
[1] 1 missing value; [2] Includes 1 outlier; 3 Includes 3 outliers; [4] Includes 4 outliers; [5] 2 missing values; [6] Includes 2 outliers; [7] 4 missing values; [8] Includes 11 outliers; [9] Includes 6 outliers; [10] Includes 10 outliers;

Table 2.3 Pilot sleep habits at home

	"Never"	"Seldom (1-4 times per year)"	"Sometimes (1-3 times per month)"	"Often (1-4 times per week)"	"Always (daily)"	Data missing
Frequency of problems falling asleep at night	9.3%	48.5%	34.7%	6.2%	0.7%	0.7% (2 participants)
Frequency of daytime nap	13.4%	30.6%	38.8%	15.1%	1.4%	0.7% (2 participants)
Frequency of use of a sleep aid	66.3%	19.9%	10.3%	2.1%	1.0%	0.3% (1 participant)

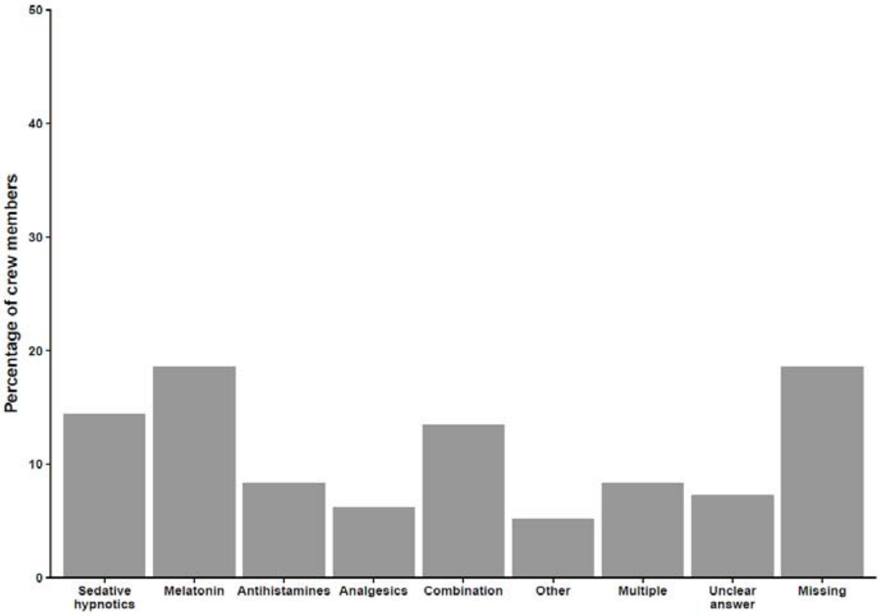
The majority of pilots reported themselves to be ‘good’ sleepers (Figure 2.2) and those who reported using a sleep aid (N=97) were asked to record what they used to help them sleep (Figure 2.3).

Figure 2.2 Self-reported type of sleeper



Note: Data missing for 3 pilots (1.0%) and answer unclear for 1 pilot (0.3%).

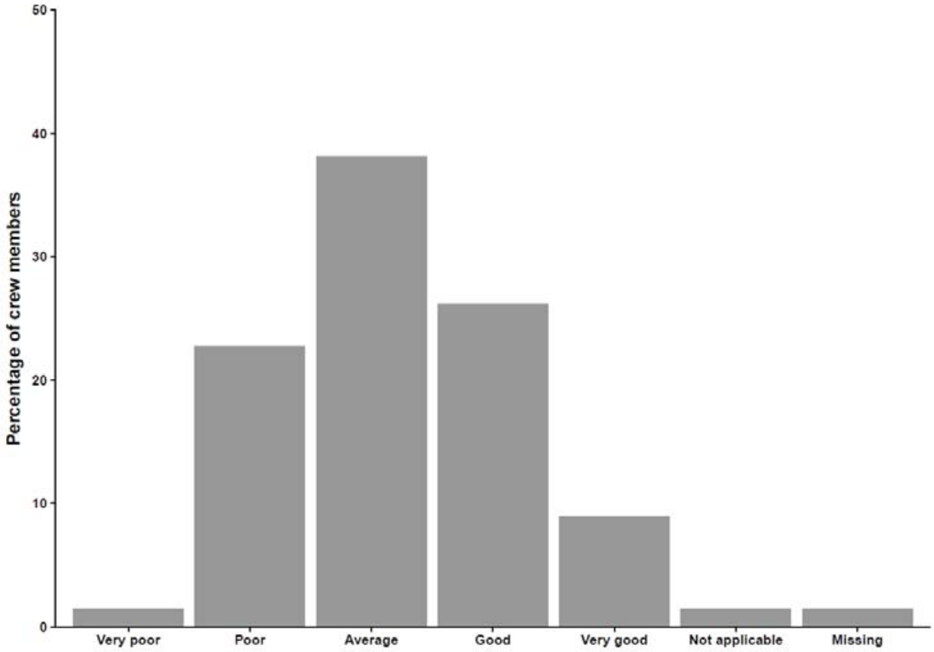
Figure 2.3 Type of sleep aid used by drug class



Note: Data missing for 18 pilots (18.6%).

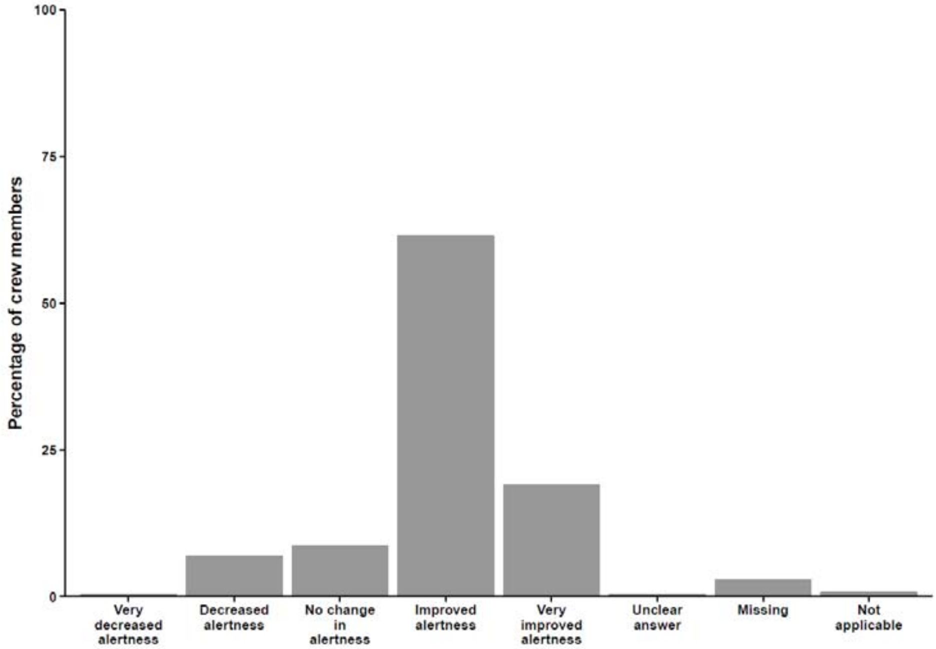
Ratings for sleep quality in the bunk tended to be similar across the different airlines and the majority of pilots rated their bunk sleep quality as "average" (Figure 2.4). The majority of pilots reported that sleep in the bunk improved their alertness (Figure 2.5) and responses tended to be similar across the included studies. Likewise, the majority of pilots reported that sleep in the bunk "improved performance" (Figure 2.6) and responses tended to be consistent across the 5 studies.

Figure 2.4 Sleep quality in the bunk



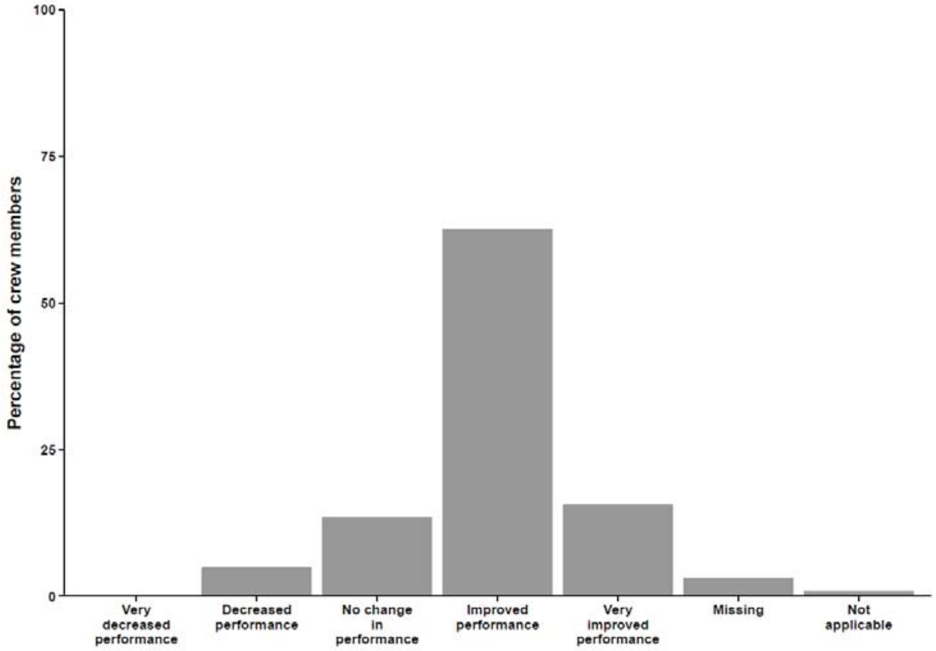
Note: Data missing for four pilots (1.4%) and not applicable (pilots had never used the bunk before) in four cases (1.4%).

Figure 2.5 Reported effects of bunk sleep on alertness



Note: Data for this question was missing for eight pilots (2.8%), it was not applicable in two cases (pilots had never used the bunk before, 0.7%), and the response for one pilot (0.3%) was unclear.

Figure 2.6 Reported effects of bunk sleep on performance



Note: Data for this question were missing for nine pilots (3.1%) and the question was not applicable to two pilots who had never used the bunk before (0.7%).

2.2.2 Correlations between self-reported sleep variables

Potential relationships between self-reported sleep variables were tested using Spearman's correlation and the results of these analyses are presented in Table 2.4.

Table 2.4 Correlations between different variables relating to sleep at home and sleep in the bunk

Correlation between:	R_s	p-value	N
Type of sleeper at home and sleep quality in the bunk	**0.301**	**<0.0001**	**280**
Sleep quality in the bunk and reported effects of sleep in the bunk on alertness	**0.519**	**<0.0001**	**280**
Sleep quality in the bunk and reported effects of sleep in the bunk on performance	**0.443**	**<0.0001**	**280**
Type of sleeper at home and reported total sleep per night at home	**0.189**	**0.0013**	**286**
Age and type of sleeper at home	-0.005	0.9289	287
Age and frequency of use of a nighttime sleep aid	**0.121**	**0.0400**	**290**
Age and frequency of daytime napping	-0.069	0.2454	289
Frequency of problems falling asleep and frequency of daytime napping	0.046	0.4393	288

Pilots who reported being better sleepers at home were more likely to report better sleep quality in the bunk. Strong positive relationships were also found between sleep quality in the bunk and the effects of sleep in the bunk on both alertness and performance. There were also weaker positive relationships between self-reported type of sleeper at home and subjective nightly sleep duration at home, as well as between age and the frequency of use of a nighttime sleep aid.

2.2.3 Factors correlated with sleep quality at home

Pilots' ratings of their type of sleeper at home were found to be significantly better than pilot ratings for sleep quality in the bunk (Wilcoxon signed-rank p<0.0001).

There was no significant relationship between age and the frequency of sleep aid use (‘seldom, sometimes, often or always’ versus ‘never’; Wilcoxon-Mann-Whitney p=0.0934).

2.2.4 Factors correlated with difficulties falling asleep

The frequency of problems falling asleep[8] was correlated with sleep onset latency (Kruskal-Wallis p<0.0001). The group who reported they “never” had problems falling asleep also reported the lowest median SOL (10min) while the largest median SOL was observed in the group who reported “often or always” having difficulties falling asleep (median SOL 30min). The frequency of problems falling asleep was not correlated with age (Kruskal Wallis p=0.3012).

2.2.5 Factors associated with reporting better than average sleep at home

A binary logistic regression model was used to identify the factors that affect self-reported type of sleeper at home. The variables included (Table 2.5) were all subjective measures relating to sleep quality. Twenty-one pilots were excluded from this model because of missing data.

The model fit was very good (Pearson’s Chi-Square=85.77, p-value <0.0001; c-statistic=0.807) and there were no issues of multi-collinearity amongst the predictor variables[9].

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[8] The categories of reported frequencies of problems falling asleep used in these analyses were “never”, “seldom”, “sometimes”, and “often or always”.

[9] However, the frequency of problems falling asleep was found to be related to difficulties resuming sleep (Chi-square p= 0.0017) and to the use of a sleep aid (Chi-square p <0.0001).

Table 2.5 Variables included in the logistic regression model

Variable	Type
Type of sleeper (outcome)	Categorical, "better than average" vs. "average or worse"
Frequency of problems falling asleep (predictor)	Categorical, "seldom or never" vs. "sometimes", "often or always"
Difficulty resuming sleep after a nighttime awakening (predictor)	Categorical, "reasonably or very easy" vs. "average or middle", "difficult or very difficult"
Age (predictor)	Continuous (range 27-63 years)
Number of nighttime awakenings (predictor)	Continuous (range 1-10)
Frequency of daytime nap (predictor)	Categorical, "seldom or never" vs. "sometimes", "often or always"
Use of a sleep aid (predictor)	Categorical, "never" vs. "seldom/sometimes/often/always"

Model findings are presented in Table 2.6. Pilots who reported more frequent difficulties falling asleep were significantly less likely to report better than average sleep at home, as were pilots who reported a greater number of nighttime awakenings.

Table 2.6 Odds ratios and 95% confidence intervals for "better than average sleep" at home

Predictor	Odds ratio (95% confidence interval)	P-value
Frequency of problems falling asleep:		
"seldom or never"	1.0 (reference)	
"sometimes"	0.206 (0.112 – 0.380)	**<0.0001**
"often or always"	0.047 (0.009 – 0.231)	**0.0002**
Difficulty resuming sleep:		
"reasonably or very easy"	1.0 (reference)	
"average or middle"	0.456 (0.176 – 1.180)	0.1055
"difficult or very difficult"	1.210 (0.306 – 4.781)	0.7856
Age:	0.980 (0.944 – 1.018)	0.2916
Number of nighttime awakenings:	0.571 (0.412 – 0.793)	**0.0008**
Frequency of daytime nap:		
"seldom or never"	1.0 (reference)	
"sometimes"	0.914 (0.484 – 1.724)	0.7809
"often or always"	1.459 (0.596 – 3.574)	0.4085
Use of a sleep aid:		
"never"	1.0 (reference)	
"seldom/sometimes/often/always"	0.639 (0.342 – 1.193)	0.1596

Other versions of the model (including a model which contained predictors related to sleep duration) were also tested but are not reported here as the model presented here explained more of the variance in ratings of type of sleeper at home.

2.2.6 Factors associated with nighttime sleep duration at home

Analysis of covariance (ANCOVA) was used to identify factors associated with self-reported nightly sleep duration at home. The variables included in the analysis (Table 2.7) were measures of sleep duration or sleep quality. One interaction (awakenings with age) was included in the model because there is evidence that the frequency of nighttime awakenings increases with age (Bonnet & Arand, 2007; Ohayon, et al., 2004).

Nineteen pilots were excluded from this model due to missing data (final N=272). Although the model did not explain much variance in the outcome variable (R^2= 0.10), the model was a good fit for the data (*F(10, 261)*= 2.82, p-value= 0.0025). There were no issues of multi-collinearity amongst the predictor variables.

Table 2.7 Variables included in ANCOVA of factors affecting self-reported nightly home sleep duration

Variable	Type
Nightly sleep duration at home (hours) (outcome)	Continuous (range 5.0-10.5)
Sleep onset latency (SOL, minutes) (predictor)	Continuous (range 0-105)
Number of nighttime awakenings (predictor)	Continuous (range 1-10)
Age (years) (predictor)	Continuous (range 27-63)
Frequency of daytime nap (predictor)	Categorical, “seldom or never”, “sometimes”, “often or always”
Frequency of problems falling asleep (predictor)	Categorical, “seldom or never”, “sometimes”, “often or always”
Difficulty resuming sleep after an awakening (predictor)	Categorical, “reasonably or very easy”, “average or middle” , “difficult or very difficult”

The findings of the ANCOVA are presented in Table 2.8. Estimated differences in nightly sleep duration for the categorical variables can be found in Table 2.9. The interaction of age and awakenings was found to be non-significant; however, it was kept in the model as its removal resulted in the variables 'age' and 'awakenings' no longer being significant predictors.

The nightly sleep duration of pilots who reported "often or always" taking a daytime nap was shorter than for those who reported "seldom or never" napping (estimated mean nightly sleep durations 7.1hrs and 7.5hrs respectively). Nightly sleep duration was also shorter with increasing age and increasing frequency of nighttime awakenings.

Other versions of this ANCOVA (including a model which contained only predictors related to sleep duration) were also tested but are not reported here as they did not explain as much of the variance in self-reported home sleep duration as the model presented here.

Table 2.8 ANCOVA of factors affecting self-reported nightly home sleep duration

Variable	Degrees of freedom	F-value	P-value
Sleep onset latency (minutes)	1, 261	0.03	0.8593
Number of nighttime awakenings	1, 261	4.36	**0.0378**
Age (years)	1, 261	6.68	**0.0103**
Frequency of daytime nap	2, 261	4.46	**0.0125**
Frequency of problems falling asleep	2, 261	1.11	0.3326
Difficulty resuming sleep after an awakening	2, 261	2.80	0.0625
Interaction: Age * Awakenings	1, 261	3.71	0.0550

Table 2.9 Estimated differences in self-reported nightly home sleep duration for the categorical variables

		Estimated difference	Bonferroni adjusted p-value
Frequency of daytime nap:			
Seldom or never	Sometimes	0.1	0.7801
Seldom or never	Often or always	0.4	**0.0094**
Sometimes	Often or always	0.3	0.1214
Frequency of problems falling asleep:			
Seldom or never	Sometimes	0.1	0.4311
Seldom or never	Often or always	0.1	1.0000
Sometimes	Often or always	0.0	1.0000
Difficulty resuming sleep after an awakening:			
Reasonably or very easy	Average or middle	0.2	0.9394
Reasonably or very easy	Difficult or very difficult	0.6	0.0767
Average or middle	Difficult or very difficult	0.4	0.5597

2.3 Summary of findings

The findings in this chapter are largely aligned with the initial hypotheses. Consistent with previous polysomnographic analyses of pilots' sleep at home and in flight (Signal, et al., 2005; Signal, Gander, et al., 2013), pilots' ratings of their sleep quality in the aircraft bunk (rated from 'very poor' to 'very good') were lower than their self-identified type of sleeper at home (rated from 'very poor' to 'very good'). In addition to this difference by sleep location, there was also a moderate positive correlation between pilots' reported type of sleeper at home and their reported sleep quality in the bunk, supporting the hypothesis that pilots who sleep poorly at home are more likely to sleep poorly in flight. Encouragingly, pilots who rated their in-flight sleep quality more favourably, also rated the effects of bunk sleep on their performance and alertness more favourably, a finding that supports the use of in-flight sleep as a fatigue mitigation strategy.

Consistent with the recent study by Wu and colleagues (Wu, et al., 2016), the pilots in Project A were generally good sleepers. Their self-reported sleep duration fell within the recommended range (Hirshkowitz, et al., 2015), and the majority reported being good sleepers and having a usual sleep duration at home of between 7 and 9 hours. Self-reported nightly sleep duration was positively correlated with type of sleeper and decreased with increasing age, frequency of nighttime awakenings and daytime napping. This aligns with the findings of a study comparing the sleep complaints of individuals who are short sleepers to those of individuals who have a normal sleep duration (Grandner & Kripke, 2004). Similarly, pilots who reported more frequent difficulties falling asleep and more frequent nighttime awakenings were less likely to report better than average sleep at home. Those who reported more frequent difficulties falling asleep also unsurprisingly reported longer sleep onset latencies, though past studies have observed that poor sleepers are more likely to overestimate their sleep on latency than good sleepers (Adam, Tomeny, & Oswald, 1986; Carskadon et al., 1976).

Pilots must undergo rigorous annual medical checks in order to maintain their flight license and are thus generally a very healthy population for their age group. This was reflected in the findings relating to age, which was not correlated with difficulties falling asleep, type of sleeper at home or the frequency of daytime napping. Findings relating to age and the use of sleep aids were inconsistent, probably due to the very low number of pilots reporting using sleep aids.

CHAPTER 3 DELTA B767-300ER BUNK STUDY (PROJECT B)

The study detailed in this chapter was conducted at the request of and with Delta Air Lines, as part of a safety case to certify a new rest facility in their A330-200 aircraft with a bunk slightly smaller narrower at one end than the specified minimum width for a Class 1 Rest Facility.[10] The study was conducted by a team of experienced researchers from the Sleep/Wake Research Centre, a research assistant at Delta Air Lines, and the author.

The analyses presented here were designed to add to existing knowledge by using standard measures to evaluate the influence of rest break patterns on the use of naps as a flight preparation technique, and on in-flight sleep duration, and sleepiness, fatigue and PVT performance at top of descent. It was hypothesised that pilots would be more likely to nap in the afternoon prior to evening departures (body time), but that this might reduce their ability to sleep early in the flight. Thus, having prior knowledge of their in-flight rest break allocation might influence their pattern of sleep in preparation for duty. Analyses also investigated whether the pattern of in-flight rest breaks affected pilots' in-flight sleep or fatigue and performance at top of descent.

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[10] At the time of this study, Delta wished to install a class 1 pilot rest facility in their Airbus A330-200 aircraft for use on long range flights. FAA Advisory Circular 117-1 (appendix 3A) describes acceptable criteria for Class 1 Crewmember Rest Facilities, which include that the minimum size of a bunk should be 78" by 30". However, the proposed location of the crew rest facility in the tail of the A330 aircraft resulted in a tapered reduction from about hip height to 21 inches at the foot of the lower bunk. If the rest facility was not classified as class 1, this would reduce the length of flights on which the aircraft could be used. A study was therefore designed to compare the amount and quality of sleep obtained by pilots in the tapered bunk versus a full-size bunk, to provide objective evidence on the effects of the taper. Total in-flight sleep was equivalent in the two bunks, as was PVT performance at top of descent, so data from both bunks were combined for the analyses presented here. The data from the safety case remains confidential and therefore is not presented here.

3.1 Methods

The study design was finalised and ethical approval obtained prior to the author's involvement in the study. The author's initial role was to manage day-to-day aspects of the data collection and to liaise with the members of the research team at Delta Air Lines. In this capacity the author:

- reviewed and adapted the study materials for data collection;
- reviewed and checked the quality of the data received;
- helped with troubleshooting when issues arose with devices used in the study;
- processed and entered the data received; and
- aided in the development of databases.

All of the analyses detailed in this chapter were completed by the author with statistical and technical support provided where necessary.

3.1.1 Ethics

This study obtained ethical approval as an extension to the series of studies informing the Delta Air Lines Fatigue Risk Management System for which the Sleep/Wake Research Centre holds ethical approval from the Massey University Human Ethics Committee Southern A (Application 11/01) (appendix 3B).

Participation in the study was voluntary and confidential. Interested eligible pilots (i.e., any Delta Air Lines pilot flying the studied route in the studied aircraft) received a detailed information sheet (appendix 3C) which described the study and its procedures and advised them of their rights as participants (including the right to withdraw from the study without consequences at any time). After reading the information sheet, pilots wishing to participate in the study signed a consent form (appendix 3C) and returned it to the Delta Air Lines member of the research team. Participants in the study were compensated for their time at a flat rate of USD 38.59 per day of participation, as required by an industrial agreement.

3.1.2 Study design

Retrofitted A330-200 aircraft were not available at the time of the study, which was therefore conducted using Delta Boeing 767-300ER aircraft with an insert fitted to the top bunk to mimic the reduction in size in the A330-200 bunk [11]. The lower B767 bunk was not modified and met the full FAA Advisory Circular 117-1 specifications. The crew rest facility on the 767-300ER is located below the mid-cabin (versus the tail in the A320).

Logistically, it was deemed impractical to conduct a within-subjects protocol where each pilot would be monitored on the same flight twice (once using the reduced-size bunk and once using the full-size bunk). As a result, participants in this study were studied on one out-and-back trip between Atlanta (USA) and Lagos (Nigeria), with half the participants using the tapered bunk on the outbound flight and full-size bunk on the inbound flight, and the other half using the full-size bunk on the outbound flight and the tapered bunk on the inbound flight.

Initially, information about the study was posted on the Delta Air Lines intranet page (deltanet) advertising for volunteers, however only two pilots volunteered in this way. The Delta Air Lines member of the research team then began recruiting for the study by calling pilots scheduled to fly the chosen study trip and asking them if they were interested in participating. Interested pilots were then sent an information sheet about the study and a consent form which they signed and returned to the Delta Air Lines team member to indicate that they agreed to participate.

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[11] In the A330-200 the reduced-size bunk is the lower bunk.

Approximately 5-7 days prior to the start of their study trip, participants were sent study materials (duty/sleep diary, actigraph for sleep monitoring, and Palm Centro smartphone for PVT performance testing). Instructions on how to use the equipment and how to complete the study were included in the parcel and were also available on the deltanet page. Additionally, participants received a training call from the Delta Air Lines member of the research team during which the instructions for the study were explained to them. The Delta Air Lines team member was also available (via email and telephone) throughout the data collection period if participants had any questions or problems.

Participants were asked to wear the sleep monitoring device continuously from 3 days prior to the outbound leg until 3 days after the inbound leg of the trip. During that time they were also asked to complete their duty/sleep diary for every sleep period longer than 10 minutes and to complete the questions on the in-flight and pre-study questionnaire pages. In addition, for both their outbound and inbound flight segments participants were asked to complete 3 to 4 performance tests at specific times. Once their data collection period was complete, participants returned their study materials to the Delta Air Lines member of the research team and were compensated for their time.

3.1.3 Measures

The measures used in this study were based on methods used in previous studies of pilot sleep and performance (Gander et al., 2013; Signal, Mulrine, et al., 2013; Signal, et al., 2004).

3.1.3.1 Pre-study questionnaire

Prior to the start of data collection, participants were asked to complete a “Pre-Study Questionnaire” included as a section of their duty/sleep diary (appendix 3D). The questionnaire was composed of three sections: the first relating to pilot demographics and professional experience, the second to sleep at home, and the third to in-flight sleep. A more detailed description of the items included in the questionnaire is provided in chapter 2.

3.1.3.2 Duty/sleep diary

Throughout their study period, participants were asked to complete a paper duty/sleep diary (appendix 3D). The diary included several different sections and was modelled on duty/sleep diaries used in previous aviation studies at the Sleep/Wake Research Centre (Gander, et al., 2011; Gander, Van den Berg, & Signal, 2013; Signal, Mulrine, et al., 2013; Signal, et al., 2004). The sections of the diary were ordered as follows:

- instructions on when to complete which sections (page 2)
- instructions on how to complete the diary (page 3)
- instructions on how to complete the PVT (page 4)
- the pre-study questionnaire (pages 5-7)
- a look back report in which pilots recorded duty periods in the 8 days prior to the start of their data collection and the 3 days immediately prior to their studied trip (page 8)
- home pre-flight days 1-3 where pilots recorded their sleep in the 3 days prior to their studied outbound flight (pages 9-11)
- a page for pilots to complete if they were deadheading on their outbound flight (page 12)
- outbound flight pages to be completed with information about the flight (a pre-flight and TOC [Top of Climb] page, an in-flight page, and a TOD [Top of Descent] and post-flight page) (pages 13-15)
- layover hours 1-24 and 25-48 where pilots recorded their sleep (pages 16 & 17)

- inbound flight pages to be completed with information about the flight (a pre-flight and TOC page, an in-flight page, and a TOD and post-flight page) (pages 18-20)
- a page for pilots to complete if they were deadheading on their inbound flight (page 21)
- home post-flight days 1-3 where pilots recorded their sleep in the 3 days following their return from their studied trip (pages 22-24)
- a chart to convert UTC to different US time zones (page 25)

3.1.3.3 Actigraphy

Sleep was measured continuously throughout the study period using the Actiwatch AW-64 (Respironics Mini Mitter, Bend, Oregon, USA). The Actiwatch is a wrist-worn watch-sized device containing an accelerometer which is used to infer sleep and wakefulness based on activity counts using the manufacturer's software (Actiware version 5.71.0, Philips Respironics, Bend, Oregon, USA). Actigraphy is widely accepted as an objective measure of sleep (reviewed in Sadeh, 2011) and the AW-64 device has been validated against polysomnography for measuring pilots' sleep (Signal, et al., 2005).

The accelerometer in the AW-64 device measures the occurrence of movement which it samples at a frequency of 32Hz and stores as "activity counts" (Philips Respironics, 2005). In this study the device was set to record in 60s epochs, i.e., activity counts were stored in one-minute bins. As the device used was not waterproof, participants were asked to remove the Actiwatch any time they were likely to be in prolonged contact with water (e.g., showering, swimming). Participants were also asked to push the event marker (a small button on the face of the device) whenever they started or stopped trying to sleep for a period of 10 minutes or longer.

3.1.3.4 Subjective ratings of sleepiness, fatigue and sleep quality

For both the outbound and inbound flights, participants were asked to complete subjective ratings for sleepiness, fatigue and sleep quality in the duty/sleep diary before and after each in-flight sleep period, as well as before take-off, at top of climb, at top of descent, and after landing. Sleepiness was rated using the Karolinska Sleepiness Scale (KSS), which uses a scale from 1= "extremely alert" to 9= "extremely sleepy, fighting sleep" (Åkerstedt & Gillberg, 1990; Gillberg, Kecklund, & Åkerstedt, 1994; Härmä, Sallinen, Ranta, Mutanen, & Müller, 2002). Fatigue was rated using the Samn-Perelli Crew Status Check (SP), a scale developed specifically to assess the fatigue of pilots which ranges from 1= "fully alert, wide awake" to 7= "completely exhausted, unable to function effectively" (Samel, Wegmann, & Vejvoda, 1997; Samel, Wegmann, Vejvoda, et al., 1997; Samn & Perelli, 1982). Sleep quality was rated after each in-flight sleep period on a 7-point scale from 1= "extremely good" to 7= "extremely poor". All three of these scales have been previously used in similar studies of pilots' sleep and performance (Gander, Signal, et al., 2013; Gander, van den Berg, Mulrine, et al., 2013; Signal, Mulrine, et al., 2013; Signal, et al., 2004; Spencer & Robertson, 2000).

3.1.3.5 Objective measures of performance

Pilot performance was measured at specific points during the outbound and inbound flights using a validated 5-minute version of the psychomotor vigilance task (PVT) (Roach, Dawson, et al., 2006). The PVT is a simple reaction-time test involving the presentation of a stimulus (in this instance visual) at random short time intervals and results in a reliable assessment of an individual's psychomotor vigilance (Dinges & Powell, 1985; Dorrian, et al., 2005). The version of the PVT that was used in this study (PalmPVT, Walter Reed Army Institute of Research) used a visual stimulus presented at intervals of 2 to 10 seconds and was loaded on a Palm Centro Smartphone (Palm, Inc., Sunnyvale, California, USA) (Thorne, et al., 2005). The four points at which participants were asked to complete the PVT during the outbound and inbound flights were:

- before take-off (but after reporting for duty, usually in flight operations);
- at the end of their first in-flight rest period;
- at the end of their second in-flight rest period; and
- within one hour of top of descent (unless the test at the end of their second in-flight rest period fell within this time).

Participants were reminded not to complete the PVT during critical phases of the flight or if they thought completion of the test could be unsafe. They were also asked to undertake the PVT in an environment that was as quiet and distraction free as possible, and if possible, away from the flight deck.

3.1.4 Data management

All data was stored in a de-identified format with each participant being allocated a study-specific identification number. Identifying crew member information was stored separately from the collected data and was held by the Delta Air Lines member of the research team. Once participants had returned their study materials, the Delta Air Lines team member downloaded the PVT and actigraphy data to a computer and uploaded the raw data files to a secure file transfer protocol (ftp) site from which the Sleep/Wake Research Centre researchers could access the data. The duty/sleep diaries were scanned and uploaded to the same ftp site. The original data files were stored in the United States until the data collection phase of this project was completed, after which all of the original documents (consent forms and paper duty/sleep diaries) were couriered to the Sleep/Wake Research Centre for archiving.

All database development and data analyses were conducted by the Sleep/Wake Research Centre.

3.1.4.1 Pre-study questionnaire and duty/sleep diary

The data from the duty/sleep diaries were entered into a MS Access database (2010, Microsoft Corporation). A sample of 12 diaries (34%) was selected at random from the complete datasets and cross-checked by a second independent researcher. Discrepancies (0.23%) were reviewed and rectified where necessary. After the completion of data entry, data were also screened for outliers and where outliers were identified, these were checked against the original duty/sleep diary data.

3.1.4.2 Actigraphy data

Each actigraphy record was downloaded and viewed using the Actiware software (version 5.71.0) set to a medium sensitivity setting, as this setting has been shown to provide the most accurate relationship with polysomnography (Signal, et al., 2005). Periods during which the participant was attempting sleep (rest intervals) were determined manually based on:

- the level of activity recorded by the device for that period;
- the use of the event marker; and
- the rest start and end times recorded by the participant in their duty/sleep diary.

A more detailed description of the scoring rules used is available in appendix 3E.

Once the rest intervals had been manually determined, the software algorithm was used to score each one-minute epoch as either "wake" or "sleep" depending on whether or not the total activity counts for the given epoch (including the weighted contributions of the surrounding data) exceeds a pre-set wake threshold value (for the medium sensitivity setting that threshold is 40 activity counts) (Philips Respironics, 2005).

Numerous device malfunctions were experienced during this project, occurring in 17 of the 54 collected data sets and often resulting in the loss of the individual's data set. These malfunctions were dealt with on a case-by-case basis as detailed in appendix 3F.

To ensure consistency and reliability in the scoring, the 35 complete actigraphy records were double scored by a second independent trained researcher. Agreement between the two scorers was defined as a difference of 15 minutes or less in the start and end times of the rest interval. Overall, discrepancies of more than 15 minutes occurred in 7.6% of rest interval start times and in 8.5% of rest interval end times resulting in an overall agreement rate of 91.9%. Where discrepancies were identified, the concerned rest interval was reviewed and discussed by the two researchers to reach agreement. Where the two researchers did not reach agreement, a third independent trained researcher was brought in to help decide on the appropriate timing of the rest interval.

3.1.4.3 Psychomotor vigilance task data

PVT data for each participant were downloaded from the Palm Centro and saved as a REACT PVT file using the Palm PVT 3.0.0 software (Walter Reed Army Institute of Research, USA). In the REACT program (Ambulatory Monitoring Inc., USA), summary statistics were generated for each test, namely response speed (1/reaction time x 1000), the slowest 10% of responses, the fastest 10% of responses, and lapses (responses exceeding 500ms in duration). These variables were exported to a MS Excel file which was then imported into a SAS (version 9.2, SAS Institute Inc., Cary, NC, USA) database for statistical analysis.

3.1.5 Data analysis

3.1.5.1 Pre-study questionnaire and look back report

Data from the pre-study questionnaire were analysed using the SAS statistics program (version 9.3, SAS Institute Inc., Cary, NC, USA). Basic descriptives of the data (mean, median, range) were generated for pilot demographics. In addition, descriptive statistics for the studied trips were generated using SPSS (version 21.0, IBM SPSS Statistics for Windows). For these analyses, only pilots with complete actigraphy data (N=35) were included. Further analyses of the data provided in the pre-study questionnaire were undertaken as part of the analyses described in chapter 2.

The information about duty days and days off provided by pilots in the look back reports of the duty/sleep diaries was entered in a MS Excel spreadsheet as a frequency table. This information was then plotted as a histogram in the R statistics program (version 3.1.0, R Core Team, Vienna, Austria).

3.1.5.2 Defining baseline, layover and post-flight days

To provide an estimate of each pilot’s total sleep per 24 hours when it was not restricted by duty demands, ‘baseline days’ were identified. These had to start at least 72 hours after the last transmeridian flight (to allow for adaptation to local time) and finish at least 24 hours before the next duty period (to avoid possible changes in sleep patterns in preparation for duty). Baseline days were identified using the look back report in conjunction with the specific criteria described below. Baseline days were defined from noon to noon Eastern Daylight Time (EDT) and Figure 3.1 illustrates how these and other periods of interest were coded.

The criteria used to identify baseline days for each pilot were as follows:

- if the participant's last duty/trip day was on day -4 or earlier (i.e., in days -11 to -4), then both baseline day 1 and baseline day 2 were used as baseline days for that participant;
- if the participant arrived home on day -3 (i.e., day -3 was their last duty/trip day), then only baseline day 2 was used as the participant's baseline sleep [12];
- if the participant's scheduled baseline day 1 and/or day 2 overlapped with the 24 hours prior to a trip, a duty/trip day, or the 24 hours immediately following a trip then they were not considered baseline days.

For each participant, post-trip days were also identified from noon to noon EDT, starting at noon on the day of the participant's arrival back in Atlanta. Days were excluded if there were no actigraphy data or if they overlapped with the 24 hours prior to a subsequent trip or a subsequent duty/trip day. The period between the early morning arrival of the inbound flight in Atlanta and noon on the day of arrival was not included.

The layover period was split into the first 24 hours of layover (starting at duty end of the outbound ATL-LOS flight) and the second 24 hours of layover (ending at duty start of the inbound LOS-ATL flight). As the layover duration was just over 24 hours, these two periods had significant overlap.

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[12] Previous studies of pilots conducted at the SWRC have found that although sleep duration was extended on the first night back from a trip pattern, on second night back, sleep duration had returned to normal and sleep efficiency remained unchanged by the trip pattern (Gander, et al., 2011; Gander, van den Berg, Mulrine, et al., 2013; Signal, Mulrine, et al., 2013).

3.1.5.3 Analysis of pilots' sleep

Pilots' sleep and duty patterns across the study period were displayed graphically using custom-built software developed by Dr. David Darwent (Appleton Institute, Central Queensland University) and modified by Dr. Alexander Smith (Sleep/Wake Research Centre, Massey University). In these plots, each individual's actigraphic sleep and duty times are plotted on a horizontal timeline, and the timelines for multiple individuals are stacked vertically to facilitate visual interpretation of the entire data set.

For these analyses, pilots' sleep data were parsed using a custom-built program (Actisoft 2.1.3 [13]) in MS Access which sums total sleep time and averages sleep efficiency across specific time periods (24-hour intervals). The specific time periods are illustrated in Figure 3.1 and were set up as follows:

- *baseline day 1 (light blue in figure)*, defined as the 24-hour period starting at 1600 UTC, 4 days prior to the day of departure of the outbound flight;
- *baseline day 2 (light blue in figure)*, defined as the 24-hour period starting at 1600 UTC, 3 days prior to the day of departure of the outbound flight;
- *the last 24 hours prior to duty start (dark green in figure)*, defined as the 24-hour period counting backwards from the earlier time of either rostered or actual report date-time (outbound and inbound flights);
- *the last 24 hours prior to TOD (light green in figure)*, defined as the 24-hour period counting backwards from participant estimated TOD date-time (outbound and inbound flights);

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[13] Actisoft version 2.1.3 was developed by Dr. Alexander Smith, Sleep/Wake Research Centre, Massey University, NZ.

- *the first 24 hours after duty end (purple in figure)*, defined as the 24-hour period beginning at the end of flight duty (outbound and inbound flights);
- *post trip day 1 (dark blue in figure)*, defined as the 24-hour period starting at 1600 UTC on the day of arrival back in ATL (inbound flight only);
- *post-trip day 2 (dark blue in figure)*, defined as the 24-hour period starting at 1600 UTC on the day after arrival back in ATL (inbound flight only); and
- *post-trip day 3 (dark blue in figure)*, defined as the 24-hour period starting at 1600 UTC on the second day after arrival back in ATL (inbound flight only).

Figure 3.1 Time periods (24-hour intervals) for analysis in Actisoft

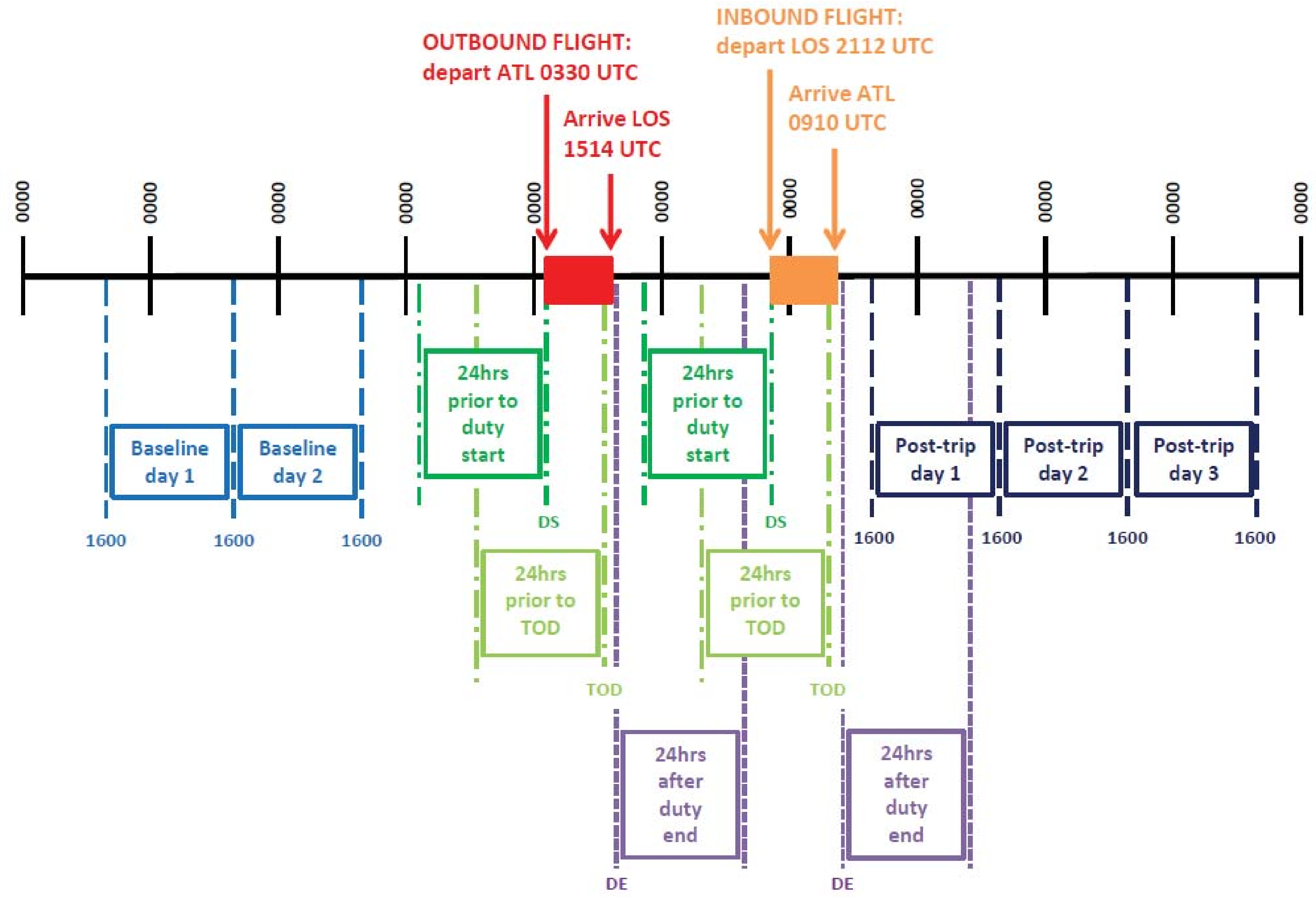

Figure key: DS= Duty start, TOD= Top of descent, DE= Duty end, all times in UTC

Actisoft was used to determine total sleep time (i.e., the number of minutes that had been scored as "sleep") and sleep efficiency (i.e., the total sleep time compared to the number of minutes spent attempting sleep, expressed as a percentage)[14] within each given 24-hour interval. For these analyses, actigraphic sleep periods that had been classified as "excluded" in the Actiware software were not included[15].

Sleep/wake history is a key determinant of pilot fatigue status. Therefore, Actisoft was also used to calculate the duration of wakefulness prior to duty start and prior to TOD, immediately before the high workload and safety risk of the approach and landing phases of flight. For these analyses, actigraphic sleep periods that had been scored as "excluded" were included. This is due to the fact that the duration of prior wakefulness is calculated as the number of minutes since the end of the last sleep period and therefore excluding these intervals could have resulted in incorrect values for some participants.

Basic descriptive statistics for the 24-hour intervals of interest were then calculated in SAS (version 9.3) and plotted as boxplots in R (version 3.1.0, R Core Team, Vienna, Austria).

Total in-flight sleep time, time awake at duty start and total sleep in the 24 hours prior to duty start and to TOD were compared between rest break patterns (between-subjects

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[14] Sleep efficiency (SE) across the 24-hour interval of interest was calculated assuming that SE is constant across the individual actigraphic rest intervals included in the 24-hour interval of interest, regardless of whether or not the entire actigraphic rest interval is included in the 24-hour interval of interest. Therefore for a given actigraphic rest interval (i), SE of the cut interval is equal to SE of the uncut interval ($SE_{i\ cut} = SE_{i\ uncut}$). It then weights the SE from each included actigraphic rest interval (SE_i) by the actual sleep time for those rest intervals (TST_i) and calculates SE across the 24-hour interval of interest as the weighted average SE for the total sleep time in the 24-hour interval of interest. Thus,

$$SE_{E\_wAS} = \frac{\sum_i SE_i * TST_i}{\sum_i TST_i}$$

[15] Sleep periods that had been recorded by the participant in the diary but for which the Actiwatch was not worn, were scored as "Excluded" periods in the Actiware software (appendix 2E). This meant that start and end times were generated for these periods but the epochs within the period were not scored as "wake" or "sleep". As result, it is not possible to calculate sleep efficiency or actual sleep duration for these sleep periods.

comparisons) using independent t-tests (parametric data) or Wilcoxon-Mann-Whitney test (non-parametric data). Comparisons between flight segments (within-subjects comparisons) were made using paired t-tests (parametric data) or Wilcoxon signed rank tests (non-parametric data).

The frequency of pre-trip napping was compared between the two main in-flight rest patterns (1st and 3rd breaks versus 2nd and 4th breaks) using the chi-square test. The frequency of pre-trip napping was also compared to the self-reported frequency of napping at home on days off (5-point Likert scale: never; seldom (1-4 times/yr); sometimes (1-3 times/month); often (1-4 times/week); always (daily)) using the chi-square test. For these analyses, two categories were created: napping rarely (never/seldom) and napping habitually (sometimes/often/always).

All of these comparisons were completed using the SAS statistics program (version 9.3).

Multilevel mixed modelling:

Multilevel mixed modelling was used to compare sleep duration and sleep efficiency on baseline days to:

- sleep in the last 24 hours pre-flight;
- sleep in the last 24 hours of layover; and
- sleep in the first three days post-trip.

Multilevel mixed modelling is an extension of conventional regression models which takes into account the aggregation of data (i.e., nesting or clustering of cases) and allows for the inclusion of both fixed and random effects[16] in the model (Field & Miles, 2010; Marx,

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[16] An effect is considered to be fixed if all of the possible conditions the researcher is interested in are present in the data (e.g., in these models the fixed effect is day type) while an effect is

Simonoff, & Scott, 2013). This is a powerful tool as it makes it possible to account for variations both within and between groups (Marx, et al., 2013).

Since missing data does not affect multilevel models (Field & Miles, 2010), only cases that were considered invalid (e.g., 'baseline days' during which participants were on duty) were excluded. For the models comparing baseline sleep to sleep in the last 24 hours pre-flight and in the last 24 hours of layover, baseline values were not averaged (i.e., some participants had one day of baseline sleep while others had two). However, for the models comparing baseline sleep to sleep in the first three days post-trip, if participants had two valid baseline days, their sleep duration and sleep efficiency were averaged across the two days. This was required as the models using post-trip days did not converge when participants had multiple values for baseline.

Multilevel mixed models assume that the relationship between the predictor variable (in this case day type) and the outcome variable (in this case sleep duration or sleep efficiency) is linear, that the residuals are normally distributed and that the variance between groups is constant. The assumption of normality of residuals was checked for each model using the Shapiro-Wilk or Kolmogorov-Smirnov[17] statistic (normally distributed if $p \geq 0.05$) and the variance between groups was checked using Levene's test (variance constant if $p \geq 0.05$). Where outlying residuals were identified, these were removed and the model was re-run without the outlier(s). The assumptions of the new model were then checked to ensure they had been met. If the exclusion of outliers did not change the outcome of the model results, the model reported here includes the outliers. If the exclusion of outliers changed the model results, then the model was reported without the outliers. For all of the analyses where

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considered random if only a random sample of the possible conditions is included in the data (e.g., in these models the random effect is participant) (Field & Miles, 2010).

[17] The Shapiro-Wilk statistic was used for samples where $N \leq 40$, while the Kolmogorov-Smirnov tests was used for samples where $N > 40$.

outliers were identified, the effect of their removal on the model outcome is reported with the model results.

For multilevel models which include a random effect or a repeated measure, a covariance structure must be specified for the data. The type of covariance structure selected is important and depends on what is appropriate with a given data set. If the covariance structure selected is too complex for the data, the risk of type II error (false negatives) increases, while a covariance structure that is too simple will increase the risk of type I error (false positives) (Field & Miles, 2010). In these analyses of pilot sleep, three repeated measures covariance structures were considered:

- The *compound symmetry* (*CS*) *covariance structure* which assumes that the within-subject correlation is constant regardless of the lag between pairs of repeated measures. This covariance structure is one of the simpler structures and was considered because the lag between repeated measures was constant (i.e., 24 hours) (Littell, Milliken, Stroup, Wolfinger, & Schabenberger, 2006).
- The *first-order auto-regressive* (*AR(1)*) *covariance structure* which assumes that the within-subject correlation is a function of lag in time with adjacent observations being more highly correlated than observations further apart in time. This structure requires that repeated measures are equally spaced in time (Littell, et al., 2006).
- The *first order ante-dependence* (*ANTE(1)*) *covariance structure* which assumes that both the variance among observations and the correlations between pairs of observations at adjacent times may change over time, allowing for unequal spacing of time points (Littell, et al., 2006).

For the models comparing baseline sleep to sleep in the last 24 hours pre-flight and to sleep in the last 24 hours of layover, only the CS covariance structure was used as there were only two time points included in these models. As the models comparing sleep at home to sleep in the first three days post-trip included multiple time points, the CS, AR(1) and ANTE(1) covariance structures were considered. The covariance structure which resulted in the model with the best fit was selected based on the Bayesian Information Criterion (BIC), a measure of goodness of fit which takes into account model complexity and is slightly more conservative than the Akaike's Information Criterion (AIC) (Field & Miles, 2010). The model which minimizes the BIC is considered to be the model with the best fit (Field & Miles, 2010; Littell, et al., 2006). Although the BIC has a tendency to choose the simpler model compared to the AIC, it is less likely to result in a loss of power which was of greater concern given the relatively small sample size in these analyses (Littell, et al., 2006).

The Kenward-Roger correction was used in all of the multilevel models tested here to correct the standard errors, F-statistics and degrees of freedom, since these would have been biased by the non-independence of errors in the absence of this correction (Littell, et al., 2006).

For post-hoc tests, estimated model means for each group were calculated and the Dunnett adjustment was chosen to correct for multiple comparisons as it compares each group to a control level (in this case 'baseline').

3.1.5.4 Analysis of subjective ratings of fatigue and sleepiness

The subjective ratings of fatigue and sleepiness were cleaned in SAS and a database with the variables for analysis created and then merged with information about in-flight break patterns.

Basic descriptive statistics were calculated in SAS and the evolution of the subjective ratings of fatigue and sleepiness across flight segments was plotted in R.

Multilevel mixed modelling:

Multilevel mixed models were fitted (using SAS) to investigate changes in pilot sleepiness and fatigue ratings across flights. These models included repeated measures therefore the CS, AR(1) and ANTE(1) covariance structures were considered with Bonferroni correction for multiple pairwise comparisons as there was no control level.

For the subjective ratings data, the AR(1) and ANTE(1) covariance structures were too complex and only the models that used the CS covariance structure converged. Although the models which used the CS covariance structure did converge, the assumptions of normality of residuals and constant variance between groups were initially violated in some of the models.

The model of sleepiness ratings and the model of fatigue ratings both yielded a significant p-value for the normality statistics. Transformations of the data were undertaken to attempt to correct this issue but were unsuccessful and in some cases resulted in a more heavily skewed distribution of residuals. Upon closer examination of the normality plots and taking into account the fact that multilevel mixed models are very robust to departures from normality, the untransformed fatigue data and the square root transformed sleepiness data (transformed for moderate positive skew, Tabachnick & Fidell, 2013) were deemed normal enough for the models to be valid. Where the data was transformed, this is noted in the results section. In the model for fatigue ratings, the assumption of homogeneity of variances was violated but this was corrected for by using a more stringent alpha level of 0.01 when interpreting the results of the affected models (Tabachnick & Fidell, 2013).

3.1.5.5 Analysis of psychomotor vigilance task performance

The psychomotor vigilance task data was imported into and analysed in SAS version 9.3. However, in order to conduct the analyses, the PVT data first needed to be checked against pre-established criteria (appendix 3G) to ensure that each test was completed at the correct time point. As part of this process, PVT tests at the end of in-flight break 4 (i.e., end of rest period 2 for participants taking the second and fourth in-flight breaks) were re-coded as 'TOD' tests because the fourth in-flight break usually ends just prior to TOD[18]. Tests were coded as 'TOD' tests instead of 'post rest period 2' tests as TOD is a more important time point from an operational standpoint for comparisons between groups.

The PVT data also needed to be merged with information about the flights themselves as some of the variables required for the analyses were not available in the original PVT data file. Basic descriptive statistics of the PVT data were generated and plots of PVT performance across flights were produced (using R version 3.1.0).

Multilevel mixed modelling:

Performance on the PVT (mean response speed, slowest 10% of responses, and fastest 10% of responses) was compared at pre-flight and top of descent using multilevel mixed modelling. Since only two time points were compared in these models, the CS covariance structure was the only one considered and no post-hoc tests were undertaken. These models were generated in the same way as the other multilevel models in this chapter:

- missing data was not removed, only invalid PVT tests were excluded (e.g., tests completed at the wrong time);
- a "*repeated*" statement was included;
- the Kenward-Roger correction was specified in the "*model*" statement*;*
- the model assumptions were checked using the Kolmogorov-Smirnov normality test and Levene's test; and

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[18] Participants on the second and fourth rest breaks took only 3 tests per flight while participants taking the first and third rest breaks completed four tests per flight.

- where outlying residuals were identified, these were removed prior to re-running the model, if their removal did not change the outcome of the results, the model reported includes these outliers.

A possible interaction of test time and in-flight break pattern was considered as at the time of the top of descent test, pilots on the first and third breaks would have been awake for longer than crew on the second and fourth breaks. Where the interaction was non-significant, it was removed and the models were re-run. A note of this is made for the corresponding models in the results section.

In the model for the slowest 10% of responses, the assumption of homogeneity of variances was violated; this was corrected for by using a more stringent alpha level of 0.01 when interpreting the results of the affected models (Tabachnick & Fidell, 2013). In the model for the fastest 10% of responses, the assumption of normality of residuals was initially violated. This was corrected for by reflecting and logarithmically transforming the data (residuals were substantially negatively skewed) prior to re-running the model (Tabachnick & Fidell, 2013).

3.1.5.6 Analysis of sleep and wakefulness prior to critical phases of flight

In preparation for analysis, the data relating to the duration of wakefulness and amount of sleep obtained in the 24 hours prior to duty start and to TOD were imported into SAS, checked and then combined with other variables required for the analyses (total in flight sleep duration, subjective ratings of sleepiness and fatigue, and PVT performance).

Basic descriptive statistics for total sleep duration and duration of wakefulness prior to duty start and TOD were generated in SAS and plots were produced using R (version 3.1.0).

Un-paired t-tests (for parametric data) and the Wilcoxon-Mann-Whitney test (for non-parametric data) were conducted in SAS to compare sleep and wake durations prior to duty start and TOD between the two primary patterns of in-flight rest. These sleep and wake durations were also compared between flight segments using paired t-tests (parametric data) and the Wilcoxon signed rank test (non-parametric data).

Multilevel mixed modelling:

Multilevel mixed modelling was used to investigate whether at duty start and TOD, PVT performance and subjective ratings of sleepiness and fatigue were related to prior sleep and prior wake. Models for duty start and for TOD were run separately but each compared the outbound flight segment to the inbound flight segment. Since only two time points were compared in these models (outbound duty start/TOD vs. inbound duty start/TOD), the CS covariance structure was the only one considered and no post-hoc tests were undertaken.

These models were generated in SAS in the same way as the other multilevel models in this chapter:

- missing data was not removed;
- a "*repeated*" statement was included;
- the Kenward-Roger correction was specified in the "*model*" statement*;*
- the model assumptions were checked using the Kolmogorov-Smirnov normality test and Levene's test; and
- where outlying residuals were identified, these were removed prior to re-running the model, if their removal did not change the outcome of the results, the model reported includes these outliers.

Models were conducted to investigate the effects of different predictors on three separate indicators of pilot fatigue status: PVT performance (assessed using mean response speed, slowest 10% of responses and fastest 10% of responses), subjective sleepiness (Karolinska Sleepiness Scale), and subjective fatigue (Samn-Perelli crew status check). Model structures are described in the respective sections of the results.

The models for fastest 10% of PVT responses all initially violated the assumption of normality of residuals. The data were therefore transformed to correct for the moderate to severe negative skew using a reflect and square root transformation or a reflect and log10 transformation depending on the skew of the data (Tabachnick & Fidell, 2013). This is noted in the results section.

The models of sleepiness ratings at TOD also violated the normality of residuals assumption. Data transformations to correct for moderate to severe positive skew were undertaken but were ultimately unsuccessful. Residuals remained non-parametric and appeared to 'band', an observation that was not surprising given that the outcome measure (KSS ratings) included only whole numbers. Visual checks of the scatter plots of the residuals and continuous predictors showed that these were not highly correlated amongst themselves. Taking into account the fact that multilevel mixed models are very robust to departures from normality and the distribution of the residuals, the models using untransformed data were considered to be valid. These are the models that are reported on in the corresponding results section, with a note of any data transformations and violations of model assumptions.

3.2 Results

3.2.1 Pilot demographics

Fifty-four pilots (52 males, 2 females) completed data collection for this study[19], and 35 data sets were of sufficient quality to be included in the final analyses. [20] Table 3.1 provides a summary of these 35 participants' home time zones and their demographic information is summarized in Table 3.2.

Table 3.1 Frequencies of different home time zones by crew position

	Captains [1]	First Officers [1]	All crew [2]
Eastern Daylight Time (UTC -4 / Atlanta)	14 (78%)	9 (60%)	23 (70%)
Central Daylight Time (UTC -5 / Atlanta -1)	4 (22%)	4 (27%)	8 (24%)
Mountain Daylight Time (UTC -6 / Atlanta -2)	0	1 (7%)	1 (3%)
Pacific Daylight Time (UTC -7 / Atlanta -3)	0	1 (7%)	1 (3%)

[1] 1 missing value; [2] 2 missing values;

The remainder of the information provided by pilots in the pre-study questionnaire was analysed as part of the combined analyses of retrospective questionnaire data detailed in chapter 2.

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[19] Data collection for the study was completed between June and October 2013.

[20] Of the 19 excluded data sets: 12 were excluded due to issues with actigraphy, 6 due to un-planned changes to the trip schedules (including one data set where there was also an issue with actigraphy), one was excluded due a health issue, and one was excluded as the participant had not attempted sleep on the inbound flight.

Table 3.2 Pilot demographics by crew position

	Captains Median (range)	First Officers Median (range)	All crew Median (range)	p-value (Captains vs. First officers)
Age (yrs)	56 (51-62)	49.5 (40-58)[1]	54 (40-62)	<0.0001[a]
Total flight hours	18000 (10000-24000)[2, 3]	12200 (6800-17000)[4]	14951 (6800-24000)[5]	<0.0001[b]
Long range experience (yrs)	7.8 (0.3-19.0)[4]	7.2 (0.6-12.3)[4]	7.6 (0.3-19.0)[2]	0.2262[a]
B767-300 experience (yrs) [21]	7.9 (3.0-14.0)[5]	8.2 (3.0-15.1)	8.0 (3.0-15.1)[5]	0.6353[b]
Commute time (hrs)	1.5 (0.6-4.0)[c, 6]	1.0 (0.5-6.0)[c, 4, 6]	1.5 (0.5-6.0)[c, 4, 7]	0.6524[d]
Total number of crew (%)	19 (54%)	16 (46%)	35	NA

[a] Independent t-test used, Satterthwaite p-value reported;
[b] Independent t-test used, Pooled p-value reported;
[c] Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05);
[d] Wilcoxon-Mann-Whitney test used;
[1] Includes 1 outlier; [2] 2 missing values; [3] Includes 4 outliers; [4] 1 missing value; [5] 3 missing values; [6] Includes 2 outliers; [7] Includes 5 outliers;

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[21] The B757 and B767 aircraft share the same type rating and both types fly domestic and international trips. Some pilots have been flying this aircraft type for a very long time, starting with domestic trips and as they gain seniority in the fleet they are able to fly the long-haul international trips.

3.2.2 Trip information

The trips studied are summarized in Table 3.3. Although the departure and arrival times for the outbound and inbound flights were quite different in domicile time or local time, both flight segments were similar in duration, allowing for rest opportunities of similar length on both flights.

Table 3.3 Flight details

Flight segment	Mean	Median	Range	N
Outbound (ATL-LOS)[a]				
Departure time (blocks off, UTC)	03:31	03:30	02:25 – 04:48	34
Departure time (blocks off, EDT/domicile time)	23:31	23:30	22:25 – 00:48	
Estimated time at top of descent (UTC) [b, c]	14:39	14:44	13:43 – 16:00	32
Estimated TOD (EDT/domicile time)	10:39	10:44	09:43 – 12:00	
Arrival time (blocks on, UTC) [1, d]	15:14	15:19	14:18 – 16:28	34
Arrival time (blocks on, EDT/domicile time)	11:14	11:19	10:18 – 12:28	
Flight duration (hours ± SD) [e, f]	11.7 ± 0.3	11.7	11.2 – 12.3	34
Layover				
Duration (arrival to departure, hrs ± SD) [c]	30.0 ± 0.5	30.0	28.8 – 31.5	35
Duration (duty end to duty start, hrs ± SD) [1, f, g]	26.2 ± 3.4	26.5	9.0[h] – 28.7	31
Inbound (LOS-ATL)				
Departure time (blocks off, UTC) [1]	21:12	21:19	20:40 – 22:12	35
Departure time (blocks off, EDT/domicile time)	17:12	17:19	16:40 – 18:12	
Estimated time at top of descent (UTC) [1, d]	08:37	08:35	08:15 – 09:15	35
Estimated TOD (EDT/domicile time)	04:37	04:35	04:15 – 05:15	
Arrival time (blocks on, UTC) [1, c]	09:10	09:09	08:51 – 09:44	35
Arrival time (blocks on, EDT/domicile time)	05:10	05:09	04:51 – 05:44	
Flight duration (hours ± SD) [1, e]	12.0 ± 0.3	11.9	11.5 – 12.5	35

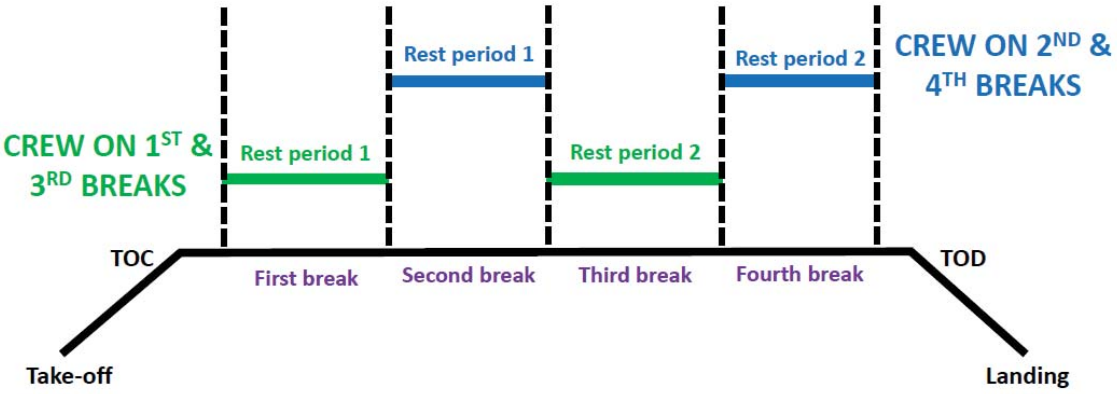
[1] Data not normally distributed;

[a] Excluding one pilot's flight where a different rest break pattern was used; [b] 2 missing values; [c] Includes 2 outliers; [d] Includes 3 outliers; [e] Calculated from blocks on to blocks off; [f] Includes 1 outlier; [g] 4 missing values; [h] Scheduled and actual report times recorded by this participant in the diary seem off.

3.2.3 In-flight break patterns and rest opportunities

All participants had two rest periods on both the outbound segment and the inbound segment Pilots split the time at cruise into four rest periods, that were not all of equal length, but each pilot was allocated the same total amount of rest time. The in-flight break pattern and break allocations were generally decided on the day of the flight, with the senior Captain having final say. The predominant break pattern was that two pilots took the first and third in-flight breaks while the other two took the second and fourth breaks. This is illustrated in Figure 3.2.

Figure 3.2 **Schematic of predominant in-flight break pattern in this study**



The majority of pilots used the 'first and third' / 'second and fourth' break pattern but one pilot used the 1st and 4th breaks on their outbound flight segment. Break patterns are summarized in Table 3.4.

Table 3.4 **Outbound flight segment break patterns by bunk type**

	First & Third breaks	Second & Fourth breaks	Other break pattern	Total
Flying crew (at landing)	5	9[a]	0	14
Relief crew (at landing)	9[b]	11	1[d]	21
Total	14	20	1	35

[a] Includes D414(did not use rest period 1); [b] Includes D415 (did not use rest period 1); [c] Includes D448 (used seat for rest during rest period 1); [d] Crewmember (D425) took first and fourth break.

Rest breaks occurred at different clock times depending on the flight segment. An estimate of the break start and end times in domicile time (EDT) is provided below (Table 3.5).

Table 3.5 Estimated break start and end times in domicile time (EDT)

Flight segment	Estimated start time (EDT)	Estimated end time (EDT)
Outbound (ATL-LOS)[a]		
First break	00:31	03:03
Second break	03:03	05:35
Third break	05:35	08:07
Fourth break	08:07	10:39
Inbound (LOS-ATL)		
First break	18:12	20:48
Second break	20:48	23:25
Third break	23:25	02:01
Fourth break	02:01	04:37

Two pilots only utilized one of their two available rest periods for sleep on each of their flights. For both the outbound and inbound flights the first pilot did not sleep during their first rest period explaining that the breaks are usually set up as two short breaks followed by two long breaks and that they are usually awake during their short break[22]. Similarly, the second pilot did not utilize their first rest period on either of their flights, using it to eat instead[23]. Another pilot used only one of their two available rest periods on the outbound

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[22] Participant had 2nd and 4th break on both.

[23] Participant had 1st and 3rd break on both flights.

flight[24], choosing to use their first rest period to rest in the seat and watch a movie. However, this pilot used both of their rest periods to sleep on the inbound flight.

Fifteen pilots kept the same break pattern for both their outbound and inbound flights (with seven taking first and third breaks on both segments and eight taking the second and fourth breaks on both segments)[25].

The chosen break patterns in this study were not necessarily tied to the allocated flight duties at landing, with some landing pilots taking the 1st and 3rd breaks while others took the 2nd and 4th breaks (see Table 3.4).

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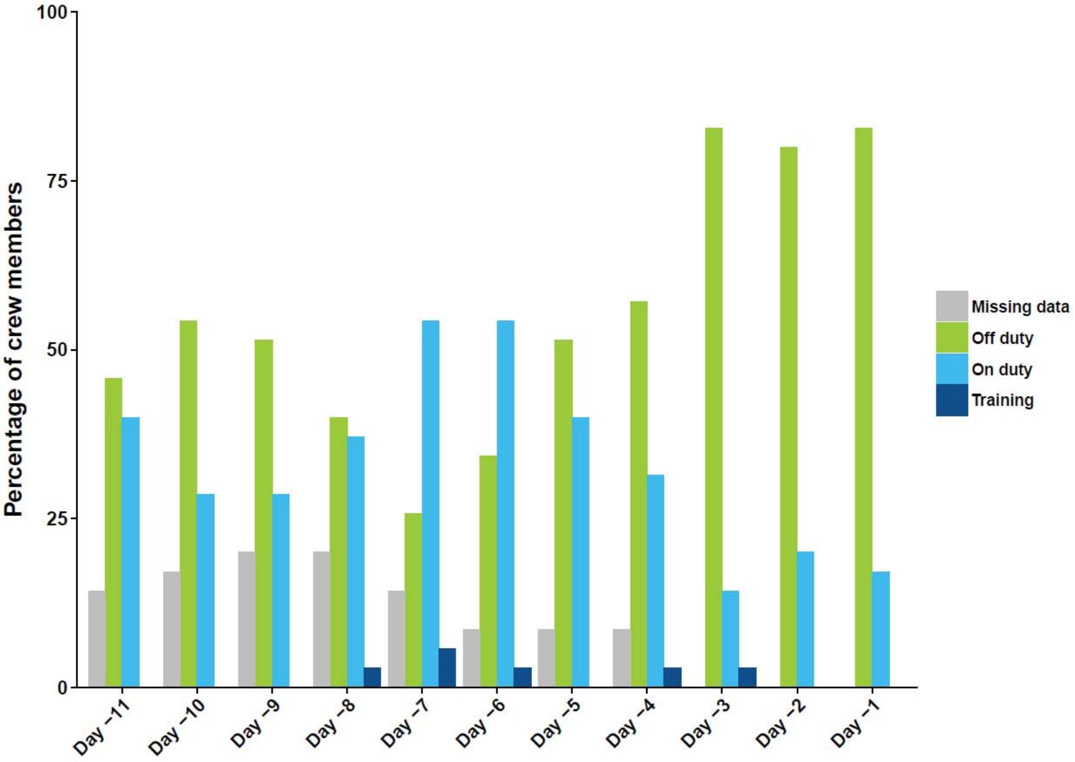
[24] Participant had 1st & 3rd breaks on their outbound and 2nd & 4th breaks on their inbound flight.

[25] Of the remaining pilots: seven took the first and third breaks on their outbound flight and the second and fourth breaks on their inbound flight; twelve took the second and fourth breaks on their outbound flight and the first and third breaks on their inbound flight; and one pilot took the first and fourth break on their outbound flight and second and fourth break on their inbound flight.

3.2.4 Duty periods prior to the study trip

In the duty/sleep diary look back report, pilots were asked to record their duty periods in the eleven days leading up to their studied trip. Days recorded by pilots as “Simulator Training” or as “Recurrent Training” were grouped as “Training”. Days recorded as “On-duty” or as “Layover” were classed as “On Duty”, while days recorded as “Off-duty” or as “Home” were classed as “Off duty”. For the three days prior to the studied trip (days -3 to -1), there was no space provided in the look back report for pilots to record whether they were on or off duty as this was already filled in as “Home”. In the absence of any comment, it was therefore assumed that the pilot was at “Home” (off duty) on those three days. An overview of the information from the look back report is provided in Figure 3.3 .

Figure 3.3 Reported duty periods in the days prior to the studied trip (all crew)



3.2.5 Sleep across the study period

3.2.5.1 Pilot preparation for the study flights

In general, pilots obtained significantly more sleep in the 24 hours prior to their outbound flight than they did on baseline days (difference 35.4 minutes) but their sleep efficiency was not significantly different. Similarly, in the last 24 hours of layover (the 24 hours prior to their inbound flight) they also obtained significantly more sleep than on baseline days. (difference 211.9 minutes, 3.5 hours) but again sleep efficiency was not significantly different. Details of these analyses and a summary of pilots' sleep patterns across the study period is provided in appendix 3H.

Pre-trip naps were identified as sleep periods occurring after the main sleep period of the last 24 hours pre-flight (i.e., on pre-trip day 3 or during the last 24 hours of layover) but before reporting for duty. Fifteen pilots (45.5%) napped prior to their outbound flight and eight pilots (23.5%) napped prior to their inbound flight.

The frequency of pre-trip naps was not related to break pattern (Table 3.6) or to the frequency of napping at home on days off (Table 3.7).

Table 3.6 Frequency of pre-trip naps by break pattern

	Crew with 1st & 3rd breaks		**Crew with 2nd & 4th breaks**		**Chi-square p-value**	**Total**
	Pre-trip nap	***No nap***	***Pre-trip nap***	***No nap***		
Outbound flight	6 (18.2%)	7 (21.2%)	9 (27.3%)	11 (33.3%)	0.9481	33
Inbound flight	4 (11.8%)	14 (41.2%)	4 (11.8%)	12 (35.3%)	0.8488	34

Table 3.7 **Frequency of pre-trip naps by frequency of napping at home**

	Habitually naps at home		Rarely naps at home		Chi-square p-value	Total[a]
	Pre-trip nap	*No nap*	*Pre-trip nap*	*No nap*		
Outbound flight	9	11	5	7	0.5296	32
Inbound flight	6	15	1	11	0.0786	33

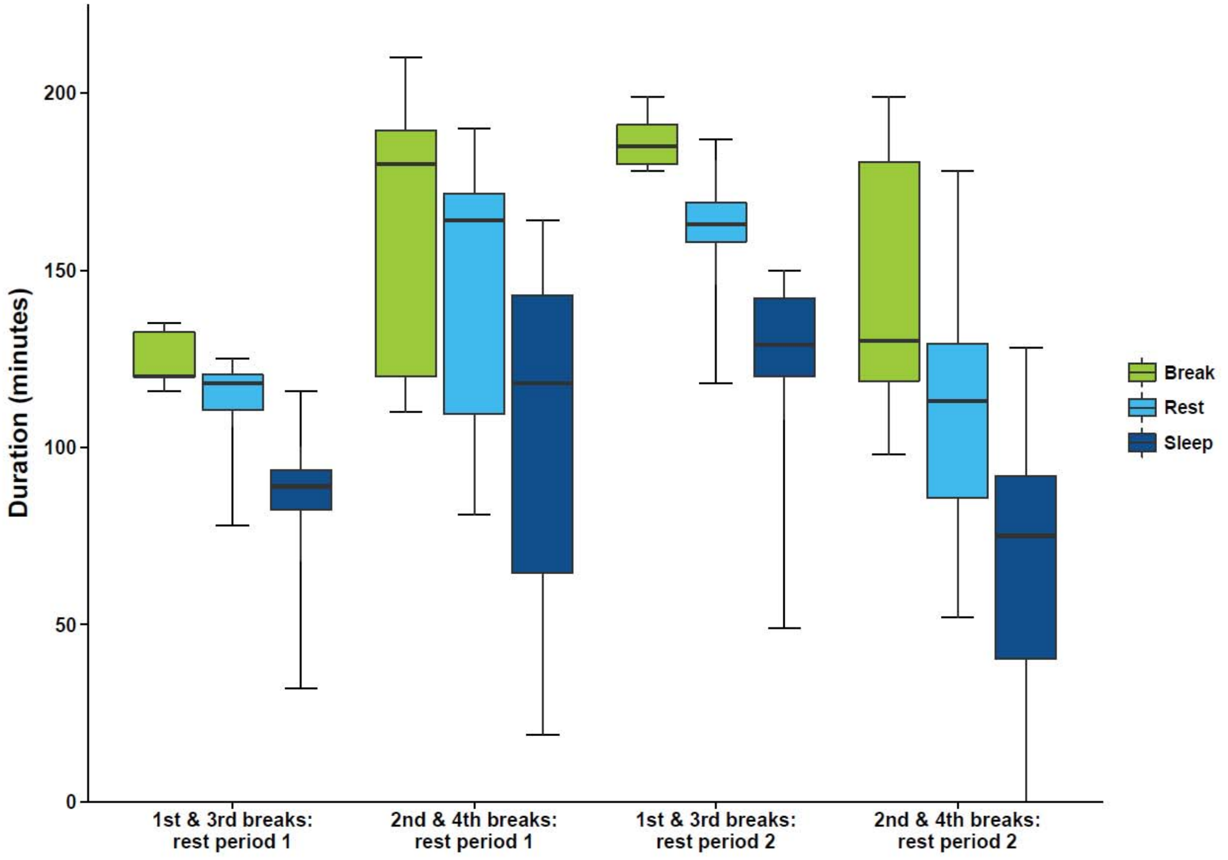
[a] Includes one missing value for the frequency of napping at home.

3.2.5.2 In-flight sleep

Thirty-three pilots were included in the analyses of in-flight sleep for the outbound flight (excluding the pilot who used the 1st and 4th breaks on the outbound flight) and 34 pilots were included in the analyses relating to the inbound flight. Information about the duration of in-flight breaks, as well as the actual rest and sleep durations per break is summarized for each flight segment by break and break pattern in appendix 3H and is illustrated in Figure 3.4 (outbound flight) and Figure 3.5 (inbound flight). In the figures, the information about break length was determined by participants' reports in the diary, whereas information about sleep and rest were determined by actigraphy. As a result there were some minor discrepancies between the rest period durations reported by pilots and the sleep and rest times from actigraphy (largest discrepancy 11 minutes).

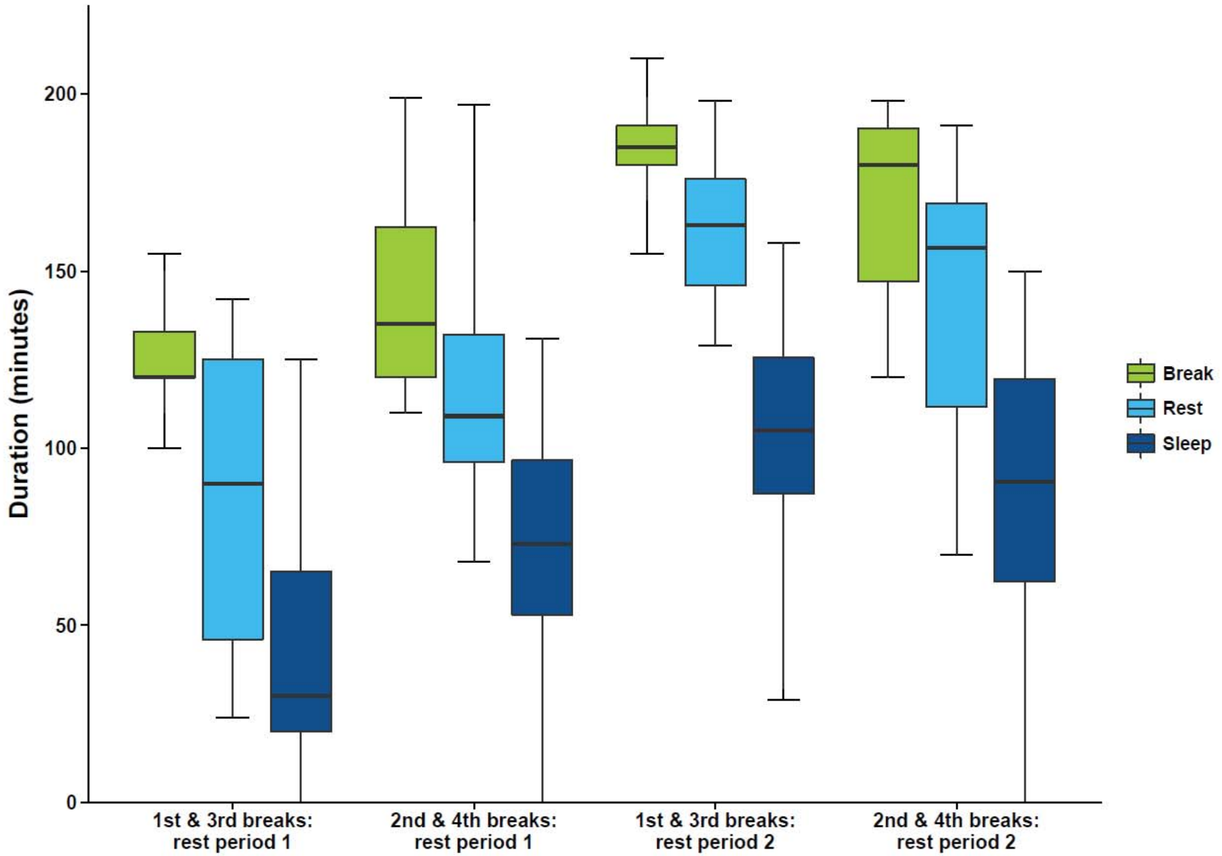
Information about total in-flight sleep, overall rest and overall break durations is also summarized in appendix 3H by flight segment and break pattern. Figure 3.6 provides an overview of this information. Although pilots obtained significantly more sleep on the outbound flight than on the inbound flight (paired t-test p-value=0.0057, mean total in-flight sleep time 179min and 151min respectively), total in-flight sleep was not affected by break pattern (Wilcoxon-Mann-Whitney p-value=0.7877).

Figure 3.4 Outbound break, rest and sleep durations by break pattern



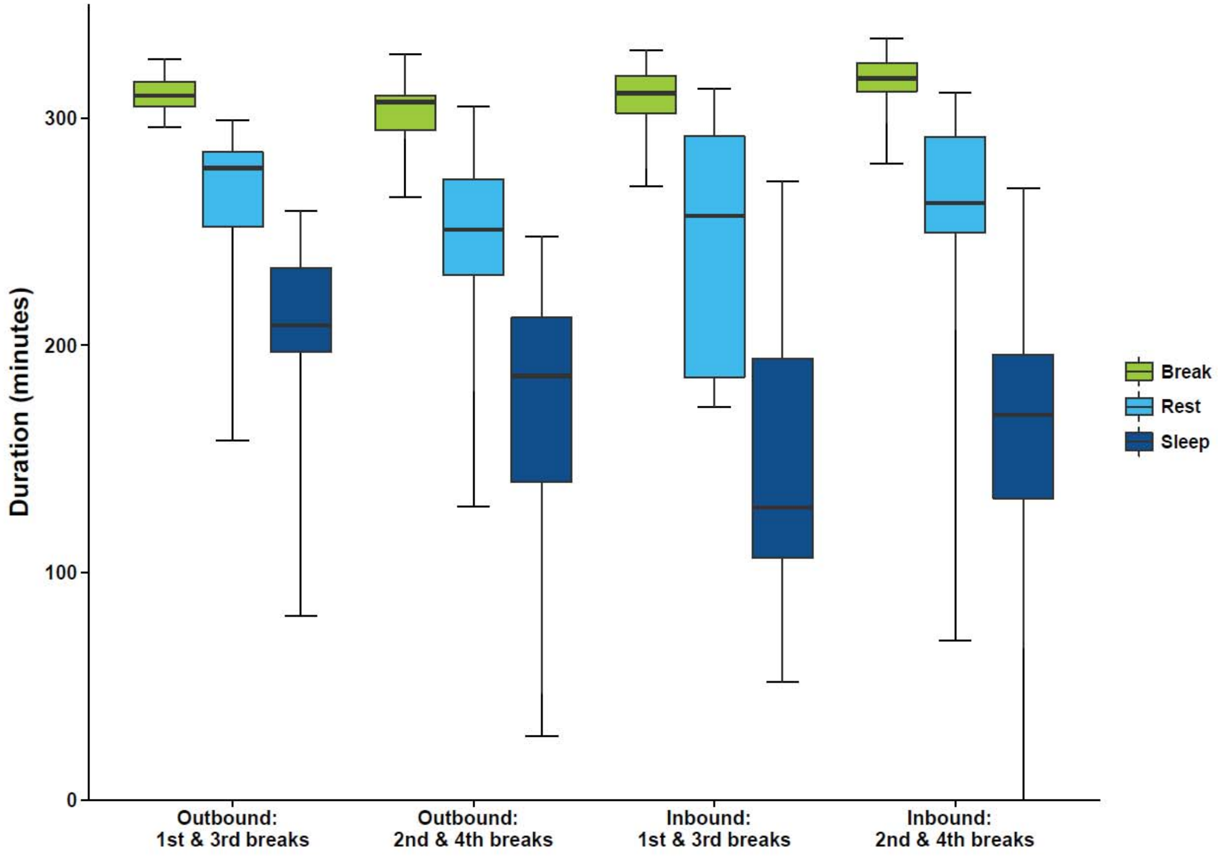
In this plot the light green boxes represent the duration of the rest break (from diary data), the light blue boxes represent the amount of time pilots spent attempting sleep (by actigraphy) and the dark blue boxes represent the amount of time pilots were actually asleep (by actigraphy). The dark line in the boxes represents the median value while the boxes themselves extend from the 25th percentile to the 75th percentile values. The whiskers represent the minimum and maximum values for each variable.

Figure 3.5 Inbound break, rest and sleep durations by break pattern



In this plot the light green boxes represent the duration of the rest break (from diary data), the light blue boxes represent the amount of time pilots spent attempting sleep (by actigraphy) and the dark blue boxes represent the amount of time pilots were actually asleep (by actigraphy). The dark line in the boxes represents the median value while the boxes themselves extend from the 25th percentile to the 75th percentile values. The whiskers represent the minimum and maximum values for each variable.

Figure 3.6 Total in-flight break, rest and sleep durations by break pattern and flight segment



In this plot the light green boxes represent the duration of the rest break (from diary data), the light blue boxes represent the amount of time pilots spent attempting sleep (by actigraphy) and the dark blue boxes represent the amount of time pilots were actually asleep (by actigraphy). The dark line in the boxes represents the median value while the boxes themselves extend from the 25th percentile to the 75th percentile values. The whiskers represent the minimum and maximum values for each variable.

3.2.6 Subjective ratings of fatigue and sleepiness

Average fatigue and sleepiness ratings across the outbound and inbound flight segments are presented in appendix 3I. Fatigue ratings at individual time points did not significantly differ between the 1st and 3rd breaks and the 2nd and 4th breaks for any time point on either the outbound or the inbound flights (2-sample t-tests). Similarly, sleepiness ratings at individual time points did not significantly differ by break pattern, with the exception of the rating at TOC on the outbound flight, for which crew on 1st and 3rd breaks reported being significantly more sleepy than crew on the 2nd and 4th breaks (appendix 3I).

When controlling for individual differences in the multilevel models, pilots' sleepiness ratings were affected by both the time at which the ratings were completed (sleepiness increased across the flight) and break pattern (sleepiness ratings were higher in crew taking the 1st & 3rd rest breaks) but did not differ by flight segment (Table 3.8 and Table 3.9).

Table 3.8 Crew sleepiness ratings: effect of flight segment, time of rating and break pattern

Fixed effect	DF	F-value	P(F)
Flight segment	1, 241	0.27	0.6052
Outbound flight			
Inbound flight			
Time of rating	3, 235	20.96	**<0.0001**
Pre-flight			
TOC			
TOD			
Post-flight			
Break pattern	1, 257	4.06	**0.0450**
1st & 3rd breaks			
2nd & 4th breaks			

Note: Model reported used the Compound Symmetry covariance structure. Residuals were non-parametric (moderately positively skewed), therefore the data were transformed using a square root transformation. Since the data were transformed, the estimated means are not reported. There were no outlying residuals for this model.

Table 3.9 Post-hoc comparisons of Karolinska Sleepiness Scale ratings at key times during the flights

Time			Difference	p-value	Adjusted p-value [a]
Pre-flight	vs.	TOC	-	0.0001	**0.0008**
Pre-flight	vs.	TOD	-	<0.0001	**<0.0001**
Pre-flight	vs.	Post-flight	-	<0.0001	**<0.0001**
TOC	vs.	TOD	-	0.0084	0.0502
TOC	vs.	Post-flight	-	0.0014	**0.0087**
TOD	vs.	Post-flight	-	0.5738	1.000

[a] Bonferroni correction used to adjust for multiple pairwise comparisons.

Pilot fatigue increased across the flights but did not differ by either flight segment or break pattern (Table 3.10 and Table 3.11).

Table 3.10 Crew fatigue ratings: effect of flight segment, time of rating and break pattern

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1, 241	0.18	0.6751
Outbound flight	3.0			
Inbound flight	2.9			
Time of rating		3, 235	35.29	**<0.0001**
Pre-flight	2.1			
TOC	2.7			
TOD	3.4			
Post-flight	3.7			
Break pattern		1, 246	6.41	0.0120
1st & 3rd breaks	3.1			
2nd & 4th breaks	2.8			

Note: Model reported used the Compound Symmetry covariance structure and untransformed data. The variance differed between groups, therefore a more stringent p-value of 0.01 used. There were no outlying residuals.

Table 3.11 Post-hoc comparisons of Samn-Perelli fatigue ratings at key times during the flights

Time			Difference	p-value	Adjusted p-value [a]
Pre-flight	vs.	TOC	-0.6512	0.0002	**0.0010**
Pre-flight	vs.	TOD	-1.3251	<0.0001	**<0.0001**
Pre-flight	vs.	Post-flight	-1.6005	<0.0001	**<0.0001**
TOC	vs.	TOD	-0.6739	<0.0001	**0.0006**
TOC	vs.	Post-flight	-0.9493	<0.0001	**<0.0001**
TOD	vs.	Post-flight	-0.2754	0.1067	0.6401

[a] Bonferroni correction used to adjust for multiple pairwise comparisons.

3.2.7 Evolution of psychomotor vigilance task performance

Pilot performance on the PVT was analysed using multilevel mixed modelling. The timing of the PVT test had a significant effect on both mean response speed and the fastest 10% of responses, while the flight segment had a significant effect on the slowest 10% of responses. Mean PVT response speed was better (faster) on the pre-flight test than on the TOD test (Table 3.12). Similarly, the fastest 10% of PVT responses were faster on the pre-flight test than on the TOD test (Table 3.14). The slowest 10% of PVT responses were not affected by the time of the PVT test but were faster on the inbound flight segment than on the outbound (Table 3.13).

The interaction of break pattern and time of test was also tested in these models but as it was non-significant it was removed from the final models. Pilot performance on the PVT tests taken across the outbound and inbound flight segments is also summarized by break pattern (1st and 3rd breaks or 2nd and 4th breaks) in appendix 3G.

Table 3.12 Mean PVT response speed: effect of flight segment, test time and break pattern

Fixed effect	**Estimated means**	**DF**	**F-value**	**P(F)**
Flight segment		1, 91.1	1.39	0.2408
Outbound flight	4.092			
Inbound flight	4.163			
Time of test		1, 88.7	16.13	**0.0001**
Pre-flight	4.244			
TOD	4.011			
Break pattern		1, 105	3.16	0.0785
1st & 3rd breaks	4.059			
2nd & 4th breaks	4.196			

Note: Model reported used the Compound Symmetry (CS) covariance structure and includes outliers.

Table 3.13 Slowest 10% of PVT responses: effect of flight segment, test time and break pattern

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1, 94.5	10.70	**0.0015**
Outbound flight	2.281			
Inbound flight	2.627			
Time of test		1, 90.5	1.70	0.1961
Pre-flight	2.521			
TOD	2.387			
Break pattern		1, 119	0.61	0.4372
1st & 3rd breaks	2.505			
2nd & 4th breaks	2.404			

Note: Model reported used the Compound Symmetry (CS) covariance structure and includes outliers.

Table 3.14 Fastest 10% of PVT responses: effect of flight segment, test time and break pattern

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1, 91	0.02	0.9003
Outbound flight	0.283			
Inbound flight	0.284			
Time of test		1, 88.7	44.31	**<0.0001**
Pre-flight	0.245			
TOD	0.322			
Break pattern		1, 105	1.13	0.2898
1st & 3rd breaks	0.276			
2nd & 4th breaks	0.292			

Note: Residuals were not normally distributed, therefore the data was transformed using a 'reflect and log10' transformation. The model reported used the transformed data and the Compound Symmetry (CS) covariance structure. There were no outliers in this model. Since the data were transformed estimated means are not reported.

3.2.8 Effects of prior sleep and wakefulness on pilot fatigue measures pre-flight and at top of descent

Sleepiness and fatigue ratings and PVT performance provide an indication of pilot fatigue status at duty start and at TOD, immediately before the high workload and safety risk associated with the approach and landing phase of the flight. Based on laboratory study findings, all three measures are expected to be influenced by prior sleep/wake history (Gander, Mulrine, et al., 2015). This information is summarized for all pilots in appendix 3H.

The duration of wakefulness and amount of sleep obtained in the 24 hours prior to duty start are illustrated in Figure 3.7 and Figure 3.8 respectively. In these figures, the data were split by flight segment and by break pattern. For these analyses, the outbound flight segment for one pilot was excluded as they had an atypical break pattern on that flight, resulting in an N of 33 for the outbound flight and 34 for the inbound flight.

Figure 3.7 Duration of prior wakefulness at duty start

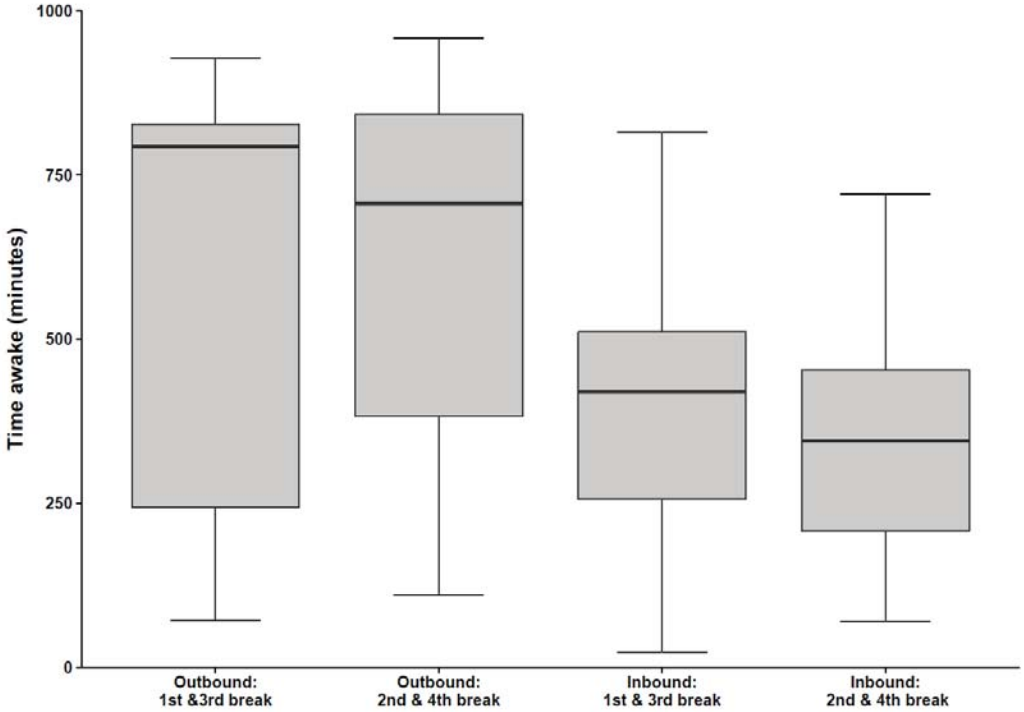
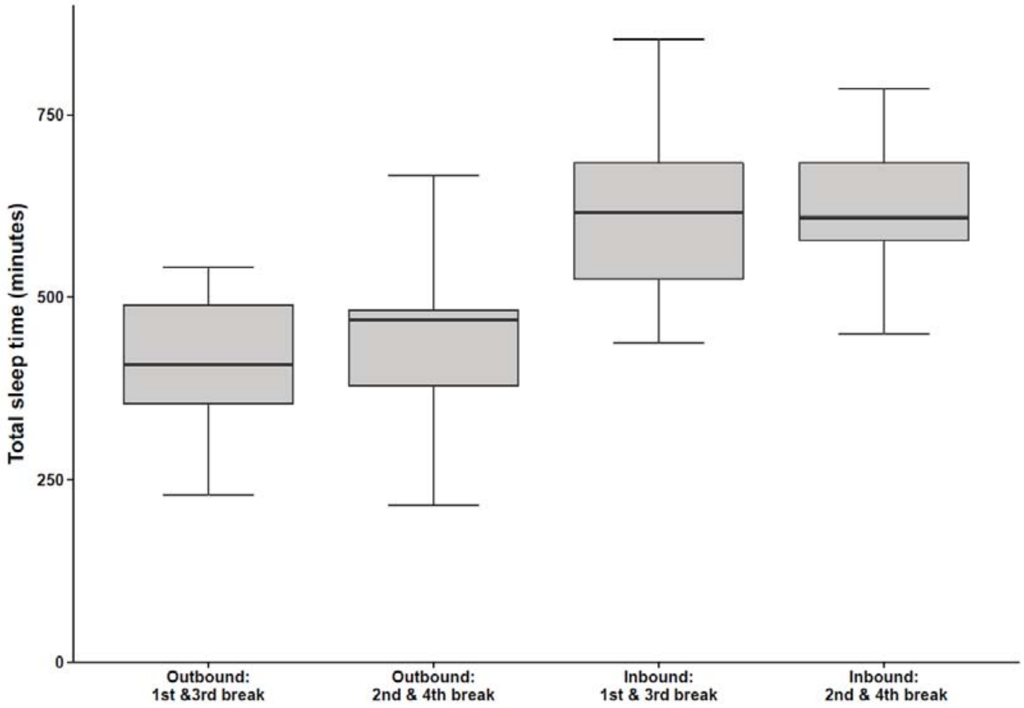


Figure 3.8 Total sleep time in the 24 hours prior to duty start



The duration of wakefulness prior to duty start did not differ by break pattern (Wilcoxon-Mann-Whitney p-value=0.9003) but was significantly different between the outbound and inbound flights (paired t-test p-value=0.0026), with a longer period of wake prior to the outbound flight (median 12.0hrs vs. 6.3hrs).

Similarly, the amount of sleep obtained in the 24 hours leading up to duty start did not differ by break pattern (independent t-test pooled p-value=0.9479) but was greater prior to the inbound flight than the outbound flight (paired t-test p-value<0.0001, mean TST 10.2hrs and 7.1hrs respectively).

The duration of wakefulness and amount of sleep obtained in the 24 hours prior to TOD are illustrated in Figure 3.9 and Figure 3.10 with the same pilots included in these analyses as in the previous figures.

Figure 3.9 Duration of prior wakefulness at TOD

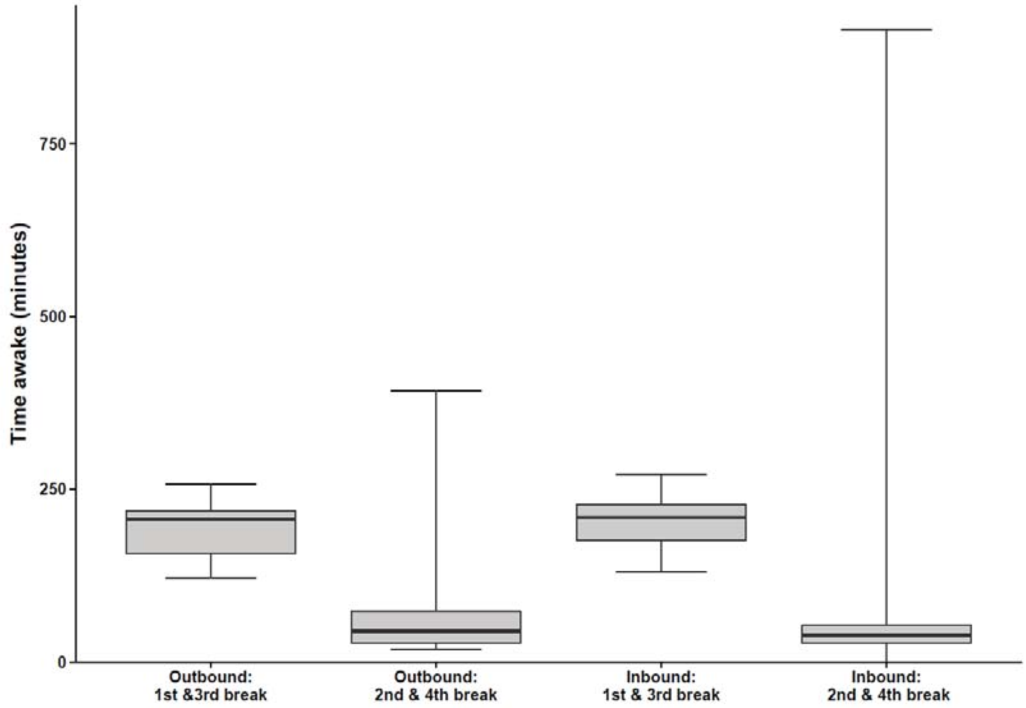
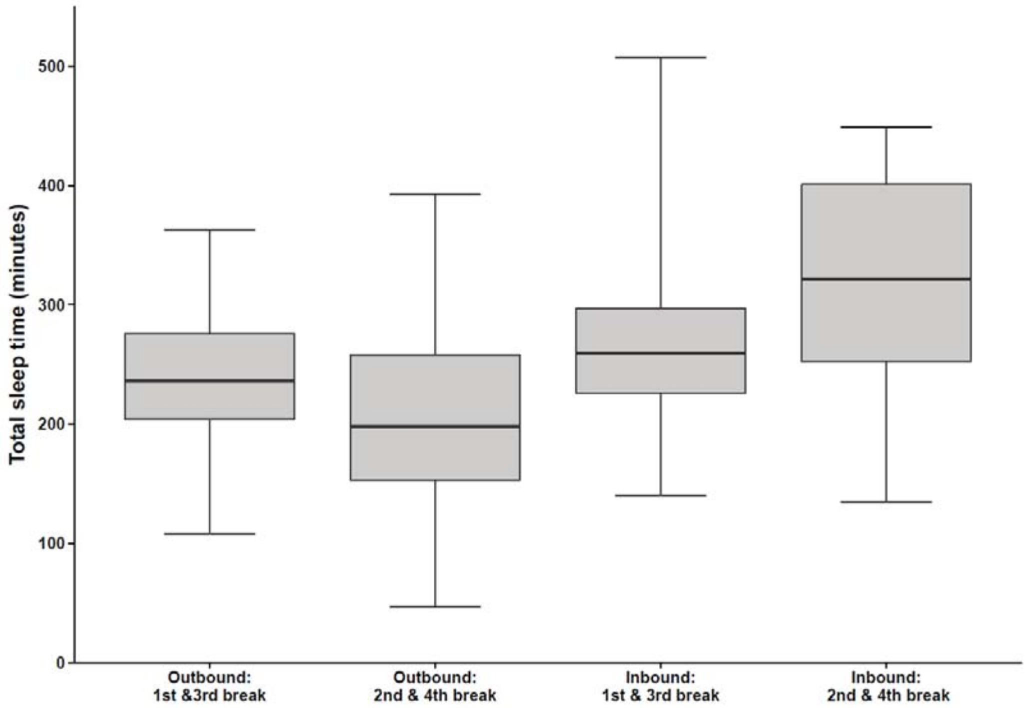


Figure 3.10 Total sleep time in the 24 hours prior to TOD



As expected, the duration of prior wakefulness at TOD was significantly affected by break pattern (Wilcoxon-Mann-Whitney p-value<0.0001), with crews who took the 2nd and 4th in-flight breaks having a much shorter period of wakefulness prior to TOD than crews who took the 1st and 3rd in-flight breaks (medians 44min and 3.5hrs respectively). The duration of wakefulness prior to TOD was not significantly different between the outbound and inbound flights (Wilcoxon-Signed-Rank p-value=0.2947).

The amount of sleep obtained in the 24 hours prior to TOD was not different between break patterns (independent t-test pooled p-value=0.7794). However, crews obtained more sleep in the 24 hours prior to TOD of the inbound flight than the outbound flight (paired t-test p-value=0.0003, mean TST 5.0hrs and 3.7hrs respectively).

3.2.8.1 Effect of prior sleep and wakefulness on pilot psychomotor vigilance task performance at duty start and top of descent

Multilevel mixed modelling was used to investigate the effects prior wakefulness, sleep duration and flight segment had on pilot PVT performance at duty start and TOD.

Models indicated that pilot performance on the PVT at duty start was not related to the duration of wakefulness, the total amount of sleep obtained in the 24 hours prior to duty start, or by break pattern on the subsequent flight (tables Table 3.15, Table 3.16 and Table 3.17). However, mean PVT response speed and the 10% slowest responses were better (faster) prior to the inbound flight than prior to the outbound flight (Table 3.15 and Table 3.16).

Table 3.15 **Pre-flight mean PVT response speed: effect of flight segment, break pattern, time awake and total sleep in the last 24 hours**

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,38.1	5.45	**0.0250**
Outbound flight	4.071			
Inbound flight	4.441			
Break pattern		1,34.2	0.65	0.4251
1st & 3rd breaks	4.304			
2nd & 4th breaks	4.208			
Time awake at DS		1,36.6	0.11	0.7441
TST in the 24hrs prior to DS		1,48.4	0.01	0.9368

Note: Model reported used the Compound Symmetry (CS) covariance structure. There were no outlying residuals.

Table 3.16 **Pre-flight slowest 10% of PVT responses: effect of flight segment, break pattern, time awake and total sleep in the last 24 hours**

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,44.1	5.67	**0.0216**
Outbound flight	2.209			
Inbound flight	2.851			
Break pattern		1,41.7	0.10	0.7594
1st & 3rd breaks	2.562			
2nd & 4th breaks	2.498			
Time awake at DS		1,46.8	0.26	0.6155
TST in the 24hrs prior to DS		1,54.5	0.27	0.6087

Note: Model reported used the Compound Symmetry (CS) covariance structure. There were no outlying residuals.

Table 3.17 Pre-flight fastest 10% of PVT responses: effect of flight segment, break pattern, time awake and total sleep in the last 24 hours

Fixed effect	DF	F-value	P(F)
Flight segment (outbound/inbound)	1,35.5	2.21	0.1460
Break pattern (1st&3rd breaks/2nd&4th breaks)	1,31.5	0.06	0.8027
Time awake at DS	1,33.5	0.01	0.9376
TST in the 24hrs prior to DS	1,45.8	0.03	0.8666

Note: Model reported used the Compound Symmetry (CS) covariance structure. Residuals were non-parametric (severely negatively skewed), therefore the data were transformed using a reflect and log10 transformation. There were no outlying residuals in the model with the transformed data. Estimated means are not reported as the data were transformed.

None of the PVT performance measures at TOD differed significantly by flight segment, duration of wakefulness or total sleep obtained in the 24 hours prior to TOD (tables Table 3.18, Table 3.19, and Table 3.20).

In similar models where total sleep duration in the 24 hours prior to TOD was replaced by total in-flight sleep duration, none of the PVT performance measures differed significantly by flight segment, duration of wakefulness, or total in-flight sleep (refer to Appendix 3J for tables).

Table 3.18 TOD mean PVT response speed: effect of flight segment, time awake and total sleep in the last 24 hours

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,32.4	1.41	0.2435
Outbound flight	4.075			
Inbound flight	3.952			
Time awake at TOD		1,53.4	0.69	0.4111
TST in the 24hrs prior to TOD		1,51	0.07	0.7959

Note: Model reported used the Compound Symmetry (CS) covariance structure and includes outliers.

Table 3.19 TOD slowest 10% of PVT responses: effect of flight segment, time awake and total sleep in the last 24 hours

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,35	0.30	0.5879
Outbound flight	2.343			
Inbound flight	2.430			
Time awake at TOD		1,57.5	1.33	0.2542
TST in the 24hrs prior to TOD		1,57.9	0.25	0.6210

Note: Model reported used the Compound Symmetry (CS) covariance structure and includes outliers.

Table 3.20 TOD fastest 10% of PVT responses: effect of flight segment, time awake and total sleep in the last 24 hours

Fixed effect	DF	F-value	P(F)
Flight segment (outbound/inbound)	1,32.6	3.31	0.0780
Time awake at TOD	1,51.5	0.00	0.9495
TST in the 24hrs prior to TOD	1,49.3	0.00	0.9520

Note: Model reported used the Compound Symmetry (CS) covariance structure. Residuals were non-parametric (moderately negatively skewed), therefore the data were transformed using a reflect and square root transformation. There were no outlying residuals in the model with the transformed data. Estimated means are not reported as the data were transformed.

3.2.8.2 Effect of prior sleep and wakefulness on pilot ratings of fatigue and sleepiness at duty start and top of descent

Multilevel mixed models indicated that subjective ratings of sleepiness and fatigue at duty start did not differ significantly by flight segment, break pattern, duration of wakefulness prior to duty start or by total sleep duration in the 24 hours prior to duty start (refer to Appendix 3J for tables).

Table 3.21 **Pre-flight KSS ratings: effect of flight segment, time awake and total in-flight sleep time**

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,53.6	0.90	0.3479
Outbound flight	2.8			
Inbound flight	2.4			
Break pattern		1,56.7	0.27	0.6032
1st & 3rd breaks	2.7			
2nd & 4th breaks	2.5			
Time awake at DS		1,56.8	1.20	0.2770
TST in the 24hrs prior to DS		1,57.9	1.96	0.1670

Note: Model reported used the Compound Symmetry (CS) covariance structure and includes outliers.

Table 3.22 **Pre-flight Samn-Perelli ratings: effect of flight segment, time awake and total in-flight sleep time**

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,51.4	2.50	0.1199
Outbound flight	2.3			
Inbound flight	1.8			
Break pattern		1,49.6	0.71	0.4019
1st & 3rd breaks	2.2			
2nd & 4th breaks	2.0			
Time awake at DS		1,49.1	0.73	0.3961
TST in the 24hrs prior to DS		1,60.6	0.90	0.3478

Note: Model reported used the Compound Symmetry (CS) covariance structure. There were no outlying residuals.

Pilot subjective ratings of sleepiness and fatigue at TOD were better (lower) at TOD on the outbound flight compared to the inbound flight but ratings were not dependent on the duration of wakefulness or on the total amount of sleep obtained in the 24 hours prior to TOD (Table 3.23 and Table 3.24).

Table 3.23 TOD KSS ratings: effect of flight segment, time awake and total sleep in the last 24 hours

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,35.7	12.65	**0.0011**
Outbound flight	3.5			
Inbound flight	4.7			
Time awake at TOD		1,60.1	0.06	0.8095
TST in the 24hrs prior to TOD		1,57.8	2.35	0.1305

Note: Model reported used the Compound Symmetry (CS) covariance structure. Residuals were non-parametric and appeared to band as all of the individual ratings were whole numbers. Data transformations for moderate and severe positive skew were undertaken in an attempt to normalise the distribution of residuals but although an improvement on the raw data distribution, these data transformations did not yield a normal distribution of residuals. Results of the model were not affected by the data transformation therefore the model with the raw data is reported here. There were no outlying residuals in this model.

Table 3.24 TOD Samn-Perelli ratings: effect of flight segment, time awake and total sleep in the last 24 hours

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,38.5	8.14	**0.0069**
Outbound flight	3.0			
Inbound flight	3.7			
Time awake at TOD		1,62.9	3.17	0.0796
TST in the 24hrs prior to TOD		1,62.1	1.21	0.2766

Note: Model reported used the Compound Symmetry (CS) covariance structure and includes outliers.

Similar models indicated that although subjective sleepiness and fatigue ratings at TOD were not affected by the duration of wakefulness at TOD or by the total amount of sleep obtained in flight, pilots were less sleepy and less fatigued at TOD on the outbound flight compared to the inbound flight (tables Table 3.25 and Table 3.26).

Table 3.25 TOD KSS ratings: effect of flight segment, time awake and total in-flight sleep time

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,35.9	8.73	**0.0055**
Outbound flight	3.6			
Inbound flight	4.6			
Time awake at TOD		1,60.4	0.02	0.8880
In-flight TST		1,61.8	0.00	0.9834

Note: Model reported used the Compound Symmetry (CS) covariance structure. Residuals were non-parametric and appeared to band as all of the individual ratings were whole numbers. Data transformations for moderate and severe positive skew were undertaken in an attempt to normalise the distribution of residuals but although an improvement on the raw data distribution, these data transformations did not yield a normal distribution of residuals. Results of the model were not affected by the data transformation therefore the model with the raw data is reported here. There were no outlying residuals in this model.

Table 3.26 TOD Samn-Perelli ratings: effect of flight segment, time awake and total in-flight sleep time

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,35.9	6.47	**0.0155**
Outbound flight	3.1			
Inbound flight	3.7			
Time awake at TOD		1,62.7	3.23	0.0769
In-flight TST		1,59	0.00	0.9989

Note: Model reported used the Compound Symmetry (CS) covariance structure and includes outliers.

3.3 Summary of findings

The analyses detailed in this chapter indicated that for the studied ATL-LOS trip pattern, rest break pattern generally did not impact on flight preparation, in-flight sleep, or PVT performance, sleepiness, and fatigue at top of decent. Total in-flight sleep duration did not differ between the 1st and 3rd rest breaks versus the 2nd and 4th rest breaks, but crews obtained significantly more sleep on the outbound than the inbound flight. Although the flights were similar in duration, the timing of the outbound flight may have been more conducive to in-flight sleep as the flight did not overlap with the evening wake maintenance zone (Gander, Mulrine, et al., 2014; Pascoe, et al., 1995; R. M. Simons, Valk, et al., 1994). Pilots also obtained more sleep and were awake for less time in the 24 hours leading up to duty start of the inbound flight, than for the equivalent period leading up to the outbound flight. This would have resulted in a reduced homeostatic sleep drive on the inbound flight compared to the outbound flight. This difference was not surprising given that pilots were confined to a compound for security reasons during the Lagos layover, and is consistent with findings from a previous study of B-777 pilots flying the Atlanta-Lagos-Atlanta trip (Gander, Signal, et al., 2013).

As a result of the longer sleep duration in the last 24 hours of layover, pilots also obtained more sleep in the 24 hours prior to TOD for the inbound flight than the outbound flight, but the duration of wakefulness at TOD did not significantly differ between flight segments. Rest break pattern did not predict the duration of wakefulness at duty start or the amount of sleep obtained in the 24 hours prior to duty start or TOD. However, the duration of wakefulness at TOD did differ by rest break pattern, with crews taking the 1st and 3rd in-flight breaks having a longer duration of wakefulness as was expected. Rest break pattern also predicted subjective sleepiness (pilots on the 1st and 3rd rest breaks rated themselves as sleepier than their counterparts on the 2nd and 4th rest breaks) but did not impact on subjective fatigue ratings.

As in previous studies (Gander, Signal, et al., 2013; Roach, Petrilli, et al., 2012), one of the flight preparation techniques used by pilots was to obtain more sleep in the last 24 hours prior to a flight (both at home and on layover) than they did on baseline days. Additionally, some pilots prepared for their trips by taking a pre-trip nap but the frequency of pre-trip naps was not linked to break pattern or to habitual napping at home.

Univariate statistical tests indicated that pilot ratings of sleepiness and fatigue increased across flights but did not differ by flight segment. However, mixed modelling indicated that at TOD, pilots rated themselves as more fatigued and sleepy on the inbound flight than on the outbound flight. This may reflect cumulative fatigue across the trip pattern.

Similarly, univariate statistics indicated that mean PVT response speed and the fastest 10% of PVT responses slowed across flights but did not significantly differ between the outbound and inbound flights. The slowest 10% of PVT responses was not significantly different at the end of the flight compared to the start of the flight but was better (faster) on the inbound flight than on the outbound flight. This may have been linked to the late evening departure time of the outbound flight and the shorter sleep durations in the 24 hours prior to the outbound flight. The results of the mixed modelling analyses supported this interpretation, with the slowest 10% of PVT responses and the mean PVT response speed being faster prior to the inbound flight than the outbound flight.

Surprisingly, mixed modelling indicated that prior wakefulness, prior sleep duration and rest break pattern were not predictors of PVT performance or subjective ratings of fatigue and sleepiness at duty start or at TOD. In this case statistical significance may not have been reached as the study had a much smaller sample size than other studies where pilots' sleep/wake history has been shown to predict performance, subjective sleepiness and fatigue at critical phases of flight (Gander, Mulrine, et al., 2015; Vejvoda et al., 2014).

After their trip pattern, pilots recovered relatively quickly with total sleep time being increased compared to baseline only on the first night post-trip. Sleep duration on post trip days 2 and 3 and sleep efficiency on all post-trip days did not differ from baseline. This rapid recovery rate was previously observed in other studies of long-haul pilots (Gander, van den Berg, Mulrine, et al., 2013; Roach, Petrilli, et al., 2012; Signal, et al., 2014).

DRC 16

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STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Jennifer Louise Zaslona

Name/Title of Principal Supervisor: Professor Philippa Gander

Name of Published Research Output and full reference:

This manuscript has not been accepted for publication. It will be submitted to the journal Accident Analysis and Prevention for consideration for publication.

In which Chapter is the Published Work: Chapter 5: Self-reported fatigue management on augmented flights (Project D)

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  Candidate re-grouped and cleaned the data for analysis, conducted the analysis with Dr. Karyn O'Keeffe and drafted the manuscript which was reviewed and approved by all authors.

Candidate's Signature

21 April 2016
Date

Philippa Gander
Principal Supervisor's signature

21 April 2016
Date

CHAPTER 4 PILOTS' PERSPECTIVES ON IN-FLIGHT SLEEP (PROJECT C)

The sleep of pilots operating long haul routes has often been investigated using studies like the bunk study detailed in the previous chapter. The analyses reported here expand on this to investigate what pilots identify as factors that affect their in-flight sleep and fatigue during long haul operations.

The findings of the analyses are presented in the form of a manuscript that is being edited to fit the submission requirements of the journal Human Factors where it will be submitted for consideration for publication. The current formatting has been edited to reflect the style conventions of this thesis and the references have been incorporated into the main bibliography.

4.1 Abstract

To reduce fatigue during long flights, multi-pilot crews are provided with in-flight rest breaks and rest facilities. Rest break patterns and facilities differ by route, aircraft type and fleet culture. The present analyses aimed to identify factors that pilots consider impact their in-flight sleep and waking function during long transmeridian flights. Questionnaire data from five studies of pilots' sleep on long range and ultra-long range flights were combined (N=291 pilots, 3-pilot or 4-pilot crews). Following three questions about in-flight sleep, pilots were offered space for written comments. Themes were identified by an iterative process of coding, categorization and review. Comments from 123 pilots (42%) were analysed. Pilots reported that their sleep duration and quality were affected by: comfort of

the rest facilities (e.g., temperature, comfort of sleeping surface, class of facility); noise (caused by passengers and cabin crew); and timing of rest breaks. Specific rest breaks were identified in which pilots found it more difficult to obtain sufficient sleep of good quality. Pilots reported that they prepared for flights differently, depending on their allocated break pattern. They also linked the duration and quality of in-flight sleep to their alertness and performance in subsequent duty periods. The pilots' views analysed here confirm the importance of good quality crew rest facilities, appropriate patterns of in-flight rest breaks, and knowledge in advance of their allocated rest breaks, as key factors influencing in-flight sleep and their ability to maintain acceptable levels of performance and alertness on long transmeridian flights.

4.2 Introduction

The International Civil Aviation Organisation defines fatigue as 'a physiological state of reduced mental or physical performance capability resulting from sleep loss, extended wakefulness, circadian phase, and/or workload (mental and/or physical activity) that can impair a person's alertness and ability to perform safety related operational duties' (International Civil Aviation Organisation, 2015).

Pilot fatigue and its effects on waking function have been well documented in long-range and ultra-long range flights through simulator studies, surveys, and field studies monitoring pilots' sleep and performance. To mitigate the fatigue risks associated with long flights, airlines are usually required by regulation to use augmented flight crews and provide them with in-flight rest facilities so that each pilot has the opportunity for in-flight sleep (International Civil Aviation Organisation, 2012).

The type of in-flight rest facility provided will normally determine the maximum duration of the flight duty period (Federal Aviation Administration). For example, the US Federal

Aviation Administration (FAA) defines 3 classes of in-flight rest facility: class 1 facilities require a bunk or other lie-flat sleeping surface in a separate location from the flight deck and passenger cabin where pilots can control a number of environmental factors; class 2 facilities require a seat in the passenger cabin which reclines to a flat or near-flat position and is separated from passengers at minimum by a curtain; and class 3 facilities require a seat, located in the passenger cabin or flight deck which reclines at least 40 degrees providing leg and foot support (Federal Aviation Administration, 2012b). Typically, for the same pilot complement, longer duty periods are allowed when pilots have access to a class 1 facility than when they have access to class 2 or 3 facilities, and longer duty periods are allowable with class 2 facilities than with class 3 facilities. The distribution and organization of in-flight rest breaks vary by airline and by flight route, but break patterns and allocations are usually designed to favor the crew members who will be operating the aircraft during the critical approach and landing phases of flight ('landing crew').

The effectiveness of such fatigue mitigation strategies has been evaluated in field studies using objective measures of sleep and performance (Gander, Mulrine, et al., 2015; Gander, Signal, et al., 2013; Signal, Mulrine, et al., 2013; Signal, et al., 2004; Wu, 2012). However, relatively little research has focused on the perspectives of pilots on these issues. Previous studies, conducted prior to the introduction of newer rest facilities and aircraft used closed answer questions to investigate the quality and duration of in-flight sleep (Pascoe, et al., 1994; Rosekind, et al., 2000) offering the studied pilots limited opportunities to comment on other factors affecting their in-flight rest. The present study addressed this gap by analyzing pilots' open-ended comments. Identifying what is important to pilots in terms of in-flight sleep and their waking function can help identify ways in which the current fatigue mitigations can be improved.

4.3 Methods

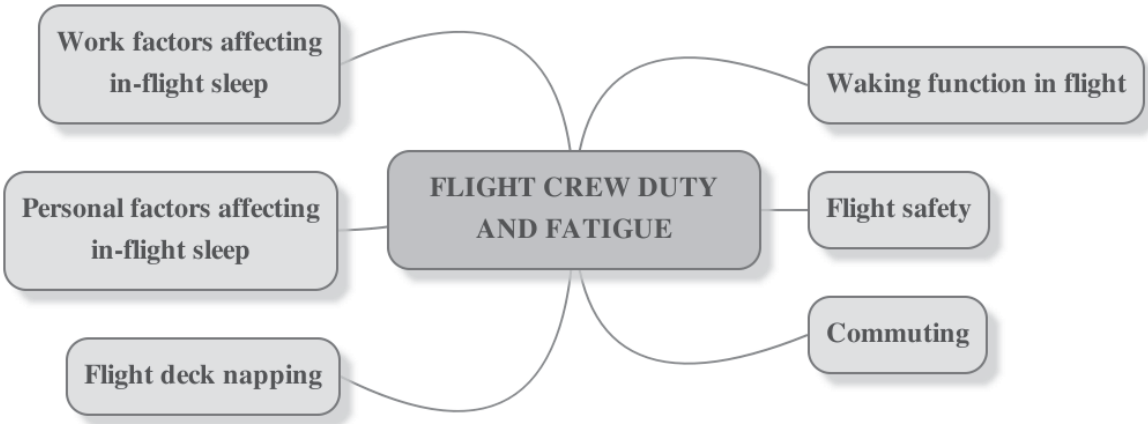
This study made use of de-identified survey data that had been collected as part of five previous studies monitoring pilots' sleep and performance (Gander, Signal, et al., 2013; Signal, Mulrine, et al., 2013; Signal, et al., 2004; Wu, 2012). All five studies received ethical approval (Massey University Human Ethics Committee Southern A, application 08/68; Massey University Human Ethics Committee, application 11/74; Massey University Human Ethics Committee, WGTN Protocol 04/03; Washington State University Institutional Review Board, IRB # 10951) and the de-identified questionnaire data was approved for use in subsequent analyses.

The survey from which these comments were gathered was given to all flight crews at the start of their study period. Pilots were instructed to complete this questionnaire prior to the end of their study period but were not asked to complete it at a specific time. The questionnaire is composed of twenty-seven questions and includes a number of items relating to in-flight sleep. The comments section of the questionnaire was a blank page (at the end of the questionnaire) labelled 'Comments'. The comments section followed three multiple choice questions about the quality and effects of in-flight sleep in bunks and seats which may have influenced the content of participants' responses. Although some pilots commented on rest facilities they had used previously, at the time of data collection all pilots had access to a class 1 rest facility on their flights.

Participants' comments were analyzed using accepted methods of thematic analysis (Braun & Clarke, 2006, 2012), which include a 6-phase iterative process of coding, categorization and review. The analysis was primarily an experiential and inductive form of thematic analysis conducted within a pragmatic framework. As such, the themes explored in this analysis focused on participants' experiences or perspectives and were generated based on what patterns were recognized in the data instead of being constructed from an existing theory (Braun & Clarke, 2013). The coding process used in this analysis was descriptive and semantic; the researchers did not attempt to go beyond the participants' meanings during the coding phase of analysis (Braun & Clarke, 2012).

After familiarizing themselves with the data, two researchers independently read through the comments and each generated initial codes based on recurring or interesting content (e.g.; 'flight attendant noise'). Each researcher then independently reviewed their codes and grouped them into broader themes (e.g.; 'sleep environment'). These initial themes were reviewed and discussed as a group by both researchers and a third independent reviewer, which resulted in the identification of two main themes and seven sub-themes. The data were then reviewed to ensure that the agreed themes provided a comprehensive description of the data and did not significantly overlap. As this was not the case, this process was repeated three more times, finally resulting in the identification of eight main themes, six of which related to sleep and fatigue on duty and are discussed here (figure below).

Figure 4.1 Thematic map illustrating the themes relating to pilots' duty



4.4 Results

In total, data from 291 pilots were eligible for inclusion in these analyses and demographic information about these pilots is presented in table 2.1 of chapter 2 where the analyses of the quantitative items of this questionnaire are reported. Of the eligible pilots, 138 (47.4%) provided written comments and response rates differed by study (range 26.8% to 62.9%). Fifteen crew members were eventually excluded from the analyses as their comments had been abridged during data entry and the original questionnaires were not available for review at the time of analysis as they were collected by a different research team and are archived at a different institution. Thus these analyses include comments from 123 pilots.

Comments about in-flight sleep were by far the most common and were grouped according to whether they mentioned personal factors affecting sleep (n=24, 19.5%) or work factors affecting sleep (n=81, 65.9%). Work factors affecting sleep were further separated into factors relating to the design, location and type of crew rest facility and factors relating to the timing and choice of rest breaks. In addition, 27 pilots (22.0%) discussed waking function, referring to fatigue, alertness and performance. Other comments addressed flight safety, commuting practices and flight preparation practices.

4.4.1 Personal factors affecting in-flight sleep

The majority of these comments were related to pilots' rest habits, including descriptions of behavior during rest periods and attitudes towards sleep. These suggested that pilots had developed personal strategies, such as the use of earplugs or specific rest routines, to improve their sleep in flight. These comments also indicated that pilots spent most of their in-flight rest opportunities attempting sleep:

> *"I always attempt to sleep, I may wake up before break is over and watch TV or read, but sleep comes first."*

Other comments suggested that crew members get used to sleeping in the crew bunk over time and that the more experienced crew members had better experiences of the bunk:

> *"During route training, I felt that it was difficult to fall asleep in the bunk as excitement, training and un-welcome disturbances was the main cause not to fall asleep and a pre-occupied mind".*

4.4.2 Work factors affecting in-flight sleep

4.4.2.1 Location, design and type of crew rest facility

The location, type and design of the on-board rest facilities available to pilots can have significant effects on in-flight sleep. Pilots made numerous complaints about noise resulting from passenger and cabin crew activities, especially during meal times, and although these disruptions were more pronounced in the crew rest seat (main cabin), they were also reported to affect sleep in the crew bunks as most of these were located near the flight deck and/or a galley:

> *"There is a substantial quality difference on which break you have in a seat. The first break coincides with dinner and a noisy cabin. The third break with breakfast and also noise. Only the second break is mostly undisturbed. In the bunk ALL breaks are quiet and undisturbed."*

> *"Sleep in bunk very difficult. Bunk too small, noise from galley & cockpit and especially the call chime from PAX [passengers] to galley the same as crew call. Keeps me awake. Crew in galley also make a lot of noise especially during meal times."*

The design and comfort of the rest facilities were also discussed, and while the crew rest seats were reported to be uncomfortable and too small for some pilots, the crew bunks did not escape criticism either, with one crew member referring to the crew bunk as *"a closet with bunk beds"* and another observing that:

> *"The mattress for crew rest is very hard and uncomfortable. In some ways like sleeping on a well padded carpet over hard floor".*

Pilots also reported that turbulence negatively impacted on their ability to sleep in flight, a complaint that was frequently associated with a specific aircraft type.

However, despite the numerous and varied complaints about the crew bunk, most crew members agreed that the horizontal bunk rest facility was a considerable improvement over the cabin seat rest facility. Pilots felt that rest in the cabin seat was much worse than sleep in the crew bunk and they expressed their dissatisfaction in comments such as:

> *"The chair sleep is a joke. Not dark, quiet, or comfortable."*

> *"Bunk is far superior. People bump you in the seat, move the curtain, it's noisy on 1st and 3rd break. This is not an issue in the bunk. Seat isn't big enough for me 6'2" 250lbs."*

By comparison, praise for the crew rest facilities included:

> *"Having flown the 757/767 for the previous 4yrs prior to the 777 and having mainly coach seats for rest (with an occasional First class seat for rest) I can attest that the rest I receive in the bunk, even though it may not seem long, is vastly superior to the 'park bench' rest I received on the 767"*

In particular, one crew member enthused:

> *"The horizontal rest facility is key though, if you could get it into all a/c [aircraft] it would be great."*

4.4.2.2 Timing and choice of rest breaks

The timing of the scheduled rest breaks did not always provide the best opportunity for in-flight sleep and pilots reported difficulties sleeping on specific breaks when these occurred earlier in their biological day:

> *"The only flight that I have trouble sleeping in the bunk is the flight to [city 5] due to the start time of my rest period at 1700 EST [Eastern Standard Time]."*

Crew members may also prepare differently for a flight depending on their planned rest breaks and on that basis, prior knowledge of which rest breaks will be taken is important in terms of flight preparation:

> *"The most critical part of being able to sleep in the bunk for me is to know what breaks to plan on before I show up for work. Generally the [relief pilot] position picks breaks after the Captain and First Officer therefore, the [relief pilot] might not be set up correctly for rest (ie should be tired because will be going on break first or vice versa) and will have a very tough flight from a proper rest standpoint."*

In these situations, crew position may influence the ability to choose break times. Those who had more senior roles (e.g., Captains) implied that they were able to optimize their sleep by choosing the most suited break times, but they also suggested that the more junior pilots and relief crew were not necessarily able to do that.

> *"The most important thing is planning breaks ahead of time - I let the [relief pilots] know at least a day ahead of time which break that I will be taking via email. I always modify my sleep so that I will be successful sleeping at*

> *my chosen break period, which is usually the first break of the first flight (for Asia trips, 2nd for India).”*

4.4.3 In-flight waking function

Pilots frequently linked waking function to in-flight sleep, referring to the effects of in-flight sleep on their fatigue, alertness and performance levels. In general, they reported that in-flight sleep improved their alertness and made it clear that they were aware of the possibility of sleep inertia upon awakening. They also remarked that in-flight sleep lead to greater improvements in alertness when the period during which they attempted sleep aligned best with their usual sleep period and/or times when they were likely to be most sleepy:

> *“[…] the sleep quality in the bunk is much better when accomplished during my normal body clock sleep hours. This significantly improves alertness during duty times […]”*

Some pilots also linked waking function to layover length indicating that inadequate recovery on layover led to decreased alertness and increased fatigue on the inbound flight. However, it was clear that there are differing opinions about the ideal layover length. Advocates of shorter (24 hour) layovers attributed the inadequate recovery to partial circadian adaptation during longer layovers, while advocates of longer (48 hour) layovers considered that shorter layovers offered insufficient rest opportunities.

In several comments, pilots also compared their waking function on the ultra-long range and long range routes selected for these studies to that on other routes they had flown. Most of these comments implied that crew members felt less fatigued and more alert on flights with augmented 4-pilot crews compared to flights with non-augmented (2-pilot crews) or augmented 3-pilot crews:

> *"[…]I am usually more tired or fatigued at landing time on 3-man or 2-man late night European trips than I ever am on the long-haul Asia trips with 4 pilots"*

The increased fatigue and decreased alertness may be linked to the shorter in-flight rest opportunities available on flights with 3- person crews,

> *"One thing I would like to add, is that, when it comes to rest (crew), I get better sleep when I work a 4-man crew instead of a 3-man crew. Coming back from Europe on a 3-man crew I come back feeling extremely exhausted as opposed to the long-haul flights of more than 12hrs. The amount of break time really makes a big difference."*

Also contributing to fatigue is the timing of flights, with nighttime flights being more difficult for pilots:

> *"I feel more rested after augmented crew trip (Africa) than I do after double all-nighter, non-augmented South America. Those HURT!"*

Several crew members also mentioned that the type of crew rest facility provided impacted on their fatigue and alertness levels, and that in this regard the availability of a crew bunk rather than a crew rest seat was key:

> *"I flew the 767 in 2000-2001 and took crew rest in a business class seat in the cabin. I never felt rested. The bunk on the 777 makes a huge difference and I feel awake and alert during all my cockpit duty periods"*

It was also suggested that issues with fatigue and alertness were worse on some routes than others:

> *"Furthermore, I would suggest that you test the 767 pilots that do the 3 day [city 8] out of [city 6] and [city 2], and the 3 day [city 1] out of [city 2]. I've flown all 3 and they will flat out turn you into a brain eating zombie!! Just ask the Mrs..."*

4.4.4 Flight safety

In a small number of comments, pilots also explicitly related waking function to flight safety by linking it to factors which affect their fatigue and alertness levels such as flight timing, the opportunity to gain in-flight sleep, crew complement, and route:

> *"Wish study would have focused on flying back side of the clock from [city 7] to Europe without [a relief pilot] - this is the most unsafe operation we do, especially commuters. Up all day, fly all night then fly an approach in poor weather - it's really hard on crews and most take a nap on the way over, would be nice to have [a relief pilot] to increase safety."*

4.4.5 Commuting

Other, less frequent, comments detailed commuting practices, techniques and habits for preparing for a flight, and personal stressors at home, including:

> *"Single parent, so weekdays always start at 0550 local time. Most of the time must ride jumpseat to work (not regular seat)."*

4.4.6 Flight deck napping

Finally, three crew members from the only airline in this sample in which flight deck napping is legal, also mentioned that flight deck napping was beneficial with regards to reducing fatigue and increasing alertness on certain operations:

> *"On the [city 4 to city 3] operation (2-man crew), flight deck napping really helps due to the time of day (night) this flight operates."*

4.5 Discussion

Few studies have examined the personal experiences and perceptions of pilots in relation to in-flight sleep, fatigue and safety. Previous survey studies used more directed questions to evaluate pilots' perceived in flight sleep duration and quality and to identify which factors disrupt in-flight sleep (Pascoe, et al., 1994; Rosekind, et al., 2000). This paper is unique in presenting the views of long-range and ultra-long range pilots on the operational factors affecting sleep and the fatigue-related degradation of waking function on such flights.

The space for written comments in the questionnaire followed a series of questions relating to sleep quality in seats and bunks and the effects of such sleep on alertness and performance during flight duty, a context that is reflected in the themes identified in this analysis. The overall response rate (47.4%) for the comments section was comparable to that of a 2011 survey of flight attendant fatigue (37%) (Avers et al., 2011), although the percentage of pilots who completed the comments section differed by study. This is likely to be a result of cultural differences (Asian versus American national cultures and fleet culture) rather than differences in the available rest facilities as all pilots had access to class 1 rest facilities on the flights they were operating.

Pilots reported that the type, design and location of the crew rest facility can adversely affect in-flight sleep duration and quality, which in turn leads to decreased alertness, increased fatigue and could potentially decrease flight safety. In particular, pilots made it clear that they preferred to use a crew bunk over a crew rest seat. Pilots felt that sleep in the crew rest seat was much more disrupted which negatively impacted on their fatigue and alertness levels when they returned to the flight deck. Crew rest seats are located in the passenger cabin which makes them less private and noisier than the crew bunks due to passenger and cabin crew noise and movement. In addition, cabin lighting, the size of the seat and the reclined position in which pilots must sleep, can impact on their comfort as well as their ability to obtain and maintain sleep, particularly in seats which recline less than 40 degrees from vertical (Nicholson & Stone, 1987). A previous study comparing in-flight rest taken in a crew rest seat to in-flight rest taken in a bunk, found that a greater proportion of pilots were able to obtain sleep in the bunk and that the sleep obtained in the bunk was of longer duration than that obtained in the crew rest seat, leading to greater improvements in performance and alertness levels (Spencer & Robertson, 2000).

Pilots' comments in the present study also highlighted possible areas for improvement in the crew bunks. The most common complaints about the bunks related to noise (caused by both passengers and cabin crew) and the general comfort of the rest facility (e.g., mattress, pillow, temperature). As a result, pilots had developed specific strategies, such as the use of earplugs, to help minimize sleep disruption. Random noise is known to be more disruptive to sleep than constant background noise. In addition, uncomfortable or inadequate bedding, as well as the dry atmosphere of the bunk facility, are all reported to contribute to disturbed sleep (Pascoe, et al., 1994; Rosekind, et al., 2000). Although sleep disturbances resulting from atmospheric turbulence are difficult to address, sleep in the bunk might be improved by addressing some of the other factors known to affect in-flight sleep. Examples include simple changes such as providing pilots with softer mattresses and a choice of pillows, along with more substantial modifications of the crew rest facilities such as enhanced sound-proofing, or locating the facility further from galleys, which could all help make the bunk more conducive to good quality sleep.

Pilots also reported that break timing was a significant issue affecting sleep in flight. Prior sleep history, time awake and the circadian body clock all affect sleep duration, quality and timing (Borbély, 1982; Dijk & Czeisler, 1994), leading to ‘windows’ of sleep opportunity across the biological day. As a result, pilots may find it more difficult to obtain sufficient sleep of good quality on breaks scheduled during their biological day (when there is a high propensity for wakefulness) or if the rest break occurs shortly after another sleep episode. Previous studies have found that sleep duration and quality are affected by both the timing of the flight and the timing of the scheduled in-flight rest periods and that bunk sleep has beneficial effects on complex task performance (Gander, Mulrine, et al., 2014; Pascoe, et al., 1995); a finding which supports pilots’ observations that the improvements in their alertness and performance were greater when their rest break aligned with their usual sleep times and they obtained more sleep.

Different airlines allowed more or less discretion in the distribution of in-flight rest breaks with some providing guidelines for pilots and others leaving the allocation of rest breaks to crew discretion. Guidelines suggested that the landing crew be allocated the most favorable rest breaks in order to maximize their alertness during the critical approach and landing phases of flight. However, regardless of whether or not guidelines existed, on the day of the flight the final decision with regards to break allocation rested with the crew and the senior Captain had final say. This allowed pilots to take into account external factors (e.g., previous night’s sleep, commuting) and use their operational knowledge to manage in-flight rest breaks.

Where guidelines regarding the distribution of rest breaks were provided, pilots generally knew ahead of time which rest breaks they would be allocated, based on whether they were rostered as ‘flying’ or ‘relief’ crew, and so could prepare for the flight based on this information. However, where guidelines were not provided and where flying duties were decided once pilots reported for duty, relief crews and more junior crew members reported that at times the uncertainty of break allocations meant they found that they had prepared for the wrong rest break. Currently, there is insufficient scientific evidence to give crews specific guidance on how to prepare pre-flight to optimize their in-flight sleep on different flights with differing rest break patterns. As in a previous study, relief crews were also often allocated the least favorable breaks (Pascoe, et al., 1994), consistent with the strategy of allocating breaks to favor the alertness of the landing crew.

Pilots also reported that the length and timing of flights (night vs. daytime flights) had an effect on their waking function and flight safety, particularly in non-augmented 2-pilot crews. Cognitive performance is affected by the time of day, leading to performance decrements during the night and early morning which are further exacerbated by sleep loss (Doran, et al., 2001; Goel, et al., 2011). The early morning period during which this low-point in performance is observed is referred to as the window of circadian low (WOCL; approximately 0200-0600) and also includes the high-point in sleep propensity (Belenky, et al., 2014). As one crew member remarked, night flights are *"really hard on crews"*. Recent studies have demonstrated that both the duration of prior wakefulness and flight departure and arrival times impact on pilots' fatigue (Gander, Mulrine, et al., 2014; Vejvoda, et al., 2014) and that flight departure and arrival times also affect the amount of in-flight sleep obtained by pilots (Gander, Mulrine, et al., 2014).

Some routes were singled out as being more fatiguing than others, and pilots implied that they were less fatigued when flying as part of an augmented 4-pilot crew than when flying as part of an augmented 3-pilot crew. Although flights with a 4-pilot crew are longer than those with a 3-pilot crew, the sleep opportunity is also longer (pilots in 4-pilot crews each get half the available flight time for rest, 3-pilot crews get only a third of the available time each). The longer 4-pilot flights also usually require a class 1 rest facility which pilots preferred.

For the only airline (in this sample) for which flight deck napping is legal, all comments in relation to flight deck napping were favorable. Crew members described flight deck napping as beneficial and suggested that it improved their alertness and performance, particularly on non-augmented flights. This observation aligns with the findings of previous studies which found that planned cockpit naps were beneficial in terms of improved alertness and performance at top of descent compared to the control (no-nap) group. However, these studies also cautioned on the potential risks of controlled flight deck napping should the alertness of the waking pilot fall below acceptable levels and issued recommendations on the safe implementation of flight deck napping (Rosekind, et al., 1994; M. Simons & Valk, 1997).

Finally, factors which affect pilots' preparation for a flight are also important in terms of pilots' waking function and flight safety. Personal stressors (such as financial pressures or being a single parent) and commuting practices can affect pilots' fatigue levels through poor sleep quality, extended periods of wakefulness and less than ideal flight preparation. Concerns about the level of preparedness of certain pilots were raised with comments such as *"[...] I work with individuals who sometimes do not prepare for flight. Even pilots who live locally, work all day and then expect to fly all night"*, which highlight the importance of educating pilots on the effects of fatigue. The sensitive nature of issues surrounding flight preparation (commuting, financial stresses, etc.) means that little research has been conducted on these topics; nonetheless these issues remain important in terms of fatigue and flight safety. In their investigation of the 2010 Colgan Air crash, the American National Transportation Safety Board concluded that *"All pilots, including those who commute to their home base of operations, have the responsibility to wisely manage their off-duty time and effectively use available rest periods so that they can arrive for work fit for duty; the accident pilots did not do so by using an inappropriate facility during their last rest period before the accident flight [...]"* (NTSB, 2010). This investigation also recommended that the American

Federal Aviation Administration amend their regulations (14 Code of Federal Regulation parts 121, 135 and 91K) to require operators to *"address fatigue risks associated with commuting [...]"*.

The present findings indicate that (at least) some pilots are aware of the effects of flight duty on the fatigue-related degradation of waking function. An important caveat is that the data are subjective. Pilots may have differing views and the non-specific way in which the "comments" section was framed may have led to an incomplete picture. Potential biases in the analyses were reduced by the researchers' commitment to an inductive approach to the coding of the data. However, the position of the "comments" section at the end of the questionnaire (immediately following a section pertaining to in-flight rest) may have skewed pilots' responses towards in-flight rest. Future studies using qualitative methods (e.g.; surveys, interviews, focus groups) drawing on the findings of this study may be of use to further investigate pilots' views on the effects of flight duty on fatigue during and around the duty period, as well as to identify ways in which the current fatigue risk management practices could be improved.

4.6 Conclusions

Maintaining acceptable levels of pilot alertness and performance during flight operations is important for flight safety and requires a shared responsibility between regulators, operators and pilots. In-flight sleep is an effective fatigue mitigation on long-range and ultra-long range flights but improvements to the comfort, type and design of the crew rest facilities provided could improve the amount and quality of in-flight sleep obtained. These benefits, however, are dependent on pilots adequately preparing for flight duty and making good use of the in-flight rest opportunities available to them. Strategies to help ensure that all pilots are adequately prepared at the start of duty and that landing crews are well-rested when they begin their final approach include: knowing which crew position a pilot is allocated to well ahead of duty start; and having guidelines on the optimal allocation of in-flight rest breaks, but allowing pilots the discretion to make decisions relevant to the situation on the day. Although the findings of this study are not unexpected, they provide a robust analysis that confirms previous anecdotal evidence about pilots' perspectives of factors affecting in-flight sleep and fatigue.

4.7 Acknowledgements

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MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Jennifer Louise Zaslona

Name/Title of Principal Supervisor: Professor Philippa Gander

Name of Published Research Output and full reference:

This manuscript has not been accepted for publication. It is being edited to fit the submission requirements of the journal Human Factors where it will be submitted for consideration for publication.

In which Chapter is the Published Work: Chapter 4: Pilots' perspectives on in-flight sleep (Project C)

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  Candidate re-grouped and cleaned the data for analysis, conducted the analysis with Dr. Karyn O'Keeffe and input from Professor Gander, then drafted the manuscript, which was reviewed and approved by all authors.

Candidate's Signature — 21 April 2016 — Date

Philippa Gander
Principal Supervisor's signature — 21 April 2016 — Date

CHAPTER 5 SELF-REPORTED FATIGUE MANAGEMENT ON AUGMENTED FLIGHTS (PROJECT D)

In-flight sleep is the most common fatigue mitigation strategy employed during long haul and ultra-long range flight operations. The previous chapter used qualitative methodology to investigate pilots' views of in-flight sleep and the analyses in this chapter build on this to examine what fatigue mitigation strategies pilots actually employ on augmented flight routes.

The findings of the analyses are presented in the form of a manuscript that will be submitted to the journal Accident Analysis & Prevention for consideration for publication. The formatting has been edited to reflect the style conventions of this thesis and the references have been incorporated into the main bibliography.

5.1 Abstract

Fatigue risk is inherent to long haul flight operations. The associated long duty periods and transmeridian travel often results in pilots experiencing periods of extended wakefulness and sleep loss. Although the use of in-flight rest is the primary recommended fatigue mitigation, anecdotal evidence suggests pilots also use other fatigue mitigation strategies. The present analyses aimed to identify how pilots manage their fatigue during these flights. Duty diary data collected as part of four previous studies of pilot sleep on different routes were combined, and responses to a question relating to how they managed fatigue on each flight segment were extracted. Accepted methods of thematic analysis were applied to the 629 responses. The main method of managing fatigue was the use of the allocated in-flight rest opportunities for sleep, although the organisation of these breaks varied by route and

fleet. Differing flight preparation techniques aimed either at maximising sleep pre-flight (e.g. taking a nap) or at encouraging good quality in-flight sleep, were also used. These practices were frequently linked to planning for specific in-flight rest breaks. Pilots also reported techniques used to increase their alertness in-flight (e.g. caffeine consumption) and strategies to improve their in-flight sleep (e.g. avoiding caffeine, relaxing). The fatigue management techniques reported imply that pilots make appropriate use of in-flight rest opportunities for sleep, which aligns with current recommendations when additional pilots are on board (augmented crews). However, responses indicated that flight preparation was another important fatigue management strategy, which highlights the importance of pilots knowing the pattern of in-flight rest breaks well ahead of the flight.

5.2 Introduction

The long duty periods, transmeridian travel, and round the clock nature of long range and ultra-long range flights means that fatigue risk is inherent to these types of operations. In aviation, fatigue is defined as ‘a physiological state of reduced mental or physical performance capability resulting from sleep loss, extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a person’s alertness and ability to perform safety related operational duties’ (International Civil Aviation Organisation, 2015).

In long range and ultra-long range flight operations, pilot fatigue and its effects on waking function have been well established using simulator studies, surveys and field studies that monitored pilot sleep and performance. Typically, fatigue risk on such flights is mitigated using augmented flight crews and in-flight rest opportunities that provide an opportunity for sleep, as recommended by the International Civil Aviation Organisation (2012).

Although studies monitoring pilot sleep and performance have clearly demonstrated that pilots make good use of the in-flight rest opportunities provided on augmented operations to obtain sleep (Gander, Signal, et al., 2013; Roach, et al., 2011), information regarding the use of other fatigue management techniques (e.g., the use of caffeine, naps, etc.) is mainly anecdotal. A previous study investigated the use of informal fatigue management strategies in a group of defense aviation personnel but the study was not specific to pilots. Additionally the study focused on strategies and behaviors that defense personnel applied to their tasks to minimize the effects of fatigue when they were *already* fatigued (Dawson, Cleggett, Thompson, & Thomas, 2015). The present analyses aimed to identify the fatigue management strategies employed by augmented commercial flight crews to minimize the likelihood of them *becoming* fatigued on a variety of long range and ultra-long range routes.

5.3 Methods

5.3.1 Study design and materials

Qualitative research methods were applied to de-identified duty diary data to investigate how pilots manage fatigue on different flight routes. The diary data used in these analyses had been collected as part of four previous studies of augmented flight crews (Gander, Signal, et al., 2013; Signal, et al., 2014; Wu, 2012) and had been used to collect prospective information about pilots' sleep and duty periods. For each of their studied flight segments, pilots had been asked to answer the question "How do you typically manage fatigue on this flight?" Their written responses to this question are the subject of the present analyses. Demographic information about the pilots from the four studies included in these analyses is provided in table 2.1 of chapter 2.

All four studies had received ethical approval (Massey University Human Ethics Committee Southern A, application 08/68; Massey University Human Ethics Committee, application

11/74; Washington State University Institutional Review Board, IRB # 10951) and the de-identified diary data were approved for use in subsequent analyses.

5.3.2 Analysis

Pilots' written responses were analyzed using accepted methods of thematic analysis (Braun & Clarke, 2006, 2012), which include a 6-phase iterative process of coding, categorization and review. This was completed in four stages by two researchers:

1. Familiarization with the data: the researchers independently read through the comments and each identified meaningful units of text (codes) based on recurring or interesting content (e.g.; 'keep hydrated').
2. Double coding: to ensure reasonable agreement of the coding, codes for each response were reviewed as a group and where codes differed between researchers, these were discussed and edited to reflect what was agreed.
3. Defining codes: coding definitions were reviewed as a group and agreed definitions were established for each individual code.
4. Identifying themes: the defined codes were grouped into themes (e.g.; 'pre-flight habits'), reviewed, and then regrouped into broader themes.

The analysis was primarily an experiential and inductive form of thematic analysis conducted within a pragmatic framework. As such, the themes explored in this analysis focused on participants' experiences or perspectives and were generated based on what patterns were recognized in the data instead of being constructed from an existing theory (Braun & Clarke, 2013). The coding process used in this analysis was descriptive and semantic; the researchers did not attempt to go beyond the participants' meanings during the coding phase of analysis (Braun & Clarke, 2012).

5.3.3 Fatigue management strategies

Data from 749 flight segments (operated by augmented flight crews, all provided with class 1 rest facilities on all flight segments) were eligible for inclusion in these analyses. Of these, responses to the question of interest were provided for 629 flight segments (84%). The majority of responses were in the form of sentence fragments.

Five main categories of fatigue management strategies were extracted and are outlined in Table 5.1 below.

Table 5.1 Categorisation and frequency of occurrence of fatigue management strategies identified by pilots

Category number	Fatigue management strategy	Number of related codes	Occurrence of related codes	%
1	In-flight rest opportunities	39	323	30.3
2	Flight preparation	62	345	32.3
3	Improving sleep and alertness in flight	34	310	29.1
4	Aligning body clock	18	75	7.0
5	Tough it out / fatigue isn't an issue	3	14	1.3
Total		156	1067	100

5.4 Findings

The aim of these analyses was to provide insight into the fatigue mitigation strategies employed by pilots to manage their fatigue on augmented flights. Current regulatory policies and guidelines recommend in-flight sleep as the primary fatigue mitigation on such flights (International Civil Aviation Organisation, 2012); however anecdotal evidence suggests that pilots also apply other strategies. The findings of these analyses support this observation: the most frequently reported fatigue management techniques related to the use of in-flight sleep, flight preparation, and strategies to improve sleep and alertness in flight (categories 1-3).

The majority of pilots indicated that they managed their fatigue by making use of "*crew rest*" and attempting to "*sleep on* [their] *rest break*" but there was considerable variability in the organisation of the in-flight rest breaks. Rest break patterns varied by fleet with some crews organising the available rest time to allocate pilots "*one long break each*" and others dividing the rest time into "*4 inflight break periods*", giving each pilot two sleep opportunities. In some cases rest time was split into "*4 even breaks*" while other crews reported using a combination of short and long breaks. This variety in the in-flight rest opportunities was often associated with specific break preferences (e.g; "*I prefer first break when available*"), habits for break use (e.g.; "*On 1st break I do not sleep so I am tired for 2nd break*") and patterns of break allocation (e.g.; "*SLLS* [short long long short] *breaks selected by flying crew*").

Although the methods and patterns of in-flight rest allocation varied across the sample, rest break allocations tended to favour the landing crews with, for instance, the organisation of breaks into "*short long short long to get landing crew in on long break*". As in previous studies, pilots indicated that relief crews "*generally get 2nd choice*" which often results in them being allocated the least favourable or desirable rest breaks (Pascoe, et al., 1994). The strategy of allocating rest breaks to benefit the alertness of the landing crew during the final phases of flight is now incorporated into Federal Aviation Administration regulations which require that "Two consecutive hours in the second half of the flight duty period are available for in-flight rest for the pilot flying the aircraft during landing" (Federal Aviation Administration). This new regulation precludes a number of rest break patterns observed in the analysed sample and effectively requires altering some established rest break allocation procedures. However, as this regulation was not in place at the time of data collection, it would not have affected the pilots in this sample who indicated that rest break allocation impacted on fatigue management as it influenced their flight preparation.

Indeed, flight preparation (category 2) was commonly reported as a fatigue management strategy with two opposing approaches emerging. While some pilots tried to maximise their sleep prior to the flight by sleeping in on the day of their trip, getting "*lots of sleep*" and attempting "*to minimize time awake before reporting to duty*"; others tried to increase the likelihood of obtaining good quality sleep in flight by trying to "*not take a nap at home*" or to "*stay up and active all day*". These opposing flight preparation techniques frequently resulted from pilots planning their rest around an anticipated or desired pattern of in-flight rest. In most cases, those who attempted to maximise their sleep prior to the flight planned on flying first and resting later in the flight, explaining for instance that they "*try to start* [the] *trip well rested and take last break to be alert for both departure and arrival*". In contrast, pilots who expected to be on the earlier rest periods tended to rely more heavily on in-flight sleep as a fatigue mitigation strategy and reported planning to "*report somewhat tired in order to sleep well on first break*".

These differences were particularly pronounced in relation to pre-flight naps with pilots explaining "*pretrip nap if I am first crew flying. No pretrip* [nap] *if I am first crew in rest facility*". This strategy makes use of the pressure for sleep which builds across the waking hours (Borbély & Achermann, 1999): pilots who anticipated flying first aimed to reduce the pressure for sleep by sleeping before their duty period, while those who expected to sleep first allowed the sleep pressure to accrue in order to more easily obtain sleep in flight (particularly on rest breaks that occurred during their normal waking hours). Currently, scientific knowledge of the effects of pre-trip naps on in-flight sleep during different flight operations is insufficient to establish general guidelines about the implementation of these naps. While a pre-trip nap prior to an evening departure does not affect in-flight sleep duration or quality either during the first rest period or across the flight as a whole (Signal, et al., 2014), it is also clear that sleep during in-flight rest breaks is affected by both the timing of the flight and the timing of the rest breaks in relation to the flight (Gander, Mulrine, et al., 2014; Pascoe, et al., 1995; R. M. Simons, Valk, et al., 1994).

In this respect it is important for crews to know their in-flight rest break pattern well ahead of time as it may influence the way in which they manage their sleep prior to the flight and "*Fatigue mgmt* [management] *usually start*[s] *before flight based on whether I'm relief crew or primary crew*". Pilots indicated that uncertainty in the rest break allocations made it more difficult for them to prepare adequately for their trips and "*recommend crews know prior to report if they are A or B crews,* [it] *is vital to preparing for trip and being well rested for flight*". Although prior knowledge of rest break pattern may assist in flight preparation, pilots are discouraged from relying too heavily on in-flight rest and encouraged to obtain as much sleep as possible prior to their trip as there is always the possibility that (for operational or other reasons) no in-flight sleep is obtained. In such a scenario, pilots who restricted their sleep prior to the flight would likely see their fitness for duty compromised by fatigue.

Additional fatigue management techniques reported by pilots were strategies to improve their in-flight sleep and alertness (category 3). In-flight sleep is known to be of poorer quality and more disrupted than sleep on the ground (Pascoe, et al., 1994; Rosekind, et al., 2000; Signal, et al., 2005; Signal, Gander, et al., 2013) and pilots indicated that they had developed a number of strategies to minimise these effects. For instance, in order to minimise sleep disruption, pilots used techniques such as limiting their liquid intake and "*avoid*[ing] *caffeine*" so that they could "*sleep all the way thru each rest break*". They also indicated using strategies such as the use of "*earplugs & eye mask*" and "*ensur*[ing] *that bunk area is cool and comfortable*" to help create an environment more conducive to good quality sleep and make the most of their in-flight rest opportunities. Techniques to improve alertness during duty periods such as the "*strategic use of caffeine*" (by using or avoiding caffeine at specific times during the flight), "*conversation*" and the use of "*bright lights in cockpit*" were also frequently reported and used as additional fatigue management strategies outside of the planned sleep opportunities.

Responses indicated that pilots were aware of circadian fluctuations in sleep propensity and waking function (category 4). Certain pilots manipulated their sleep timing to "*try to sleep on normal body clock time*" while others preferred to try to "*adjust to local time sleep pattern*", a finding that is consistent with that of a previous study where a number of pilots shifted their sleep timing on layover despite being advised to remain on their home time zone (Holmes, et al., 2012). As in previous studies, pilots indicated obtaining sleep on certain rest breaks was difficult "*due to body clock*" (Pascoe, et al., 1994). Others tried to select their rest breaks "*so as to keep as normal a sleep cycle as possible inflight*".

A small group of pilots reported that "*Fatigue is never an issue!*" or that they just "*live with it*" (category 5) but it was unclear from some of their responses what, if any, fatigue mitigations they used. Encouragingly, the first attitude appears to suggest that the fatigue mitigations currently in place on these operations are effective, with one pilot explaining "*This is actually a very easy flight with regards to fatigue. The scattered rest periods make it easy to manage fatigue. Just as you get tired your next rest period is there again*". This aligns with the findings of previous quantitative studies in which in-flight sleep had beneficial effects on pilot performance and alertness levels at the critical end of flight phases (Gander, Mulrine, et al., 2015; Holmes, et al., 2012; R. M. Simons, de Ree, et al., 1994). However, the contrary "*tough it out*" attitude raises the question of whether these fatigue mitigations are sufficient and highlights the importance of educating pilots on the negative effects of fatigue and personal countermeasure strategies that they can use in flight.

5.5 Conclusion

These observations support the findings of quantitative studies regarding the use of in-flight sleep as a fatigue mitigation on augmented flights (Gander, Signal, et al., 2013; Holmes, et al., 2012; Lamond, et al., 2006; Roach, et al., 2011; Signal, Gander, et al., 2013; Signal, et al., 2014). Pilots used their rest breaks and relied on them as a strategy to manage their fatigue during the studied flights with a variety of different break patterns and allocations emerging. Pilots also employed specific flight preparation techniques which were frequently linked to planned or expected rest break allocations. This highlights the importance of pilots knowing the in-flight rest break allocations well ahead of their flight as it appears to influence their flight preparation. Supplemental fatigue management strategies were also reported and used to improve in-flight sleep and alertness.

Although the findings of these analyses provide insight into how pilots manage their fatigue on augmented flights, the use of qualitative data means that the effectiveness of the reported fatigue mitigation strategies cannot be determined from these analyses. Qualitative data also introduces subjectivity and these results may provide an incomplete overview of fatigue mitigations used by augmented crews. The comments analysed were from a wide range of different flights, and they were not categorised according to flight characteristics that are likely to influence pilots' choices of fatigue management strategies. These include factors such as inbound versus outbound flights, flight departure and arrival times, flight and durations, which could not be teased apart here.

5.6 Acknowledgements

The authors thank the crew members who participated with outstanding professionalism and attention to the details of the study protocols. We gratefully acknowledge the following individuals and organizations for their permission to include data in these analyses: Dr Jarnail Singh, the Civil Aviation Authority of Singapore, and Singapore Airlines; Captain Wynand Serfontein and South African Airways; Captain Chip Benton and United Airlines; and Captain Jim Mangie and the Fatigue Risk Management Team at Delta Air Lines.

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CHAPTER 6 DISCUSSION

The main aim of this research was to evaluate the use and effectiveness of in-flight sleep as a pilot fatigue mitigation strategy during long range and ultra-long range flight operations. Two of the studies included used quantitative research methods: Project A analysed retrospective survey data (combined from 5 studies with 4 airlines) addressing the sleep of pilots at home and its potential relationship to sleep in flight; and Project B evaluated in-flight sleep in the context of a prospective monitoring study of sleep and fatigue across a particular out-and-back long haul trip pattern. Here, the findings from these quantitative analyses are integrated with the qualitative analyses of open field comments from the 291 pilots in Project A, which includes their comments on in-flight sleep (Project C) and on other fatigue management strategies that they use in long range and ultra-long range flight operations (Project D).

6.1 Integration of findings

6.1.1 Sleep at home versus sleep in flight

In the combined analyses of retrospective survey data (Project A, n=291 pilots), analysis of covariance indicated that shorter night time sleep duration was associated with being older, more awakenings during sleep, and more frequent daytime napping. These findings are consistent with other studies on changes in sleep across adulthood (Bliwise, 2011) and with findings relating to subjective sleep complaints of short sleepers (Grandner & Kripke, 2004). Logistic regression modelling indicated that pilots who reported better-than-average sleep at home (on a 5-point scale very poor/poor/average/good/very good) were also more likely to report seldom or never having difficulty falling asleep (versus sometimes, often or always) and fewer nightly awakenings, compared to pilots who rated their sleep at home as average or worse than average. These relationships are consistent with the polysomnographic definition of sleep efficiency, an indicator of sleep quality, calculated as the total amount of actual sleep relative to the time spent trying to sleep (Keenan & Hirshkowitz, 2011). Overall, the consistency of the observed relationships with findings from the general population suggest that the subjective measures of sleep duration and quality at home used in Project A can be considered reliable estimates of pilots' sleep for this large group. This conclusion is further supported by studies that have compared long haul pilots' self-reported sleep duration to objective measures of sleep (Dement, Seidel, Cohen, Bliwise, & Carskadon, 1986; Signal, et al., 2005), which suggest that these pilots may be more reliable than the general population in estimating their objective sleep duration (Van Dongen, et al., 2003).

Interestingly, age was not associated with the reported frequency of difficulties falling asleep and was not consistently related to the use of sleep aids. This may in part be a result of the demographics of the pilot population studied. In general, long range and ultra-long range routes are staffed based on seniority and thus pilots are often older (median age in Project A was 50.5 years), but strict medical requirements for pilots are also likely to result in a population with fewer age-related health changes. In addition, senior pilots are likely to have developed strategies, or to have become used to the sleep disruption associated with long-haul trans-meridian flights.

Reporting better-than-average sleep at home was associated with reporting better sleep quality in on-board bunks (rated on the same 5-point scale from very poor to very good). However, sleep quality in bunks was rated as poorer overall than night time sleep at home. Although subjective ratings of sleep quality are more variable than polysomnographic sleep efficiency, the two measures are moderately correlated (Signal, et al., 2005) and pilots' indication that in-flight sleep quality is poorer than sleep at home is consistent with previous PSG studies comparing in-flight sleep to sleep on the ground (Signal, et al., 2005; Signal, Gander, et al., 2013). This difference does not appear to be due to altitude (Muhm, et al., 2009).

6.1.2 In-flight sleep and waking function

In Project A, pilots who rated their bunk sleep quality more favourably also reported greater improvements in alertness and performance (on a 5-point scale from very decreased to very improved) after in-flight sleep, compared to pilots who reported poorer sleep quality in the bunk. This suggests that pilots perceive in-flight sleep to be a useful fatigue mitigation strategy, an observation that is supported by their extensive use of in-flight sleep in Project B. The link between in-flight sleep quality and its perceived beneficial effects on alertness and performance is also echoed in the comments in Projects C and D.

Project B (35 pilots) evaluated sleep, subjective sleepiness and fatigue ratings, and PVT performance across outbound and inbound flights between Atlanta and Lagos. Pilots obtained more total in-flight sleep on the outbound flight (mean=3.0hrs) than on the inbound flight (mean=2.5hrs, paired t-test p=0.0057), and total in-flight sleep did not differ between rest break patterns (1st and 3rd breaks versus 2nd and 4th breaks). Possible reasons for the difference in total in-flight sleep on outbound versus inbound flights were considered. The total time available for in-flight rest was comparable because the flights were comparable in length (outbound mean duration=11.7hrs, SD=0.3hrs; inbound mean duration=12.0hrs, SD=0.3hrs). The flights departed at similar local times (mean for the outbound flight=23:31 EDT; mean for the inbound flight=22:12 WAT) but assuming minimal adaptation to the layover time zone during a 1-day layover (Gander, Mulrine, et al., 2015), departed at different domicile times (means 23:31 EDT and 17:12 EDT for the outbound and inbound respectively). The later departure time of the outbound flight likely meant that the timing of the in-flight breaks on the outbound flight aligned more closely with crew members' habitual sleep times than they did on the inbound flight, which would have included the evening wake maintenance zone that may have limited in-flight sleep duration (Gander, Mulrine, et al., 2014; Pascoe, et al., 1995; R. M. Simons, Valk, et al., 1994). Pilots also obtained significantly less sleep in the 24 hours before duty start on the outbound flight (mean=7.2hrs, SD=1.7hrs) than on the inbound flight (mean=10.2hrs, SD=1.7hrs), so would have had less homeostatic pressure for sleep on the inbound flight. The lengthy sleep duration on layover is likely linked to the unusual conditions in Lagos where, upon arrival, pilots are escorted to a secure compound where they remain for the duration of their layover. Distractions and activities at the compound are limited (i.e., a hotel with a gym and pool) which leaves pilots with more time in which to attempt sleep.

Overall, fatigue and sleepiness ratings were not significantly different between the outbound and inbound flights. There was a tendency for fatigue and sleepiness ratings to be higher at the start of rest breaks than at the end of rest breaks (Figures 3.12-3.15), suggesting improvement due to in-flight sleep, but this was superimposed on an overall significant increase in fatigue and sleepiness across flights. Pilots who took the 1st and 3rd rest breaks also rated their sleepiness as higher than those who took the 2nd and 4th breaks.

Similarly, mean response speed on the PVT and the fastest 10% of responses did not differ between outbound and inbound flights, and slowed across flights. The slowest 10% of PVT responses was worse on the outbound flight but did not increase significantly across the flights. This measure, which includes any lapses in attention, reflects the instability of performance in fatigued individuals. Pilots' performance at duty start may have been affected by the late evening departure time of the outbound flight (at 23:31 EDT/domicile time) as circadian pressure for wakefulness during this time would have been reduced compared to duty start time for the inbound flight.

In Project B, PVT performance and subjective ratings of sleepiness and fatigue at duty start and TOD were not significantly associated with the duration of prior wake, prior sleep duration or total in-flight sleep duration. This was unexpected as previous studies have shown that a shorter period of wake and more prior sleep are associated with lower sleepiness and fatigue and better performance at this critical phase of flight leading into the higher workload and safety risk associated with approach and landing (Gander, Mulrine, et al., 2015; Vejvoda, et al., 2014). There are several possible explanations for the observed lack of relationship between pilots' sleep/wake history and performance measures at duty start and TOD in Project B. The sample size in project B (N=35 pilots with N=70 flight duty periods [FDPs]) was smaller than that in the studies by Gander and colleagues (N=237 pilots with N=730 FDPs) and Vejvoda and colleagues (N=40 pilots with N=188 FDPs). Project B data were also limited to a single out-and-back trip (Atlanta-Lagos-Atlanta). In contrast, the larger studies included a variety of routes with different flight departure and arrival times and showed wider ranges for all of the variables of interest (PVT performance, subjective sleepiness and subjective fatigue), compared to Project B. Taken together, these comparisons suggest that the smaller number of participants and the restricted range of variability in Project B may have contributed to the failure to find the expected relationships between sleep history and waking function in Project B. Additionally, the sample in Project B showed greater variability than the B777 sample on which the power calculations were based. This suggests that Project B may have been somewhat underpowered statistically, i.e., that more significant relationships might have been found with a larger number of participants.

Linear mixed modelling indicated that, after controlling for prior wake and prior sleep duration, subjective sleepiness and fatigue ratings at TOD were higher on the inbound flight than on the outbound flight. This suggests that sleepiness and fatigue accumulated across the trip pattern. However, assuming minimal circadian adaptation during layover, the relatively earlier arrival time of the inbound flight (at 05:10 EDT/domicile time) compared to the outbound flight (arriving at 11:14 EDT/domicile time), would also explain at least some of this difference, since it corresponds to an earlier time in the circadian pacemaker cycle when sleepiness and fatigue ratings would be expected to be higher (Babkoff, Caspy, & Mikulincer, 1991; Ferguson et al., 2012; Monk, 1987). The earlier arrival of the inbound flight would also be expected to have contributed to the slower PVT responses at TOD on the inbound versus the outbound flight.

In the comments analysed in Project C, pilots reported that the timing and length of flights impacted on their alertness and performance, with night flights being particularly difficult. This was frequently linked to crew complement, with un-augmented (2-pilot) and 3-pilot flights reported to be more challenging as a result of reduced in-flight sleep opportunities. Reports from the sub-sample of pilots based in countries where flight deck napping is legal aligned with the findings of previous studies, indicating that on operations with limited in-flight rest opportunities, flight deck napping was beneficial for maintaining their alertness and performance levels (Rosekind, et al., 1994; M. Simons & Valk, 1997).

Comments also indicated that in-flight sleep was affected by the location, type and design of rest facilities. Consistent with the findings of previous research, pilots reported that sleep was often disrupted by noise and discomfort (Pascoe, et al., 1994; Rosekind, et al., 2000) and that sleep was less disturbed in class 1 facilities compared to class 2 or 3 facilities (Nicholson & Stone, 1987; M. Simons & Spencer, 2007; Spencer & Robertson, 2000). As a result, pilots had developed strategies to minimise sleep disruptions such as the use of earplugs or limiting their caffeine and fluid intake (Project D). They also reported employing strategies such as the consumption of caffeine, use of bright lighting, and activity to boost their alertness between rest periods.

6.1.3 Allocation of in-flight breaks

There was considerable variability in when and how in-flight rest break allocation was decided and the number of breaks allocated to each pilot. Pilots in Projects C and D described a number of different methods of break organisation, from a single long break for each crew member, to combinations of short and long breaks to ensure each crew member was allocated two in-flight breaks. In Project B, crews followed the airline's recommendation for four in-flight breaks with pilots taking either the 1st and 3rd breaks or the 2nd and 4th breaks.

Consistent with the findings of previous studies, relief crews were frequently given second choice of breaks and allocated the least favourable or desirable breaks (Pascoe, et al., 1994). Although break allocations in all of the included studies tended to favour the alertness of the landing crew by allocating them the later breaks, there were instances in which the landing crew took the earlier breaks (i.e., 1st break in the two break system, 1st & 3rd in the four break system). For US-based crews, this is now restricted by new FAA regulations which require the landing crew to have at least two consecutive hours for rest during the second half of the flight (Federal Aviation Administration, 2012a).

Preferences relating to the organisation of in-flight breaks differed, with some fleets favouring a 2-break system and others choosing to use a 4-break system. Current scientific evidence comparing these break systems is limited and flight timing, duration and the type of rest facility are all likely to influence which break system is more advantageous for any given flight. Previous PSG studies of in-flight sleep using the 2-break system found that sleep duration was shorter and sleep efficiency was lower in the first half of long range flights (Signal, Gander, et al., 2013; R. M. Simons, Valk, et al., 1994). Studies where a 4-break system was used have not reported significant issues, with crew performance and subjective ratings at the end of these flights remaining within an acceptable range (Gander, Signal, et al., 2013; Holmes, et al., 2012; Signal, et al., 2014). Interestingly, the only study which compared the in-flight sleep of pilots between a single long rest period and two shorter rest periods (on the same flight route) found that crews using a single long rest period obtained more sleep (assessed using PSG) than crews who used two shorter rest periods (Roberston, et al., 1997). This may be a result of pilots spending less of their total available rest time preparing for sleep (i.e., getting into rest facility and sleep onset latency) or preparing to return to duty (i.e., waking early to ensure they are fully awake prior to returning to the flight deck). However, in the same study, three crew members highlighted that their preferred break organisation system depended on the flight departure time. This suggests that there is no single 'best break system' and that a break system that works well on one operation may not necessarily be the ideal break system for another operation.

The timing of in-flight breaks can also impact on sleep duration and quality. Pilots reported that certain breaks were less desirable due to their timing coinciding with passenger meal times (a particularly noisy period of the flight) or their occurrence at a time during which pilots would usually be awake. This aligns with the findings of previous studies in which in-flight sleep was affected by both the timing of the flight and the timing of the rest breaks within the flight (Gander, Mulrine, et al., 2014; Pascoe, et al., 1995; R. M. Simons, Valk, et al., 1994). Some pilots also reported selecting their in-flight breaks in order to sleep as close as possible to their usual sleep times. However, despite these reports of less desirable in-flight breaks and previous evidence of the effects of break timing on in-flight sleep, break pattern did not significantly affect total in-flight sleep duration or total sleep duration in the 24 hours prior to TOD in Project B. This may in part be explained by the timing of the individual rest breaks in relation to pilots' usual periods of wake: on the outbound flight all four rest breaks overlapped with the domicile night, while on the inbound flight the first two rest breaks (1st break & 2nd break) overlapped with a period (relative to domicile time) during which pilots would usually be awake. As such pilots would have encountered less favourably-timed rest periods regardless of the break pattern used.

In Project B, break pattern was not a significant predictor of pilots' fatigue status at duty start (subjective sleepiness, subjective fatigue, or PVT performance), suggesting that they did not prepare by sleeping differently according to their rest break pattern on the subsequent flight. However, it is not clear whether they knew their allocated rest break pattern ahead of reporting for duty, as company policy was that flight duties (landing and relief) were allocated by the senior Captain on the day of the flight (Delta Flight Operations, 2010). Across the flights, subjective sleepiness ratings were higher in crews taking the 1st and 3rd in-flight breaks but this was not reflected in the subjective fatigue ratings. This may be a result of the small sample size, as the variability in fatigue ratings differed between rest break patterns, which required the use of a more stringent p value (<0.01) for statistical significance. As expected, crews taking the 1st and 3rd in-flight breaks had a significantly longer duration of wakefulness at TOD compared to crews taking the 2nd and 4th in-flight breaks.

6.1.4 Flight preparation

In Projects C and D, pilots reported that break patterns affected their flight preparation, as they tended to modify their sleep based on an anticipated or desired pattern of break allocation. Two different flight preparation strategies resulted from this: pilots expecting to fly first tried to maximise their sleep prior to the trip while those expecting to rest first relied more heavily on in-flight sleep and allowed homeostatic pressure for sleep to build.

Pilots indicated that when their break allocation was uncertain, it was more difficult for them to adequately prepare for their flight and to manage the associated fatigue. Specifically, in Project D, pilots reported that their decision to nap prior to departure or to opt out of a pre-trip nap was linked to what in-flight breaks they expected to take. In Project B the frequency of pre-trip naps was not associated with break pattern, but it is unclear when pilots in this study were informed of their allocated rest breaks.

In Project B, in the last 24 h before duty start for both the outbound and inbound flight segments, pilots slept longer than they did on baseline days and the occurrence of pre-trips naps during this time was not related to habitual daytime napping at home. This may reflect 'banking sleep' or extending sleep duration prior to a period of sleep restriction, which can facilitate speedier recovery after the sleep loss (Rupp, Wesensten, Bliese, & Balkin, 2009).

In the qualitative analyses, pilots also reported that personal factors such as commuting and family commitments could impact on their flight preparation. This is consistent with the findings of Project B, where pilots obtained significantly more sleep and were awake for less time prior to the inbound flight than the outbound flight. In Project B, the layover location (Lagos) provides very few opportunities for distractions, which combined with the absence of family commitments, likely allowed pilots more time for sleep in preparation for the inbound flight. Other studies have also found that pilots obtained more sleep prior to the inbound flight than the outbound flight or on baseline days at home (Gander, Signal, et al., 2013; Roach, Petrilli, et al., 2012). This likely reflects pilots continuing recovery from the sleep loss experienced during the outbound flight and is facilitated by pilots having fewer commitments and activities during the layover period compared to when they are at home.

6.1.5 Layover duration and sleep strategies

Pilots' comments indicated different preferences relating to layover duration, with some preferring a shorter (24-hour) layover and others preferring a longer (48-hour) layover. Those advocating for a longer layover felt that there were insufficient sleep opportunities during a 24-hour layover to adequately recover, while those advocating for a shorter layover felt that during a 48-hour layover they began to adapt to the layover time zone which led to poorer quality sleep and negatively impacted on their recovery during the layover. In both cases, pilots indicated that inadequate recovery during the layover resulted in increased fatigue on the inbound flight segment. Pilots reported different strategies relating to sleep timing while on layover. Some attempted to sleep at times that were close to their normal home sleep times while others preferred to adjust their sleep to the local night. This latter approach has been reported in other studies of long range and ultra-long range flights, where despite being advised to remain on their home time zone, a number of crew shifted their sleep timing to align with the time zone of their layover destination (Holmes, et al., 2012; Signal, et al., 2014). Anecdotal evidence suggests that those who elect to shift their sleep timing to align with the local layover night do so in order to make the most of the layover location (e.g., sightseeing) while those who attempt to sleep close to their usual sleep times do so to facilitate recovery after their trip.

6.1.6 Post-trip recovery sleep

Recovery following the ATL-LOS-ATL trip (Study B) was relatively rapid, with pilots obtaining more total sleep on post-trip day 1 than on baseline days prior to the trip and sleep duration returning to baseline levels from post-trip day 2. Sleep efficiency did not differ from baseline on any on post-trip days. However this lack of change in sleep efficiency should not be over-interpreted, as actigraphic measures of sleep efficiency do not reliably reflect PSG measures of sleep efficiency (Signal, et al., 2005). Similar post-trip recovery rates have been observed in some studies of long haul pilots (Gander, van den Berg, Mulrine, et al., 2013; Roach, Petrilli, et al., 2012; Signal, et al., 2014) but slower recovery may be associated with trip patterns on which pilots remain out of their home time zone for extended periods (Gander, Signal, et al., 2013; Roach, Petrilli, et al., 2012).

6.2 Strengths and limitations

6.2.1 Strengths

The projects included in this thesis research brought together data from five different fleets and a number of different flight routes of varying lengths. This provided a good snapshot of current long range and ultra-long range flight operations with augmented pilots. Each of the included studies was conducted with a different group of pilots operating as part of different fleets for four airlines from three different countries. Organisational and national culture are known to influence pilot behaviour (Merritt, 2000). The inclusion of data from different cultures provided a broader picture of pilot perspectives, particularly with regards to the allocation and use of in-flight breaks.

The different flight routes included in these analyses also meant that a range of flight characteristics that can impact on in-flight sleep were captured. Aircraft type can influence the type and design of the on-board rest facilities, as was observed in the comments analysed in Projects C and D where four aircraft types were included. Crew complement and flight duration also have an impact on the amount of time available for in-flight rest breaks, while departure and arrival times can influence pilots' in-flight sleep duration and quality. The diversity of operations in the data may have highlighted differences in pilots' perspectives on these factors, but also revealed where they have a similar influence on in-flight sleep across a range of operations.

The mixed methods approach was also a strength of this research. It included methods that are well-accepted in the aviation industry (Project B) but also went beyond what is typically investigated by evaluating pilots' perspectives on in-flight sleep and fatigue management during these operations. The quantitative findings can be generalised to a wider range of operations while the qualitative analyses provide a richer understanding of context (e.g., about the factors that influence in-flight sleep). The integration of findings from the quantitative and qualitative analyses has also highlighted areas of research which (to date) have not been investigated as they are less apparent in quantitative findings (e.g., difficulties with flight preparation and break allocation strategies). This approach also highlighted current fatigue management strategies that are effective on these routes (e.g., use of in-flight rest and of class 1 rest facilities) and provided support for previous anecdotal reports of pilots' views.

6.2.2 Limitations

The findings of this thesis research are limited to augmented flight operations, primarily 4-pilot crews, as data from pilots in 3-pilot crews were not included in the analyses for Project B and no data was collected for un-augmented (2-pilot) crews. Un-augmented crews have no opportunity for in-flight rest, while the rest opportunities for 3-pilot crews are shorter and organised differently from those of 4-pilot crews. The limited data on 3-pilot crews in these analyses was all self-reported (survey and comments) with no objective measures of sleep or performance. Differences in flight characteristics (e.g., flight duration, organisation of rest breaks, on-board rest facility) between 3-pilot and 4-pilot crews also limit the applicability of present findings to 3-pilot crews.

In Project B the small sample size requires caution when interpreting the results as outliers would have had a greater impact on errors and group means (Osborne & Overbay, 2004), while statistical significance may not have been reached in some cases due to a lack of power in the analyses. Power calculations indicated that with a sample size of 30 pilots, it would be possible to detect a 30-minute difference in total sleep time and a 10% difference in PVT response speed at TOD. Although the analyses included 34-35 pilots (depending on the analyses), there was more inter-individual variability (in in-flight sleep duration and PVT performance) among the participants in Project B compared with the sample of B777 pilots on which the power calculations were based. In the qualitative analyses this was not a concern and theme saturation was reached.

Findings from qualitative analyses are not intended to be generalizable. Comments were provided voluntarily, introducing the potential for response bias, particularly in Project C where the response rate was lower. Overall, responses had a slightly negative tone (more focus on negative aspects of in-flight sleep than on the positive) and individuals who had no complaints may have opted to skip the "Comments" section of the questionnaire (Poncheri, Lindberg, Thompson, & Surface, 2007). Time pressures and the workload associated with the study protocols may have meant that certain participants did not have time to write more detailed responses.

Also likely to limit the generalizability of findings is the fact that the qualitative data were not collected with the present analyses in mind. The unspecific way in which the questions were framed (particularly in Project C) and the limited space available for responses (particularly in Project D) may have affected the amount of information provided by pilots, leading to shorter, less detailed responses and a larger number of responses not related to the research question. The questionnaire in Project C was designed to collect demographic information and did not include detailed questions relating to in-flight sleep. The comments section analysed as part of that project (preceded only by the word 'Comments') did not include any instructions or invite participants to comment on a particular subject. As a result, participants used this section to comment on a variety of subjects, some of which were not of interest in this research (e.g., "Phoenix is 2 hours earlier than Atlanta (3 hours during daylight time)") which potentially led to an incomplete picture of pilots' perspectives on in-flight sleep. In Project D, the question of interest was located on the "pre-flight and TOC" page of the duty/sleep diary where only two lines were provided for participants to record their response. In addition, since participants were asked to complete this page prior to take-off, time and operational constraints likely limited the amount of time available and the information pilots provided. The combination of these factors may explain why comments in Project D were primarily sentence fragments and may have led to an incomplete overview of the fatigue mitigations used by pilots.

Finally, the applicability of these findings to current operations is limited by the introduction (since these data were collected) of new FAA regulations relating to in-flight rest break allocation. The new regulations may have led some pilots to modify their in-flight rest habits and would have forced some crews to change their preferred in-flight breaks, thus making some of the break patterns observed in these data obsolete. For instance, in operations with a three-pilot crew (where the flight is split into three rest breaks) the pilot flying the aircraft during landing frequently takes the middle (2nd) break. However, this regulatory change means that for US pilots operating such trips, the landing pilot must now take the last (3rd) break, which often does not provide the best opportunity for in-flight sleep as it can coincide with the passenger meal service (a noisier time during the flight). In augmented four-pilot crews, the requirement that the landing crew take the later breaks also means that in crews using the two break system, the landing pilots will not be able to select the 1st break even if the timing of that break better aligns with their usual sleep times as was reported in Project D by some of the pilots who commuted across the country. However, the regulatory change may be beneficial in reducing uncertainties in break allocation. In fleets where pilots are rostered as either flying or relief, the regulatory requirement can allow them to deduce their break allocation. However, in fleets where flying duties are allocated on the day, the new regulations do not reduce uncertainties in break allocation.

6.3 Recommendations and further research

6.3.1 Recommendations to operators

Overall, the findings of this thesis research indicate that in-flight sleep is well-utilized and an effective fatigue mitigation during augmented flight operations, and the qualitative findings support the position that a class 1 rest facility provides conditions that are more conducive to good quality sleep than class 2 or class 3 facilities.

In-flight sleep could be further improved by making the rest facilities more comfortable for pilots. Pilots' comments in Project C imply that adjustments to class 1 rest facilities such as the provision of better bedding, softer pillows and mattresses as well as enhanced sound-proofing are likely to have beneficial effects on the duration and quality of pilots' sleep. Where class 2 facilities are used, providing pilots with ear plugs and eye masks could help reduce sleep disturbances as these have been shown to be effective in improving subjective assessments of sleep in non-sedated critical care hospital patients (Jones & Dawson, 2012; Richardson, Allsop, Coghill, & Turnock, 2007; Scotto, McClusky, Spillan, & Kimmel, 2009). Further reduction of disturbances in such cases may also be possible if the seats allocated for crew rest can be located in an area of the cabin with fewer disturbances resulting from passenger noise and activity (e.g., towards the front of the cabin or further from small children) or away from cabin crew galleys.

The findings also highlight the importance of pilots being aware of in-flight break allocations well ahead of a flight, as this can affect the way that they prepare for the flight. However, this should not over-ride the current approach which gives the pilot-in-command the flexibility to make changes in rest break allocation according to the fatigue status of crewmembers on the day.

Within a given fleet, pilots typically have a preferred break system (e.g., a two break system or a four break system). However, an increasing body of research is confirming that the amount of in-flight sleep obtained also depends on the timing (relative to the circadian pacemaker cycle) and duration of flights. Thus on some flights, the traditional rest break pattern preferred by a fleet may not be the most appropriate for ensuring the alertness and performance of the landing crew.

6.3.2 Recommendations to crews

Based on the findings of previous field and laboratory studies, where in-flight rest break patterns are not known ahead of the duty period, it is recommended that pilots begin each duty period as well-rested as possible. Although Project B was an exception, other larger studies have shown that measures of flight crew performance at key times during the flight duty period (pre-flight and top of descent) are related to the duration of prior sleep and prior wakefulness (Gander, Mulrine, et al., 2015).

Given that in-flight sleep is an effective fatigue mitigation strategy, pilots should make the most of all of their in-flight sleep opportunities. Operational experience may indicate that sleep is more difficult during particular rest breaks on particular flights, but more sleep is always better. Use of strategies to improve in-flight sleep, for example the use of ear plugs and eye masks, is recommended.

6.3.3 Future research

The findings of this thesis research, in particular those of the qualitative analyses, highlight areas which require further investigation. Broadly speaking these areas relate to flight preparation, rest break allocation, and the layover period. The limited research currently available in these areas makes it difficult to provide more specific guidelines for the management of fatigue on long range flights.

6.3.3.1 Flight Preparation

Currently there is only limited information relating to the effects of pre-trip naps on in-flight sleep during different flight operations. Flight timing and the timing of rest breaks are known to affect in-flight sleep (Gander, Mulrine, et al., 2014; Pascoe, et al., 1995; R. M. Simons, Valk, et al., 1994). However to date only one study has investigated the effects of a pre-trip nap on in-flight sleep and findings from this study indicated that a nap prior to an evening departure does not impact on in-flight sleep duration or quality, either during the first rest period or across the flight (Signal, et al., 2014). It is likely that the timing of the flight and pre-trip nap relative to the circadian body clock cycle interact to impact on in-flight sleep.

Additional studies are needed to examine the effects of pre-trip naps on in-flight sleep across a range of flights with differing departure times. It is likely that the effects of a pre-trip nap on in-flight sleep vary depending on the timing and length of the nap as well as the flight's departure time but this also requires further investigation. Such studies would provide a scientific basis for recommendations to pilots on how best to prepare for different flights.

6.3.3.2 In-Flight Rest Break Allocation

Further studies of the effects of different break allocations and patterns would also be beneficial to improve the effective use of in-flight sleep as a fatigue mitigation strategy. Studies comparing the effects of different break patterns (e.g., one long break per pilot vs. two shorter breaks per pilot) on in-flight sleep and other safety performance indicators could help identify whether certain patterns of in-flight rest are more advantageous on specific routes (this is likely to depend on flight duration as well as departure and arrival times).

Focus groups could provide valuable insight into the effects that the FAA's new regulatory requirements for rest break allocation have had on how pilots allocate and use rest breaks. Focus groups have the particular strength in that they make it possible to centre questions around the research interests while allowing flexibility to add or modify questions based on participant responses. Such qualitative studies could also be used to investigate whether the regulatory change has affected the way in which pilots prepare for and manage their fatigue on these flights.

6.3.3.3 Layover Duration

Pilots' comments indicated different preferences relating to layover duration. Information relating to the effects of layover length on pilot fatigue is limited and findings are inconsistent, probably due to differences between studies in layover timing relative to the circadian body clock cycle (Lamond, et al., 2006; Powell, Spencer, & Petrie, 2010; Roach, Petrilli, et al., 2012).

In addition to layover duration, the timing of the layover in relation to local time and to pilots' domicile time, are likely to impact on sleep and recovery during the layover period. A better understanding of the factors that influence layover sleep and pilot recovery could help establish recommendations for airlines about layover duration based on flight arrival and departure times, and for pilots about the most effective use of the layover period for sleep. Similarly, additional research into the sleep and fatigue of pilots in the days following long haul flights could help provide crews with information on how to maximise their recovery and better prepare for subsequent trips.

6.3.3.4 Fatigue Management Education

It is also important to educate pilots on the effects of fatigue and on the effective use of available fatigue mitigation strategies. Certain comments from the qualitative analyses suggested that some pilots may underestimate the effects of fatigue and/or be uncertain as to how to best manage their fatigue. For instance, comments from pilots who “just live with it [fatigue]” or “tough it out” indicates that these individuals are unlikely to be adequately managing their fatigue and may be unaware of the adverse effects it has on their abilities. In such cases, this poor understanding of fatigue and its consequences could lead to inadequate flight preparation and may (in cases where pilots “tough it out”) result in pilots operating the aircraft while fatigued.

6.4 Conclusions

The ICAO defines a fatigue risk management system as *‘a data-driven means of continuously monitoring and managing fatigue-related safety risks, based upon scientific principles, knowledge and operational experience that aims to ensure relevant personnel are performing at adequate levels of alertness.’* (International Civil Aviation Organisation, 2015) In contrast to most research on the factors affecting pilot fatigue, the mixed methods approach taken in this thesis research compares and contrasts knowledge obtained from quantitative scientific methods with the knowledge obtained through a qualitative analysis of pilots’ perspectives and experiences.

Findings indicated that although the organisation and allocation of in-flight rest may vary, pilots generally make good use of their rest opportunities. Pilots use in-flight rest as the primary fatigue mitigation on long range flights but often also combine it with other fatigue mitigation strategies aimed at boosting alertness between rest periods and/or reducing sleep disruptions. Disturbances to in-flight sleep were frequently reported by the studied pilots who indicated that comfort, noise and timing all affect in-flight sleep duration and quality. In the qualitative component of this thesis, rest break pattern was reported to influence in-flight sleep and flight preparation but this was not supported by the quantitative findings on a specific trip and warrants further investigation.

Overall, this thesis research supports the findings of previous research relating to the use of in-flight sleep as an effective fatigue mitigation on long trans-meridian flights. The use of a mixed methods approach has led to a broader understanding of the factors affecting the effectiveness of in-flight sleep as a pilot fatigue mitigation strategy and the diverse range of operations included in the analyses has emphasised the differences and similarities in the factors that influence in-flight sleep across different flight routes. The integration of findings from the quantitative and qualitative analyses has also highlighted areas of research (including flight preparation, break allocation, and layover duration) which have not yet been investigated as they are less apparent in the findings of previous quantitative studies.

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CHAPTER 2 APPENDICES

APPENDIX 2A OVERVIEW OF METHODS FROM PREVIOUS STUDIES

Four previous aviation studies were included in the combined analyses of the retrospective questionnaire data on sleep at home and in-flight. A brief overview of these studies and the associated methods of data collection is provided below. As the Delta Air Lines B767 bunk study was modelled on previously conducted aviation studies, the methods described here are at times very similar to those of the bunk study.

2A.1 "Assessing Aircrew Sleep, Performance, and Fatigue on Ultra-Long Range and Long Range Flights" (United Airlines study) (Wu, 2012)

This study, conducted with United Airlines, was part of a larger three-airline study commissioned by the FAA, Delta Air Lines, United Airlines and a third US-based airline to provide scientific evidence on the safety of ultra-long range (ULR) flights following these three airlines' public opposition of the FAA's draft of proposed rulemaking (OpSpec A332) which aimed to regulate ULR flights. ULR flights were compared to long range (LR) flights, which are generally regarded as "safe" in the aviation industry, to establish whether they posed a safety risk from a sleep and fatigue point of view.

The three-airline study was monitored by a Scientific Steering Committee (SSC), a group made up of representatives from each airline's management and independent scientific research teams, of representatives from the FAA, and of union representatives (including two independent scientific reviewers chosen by the unions). In addition to the individual ethical approvals received by the three research groups for their part in the study, a Certificate of Confidentiality was obtained from the United States National Institutes of Health (NIH) to further protect the confidentiality of the participants.

This part of the three-airline study was reviewed by, and obtained ethical approval from the Washington State University Institutional Review Board (IRB# 10951). Data was collected between November 2009 and April 2011 by a team of researchers at the Sleep and Performance Research Center at Washington State University. The author was a member of this research team during the recruitment and data collection phases of this project.

In this study, objective and subjective measures of sleep and performance were collected and compared, using a within subjects design, between ULR and LR flights. Participants were studied on one LR flight pairing and one ULR pairing (four flights total). Their sleep was monitored continuously using an actigraph (the Actiwatch Spectrum, from Philips Respironics, Bend, Oregon, USA, set to record in 60 second epochs) from three days before the outbound flight of their first pairing to three days after the inbound flight of their second pairing. During this time participants were also asked to complete a duty/sleep diary (virtually identical to the one used in the Delta Air Lines B767 bunk study) where they recorded any sleep period longer than 10 minutes, completed fatigue (Samn-Perelli Crew Status Check, SP), sleepiness (Karolinska Sleepiness Scale, KSS) and sleep quality ratings for each sleep period, and provided information about their flights (including subjective fatigue [SP] and sleepiness [KSS] ratings). They also completed Psychomotor Vigilance Task (PVT) tests at various points during all four of their flights using the same version of the PVT as in the Delta Air Lines B767 bunk study (PalmPVT ported to a PalmCentro Smartphone). The times the PVT tests were taken were: prior to take-off but after reporting for duty, within 30 minutes after top of climb (TOC) (except where the participant was taking the first break), before each in-flight break, after their last in-flight break, and within 30 minutes prior to top of descent (TOD) (except where the participant had taken the last break). This is illustrated in Figure 2A.1 below. Participants were also asked to complete a paper "Pre-Study Questionnaire" before their data collection period which included questions relating to flight crew experience, sleep at home and in-flight sleep (Appendix 3B, similar to that of the Delta Air Lines B767 bunk study).

Figure 2A.1 Timing of in-flight tests and ratings (United Airlines study)

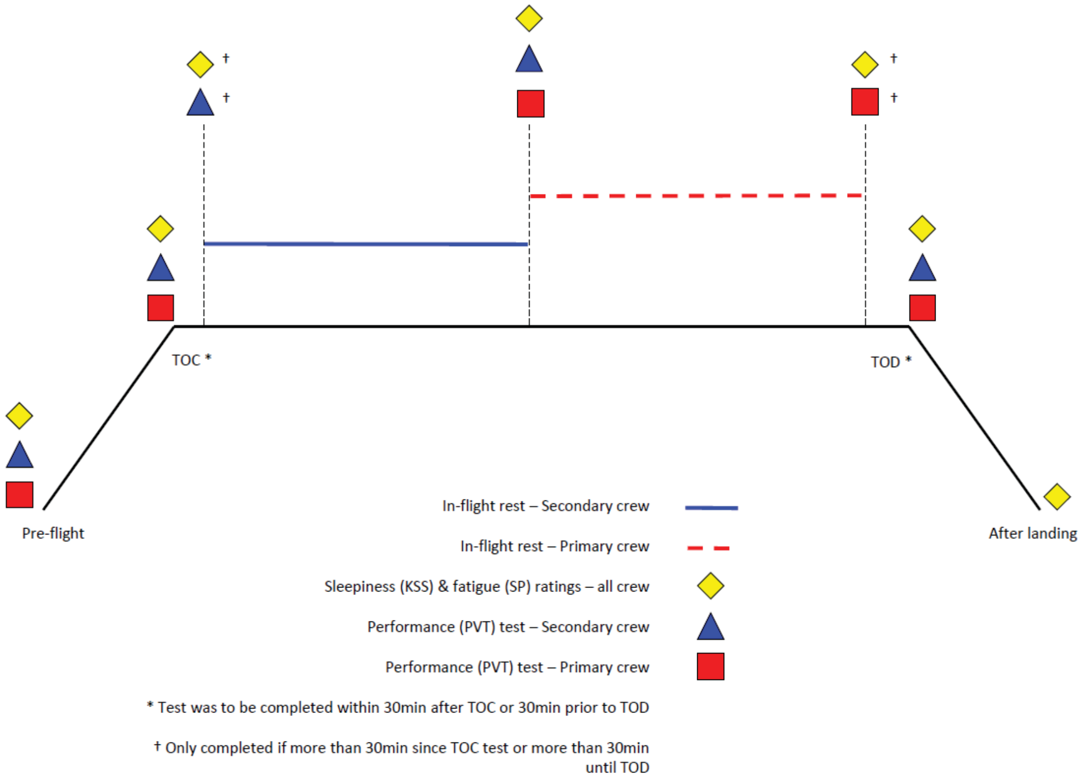


Figure key: TOC= Top of climb [when levelling off at cruising altitude], TOD= Top of descent [when beginning descent from cruising altitude for landing]

2A.2 “Comparison of Flight Crew Sleep and Fatigue during Delta Air Lines Long Range and Ultra-Long Range Operations” (Delta Air Lines B777 study) (Gander, et al., 2011)

This study, conducted with Delta Air Lines, was part of the previously mentioned three airline study comparing ULR and LR flights. In addition to the previously mentioned NIH Certificate of Confidentiality, the study was reviewed by, and received ethical approval from the Massey University Human Ethics Committee: Southern A (application 08/68) which is also a registered Independent Review Board (IRB# 00006014, FWA #00011627). Data was collected between November 2009 and November 2010 by a data collection team at Delta Air Lines in collaboration with researchers at the Sleep/Wake Research Centre at Massey University.

The aims and methods of this study were agreed by the SSC and therefore were identical to those described (above) for the United Airlines part of this three-airline study. The only exceptions were:

- the model of actigraph used (in this case the Actiwatch AW-64, from Respironics Mini Mitter, Bend, Oregon, USA, set to record in 60 second epochs); and
- the number and timing of required PVT tests: in this study, participants were only asked to complete PVT tests pre-flight, at the start of each of their rest breaks, and at the end of their last rest break (no test was required at TOD) as is illustrated in Figure 2A.2.

Figure 2A.2 Timing of in-flight tests and ratings (Delta Air Lines B777 study)

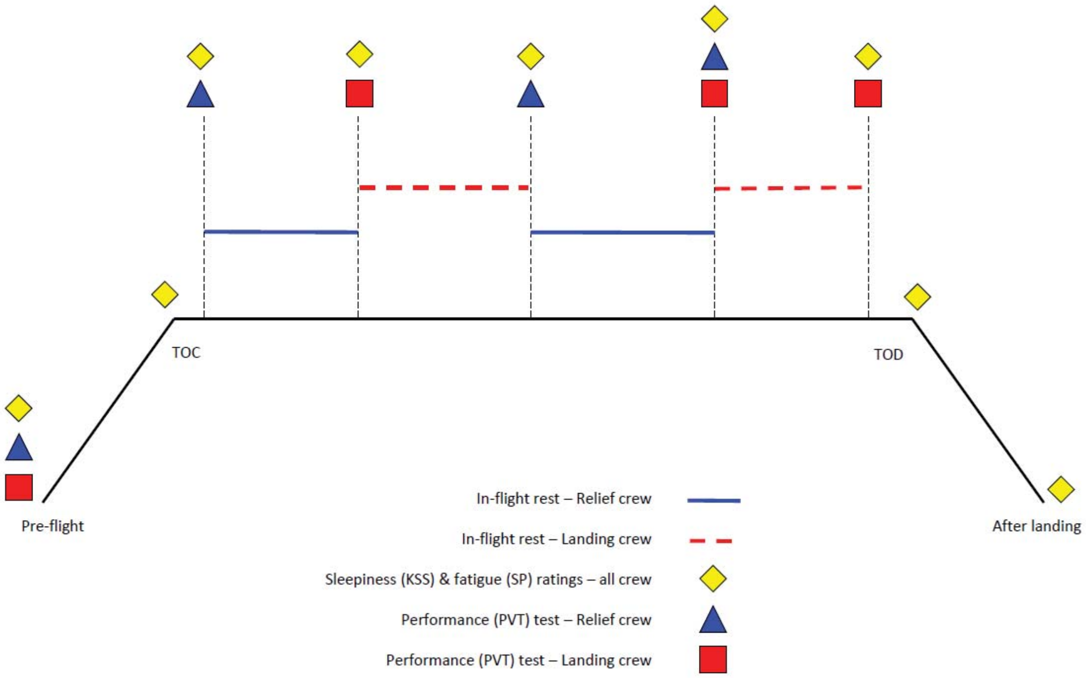


Figure key: TOC= Top of climb [when levelling off at cruising altitude], TOD= Top of descent [when beginning descent from cruising altitude for landing]

2A.3 “Evaluation of the Sleep and Performance of South African Airways Flight Crew on the Johannesburg-New York Ultra-Long Range Flight” (South African Airways study) (Signal, Mulrine, et al., 2013)

This study, conducted with South African Airways, aimed to evaluate the effects of a specific ULR route (the Johannesburg [JNB] to New York [JFK] pairing) on pilots’ sleep and performance. In particular, it was aimed at:

- establishing whether the JNB-JFK-JNB trip degraded pilots’ performance and alertness;
- documenting the timing and duration of pilots’ sleep on layovers;
- documenting the timing and duration of in-flight sleep;
- establishing how many recovery days are required post-trip for fatigue and sleep to return to their pre-trip levels; and
- benchmarking the JNB-JFK-JNB ULR trip against similar ULR routes where sleep and performance data had previously been collected.

In addition, the study aimed to help South African Airways in the development of their own Fatigue Risk Management System (FRMS).

The study was reviewed by, and received ethical approval from the Massey University Human Ethics Committee (application 11/74). Data was collected between December 2011 and May 2012 by a data collection team at South African Airways in collaboration with researchers at the Sleep/Wake Research Centre at Massey University.

The methods in this study were similar to those of the Delta Air Lines B767 bunk study. During their study period, participants were asked to complete a duty/sleep diary where they recorded all sleep periods longer than 10 minutes, completed fatigue (SP), sleepiness (KSS) and sleep quality ratings for each of these sleep periods, and provided information about their flights. Their sleep was monitored continuously from 3 days prior to their outbound flight until 5 days after their inbound flight using an actigraph (the Actiwatch

Spectrum, from Philips Respironics, Bend, Oregon, USA, set to record in 60 second epochs). Their performance across the flights was measured using the same PVT test as in the Delta Air Lines B767 bunk study (PalmPVT ported to a PalmCentro Smartphone). Participants were asked to complete the PVT: prior to take-off but after reporting for duty, at TOC, at the beginning of their first in-flight rest break (unless this was within an hour of TOC), at the beginning of their second rest break, at the end of their second rest break, and within one hour of TOD (unless their last PVT fell within this time frame) (see Figure 2A.3). Participants were also asked to complete a "Pre-Study Questionnaire" (Appendix 3C, similar to that of the Delta Air Lines B767 bunk study) prior to the commencement of their data collection period.

Figure 2A.3 Timing of in-flight tests and ratings (South African Airways study)

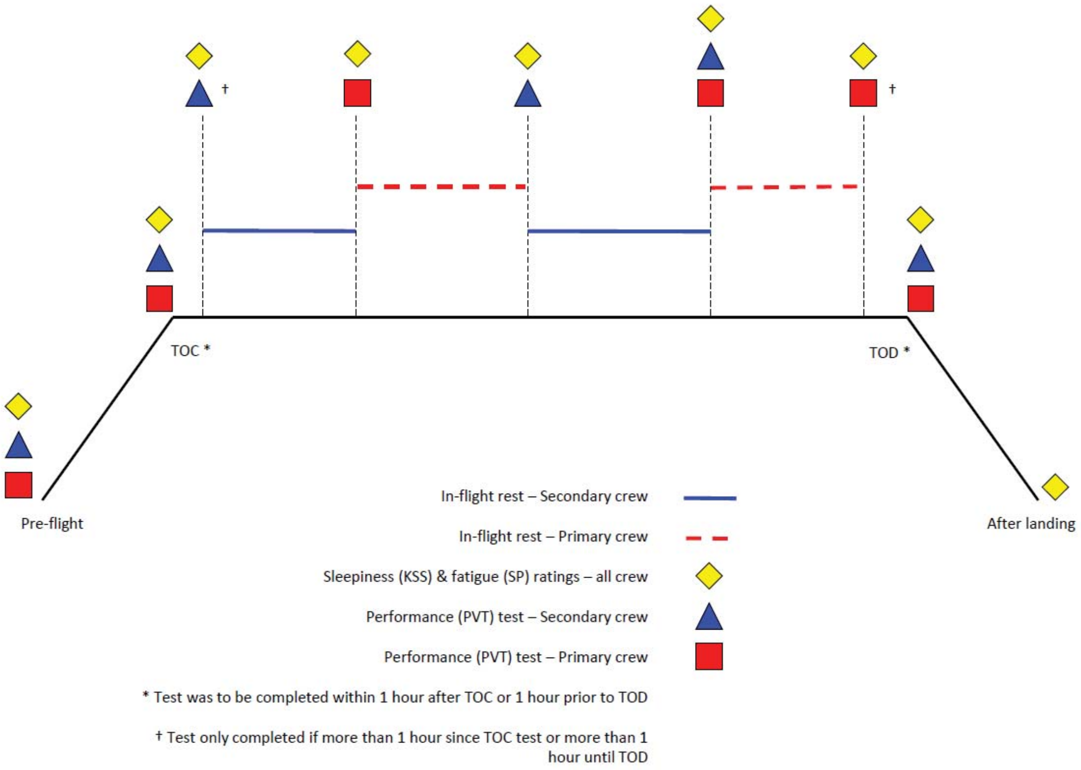


Figure key: TOC= Top of climb [when levelling off at cruising altitude], TOD= Top of descent [when beginning descent from cruising altitude for landing]

2A.4 "Phase 3 Ultra-Long-Range Validation: Polysomnographic Sleep and Psychomotor Performance" (Singapore Airlines study) (Signal, et al., 2004)

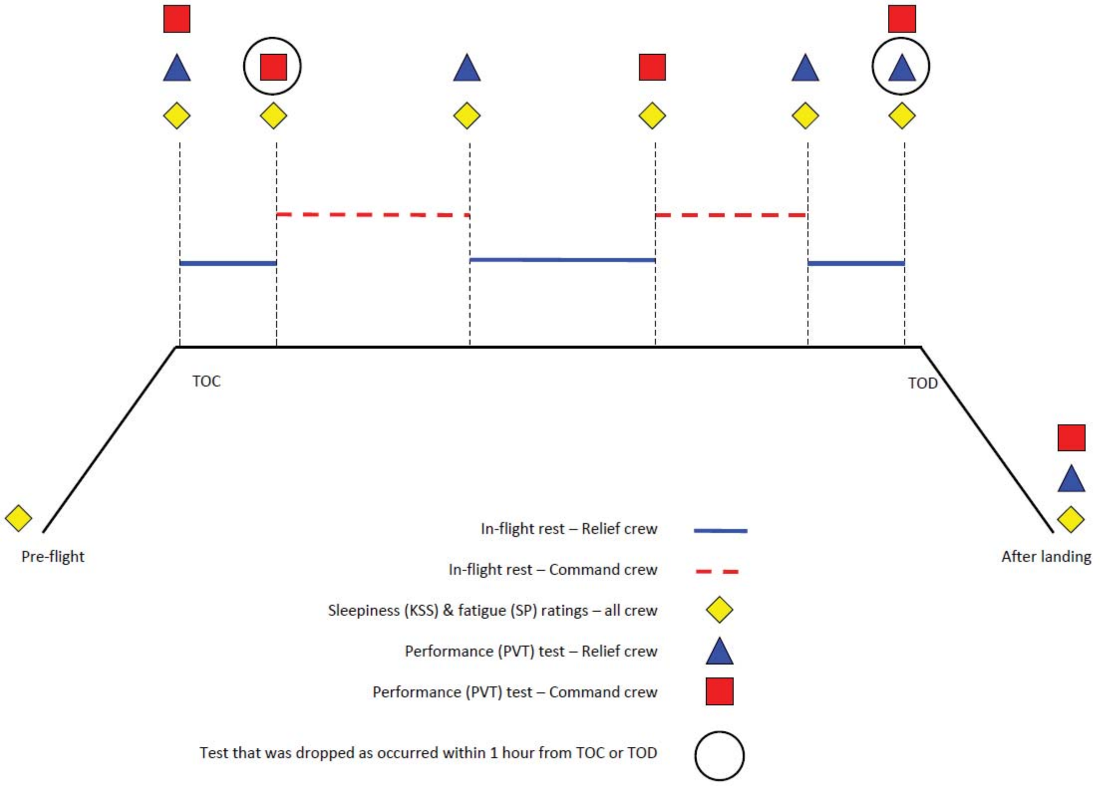
This study, conducted with Singapore Airlines, was part of a larger validation study commissioned by the Civil Aviation Authority of Singapore (CAAS) to validate the Singapore (SIN) to Los Angeles (LAX) ULR operation (the first of its kind). This part of the study aimed to document the amount and quality of sleep obtained by pilots on the SIN-LAX-SIN ULR pairing, as well as to document the alertness of pilots on ULR flights.

The study was reviewed by, and received ethical approval from the Massey University Human Ethics Committee (WGTN Protocol 04/03). Data was collected in April and June of 2004 by researchers from the Sleep/Wake Research Centre at Massey University.

The methods in this study were similar to those of Delta Air Lines B767 bunk study. Participants were asked to complete a "Pre-Study Questionnaire" prior to their study period (Appendix 3D). During their data collection period they were asked to complete a duty/sleep diary (in which they recorded any sleep periods longer than 10 minutes, completed fatigue [SP], sleepiness [KSS] and sleep quality ratings, and provided information about their flights). Their sleep was monitored continuously from 4 days prior to their outbound flight until 4 days after their inbound flight using an actigraph (the Actiwatch AW-64, from Mini Mitter, Bend, Oregon, set to record in 30 second epochs). Some pilots also had their in-flight sleep monitored by polysomnography (PSG). Pilots performance was measured in-flight using a 10-minute version of the PVT (PVT-192, produced by CWE Inc., distributed by Ambulatory Monitoring, Inc.). Due to the pattern of rest breaks, relief and command crews completed their PVTs at different times (Figure 2A.4):

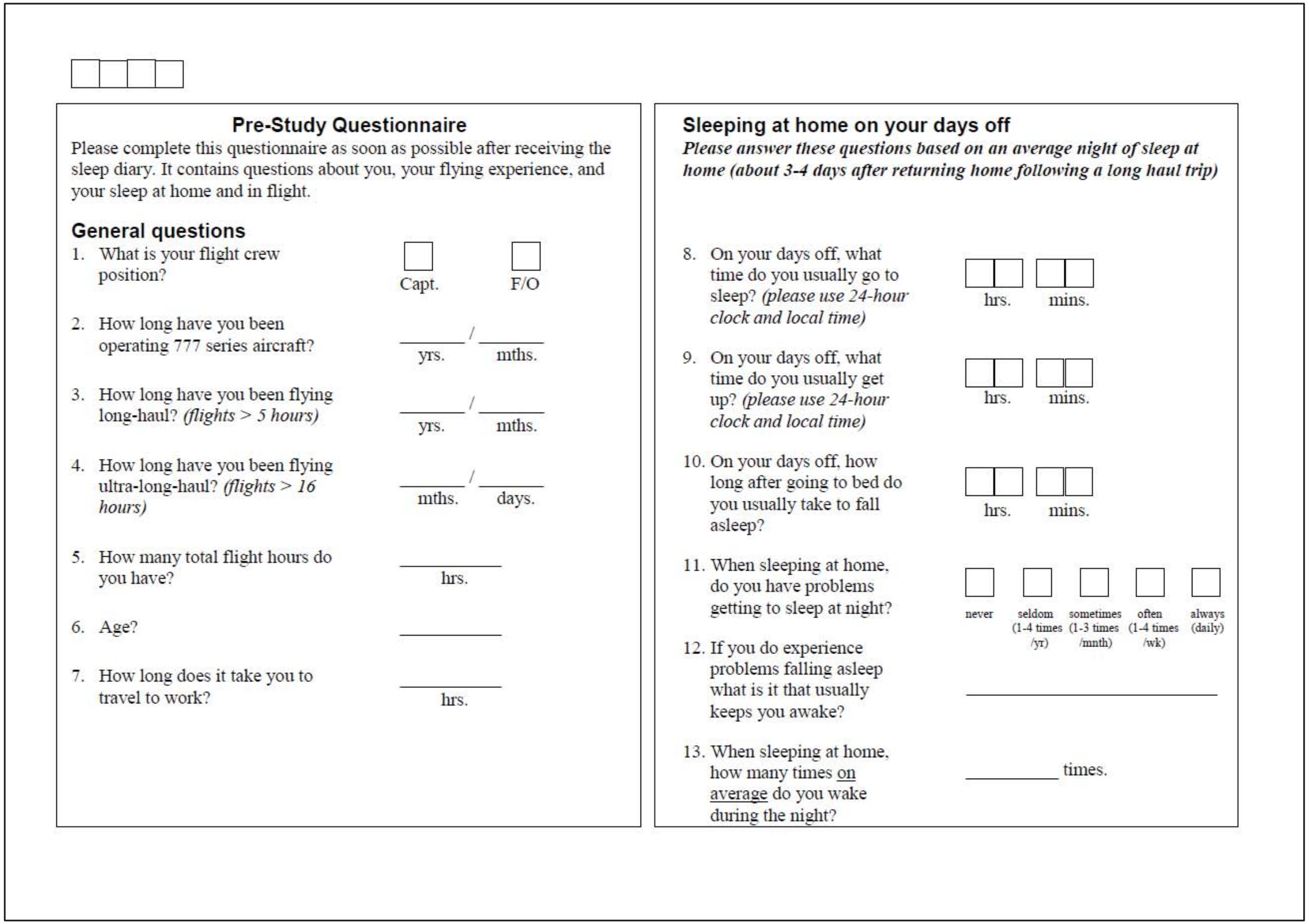
- command crews completed the PVT at TOC, at the beginning of their second rest break, at TOD, and after landing prior to disembarking the aircraft; while
- relief crews completed the PVT at TOC, at the beginning of their second and third rest breaks, and after landing prior to disembarking the aircraft.

Figure 2A.4 Timing of in-flight tests and ratings (Singapore Airlines study)



<u>Figure key:</u> TOC= Top of climb [when levelling off at cruising altitude], TOD= Top of descent [when beginning descent from cruising altitude for landing]

APPENDIX 2B PRE-STUDY QUESTIONNAIRE (B777 STUDIES)



☐☐☐☐

Pre-Study Questionnaire

Please complete this questionnaire as soon as possible after receiving the sleep diary. It contains questions about you, your flying experience, and your sleep at home and in flight.

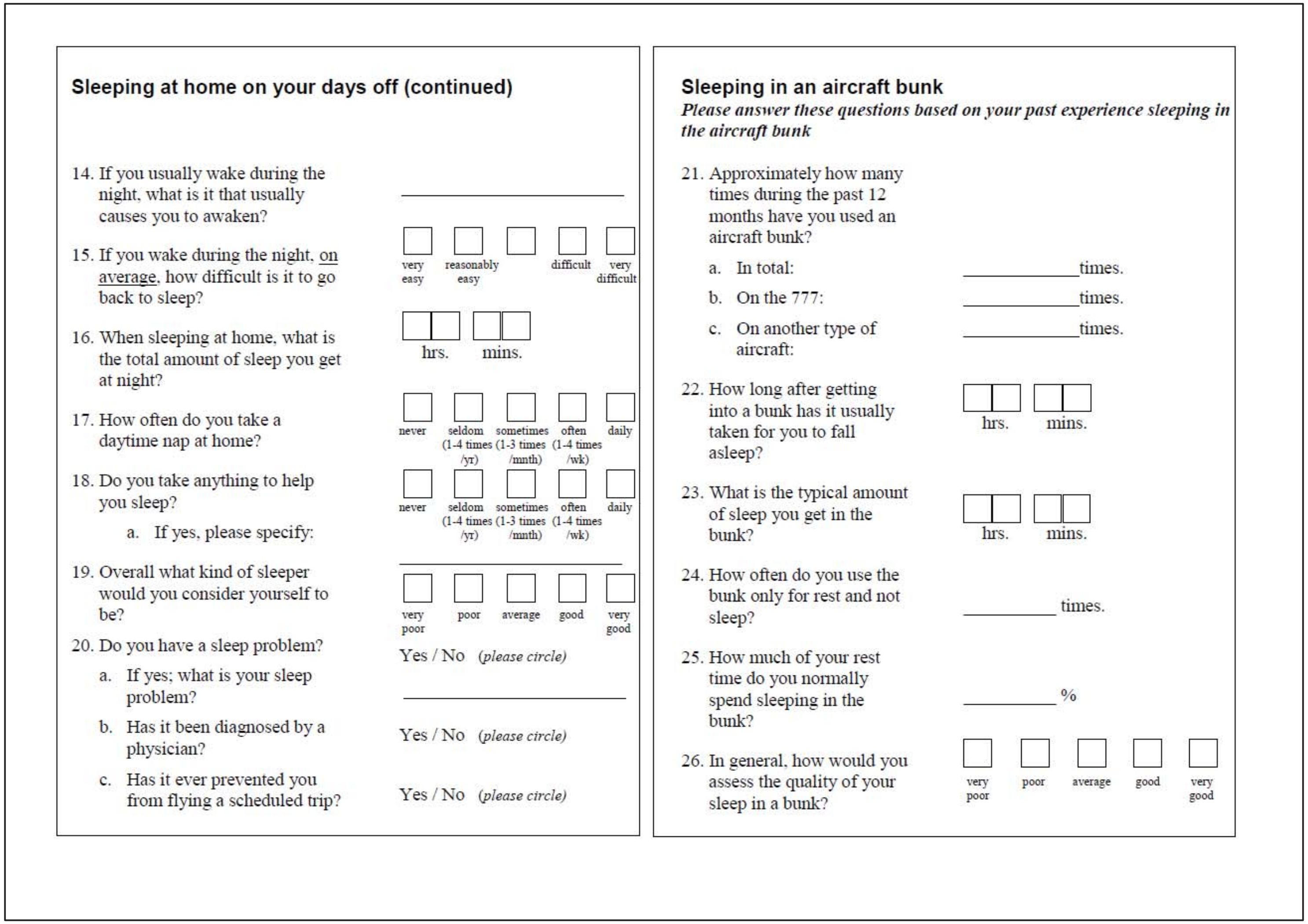
General questions

1. What is your flight crew position? ☐ Capt. ☐ F/O
2. How long have you been operating 777 series aircraft? ______ yrs. / ______ mths.
3. How long have you been flying long-haul? *(flights > 5 hours)* ______ yrs. / ______ mths.
4. How long have you been flying ultra-long-haul? *(flights > 16 hours)* ______ mths. / ______ days.
5. How many total flight hours do you have? ______ hrs.
6. Age? ______
7. How long does it take you to travel to work? ______ hrs.

Sleeping at home on your days off

Please answer these questions based on an average night of sleep at home (about 3-4 days after returning home following a long haul trip)

8. On your days off, what time do you usually go to sleep? *(please use 24-hour clock and local time)* ☐☐ hrs. ☐☐ mins.
9. On your days off, what time do you usually get up? *(please use 24-hour clock and local time)* ☐☐ hrs. ☐☐ mins.
10. On your days off, how long after going to bed do you usually take to fall asleep? ☐☐ hrs. ☐☐ mins.
11. When sleeping at home, do you have problems getting to sleep at night? ☐ never ☐ seldom (1-4 times /yr) ☐ sometimes (1-3 times /mnth) ☐ often (1-4 times /wk) ☐ always (daily)
12. If you do experience problems falling asleep what is it that usually keeps you awake? ______________________
13. When sleeping at home, how many times <u>on average</u> do you wake during the night? ______ times.



Sleeping at home on your days off (continued)

14. If you usually wake during the night, what is it that usually causes you to awaken? ____________________

15. If you wake during the night, <u>on average</u>, how difficult is it to go back to sleep?
☐ very easy ☐ reasonably easy ☐ ☐ difficult ☐ very difficult

16. When sleeping at home, what is the total amount of sleep you get at night?
☐☐ hrs. ☐☐ mins.

17. How often do you take a daytime nap at home?
☐ never ☐ seldom (1-4 times /yr) ☐ sometimes (1-3 times /mnth) ☐ often (1-4 times /wk) ☐ daily

18. Do you take anything to help you sleep?
☐ never ☐ seldom (1-4 times /yr) ☐ sometimes (1-3 times /mnth) ☐ often (1-4 times /wk) ☐ daily

a. If yes, please specify: ____________________

19. Overall what kind of sleeper would you consider yourself to be?
☐ very poor ☐ poor ☐ average ☐ good ☐ very good

20. Do you have a sleep problem? Yes / No *(please circle)*

a. If yes; what is your sleep problem? ____________________

b. Has it been diagnosed by a physician? Yes / No *(please circle)*

c. Has it ever prevented you from flying a scheduled trip? Yes / No *(please circle)*

Sleeping in an aircraft bunk

Please answer these questions based on your past experience sleeping in the aircraft bunk

21. Approximately how many times during the past 12 months have you used an aircraft bunk?

a. In total: ____________times.

b. On the 777: ____________times.

c. On another type of aircraft: ____________times.

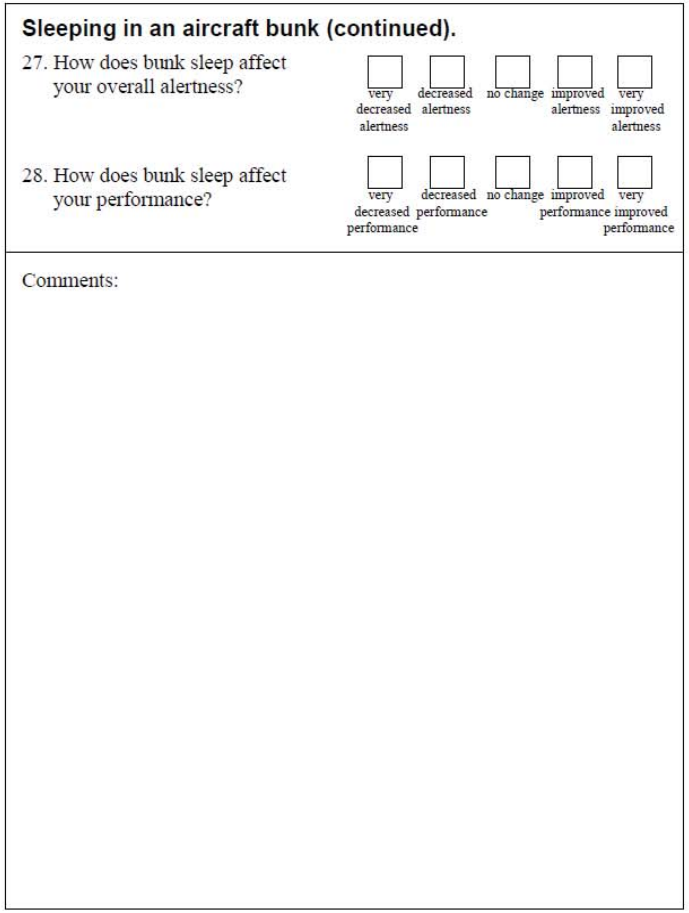
22. How long after getting into a bunk has it usually taken for you to fall asleep?
☐☐ hrs. ☐☐ mins.

23. What is the typical amount of sleep you get in the bunk?
☐☐ hrs. ☐☐ mins.

24. How often do you use the bunk only for rest and not sleep? __________ times.

25. How much of your rest time do you normally spend sleeping in the bunk? __________ %

26. In general, how would you assess the quality of your sleep in a bunk?
☐ very poor ☐ poor ☐ average ☐ good ☐ very good

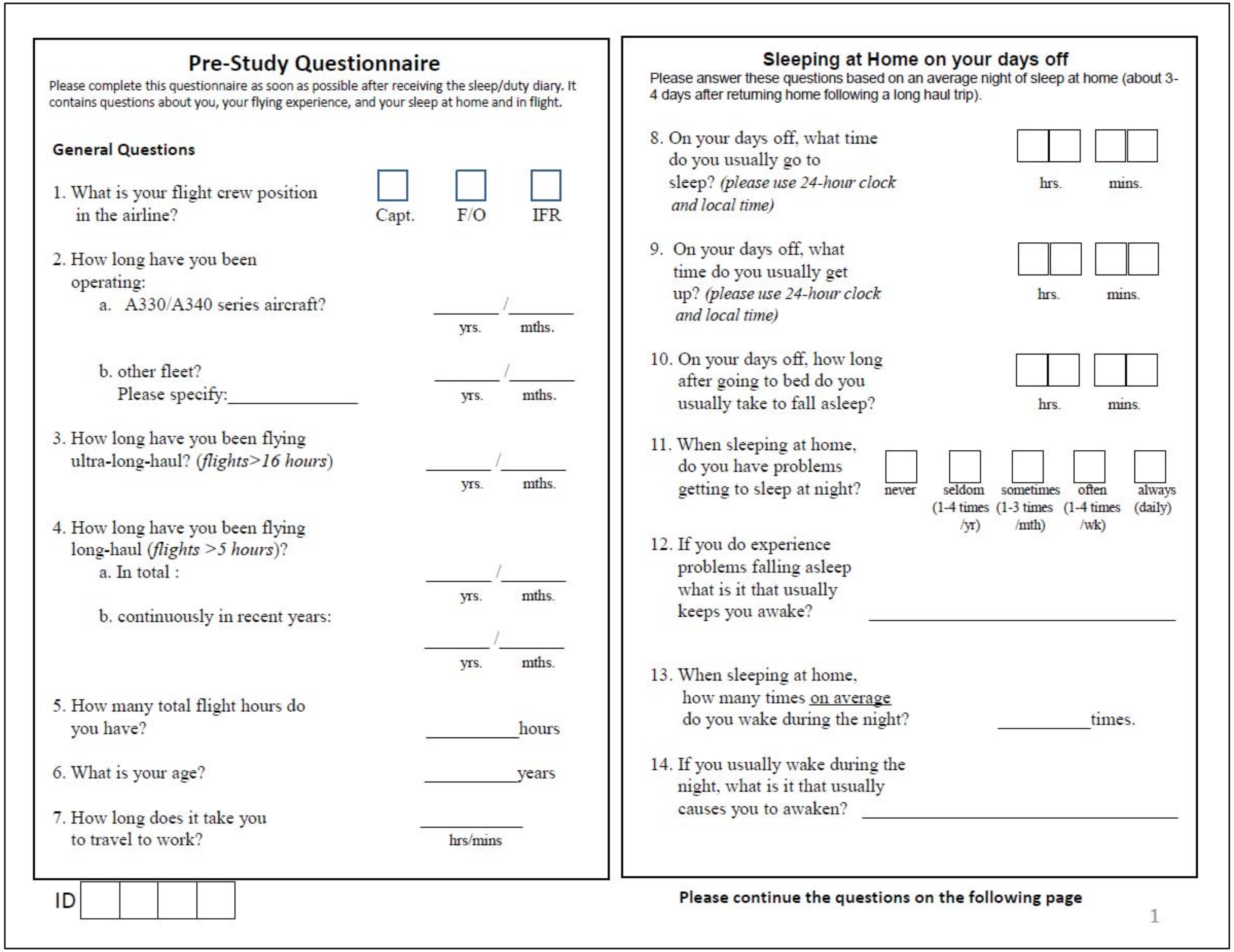


Sleeping in an aircraft bunk (continued).

27. How does bunk sleep affect your overall alertness?	☐ very decreased alertness	☐ decreased alertness	☐ no change	☐ improved alertness	☐ very improved alertness
28. How does bunk sleep affect your performance?	☐ very decreased performance	☐ decreased performance	☐ no change	☐ improved performance	☐ very improved performance

Comments:

APPENDIX 2C PRE-STUDY QUESTIONNAIRE (SOUTH AFRICAN AIRWAYS STUDY)



Pre-Study Questionnaire

Please complete this questionnaire as soon as possible after receiving the sleep/duty diary. It contains questions about you, your flying experience, and your sleep at home and in flight.

General Questions

1. What is your flight crew position in the airline? ☐ Capt. ☐ F/O ☐ IFR

2. How long have you been operating:
    a. A330/A340 series aircraft? ______ yrs. / ______ mths.
    b. other fleet? Please specify:____________ ______ yrs. / ______ mths.

3. How long have you been flying ultra-long-haul? (*flights>16 hours*) ______ yrs. / ______ mths.

4. How long have you been flying long-haul (*flights >5 hours*)?
    a. In total : ______ yrs. / ______ mths.
    b. continuously in recent years: ______ yrs. / ______ mths.

5. How many total flight hours do you have? ________hours

6. What is your age? ________years

7. How long does it take you to travel to work? ________ hrs/mins

ID ☐☐☐☐

Sleeping at Home on your days off

Please answer these questions based on an average night of sleep at home (about 3-4 days after returning home following a long haul trip).

8. On your days off, what time do you usually go to sleep? *(please use 24-hour clock and local time)* ☐☐ hrs. ☐☐ mins.

9. On your days off, what time do you usually get up? *(please use 24-hour clock and local time)* ☐☐ hrs. ☐☐ mins.

10. On your days off, how long after going to bed do you usually take to fall asleep? ☐☐ hrs. ☐☐ mins.

11. When sleeping at home, do you have problems getting to sleep at night? ☐ never ☐ seldom (1-4 times /yr) ☐ sometimes (1-3 times /mth) ☐ often (1-4 times /wk) ☐ always (daily)

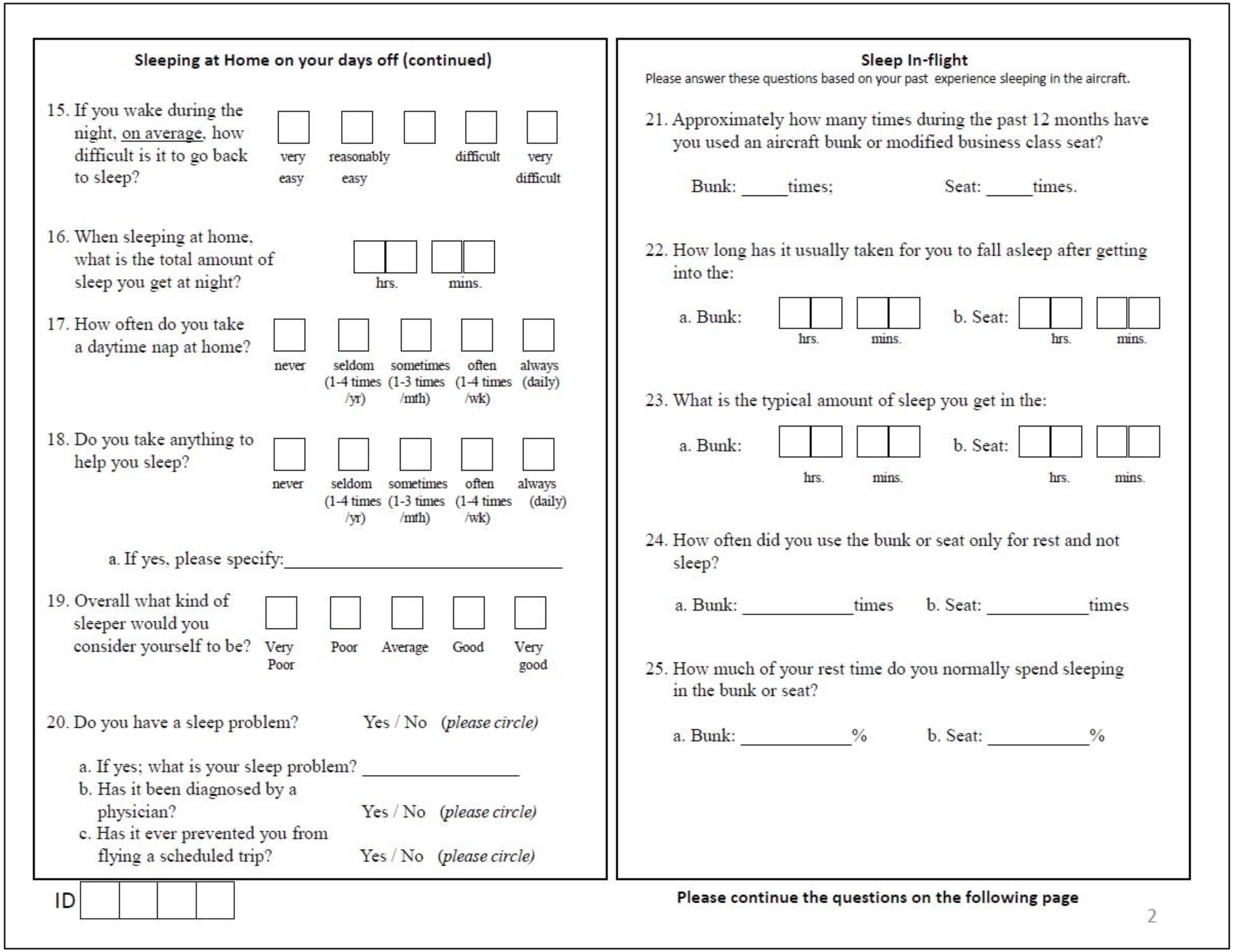
12. If you do experience problems falling asleep what is it that usually keeps you awake? ______________________________

13. When sleeping at home, how many times on average do you wake during the night? ________times.

14. If you usually wake during the night, what is it that usually causes you to awaken? ______________________________

Please continue the questions on the following page

1



Sleeping at Home on your days off (continued)

15. If you wake during the night, on average, how difficult is it to go back to sleep?
☐ very easy ☐ reasonably easy ☐ ☐ difficult ☐ very difficult

16. When sleeping at home, what is the total amount of sleep you get at night?
☐☐ hrs. ☐☐ mins.

17. How often do you take a daytime nap at home?
☐ never ☐ seldom (1-4 times /yr) ☐ sometimes (1-3 times /mth) ☐ often (1-4 times /wk) ☐ always (daily)

18. Do you take anything to help you sleep?
☐ never ☐ seldom (1-4 times /yr) ☐ sometimes (1-3 times /mth) ☐ often (1-4 times /wk) ☐ always (daily)

a. If yes, please specify:______________________________

19. Overall what kind of sleeper would you consider yourself to be?
☐ Very Poor ☐ Poor ☐ Average ☐ Good ☐ Very good

20. Do you have a sleep problem? Yes / No *(please circle)*

a. If yes; what is your sleep problem? ________________

b. Has it been diagnosed by a physician? Yes / No *(please circle)*

c. Has it ever prevented you from flying a scheduled trip? Yes / No *(please circle)*

ID ☐☐☐☐

Sleep In-flight

Please answer these questions based on your past experience sleeping in the aircraft.

21. Approximately how many times during the past 12 months have you used an aircraft bunk or modified business class seat?

Bunk: _____times; Seat: _____times.

22. How long has it usually taken for you to fall asleep after getting into the:

a. Bunk: ☐☐ hrs. ☐☐ mins. b. Seat: ☐☐ hrs. ☐☐ mins.

23. What is the typical amount of sleep you get in the:

a. Bunk: ☐☐ hrs. ☐☐ mins. b. Seat: ☐☐ hrs. ☐☐ mins.

24. How often did you use the bunk or seat only for rest and not sleep?

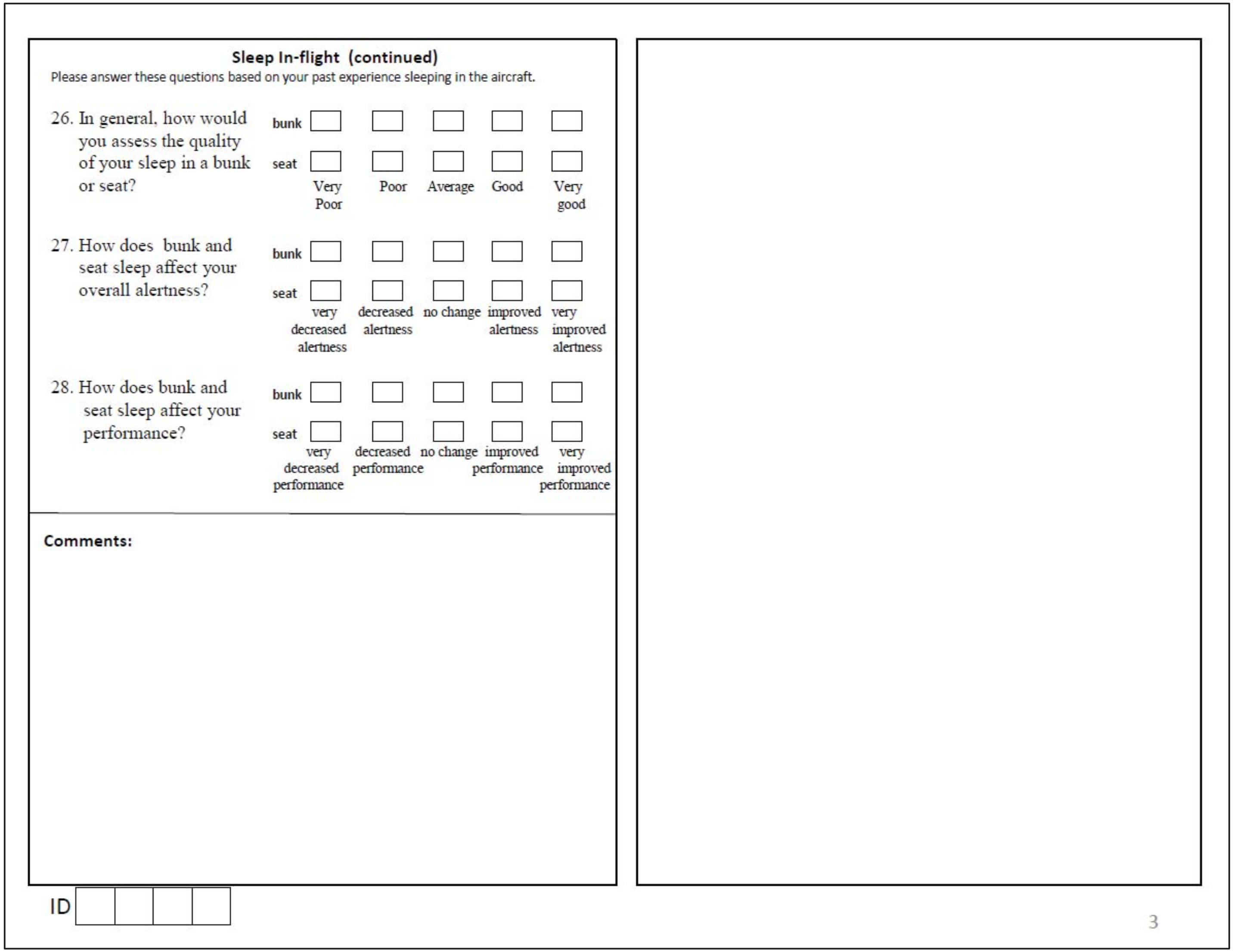
a. Bunk: ___________times b. Seat: ___________times

25. How much of your rest time do you normally spend sleeping in the bunk or seat?

a. Bunk: ___________% b. Seat: ___________%

Please continue the questions on the following page

2



Sleep In-flight (continued)

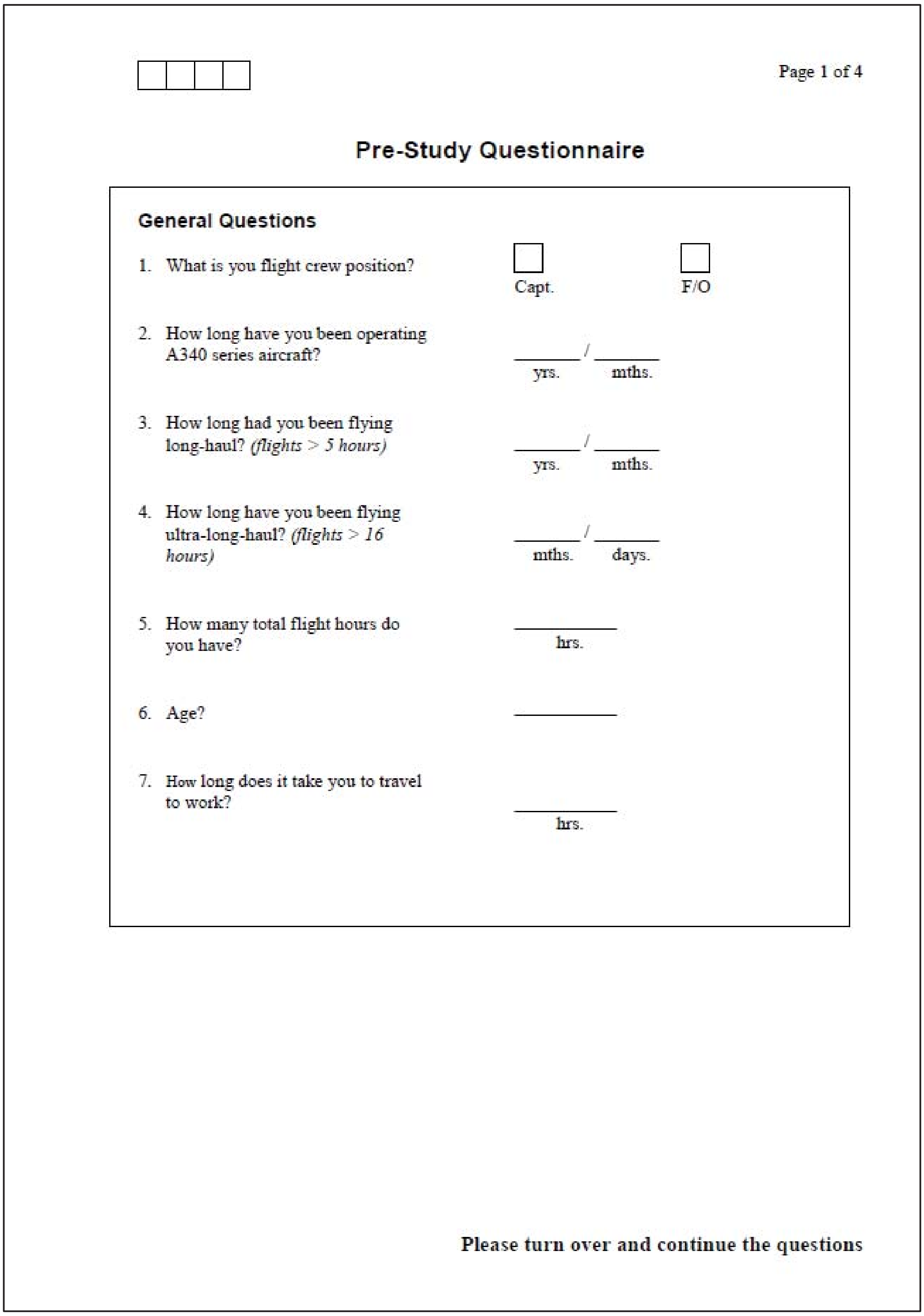
Please answer these questions based on your past experience sleeping in the aircraft.

26. In general, how would you assess the quality of your sleep in a bunk or seat?	bunk	☐	☐	☐	☐	☐
	seat	☐	☐	☐	☐	☐
		Very Poor	Poor	Average	Good	Very good
27. How does bunk and seat sleep affect your overall alertness?	bunk	☐	☐	☐	☐	☐
	seat	☐	☐	☐	☐	☐
		very decreased alertness	decreased alertness	no change	improved alertness	very improved alertness
28. How does bunk and seat sleep affect your performance?	bunk	☐	☐	☐	☐	☐
	seat	☐	☐	☐	☐	☐
		very decreased performance	decreased performance	no change	improved performance	very improved performance

Comments:

ID ☐☐☐☐

APPENDIX 2D PRE-STUDY QUESTIONNAIRE (SINGAPORE AIRLINES STUDY)



☐☐☐☐

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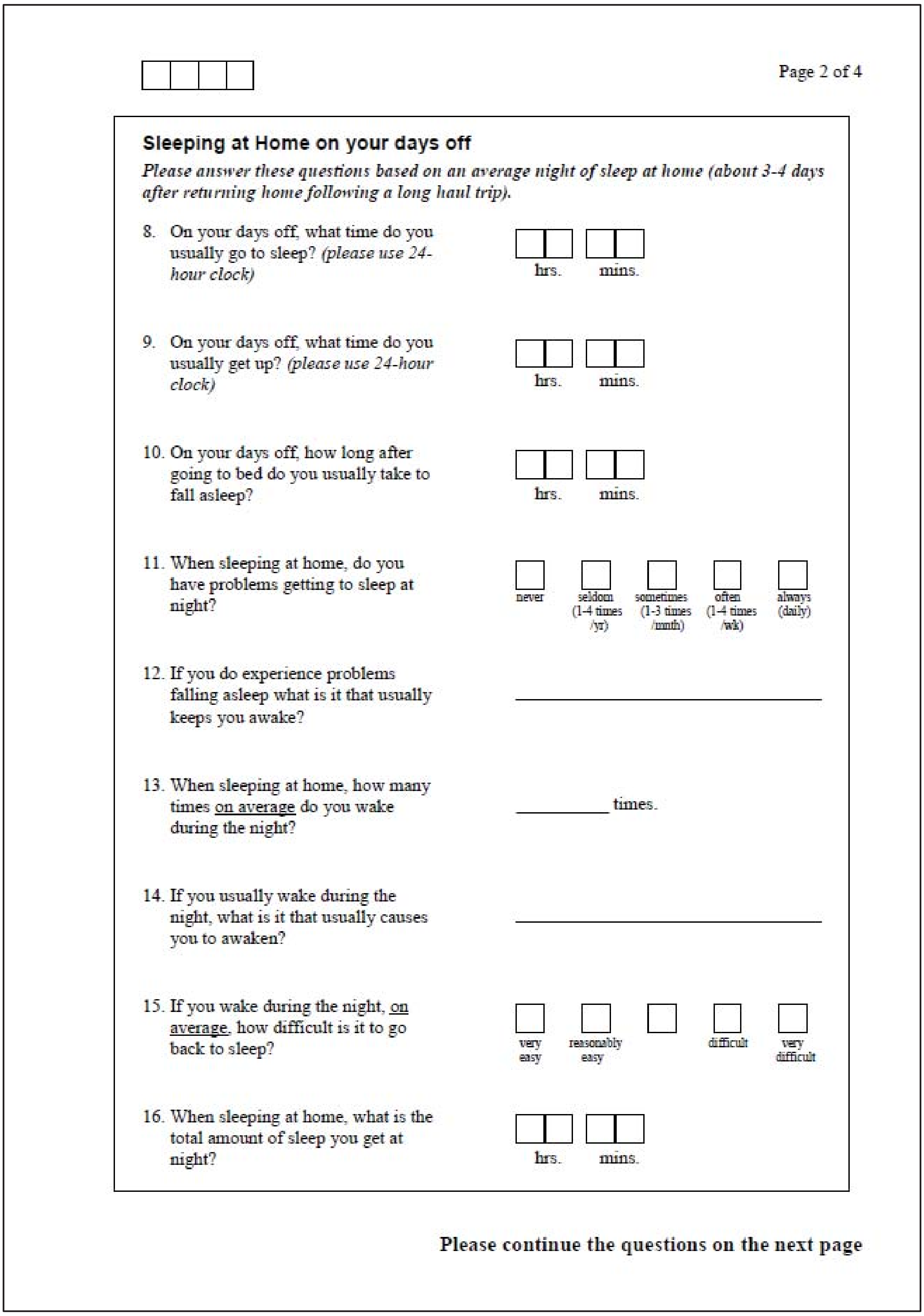
Pre-Study Questionnaire

General Questions

1. What is you flight crew position? ☐ Capt. ☐ F/O
2. How long have you been operating A340 series aircraft? ______ / ______ yrs. mths.
3. How long had you been flying long-haul? *(flights > 5 hours)* ______ / ______ yrs. mths.
4. How long have you been flying ultra-long-haul? *(flights > 16 hours)* ______ / ______ mths. days.
5. How many total flight hours do you have? __________ hrs.
6. Age? __________
7. How long does it take you to travel to work? __________ hrs.

Please turn over and continue the questions



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Sleeping at Home on your days off

Please answer these questions based on an average night of sleep at home (about 3-4 days after returning home following a long haul trip).

8. On your days off, what time do you usually go to sleep? *(please use 24-hour clock)*
   ☐☐ hrs. ☐☐ mins.

9. On your days off, what time do you usually get up? *(please use 24-hour clock)*
   ☐☐ hrs. ☐☐ mins.

10. On your days off, how long after going to bed do you usually take to fall asleep?
    ☐☐ hrs. ☐☐ mins.

11. When sleeping at home, do you have problems getting to sleep at night?
    ☐ never ☐ seldom (1-4 times /yr) ☐ sometimes (1-3 times /mnth) ☐ often (1-4 times /wk) ☐ always (daily)

12. If you do experience problems falling asleep what is it that usually keeps you awake?
    ____

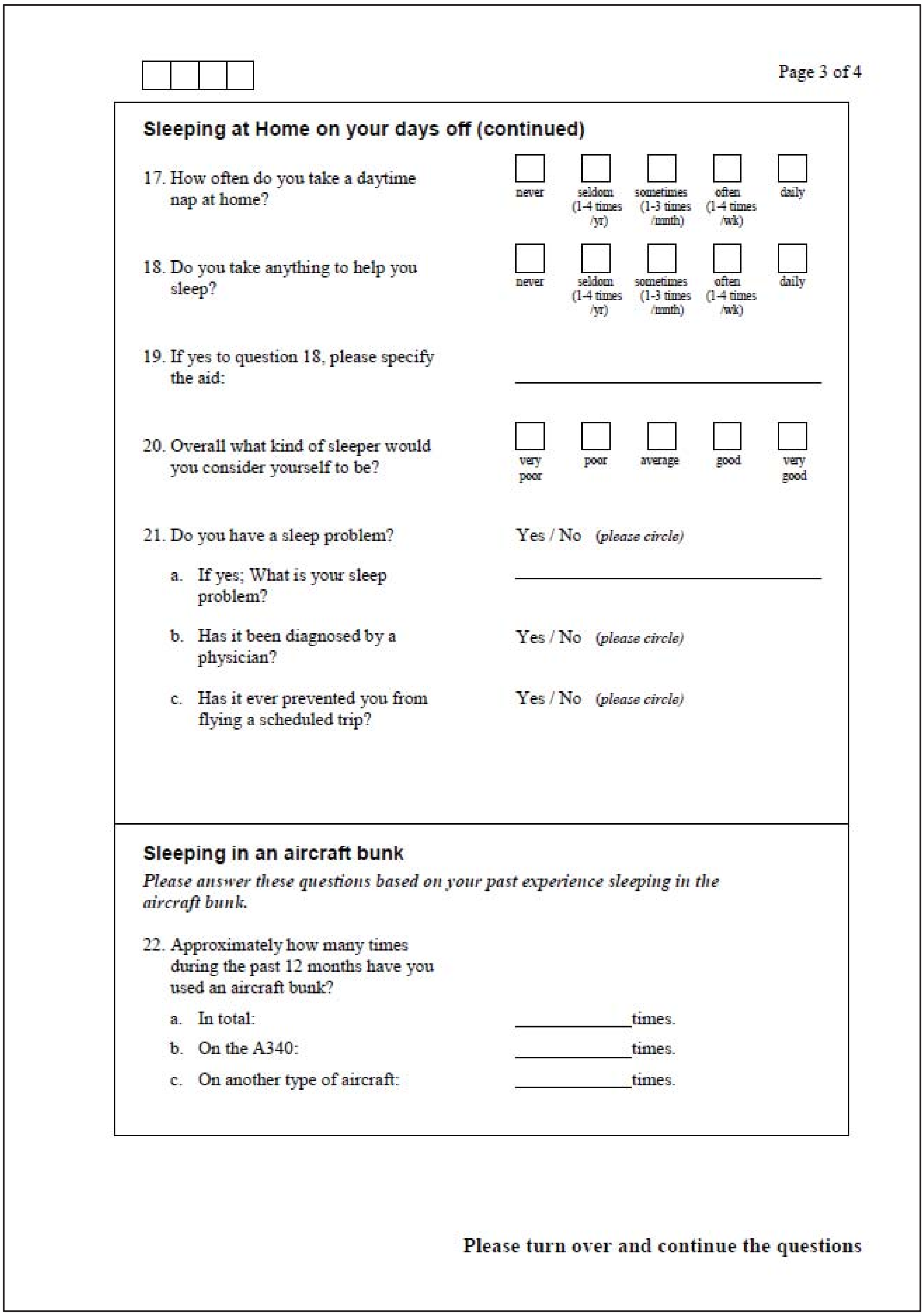
13. When sleeping at home, how many times on average do you wake during the night?
    __________ times.

14. If you usually wake during the night, what is it that usually causes you to awaken?
    ____

15. If you wake during the night, on average, how difficult is it to go back to sleep?
    ☐ very easy ☐ reasonably easy ☐ ☐ difficult ☐ very difficult

16. When sleeping at home, what is the total amount of sleep you get at night?
    ☐☐ hrs. ☐☐ mins.

Please continue the questions on the next page



☐☐☐☐

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Sleeping at Home on your days off (continued)

17. How often do you take a daytime nap at home?	☐ never	☐ seldom (1-4 times /yr)	☐ sometimes (1-3 times /mnth)	☐ often (1-4 times /wk)	☐ daily
18. Do you take anything to help you sleep?	☐ never	☐ seldom (1-4 times /yr)	☐ sometimes (1-3 times /mnth)	☐ often (1-4 times /wk)	☐ daily
19. If yes to question 18, please specify the aid:	________________				
20. Overall what kind of sleeper would you consider yourself to be?	☐ very poor	☐ poor	☐ average	☐ good	☐ very good

21. Do you have a sleep problem? Yes / No *(please circle)*

a. If yes; What is your sleep problem? ________________

b. Has it been diagnosed by a physician? Yes / No *(please circle)*

c. Has it ever prevented you from flying a scheduled trip? Yes / No *(please circle)*

Sleeping in an aircraft bunk

Please answer these questions based on your past experience sleeping in the aircraft bunk.

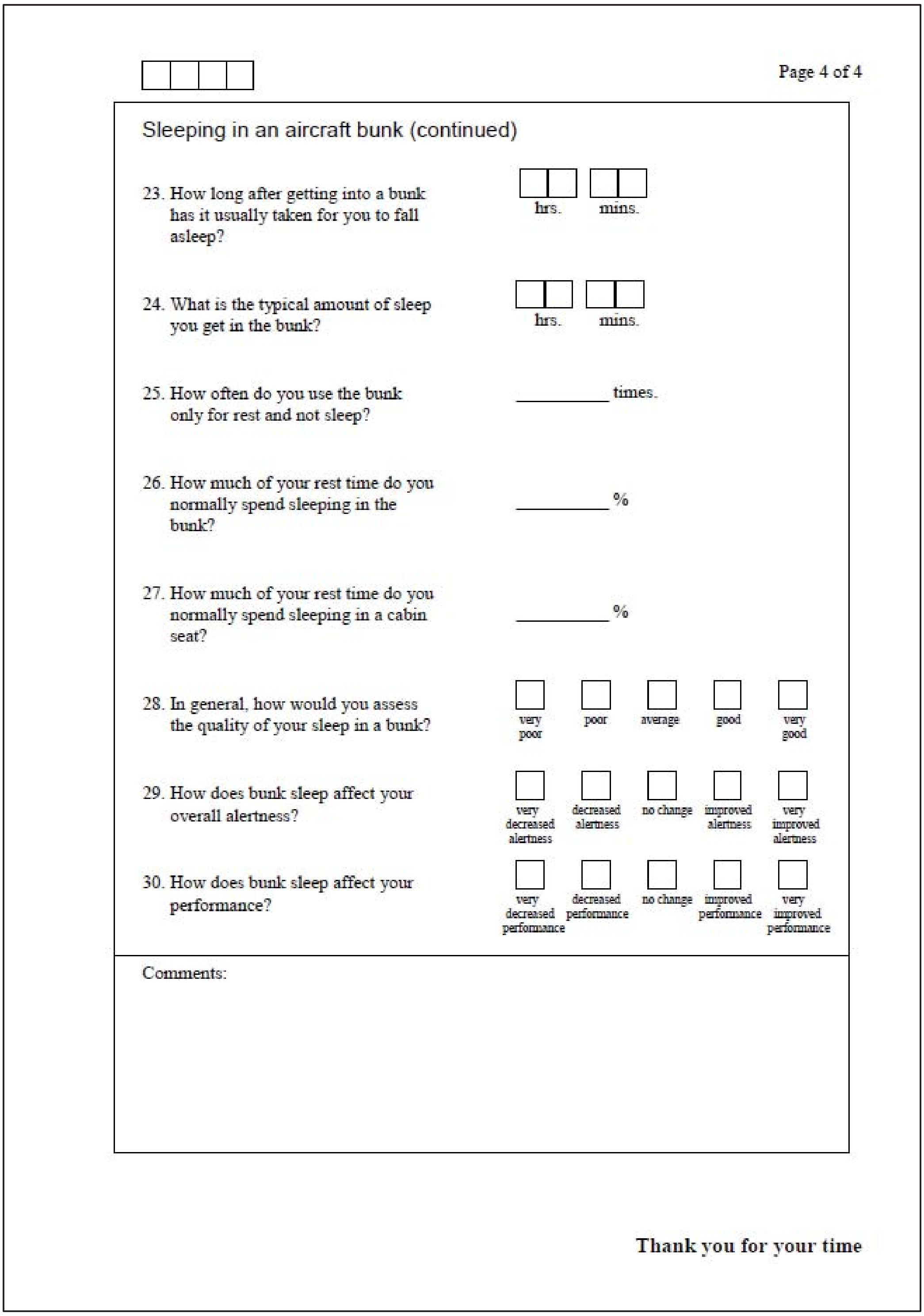
22. Approximately how many times during the past 12 months have you used an aircraft bunk?

a. In total: ____________times.

b. On the A340: ____________times.

c. On another type of aircraft: ____________times.

Please turn over and continue the questions



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Sleeping in an aircraft bunk (continued)

23. How long after getting into a bunk has it usually taken for you to fall asleep? ☐☐ hrs. ☐☐ mins.

24. What is the typical amount of sleep you get in the bunk? ☐☐ hrs. ☐☐ mins.

25. How often do you use the bunk only for rest and not sleep? __________ times.

26. How much of your rest time do you normally spend sleeping in the bunk? __________ %

27. How much of your rest time do you normally spend sleeping in a cabin seat? __________ %

28. In general, how would you assess the quality of your sleep in a bunk? ☐ very poor ☐ poor ☐ average ☐ good ☐ very good

29. How does bunk sleep affect your overall alertness? ☐ very decreased alertness ☐ decreased alertness ☐ no change ☐ improved alertness ☐ very improved alertness

30. How does bunk sleep affect your performance? ☐ very decreased performance ☐ decreased performance ☐ no change ☐ improved performance ☐ very improved performance

Comments:

Thank you for your time

APPENDIX 2E PROTOCOL FOR ANOMALIES IN DATA

When combining the pre-study questionnaire data from the five study databases into a common database for the project, the data were also checked for anomalies. Where anomalies were identified, these were dealt with on a case-by-case basis according to the criteria set out below.

- In cases where an answer did not seem plausible (e.g., a participant age of "6"), data was first checked in the original individual airline database to see if the anomaly had occurred while creating the common database, and if required was then checked in the original questionnaire to verify what the participant had written. If an error was found, the data was changed to reflect what the participant had recorded in the questionnaire and a note was made in the comments section of the database. If no error was found in the way data had been entered, a note was made in the comments section but the data were not changed.
- In cases where a participant's answer was recorded correctly but did not seem plausible (e.g., the combined total of a participant's use of the bunk on a B777 and on other aircraft types was larger than the participant's total bunk use), a note was made in the comments section of the database but the data were not changed.
- In cases where a participant had answered a question with a description instead of a numerical value (e.g., a participant answered the question "how many times have you used the bunk for rest not sleep?" with "always"), a note was made in the comments section of the database and the answer to that question was recorded as "missing".

- In cases where a participant gave two answers to a categorical question (e.g., a participant answered that sleep quality in the bunk was between "average" and "good"), a note was made in the comments section of the database and the answer was rounded in the most conservative way (in the case of sleep quality, the answer was rounded up).
- In cases where a participant answered using a range for a continuous question (e.g., a participant answered the question "when sleeping at home, how many times on average do you wake during the night?" with "1-2 times"), the mean value was used (in this example "1.5").
- In cases where data were missing for questions derived from the answer to a previous question (e.g., data was missing for the question "if yes, what is your sleep problem?" for a participant who reported not having a sleep problem), data for those questions were recorded as "not applicable" instead of "missing".
- In cases where participant responses to questions derived from the answer to a previous question were odd or did not seem plausible (e.g., a participant reported using the cabin seat 0 times in the past 12 months and answered all the ensuing questions about sleep in the seat with 0), data for those questions were recorded as "not applicable" (for categorical questions) and "missing" (for numerical questions).

APPENDIX 2F DESCRIPTIVES FROM RETROSPECTIVE QUESTIONNAIRE ANALYSES

2F.1 Commute time:

Information on commute time to work is summarized by study in Table 2F.1 below. The range of commute times was very large (0.2 to 24.0 hours). This included 7 outliers, one of which had a commute time of 24 hours as the pilot travelled to their base from a different country.

Table 2F.1 Commute time in hours (median, range) by study

United Airlines	Delta Air Lines B777	Delta Air Lines B767 bunk	South African Airways	Singapore Airlines	Combined
3.1 (0.5-24.0)[1]	2.0 (0.3-9.0)[2, 3]	1.5 (0.5-7.0)[4, 3]	0.7 (0.2-5.0)[5]	0.3 (0.2-1.0)[3]	1.5 (0.2-24.0)[6, 7]

Note: Data not normally distributed (i.e., Kolmogorov-Smirnov p-value <0.05)

[1] Includes 2 outliers; [2] 3 missing values; [3] Includes 1 outlier; [4] 1 missing value; [5] Includes 4 outliers; [6] 4 missing values; [7] Includes 7 outliers

2F.2 Sleep at home:

Basic descriptive statistics of pilots' usual sleep at home was included in chapter 2 (refer to section 2.2.1). As such, that information is not presented here however data from additional questions not analysed in chapter 2 are presented in this section.

Pilots were asked what the causes of their problems falling asleep were and their replies were grouped in Figure 2F.1. For this question data were missing for 25 pilots (9.5%). Pilots who reported nighttime awakenings (N=255) were asked what caused them to wake during the night and their answers are grouped in Figure 2F.2. Data for this question were missing for 3 pilots (1.2%).

Figure 2F.1 Categories of reported causes of problems falling asleep

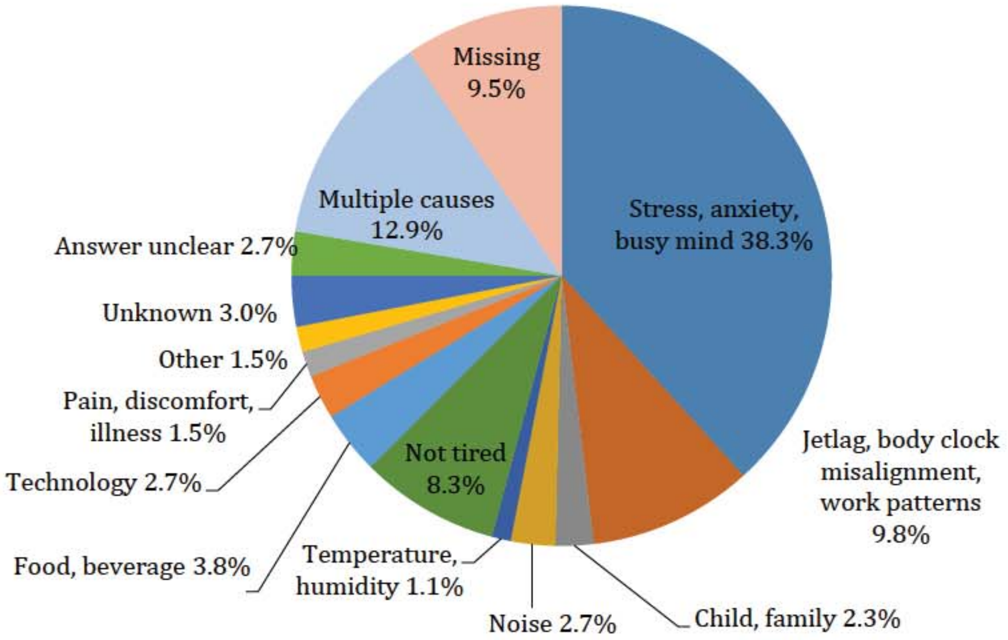
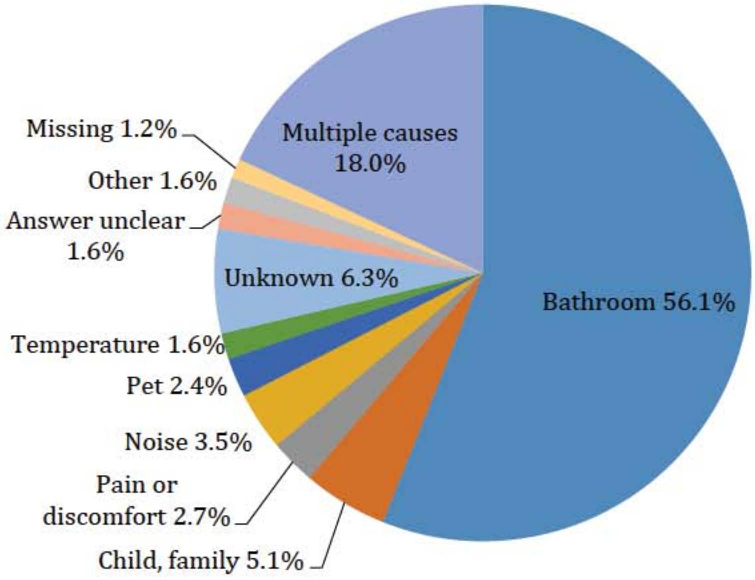
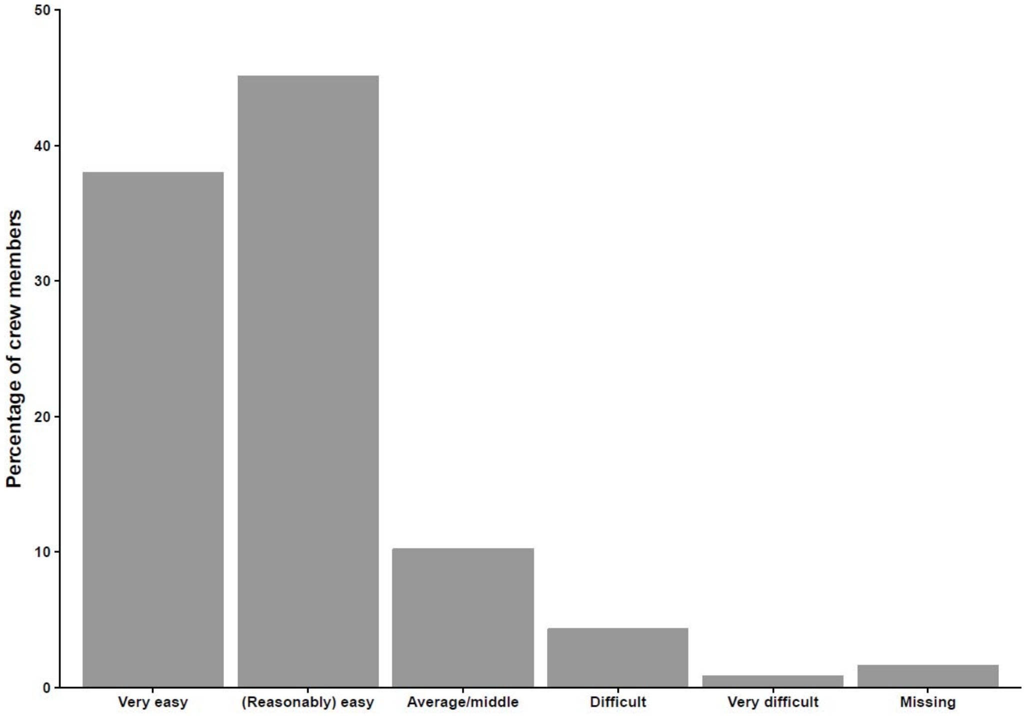


Figure 2F.2 Categories of reported causes of nighttime awakenings



Pilots who reported nighttime awakenings were also asked how difficult it was for them to resume sleep after an awakening (Figure 2F.3). Data for this question were missing for 4 pilots (1.6%).

Figure 2F.3 Difficulty resuming sleep following a nighttime awakening



Pilots were also asked if they had a sleep problem: 8.6% (25 crewmembers) answered “yes” and 91.1% answered “no”. Data was missing for one crewmember for this question (0.3%). Pilots who reported having a sleep problem were then asked if their sleep problem was diagnosed, to which only one crewmember answered “yes” (4.0%) and if their sleep problem had ever prevented them from flying a scheduled trip where, again, only one crewmember answered “yes” (4.0%).

2F.3 Sleep in the aircraft bunk:

Information regarding the use of the bunk in the last 12 months by airline is summarized in Table 2F.2 (page 253) and Table 2F.3 (page 253), while Table 2F.4 (page 254) summarizes information on sleep in the bunk by airline.

Pilots from the United Airlines, Delta Air Lines and Singapore Airlines studies were asked about their use of the bunk on the study specific aircraft as well as on other aircraft types. Pilots from South African Airways were not asked about their use of specific bunks and reported only their total use of aircraft bunks in the last 12 months.

Table 2F.3 summarizes information on the use of the bunk in the last 12 months only for pilots that had been flying the study specific aircraft type for 12 months or longer at the time of the studies. Pilots who reported fewer than 12 months of experience flying their study specific aircraft type were excluded from this analysis as their inclusion was likely to skew results (a crewmember who has only been flying for 1 of the past 12 months has had fewer opportunities to use the bunk than a crewmember who has been flying for all 12 of the past 12 months).

All pilots were included in the analysis of sleep in the aircraft bunk regardless of their flight experience (Table 2F.4). The range of TST in the bunk was large (0.0 to 6.5 hours) possibly as a result of differences in flight duration and in-flight rest break patterns.

Information about pilots' perceptions of their sleep quality in the bunk and of the effects of sleep in the bunk on their performance and alertness was presented in section 2.2.1 of chapter 2 and is therefore not included here.

Table 2F.2 Number of occasions on which the aircraft bunk was used in the last 12 months

	United Airlines	Delta Air Lines B777	Delta Air Lines B767 bunk	South African Airways	Singapore Airlines	Combined
Total use of bunk (median, range)	52.5 (3-160) [1, 2]	60 (0-150)[a, 3]	12 (0-80)[a, 1, 4]	60 (10-100)[a, 5]	20 (0-163)[b, 6, 4]	36 (0-163)[a, 7, 8]
Use of bunk on specific aircraft type (median, range)	B777 series 52.5 (3-160)[1, 2]	B777 series 60 (10-150)[a, 9]	B767-300ER 12 (0-80)[a, 1, 4]	N/A	A340 series 6 (0-81)[b, 6, 2]	30 (0-160)[a, 10, 8]
Use of bunk on another type of aircraft (median, range)	0 (0-40)[a, 9, 2]	0 (0-96)[a, 11, 12]	0 (0-30)[a, 3, 12]	N/A	12 (0-82)[b, 1, 2]	0 (0-96)[a, 13, 14]

[a] Data not normally distributed (i.e., Kolomogorov-Smirnov p-value <0.05); [b] Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05, as N≤40)

[1] 2 missing values; [2] Includes 1 outlier; [3] 6 missing values; [4] Includes 3 outliers; [5] 7 missing values; [6] 1 missing value; [7] 18 missing values; [8] Includes 9 outliers; [9] 5 missing values; [10] 10 missing values; [11] 8 missing values; [12] Includes 2 outliers; [13] 21 missing values; [14] Includes 35 outliers

Table 2F.3 Use of the aircraft bunk in the last 12 months (where have flown study specific aircraft type longer than 12 months)

	United Airlines	Delta Air Lines B777	Delta Air Lines B767 bunk	South African Airways	Singapore Airlines	Combined
Total use of bunk (median, range)	60 (3-160)[a, 1, 2]	60 (0-150)[a, 3]	12 (0-80)[a, 4, 5]	70 (20-100)[b, 4]	20 (2-163)[c, 1, 6]	40 (0-163)[a, 7, 8]
Use of bunk on specific aircraft type (median, range)	B777 series 60 (3-160)[a, 1, 2]	B777 series 60 (18-150)[a, 9]	B767-300ER 12 (0-80)[a, 4, 5]	N/A	A340 series 6 (0-81)[c, 1, 2]	36 (0-160)[a, 10, 2]

[a] Data not normally distributed (i.e., Kolomogorov-Smirnov p-value <0.05); [b] Data normally distributed (i.e., Shapiro-Wilk p-value >0.05, as N≤40); [c] Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05, as N≤40);

[1] 1 missing value; [2] Includes 1 outlier; [3] 6 missing values; [4] 2 missing values; [5] Includes 3 outliers; [6] Includes 4 outliers; [7] 12 missing values; [8] Includes 2 outliers; [9] 5 missing values; [10] 9 missing values;

Table 2F.4 Sleep in the aircraft bunk

	United Airlines	Delta Air Lines B777	Delta Air Lines B767 bunk	South African Airways	Singapore Airlines	Combined
Sleep onset latency (min) (median, range)[a]	25 (5-90) [1, 2]	20 (5-150) [3, 4]	20 (5-90) [5, 6]	30 (5-180) [7, 4]	30 (10-180)[b, 1, 4]	25 (5-180) [8, 9]
Total sleep time (hrs) (median, range)[a]	4.0 (1.0-6.5) [10, 4]	2.0 (0.0-3.5) [7, 11]	2.0 (0.8-4.0) [3]	2.5 (0.7-4.0) [7]	3.0 (1.5-6.0)[b, 1, 12]	2.5 (0.0-6.5) [13, 6]
Times bunk used for rest only (median, range)[a]	0 (0-12) [14, 15]	0 (0-720) [10, 16]	0 (0-15) [17, 15]	0 (0-30) [18, 12]	0 (0-10)[b, 10, 12]	0 (0-72) [19, 20]
Percentage of rest time spent sleeping in the bunk (median, range)[a]	85.0% (20.0-100.0)[1, 21]	83.5% (0.0-100.0) [7, 4]	85.0% (40.0-100.0) [5, 11]	80.0% (0.0-100.0) [1, 4]	75.0% (20.0-90.0)[b, 1]	80.0% (0.0-100.0) [22, 23]

[a] Data not normally distributed (i.e., Kolomogorov-Smirnov p-value <0.05);
[b] Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05, as N≤40);

[1] 1 missing value; [2] Includes 9 outliers; [3] 4 missing values; [4] Includes 3 outliers; [5] 3 missing values; [6] Includes 7 outliers; [7] 2 missing values; [8] 11 missing values; [9] Includes 37 outliers; [10] 7 missing values; [11] Includes 1 outlier; [12] Includes 2 outliers; [13] 16 missing values; [14] 12 missing values; [15] Includes 6 outliers; [16] Includes 10 outliers; [17] 5 missing values; [18] 9 missing values; [19] 40 missing values; [20] includes 31 outliers; [21] Includes 4 outliers; [22] 8 missing values; [23] Includes 13 outliers

2F.4 Sleep in a cabin seat:

Questions relating to the use of a cabin seat for in-flight rest were only asked in the Delta Air Lines B767 bunk and South African Airways studies and therefore results reported here refer only to pilots from these two studies. The only exception being the question relating to the percentage of rest time spent sleeping in the seat which was also asked in the Singapore Airlines study and therefore includes the Singapore Airlines flight crew sample in the results.

The majority of data regarding the use of a cabin seat for in-flight rest was not normally distributed. Information on the use of a cabin seat for in-flight rest is summarized in Table 2F.5 on the next page.

Table 2F.5 Cabin seat for in-flight rest

	United Airlines B777 study	Delta Air Lines B777	Delta Air Lines B767 bunk	South African Airways	Singapore Airlines	Combined
Total use of cabin seat in last 12 months (median, range)	N/A	N/A	12.0 (0-70)[a, 1, 2]	0 (0-6)[b, 3]	N/A	6 (0-70)[a, 4,5]
Use of cabin seat on specific aircraft type (median, range)	N/A	N/A	B767-300ER 10.0 (0-70)[a, 1, 2]	N/A	N/A	N/A
Use of cabin seat on other aircraft type (median, range)	N/A	N/A	0.0 (0-14)[a, 6, 7]	N/A	N/A	N/A
Sleep onset latency (min) (median, range)	N/A	N/A	30 (0-135)[a, 6, 8]	30 (5-120)[b, 9]	N/A	30 (0-135)[a, 10, 8]
Total sleep time (hrs) (median, range)	N/A	N/A	1.3 (0.0-2.5)[a, 11]	1.0 (0.0-5.0)[b, 12, 8]	N/A	1.3 (0.0-5.0)[a, 13, 8]
Number of times cabin seat used for rest only (median, range)	N/A	N/A	2 (0-30)[a, 6, 8]	0 (0-10)[b, 14, 15]	N/A	2 (0-30)[a, 16, 8]
Percentage of rest time spent sleeping in the cabin seat (median, range)	N/A	N/A	60.0% (0.0-100.0)[17]	0.0% (0.0-90.0)[b, 18, 15]	10.0% (0.0-80.0)[b, 19, 8]	25.0% (0.0-100.0)[a, 20]

[a] Data not normally distributed (i.e., Kolomogorov-Smirnov p-value <0.05);
[b] Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05, as N≤40);

[1] 2 missing values; [2] Includes 3 outliers; [3] 20 missing values; [4] 22 missing values; [5] Includes 6 outliers; [6] 5 missing values; [7] Includes 5 outliers; [8] Includes 1 outlier; [9] 37 missing values; [10] 42 missing values; [11] 3 missing values; [12] 36 missing values; [13] 39 missing values; [14] 23 missing values; [15] Includes 2 outliers; [16] 28 missing values; [17] 4 missing values; [18] 27 missing values; [19] 1 missing value; [20] 32 missing values

Although the range of responses with regards to use of the cabin seat was large, 25% of pilots reported using a cabin seat 0 times in the last 12 months and 75% of pilots reported using a cabin seat less than 18 times in the last 12 months. Similarly, despite a wide range in responses, 75% of pilots reported that they had used the cabin seat for rest (not sleep) only 6 times or less in the past 12 months.

The range of responses for estimated sleep onset latency (SOL) in the cabin seat was large as well but 75% of pilots reported a SOL of 60 minutes or less. Similarly, for total sleep time in the cabin seat, 75% of pilots reported a TST in a cabin seat of 1.5 hours or less.

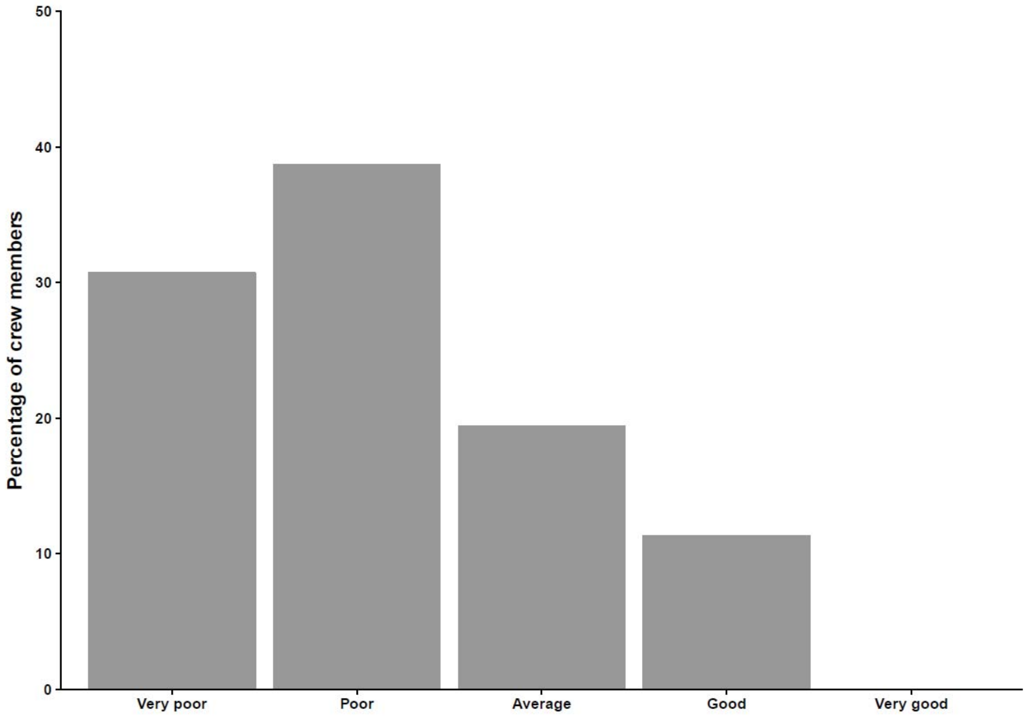
When pilots were asked to report on the percentage of their rest time that they spent sleeping in the cabin seat, the range of responses was large, however 50% of pilots reported spending 25% or less of their rest time sleeping the cabin seat. The percentage of rest time spent sleeping in the cabin seat varied between the studies and was lower in the South African Airways and Singapore Airlines studies:

- in the Delta Air Lines B767 bunk study only 25% of pilots reported spending less than 50% of their rest time sleeping in the cabin seat;
- by contrast, in the South African Airways study 75% of pilots reported spending 25% or less of their rest time sleeping in the cabin seat,
- and in the Singapore Airlines study 75% of pilots reported spending less than 25% of their rest time sleeping in the cabin seat.

In the Delta Air Lines B767 bunk and South African Airways studies, pilots were also asked to rate their sleep quality in the cabin seat and the effects sleeping in the cabin seat had on their alertness and performance based on previous experiences of in-flight sleep.

Of the pilots that had reported using a cabin seat at least once in the past 12 months (N=62), the majority rated their sleep quality in the cabin seat as "poor" or "very poor" (Figure 2F.4). For this question, there were no missing data and no one rated their sleep quality in the seat as "very good".

Figure 2F.4 Reported sleep quality in the cabin seat



Pilots ratings of the effects of sleep in the cabin seat on their alertness and performance in the ensuing duty period are summarized in Figure 2F.5 and Figure 2F.6 respectively (opposite). For these two questions, data were missing for two pilots (3.2%).

Figure 2F.5 Reported effects of sleep in the cabin seat on alertness

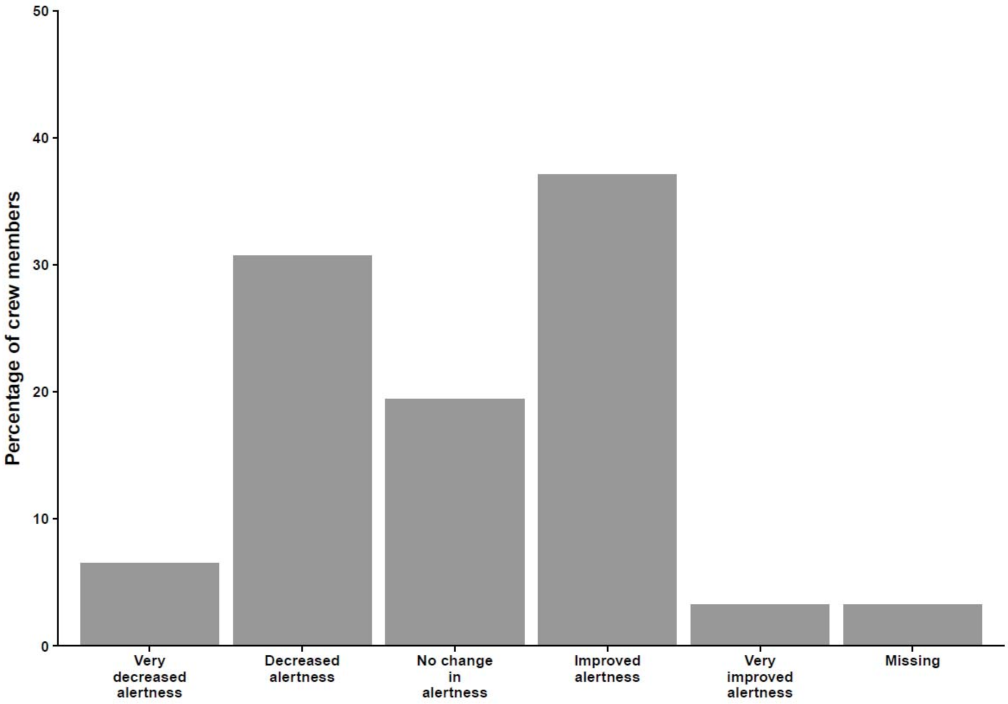
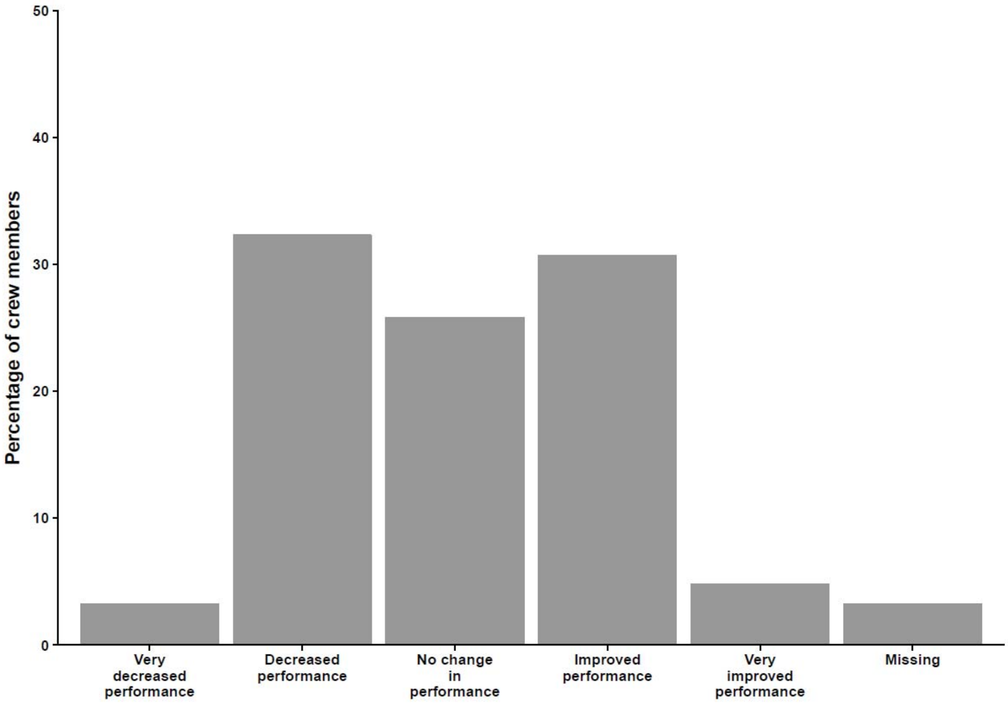
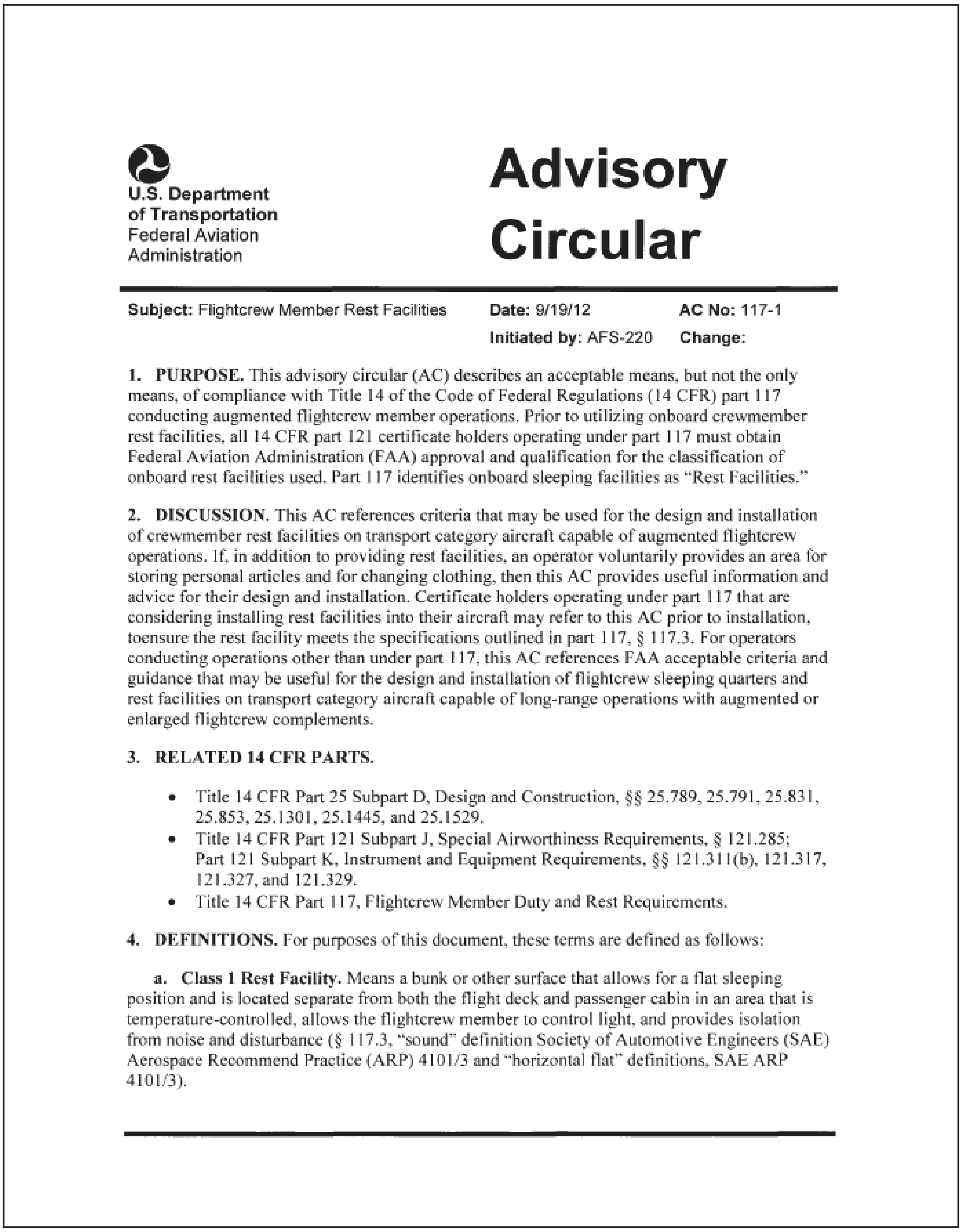


Figure 2F.6 Reported effects of sleep in the cabin seat on performance



CHAPTER 3 APPENDICES

APPENDIX 3A FAA ADVISORY CIRCULAR 117-1



U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

Subject: Flightcrew Member Rest Facilities
Date: 9/19/12
AC No: 117-1
Initiated by: AFS-220
Change:

1. **PURPOSE.** This advisory circular (AC) describes an acceptable means, but not the only means, of compliance with Title 14 of the Code of Federal Regulations (14 CFR) part 117 conducting augmented flightcrew member operations. Prior to utilizing onboard crewmember rest facilities, all 14 CFR part 121 certificate holders operating under part 117 must obtain Federal Aviation Administration (FAA) approval and qualification for the classification of onboard rest facilities used. Part 117 identifies onboard sleeping facilities as "Rest Facilities."

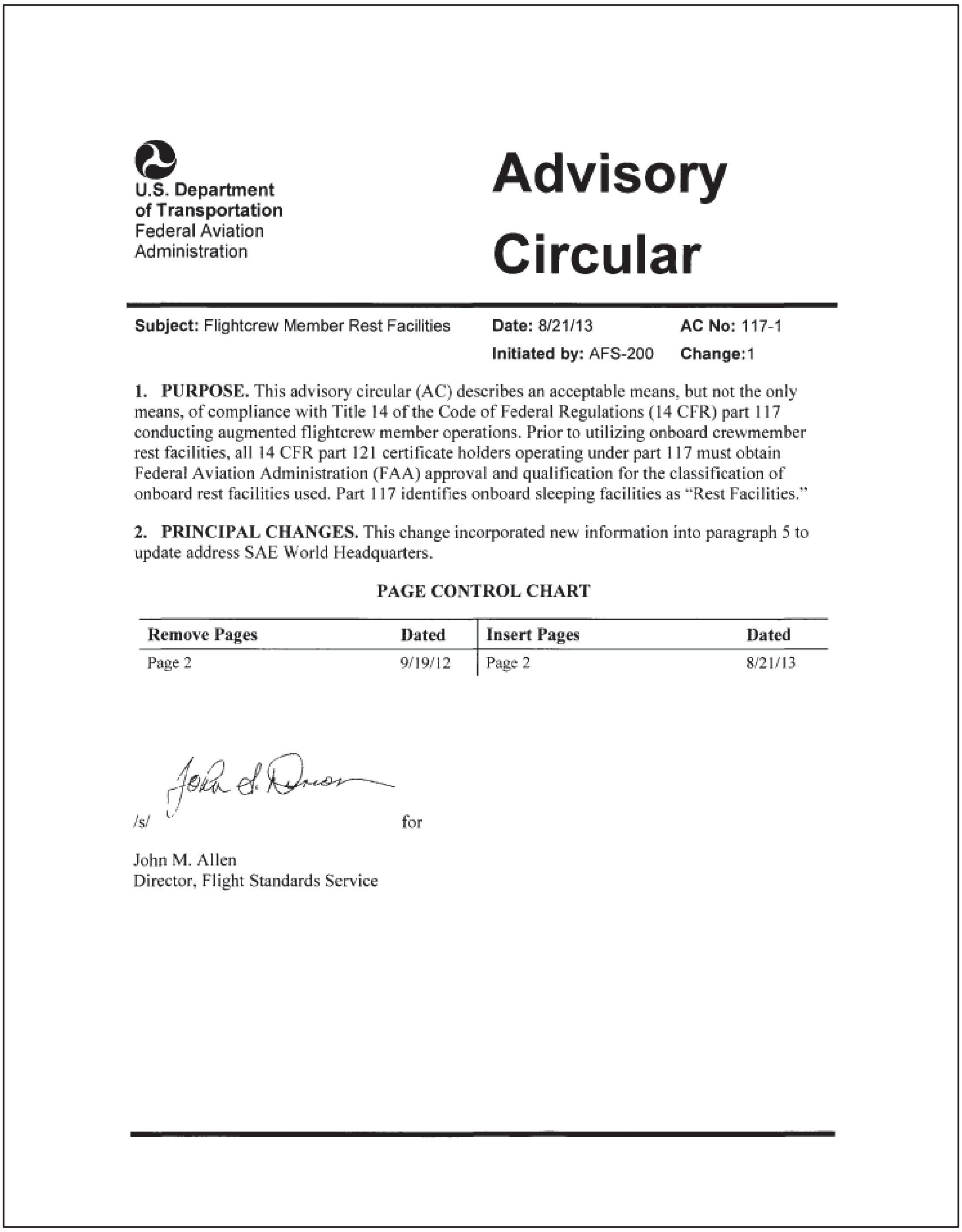
2. **DISCUSSION.** This AC references criteria that may be used for the design and installation of crewmember rest facilities on transport category aircraft capable of augmented flightcrew operations. If, in addition to providing rest facilities, an operator voluntarily provides an area for storing personal articles and for changing clothing, then this AC provides useful information and advice for their design and installation. Certificate holders operating under part 117 that are considering installing rest facilities into their aircraft may refer to this AC prior to installation, toensure the rest facility meets the specifications outlined in part 117, § 117.3. For operators conducting operations other than under part 117, this AC references FAA acceptable criteria and guidance that may be useful for the design and installation of flightcrew sleeping quarters and rest facilities on transport category aircraft capable of long-range operations with augmented or enlarged flightcrew complements.

3. **RELATED 14 CFR PARTS.**

- Title 14 CFR Part 25 Subpart D, Design and Construction, §§ 25.789, 25.791, 25.831, 25.853, 25.1301, 25.1445, and 25.1529.
- Title 14 CFR Part 121 Subpart J, Special Airworthiness Requirements, § 121.285; Part 121 Subpart K, Instrument and Equipment Requirements, §§ 121.311(b), 121.317, 121.327, and 121.329.
- Title 14 CFR Part 117, Flightcrew Member Duty and Rest Requirements.

4. **DEFINITIONS.** For purposes of this document, these terms are defined as follows:

a. **Class 1 Rest Facility.** Means a bunk or other surface that allows for a flat sleeping position and is located separate from both the flight deck and passenger cabin in an area that is temperature-controlled, allows the flightcrew member to control light, and provides isolation from noise and disturbance (§ 117.3, "sound" definition Society of Automotive Engineers (SAE) Aerospace Recommend Practice (ARP) 4101/3 and "horizontal flat" definitions, SAE ARP 4101/3).



U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

Subject: Flightcrew Member Rest Facilities

Date: 8/21/13
Initiated by: AFS-200

AC No: 117-1
Change:1

1. **PURPOSE.** This advisory circular (AC) describes an acceptable means, but not the only means, of compliance with Title 14 of the Code of Federal Regulations (14 CFR) part 117 conducting augmented flightcrew member operations. Prior to utilizing onboard crewmember rest facilities, all 14 CFR part 121 certificate holders operating under part 117 must obtain Federal Aviation Administration (FAA) approval and qualification for the classification of onboard rest facilities used. Part 117 identifies onboard sleeping facilities as "Rest Facilities."

2. **PRINCIPAL CHANGES.** This change incorporated new information into paragraph 5 to update address SAE World Headquarters.

PAGE CONTROL CHART

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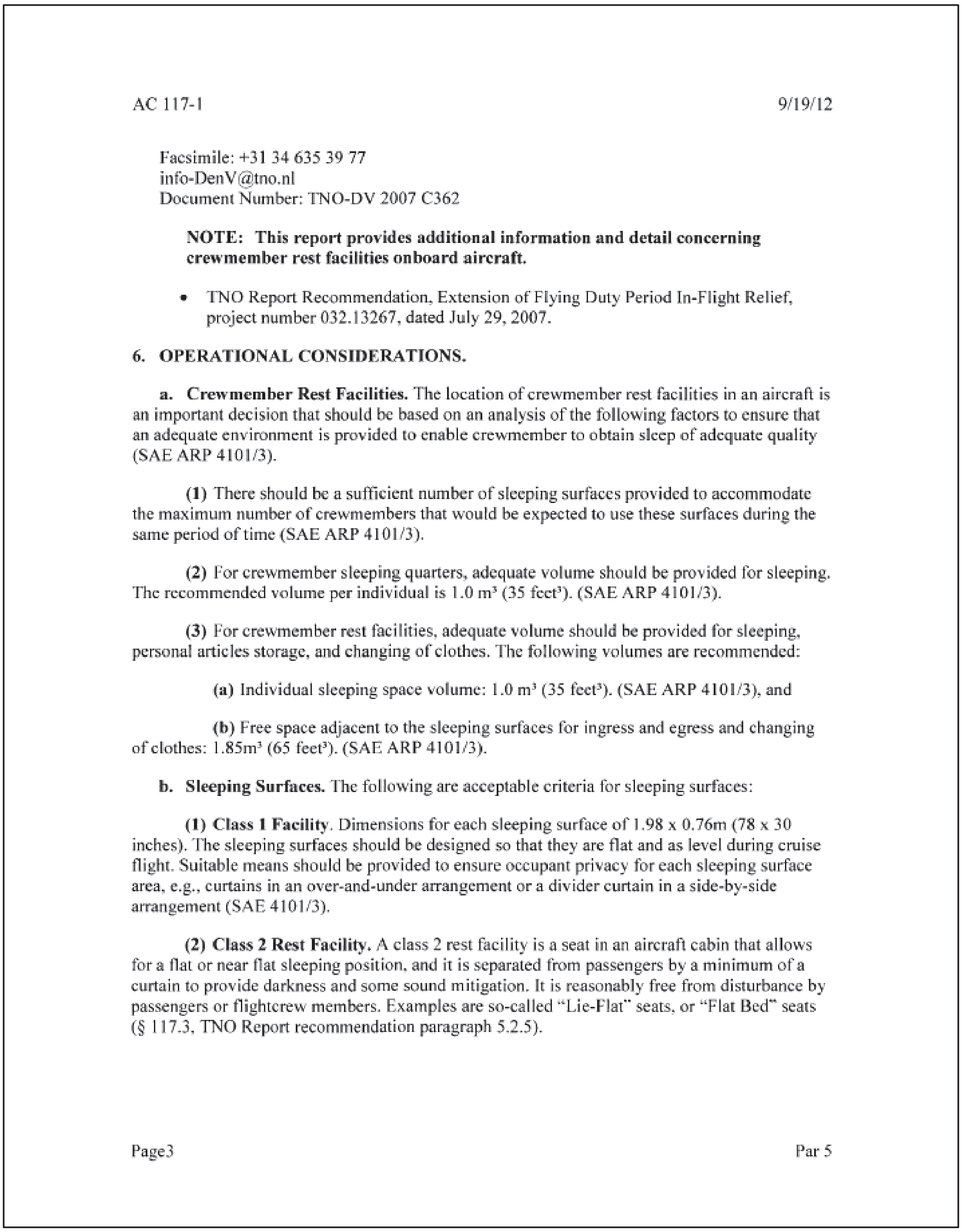
Page 2	9/19/12	Page 2	8/21/13

/s/ for

John M. Allen
Director, Flight Standards Service



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Document Number: TNO-DV 2007 C362

NOTE: This report provides additional information and detail concerning crewmember rest facilities onboard aircraft.

- TNO Report Recommendation, Extension of Flying Duty Period In-Flight Relief, project number 032.13267, dated July 29, 2007.

6. OPERATIONAL CONSIDERATIONS.

a. Crewmember Rest Facilities. The location of crewmember rest facilities in an aircraft is an important decision that should be based on an analysis of the following factors to ensure that an adequate environment is provided to enable crewmember to obtain sleep of adequate quality (SAE ARP 4101/3).

(1) There should be a sufficient number of sleeping surfaces provided to accommodate the maximum number of crewmembers that would be expected to use these surfaces during the same period of time (SAE ARP 4101/3).

(2) For crewmember sleeping quarters, adequate volume should be provided for sleeping. The recommended volume per individual is 1.0 m^3 (35 $feet^3$). (SAE ARP 4101/3).

(3) For crewmember rest facilities, adequate volume should be provided for sleeping, personal articles storage, and changing of clothes. The following volumes are recommended:

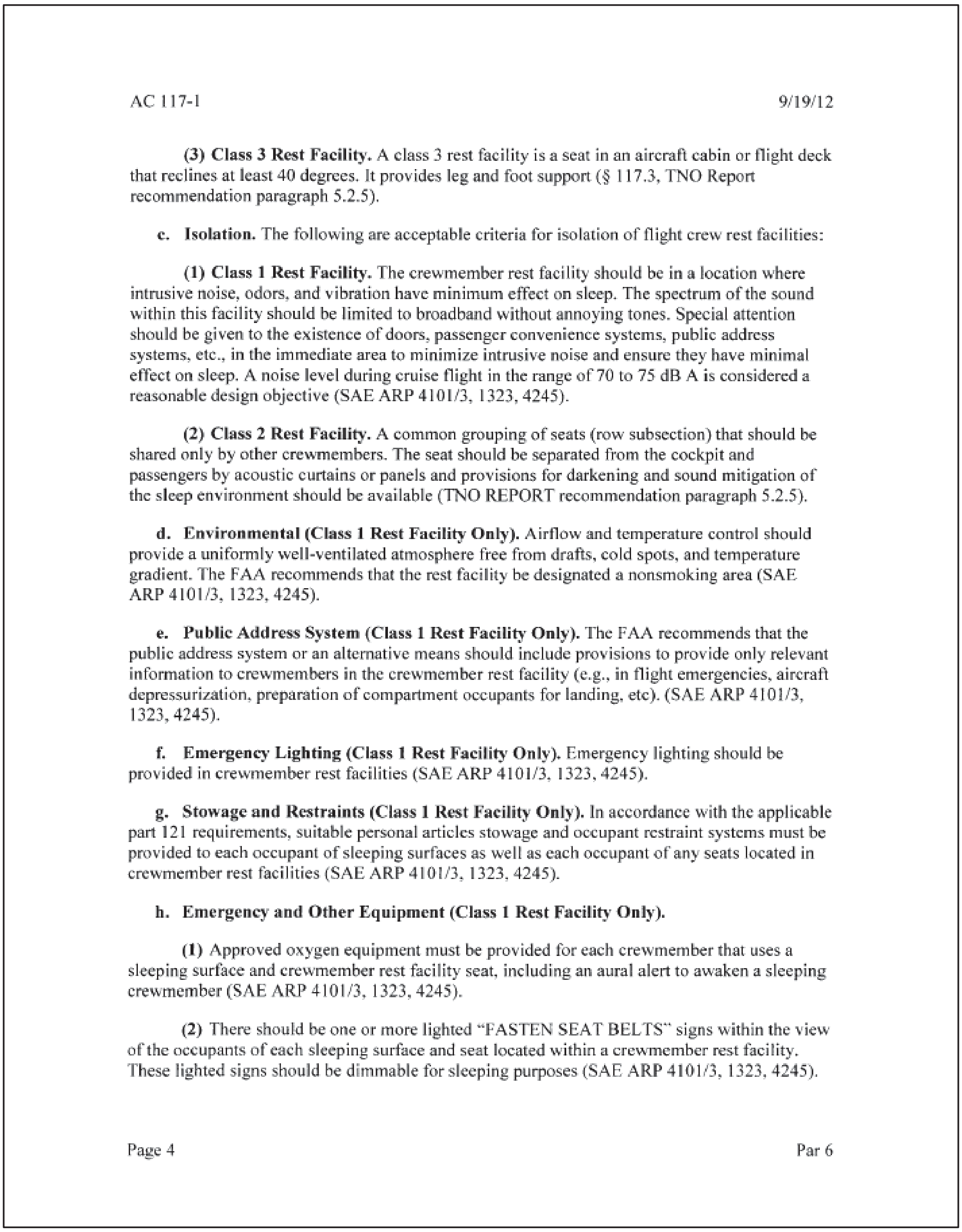
(a) Individual sleeping space volume: 1.0 m^3 (35 $feet^3$). (SAE ARP 4101/3), and

(b) Free space adjacent to the sleeping surfaces for ingress and egress and changing of clothes: 1.85m^3 (65 $feet^3$). (SAE ARP 4101/3).

b. Sleeping Surfaces. The following are acceptable criteria for sleeping surfaces:

(1) Class 1 Facility. Dimensions for each sleeping surface of 1.98 x 0.76m (78 x 30 inches). The sleeping surfaces should be designed so that they are flat and as level during cruise flight. Suitable means should be provided to ensure occupant privacy for each sleeping surface area, e.g., curtains in an over-and-under arrangement or a divider curtain in a side-by-side arrangement (SAE 4101/3).

(2) Class 2 Rest Facility. A class 2 rest facility is a seat in an aircraft cabin that allows for a flat or near flat sleeping position, and it is separated from passengers by a minimum of a curtain to provide darkness and some sound mitigation. It is reasonably free from disturbance by passengers or flightcrew members. Examples are so-called "Lie-Flat" seats, or "Flat Bed" seats (§ 117.3, TNO Report recommendation paragraph 5.2.5).



(3) Class 3 Rest Facility. A class 3 rest facility is a seat in an aircraft cabin or flight deck that reclines at least 40 degrees. It provides leg and foot support (§ 117.3, TNO Report recommendation paragraph 5.2.5).

c. Isolation. The following are acceptable criteria for isolation of flight crew rest facilities:

(1) Class 1 Rest Facility. The crewmember rest facility should be in a location where intrusive noise, odors, and vibration have minimum effect on sleep. The spectrum of the sound within this facility should be limited to broadband without annoying tones. Special attention should be given to the existence of doors, passenger convenience systems, public address systems, etc., in the immediate area to minimize intrusive noise and ensure they have minimal effect on sleep. A noise level during cruise flight in the range of 70 to 75 dB A is considered a reasonable design objective (SAE ARP 4101/3, 1323, 4245).

(2) Class 2 Rest Facility. A common grouping of seats (row subsection) that should be shared only by other crewmembers. The seat should be separated from the cockpit and passengers by acoustic curtains or panels and provisions for darkening and sound mitigation of the sleep environment should be available (TNO REPORT recommendation paragraph 5.2.5).

d. Environmental (Class 1 Rest Facility Only). Airflow and temperature control should provide a uniformly well-ventilated atmosphere free from drafts, cold spots, and temperature gradient. The FAA recommends that the rest facility be designated a nonsmoking area (SAE ARP 4101/3, 1323, 4245).

e. Public Address System (Class 1 Rest Facility Only). The FAA recommends that the public address system or an alternative means should include provisions to provide only relevant information to crewmembers in the crewmember rest facility (e.g., in flight emergencies, aircraft depressurization, preparation of compartment occupants for landing, etc). (SAE ARP 4101/3, 1323, 4245).

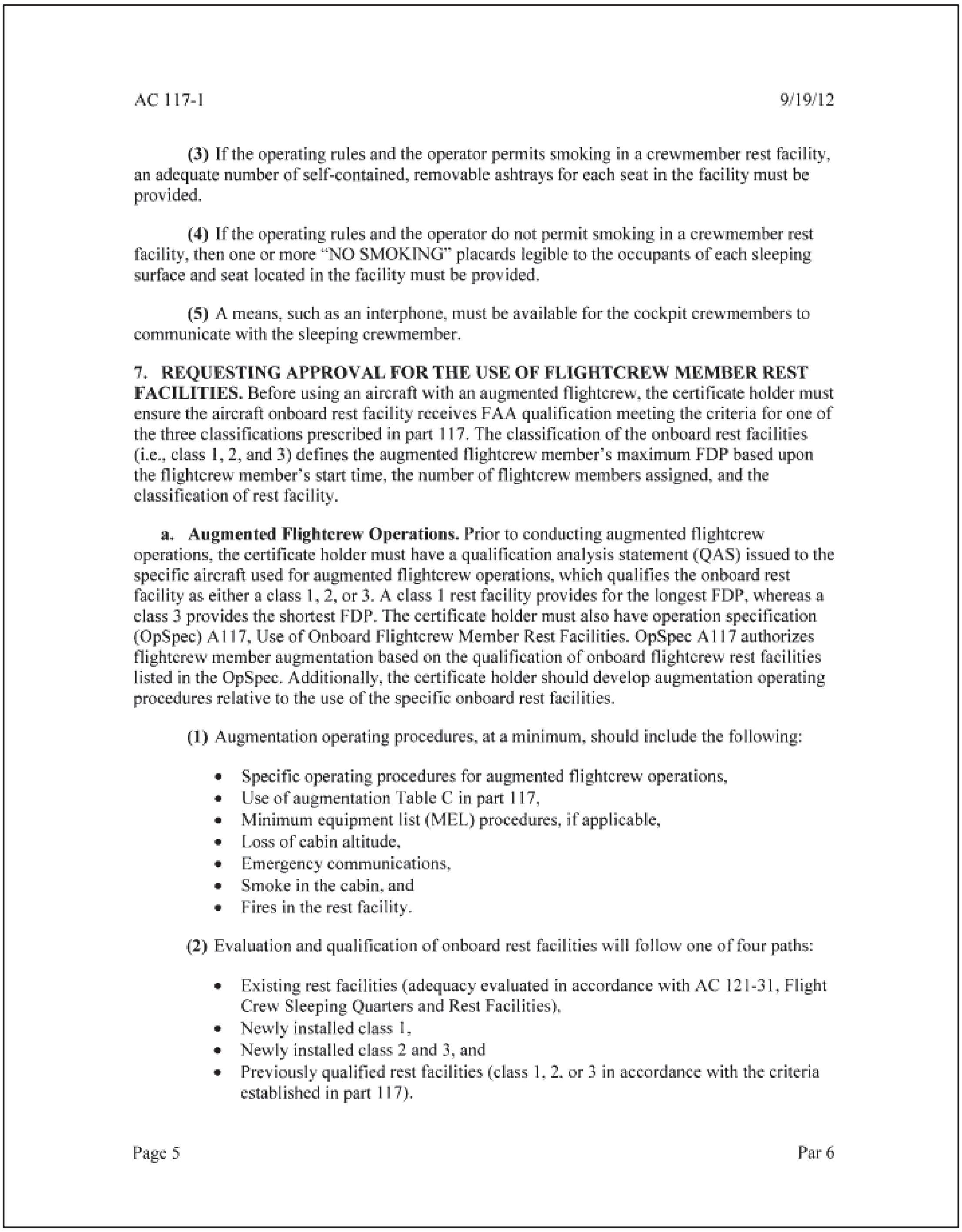
f. Emergency Lighting (Class 1 Rest Facility Only). Emergency lighting should be provided in crewmember rest facilities (SAE ARP 4101/3, 1323, 4245).

g. Stowage and Restraints (Class 1 Rest Facility Only). In accordance with the applicable part 121 requirements, suitable personal articles stowage and occupant restraint systems must be provided to each occupant of sleeping surfaces as well as each occupant of any seats located in crewmember rest facilities (SAE ARP 4101/3, 1323, 4245).

h. Emergency and Other Equipment (Class 1 Rest Facility Only).

(1) Approved oxygen equipment must be provided for each crewmember that uses a sleeping surface and crewmember rest facility seat, including an aural alert to awaken a sleeping crewmember (SAE ARP 4101/3, 1323, 4245).

(2) There should be one or more lighted "FASTEN SEAT BELTS" signs within the view of the occupants of each sleeping surface and seat located within a crewmember rest facility. These lighted signs should be dimmable for sleeping purposes (SAE ARP 4101/3, 1323, 4245).



AC 117-1 9/19/12

(3) If the operating rules and the operator permits smoking in a crewmember rest facility, an adequate number of self-contained, removable ashtrays for each seat in the facility must be provided.

(4) If the operating rules and the operator do not permit smoking in a crewmember rest facility, then one or more "NO SMOKING" placards legible to the occupants of each sleeping surface and seat located in the facility must be provided.

(5) A means, such as an interphone, must be available for the cockpit crewmembers to communicate with the sleeping crewmember.

7. REQUESTING APPROVAL FOR THE USE OF FLIGHTCREW MEMBER REST FACILITIES. Before using an aircraft with an augmented flightcrew, the certificate holder must ensure the aircraft onboard rest facility receives FAA qualification meeting the criteria for one of the three classifications prescribed in part 117. The classification of the onboard rest facilities (i.e., class 1, 2, and 3) defines the augmented flightcrew member's maximum FDP based upon the flightcrew member's start time, the number of flightcrew members assigned, and the classification of rest facility.

a. Augmented Flightcrew Operations. Prior to conducting augmented flightcrew operations, the certificate holder must have a qualification analysis statement (QAS) issued to the specific aircraft used for augmented flightcrew operations, which qualifies the onboard rest facility as either a class 1, 2, or 3. A class 1 rest facility provides for the longest FDP, whereas a class 3 provides the shortest FDP. The certificate holder must also have operation specification (OpSpec) A117, Use of Onboard Flightcrew Member Rest Facilities. OpSpec A117 authorizes flightcrew member augmentation based on the qualification of onboard flightcrew rest facilities listed in the OpSpec. Additionally, the certificate holder should develop augmentation operating procedures relative to the use of the specific onboard rest facilities.

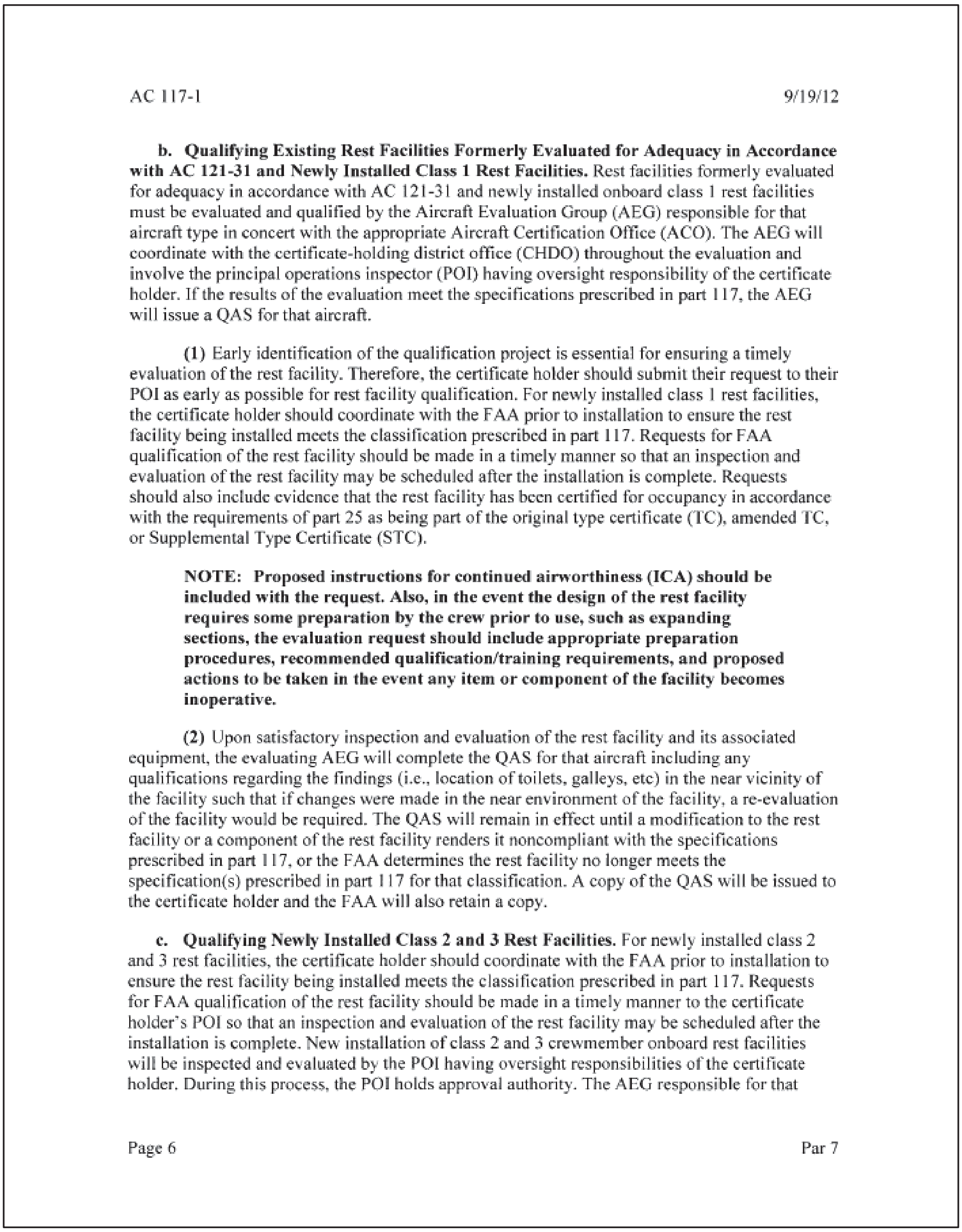
(1) Augmentation operating procedures, at a minimum, should include the following:

- Specific operating procedures for augmented flightcrew operations,
- Use of augmentation Table C in part 117,
- Minimum equipment list (MEL) procedures, if applicable,
- Loss of cabin altitude,
- Emergency communications,
- Smoke in the cabin, and
- Fires in the rest facility.

(2) Evaluation and qualification of onboard rest facilities will follow one of four paths:

- Existing rest facilities (adequacy evaluated in accordance with AC 121-31, Flight Crew Sleeping Quarters and Rest Facilities),
- Newly installed class 1,
- Newly installed class 2 and 3, and
- Previously qualified rest facilities (class 1, 2, or 3 in accordance with the criteria established in part 117).

Page 5 Par 6



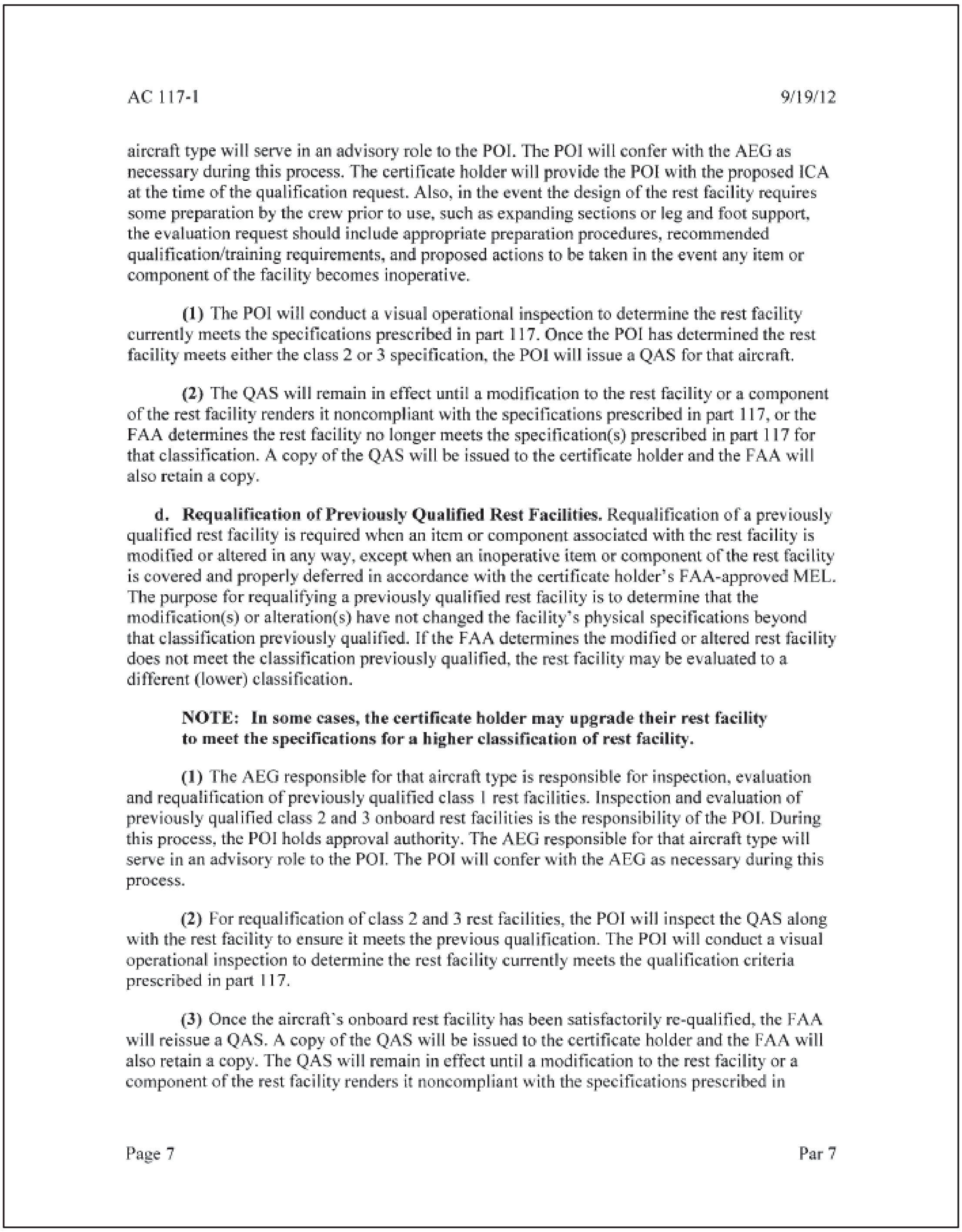
b. Qualifying Existing Rest Facilities Formerly Evaluated for Adequacy in Accordance with AC 121-31 and Newly Installed Class 1 Rest Facilities. Rest facilities formerly evaluated for adequacy in accordance with AC 121-31 and newly installed onboard class 1 rest facilities must be evaluated and qualified by the Aircraft Evaluation Group (AEG) responsible for that aircraft type in concert with the appropriate Aircraft Certification Office (ACO). The AEG will coordinate with the certificate-holding district office (CHDO) throughout the evaluation and involve the principal operations inspector (POI) having oversight responsibility of the certificate holder. If the results of the evaluation meet the specifications prescribed in part 117, the AEG will issue a QAS for that aircraft.

(1) Early identification of the qualification project is essential for ensuring a timely evaluation of the rest facility. Therefore, the certificate holder should submit their request to their POI as early as possible for rest facility qualification. For newly installed class 1 rest facilities, the certificate holder should coordinate with the FAA prior to installation to ensure the rest facility being installed meets the classification prescribed in part 117. Requests for FAA qualification of the rest facility should be made in a timely manner so that an inspection and evaluation of the rest facility may be scheduled after the installation is complete. Requests should also include evidence that the rest facility has been certified for occupancy in accordance with the requirements of part 25 as being part of the original type certificate (TC), amended TC, or Supplemental Type Certificate (STC).

> **NOTE: Proposed instructions for continued airworthiness (ICA) should be included with the request. Also, in the event the design of the rest facility requires some preparation by the crew prior to use, such as expanding sections, the evaluation request should include appropriate preparation procedures, recommended qualification/training requirements, and proposed actions to be taken in the event any item or component of the facility becomes inoperative.**

(2) Upon satisfactory inspection and evaluation of the rest facility and its associated equipment, the evaluating AEG will complete the QAS for that aircraft including any qualifications regarding the findings (i.e., location of toilets, galleys, etc) in the near vicinity of the facility such that if changes were made in the near environment of the facility, a re-evaluation of the facility would be required. The QAS will remain in effect until a modification to the rest facility or a component of the rest facility renders it noncompliant with the specifications prescribed in part 117, or the FAA determines the rest facility no longer meets the specification(s) prescribed in part 117 for that classification. A copy of the QAS will be issued to the certificate holder and the FAA will also retain a copy.

c. Qualifying Newly Installed Class 2 and 3 Rest Facilities. For newly installed class 2 and 3 rest facilities, the certificate holder should coordinate with the FAA prior to installation to ensure the rest facility being installed meets the classification prescribed in part 117. Requests for FAA qualification of the rest facility should be made in a timely manner to the certificate holder's POI so that an inspection and evaluation of the rest facility may be scheduled after the installation is complete. New installation of class 2 and 3 crewmember onboard rest facilities will be inspected and evaluated by the POI having oversight responsibilities of the certificate holder. During this process, the POI holds approval authority. The AEG responsible for that



aircraft type will serve in an advisory role to the POI. The POI will confer with the AEG as necessary during this process. The certificate holder will provide the POI with the proposed ICA at the time of the qualification request. Also, in the event the design of the rest facility requires some preparation by the crew prior to use, such as expanding sections or leg and foot support, the evaluation request should include appropriate preparation procedures, recommended qualification/training requirements, and proposed actions to be taken in the event any item or component of the facility becomes inoperative.

(1) The POI will conduct a visual operational inspection to determine the rest facility currently meets the specifications prescribed in part 117. Once the POI has determined the rest facility meets either the class 2 or 3 specification, the POI will issue a QAS for that aircraft.

(2) The QAS will remain in effect until a modification to the rest facility or a component of the rest facility renders it noncompliant with the specifications prescribed in part 117, or the FAA determines the rest facility no longer meets the specification(s) prescribed in part 117 for that classification. A copy of the QAS will be issued to the certificate holder and the FAA will also retain a copy.

d. Requalification of Previously Qualified Rest Facilities. Requalification of a previously qualified rest facility is required when an item or component associated with the rest facility is modified or altered in any way, except when an inoperative item or component of the rest facility is covered and properly deferred in accordance with the certificate holder's FAA-approved MEL. The purpose for requalifying a previously qualified rest facility is to determine that the modification(s) or alteration(s) have not changed the facility's physical specifications beyond that classification previously qualified. If the FAA determines the modified or altered rest facility does not meet the classification previously qualified, the rest facility may be evaluated to a different (lower) classification.

NOTE: In some cases, the certificate holder may upgrade their rest facility to meet the specifications for a higher classification of rest facility.

(1) The AEG responsible for that aircraft type is responsible for inspection, evaluation and requalification of previously qualified class 1 rest facilities. Inspection and evaluation of previously qualified class 2 and 3 onboard rest facilities is the responsibility of the POI. During this process, the POI holds approval authority. The AEG responsible for that aircraft type will serve in an advisory role to the POI. The POI will confer with the AEG as necessary during this process.

(2) For requalification of class 2 and 3 rest facilities, the POI will inspect the QAS along with the rest facility to ensure it meets the previous qualification. The POI will conduct a visual operational inspection to determine the rest facility currently meets the qualification criteria prescribed in part 117.

(3) Once the aircraft's onboard rest facility has been satisfactorily re-qualified, the FAA will reissue a QAS. A copy of the QAS will be issued to the certificate holder and the FAA will also retain a copy. The QAS will remain in effect until a modification to the rest facility or a component of the rest facility renders it noncompliant with the specifications prescribed in

APPENDIX 3B HUMAN ETHICS APPROVAL LETTERS

MASSEY UNIVERSITY

3 June 2011

Prof Philippa Gander
Sleep/Wake Research Centre
WELLINGTON

Dear Philippa

Re: HEC: Southern A Application – 11/01
Evaluation of sleep and performance of flight crew during commercial flight operations

Thank you for your letter dated 7 June 2011.

On behalf of the Massey University Human Ethics Committee: Southern A I am pleased to advise you that the ethics of your application are now approved. This approval includes the minor amendments made to the questionnaire. Approval is for three years. If this project has not been completed within three years from the date of this letter, reapproval must be requested.

Please note that the first progress report is due six months from the date of this letter.

If the nature, content, location, procedures or personnel of your approved application change, please advise the Secretary of the Committee.

Yours sincerely

JMBoddy

Prof Julie Boddy, Chair
Massey University Human Ethics Committee: Southern A

Massey University Human Ethics Committee
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MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA

19 September 2011

Prof Philippa Gander
Sleep/Wake Research Centre
WELLINGTON

Dear Philippa

Re: HEC: Southern A Application – 11/01
Evaluation of sleep and performance of flight crew during commercial flight operations

Thank you for your letter dated 9 September 2011 outlining the changes you wish to make to the above application.

The changes made to the information sheet and consent form in relation to the Certificate of Confidentiality not being granted; and the minor changes to the duty/sleep diary have been approved and noted.

If the nature, content, location, procedures or personnel of your approved application change, please advise the Secretary of the Committee. If over time, more than one request to change the application is received, the Chair may request a new application.

Yours sincerely

R Hugh Morton

A/Prof Hugh Morton, Chair
Massey University Human Ethics Committee: Southern A

Massey University Human Ethics Committee
Accredited by the Health Research Council

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MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA

1 March 2013

Prof Philippa Gander
Sleep/Wake Research Centre
WELLINGTON

Dear Philippa

Re: HEC: Southern A Application – 11/01
Evaluation of sleep and performance of flight crew during commercial flight operations

Thank you for your letter dated 11 January 2013 outlining the change you wish to make to the above application.

The change has been approved and noted as follows:

- As per conditions in the original application, notification of a new route for data collection to cover routes between US East Coast and Europe or Africa.

If the nature, content, location, procedures or personnel of your approved application change, please advise the Secretary of the Committee. If over time, more than one request to change the application is received, the Chair may request a new application.

Yours sincerely

Dr Brian Finch, Chair
Massey University Human Ethics Committee: Southern A

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APPENDIX 3C PARTCIPANT INFORMATION SHEET AND CONSENT FORM

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MOE TIKA, MOE PAI

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COMPARISON OF FULL-SIZE BUNK WITH BUNK TAPERED AT THE FOOT:

B767-300 ER STUDY

INFORMATION SHEET

Introduction

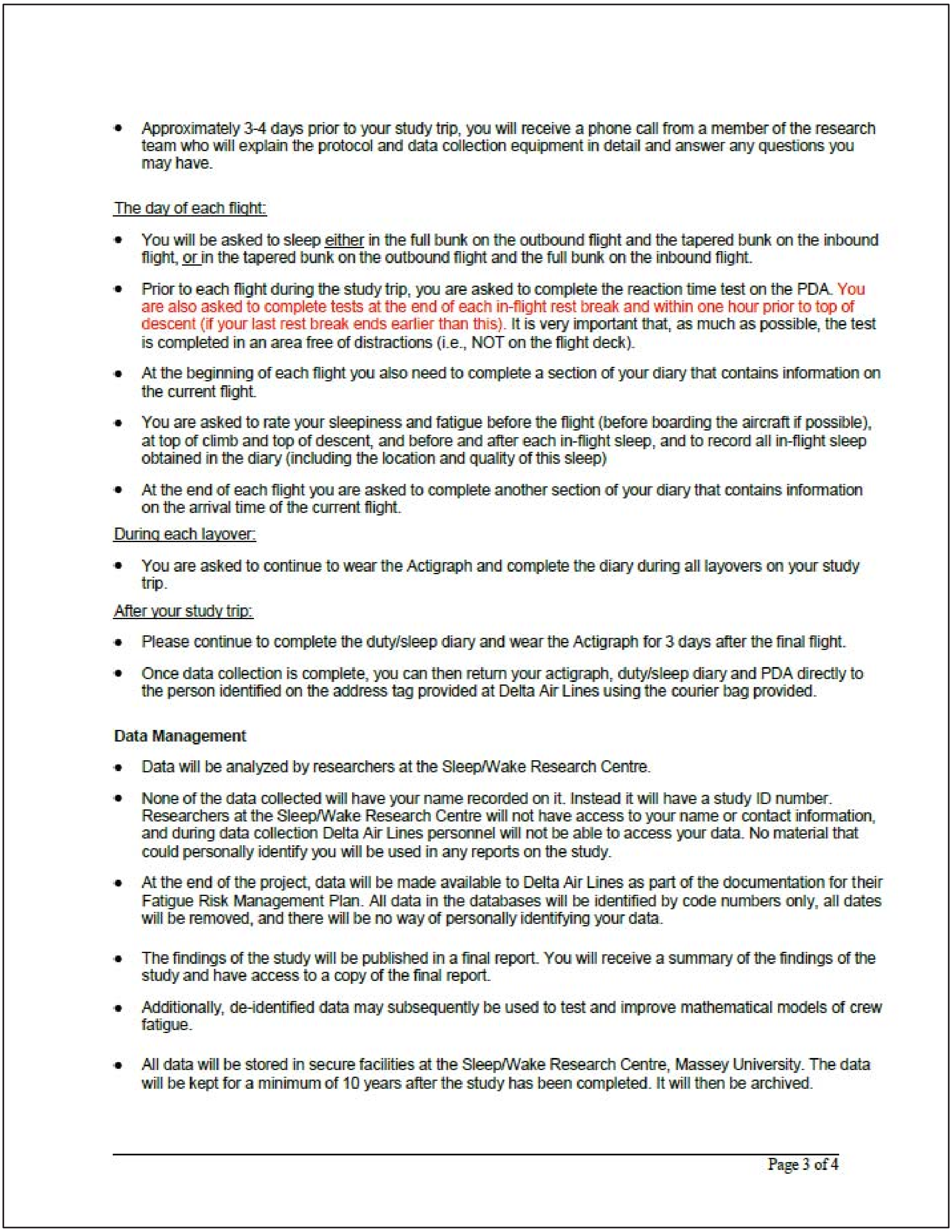
As part of its Fatigue Risk Management Plan (FRMP), Delta Air Lines will monitor in-flight sleep and flight crew fatigue levels on B767-300 ER operations between the USA and Europe or Africa. Researchers from the Sleep/Wake Research Centre, Massey University, New Zealand are assisting with the collection and analysis of data for this purpose. Members of the research team from the Sleep/Wake Research Centre include Professor Philippa Gander, Dr. Leigh Signal, Dr Alexander Smith, Ms. Hannah Mulrine, Ms. Margo van den Berg, and Ms. Jennifer Zaslona - contact details can be found below.

Project Description and Invitation

The aims of the project are to:

- objectively measure the amount and quality of in-flight sleep that flight crew are able to obtain in a full size bunk (78" by 30") verses a bunk which tapers to 21" at the foot (see photos below);
- document the subjective sleepiness and fatigue of flight crew during these trips;
- document alertness (using a 5-minute psychomotor vigilance task) of flight crew during flights on these trips; and
- compare sleep, subjective ratings and alertness on these trips to the same measures gathered during Delta B-777 flight operations on similar routes.

Figure 1: Showing the reduction in bunk width from 30 inches to 21 inches at the foot



- Approximately 3-4 days prior to your study trip, you will receive a phone call from a member of the research team who will explain the protocol and data collection equipment in detail and answer any questions you may have.

The day of each flight:

- You will be asked to sleep either in the full bunk on the outbound flight and the tapered bunk on the inbound flight, or in the tapered bunk on the outbound flight and the full bunk on the inbound flight.
- Prior to each flight during the study trip, you are asked to complete the reaction time test on the PDA. You are also asked to complete tests at the end of each in-flight rest break and within one hour prior to top of descent (if your last rest break ends earlier than this). It is very important that, as much as possible, the test is completed in an area free of distractions (i.e., NOT on the flight deck).
- At the beginning of each flight you also need to complete a section of your diary that contains information on the current flight.
- You are asked to rate your sleepiness and fatigue before the flight (before boarding the aircraft if possible), at top of climb and top of descent, and before and after each in-flight sleep, and to record all in-flight sleep obtained in the diary (including the location and quality of this sleep)
- At the end of each flight you are asked to complete another section of your diary that contains information on the arrival time of the current flight.

During each layover:

- You are asked to continue to wear the Actigraph and complete the diary during all layovers on your study trip.

After your study trip:

- Please continue to complete the duty/sleep diary and wear the Actigraph for 3 days after the final flight.
- Once data collection is complete, you can then return your actigraph, duty/sleep diary and PDA directly to the person identified on the address tag provided at Delta Air Lines using the courier bag provided.

Data Management

- Data will be analyzed by researchers at the Sleep/Wake Research Centre.
- None of the data collected will have your name recorded on it. Instead it will have a study ID number. Researchers at the Sleep/Wake Research Centre will not have access to your name or contact information, and during data collection Delta Air Lines personnel will not be able to access your data. No material that could personally identify you will be used in any reports on the study.
- At the end of the project, data will be made available to Delta Air Lines as part of the documentation for their Fatigue Risk Management Plan. All data in the databases will be identified by code numbers only, all dates will be removed, and there will be no way of personally identifying your data.
- The findings of the study will be published in a final report. You will receive a summary of the findings of the study and have access to a copy of the final report.
- Additionally, de-identified data may subsequently be used to test and improve mathematical models of crew fatigue.
- All data will be stored in secure facilities at the Sleep/Wake Research Centre, Massey University. The data will be kept for a minimum of 10 years after the study has been completed. It will then be archived.

Page 3 of 4

Risks, Discomforts, and Inconveniences

Risks. The possible risks from this data collection effort may include minor discomfort due to the wristband on the Actigraph from a local allergic reaction to its metallic surfaces. If redness and itching occurs, please notify the research team and corrective measures can be taken, such as applying tape to the underside of the Actigraph where skin contact is apparent.

Discomforts. Wearing the wrist activity monitor during sleep may be considered uncomfortable if you are not accustomed to wearing a wristwatch during that time.

Inconveniences. Wearing the Actigraph during this study may be considered an inconvenience, as well as the special care required to prevent exposing it to water/moisture. The Actigraph must be removed during routine showering and potential water exposure. With repeated PDA testing, boredom may occur, though optimal effort is required throughout the assessment period for meaningful data. Tests will require 5 min each time and diary entries will require an estimated 1-2 min each time.

Benefits

You will be contributing to an improved understanding of the fatigue associated with flight operations, and the influence of bunk design on in-flight sleep.

Once your participation in the study is complete you may contact researchers at the Sleep/Wake Research Centre to receive feedback on your individual data. To identify your data you will need to provide the researchers with your identification code.

Compensation and Injury: Medical care and compensation is available through your Delta Air Lines employee procedure if an injury occurs through your participation in this data collection effort.

Participant's Rights

You are under no obligation to accept this invitation to participate in this research. If you decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw from the study at any time and take your data;
- ask any questions about the study at any time during participation;
- provide information on the understanding that none of your data will have your name on it (an identification number is used instead), and you will not be identified in any reports on the study;
- have any of your personal data handed back to you;
- be given access to a summary of the study findings when it is concluded.

Committee Approval Statement

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 11/01. If you have any concerns about the conduct of this research, please contact Dr Brian Finch, Chair, Massey University Human Ethics Committee: Southern A, telephone +646 356 9099 x 8717, email humanethicsoutha@massey.ac.nz.

Project Contacts

If you have any further questions about this study please do not hesitate to contact us by phone or e-mail.

Prof. Philippa Gander	Dr. Leigh Signal	Jennifer Zaslona
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COMPARISON OF FULL-SIZE BUNK WITH BUNK TAPERED AT THE FOOT: B767-300 ER STUDY

PARTICIPANT CONSENT FORM

This consent form will be held by the Sleep/Wake Research Centre for a period of five (5) years

Delta Air Lines and researchers from the Sleep/Wake Research Centre have adequately answered any and all questions I have about this data collection effort, my participation, and the procedures involved. I understand that personnel from Delta Air Lines will be available to answer any questions concerning procedures throughout the time of my participation and that I may also contact researchers from the Sleep/Wake Research Centre.

I understand that if new findings develop during the course of my participation, I will be informed.

I have not given up any of my legal rights or released any individual or institution from liability for negligence.

I understand that records of my participation will be kept confidential, and that I will not be identifiable by name or description in any reports or publications about this effort.

I understand that I may withdraw from participation at any time without penalty or loss of benefits to which I am otherwise entitled. I also understand that Delta Air Lines management, or the researcher may terminate my participation if he/she feels this to be in my best interest.

I understand that de-identified data from all pilots in this study may subsequently be used to test and improve mathematical models of crew fatigue.

If I have questions about this data collection effort, or need to report any adverse effects from participation, I will contact Delta Air Lines management or researchers from the Sleep/Wake Research Centre.

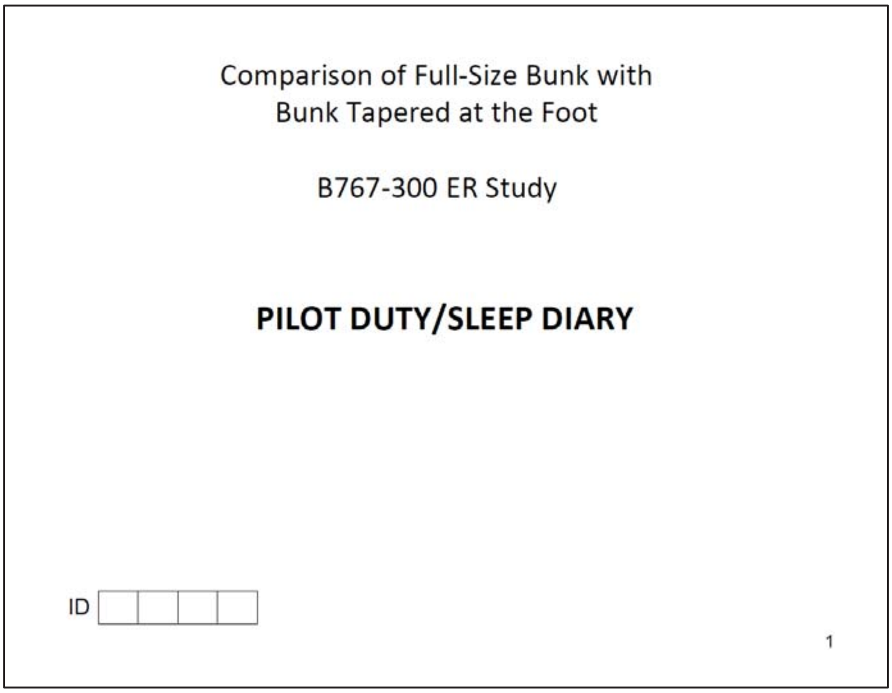
I have read the attached Information Sheet. I understand its contents, and I consent to participate in this study under the conditions described. I have received a copy of the Information Sheet.

Signature: ____________________ **Date:** __________

Full Name - printed ____________________

Page 1 of 1

APPENDIX 3D PRE-STUDY QUESTIONNAIRE AND DUTY/SLEEP DIARY



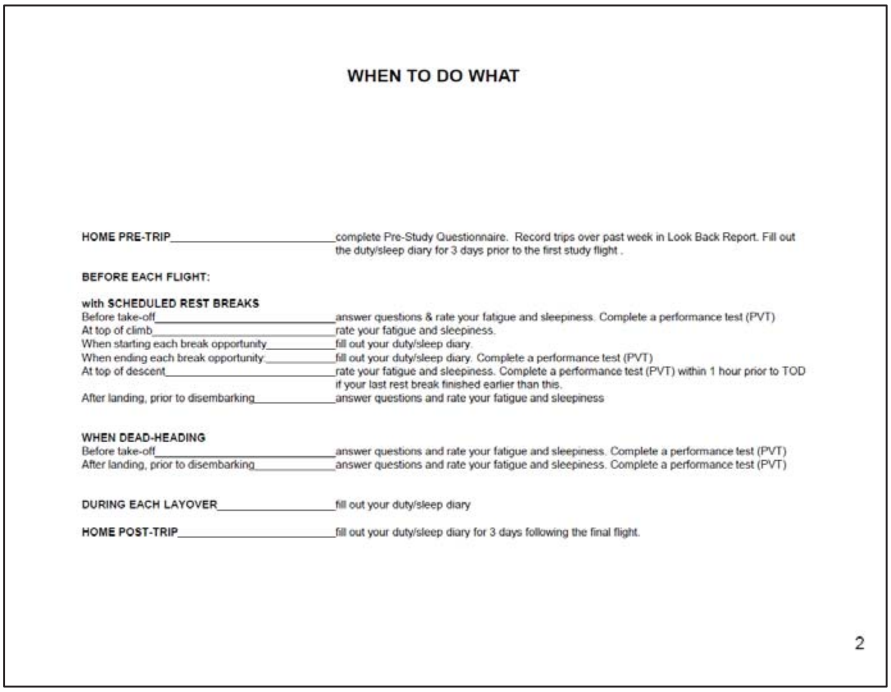
Comparison of Full-Size Bunk with
Bunk Tapered at the Foot

B767-300 ER Study

PILOT DUTY/SLEEP DIARY

ID ☐☐☐☐

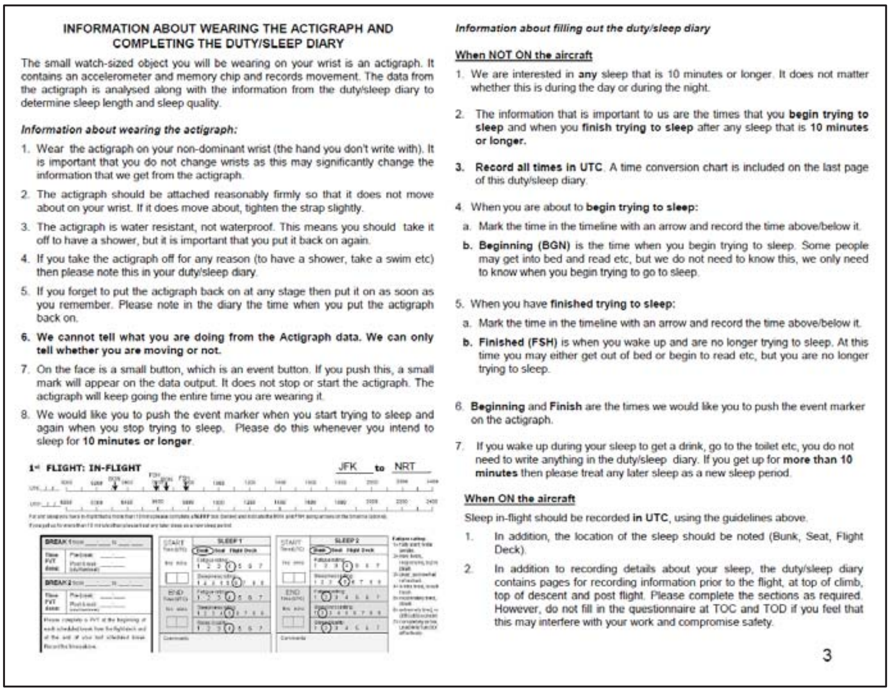
1



WHEN TO DO WHAT

HOME PRE-TRIP	complete Pre-Study Questionnaire. Record trips over past week in Look Back Report. Fill out the duty/sleep diary for 3 days prior to the first study flight .
BEFORE EACH FLIGHT:	
with SCHEDULED REST BREAKS	
Before take-off	answer questions & rate your fatigue and sleepiness. Complete a performance test (PVT)
At top of climb	rate your fatigue and sleepiness.
When starting each break opportunity	fill out your duty/sleep diary.
When ending each break opportunity:	fill out your duty/sleep diary. Complete a performance test (PVT)
At top of descent	rate your fatigue and sleepiness. Complete a performance test (PVT) within 1 hour prior to TOD if your last rest break finished earlier than this.
After landing, prior to disembarking	answer questions and rate your fatigue and sleepiness
WHEN DEAD-HEADING	
Before take-off	answer questions and rate your fatigue and sleepiness. Complete a performance test (PVT)
After landing, prior to disembarking	answer questions and rate your fatigue and sleepiness. Complete a performance test (PVT)
DURING EACH LAYOVER	fill out your duty/sleep diary
HOME POST-TRIP	fill out your duty/sleep diary for 3 days following the final flight.

2



INFORMATION ABOUT WEARING THE ACTIGRAPH AND COMPLETING THE DUTY/SLEEP DIARY

The small watch-sized object you will be wearing on your wrist is an actigraph. It contains an accelerometer and memory chip and records movement. The data from the actigraph is analysed along with the information from the duty/sleep diary to determine sleep length and sleep quality.

Information about wearing the actigraph:

1. Wear the actigraph on your non-dominant wrist (the hand you don't write with). It is important that you do not change wrists as this may significantly change the information that we get from the actigraph.
2. The actigraph should be attached reasonably firmly so that it does not move about on your wrist. If it does move about, tighten the strap slightly.
3. The actigraph is water resistant, not waterproof. This means you should take it off to have a shower, but it is important that you put it back on again.
4. If you take the actigraph off for any reason (to have a shower, take a swim etc) then please note this in your duty/sleep diary.
5. If you forget to put the actigraph back on at any stage then put it on as soon as you remember. Please note in the diary the time when you put the actigraph back on.
6. **We cannot tell what you are doing from the Actigraph data. We can only tell whether you are moving or not.**
7. On the face is a small button, which is an event button. If you push this, a small mark will appear on the data output. It does not stop or start the actigraph. The actigraph will keep going the entire time you are wearing it.
8. We would like you to push the event marker when you start trying to sleep and again when you stop trying to sleep. Please do this whenever you intend to sleep for **10 minutes or longer**.

1st FLIGHT: IN-FLIGHT JFK to NRT

Information about filling out the duty/sleep diary

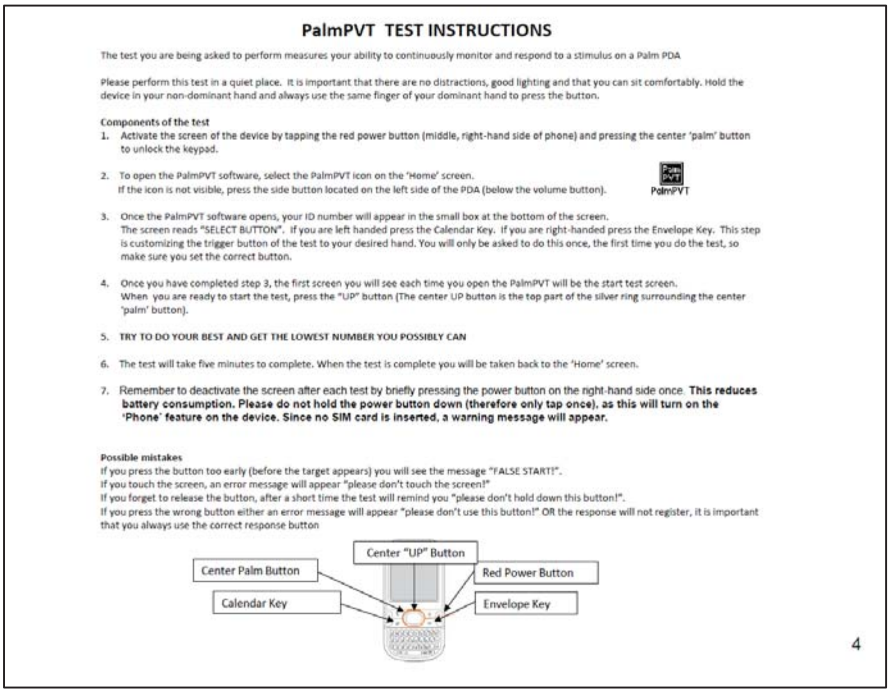
When NOT ON the aircraft

1. We are interested in **any** sleep that is 10 minutes or longer. It does not matter whether this is during the day or during the night.
2. The information that is important to us are the times that you **begin trying to sleep** and when you **finish trying to sleep** after any sleep that is **10 minutes or longer.**
3. **Record all times in UTC**. A time conversion chart is included on the last page of this duty/sleep diary.
4. When you are about to **begin trying to sleep:**
   a. Mark the time in the timeline with an arrow and record the time above/below it.
   b. **Beginning (BGN)** is the time when you begin trying to sleep. Some people may get into bed and read etc, but we do not need to know this, we only need to know when you begin trying to go to sleep.
5. When you have **finished trying to sleep:**
   a. Mark the time in the timeline with an arrow and record the time above/below it.
   b. **Finished (FSH)** is when you wake up and are no longer trying to sleep. At this time you may either get out of bed or begin to read etc, but you are no longer trying to sleep.
6. **Beginning** and **Finish** are the times we would like you to push the event marker on the actigraph.
7. If you wake up during your sleep to get a drink, go to the toilet etc, you do not need to write anything in the duty/sleep diary. If you get up for **more than 10 minutes** then please treat any later sleep as a new sleep period.

When ON the aircraft

Sleep in-flight should be recorded **in UTC**, using the guidelines above.

1. In addition, the location of the sleep should be noted (Bunk, Seat, Flight Deck).
2. In addition to recording details about your sleep, the duty/sleep diary contains pages for recording information prior to the flight, at top of climb, top of descent and post flight. Please complete the sections as required. However, do not fill in the questionnaire at TOC and TOD if you feel that this may interfere with your work and compromise safety.



PalmPVT TEST INSTRUCTIONS

The test you are being asked to perform measures your ability to continuously monitor and respond to a stimulus on a Palm PDA

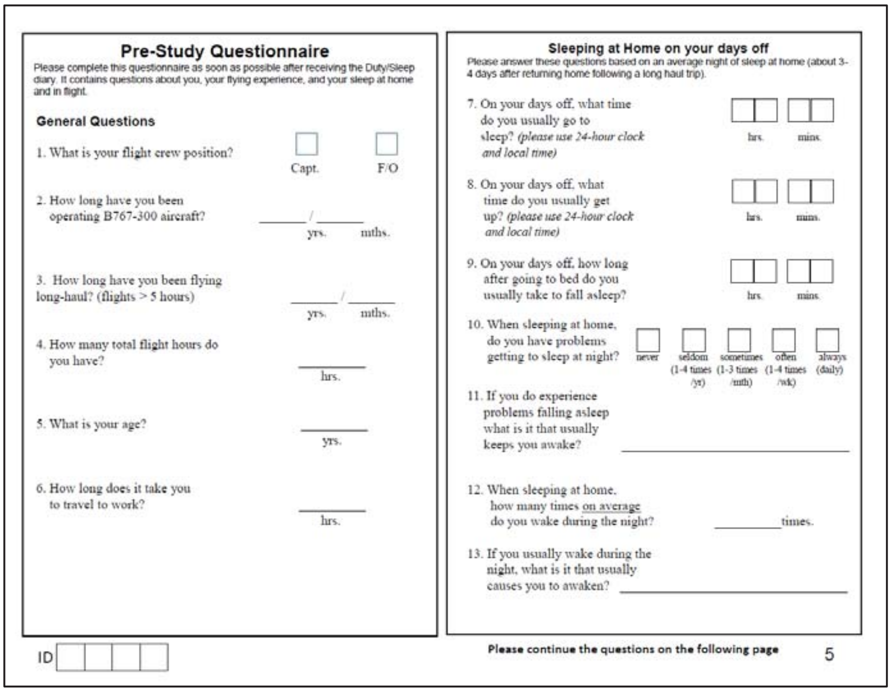
Please perform this test in a quiet place. It is important that there are no distractions, good lighting and that you can sit comfortably. Hold the device in your non-dominant hand and always use the same finger of your dominant hand to press the button.

Components of the test

1. Activate the screen of the device by tapping the red power button (middle, right-hand side of phone) and pressing the center 'palm' button to unlock the keypad.
2. To open the PalmPVT software, select the PalmPVT icon on the 'Home' screen.
   If the icon is not visible, press the side button located on the left side of the PDA (below the volume button).
3. Once the PalmPVT software opens, your ID number will appear in the small box at the bottom of the screen.
   The screen reads "SELECT BUTTON". If you are left handed press the Calendar Key. If you are right-handed press the Envelope Key. This step is customizing the trigger button of the test to your desired hand. You will only be asked to do this once, the first time you do the test, so make sure you set the correct button.
4. Once you have completed step 3, the first screen you will see each time you open the PalmPVT will be the start test screen.
   When you are ready to start the test, press the "UP" button (The center UP button is the top part of the silver ring surrounding the center 'palm' button).
5. **TRY TO DO YOUR BEST AND GET THE LOWEST NUMBER YOU POSSIBLY CAN**
6. The test will take five minutes to complete. When the test is complete you will be taken back to the 'Home' screen.
7. Remember to deactivate the screen after each test by briefly pressing the power button on the right-hand side once. **This reduces battery consumption. Please do not hold the power button down (therefore only tap once), as this will turn on the 'Phone' feature on the device. Since no SIM card is inserted, a warning message will appear.**

Possible mistakes

If you press the button too early (before the target appears) you will see the message "FALSE START!".
If you touch the screen, an error message will appear "please don't touch the screen!"
If you forget to release the button, after a short time the test will remind you "please don't hold down this button!".
If you press the wrong button either an error message will appear "please don't use this button!" OR the response will not register, it is important that you always use the correct response button



Pre-Study Questionnaire

Please complete this questionnaire as soon as possible after receiving the Duty/Sleep diary. It contains questions about you, your flying experience, and your sleep at home and in flight.

General Questions

1. What is your flight crew position? ☐ Capt. ☐ F/O

2. How long have you been operating B767-300 aircraft? ______ / ______ yrs. mths.

3. How long have you been flying long-haul? (flights > 5 hours) ______ / ______ yrs. mths.

4. How many total flight hours do you have? ______ hrs.

5. What is your age? ______ yrs.

6. How long does it take you to travel to work? ______ hrs.

ID ☐☐☐☐

Sleeping at Home on your days off

Please answer these questions based on an average night of sleep at home (about 3-4 days after returning home following a long haul trip).

7. On your days off, what time do you usually go to sleep? *(please use 24-hour clock and local time)* ☐☐ hrs. ☐☐ mins.

8. On your days off, what time do you usually get up? *(please use 24-hour clock and local time)* ☐☐ hrs. ☐☐ mins.

9. On your days off, how long after going to bed do you usually take to fall asleep? ☐☐ hrs. ☐☐ mins.

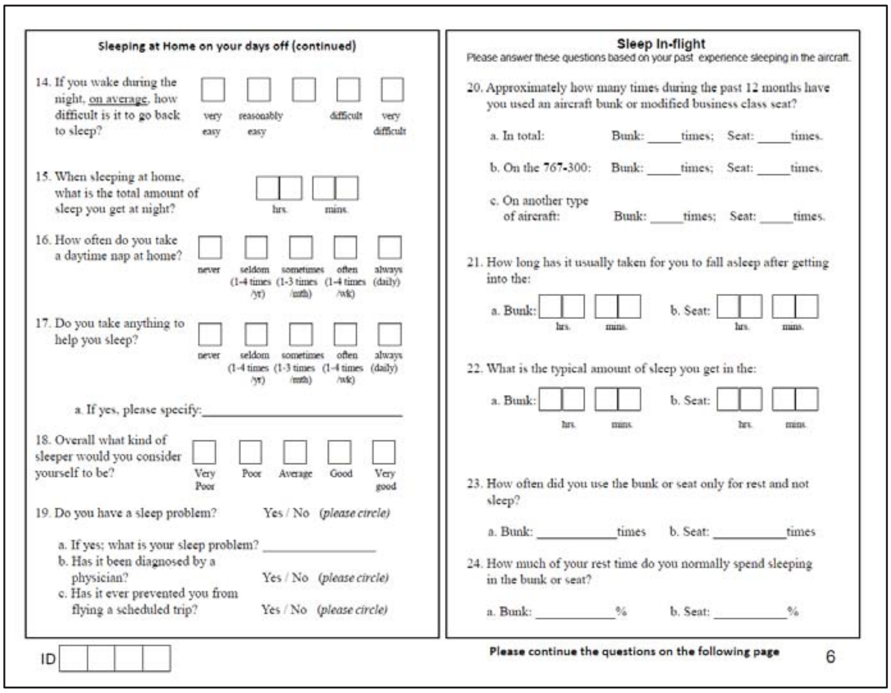
10. When sleeping at home, do you have problems getting to sleep at night? ☐ never ☐ seldom (1-4 times /yr) ☐ sometimes (1-3 times /mth) ☐ often (1-4 times /wk) ☐ always (daily)

11. If you do experience problems falling asleep what is it that usually keeps you awake? ______________________

12. When sleeping at home, how many times on average do you wake during the night? ________ times.

13. If you usually wake during the night, what is it that usually causes you to awaken? ______________________

Please continue the questions on the following page 5



Sleeping at Home on your days off (continued)

14. If you wake during the night, on average, how difficult is it to go back to sleep? ☐ very easy ☐ reasonably easy ☐ ☐ difficult ☐ very difficult

15. When sleeping at home, what is the total amount of sleep you get at night? ☐☐ hrs. ☐☐ mins.

16. How often do you take a daytime nap at home? ☐ never ☐ seldom (1-4 times /yr) ☐ sometimes (1-3 times /mth) ☐ often (1-4 times /wk) ☐ always (daily)

17. Do you take anything to help you sleep? ☐ never ☐ seldom (1-4 times /yr) ☐ sometimes (1-3 times /mth) ☐ often (1-4 times /wk) ☐ always (daily)

a. If yes, please specify: ______________________

18. Overall what kind of sleeper would you consider yourself to be? ☐ Very Poor ☐ Poor ☐ Average ☐ Good ☐ Very good

19. Do you have a sleep problem? Yes / No *(please circle)*

a. If yes; what is your sleep problem? ______________
b. Has it been diagnosed by a physician? Yes / No *(please circle)*
c. Has it ever prevented you from flying a scheduled trip? Yes / No *(please circle)*

ID ☐☐☐☐

Sleep In-flight

Please answer these questions based on your past experience sleeping in the aircraft.

20. Approximately how many times during the past 12 months have you used an aircraft bunk or modified business class seat?

a. In total: Bunk: _____times; Seat: _____times.
b. On the 767-300: Bunk: _____times; Seat: _____times.
c. On another type of aircraft: Bunk: _____times; Seat: _____times.

21. How long has it usually taken for you to fall asleep after getting into the:

a. Bunk: ☐☐ hrs. ☐☐ mins. b. Seat: ☐☐ hrs. ☐☐ mins.

22. What is the typical amount of sleep you get in the:

a. Bunk: ☐☐ hrs. ☐☐ mins. b. Seat: ☐☐ hrs. ☐☐ mins.

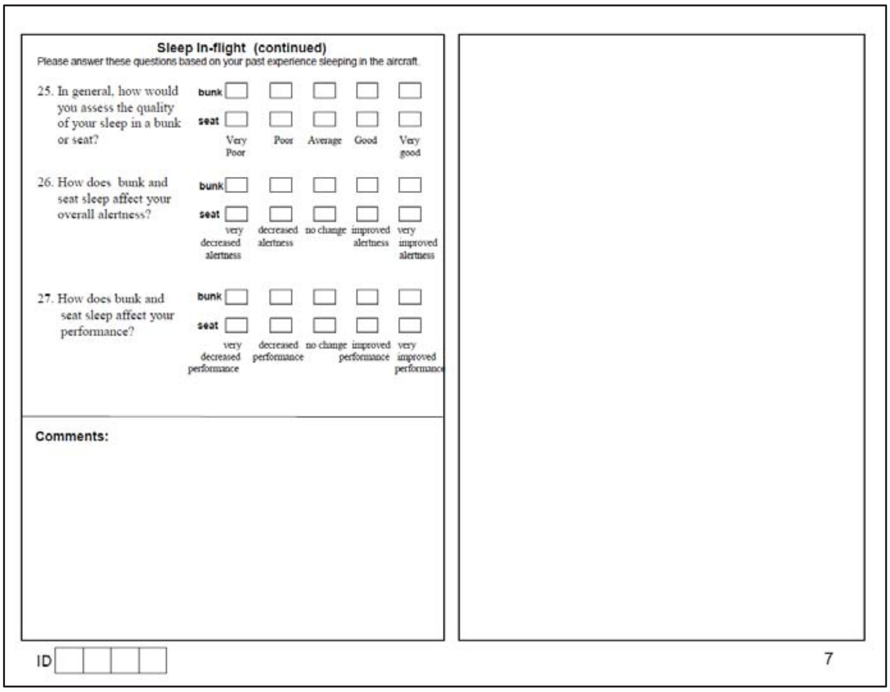
23. How often did you use the bunk or seat only for rest and not sleep?

a. Bunk: __________times b. Seat: __________times

24. How much of your rest time do you normally spend sleeping in the bunk or seat?

a. Bunk: __________% b. Seat: __________%

Please continue the questions on the following page 6



Sleep In-flight (continued)

Please answer these questions based on your past experience sleeping in the aircraft.

25\. In general, how would you assess the quality of your sleep in a bunk or seat?

	Very Poor	Poor	Average	Good	Very good
bunk	☐	☐	☐	☐	☐
seat	☐	☐	☐	☐	☐

26\. How does bunk and seat sleep affect your overall alertness?

	very decreased alertness	decreased alertness	no change	improved alertness	very improved alertness
bunk	☐	☐	☐	☐	☐
seat	☐	☐	☐	☐	☐

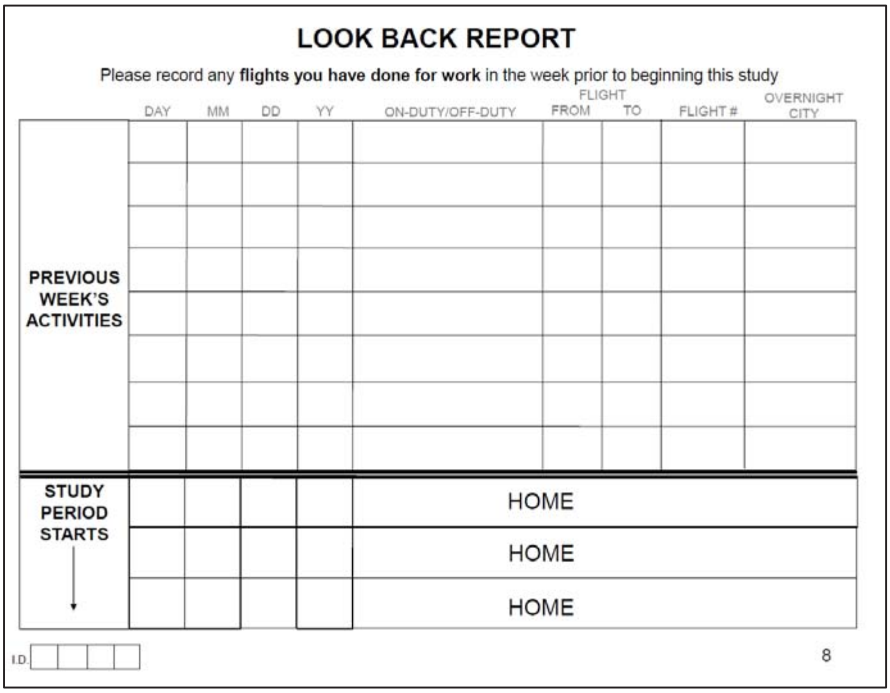
27\. How does bunk and seat sleep affect your performance?

	very decreased performance	decreased performance	no change	improved performance	very improved performanc
bunk	☐	☐	☐	☐	☐
seat	☐	☐	☐	☐	☐

Comments:

ID ☐☐☐☐

7



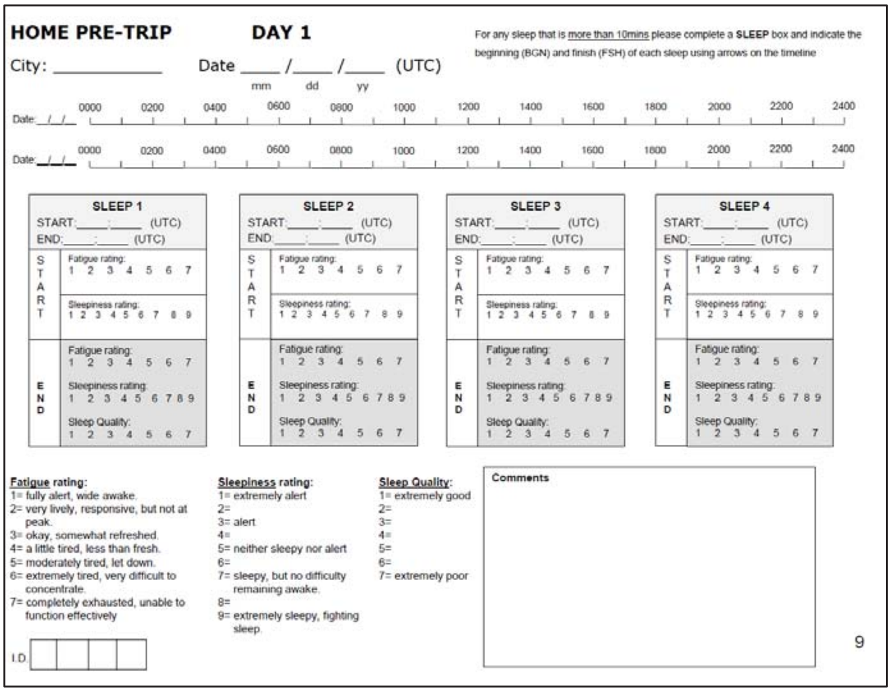
LOOK BACK REPORT

Please record any **flights you have done for work** in the week prior to beginning this study

	DAY	MM	DD	YY	ON-DUTY/OFF-DUTY	FLIGHT FROM	TO	FLIGHT #	OVERNIGHT CITY
PREVIOUS WEEK'S ACTIVITIES									
STUDY PERIOD STARTS ↓					HOME				
					HOME				
					HOME				

I.D. ☐☐☐☐

8



HOME PRE-TRIP **DAY 1**

City: ___________ Date ____ /____ /____ (UTC)
mm dd yy

For any sleep that is more than 10mins please complete a **SLEEP** box and indicate the beginning (BGN) and finish (FSH) of each sleep using arrows on the timeline

Date:__/__/__ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

Date:__/__/__ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

	SLEEP 1	SLEEP 2	SLEEP 3	SLEEP 4
	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)
START	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7
	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9
END	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7

Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

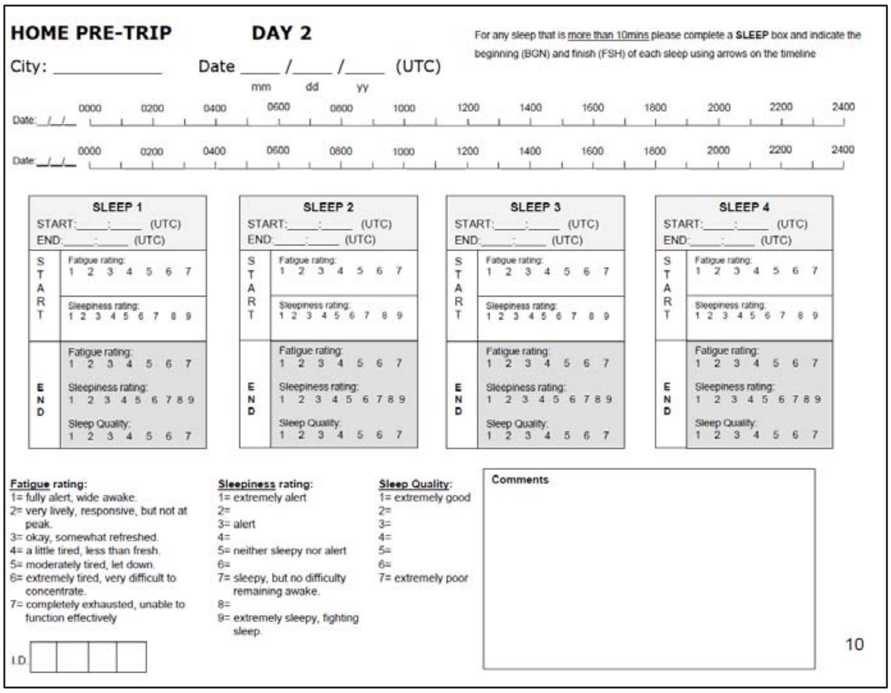
Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep.

Sleep Quality:
1= extremely good
2=
3=
4=
5=
6=
7= extremely poor

Comments

I.D. ☐☐☐☐

9



HOME PRE-TRIP **DAY 2**

City: ___________ Date ____ /____ /____ (UTC)
mm dd yy

For any sleep that is more than 10mins please complete a **SLEEP** box and indicate the beginning (BGN) and finish (FSH) of each sleep using arrows on the timeline

Date:__/__/__ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

Date:__/__/__ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

	SLEEP 1	SLEEP 2	SLEEP 3	SLEEP 4
	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)
START	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7
	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9
END	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7

Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

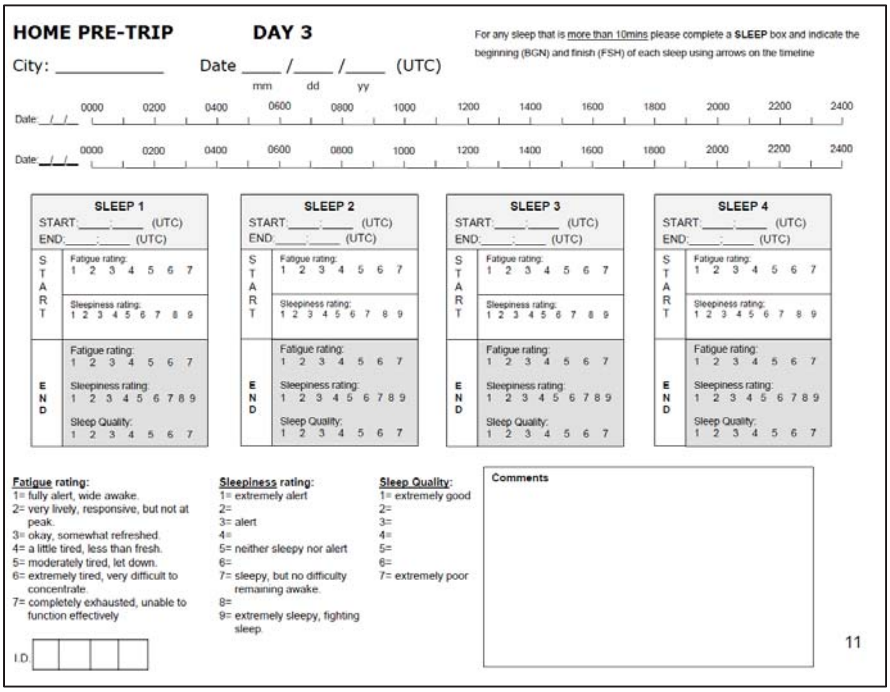
Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep.

Sleep Quality:
1= extremely good
2=
3=
4=
5=
6=
7= extremely poor

Comments

I.D. ☐☐☐☐

10



HOME PRE-TRIP **DAY 3**

City: ___________ Date ____ /____ /____ (UTC)
mm dd yy

For any sleep that is more than 10mins please complete a **SLEEP** box and indicate the beginning (BGN) and finish (FSH) of each sleep using arrows on the timeline

Date: / / 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

Date: / / 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

	SLEEP 1	**SLEEP 2**	**SLEEP 3**	**SLEEP 4**
	START: ____:____ (UTC) END: ____:____ (UTC)	START: ____:____ (UTC) END: ____:____ (UTC)	START: ____:____ (UTC) END: ____:____ (UTC)	START: ____:____ (UTC) END: ____:____ (UTC)
START	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9
END	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7

Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

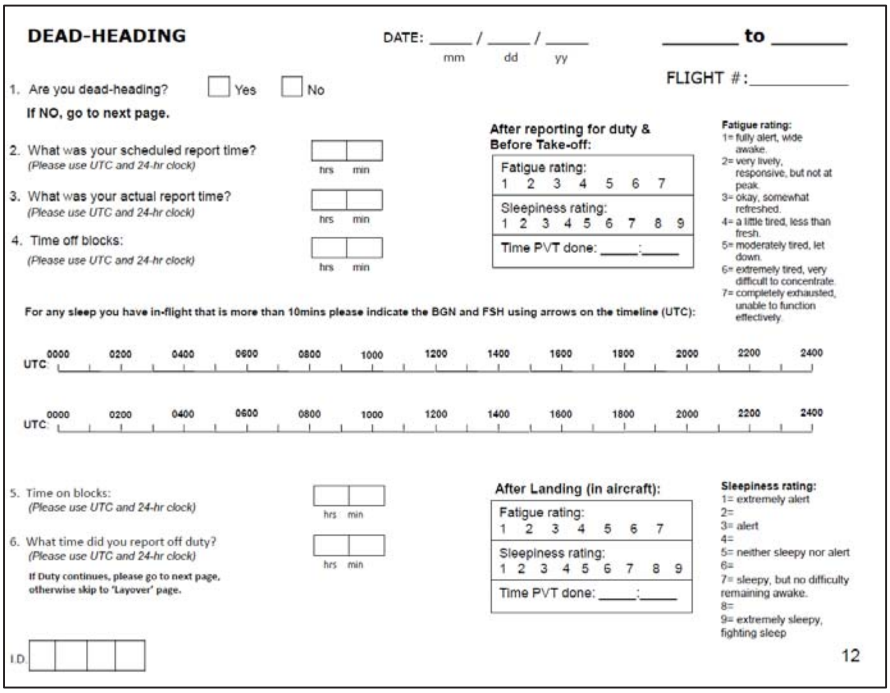
Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep.

Sleep Quality:
1= extremely good
2=
3=
4=
5=
6=
7= extremely poor

Comments

I.D. ☐☐☐☐

11



DEAD-HEADING DATE: _____ / _____ / _____ _______ **to** _______
mm dd yy

FLIGHT #:__________

1. Are you dead-heading? ☐ Yes ☐ No

If NO, go to next page.

2. What was your scheduled report time? ☐☐ hrs min
(Please use UTC and 24-hr clock)
3. What was your actual report time? ☐☐ hrs min
(Please use UTC and 24-hr clock)
4. Time off blocks: ☐☐ hrs min
(Please use UTC and 24-hr clock)

After reporting for duty & Before Take-off:

Fatigue rating:
1 2 3 4 5 6 7
Sleepiness rating:
1 2 3 4 5 6 7 8 9
Time PVT done: _____:_____

Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively.

For any sleep you have in-flight that is more than 10mins please indicate the BGN and FSH using arrows on the timeline (UTC):

UTC 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

UTC 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

5. Time on blocks: ☐☐ hrs min
(Please use UTC and 24-hr clock)
6. What time did you report off duty? ☐☐ hrs min
(Please use UTC and 24-hr clock)

If Duty continues, please go to next page, otherwise skip to 'Layover' page.

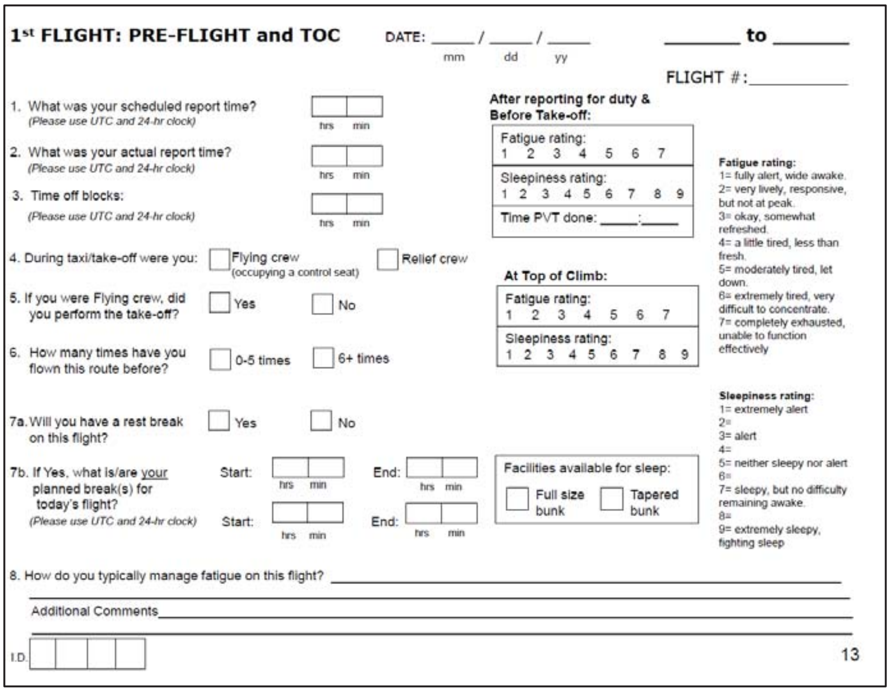
After Landing (in aircraft):

Fatigue rating:
1 2 3 4 5 6 7
Sleepiness rating:
1 2 3 4 5 6 7 8 9
Time PVT done: _____:_____

Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep

I.D. ☐☐☐☐

12



1st FLIGHT: PRE-FLIGHT and TOC DATE: _____ / _____ / _____ (mm dd yy) _______ to _______

FLIGHT # :__________

1. What was your scheduled report time? ☐☐ hrs min
   (Please use UTC and 24-hr clock)
2. What was your actual report time? ☐☐ hrs min
   (Please use UTC and 24-hr clock)
3. Time off blocks: ☐☐ hrs min
   (Please use UTC and 24-hr clock)
4. During taxi/take-off were you: ☐ Flying crew (occupying a control seat) ☐ Relief crew
5. If you were Flying crew, did you perform the take-off? ☐ Yes ☐ No
6. How many times have you flown this route before? ☐ 0-5 times ☐ 6+ times

7a. Will you have a rest break on this flight? ☐ Yes ☐ No

7b. If Yes, what is/are your planned break(s) for today's flight? *(Please use UTC and 24-hr clock)*
Start: ☐☐ hrs min End: ☐☐ hrs min
Start: ☐☐ hrs min End: ☐☐ hrs min

8. How do you typically manage fatigue on this flight? ________________________________

Additional Comments________________________________

After reporting for duty & Before Take-off:

Fatigue rating: 1 2 3 4 5 6 7
Sleepiness rating: 1 2 3 4 5 6 7 8 9
Time PVT done: _____:_____

At Top of Climb:

Fatigue rating: 1 2 3 4 5 6 7
Sleepiness rating: 1 2 3 4 5 6 7 8 9

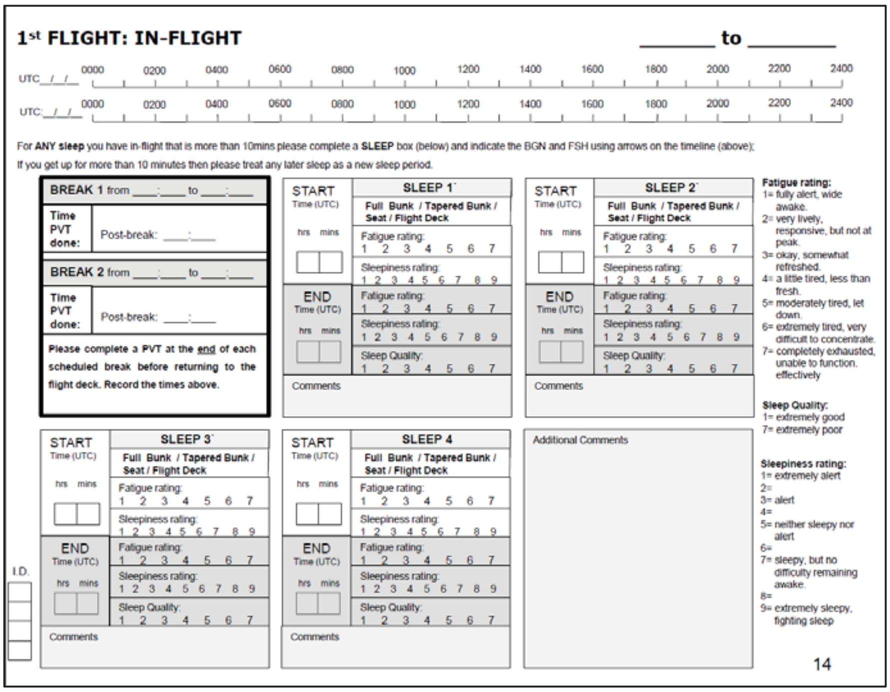
Facilities available for sleep: ☐ Full size bunk ☐ Tapered bunk

Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep

I.D. ☐☐☐☐

13



1st FLIGHT: IN-FLIGHT _______ to _______

UTC__/__/__ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400
UTC:__/__/__ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

For **ANY sleep** you have in-flight that is more than 10mins please complete a **SLEEP** box (below) and indicate the BGN and FSH using arrows on the timeline (above);
If you get up for more than 10 minutes then please treat any later sleep as a new sleep period.

BREAK 1 from ____:____ to ____:____
Time PVT done: Post-break: ____:____

BREAK 2 from ____:____ to ____:____
Time PVT done: Post-break: ____:____

Please complete a PVT at the end of each scheduled break before returning to the flight deck. Record the times above.

SLEEP 1
START Time (UTC) hrs mins ☐☐
Full Bunk / Tapered Bunk / Seat / Flight Deck
Fatigue rating: 1 2 3 4 5 6 7
Sleepiness rating: 1 2 3 4 5 6 7 8 9
END Time (UTC) hrs mins ☐☐
Fatigue rating: 1 2 3 4 5 6 7
Sleepiness rating: 1 2 3 4 5 6 7 8 9
Sleep Quality: 1 2 3 4 5 6 7
Comments

SLEEP 2
START Time (UTC) hrs mins ☐☐
Full Bunk / Tapered Bunk / Seat / Flight Deck
Fatigue rating: 1 2 3 4 5 6 7
Sleepiness rating: 1 2 3 4 5 6 7 8 9
END Time (UTC) hrs mins ☐☐
Fatigue rating: 1 2 3 4 5 6 7
Sleepiness rating: 1 2 3 4 5 6 7 8 9
Sleep Quality: 1 2 3 4 5 6 7
Comments

SLEEP 3
START Time (UTC) hrs mins ☐☐
Full Bunk / Tapered Bunk / Seat / Flight Deck
Fatigue rating: 1 2 3 4 5 6 7
Sleepiness rating: 1 2 3 4 5 6 7 8 9
END Time (UTC) hrs mins ☐☐
Fatigue rating: 1 2 3 4 5 6 7
Sleepiness rating: 1 2 3 4 5 6 7 8 9
Sleep Quality: 1 2 3 4 5 6 7
Comments

SLEEP 4
START Time (UTC) hrs mins ☐☐
Full Bunk / Tapered Bunk / Seat / Flight Deck
Fatigue rating: 1 2 3 4 5 6 7
Sleepiness rating: 1 2 3 4 5 6 7 8 9
END Time (UTC) hrs mins ☐☐
Fatigue rating: 1 2 3 4 5 6 7
Sleepiness rating: 1 2 3 4 5 6 7 8 9
Sleep Quality: 1 2 3 4 5 6 7
Comments

Additional Comments

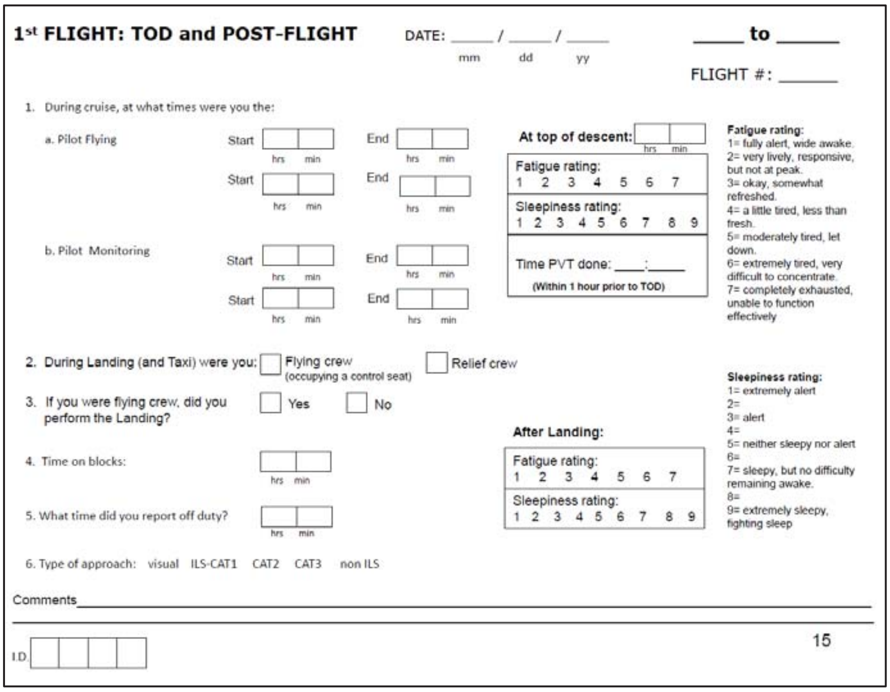
Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function, effectively

Sleep Quality:
1= extremely good
7= extremely poor

Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep

I.D. ☐☐☐☐

14



1st FLIGHT: TOD and POST-FLIGHT

DATE: _____ / _____ / _____
mm dd yy

_____ to ______

FLIGHT #: ______

1. During cruise, at what times were you the:
   - a. Pilot Flying
     - Start ☐☐ hrs min End ☐☐ hrs min
     - Start ☐☐ hrs min End ☐☐ hrs min
   - b. Pilot Monitoring
     - Start ☐☐ hrs min End ☐☐ hrs min
     - Start ☐☐ hrs min End ☐☐ hrs min

At top of descent: ☐☐ hrs min

Fatigue rating:
1 2 3 4 5 6 7

Sleepiness rating:
1 2 3 4 5 6 7 8 9

Time PVT done: ____:_____
(Within 1 hour prior to TOD)

Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

2. During Landing (and Taxi) were you: ☐ Flying crew (occupying a control seat) ☐ Relief crew
3. If you were flying crew, did you perform the Landing? ☐ Yes ☐ No
4. Time on blocks: ☐☐ hrs min
5. What time did you report off duty? ☐☐ hrs min
6. Type of approach: visual ILS-CAT1 CAT2 CAT3 non ILS

After Landing:

Fatigue rating:
1 2 3 4 5 6 7

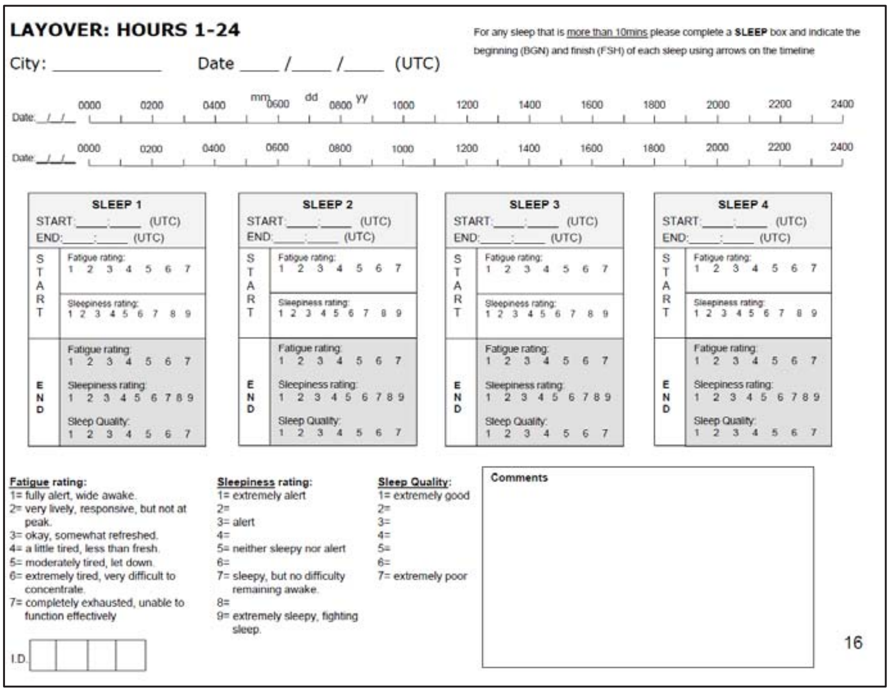
Sleepiness rating:
1 2 3 4 5 6 7 8 9

Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep

Comments___________________________________

I.D. ☐☐☐☐

15



LAYOVER: HOURS 1-24

For any sleep that is more than 10mins please complete a **SLEEP** box and indicate the beginning (BGN) and finish (FSH) of each sleep using arrows on the timeline

City: ___________ Date ____ /____ /____ (UTC)
mm dd yy

Date:_/_/_ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

Date:_/_/_ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

	SLEEP 1	SLEEP 2	SLEEP 3	SLEEP 4
	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)
START	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7
	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9
END	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7
	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9
	Sleep Quality: 1 2 3 4 5 6 7	Sleep Quality: 1 2 3 4 5 6 7	Sleep Quality: 1 2 3 4 5 6 7	Sleep Quality: 1 2 3 4 5 6 7

Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

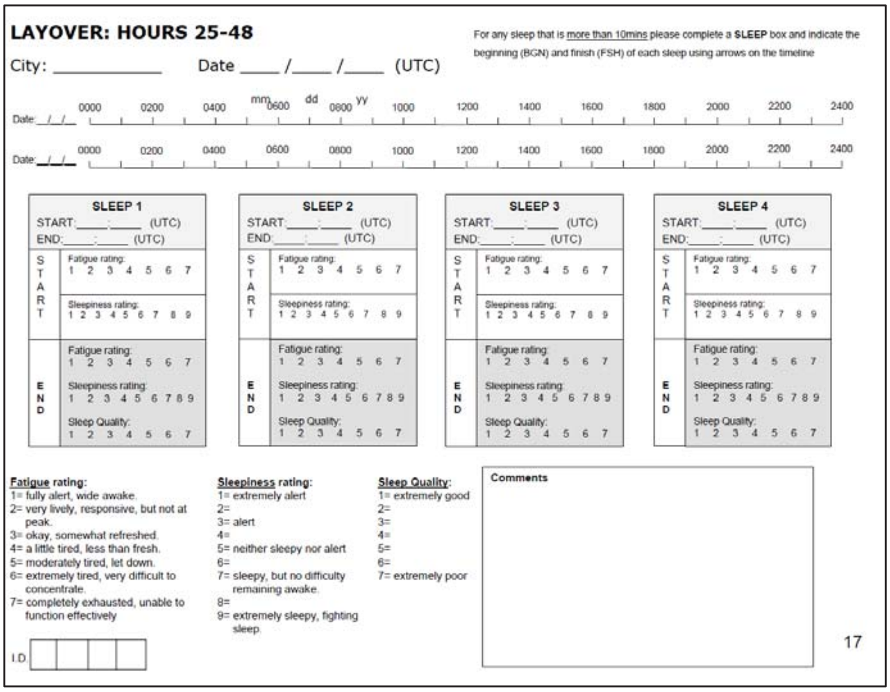
Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep.

Sleep Quality:
1= extremely good
2=
3=
4=
5=
6=
7= extremely poor

Comments

I.D. ☐☐☐☐

16



LAYOVER: HOURS 25-48

City: ____________ Date ____ /____ /____ (UTC)

For any sleep that is more than 10mins please complete a **SLEEP** box and indicate the beginning (BGN) and finish (FSH) of each sleep using arrows on the timeline

mm dd yy

Date:__/__/__ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

Date:__/__/__ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

	SLEEP 1	**SLEEP 2**	**SLEEP 3**	**SLEEP 4**
	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)
START	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7
	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9
END	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7
	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9
	Sleep Quality: 1 2 3 4 5 6 7	Sleep Quality: 1 2 3 4 5 6 7	Sleep Quality: 1 2 3 4 5 6 7	Sleep Quality: 1 2 3 4 5 6 7

Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

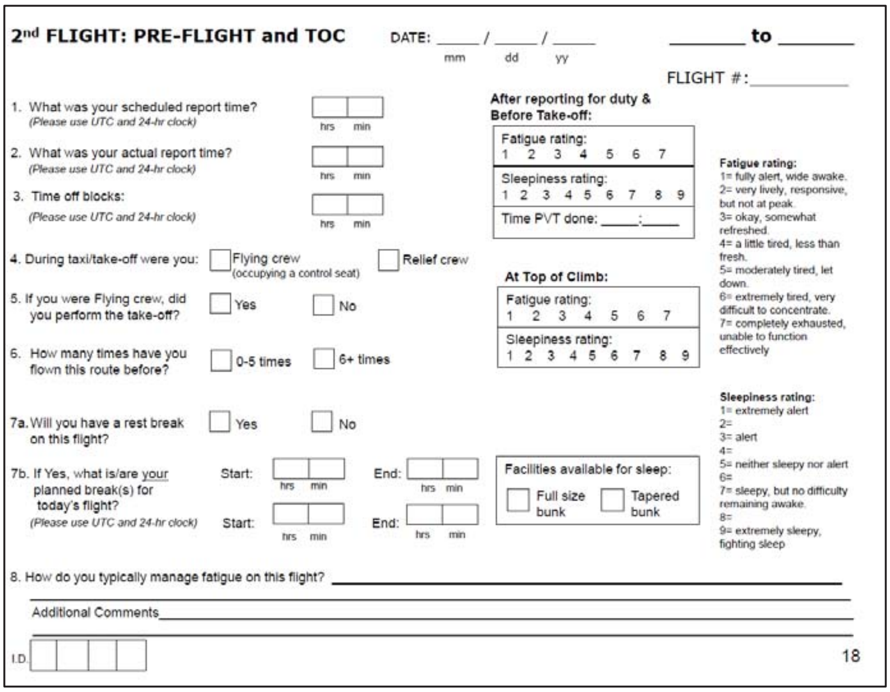
Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep.

Sleep Quality:
1= extremely good
2=
3=
4=
5=
6=
7= extremely poor

Comments

I.D. ☐☐☐☐

17



2nd FLIGHT: PRE-FLIGHT and TOC

DATE: _____ / _____ / _____
mm dd yy

________ to ________

FLIGHT #:__________

1. What was your scheduled report time? ☐☐ hrs min
(Please use UTC and 24-hr clock)

2. What was your actual report time? ☐☐ hrs min
(Please use UTC and 24-hr clock)

3. Time off blocks: ☐☐ hrs min
(Please use UTC and 24-hr clock)

4. During taxi/take-off were you: ☐ Flying crew (occupying a control seat) ☐ Relief crew

5. If you were Flying crew, did you perform the take-off? ☐ Yes ☐ No

6. How many times have you flown this route before? ☐ 0-5 times ☐ 6+ times

7a. Will you have a rest break on this flight? ☐ Yes ☐ No

7b. If Yes, what is/are your planned break(s) for today's flight?
(Please use UTC and 24-hr clock)
Start: ☐☐ hrs min End: ☐☐ hrs min
Start: ☐☐ hrs min End: ☐☐ hrs min

8. How do you typically manage fatigue on this flight? ______________________

Additional Comments______________________

After reporting for duty & Before Take-off:

Fatigue rating:
1 2 3 4 5 6 7

Sleepiness rating:
1 2 3 4 5 6 7 8 9

Time PVT done: _____:_____

At Top of Climb:

Fatigue rating:
1 2 3 4 5 6 7

Sleepiness rating:
1 2 3 4 5 6 7 8 9

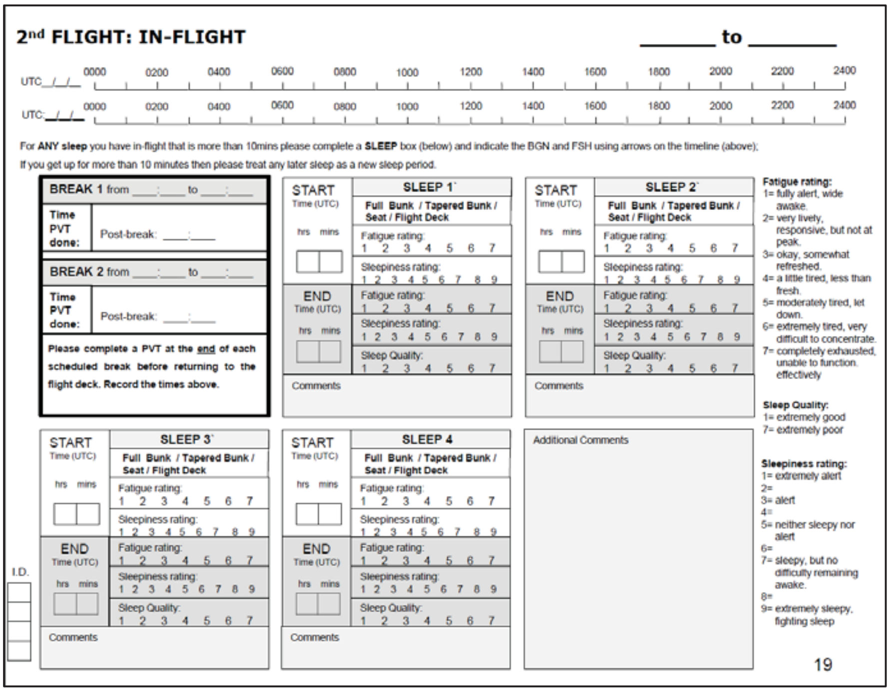
Facilities available for sleep:
☐ Full size bunk ☐ Tapered bunk

Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep

I.D. ☐☐☐☐

18



2nd FLIGHT: IN-FLIGHT

______ to ________

UTC__/__/__ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

UTC:__/__/__ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

For **ANY sleep** you have in-flight that is more than 10mins please complete a **SLEEP** box (below) and indicate the BGN and FSH using arrows on the timeline (above);

If you get up for more than 10 minutes then please treat any later sleep as a new sleep period.

BREAK 1 from ____:____ to ____:____

Time PVT done: Post-break: ____:____

BREAK 2 from ____:____ to ____:____

Time PVT done: Post-break: ____:____

Please complete a PVT at the end of each scheduled break before returning to the flight deck. Record the times above.

START Time (UTC) hrs mins ☐☐

SLEEP 1

Full Bunk / Tapered Bunk / Seat / Flight Deck

Fatigue rating: 1 2 3 4 5 6 7

Sleepiness rating: 1 2 3 4 5 6 7 8 9

END Time (UTC) hrs mins ☐☐

Fatigue rating: 1 2 3 4 5 6 7

Sleepiness rating: 1 2 3 4 5 6 7 8 9

Sleep Quality: 1 2 3 4 5 6 7

Comments

START Time (UTC) hrs mins ☐☐

SLEEP 2

Full Bunk / Tapered Bunk / Seat / Flight Deck

Fatigue rating: 1 2 3 4 5 6 7

Sleepiness rating: 1 2 3 4 5 6 7 8 9

END Time (UTC) hrs mins ☐☐

Fatigue rating: 1 2 3 4 5 6 7

Sleepiness rating: 1 2 3 4 5 6 7 8 9

Sleep Quality: 1 2 3 4 5 6 7

Comments

START Time (UTC) hrs mins ☐☐

SLEEP 3

Full Bunk / Tapered Bunk / Seat / Flight Deck

Fatigue rating: 1 2 3 4 5 6 7

Sleepiness rating: 1 2 3 4 5 6 7 8 9

END Time (UTC) hrs mins ☐☐

Fatigue rating: 1 2 3 4 5 6 7

Sleepiness rating: 1 2 3 4 5 6 7 8 9

Sleep Quality: 1 2 3 4 5 6 7

Comments

START Time (UTC) hrs mins ☐☐

SLEEP 4

Full Bunk / Tapered Bunk / Seat / Flight Deck

Fatigue rating: 1 2 3 4 5 6 7

Sleepiness rating: 1 2 3 4 5 6 7 8 9

END Time (UTC) hrs mins ☐☐

Fatigue rating: 1 2 3 4 5 6 7

Sleepiness rating: 1 2 3 4 5 6 7 8 9

Sleep Quality: 1 2 3 4 5 6 7

Comments

Additional Comments

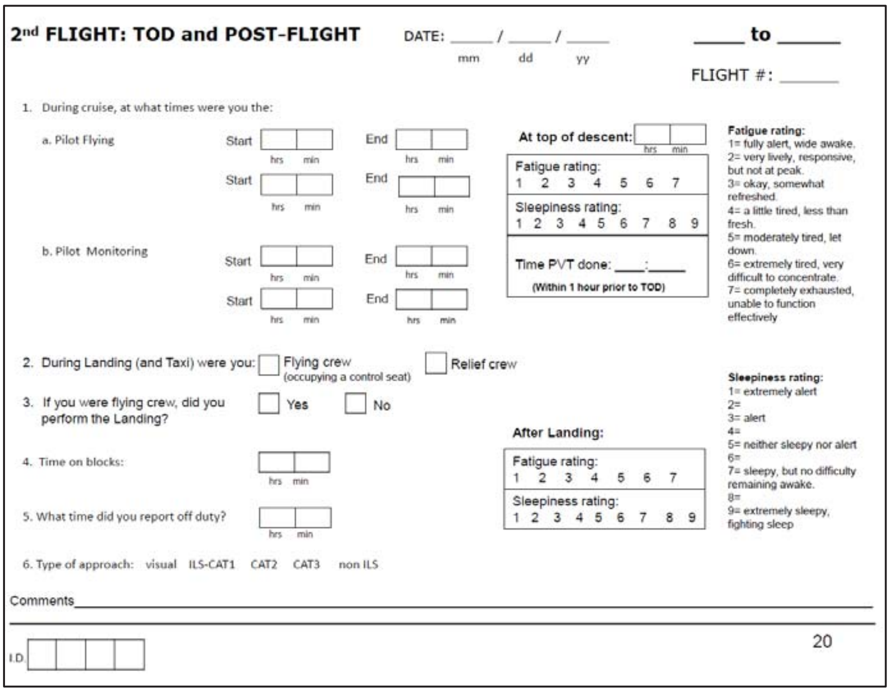
Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

Sleep Quality:
1= extremely good
7= extremely poor

Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep

I.D. ☐☐☐☐

19



2nd FLIGHT: TOD and POST-FLIGHT DATE: _____ / _____ / _____
mm dd yy

_____ to _____

FLIGHT #: _______

1. During cruise, at what times were you the:

a. Pilot Flying Start ☐☐ (hrs min) End ☐☐ (hrs min)
Start ☐☐ (hrs min) End ☐☐ (hrs min)

b. Pilot Monitoring Start ☐☐ (hrs min) End ☐☐ (hrs min)
Start ☐☐ (hrs min) End ☐☐ (hrs min)

At top of descent: ☐☐ (hrs min)

Fatigue rating: 1 2 3 4 5 6 7

Sleepiness rating: 1 2 3 4 5 6 7 8 9

Time PVT done: ____:_____

(Within 1 hour prior to TOD)

2. During Landing (and Taxi) were you: ☐ Flying crew (occupying a control seat) ☐ Relief crew

3. If you were flying crew, did you perform the Landing? ☐ Yes ☐ No

4. Time on blocks: ☐☐ (hrs min)

5. What time did you report off duty? ☐☐ (hrs min)

6. Type of approach: visual ILS-CAT1 CAT2 CAT3 non ILS

After Landing:

Fatigue rating: 1 2 3 4 5 6 7

Sleepiness rating: 1 2 3 4 5 6 7 8 9

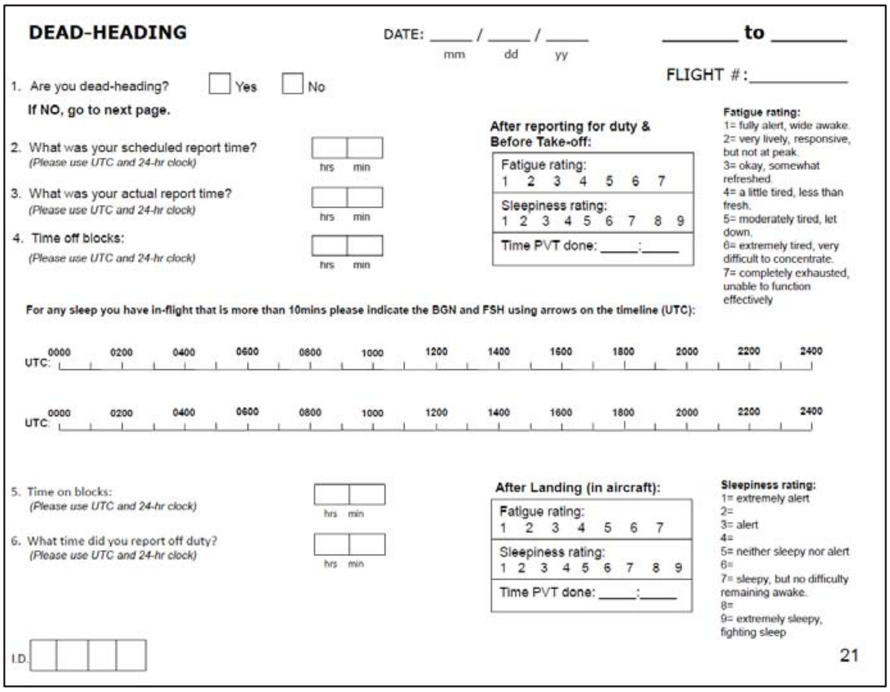
Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep

Comments____________________

I.D. ☐☐☐☐

20



DEAD-HEADING

DATE: _____ / _____ / _____
mm dd yy

_______ to _______

FLIGHT # :__________

1. Are you dead-heading? ☐ Yes ☐ No

If NO, go to next page.

2. What was your scheduled report time? ☐☐ hrs min
(Please use UTC and 24-hr clock)
3. What was your actual report time? ☐☐ hrs min
(Please use UTC and 24-hr clock)
4. Time off blocks: ☐☐ hrs min
(Please use UTC and 24-hr clock)

After reporting for duty & Before Take-off:

Fatigue rating: 1 2 3 4 5 6 7
Sleepiness rating: 1 2 3 4 5 6 7 8 9
Time PVT done: _____:_____

Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

For any sleep you have in-flight that is more than 10mins please indicate the BGN and FSH using arrows on the timeline (UTC):

UTC: 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

UTC: 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

5. Time on blocks: ☐☐ hrs min
(Please use UTC and 24-hr clock)
6. What time did you report off duty? ☐☐ hrs min
(Please use UTC and 24-hr clock)

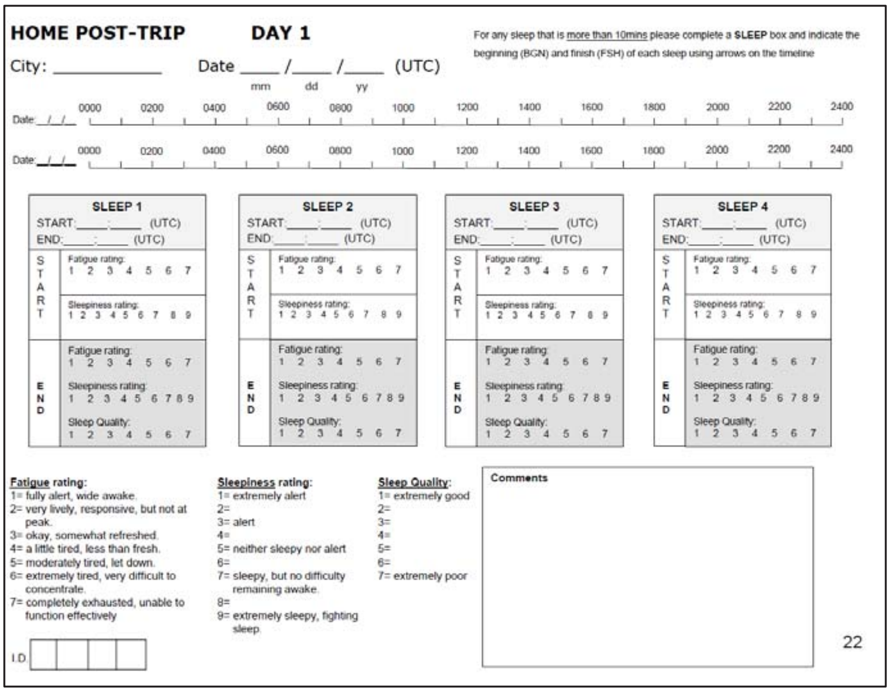
After Landing (in aircraft):

Fatigue rating: 1 2 3 4 5 6 7
Sleepiness rating: 1 2 3 4 5 6 7 8 9
Time PVT done: _____:_____

Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep

I.D. ☐☐☐☐

21



HOME POST-TRIP **DAY 1**

City: __________ Date ____ /____ /____ (UTC)
mm dd yy

For any sleep that is more than 10mins please complete a **SLEEP** box and indicate the beginning (BGN) and finish (FSH) of each sleep using arrows on the timeline

Date:_/_/_ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

Date:_/_/_ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

	SLEEP 1	SLEEP 2	SLEEP 3	SLEEP 4
	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)
START	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9
END	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7 Sleepiness rating: 1 2 3 4 5 6 7 8 9 Sleep Quality: 1 2 3 4 5 6 7

Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

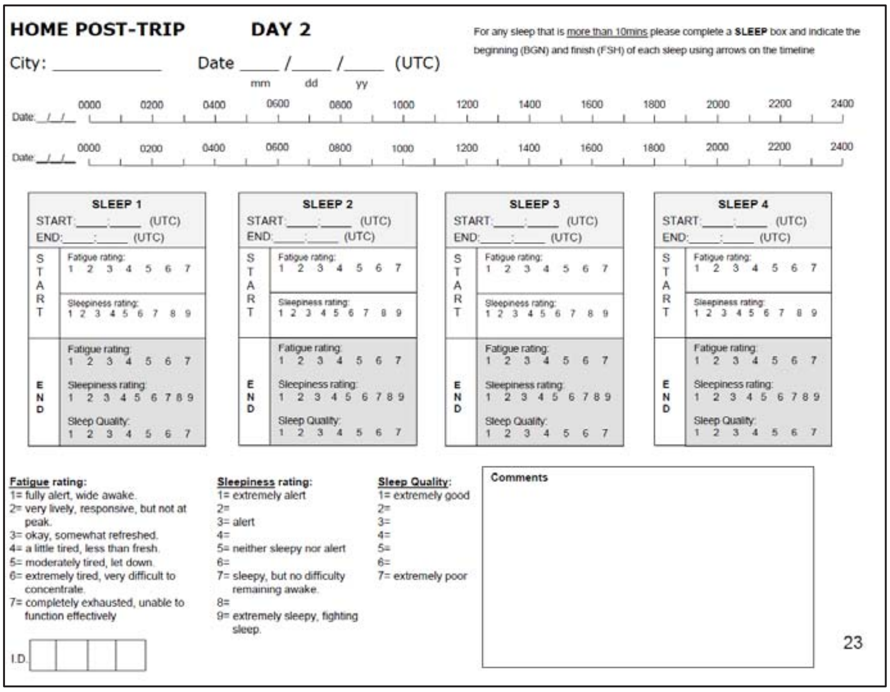
Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep.

Sleep Quality:
1= extremely good
2=
3=
4=
5=
6=
7= extremely poor

Comments

I.D. ☐☐☐☐

22



HOME POST-TRIP **DAY 2**

For any sleep that is more than 10mins please complete a **SLEEP** box and indicate the beginning (BGN) and finish (FSH) of each sleep using arrows on the timeline

City: ___________ Date ____ /____ /____ (UTC)
mm dd yy

Date:_/_/_ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400
Date:_/_/_ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

	SLEEP 1	SLEEP 2	SLEEP 3	SLEEP 4
	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)
START	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7
	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9
END	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7
	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9
	Sleep Quality: 1 2 3 4 5 6 7	Sleep Quality: 1 2 3 4 5 6 7	Sleep Quality: 1 2 3 4 5 6 7	Sleep Quality: 1 2 3 4 5 6 7

Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

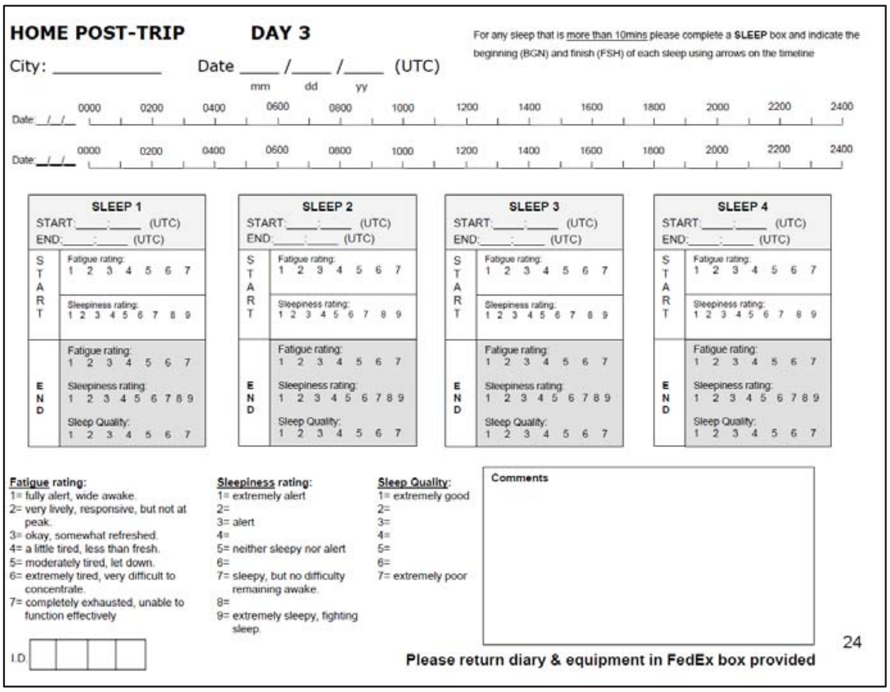
Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep.

Sleep Quality:
1= extremely good
2=
3=
4=
5=
6=
7= extremely poor

Comments

I.D. ☐☐☐☐

23



HOME POST-TRIP **DAY 3**

For any sleep that is more than 10mins please complete a **SLEEP** box and indicate the beginning (BGN) and finish (FSH) of each sleep using arrows on the timeline

City: ___________ Date ____ /____ /____ (UTC)
mm dd yy

Date:_/_/_ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400
Date:_/_/_ 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

	SLEEP 1	SLEEP 2	SLEEP 3	SLEEP 4
	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)	START:____:____ (UTC) END:____:____ (UTC)
START	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7
	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9
END	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7	Fatigue rating: 1 2 3 4 5 6 7
	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9	Sleepiness rating: 1 2 3 4 5 6 7 8 9
	Sleep Quality: 1 2 3 4 5 6 7	Sleep Quality: 1 2 3 4 5 6 7	Sleep Quality: 1 2 3 4 5 6 7	Sleep Quality: 1 2 3 4 5 6 7

Fatigue rating:
1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
4= a little tired, less than fresh.
5= moderately tired, let down.
6= extremely tired, very difficult to concentrate.
7= completely exhausted, unable to function effectively

Sleepiness rating:
1= extremely alert
2=
3= alert
4=
5= neither sleepy nor alert
6=
7= sleepy, but no difficulty remaining awake.
8=
9= extremely sleepy, fighting sleep.

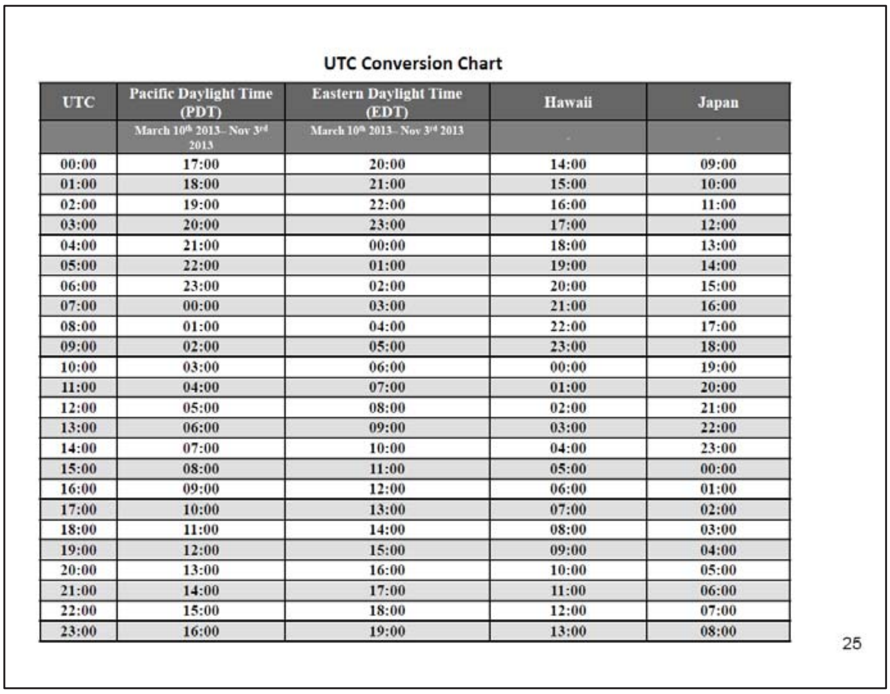
Sleep Quality:
1= extremely good
2=
3=
4=
5=
6=
7= extremely poor

Comments

I.D. ☐☐☐☐

24

Please return diary & equipment in FedEx box provided



UTC Conversion Chart

UTC	Pacific Daylight Time (PDT)	Eastern Daylight Time (EDT)	Hawaii	Japan
	March 10th 2013– Nov 3rd 2013	March 10th 2013– Nov 3rd 2013	-	-
00:00	17:00	20:00	14:00	09:00
01:00	18:00	21:00	15:00	10:00
02:00	19:00	22:00	16:00	11:00
03:00	20:00	23:00	17:00	12:00
04:00	21:00	00:00	18:00	13:00
05:00	22:00	01:00	19:00	14:00
06:00	23:00	02:00	20:00	15:00
07:00	00:00	03:00	21:00	16:00
08:00	01:00	04:00	22:00	17:00
09:00	02:00	05:00	23:00	18:00
10:00	03:00	06:00	00:00	19:00
11:00	04:00	07:00	01:00	20:00
12:00	05:00	08:00	02:00	21:00
13:00	06:00	09:00	03:00	22:00
14:00	07:00	10:00	04:00	23:00
15:00	08:00	11:00	05:00	00:00
16:00	09:00	12:00	06:00	01:00
17:00	10:00	13:00	07:00	02:00
18:00	11:00	14:00	08:00	03:00
19:00	12:00	15:00	09:00	04:00
20:00	13:00	16:00	10:00	05:00
21:00	14:00	17:00	11:00	06:00
22:00	15:00	18:00	12:00	07:00
23:00	16:00	19:00	13:00	08:00

APPENDIX 3E ACTIGRAPHY SCORING PROTOCOL

3E.1 Scoring of individual actigraphy records

The rules used for scoring each individual actigraphy record in this research are provided below:

- **Rest Interval** start- and end times are set by the researcher using 3 sources of information:
    - Change in actigraphy data
    - Event marker
    - Sleep diary

- **Compare all 3 sources of information; when information doesn't match**:
    - Actigraphy and event marker match, diary doesn't:
        - ➔ Use actigraphy and event marker
    - Actigraphy and diary match, event marker doesn't:
        - ➔ Use actigraphy and diary
    - Event marker and diary match, actigraphy doesn't:
        - ➔ Use event marker and diary
    - None match:
        - ➔ Actigraphy data primary source, then event marker, followed by sleep diary

3E.2 Double scoring

To assess the reliability of manual selection of rest intervals, all files (100%) are to be double scored by a second independent trained researcher. Any discrepancies of more than 15 minutes for either 'start time' or 'end time' of the rest interval need to be flagged, , re-analysed, and checked by a third independent person if the two researchers can not reach agreement.

The percentage of start times and the percentage of end times where the discrepancy between scorers was greater than 15 minutes are reported, as is the overall agreement rate (agreement being classed as 15 minutes or less difference between scorers).

3E.3 Notes specific to the Delta B767-300ER bunk study

All files will be double scored. Files scored by first researcher (JLZ) are the ones used unless corrections are made, in which case the corrected file is used.

Only sleep periods that are either recorded in the duty/sleep diary, or not recorded but clearly marked in the actigraphy record by event markers and drop in activity are scored.

If a sleep period was recorded in the diary but does not appear in the actigraphy record due to the device being off-wrist, the concerned sleep period is scored as “Excluded”.

Sleep periods that occur before the study starts or after the study ends (e.g.; on pre-trip day 0 or post-trip day 4,...) are not counted in the double scoring.

A difference in sleep times of 15 minutes is still considered as valid.

Where differences in sleep times are greater than 15min, scoring of sleep period is reviewed and discussed by the two scorers (JLZ & DM). Where JLZ has scored incorrectly, the correction is made to the record scored by JLZ and saved as a new file “Scored_corrected”. If JLZ and DM can not reach agreement, the concerned interval is reviewed with a third independent researcher (PG).

APPENDIX 3F PROTOCOL FOR ACTIGRAPHY MALFUNCTIONS

Numerous device malfunctions were experienced during Delta B767 bunk study project, occurring in 17 of the 54 collected data sets. These malfunctions resulted in the loss of certain data sets and were dealt with on a case by case basis as follows:

- In cases where the research team was unable to download the data from the device, it was returned to the manufacturer (Philips Respironics) to attempt to salvage the data. This occurred in two cases (D401 & D402), both resulting in the loss of the data set in question. In an additional two cases (D440 & D449), the device stopped collecting data part way through data collection resulting in the loss of another two data sets.

- In cases where the epoch length of the recording was not 60s, the data was excluded as the epoch length may effect the way in which the software algorithm scores the data. This occurred in four cases (D403, D408, D436, & D450), all of which resulted in the loss of the concerned data set[26].

- In cases where a time shift was observed in the recording as compared to the dates and times of the duty/sleep diary (7 cases), the actigraphy record was first scored relying solely on the level of activity recorded and then was separately re-scored relying solely on the diary information. The start and end times of each rest period were then compared between the activity-based scoring and the diary-based scoring to determine whether or not the time shift was consistent. Where the time

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[26] All four of these cases also experienced a significant time shift.

shift was deemed consistent, the data set was included in the final analyses (5 cases: D413, D434, D443, D446, & D452); where the time shift was inconsistent the data set was excluded (2 cases: D424 & D456).

- In cases where the sensitivity of the device was not within the normal range[27], the concerned data sets were excluded (2 cases: D412 & D441).

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[27] A normal sensitivity setting for these devices is ranges from 70 to 150. In these cases the abnormal sensitivity of the devices led to a very low amplitude on the activity curve of the actigraphy recording. This effected the reliability and scoring of the records in question as it appeared that not all movements had been recorded or detected by the device.

APPENDIX 3G CRITERIA FOR INCLUDING PSYCHOMOTOR VIGILANCE TASK DATA

Pilots were asked to complete the 5 minute PVT test at four specific times during each of their flight segments (pre-flight, at the end of their 1st rest break, at the end of their 2nd rest break, and within 60min prior to TOD). For pilots who were allocated to the 2nd and 4th in-flight rest breaks, the PVT tests at the end of their 2nd rest break and the test at TOD often coincided, therefore they took only one of these two tests resulting in a total of three PVT tests per flight segment for these pilots.

Criteria for including psychomotor vigilance task data and frequencies of included and excluded PVT test is provided in Table 3G.1 on the next page.

A summary of the descriptive statistics for the PVT data is provided in Table 3G.2 through to Table 3G.6 on the pages that follow.

Table 3G.1 **Number of PVT tests included and excluded based on pre-defined criteria**

Test time	Inclusion criteria	Included (n)	Excluded (n)	Reasons for exclusion
Pre-flight	≤270min prior to departure	63	7	4 tests were completed after departure 1 test was completed more than 270min prior to departure 1 participant reported being distracted during the test 1 test was missing / not completed
Post-break 1	±30min from the end of participant's 1st rest break	63	7	4 tests were completed more than 30min after break end (55-87min after break end) 2 tests were completed more than 30min prior to break end (58-74min before break end) 1 participant reported being distracted during the test
Post-break 2	±30min from the end of participant's 2nd rest break	32	38	1 test was completed more than 30min after break end (55min after break end) 1 tests was completed more than 30min prior to break end (52min prior to break end) 32 tests were not completed as participant was on 4th break (test was taken at TOD instead) 4 tests were completed very close to the TOD test (9-17min between tests) by participants on last break. Therefore, only the first of the two tests was used (due to possible time on task effects) and was used as the TOD test.

TOD	**≤60min prior to recorded TOD**	**65**	**5**	**2 tests were taken after TOD and landing** **1 participant reported being distracted during the test** **1 participant was unable to complete this test as it would have interfered with their flight duties** **1 test was missing / not completed (participant on 1st&3rd break)**
Other tests	NA	0	11	11 extra tests were completed at times other than the four timepoints specified to pilots.

Table 3G.2 Mean PVT response speed at each test time on outbound and inbound flights by rest break pattern

	Test time	Crew with 1st and 3rd breaks					Crew with 2nd and 4th breaks				
		Mean	*SD*	*Median*	*Range*	*N*	*Mean*	*SD*	*Median*	*Range*	*N*
Outbound	**Pre-flight**	4.079	0.597	4.015	3.196-5.088	12	4.038	0.703	4.184	2.797-5.061	19
	Post-break 1	4.183	0.396	4.186	3.534-4.994	13	4.170^{1,a}	0.609	4.257	2.337-4.995	20
	Post-break 2	4.136	0.440	4.117	3.601-5.046	14	-	-	-	-	-
	TOD	4.118	0.438	4.057	3.555-4.860	13	4.029^{b}	0.538	4.155	2.871-4.926	19
Inbound	**Pre-flight**	4.461^{a}	0.424	4.384	3.657-5.411	16	4.484	0.566	4.452	3.831-5.450	15
	Post-break 1	4.158^{1,a}	0.680	4.250	2.179-5.209	16	4.331	0.475	4.256	3.231-4.990	13
	Post-break 2	4.068	0.553	4.068	2.762-5.094	18	-	-	-	-	-
	TOD	3.974^{a}	0.570	4.081	2.648-4.886	18	3.976	0.472	4.095	2.828-4.508	14

Note: The outbound flight of one pilot was excluded in these analyses as they had an atypical rest break pattern (1st&4th breaks) on that flight, therefore N=34 (not 35) for the outbound flight. Additionally, due to missing and excluded tests (refer to appendix 3G), totals may vary depending on the time points analysed.

[1] Data not normally distributed (Shapiro-Wilk $p<0.05$);

[a] Includes 1 outlier; [b] Includes 4 outliers;

Table 3G.3 Slowest 10% of PVT responses at each test time on outbound and inbound flights by rest break pattern

	Test time	Crew with 1st and 3rd breaks					Crew with 2nd and 4th breaks				
		Mean	*SD*	*Median*	*Range*	*N*	*Mean*	*SD*	*Median*	*Range*	*N*
Outbound	**Pre-flight**	2.207	0.799	2.169	0.736-4.007	12	2.150	1.055	2.377	0.166-3.836	19
	Post-break 1	2.562	0.551	2.489	1.802-3.571	13	2.642[a]	0.735	2.528	1.256-4.226	20
	Post-break 2	2.463	0.564	2.333	1.699-3.230	14	-	-	-	-	-
	TOD	2.391	0.619	2.273	1.541-3.418	13	2.318	0.600	2.365	1.334-3.390	19
Inbound	**Pre-flight**	2.843	0.559	2.871	1.719-3.708	16	2.995	0.787	2.924	1.898-4.321	15
	Post-break 1	2.690[b]	0.955	2.661	0.348-4.545	16	2.886[b]	0.546	2.767	1.882-4.153	13
	Post-break 2	2.512	0.736	2.451	1.296-3.793	18	-	-	-	-	-
	TOD	2.434	0.611	2.674	1.137-3.178	18	2.429[c]	0.701	2.516	0.680-3.504	14

Note: The outbound flight of one pilot was excluded in these analyses as they had an atypical rest break pattern (1st&4th breaks) on that flight, therefore N=34 (not 35) for the outbound flight. Additionally, due to missing and excluded tests (refer to appendix 3G), totals may vary depending on the time points analysed.

[a] Includes 2 outliers; [b] Includes 1 outlier; [c] Includes 3 outliers;

Table 3G.4 **Fastest 10% of PVT responses at each test time on outbound and inbound flights by rest break pattern**

	Test time	**Crew with 1st and 3rd breaks**					**Crew with 2nd and 4th breaks**				
		Mean	***SD***	***Median***	***Range***	***N***	***Mean***	***SD***	***Median***	***Range***	***N***
Outbound	**Pre-flight**	5.404	0.537	5.473	4.505-6.103	12	5.395	0.532	5.562	4.257-6.039	19
	Post-break 1	5.335	0.484	5.327	4.632-6.029	13	5.213[1, a]	0.641	5.475	3.577-6.103	20
	Post-break 2	5.293	0.600	5.132	4.239-6.204	14	-	-	-	-	-
	TOD	5.315	0.464	5.240	4.549-6.029	13	5.198	0.558	5.322	3.938-5.956	19
Inbound	**Pre-flight**	5.597	0.470	5.756	4.553-6.333	16	5.648	0.550	5.825	4.466-6.250	15
	Post-break 1	5.313[1, b]	0.608	5.504	3.630-5.956	16	5.380	0.501	5.414	4.434-6.039	13
	Post-break 2	5.217[a]	0.725	5.187	3.729-7.196	18	-	-	-	-	-
	TOD	5.064	0.618	5.240	3.607-5.956	18	5.148[1]	0.464	5.325	4.397-5.686	14

Note: The outbound flight of one pilot was excluded in these analyses as they had an atypical rest break pattern (1st&4th breaks) on that flight, therefore N=34 (not 35) for the outbound flight. Additionally, due to missing and excluded tests (refer to appendix 3G), totals may vary depending on the time points analysed.

[1] Data not normally distributed (Shapiro-Wilk $p<0.05$);

[a] Includes 2 outliers; [b] Includes 1 outlier;.

Table 3G.5 Percentage of pilots experiencing lapses (≥1 response with a reaction time >500ms) or no lapses on the PVT at each test time on the outbound and inbound flights

	Test time	Crew with 1st and 3rd breaks				Crew with 2nd and 4th breaks			
		Lapsed (%)	*N*	*Did not lapse (%)*	*N*	*Lapsed (%)*	*N*	*Did not lapse (%)*	*N*
Outbound	**Pre-flight**	71.4	10	14.3	2	60.0	12	35.0	7
	Post-break 1	57.1	8	35.7	5	65.0	13	35.0	7
	Post-break 2	57.1	8	42.9	6	-	-	-	-
	TOD	57.1	8	35.7	5	70.0	14	25.0	5
Inbound	**Pre-flight**	57.9	11	26.3	5	37.5	6	56.3	9
	Post-break 1	52.6	10	31.6	6	37.5	6	43.8	7
	Post-break 2	73.7	14	21.1	4	-	-	-	-
	TOD	63.2	12	31.6	6	56.3	9	31.3	5

Note: The outbound flight of one pilot was excluded in these analyses as they had an atypical rest break pattern (1st&4th breaks) on that flight, therefore N=34 (not 35) for the outbound flight. Additionally, due to missing and excluded tests (refer to appendix 3G), totals may vary depending on the time points analysed.

Table 3G.6 Number of lapses on the PVT at each test time on outbound and inbound flights by rest break pattern

	Test time	Crew with 1st and 3rd breaks					Crew with 2nd and 4th breaks				
		Mean	*SD*	*Median*	*Range*	*N*	*Mean*	*SD*	*Median*	*Range*	*N*
Outbound	**Pre-flight**	1.6[1, a]	1.4	1.0	0-5	12	2.3[1]	3.0	1.0	0-10	19
	Post-break 1	0.9[1]	0.9	1.0	0-2	13	1.7[1, a]	3.7	1.0	0-17	20
	Post-break 2	1.3[1]	1.3	1.0	0-3	14	-	-	-	-	-
	TOD	1.5[1]	1.5	2.0	0-4	13	1.8[1]	1.8	1.0	0-6	19
Inbound	**Pre-flight**	0.9[1, a]	1.0	1.0	0-4	16	0.5[1]	0.7	0.0	0-2	15
	Post-break 1	1.8[1, a]	3.9	1.0	0-16	16	0.9[1]	1.3	0.0	0-4	13
	Post-break 2	1.5[1, b]	1.5	1.0	0-5	18	-	-	-	-	-
	TOD	1.8[1, c]	2.9	1.0	0-12	18	1.9[1, a]	3.0	1.0	0-11	14

Note: The outbound flight of one pilot was excluded in these analyses as they had an atypical rest break pattern (1st&4th breaks) on that flight, therefore N=34 (not 35) for the outbound flight. Additionally, due to missing and excluded tests (refer to appendix 3G), totals may vary depending on the time points analysed.

[1] Data not normally distributed (Shapiro-Wilk $p<0.05$);

[a] Includes 1 outlier; [b] Includes 3 outliers; [c] Includes 2 outliers;

The evolution of PVT performance across flights by rest break pattern is presented below in Figure 3G.1 and Figure 3G.2 (mean response speed on the outbound and inbound flights respectively), Figure 3G.3 and Figure 3G.4 (slowest 10% of responses on the outbound and inbound flights), and Figure 3G.5 and Figure 3G.6 (fastest 10% of responses, outbound and inbound flights respectively).

Flight crew who were allocated the 2nd and 4th breaks only have three time points on these figures as their 'end of rest period 2' and 'TOD' PVT tests coincided. Data from one crew member were also excluded for the outbound flight segment as they had an atypical break pattern (1st and 4th break). In these figures, a higher value indicates better performance.

Figure 3G.1 Mean PVT response speed on the outbound flight segment by break pattern

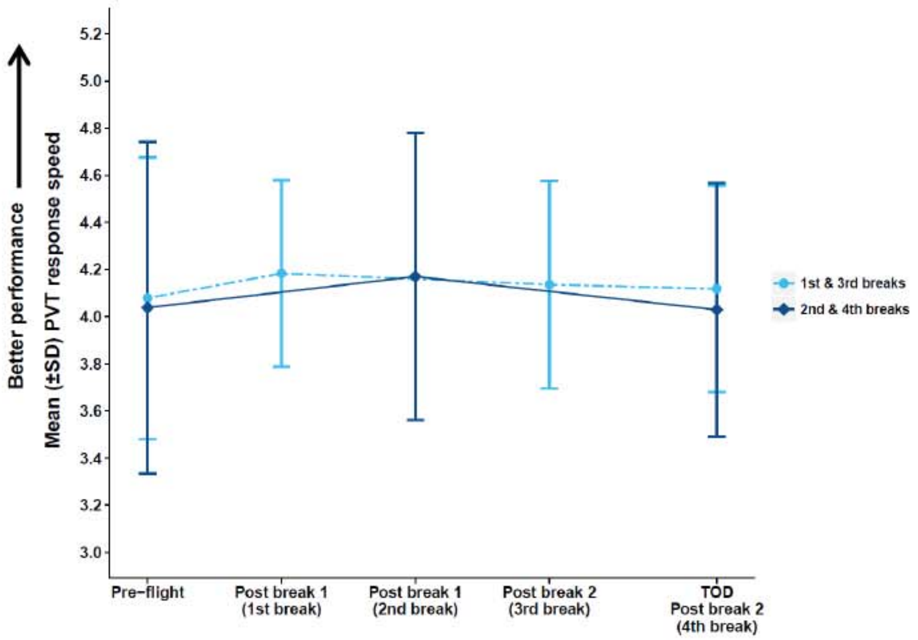


Figure 3G.2 Mean PVT response speed on the inbound flight segment by break pattern

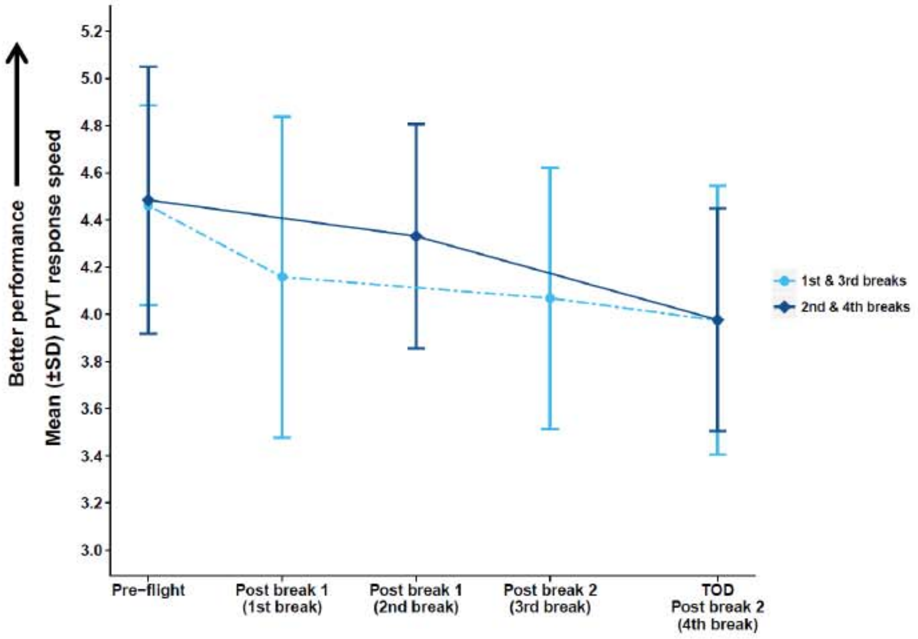


Figure 3G.3 **Slowest 10% of PVT responses across the outbound flight segment by break pattern**

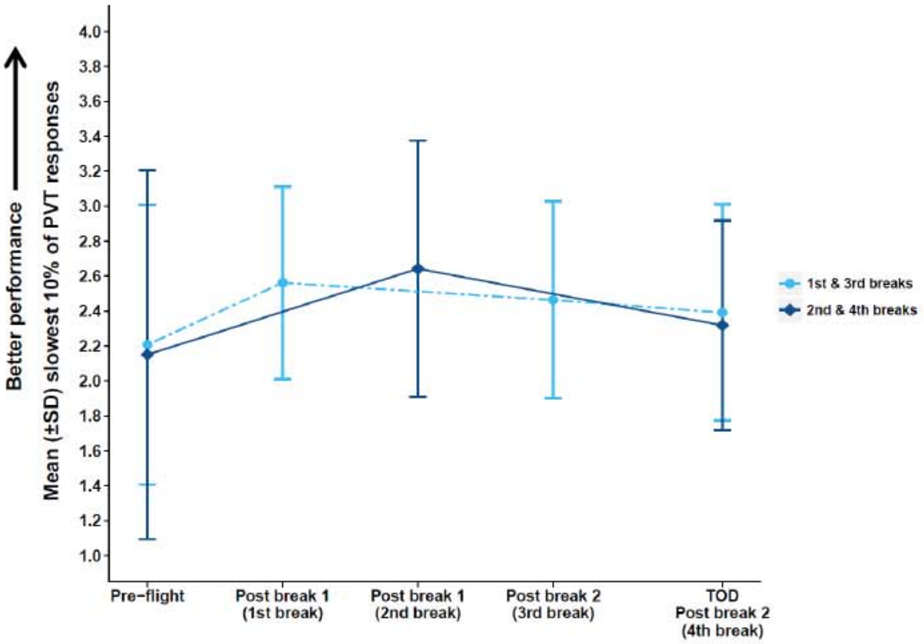


Figure 3G.4 **Slowest 10% of PVT responses across the inbound flight segment by break pattern**

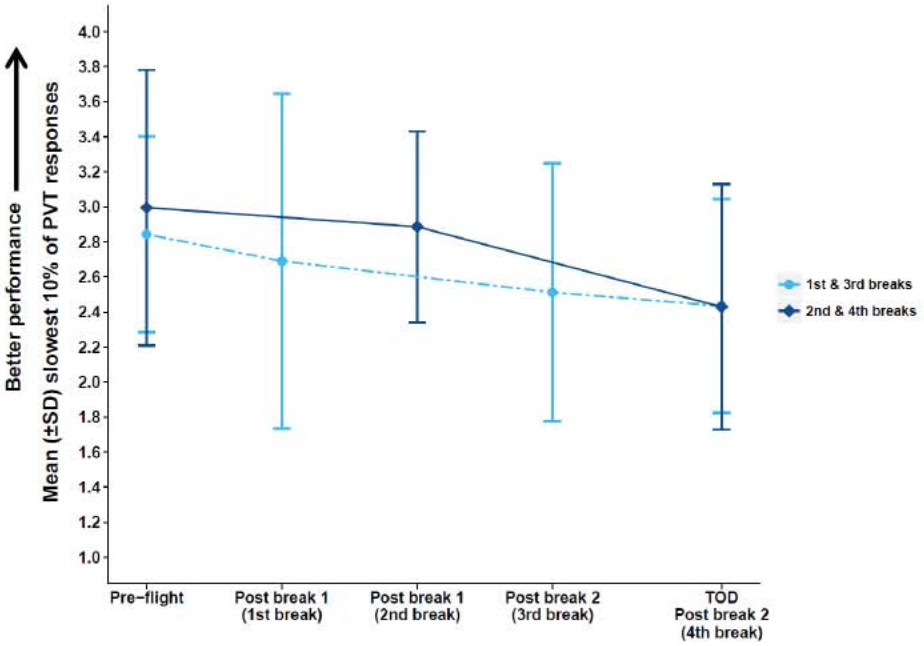


Figure 3G.5 Fastest 10% of PVT responses across the outbound flight segment by break pattern

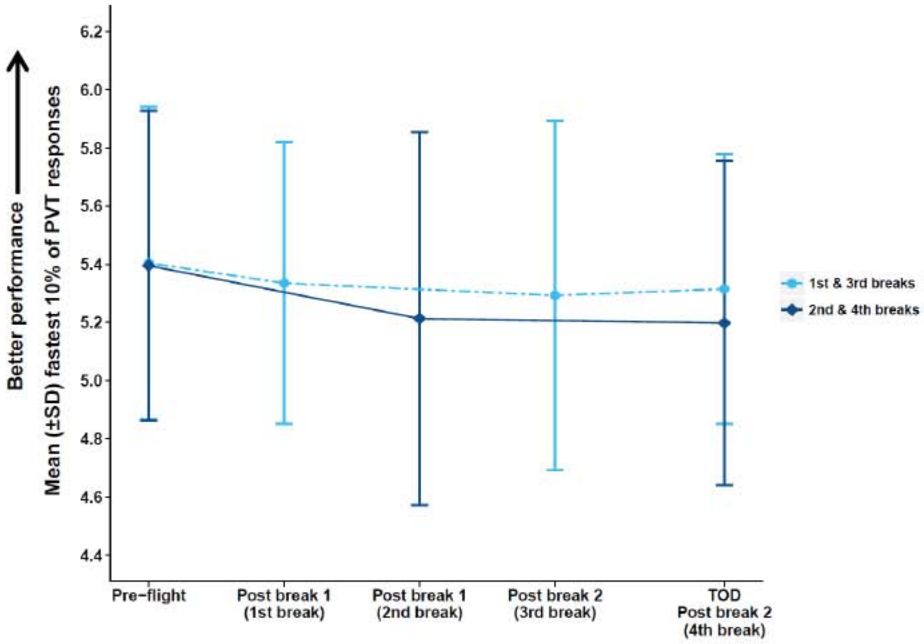
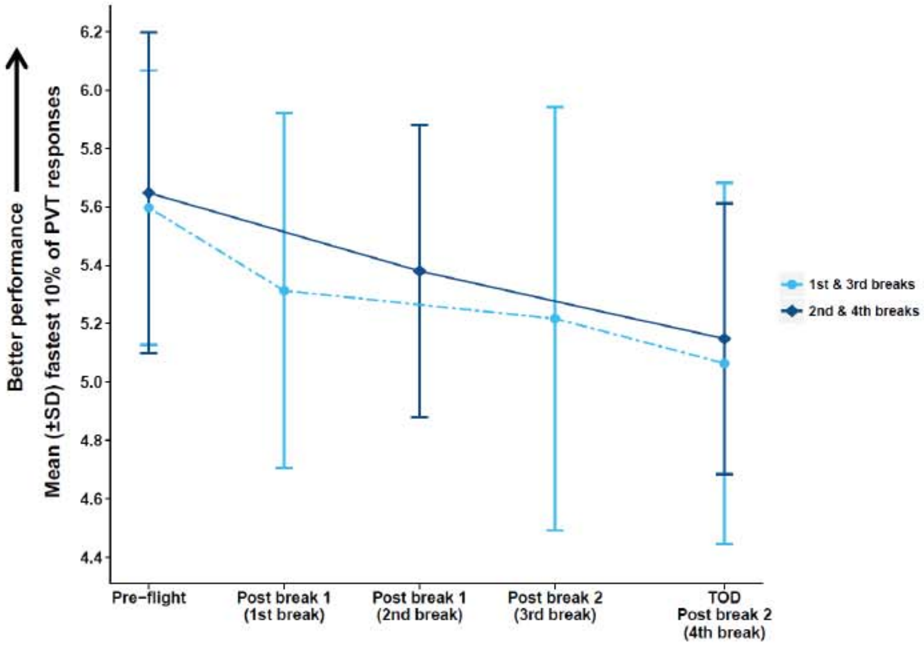


Figure 3G.6 Fastest 10% of PVT responses across the inbound flight segment by break pattern



APPENDIX 3H ACTISOFT SLEEP DESCRIPTIVES

In these analyses, the failure of an actigraphic device led to the exclusion of one participant's data and a total of 34 participants being included. In addition, in some cases, the outbound flight segment of another participant was excluded as that participant had an atypical rest break pattern on the concerned flight segment. Finally, since some participants did not have any baseline days (refer to chapter 3, section 3.1.5.2) and others were missing post-trip days, the totals may vary depending on the time periods analysed.

3H.1 Summary information for flight crew sleep duration, sleep efficiency and duration of wakefulness across 24-hour intervals

Information about pilots' sleep across the study period (sleep duration, sleep efficiency, and number of sleep periods per 24 hours) is presented in tables 3H.1 through 3H.6 on pages 310-315. Tables 3H.1 through 3H.3 include only data from the 26 pilots with at least one day of baseline while tables 3H.4 through 3H.6 refer to all pilots.

Information regarding in-flight sleep duration and efficiency by rest break pattern can be found (for all pilots) in table 3H.7 on page 316.

Information about sleep duration, sleep efficiency and the duration of wakefulness prior to duty start and top of descent is presented by rest break pattern in tables 3H.8 through 3H.11 on pages 318-322.

Table 3H.1 Total Sleep Time (minutes) across the study period (26 pilots with at least one day of baseline)

Time Period	Mean	SD	Median	Range	N
Baseline day 1	384	81	386	243-516	22
Baseline day 2	415	76	393	305-560	26
Last 24hrs prior to duty start (outbound)	443	74	444	296-590	26
Last 24hrs prior to TOD (outbound)[a]	206	72	202	47-363	26
First 24hrs after duty end (outbound) [First 24hrs layover]	601	99	614	424-786	26
Last 24hrs prior to duty start (inbound) [Last 24hrs layover]	612	100	617	438-786	26
Last 24hrs prior to TOD (inbound)	300	100	270	135-508	26
First 24hrs after duty end (inbound)	411	111	412	190-620	26
Post-flight day 1[b]	474	107	454	269-729	25
Post-flight day 2	384	63	371	295-510	24
Post-flight day 3	418	71	419	311-559	18

[a] Includes 2 outliers; [b] Includes 1 outlier;

Table 3H.2 Sleep efficiency (%) across the study period (26 pilots with at least one day of baseline)

Time Period	Mean	SD	Median	Range	N
Baseline day 1	81.8	8.0	84.6	65.0-92.5	22
Baseline day 2	82.0	7.3	81.8	69.1-92.4	26
Last 24hrs prior to duty start (outbound)[1, a]	83.3	5.6	84.0	66.0-91.2	26
Last 24hrs prior to TOD (outbound)[1, b]	74.6	14.2	78.6	23.2-90.9	26
First 24hrs after duty end (outbound) [First 24hrs layover]	82.9	6.4	82.7	70.9-95.4	26
Last 24hrs prior to duty start (inbound) [Last 24hrs layover]	82.7	6.5	82.7	70.9-95.4	26
Last 24hrs prior to TOD (inbound)[c]	74.6	10.0	76.5	47.1-91.6	26
First 24hrs after duty end (inbound)	82.8	7.0	85.0	66.3-93.2	26
Post-flight day 1	83.6	6.8	85.0	70.3-94.2	25
Post-flight day 2	82.8	7.2	83.7	72.1-93.7	24
Post-flight day 3[a]	83.5	8.6	85.5	64.7-96.2	18

[1] Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05);

[a] Includes 2 outliers; [b] Includes 3 outliers; [c] Includes 1 outlier;

Table 3H.3 Frequency of pilots with multiple sleep periods per 24 hours across the study (26 pilots with at least one day of baseline)

Time Period	1 sleep period % (N)	2 sleep periods % (N)	3 sleep periods % (N)	4 sleep periods % (N)	Total N
Baseline day 1	95.5 (21)	4.6 (1)	-	-	22
Baseline day 2	92.3 (24)	7.7 (2)	-	-	26
Last 24hrs prior to duty start (outbound)	65.4 (17)	30.8 (8)	3.9 (1)	-	26
Last 24hrs prior to TOD (outbound)	3.9 (1)	73.1 (19)	19.2 (5)	3.9 (1)	26
First 24hrs after duty end (outbound) [First 24hrs layover]	50.0 (13)	46.2 (12)	3.9 (1)	-	26
Last 24hrs prior to duty start (inbound) [Last 24hrs layover]	42.3 (11)	42.3 (11)	15.4 (4)	-	26
Last 24hrs prior to TOD (inbound)	19.2 (5)	57.7 (15)	23.1 (6)	-	26
First 24hrs after duty end (inbound)	38.5 (10)	28.5 (10)	23.1 (6)	-	26
Post-flight day 1	52.0 (13)	44.0 (11)	4.0 (1)	-	25
Post-flight day 2	95.8 (23)	4.2 (1)	-	-	24
Post-flight day 3	88.9 (16)	11.1 (2)	-	-	18

Table 3H.4 Total Sleep Time (minutes) across the study (all pilots)

Time Period	Mean	SD	Median	Range	N
Baseline day 1	384	81	386	243-516	22
Baseline day 2	415	76	393	305-560	26
Last 24hrs prior to duty start (outbound)	429	103	444	215-668	34
Last 24hrs prior to TOD (outbound)	224	81	216	47-393	34
First 24hrs after duty end (outbound) [First 24hrs layover]	607	102	612	424-854	34
Last 24hrs prior to duty start (inbound) [Last 24hrs layover]	614	102	614	438-854	34
Last 24hrs prior to TOD (inbound)	300	92	281	135-508	34
First 24hrs after duty end (inbound)	422	112	429	190-620	34
Post-flight day 1[a]	472	97	458	269-729	33
Post-flight day 2[b]	381	62	374	236-510	31
Post-flight day 3	408	73	403	272-559	24

[1] Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05);

[a] Includes 1 outlier; [b] Includes 3 outliers;

Table 3H.5 Sleep efficiency (%) across the study (all pilots)

Time Period	Mean	SD	Median	Range	N
Baseline day 1[1]	81.8	8.0	84.6	65.0-92.5	22
Baseline day 2	82.0	7.3	81.8	69.1-92.4	26
Last 24hrs prior to duty start (outbound)[1, a]	82.3	6.2	83.5	65.4-91.2	34
Last 24hrs prior to TOD (outbound)[1, b]	74.8	13.0	78.6	23.2-90.9	34
First 24hrs after duty end (outbound) [First 24hrs layover]	83.3	6.3	83.6	70.9-95.4	34
Last 24hrs prior to duty start (inbound) [Last 24hrs layover]	83.2	6.4	83.6	70.9-95.4	34
Last 24hrs prior to TOD (inbound)[c]	75.0	9.1	77.1	47.1-91.6	34
First 24hrs after duty end (inbound)	81.7	7.1	84.0	66.3-93.2	34
Post-flight day 1	82.9	6.7	84.9	70.3-94.2	33
Post-flight day 2	82.0	7.0	81.6	72.1-93.7	31
Post-flight day 3[b]	83.1	7.9	84.2	64.7-96.2	24

[a] Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05);

[a] Includes 3 outliers; [b] Includes 2 outliers; [c] Includes 1 outlier;

Table 3H.6 Frequency of pilots with multiple sleep periods per 24 hours across the study (all pilots)

Time Period	1 sleep period % (N)	2 sleep periods % (N)	3 sleep periods % (N)	4 sleep periods % (N)	Total N
Baseline day 1	95.5 (21)	4.6 (1)	-	-	22
Baseline day 2	92.3 (24)	7.7 (2)	-	-	26
Last 24hrs prior to duty start (outbound)	58.8 (20)	38.2 (13)	2.9 (1)	-	34
Last 24hrs prior to TOD (outbound)	5.9 (2)	55.9 (19)	35.3 (12)	2.9 (1)	34
First 24hrs after duty end (outbound) [First 24hrs layover]	58.8 (20)	38.2 (13)	2.9 (1)	-	34
Last 24hrs prior to duty start (inbound) [Last 24hrs layover]	50.0 (17)	38.2 (13)	11.8 (4)	-	34
Last 24hrs prior to TOD (inbound)	17.7 (6)	58.8 (20)	23.5 (8)	-	34
First 24hrs after duty end (inbound)	32.4 (11)	44.1 (15)	20.6 (7)	2.9 (1)	34
Post-flight day 1	57.6 (19)	39.4 (13)	3.0 (1)	-	33
Post-flight day 2	93.6 (29)	6.5 (2)	-	-	31
Post-flight day 3	91.7 (22)	8.3 (2)	-	-	24

Table 3H.7 In-flight sleep by rest break pattern (all pilots)

	Sleep variable	Crew with 1st and 3rd breaks					Crew with 2nd and 4th breaks				
		Mean	*SD*	*Median*	*Range*	*N*	*Mean*	*SD*	*Median*	*Range*	*N*
Outbound, break 1:	**Break duration (mins)***	126^1	7	120	116-135	11	162^1	33	180	110-210	19
	Rest duration (mins)	113^1	13	118	78-125^a	11	142^1	35	164	81-190	19
	Total sleep time (mins)	85	21	89	32-116^b	11	103	48	118	19-164	19
	Sleep efficiency (%)	74^1	14	78	41-93^b	11	71^1	23	81	11-96^c	19
Outbound, break 2:	**Break duration (mins)***	186^1	7	185	178-199	13	145^1	34	130	98-199	20
	Rest duration (mins)	162	17	163	118-187^c	13	112	33	113	52-178	20
	Total sleep time (mins)	125^1	26	129	49-150^a	13	69	38	75	0-128	20
	Sleep efficiency (%)	77^1	13	80	42-90^a	13	65	16	69	31-86	18^d
Outbound, total breaks:	**Total break duration (mins)*^**	310	9	310	296-326	13	304	14	307	265-328	20
	Total rest duration (mins)	257^1	49	278	158-299^c	13	247^1	40	251	129-305^a	20
	Total sleep time (mins)	197^1	54	209	81-259^c	13	167	64	187	28-248	20
	Sleep efficiency (%)	76^1	13	79	41-91^a	13	71^1	18	74	22-90^b	20

Inbound, break 1:	**Break duration (mins)***	**124**	**15**	**120**	**100-155[e]**	**17**	**145[1]**	**29**	**135**	**110-199**	**15**
	Rest duration (mins)	86	39	90	24-142	17	117	33	109	68-197	15
	Total sleep time (mins)	47[1]	41	30	0-125	17	72	35	73	0-131	15
	Sleep efficiency (%)	62	25	67	10-95	14[f]	66	20	70	31-93	14[g]
Inbound, break 2:	**Break duration (mins)***	185	12	185	155-210[b]	18	168[1]	29	180	120-198	16
	Rest duration (mins)	162	19	163	129-198	18	143	37	157	70-191	16
	Total sleep time (mins)	103	38	105	29-158	18	89	45	91	0-150	16
	Sleep efficiency (%)	64	22	70	17-93	18	65	17	68	30-86	15[g]
Inbound, total breaks:	**Total break duration (mins)*^**	309	16	311	270-330	18	316	13	318	280-335	16
	Total rest duration (mins)	244[1]	52	257	173-313	18	253[1]	60	263	70-311[b]	16
	Total sleep time (mins)	147	63	129	52-272	18	157	73	170	0-269[b]	16
	Sleep efficiency (%)	66	17	66	30-94	18	65	16	69	37-87	15[g]

Note: Total N=34 for the inbound flight while N=33 for the outbound flight since one participant's outbound flight segment was excluded (participant had an atypical rest break pattern, 1st & 4th breaks, on this flight).

* The values for break duration were calculated from the break start and end times recorded by participants in the diary, at times these did not quite match actigraphic sleep times but the maximum discrepancy between the times reported in the diary and the actigraphy was 11 minutes.

^ As total rest break duration was calculated in R, the descriptives statistics were also run in R.

[1] Data not normally distributed (Shapiro-Wilk $p<0.05$);

[a] Includes 1 outlier; [b] Includes 2 outliers; [c] Includes 3 outliers; [d] 2 missing values; [e] Includes 4 outliers; [f] 3 missing values; [g] 1 missing value;

Table 3H.8 Total sleep time, sleep efficiency, and time awake prior to duty start and TOD (26 pilots with at least one day of baseline)

Sleep variable	Crew with 1st and 3rd breaks					Crew with 2nd and 4th breaks				
	Mean	*SD*	*Median*	*Range*	*N*	*Mean*	*SD*	*Median*	*Range*	*N*
Outbound*										
TST in the 24hrs prior to duty start (mins)	429	64	411	352-541	10	451	82	465	296-590	15
SE in the 24hrs prior to duty start (%)	84.1[1]	3.5	84.3	75.6-89.4[a]	10	82.8	7.0	82.9	66.0-91.2[b]	15
Time awake at duty start (mins)	600[1]	355	818	72-927	10	662[1]	281	755	110-958	15
TST in the 24hrs prior to TOD (mins)	254	62	235	197-363	10	169	58	175	47-281	15
SE in the 24hrs prior to TOD (%)	80.2	6.8	82.1	69.2-90.9	10	70.1[1]	16.6	74.2	23.2-86.1[b]	15
Time awake at TOD (mins)	181[1]	38	205	122-221	10	93[1]	119	59	20-393[a]	15
TST in-flight (mins)	213	33	218	138-259[b]	10	153	66	160	28-248	15
SE in-flight (%)	80.3	6.9	81.2	69.2-90.9	10	68.2[1]	20.4	74.2	21.9-88.7[a]	15
Inbound										
TST in the 24hrs prior to duty start (mins)	595	94	617	438-707	12	627	106	616	450-786	14
SE in the 24hrs prior to duty start (%)	81.4	5.8	80.5	71.8-88.8	12	83.9	7.1	83.6	70.9-95.4[a]	14
Time awake at duty start (mins)	349	219	336	23-815	12	351	182	345	70-720	14

TST in the 24hrs prior to TOD (mins)	277	99	255	140-508[a]	12	321	99	303	135-449	14
SE in the 24hrs prior to TOD (%)	72.9	10.1	73.3	59.5-91.6	12	76.0[1]	10.1	78.1	47.1-89.6[b]	14
Time awake at TOD (mins)	207	45	213	130-271	12	97[1]	236	39	0-915[a]	14
TST in-flight (mins)	141	72	125	52-272	12	154	78	170	0-269[a]	14
SE in-flight (%)	63.6	19.9	64.5	29.5-94.1	12	65.8	17.1	69.4	37.1-86.5[c]	13

* N=25 (not 26) as one participant's outbound flight segment was excluded (participant had an atypical rest break pattern, 1st & 4th breaks, on this flight)

[1] Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05);

[a] Includes 2 outliers; [b] Includes 1 outlier; [c] 1 missing value:

Table 3H.9 Total sleep time, sleep efficiency, and time awake prior to duty start and TOD (all pilots)

Sleep variable (minutes)	Crew with 1st and 3rd breaks					Crew with 2nd and 4th breaks				
	Mean	*SD*	*Median*	*Range*	*N*	*Mean*	*SD*	*Median*	*Range*	*N*
Outbound*										
TST in the 24hrs prior to duty start (mins)	403	95	408	229-541	13	444	109	469	215-668[a]	20
SE in the 24hrs prior to duty start (%)	81.3[1]	6.8	83.8	65.4-89.4[b]	13	83.0	6.1	82.9	66.0-91.2[a]	
Time awake at duty start (mins)	569[1]	337	793	72-927	13	591[1]	293	707	110-958	20
TST in the 24hrs prior to TOD (mins)	246	69	236	108-363	13	207	87	198	47-393	20
SE in the 24hrs prior to TOD (%)	77.3	8.7	78.6	61.9-90.9	13	72.5[1]	15.0	78.3	23.2-86.5[b]	
Time awake at TOD (mins)	194	41	207	122-257	13	79[1]	106	45	19-393[b]	20
TST in-flight (mins)	197[1]	54	209	81-259[c]	13	167	64	187	28-248	20
SE in-flight (%)	75.9[1]	12.8	78.9	41.3-90.9[a]	13	70.6[1]	18.3	74.3	21.9-89.8[c]	20
Inbound										
TST in the 24hrs prior to duty start (mins)	606	105	617	438-854	18	622	100	609	450-786	16
SE in the 24hrs prior to duty start (%)	82.3	6.2	82.0	71.8-92.4	18	84.1	6.7	84.2	70.9-95.4[c]	16
Time awake at duty start (mins)	396	200	420	23-815	18	342	177	345	70-720	16

TST in the 24hrs prior to TOD (mins)	279	88	259	140-508[b]	18	324	93	321	135-449	16
SE in the 24hrs prior to TOD (%)	74.4	8.8	74.1	39.5-91.6	18	75.7[1]	9.6	77.8	47.1-89.6[a]	16
Time awake at TOD (mins)	204	40	209	130-271	18	91[1]	221	39	0-915[a]	16
TST in-flight (mins)	147	63	129	52-272	18	157	73	170	0-269[b]	16
SE in-flight (%)	66.3	16.9	66.4	29.5-94.1	18	65.4	16.3	69.4	37.1-86.5[d]	15

* N=33 (not 34) as one participant's outbound flight segment was excluded (participant had an atypical rest break pattern, 1st & 4th breaks, on this flight)

1 Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05);

a Includes 1 outlier; b Includes 3 outliers; c Includes 2 outliers; d 1 missing value;

Table 3H.10 Time since end of last rest period at duty start and at TOD (26 pilots with at least one day of baseline)

	Sleep variable (minutes)	Crew with 1st and 3rd breaks					Crew with 2nd and 4th breaks				
		Mean	*SD*	*Median*	*Range*	*N*	*Mean*	*SD*	*Median*	*Range*	*N*
Outbound*	**Time since end of last rest period at duty start**	539[1]	360	621	69-920	10	611	291	718	75-950	15
	Time since end of last rest period at TOD	174[1]	35	193	116-207	10	38	21	40	5-71	15
Inbound	**Time since end of last rest period at duty start**	334	213	315	21-771	12	343	183	340	65-718	14
	Time since end of last rest period at TOD	174	50	187	56-239[a]	12	23	18	25	0-52	14

* N=25 (not 26) as one participant's outbound flight segment was excluded (participant had an atypical rest break pattern, 1st & 4th breaks, on this flight)

[1] Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05); [a] Includes 1 outlier;

Table 3H.11 Time since end of last rest period at duty start and at TOD (all pilots)

	Sleep variable (minutes)	Crew with 1st and 3rd breaks					Crew with 2nd and 4th breaks				
		Mean	*SD*	*Median*	*Range*	*N*	*Mean*	*SD*	*Median*	*Range*	*N*
Outbound*	**Time since end of last rest period at duty start**	520[1]	338	434	69-920	13	550	293	618	75-950	20
	Time since end of last rest period at TOD	181[1]	34	195	116-225	13	33	21	26	5-71	20
Inbound	**Time since end of last rest period at duty start**	380	199	396	21-771	18	334	177	340	65-718	16
	Time since end of last rest period at TOD	178[1]	44	197	56-239[a]	18	22	17	23	0-52	16

* N=33 (not 34) as one participant's outbound flight segment was excluded (participant had an atypical rest break pattern, 1st & 4th breaks, on this flight)

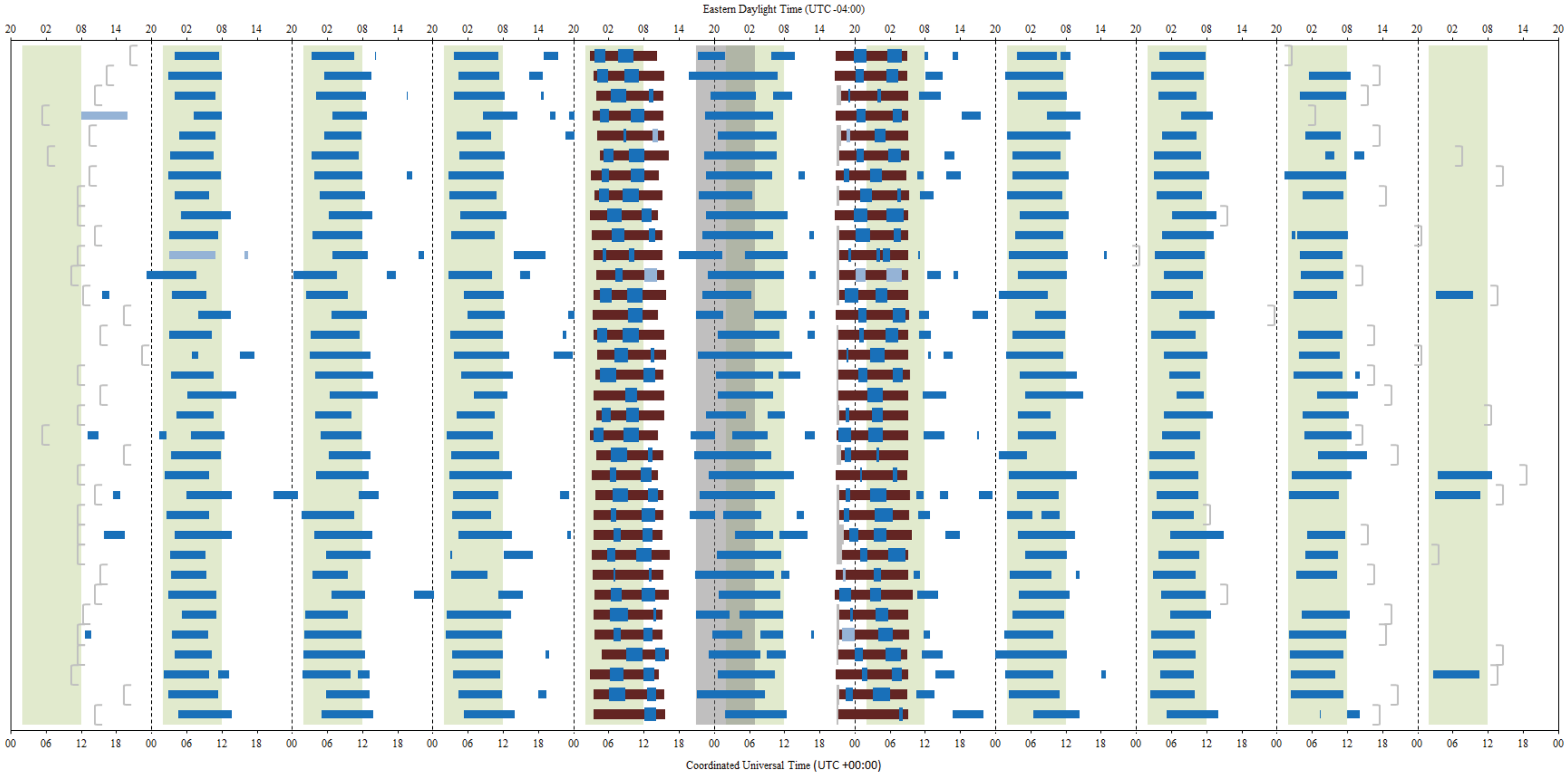
[1] Data not normally distributed (i.e., Shapiro-Wilk p-value <0.05); [a] Includes 1 outlier;

3H.2 Overview of flight crew sleep across the study period

Flight crew sleep and duty patterns across the study period are illustrated in Figure 3H.1. In the figure, each row represents data from one crew member. The duty periods are determined from the information recorded by flight crew in their duty/sleep diary and the sleep periods are determined from the actigraphy recordings.

One crew member was excluded from this figure and all actigraphy analyses as their actigraphy recording was affected by an inconsistent time shift. Consequently, the total N for the actigraphy analyses was reduced to 34.

Figure 3H.1 Pattern of sleep and work for each crew member across the ATL-LOS-ATL study trip



<u>Figure key:</u> dark blue bars = sleep periods (actigraphy); light blue bars (at home) = sleep periods (diary); brown bars = flight segments; light blue bars (in flight) = unsuccessful attempt at in-flight sleep; light green shading = ATL night (home); light grey shading = LOS night (layover); brackets = start and end of participation

For baseline days:

- twenty-six crew members had at least one day of baseline sleep data[28];
- eight crew members had no sleep data for baseline days.

For post-trip days:

- twenty-three crew members had sleep data for three post-trip days;
- eight crew members had sleep data for two post-trip days; and
- three crew members had sleep data for one post-trip day.

Since the inbound flight landed in Atlanta on average at 0934 UTC and post-trip days were defined as from 1600 UTC to 1600 UTC (noon to noon EDT/local), there was a period of time (not captured in our analyses) during which flight crew had the opportunity to sleep. Prior to noon EDT on the day of their arrival back in Atlanta, eighteen crew members napped and five crew members began their first sleep of post-trip day 1.

Average sleep duration and efficiency throughout the study period are illustrated in Figure 3H.2 and Figure 3H.3 respectively (for crew members with baseline sleep data). Information about the average sleep duration and efficiency of all crew members' sleep across the study period is provided in appendix 3H.

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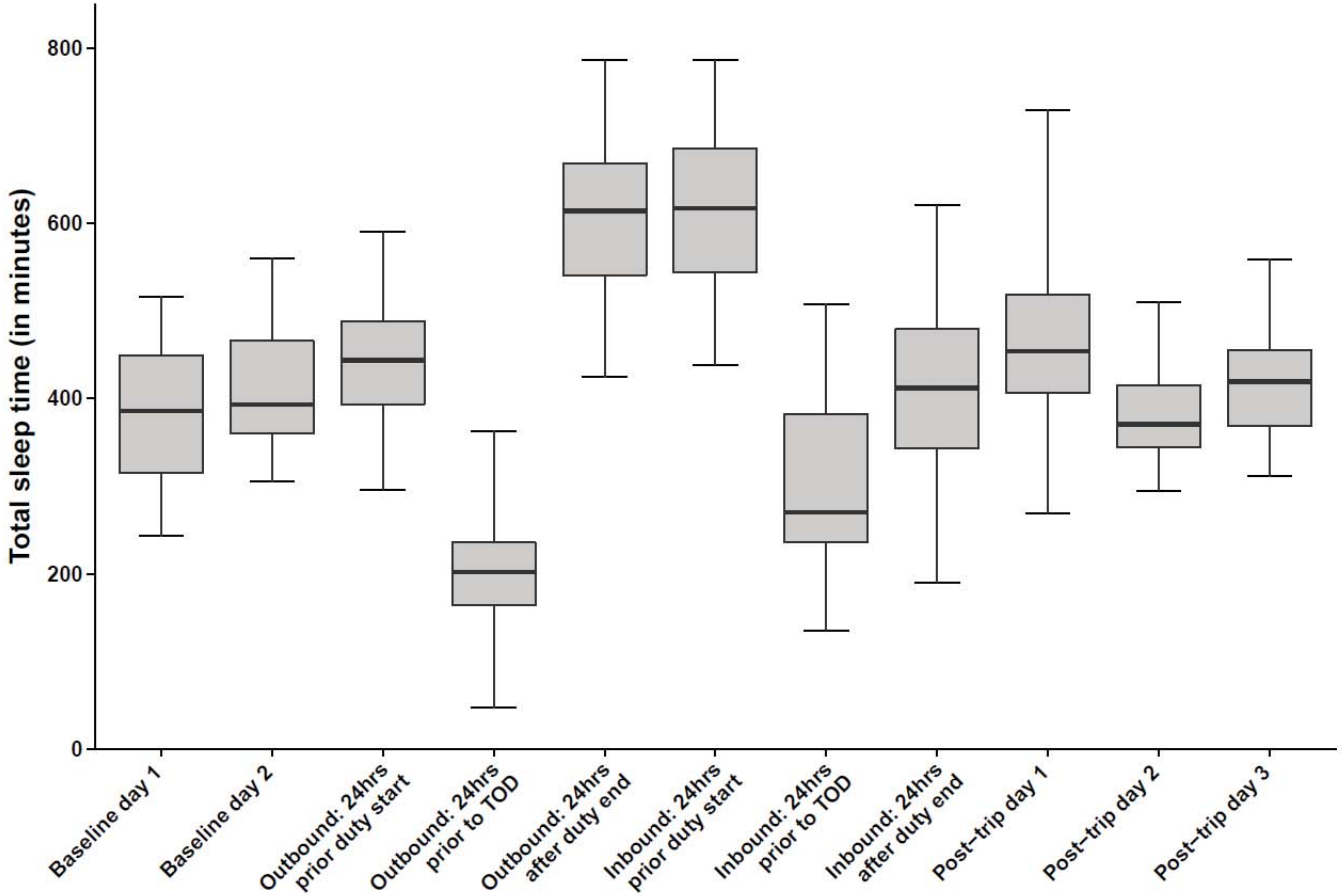
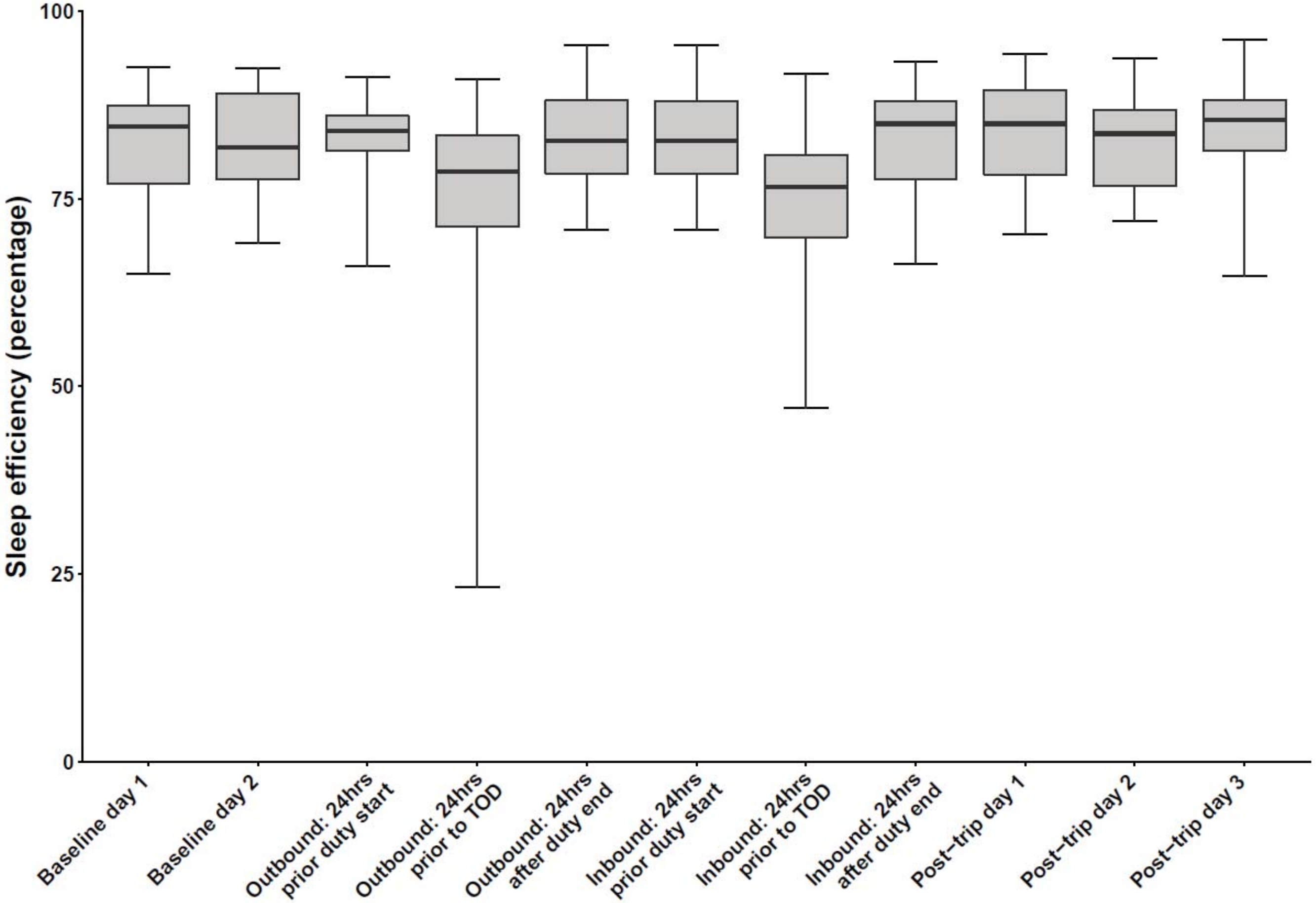
[28] Of these, 22 individuals had two days of valid baseline sleep data and 4 had one day of valid baseline sleep.

Figure 3H.2 Total sleep time across the study (crew members with at least one day of baseline)



In this plot the boxes represent the interquartile range, they extend from the 25th percentile to the 75th percentile values. The dark line in the boxes represents the median value and the whiskers represent the minimum and maximum values for each variable.

Figure 3H.3 Sleep efficiency across the study period (crew members with at least one day of baseline)



In this plot the boxes represent the interquartile range, they extend from the 25th percentile to the 75th percentile values. The dark line in the boxes represents the median value and the whiskers represent the minimum and maximum values for each variable.

3H.3 Comparisons of flight crew sleep on baseline days with total sleep/24 h across the trip

Flight crew obtained more sleep in the last 24 hours prior to a trip (at home [Table 3H.12] and on layover [Table 3H.13]) than they did on baseline days at home but sleep efficiency didn't differ significantly.

Flight crew sleep duration and efficiency was also compared between baseline days and the first three days post-trip (Table 3H.14 and Table 3H.15). Sleep duration was extended on the first day post trip compared to baseline sleep duration but by post-trip days 2 and 3, sleep duration was not statistically different from baseline levels. By contrast, sleep efficiency did not significantly differ between baseline days and any of the post-trip days.

Table 3H.12 Comparison of sleep duration and sleep efficiency in the last 24 hours pre-flight to baseline

Sleep variable	Fixed effect	Estimated mean	DF	F-value	P(F)
Total sleep time (mins)^					
	Day type		1, 45.3	6.39	**0.0150**
	Baseline days 1 & 2	393.8			
	Outbound, last 24 hours pre-flight	429.2			
Sleep efficiency (%)*					
	Day type		1, 50.8	0.77	0.3840
	Baseline days 1 & 2	81.5			
	Outbound, last 24 hours pre-flight	82.3			

^ Compound Symmetry covariance structure for which there were no outliers
* Compound Symmetry covariance structure with outliers included

Table 3H.13 Comparison of sleep duration and sleep efficiency in the last 24 hours of layover to baseline

Sleep variable	Fixed effect	Estimated mean	DF	F-value	P(F)
Total sleep time (mins)*					
	Day type		1, 54.2	155.49	**<0.0001**
	Baseline days 1 & 2	401.8			
	Layover, last 24 hours	613.7			
Sleep efficiency (%)^					
	Day type		1, 52.1	0.51	0.4786
	Baseline days 1 & 2	82.5			
	Layover, last 24 hours	83.2			

* Compound Symmetry covariance structure with outliers included
^ Compound Symmetry covariance structure for which there were no outliers

Table 3H.14 Effect of post-trip days on sleep duration and efficiency

Sleep variable	Fixed effect	Estimated mean	DF	F-value	P(F)
Total sleep time (mins)*					
	Day type		3, 79.1	11.49	**<0.0001**
	Baseline days 1 & 2	401.4			
	Post-trip day 1	473.0			
	Post-trip day 2	382.9			
	Post-trip day 3	410.1			
Sleep efficiency (%)^					
	Day type		3, 78	0.91	0.4404
	Baseline days 1 & 2	81.8			
	Post-trip day 1	83.0			
	Post-trip day 2	81.7			
	Post-trip day 3	83.1			

* Compound Symmetry covariance structure with outliers included
^ Compound Symmetry covariance structure for which there were no outliers

Table 3H.15 Post-hoc comparisons of effects of post-trip days compared to baseline days

Day			Difference	p-value	Adjusted p-value [a]
Total sleep time (mins)					
Post-trip day 1	vs.	Baseline days 1 & 2	71.6	<0.0001	**0.0002**
Post-trip day 2	vs.	Baseline days 1 & 2	-18.5	0.2937	0.5779
Post-trip day 3	vs.	Baseline days 1 & 2	8.8	0.6432	0.9350
Sleep efficiency (%)					
Post-trip day 1	vs.	Baseline days 1 & 2	1.3	0.2547	0.5154
Post-trip day 2	vs.	Baseline days 1 & 2	0.0	0.9860	1.0000
Post-trip day 3	vs.	Baseline days 1 & 2	1.3	0.2853	0.5642

[a] Dunnett's test was used to adjust for multiple comparisons to a "control" group (i.e., 'baseline').

APPENDIX 3I SUBJECTIVE RATINGS DESCRIPTIVES

In these analyses, pilots' ratings of sleepiness and fatigue were analysed for each participant's main sleep episode for the period of interest. For that reason, ratings for layover days were not analysed as the patterns of sleep on layover varied greatly from one individual to the next and it was not possible to clearly identify a main sleep episode for each participant. Additionally, for the analysis of ratings across the pre- and post- flight days, invalid baseline and post-flight days (refer to chapter 3, section 3.1.5.2) were excluded as the various duty patterns on those days lead to a large variability in sleep patterns and difficulty identifying the main sleep episode on those days. Ratings were only analysed for the main sleep episodes as the differing timings and durations of naps were likely to skew pilots' ratings depending on the time of day. Where crew experienced split sleep[29] during their main sleep episode, the ratings taken at the start of the first split sleep period and those taken at the end of the last split sleep period were the ones analysed.

Pilots' ratings across the pre- and post- flight days are presented in Table 3I.1, while crew sleepiness and fatigue ratings across the studied flights are summarized in Table 3I.2 and Table 3I.3 respectively. These tables include the comparison of pilots' ratings at pre-flight, TOC, TOD and post-flight between the two main rest break patterns. The percentage of pilots rating excessive sleepiness and/or fatigue (KSS≥7 or SP≥5) are presented in Table 3I.4 and Table 3I.5.

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[29] Split sleep was defined as a main sleep episode composed of two or more shorter sleep periods separated by short periods of wake. Split sleep was identified using actigraphy and diary data for participants who had multiple shorter sleep periods within their usual nighttime sleep episode and where the inclusion of only one of these episodes would have resulted in an atypical sleep duration for the concerned participant. Where diary comments were available for any the concerned sleep periods, these were reviewed for a possible explanation of the split sleep.

Table 3I.1 Sleepiness, fatigue and sleep quality ratings for pilots' main sleep period on pre- and post- flight days

	Pre-sleep					Post-sleep				
	Mean	*SD*	*Median*	*Range*	*N*	*Mean*	*SD*	*Median*	*Range*	*N*
Karolinska Sleepiness Scale rating:										
Pre-flight day 1	6.0$^{1, a}$	1.6	7.0	3-9	21	3.2$^{1, b, a}$	1.6	3.0	1-7	21
Pre-flight day 2	6.7$^{1, a, c}$	1.5	7.0	3-9	25	2.5$^{1, d, a}$	0.9	3.0	1-5	25
Pre-flight day 3	6.8$^{1, a}$	1.3	7.0	4-9	33	2.5$^{1, e, f}$	1.1	2.0	1-6	32
Post-flight day 1	7.7$^{1, d}$	1.0	8.0	4-9	33	2.7$^{1, b, a}$	1.3	2.0	1-7	32
Post-flight day 2	6.2$^{1, d, f}$	2.0	7.0	1-9	29	2.6$^{1, e, a}$	1.3	2.0	1-7	30
Post-flight day 3	6.3$^{1, g, a}$	1.7	7.0	2-8	23	2.5$^{1, a}$	1.0	3.0	1-4	23
Samn-Perelli Fatigue Scale rating:										
Pre-flight day 1	4.2$^{e, a}$	1.3	4.0	1-6	21	2.8^{a}	1.1	3.0	1-5	21
Pre-flight day 2	4.8$^{1, h, a}$	1.2	5.0	2-7	25	2.1$^{1, a}$	1.0	2.0	1-4	25
Pre-flight day 3	4.8$^{1, i, a}$	1.1	5.0	2-7	33	2.2$^{1, a}$	1.0	2.0	1-5	33
Post-flight day 1	5.7$^{1, d, a}$	0.8	6.0	3-7	32	2.1$^{1, j, a}$	0.8	2.0	1-5	32
Post-flight day 2	4.7$^{1, e, a}$	1.2	5.0	1-6	30	2.0$^{1, e, a}$	0.9	2.0	1-5	30
Post-flight day 3	4.6$^{1, e, a}$	1.2	5.0	1-6	23	1.9$^{1, a}$	0.8	2.0	1-3	23

Sleep Quality Scale rating:										
Pre-flight day 1	NA	NA	NA	NA	NA	$2.8^{1, a}$	1.5	2.0	1-6	21
Pre-flight day 2	NA	NA	NA	NA	NA	$2.6^{1, a}$	1.5	2.0	1-6	25
Pre-flight day 3	NA	NA	NA	NA	NA	$2.5^{1, b, a}$	1.3	2.0	1-6	33
Post-flight day 1	NA	NA	NA	NA	NA	$1.9^{1, a}$	0.8	2.0	1-3	32
Post-flight day 2	NA	NA	NA	NA	NA	$2.3^{1, a}$	1.2	2.0	1-6	30
Post-flight day 3	NA	NA	NA	NA	NA	$2.3^{1, d, a}$	1.1	2.0	1-6	23

[1] Data not normally distributed (Shapiro-Wilk p<0.05);

[a] 1 missing value; [b] Includes 3 outliers; [c] Includes 6 outliers; [d] Includes 1 outlier; [e] Includes 2 outliers; [f]2 missing values; [g] Includes 5 outliers; [h] Includes 11 outliers; [i] Includes 4 outliers; [j] Includes 10 outliers;

Table 3I.2 Karolinska Sleepiness Scale ratings across flights by break pattern

Test Time	Crew with 1st and 3rd breaks					Crew with 2nd and 4th breaks					p-value
	Mean	*SD*	*Median*	*Range*	*N*	*Mean*	*SD*	*Median*	*Range*	*N*	
Outbound flight:											
Pre-flight	2.9	1.4	3.0	1-5	14	2.9	1.1	3.0	1-5	19^{a}	0.9653^
TOC	4.9	1.6	5.0	2-7	14	3.6^{b}	1.6	3.0	1-7	20	**0.0336^**
Pre-break 1	$5.3^{1, c}$	1.5	6.0	3-7	13*	5.6	1.5	6.0	3-8	19*	-
Post-break 1	3.7^{d}	1.0	4.0	2-6	13*	4.5	1.5	4.0	2-7	19*	-
Pre-break 2	6.1	1.7	6.5	2-9	14	6.1^{1}	1.6	7.0	2-8	20	-
Post-break 2	$3.7^{1, d}$	1.2	3.0	2-7	14	3.3	1.4	3.0	1-7	19^{a}	-
TOD	4.1	1.6	3.5	2-7	14	3.3^{1}	1.8	3.0	1-7	20	0.2037^
Post-flight	4.1	1.5	4.0	2-7	14	3.4^{1}	1.8	2.5	1-7	20	0.2238^
Inbound flight:											
Pre-flight	$2.5^{1, d}$	1.5	3.0	1-7	19	$2.1^{1, c}$	0.7	2.0	1-3	16	$0.3829^{\#}$
TOC	3.3^{1}	1.6	3.0	1-7	19	2.3^{1}	0.9	2.0	1-4	16	$0.0570^{\#}$
Pre-break 1	4.7	1.4	4.5	2-7	18*	4.4	1.7	4.0	2-7	15*	-
Post-break 1	3.5^{b}	1.4	3.0	1-7	18*	3.5^{d}	1.4	3.0	2-7	15*	-

Pre-break 2	5.9$^{1, c}$	1.5	6.5	2-7	18^{a}	5.8	1.4	6.0	3-8	16	-
Post-break 2	4.6^{1}	1.4	4.0	3-7	19	4.8	1.6	4.5	2-7	16	-
TOD	4.6^{1}	1.6	4.0	3-8	19	4.4	1.5	4.0	2-7	16	0.9590$^{\#}$
Post-flight	4.7	1.4	5.0	2-7	19	4.7	1.7	4.5	2-8	16	0.9267^

Note: The outbound flight of one pilot was excluded in these analyses as they had an atypical rest break pattern (1st&4th breaks) on that flight, therefore N=34 (not 35) for the outbound flight.

^ Independent t-test, 'Pooled' p-value reported

* One participant did not use their first in-flight rest break on this flight

[#] Wilcoxon-Mann-Whitney test

[1] Data not normally distributed (Shapiro-Wilk $p<0.05$);

[a] 1 missing value; [b] Includes 2 outliers; [c] Includes 3 outliers; [d] Includes 1 outlier;

Table 3I.3 Samn-Perelli Crew Status Check fatigue ratings across flights by break pattern

Test Time	Crew with 1st and 3rd breaks					Crew with 2nd and 4th breaks					p-value
	Mean	*SD*	*Median*	*Range*	*N*	*Mean*	*SD*	*Median*	*Range*	*N*	
Outbound flight:											
Pre-flight	2.6^{a}	1.2	2.0	1-5	14	2.2^{1}	1.0	2.0	1-4	19^{b}	$0.3407^{\#}$
TOC	3.6^{1}	1.2	4.0	2-5.5	14	2.9	1.2	3.0	1-5	20	$0.1127^{\#}$
Pre-break 1	4.2	0.9	4.0	3-5.5	13	4.3^{1}	0.9	4.0	3-6	19	-
Post-break 1	3.2^{1}	0.7	3.0	2-4	13	3.5^{1}	0.9	4.0	2-5	19	-
Pre-break 2	$4.6^{1, a}$	0.9	5.0	2-6	14	4.6^{1}	1.0	5.0	2-6	20	-
Post-break 2	2.9^{1}	1.0	3.0	2-5	14	$2.7^{1, a}$	0.9	3.0	2-5	19^{b}	-
TOD	3.2	1.3	3.0	1-5	14	$3.0^{1, d}$	1.1	3.0	2-5	20	$0.5385^{\#}$
Post-flight	3.6	1.2	4.0	1-5	14	2.9^{1}	1.3	2.0	1-6	20	$0.0774^{\#}$
Inbound flight:											
Pre-flight	$1.9^{1, a}$	0.9	2.0	1-4	19	1.7^{1}	0.7	2.0	1-3	16	$0.5351^{\#}$
TOC	2.5^{1}	1.0	3.0	1-4	19	$1.9^{1, a}$	0.9	2.0	1-4	16	$0.1091^{\#}$
Pre-break 1	3.3^{1}	1.0	3.0	2-5	18	3.3^{1}	1.2	3.0	2-5	15	-

Post-break 1	3.7[1, a]	0.9	3.0	1-5	18	2.8	0.9	3.0	1-4	15	-
Pre-break 2	4.4[1, a]	0.9	5.0	2-5	18[b]	4.4[1]	0.6	4.0	4-6	16	-
Post-break 2	3.4[1]	1.0	3.0	2-5	19	3.7[1]	1.2	3.0	2-6	16	-
TOD	3.9[1, e]	0.9	4.0	2-5	19	3.4[1]	0.9	3.0	2-5	16	0.0552#
Post-flight	4.2[1, a]	0.9	4.0	2-5	19	3.9	1.2	4.0	2-6	16	0.4593#

Note: The outbound flight of one pilot was excluded in these analyses as they had an atypical rest break pattern (1st&4th breaks) on that flight, therefore N=34 (not 35) for the outbound flight.

* One participant did not use their first in-flight rest break on this flight

Wilcoxon-Mann-Whitney test

[1] Data not normally distributed (Shapiro-Wilk $p<0.05$);

[a] Includes 1 outlier; [b] 1 missing value; [c] Includes 5 outliers; [d] Includes 3 outliers; [e] Includes 2 outliers;

Table 3I.4 **Percentage of pilots with Karolinska Sleepiness Scale ratings ≥7 on outbound and inbound flights by rest break pattern**

	Crew with 1st and 3rd breaks (%)				Crew with 2nd and 4th breaks (%)			
	KSS≥7 (%)	*N*	*KSS<7 (%)*	*N*	*KSS≥7 (%)*	*N*	*KSS<7 (%)*	*N*
Outbound flight:								
Pre-flight	0	0	100	14	0	0	95.0	19
TOC	14.3	2	85.7	12	10.0	2	90.0	18
TOD	7.1	1	92.9	13	10.0	2	90.0	18
Post-flight	7.1	1	92.9	13	10.0	2	90.0	18
Inbound flight:								
Pre-flight	5.3	1	94.7	18	0	0	100	16
TOC	5.3	1	94.7	18	0	0	100	16
TOD	21.1	4	78.9	15	12.5	2	87.5	14
Post-flight	15.8	3	84.2	16	18.8	3	81.2	13

Note: The outbound flight of one pilot was excluded in these analyses as they had an atypical rest break pattern (1st&4th breaks) on that flight, therefore N=34 (not 35) for the outbound flight. Additionally, due to missing data, percentages may not always add up to 100.

Table 3I.5 Percentage of pilots with Samn-Perelli Crew Status Check fatigue ratings ≥5 on outbound and inbound flights by rest break pattern

	Crew with 1st and 3rd breaks (%)				**Crew with 2nd and 4th breaks (%)**			
	SP≥5 (%)	***N***	***SP<5 (%)***	***N***	***SP≥5 (%)***	***N***	***SP<5 (%)***	***N***
Outbound flight:								
Pre-flight	7.1	1	92.9	13	0	0	95.0	19
TOC	21.4	3	78.6	11	5.0	1	95.0	19
TOD	21.4	3	78.6	11	15.0	3	85.0	17
Post-flight	28.6	4	71.4	10	10.0	2	90.0	18
Inbound flight:								
Pre-flight	0	0	100	19	0	0	100	16
TOC	0	0	100	19	0	0	100	16
TOD	26.3	5	73.7	14	12.5	2	87.5	14
Post-flight	47.4	9	52.6	10	37.5	6	62.5	10

Note: The outbound flight of one pilot was excluded in these analyses as they had an atypical rest break pattern (1st&4th breaks) on that flight, therefore N=34 (not 35) for the outbound flight. Additionally, due to missing data, percentages may not always add up to 100.

The evolution of flight crew fatigue and sleepiness ratings across the flights is also presented in Figure 3I.1 to Figure 3I.4. The use of the four in-flight breaks pattern meant that the clock times at which flight crew completed their pre- and post- rest period ratings differed by break pattern (the end of the first rest break was the beginning of the second rest break, etc.).

Mean fatigue ratings across the outbound and inbound flight segments are presented in Figure 3I.1 and Figure 3I.2 while the mean sleepiness ratings across the flights are presented in Figure 3I.3 and Figure 3I.4.

Figure 3I.1 **Mean fatigue ratings across the outbound flight by break pattern**

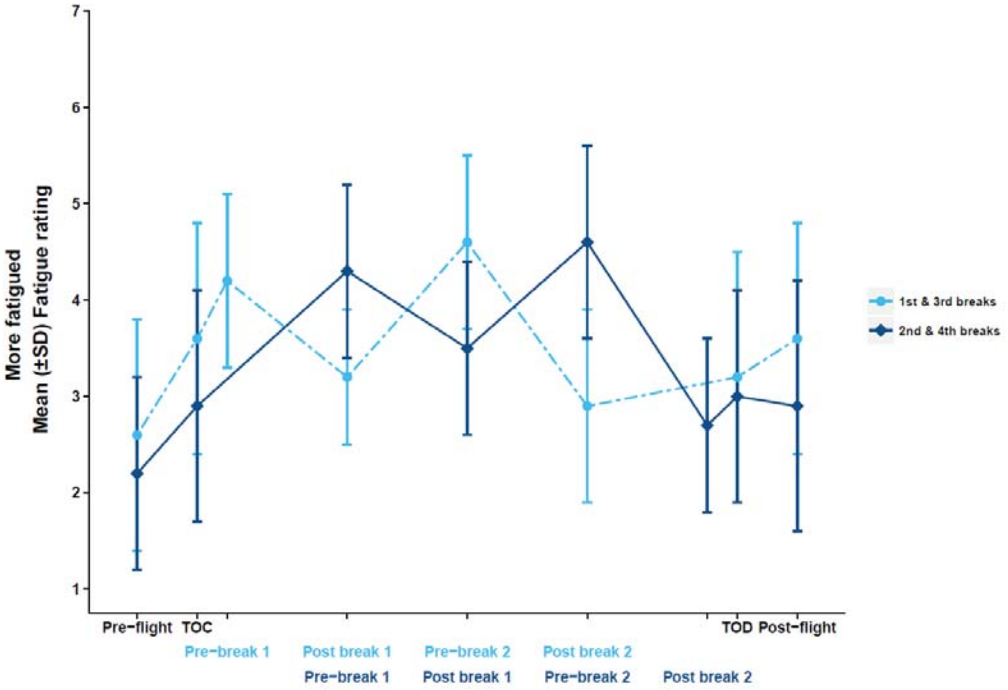


Figure 3I.2 **Mean fatigue ratings across the inbound flight by break pattern**

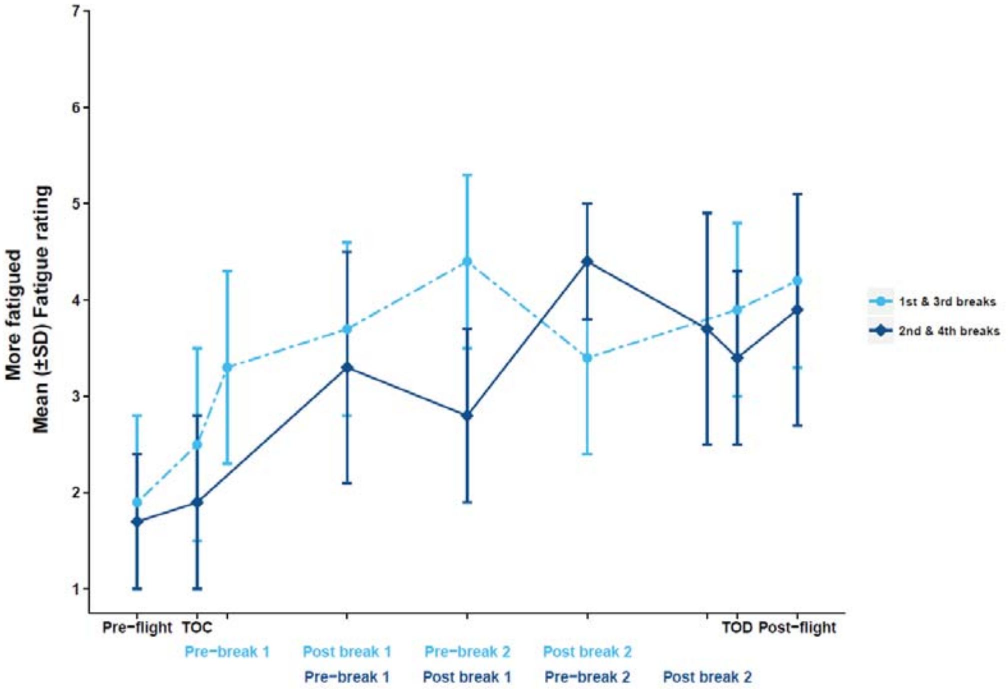


Figure 3I.3 Mean sleepiness ratings across the outbound flight by break pattern

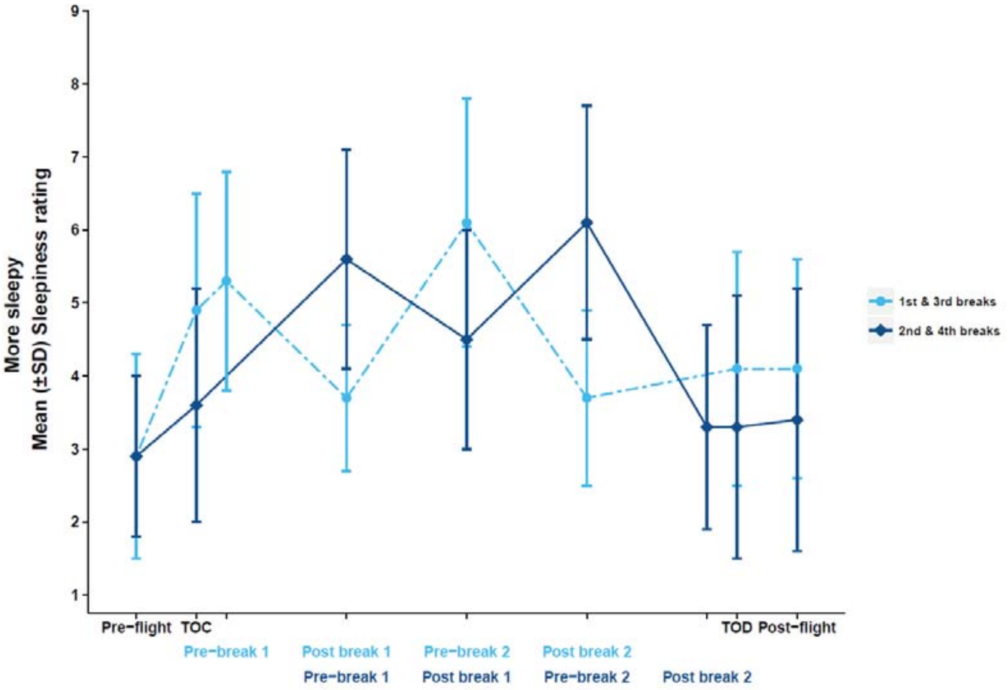
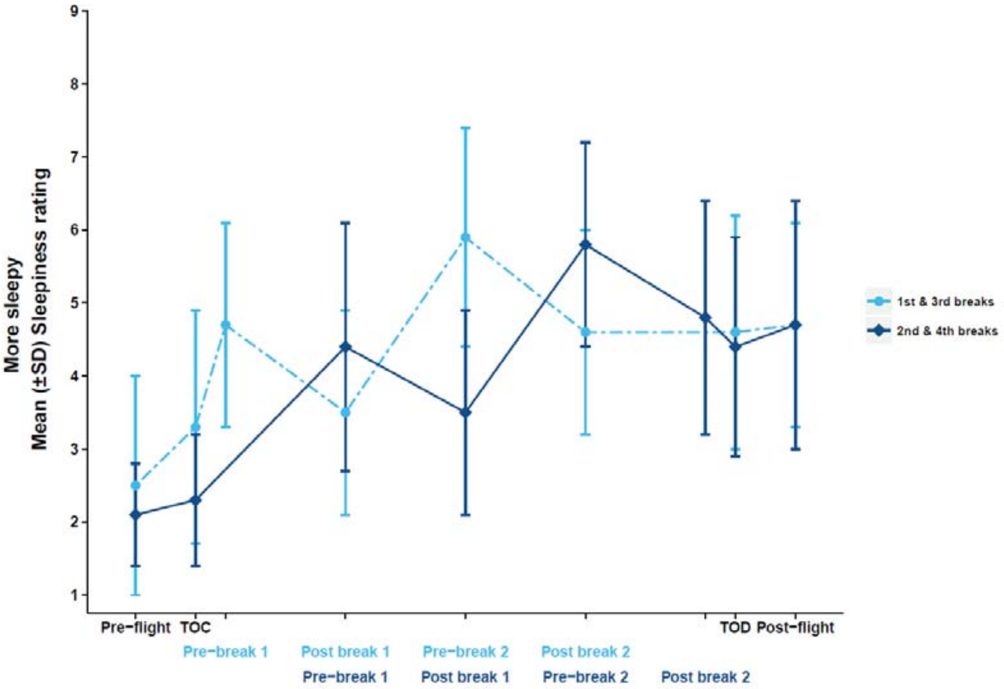


Figure 3I.4 Mean sleepiness ratings across the inbound flight by break pattern



APPENDIX 3J MULTILEVEL MIXED MODELS OF THE EFFECTS OF PRIOR SLEEP AND WAKE ON SAFETY PERFORMANCE INDICATORS

Multilevel mixed modelling was used to investigate the effects prior wakefulness, total in-flight sleep duration and flight segment had on pilot PVT performance at TOD. In these models, none of the PVT performance measures differed significantly by flight segment, duration of wakefulness, or total in-flight sleep (see Table 3J.1, Table 3J.2, and Table 3J.3).

Table 3J.1 TOD mean PVT response speed: effect of flight segment, time awake and total in-flight sleep time

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,33	2.55	0.1196
Outbound flight	4.086			
Inbound flight	3.941			
Time awake at TOD		1,52.5	0.48	0.4898
In-flight TST		1,58	0.09	0.7649

Note: Model reported used the Compound Symmetry (CS) covariance structure and includes outliers.

Table 3J.2 TOD slowest 10% of PVT responses: effect of flight segment, time awake and total in-flight sleep time

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,32.6	0.01	0.9370
Outbound flight	2.382			
Inbound flight	2.393			
Time awake at TOD		1,57.5	0.44	0.5116
In-flight TST		1,50.6	1.81	0.1846

Note: Model reported used the Compound Symmetry (CS) covariance structure and includes outliers.

Table 3J.3 TOD fastest 10% of PVT responses: effect of flight segment, time awake and total in-flight sleep time

Fixed effect	DF	F-value	P(F)
Flight segment (outbound/inbound)	1,33.4	3.70	0.0630
Time awake at TOD	1,50.6	0.04	0.8463
In-flight TST	1,57.9	0.15	0.6957

Note: Model reported used the Compound Symmetry (CS) covariance structure. Residuals were non-parametric (moderately negatively skewed), therefore the data were transformed using a reflect and square root transformation. There were no outlying residuals in the model with the transformed data. Estimated means are not reported as the data were transformed.

Multilevel mixed models also indicated that subjective ratings of sleepiness and fatigue at duty start did not differ significantly by flight segment, break pattern, duration of wakefulness prior to duty start or by total sleep duration in the 24 hours prior to duty start

Table 3J.4 Pre-flight KSS ratings: effect of flight segment, time awake and total in-flight sleep time

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,53.6	0.90	0.3479
Outbound flight	2.8			
Inbound flight	2.4			
Break pattern		1,56.7	0.27	0.6032
1st & 3rd breaks	2.7			
2nd & 4th breaks	2.5			
Time awake at DS		1,56.8	1.20	0.2770
TST in the 24hrs prior to DS		1,57.9	1.96	0.1670

Note: Model reported used the Compound Symmetry (CS) covariance structure and includes outliers.

Table 3J.5 Pre-flight Samn-Perelli ratings: effect of flight segment, time awake and total in-flight sleep time

Fixed effect	Estimated means	DF	F-value	P(F)
Flight segment		1,51.4	2.50	0.1199
Outbound flight	2.3			
Inbound flight	1.8			
Break pattern		1,49.6	0.71	0.4019
1st & 3rd breaks	2.2			
2nd & 4th breaks	2.0			
Time awake at DS		1,49.1	0.73	0.3961
TST in the 24hrs prior to DS		1,60.6	0.90	0.3478

Note: Model reported used the Compound Symmetry (CS) covariance structure. There were no outlying residuals.

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