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TNO report

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Extension of flying duty period by in-flight relief

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Summary

Based on EU OPS subpart Q, the Ministry of Transport of the Netherlands made a concept of requirements related to the extension of the maximum flight duty period (FDP), in case of augmentation of the cockpit crew and the availability of on-board rest facilities.

Aim of the project
The Ministry of Transport commissioned TNO to give science-based advice concerning the maximum permissible extension of the FDP, related to the quality of the available on-board rest facility and the augmentation of the crew with one or two pilots.

Method
Relevant national and international literature and databases have been studied and analysed, addressing the quality of the different in-flight rest facilities in relation to the yield in terms of sleep, alertness, and performance. Based on careful evaluation of the evidence, recommendations have been made concerning extensions of FDP in relation to the different rest facilities and the extent of augmentation. Areas where scientific data were lacking have been identified and expert judgement was used in these cases.

Outcome
In-flight sleep periods are an effective measure in maintaining alertness and performance at sufficient levels throughout a long-haul flight. Alertness and performance are better maintained after sleep periods of longer duration. However, the benefit of longer sleep periods has to be balanced against the risk of sleep inertia. The principal factors influencing the efficiency of in-flight sleep are the time of day and the length of the rest period. Other factors influencing sleep efficiency are the duty start time, the duration of prior wakefulness, and sleep disturbing factors, such as noise, light, and lack of comfort.

Based on extensive data of aircrew sleeping in bunks, it is estimated that, in the majority of situations, a pilot resting in a bunk will sleep on average for at least 25% of the allotted rest period. It is assumed that –if the environment is sufficiently restful– rest in a first class or top range business class seat (‘Lie-Flat’ or ‘Flat Bed’ seats) may be as good as in a bunk. This type of seat is categorized as a Class I seat (see Section 5.2.5 for specifications of all seats). Either a bunk, or Class I seat offers the best opportunity of obtaining recuperative sleep in order to maintain adequate levels of alertness throughout the flight. It is estimated that sleep in a ‘normal’ business class seat (a Class II seat) is degraded to 75% of sleep in a bunk or Class I seat, whereas sleep in a flight-deck or other seat which reclines by at least 40º to the vertical, with sufficient leg and foot support (a Class III seat) is degraded to 33% of sleep in a bunk/Class I seat. No data are available concerning on-board sleep in a normal economy class seat (Class IV seat). Based on laboratory data and ergonomic considerations, sleep in a Class IV seat is considered to be degraded to 0% of bunk/Class I seat rest (i.e. it provides no beneficial sleep).

Recommendations
Allow an extension to the FDP based on the duration of the rest period available to the pilot (which could be the sum of two separate rest periods) and on the environment which is available for rest. The allowable extension should depend also on whether the crew member is ‘acclimatized’, i.e. departing from the home base, having adjusted to local time, or is unacclimatized to a time zone transition (see section 4 for definition).

For the fully acclimatized individual, and based on the bunk/seat classification given above, allow the following extensions to the maximum permitted FDP.

- Bunk or class I seat: a period of time equivalent to 75% of the duration of the rest period.
- Class II seat: a period of time equivalent to 56% of the rest period.
- Class III seat: a period of time equivalent to 25% of the rest period.
- Class IV seat: no extension.

For an unacclimatized individual, allow 80% of the acclimatized extension.

To conform to the recommendations of the ultra-long range (ULR) workshops organized by the Flight Safety Foundation, the maximum FDP permitted under these regulations should be limited to 18 h. If augmentation is only by one additional pilot, the maximum FDP should be 16 h.

Based on the above-mentioned considerations the maximum FDP allowed under different conditions has been calculated for cases where the unaugmented FDP is 11 h. The adjustments necessary when the unaugmented FDP is different from 11 h are also given, thus enabling the maximum permissible FDP to be calculated in all situations.

The recommendations in the present report are the product of applied scientific knowledge that is generally accepted by scientists dealing with sleep and alertness issues in the context of FTL requirements.

Contents

Background of the project team

Since 1986 researchers of TNO (until 2002 incorporated in the Aeromedical Institute) have performed studies into the effects of fatigue on alertness and performance of flight crew. Projects have been commissioned by national (Ministry of Transport, Ministry of Defense) and international authorities and airlines (JAA, CAA Singapore, CAA Hong Kong, KLM, Aer Lingus). In the context of a Fatigue Countermeasures programme, studies have been performed of different types of flight operations (short-haul, long-haul, ultra long-haul, cargo, helicopter). Central research issues were time-zone transitions, night flights, in-flight and layover sleep, and their effects on alertness and performance. Effects of different countermeasures, such as in-flight sleep, cockpit napping, crew augmentation and layover policy, have been assessed in field studies. With the results of these studies a database has been developed which enables determination of the relationships between the different operational and human factors.

Since 1986, Ries Simons, MD has been the project leader of the TNO team. He is a founding member of ECASS (the European Committee for Aircrew Scheduling and Safety) and the present project is performed in close consultation with Mick Spencer, BA MSc, who is also a founding member of ECASS. He has collaborated as an ECASS member with the TNO team in many studies concerning FTL issues.

For over 15 years until his retirement in 2006, Mick Spencer led a team at the QinetiQ Centre for Human Sciences in Farnborough UK carrying out research into sleep, circadian rhythms and fatigue. He has developed mathematical models related to the regulation of sleep and wakefulness. Practical applications in this area have included the design and development of the computer program SAFE (System for Aircrew Fatigue Evaluation) for the assessment of duty schedules in civil air operations. He is an acknowledged expert in the field of aircrew fatigue, and has been invited to present at a broad range of conferences and workshops, including those organized by the Royal Aeronautical Society, the International Federation of Airline Pilots, and the Flight Safety Foundation. He sits on the International Aviation Advisory Panel that reviews the fatigue monitoring programme of Air New Zealand. Other organizations he has advised include the Civil Aviation Department of Hong Kong, the Civil Aviation Authority of Singapore, Singapore Airlines and the JAA. He designed and developed the Fatigue Index that is currently being used by the UK Health and Safety Executive to assess the fatigue implications of shift systems throughout British industry. Since his retirement, Mick Spencer has continued to work as a consultant to QinetiQ and to other organizations.

1 Introduction

This report is a deliverable item under order number 4500094284 concerning a contract between TNO Defence, Security, and Safety – Human Factors and the Civil Aviation Authority the Netherlands.

2 Background of the project

After years of political and legislative debate, the new EU-OPS Regulation 1899/2006 was published on 27 December 2006 (Ref 1). On 16 July 2008, these pan-European minimum standards for Flight Time Limitations (‘Subpart Q’) will become mandatory in all EU Member States. National authorities will use 2007 to prepare for changes in their legislation to ensure they can meet the deadline and to allow operators and their crew to adapt to the new rules. Based on EU OPS subpart Q, the Ministry of Transport of the Netherlands made a concept of requirements related to the extension of the maximum flight duty time (NL: vliegdienstperiode), in case of augmentation of the cockpit crew and the availability of on-board rest facilities. This concept of requirements refers to the following articles in EU-OPS Regulation 1899/2006.

- OPS 1.1095 – 1.6: Flight duty period.
  A flight duty period (FDP) is any time during which a person operates in an aircraft as a member of its crew. The FDP starts when the crew member is required by an operator to report for a flight or a series of flights; it finishes at the end of the last flight on which he/she is an operating crew member.
- OPS 1.1105.
  - 1.3: The maximum basic daily FDP is 13 hours.
  - 1.4: These 13 hours will be reduced by 30 minutes for each sector from the third sector onwards with a maximum total reduction of two hours.
  - 1.5: When the FDP starts in the WOCL[1], the maximum stated in point 1.3 and 1.4 will be reduced by 100% of its encroachment up to a maximum of two hours. When the FDP ends in or fully encompasses the WOCL, the maximum FDP stated in point 1.3 and 1.4 will be reduced by 50% of its encroachment.
- OPS 1.1115: Extension of flight duty period due to in-flight rest.
  - 1. Subject to the provisions of Article 8 and providing each operator demonstrates to the Authority, using operational experience and taking into account other relevant factors such as current scientific knowledge, that its request produces an equivalent level of safety:
  - 1.1. Flight crew augmentation – the Authority shall set the requirements in connection with augmentation of a basic flight crew for the purpose of extending the flight duty period beyond the limits in OPS 1.1105 above.

Proposed Dutch CAA FTL requirements: augmentation of cockpit personnel

1 When a standard crew of two pilots is augmented with one extra –fully qualified– pilot:
   a the operator shall provide *a seat* that is at least equal to a passenger seat, separated from the cockpit and –if possible– physically separated from the passengers;
   b in that case the maximum basic flight duty time can be increased with *4 hours*.
2 When a standard crew of two pilots is augmented with one extra –fully qualified– pilot:
   a the operator shall provide an onboard *sleep facility*, which is separated from the cockpit and passengers;
   b in that case the maximum basic flight duty time can be increased with *6 hours*.

[1] The window of circadian low (WOCL) is the period between 02:00 hours and 05:59 hours. Within a band of three time zones the WOCL refers to home base time. Beyond these three time zones the WOCL refers to home base time for the first 48 hours after departure from home base time zone, and to local time thereafter.

3 When a standard crew of two pilots is augmented with two extra –fully qualified– pilots:
   a the operator shall provide onboard *sleep facilities*, which are separated from the cockpit and passengers;
   b in that case the maximum basic flight duty time can be increased with *8 hours*.

2.1 Aim of the project

TNO is asked to give advice concerning extension of the maximum flight duty time in relation to the quality of the available rest facility. In this context, the Authority asks TNO to answer the following questions.

- With reference to point 1 of the proposed requirements:
  Study the possibilities for differentiation of the flight duty time extension taking into consideration seat comfort and the extent of separation of the passengers.
  Consider the following seats:
  - economy class seat;
  - business class seat;
  - business class ‘plus’ seat (the ‘ideal’ business class seat);
- With references to points 2 and 3:
  Study the amount of extension of the flight duty time for augmentation with one and two pilots respectively in relation to the availability of a sleep facility, which is separated from passengers and crew.

2.2 Method

Relevant national and international literature and data have been studied and analysed and recommendations have been made concerning:

- the quality of the different in-flight rest facilities in relation to the yield in terms of sleep, alertness, and performance;
- advice, based on careful evaluation of the evidence, on extensions of flight duty time in relation to the different rest facilities and augmentation.

The study is performed in close consultation with Mick Spencer, BA MSc
(see background of the project team).

In this report we describe:

- considerations concerning sleep and in-flight sleep;
- the relationship of in-flight sleep/rest with alertness and performance (flight safety);
- considerations concerning the different onboard rest facilities;
- probability of recuperative sleep/rest in the different onboard rest facilities;
- an arithmetic method to calculate permissible extensions of the maximum basic FDP;
- recommendations concerning extension of a maximum basic FDP of 13 hours (as mentioned in OPS 1.1105-1.3) and of a maximum basic FDP of 11 hours (OPS 1.1105-1.4 and 1.5) for each type of onboard rest facility.

The report is based on scientific evidence of available data. Areas where scientific data were lacking were identified and expert judgement was used in these cases.

3 Requirements of maximum FDP extensions of other European CAAs

An Internet search was performed and personal information was requested from several European Civil Aviation Authorities (CAAs). To date, we have information from the CAAs of the Czech Republic and UK. We are presently not aware of the requirements or proposed requirements concerning this issue of other European States.

3.1 Requirements of the Czech Republic

Augmented Crew (FLT-AC) (art 7.7)
If an augmented crew is used (i.e. one pilot extra), the maximum permissible planned FDP is 16 hours irrespective of the FDP reporting time, with a maximum of 4 landings and provided the following conditions are met.

1 A comfortable reclining seat in the area of cabin arranged for higher than an economy class (for a multiple class cabin configuration) is available for each resting crew member.
2 A common group of seats (row subsection) may be shared only by another crew member; under no circumstances may the common group of seats be shared by any crew member and a passenger.
3 Seats intended for crew member(s) rest shall be separated from the flight deck and screened from the passengers, preferably by a cabin divider.

Double crew (FLT-DC) (art 7.8)
If a double crew is used (i.e. two pilots extra) the maximum permissible planned FDP is 18 hours irrespective of the FDP reporting time, with a maximum of 6 landings and provided the following conditions are met.

1 For crew members replacing other crew members in flight a sleeping bunk separated and screened both from the flight deck and from the passenger cabin is available, and
2 Also comfortable reclining seats which do not necessarily need to be screened from the passengers are available.

3.2 Requirements of the United Kingdom

Extension of Flying Duty Period by In-flight Relief

1 When any additional crew member is carried to provide in-flight relief with the intent of extending an FDP, that individual shall hold qualifications which are equal or superior to those held by the crew member who is to be rested. To take advantage of this facility the division of duty and rest between crew members must be kept in balance. It is unnecessary for the relieving crew member to rest in between the times relief is provided for other crew members.
2 When in-flight relief is utilised there must be, for the crew members resting, a comfortable reclining seat, or bunk, separated and screened from the flight deck and passengers.
3 A total in-flight rest of less than three hours does not allow for the extension of an FDP, but where the total in-flight rest, which need not be consecutive, is three hours or more, then the permitted FDP may be extended as follows:

3.1 *If rest is taken in a bunk*: A period equal to one half of the total rest taken, provided that the maximum FDP permissible shall be 18 hours; 19 hours in the case of cabin crew.

3.2 *If rest is taken in a seat*: A period equal to one third of the total rest taken, provided that the maximum FDP permissible shall be 15 hours; 16 hours in the case of cabin crew.

4 Background on sleep and alertness

To maintain round the clock operations, members of an aircrew often have to sleep when their circadian clock dictates wakefulness and to fly when their clock dictates sleep. Short haul aircrew are often faced with irregular work schedules, early morning departures, and late arrivals, resulting in impaired sleep and in-flight sleepiness (Simons & Valk, 1998; Gander & Graeber, 1987). Long haul operations are characterized by rapidly alternating time-zone transitions and night flying (e.g. Graeber et al. 1986; Petrilli et al. 2006). Layovers are often too long to keep sleep and activity patterns anchored to home time and too short for complete circadian adaptation to the local environment. The unique combination of shifted time and shifted work results in compound circadian disruptions. Consequences, such as impaired sleep, lowered alertness, and fatigue may affect flight safety and health (e.g. Samel et al. 1993; Petrie et al. 2004; Eriksen & Akerstedt, 2006; Jackson & Earl, 2006). Sleep reduction may lead to lowered alertness and impaired performance (Carskadon & Dement, 1981; Horne & Wilkinson, 1985; Valk et al. 2003), while flying requires optimal cognition and alertness (Valk et al. 1997).

Sleep is a vital physiological body function and sufficient sleep is a major countermeasure against fatigue, lowered alertness, and in-flight sleepiness.
It is therefore important for flight crew to use the scheduled rest periods to obtain the best possible sleep.

Sleep is composed of two distinct states: non-rapid eye movement, or NREM, and rapid eye movement, or REM, sleep. During NREM sleep, physiological and mental activities slow (e.g., heart rate and breathing rate slow and become regular). NREM sleep is divided into four stages, with the deepest sleep occurring during stages 3 and 4. Deep sleep, also called slow-wave sleep (SWS), has important recuperative properties and growth-inducing properties involved in maintaining general health. If awakened during this deep sleep, an individual may take some time to wake up and then continue to feel groggy, sleepy, and perhaps disoriented for 10 to 15 minutes. This phenomenon is called sleep inertia.
REM sleep is associated with an extremely active brain that is dreaming, and with bursts of rapid eye movements; during REM sleep, the major motor muscles of the body are immobile. If awakened during REM sleep, individuals can often provide detailed reports of their dreams. REM sleep is important for mental recuperation and mental capacities, such as memory, learning, cognitive performance and mental health.

Over the course of a typical night, NREM and REM sleep occur in cycles. Stage 1 or drowsy sleep usually occurs during the transition from waking to sleep. Stage 2 sleep normally occupies 50% of the sleep period. The time taken to reach the first episode of stage 2 is termed ‘sleep onset latency’. Deep sleep (stages 3 and 4), also called slow wave sleep (SWS), predominates in the early part of the sleep period and is influenced by the duration of prior wakefulness. Episodes of rapid eye movement sleep (REM) occur at intervals and are associated with dreaming. The normal sequence of sleep stages during the night is: waking, stage 1, stage 2, stage 3, stage 4, stage 3, stage 2, REM sleep, followed by the next cycle starting with stage 2, etcetera. Each sleep cycle lasts around 90-100 minutes. As the night proceeds, the content of the sleep cycles alters, with less slow wave sleep and more REM sleep in later cycles. The last part of a normal night’s sleep generally consists mainly of sleep stages 1 and 2.

Recuperative sleep
It can be concluded that for optimal recuperation of physical and psychological functions both NREM and REM sleep are important. To be recuperative, the duration of sleep should be sufficiently long to allow for NREM and REM. Sleep duration is the principal determinant of the recuperative value of sleep (Dinges et al., 1997; Wilkinson et al., 1966).

The literature provides sufficient evidence that duration and quality of pre-trip sleep are important determinants of pilot performance and alertness (e.g. Carskadon & Dement, 1981; Carskadon & Dement, 1982; Rosekind, Graeber, Dinges, Connell, Rountree & Gillen, 1992; Pascoe et al. 1994; Valk & Simons, 1998). In aircrew, quality and duration of pre-flight sleep may be impaired by operational demands and circadian disruptions. Several studies of the sleep of aircrew during layovers after time zone transitions found impaired sleep. In particular, the second and third night during layovers showed poorer sleep quality (e.g. Simons et al. 1994). In circadian terms, aircrew with circadian disruption and poor sleep quality during layovers are considered as *unacclimatized* (i.e. to have some degree of 'jet lag'). Unacclimatized aircrew may experience more alertness problems on a (return) flight than aircrew that have their body clock acclimatized to the local environment.

For regulatory purposes, '*acclimatized*' is defined as follows (e.g. CAP371): 'When a crew member has spent 3 consecutive local nights on the ground within a time zone which is 3 hours wide, centred on the home base, and is able to take uninterrupted nights sleep. The crew member will remain acclimatized thereafter until a duty period finishes at a place where local time differs by more than 3 hours from that at point of departure'. Based on the principles of circadian physiology, we consider this definition to be too generous. Therefore, we recommend using the following definition for regulatory purposes: 'When a crew member has spent 4 consecutive local nights on the ground within a time zone which is 2 hours wide, centred on the home base, and is able to take uninterrupted nights sleep. The crew member will remain acclimatized thereafter until a duty period finishes at a place where local time differs by more than 2 hours from that at point of departure'. As mentioned, this definition is used for regulatory purposes. From a scientific point of view this definition does not guarantee full physiological acclimatization, as some individuals may need a longer period of time to acclimatize completely. Moreover, acclimatization generally takes more time after eastward than after westward time zone transitions.

Impaired pre-flight sleep and circadian disruption may result in lowered alertness and performance levels during the flight. In-flight alertness and performance levels may further be lowered by long work periods, night flying, and monotony during cruise flight. Analysis of the data of 156 cockpit crew flying eastward, westward, and southward intercontinental trips showed that after more than 8 hours continuous flight duty, alertness and vigilance levels are significantly impaired compared to those found earlier during the flight (Roelen et al. 2002). Table 1, based on an alertness model derived from a large database of experimental data, clearly shows that alertness decreases as FDPs become longer (Spencer et al. 1998). Therefore, augmentation of the crew and implementation of in-flight sleep periods may be necessary to maintain sufficient alertness and performance levels during a long-haul flight. Moreover, Table 1 shows that in-flight alertness levels are also highly influenced by the time of day that an FDP starts. This is particularly important for scheduling of rest periods on ultra-long range flights.

Table 1 Alertness scores (Visual Analogue Scale) and equivalent blood-alcohol levels (BAC promille ‰) related to FDP hours and start of FDP. Highest alertness scores 100. When the FDP starts at 10:00 alertness is impaired to a BAC level of 0.42‰ after 15.2 hrs. When the FDP starts at 18:00 this level is reached after 10.3 hrs (Spencer et al. 1998).

	Alertness score						
	80	70	60	50	40	30	20
Hours before level reached during FDP starting at 10:00	6.1	8.4	10.7	12.9	15.2	17.5	19.7
Hours before level reached during FDP starting at 18:00	1.2	3.5	5.7	8	10.3	12.6	14.9
Equivalent level BAC (‰)	0.00	0.03	0.14	0.27	0.42	0.62	0.85

In-flight sleep

In-flight sleep is considered as recuperative or restorative, when it enables aircrew to maintain sufficient performance and alertness levels throughout the entire flight. Many studies have demonstrated the benefits of short periods of sleep on subsequent performance and alertness during a prolonged period of work (e.g. Nicholson et al. 1985; Dinges et al. 1987; Simons et a. 1994, Rosekind et al. 1994; Robertson & Stone, 2002, etcetera), and there is evidence to suggest that this is more effective than a nap taken when impaired performance is already established and the time available for sleep is very short (Rogers et al. 1989; Dinges et al. 1988; Naitoh et al. 1982). The longer the length of prior wakefulness, the greater the amount of sleep needed for the recovery of performance (Rosa et al. 1983; Wilkinson, 1972).

There is extensive evidence that performance is better maintained after sleep periods of longer duration (Naitoh et al. 1982, Spencer, 2002; Robertson & Stone, 2002; Signal et al. 2003). In a survey comprising aircrew on 851 intercontinental 747-400 flights, it was found that alertness, measured on a Visual Analogue Scale, increased with 5% for each hour of sleep (Spencer, 2002). Although longer sleep periods are more beneficial than very short periods (< 1 h), longer sleep increases the probability of sleep inertia after awakening. Therefore, after a sleep of more than 1 hour a pilot should take at least 15-20 min to overcome sleep inertia before he/she relieves a colleague in the cockpit (Simons et al. 1994; Robertson & Stone, 2002). Very short sleep periods (45 min in a cockpit seat) have been shown to enhance performance and alertness briefly in those pilots who slept for that time (Rosekind et al. 1994; Simons & Valk, 1997). However, these short cockpit naps are generally considered as an emergency measure to prevent pilots from falling asleep and they should not be considered in FTL planning, because they do not guarantee that a sufficient level of alertness will be maintained throughout the flight until landing.

Several studies demonstrated the benefits of in-flight sleep in terms of improved alertness, although they also indicated that the ability to obtain adequate sleep is influenced by the sleep environment, by the timing of the flight in relation to the circadian sleep-wake cycle, and by the duration of wakefulness prior to the allocated rest period (Pascoe et al. 1994; Simons et al. 1994; Rosekind et al. 1994; Pascoe et al. 1995; Spencer, 2002; Signal et al. 2003). Onboard sleep will be most efficient, when the in-flight rest is taken during the normal sleep period of the body clock; e.g. during the night (e.g. Simons et al., 1994; Valk & Simons, 1998; Pascoe et al. 1994). When the rest period coincides with the circadian activity phase, one needs to take into account that at least some pilots will not be able to sleep at all, or will have a very low sleep efficiency.

In *summary* it is concluded that:

- Short in-flight sleep periods are an effective measure to maintain alertness and performance at sufficient levels throughout a long-haul flight.
- Alertness and performance are better maintained after sleep periods of longer duration.
- The benefit of sleep periods of longer duration has to be balanced against the risk of sleep inertia.
- The principal factors influencing the efficiency of in-flight sleep (the proportion of the rest period occupied by sleep) are the time of day and the length of the rest period. Other factors influencing sleep efficiency are the duty start time and the duration of prior wakefulness.

Causes of sleep disturbance
The quality of sleep can be as critical to well-being as the quantity of sleep. If an individual obtains 8 hours of sleep but the sleep is disturbed, then upon awakening, the individual may feel as if less sleep was obtained. There are many diverse reasons for disturbed sleep, from environmental factors (e.g. noise, light) to physical sleep disorders. Noise, light, temperature, and a variety of other factors may decrease the quantity and quality of sleep, in particular, when sleep is taken at a time when the body is not ‘ready’ for sleep (during the circadian activity phase) or in an environment that is not conducive for sleep (lack of privacy, seat reclines less than 40º). Of those factors, noise and light are the most cited and established sleep disturbing factors (see e.g. Miedema & Vos, 2007 for noise and Campbell et al. 1995 for light).

5 Crew rest facilities

Onboard crew rest facilities include sleep bunks, first class/top range business class seats, normal business class seats, flight deck seats or other seats which recline at least 40º, and a normal economy class seat. In this section, we review the above-mentioned rest facilities in relation with the probability of obtaining recuperative sleep.

5.1 Sleep in a sleep bunk

A sleep bunk is an onboard rest facility that is completely separated from the cockpit and the passenger compartment. In most cases, it has two beds (double-decker) allowing for horizontal rest. The facility can be completely darkened. The ideal sleep bunk also has a comfortable seat, climate and humidity control systems, and is adequately insulated and situated to minimize random and aircraft noise. An example of the requirements of an adequate sleep bunk is provided by the Australian and International Pilots Association facility standard AIPA-RS 001-1998 (Flight Safety Foundation, 2003).

There have been many surveys of the quality of the sleep bunks (e.g. De Ree et al. 1993; Pascoe et al. 1994; Rosekind et al. 1994). Results of these surveys showed high conformity concerning the factors that can improve or degrade the quality of sleep obtained in the bunk. Issues include:

- sudden noises, e.g. slamming of doors, passenger announcements, toilets flushing, galley noises. In this context the positioning of bunks is very important;
- background noise from aircraft;
- turbulence. In this context the positioning of bunks is important (front/back of aircraft, transverse/ longitudinal);
- temperature: sleep is degraded when the temperature is too high or too low;
- humidity: complaints concern dehydration of the mucous membranes (nose, throat, eyes);
- bedding: this is often inadequate;
- privacy: other bunk occupant may hinder sleep;
- thoughts on mind: falling asleep may be hindered by responsibility for the flight operation, or personal problems.

Studies of sleep characteristics have been carried out in bunks of different types of aircraft (B747-400, MD 11, B 777 and 777-200ER, Airbus 340-500). Full objective (EEG: electro-encephalography) and subjective monitoring demonstrated that, in most cases, the quality of sleep that aircrew achieved was relatively good: at times when they were particularly tired, they managed to get lengthy periods of SWS. At other times sleep was disturbed, but that was often because they were attempting to sleep at an unusual time relative to their body clock. In general, the studies established that there was no major problem with sleeping on aircraft, given the appropriate facilities (e.g. Spencer et al. 1990; Pascoe et al. 1995; Simons et al. 1994; Rosekind et al. 2000; Signal et al. 2003; Spencer & Robertson, 2004).

These studies have shown that sleep periods of six hours and even longer are possible. This is important particularly with the new generation of ultra-long-range (ULR) aircraft capable of continuous flights in excess of 18 hours (Signal et al. 2003).

Models to predict the amount of sleep achieved have been developed from the large amount of data (mainly subjective and actigraphic) that have been collected (Spencer, 2002). These models have demonstrated the influence of various factors on the amount of sleep obtained, the most important of these factors being the duration of the rest period (i.e. the time available for sleep) and the time of day at which sleep is attempted (see Figure 1). It has also been shown that bunk sleep is associated with an increase in alertness (Spencer, 2002; Spencer & Robertson, 2000). Longer periods of sleep tend to be associated with higher subsequent levels of alertness (Spencer et al 2004). However, the increase has been shown to be less strong (approximately 80% effective) on a return flight than on an outward flight (Spencer 2002), suggesting that the recuperative value of the sleep obtained may be less pronounced during a period of circadian disruption. This model has been validated on a further set of data, where it was confirmed that the average amount sleep obtained was close to the predicted values (Robertson et al 2002).

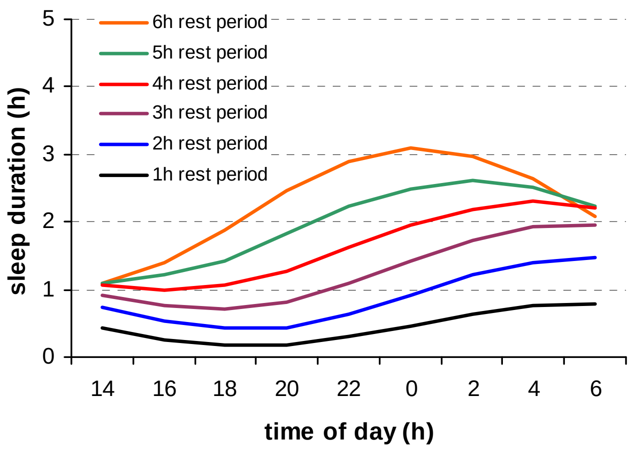

Figure 1 Model of sleep duration as a function of the length of the rest period and time of day.

5.1.1 *Sleep in a crew bunk: implications for FTL*

Figure 1 suggests that, except at the least favourable times (which are normally when people are not very tired), it is normally possible to sleep for around 33% of the allotted rest period. Allowing for less restful sleep than the ideal (as discussed above), and to err on the conservative side, a reasonable working figure would be 25%. On the basis of 1 h sleep for 2 h wake, this would suggest that the sleep obtained could allow an addition to the FDP of 25 x 3 = 75% of the length of the rest period. This builds in a conservative element, as short sleeps tend to contain more deep (slow-wave) sleep. However, this would need to be reduced, say to 50%, for the return flight. This would assume bunks of a reasonable standard (see the discussion in Section 5.1).

The question arises whether this approach is still valid for duty periods which are considerably longer than those from which this information has been drawn.
The requirement to regulate for very long FDPs has become a pressing issue with the arrival into service of a new generation of aircraft able to fly continuously, with a full complement of passengers, for 16 h or more. To address this question, the Flight Safety Foundation organized a series of international workshops between 2001 and 2005, bringing together representatives from the aircraft industry as well as regulators and scientific and medical experts. A consensus was reached that, until these new operations

have become firmly established, each new schedule would require separate evaluation, based on the concept of the 'city-pair' (Flight Safety Foundation, 2003).
To conform with the recommendations from these workshops, it would be necessary to limit the extensions proposed here so that the maximum FDP does not exceed 18 h, even where a double crew is provided. Beyond this limit, the city-pair approach should be adopted. To ensure consistency with the 18 h limit for 4-crew operations, it is recommended that a limit of 16 h be imposed for a 3-crew operation (Flight Safety Foundation, 2003).

5.2 Sleep on the aircraft elsewhere than in a bunk

5.2.1 First Class seat or top range business class seat

A first class or top range business class seat may offer a quality of sleep that is comparable to sleep in a bunk facility, because the seat offers horizontal rest, which is similar to a bed. However, sleep can only be as good as in a bunk under the condition that this seat is completely separable from the passengers (privacy is important) and offers a completely darkened environment. The seat has to be screened by curtains or panels. Under these conditions, we consider the probability of obtaining recuperative sleep to be equal to the sleep bunk.

5.2.2 Normal Business class seat

A normal business class seat cannot be completely reclined to offer a horizontal sleeping position for the whole body (including legs). There is often less space around the sleeping position than around a first class/top range business seat, which makes adequate separation from the passengers and random noise more difficult. Based on these ergonomic considerations, it is surmised that it will be more difficult getting to sleep and remaining asleep. Of course, resting crew members can use eyeshades and earplugs, which helps to some extent. However, this might interfere with getting to sleep in individuals who experience these aids as irritating.

Data of in-flight sleep characteristics are scarce. QinetiQ has studied sleep and alertness of flight crew using business class seats as crew rest on the Dubai-Perth route (Emirates Airline), where bunk facilities were not provided on the B777 aircraft (Spencer et al. 2004). On average, sleep in the seat was reduced by approximately 25% compared with sleep during similar rest periods in a bunk on the B747. Crews reported greater difficulty in getting to sleep and remaining asleep than in the bunk studies. They also made more frequent use of earplugs and eyeshades. Nevertheless, the amount of sleep that they did get was as effective in improving alertness as a similar amount of bunk sleep. This suggests that any relative impairment associated with sleeping in a seat was due to the duration rather than the quality of the sleep obtained.

5.2.3 Flight deck or other seat that reclines at least 40º

Lying down is the preferred position to sleep for adult human beings. Sleeping in a seat with back angles to the vertical of less than 90º has been studied by Nicholson and Stone (Nicholson & Stone, 1987). Nocturnal sleep was assessed electroencephalo-graphically in men between 29 and 48 years of age, sleeping in a bed and in three seats with back angles to the vertical of 49.5º ('sleeperette'), 37.0º (reclining seat), and 17.5º (armchair). It was found that sleep in the sleeperette did not differ from that in bed, but in the reclining seat the duration of sleep was reduced and the amount of awake activity was increased. Sleep in the armchair was markedly worse than in any of the other three

conditions. The investigators concluded that adequate sleep may be obtained in seats as long as the back angle with the vertical approaches 40º.
It is anecdotally known that pilots often prefer to try and sleep in the seat at the back of the flight deck instead of an economy class seat. Although the location of the seat offers no separation from the cockpit, most types of seats at the back of the flight deck can (fully) recline and offer separation from the passengers. For a seat at the back of the flight deck, there is evidence from one of the Haj studies (route Solo-Batam-Jeddah v.v.) that were performed by QinetiQ (Spencer & Robertson 1999). The schedules involved flights of between 10 h and 12 h at all times of day across three or four time zones in both directions. In this study, the pilots used the jump seat in the B767, which rotated into a position where it would fully recline. They had to improvise a foot/leg-rest. The sleep they obtained was between 40% and 50% of that achieved in the B767 bunk (which was of a lower specification that the B747 bunks used in most of the above studies).
Sleep was also of poorer subjective quality.

5.2.4 *Economy class seat*

Although there have been no studies of sleep and alertness of aircrew seated in an economy class seat, it can be assumed that the probability of obtaining recuperative sleep in such seat will be minimal. This assumption is based on the following arguments.

- The seat does not recline more than 40º back angle to the vertical and has no opportunities for adequate foot and leg rest, which diminishes the probability of recuperative sleep (Nicholson & Stone, 1987).
- Space around the seat is not sufficient to create an adequate separation from the passengers (jostle in economy class), or guarantee any privacy.
- A majority of passengers are unable to sleep at all in an economy seat. Some passengers succeed in obtaining some sleep, but they often feel a general malaise after sleeping in a cramped position.

5.2.5 *Sleep on the aircraft elsewhere than in a bunk– implications for FTL*

In this section, seats are classified according to their capacity to allow for recuperative sleep:

1 A fully-reclining first-class seat or top of the range business class seat, separated from other passengers. If the environment is sufficiently restful, then this should be as good as a bunk (see Section 5.1 for requirements of a crew bunk). In the context of the present report this seat is classified as *Class I seat*.
   - *Requirements of a Class I seat:*
     The seat should provide horizontal rest as in a bed. It should be reclining to at least 80º back angle to the vertical. Examples are so-called 'Lie-Flat' seats, or 'Flat Bed' seats. The seat should be separated from the cockpit and passengers (by curtains or panels) and provisions for darkening of the sleep environment should be available.

2 A 'normal' business class seat. The considerations mentioned in 5.2.2 would suggest a degradation to 75% of bunk rest. This seat is classified as *Class II seat*.
   - *Requirements of a Class II seat:*
     A seat outside the cockpit and separated from the passengers by –at least– a dark curtain. A common group of seats (row subsection) may be shared only by another crew member; under no circumstances may the common group of seats be shared by any crew member and a passenger.

Minimal requirements of the seat are:
– reclining to at least 45º back angle to the vertical;
– seat pitch[2] at least 55 inches (137.5 cm);
– seat width at least 20 inches (50 cm);
– sufficient leg and foot support.

3 A flight-deck or other seat which reclines by at least 40º back angle to the vertical and offers sufficient leg and foot rest. The considerations mentioned in 5.2.3 would suggest a degradation to 33% of bunk rest. This seat is classified as *Class III seat*.

- *Requirements of a Class III seat:*
  A seat in the cockpit or in the passenger cabin reclining to at least 40º from the vertical and providing sufficient leg and foot support.

4 A normal economy class seat. It is assumed that the probability of obtaining recuperative sleep in a normal economy class seat is negligible. This seat is classified as *Class IV seat*. Until a study is carried out on this, we recommend no extension of FDP.

[2] Seat pitch is the distance between the rows of seats and is measured from the back of one seat to the back of the seat behind, the measurements being taken from the same position on each seat.

6 Recommendations

Allow an extension to the FDP based on the duration of the rest period available to the pilot (which could be the sum of two separate rest periods) and on the environment which is available for rest. The allowable extension should depend also on whether the crew member is ‘acclimatized’, i.e. departing from the home base, having adjusted to local time, or is unacclimatized. A more precise definition of acclimatization is given in Section 4 and below under ‘Implications for FTL’. This is provided as a working definition for the purpose of the regulations, and does not guarantee full physiological acclimatization.

For the fully acclimatized individual, and based on the bunk/seat classification given above, allow the following extensions to the maximum permitted FDP.

- Bunk or class I seat: a period of time equivalent to 75% of the duration of the rest period.
- Class II seat: a period of time equivalent to 56% of the rest period.
- Class III seat: a period of time equivalent to 25% of the rest period.
- Class IV seat: no extension.

In accordance with the considerations mentioned in Section 5.1, it is recommended to allow 80% of the acclimatized extension for an unacclimatized individual.

The maximum FDP permitted under these regulations should be limited to 18 h.
If augmentation is only by one additional pilot, the maximum FDP should be 16 h (see Section 5.1.1).

Example
The following assumes that the time available for rest is 3 h less than the FDP time. This allows for pre-TOC and post-TOD and possibly some time lost in handover and recuperation from sleep inertia. It also assumes an equal division of rest between the crews. The following formula allows calculation of the maximum permitted extension:

Max. permitted extension = pq(L-3) / (R-pq)

Where:
L is the unaugmented max. FDP of which 3 h are unavailable for rest (L-3)
R is the number of rest periods (3 for 3-crew, 2 for 4-crew)
p is the seat factor (0.75, 0.56, 0.25, or 0)
q is the acclimatization factor (1 or 0.8)

Consider a return flight with three pilots and with bunk facilities, where the maximum unaugmented flight duty time is 13 h and the crew is unacclimatized. The permitted extension would be 2 h 30 min.
The working is as follows:

max. permitted extension = (0.75 x 0.80) x (13 -3) / (3 – 0.6) = 2.5 = 2:30 (hrs:min)
For practical reasons, the results of the calculations are rounded to the nearest 15 or 5 minutes.

6.1 Implications for FTL

The maximum FDP allowed under different conditions can be calculated in a similar manner to the above, and these calculations can be made the basis for the FTL rules. The following table, applicable to a duty in which the maximum unaugmented FDP is 11h, is based on this approach. As indicated in the table, the limits that are applicable in the general case can be extended if the crew member is acclimatized prior to departure. A crew member may be considered, for the purpose of these recommendations, to be acclimatized when he/she has spent four consecutive local nights on the ground within a time zone which is two hours wide, centred on the home base.

Table 2 Max. permissible extended FDP in case unaugmented FDP = 11 h, (extended FDPs in hrs:min).

	Ynacclimatized		Acclimatized	
	3-crew	Double crew	3-crew	Double crew
Bunk / class I	13:00	14:30	13:45	15:45
Class II	12:30	13:15	12:45	14:00
Class III	11:30	12:00	11:45	12:15
Class IV	11:00	11:00	11:00	11:00

Where the unaugmented FDP is greater than 11 h, the additional allowable duty time can be calculated from Table 3. This table shows the additional time that is allowed for each hour by which the unaugmented FDP exceeds 11 h.

Table 3 Permissible additional time (hrs:min) per hour for unaugmented FDPs different from 11 h.

	Unacclimatized		Acclimatized	
	3-crew	Double crew	3-crew	Double crew
Bunk / class I	1:15	1:25	1:20	1:35
Class II	1:10	1:15	1:15	1:25
Class III	1:05	1:05	1:05	1:10
Class IV	1:00	1:00	1:00	1:00

For example, if the unaugmented FDP is 13 h, the maximum for an acclimatized three-crew operation in a class II seat is 12:45 + 2 x 1:15 = 15:15. If the unaugmented FDP is less than 11 h, the new value is obtained similarly by subtraction.

As discussed in Section 5.1.1, the maximum for augmented crews should be limited to 18 h (double crew) and 16 h (3-crew).

Taking above-mentioned limits into consideration and using Tables 2 and 3, calculations can be made that provide the science-based answers to the questions of the Dutch Authority concerning the extent of permissible extension of the maximum basic FDP.

Recommended maximal permissible extensions for a basic maximum FDP of 13 h
With a basic maximum FDP of *13 hours*, the recommended maximal permissible extensions are:

1. augmentation with *one pilot* and availability of a rest facility that is a:
   - Sleep bunk or Class I seat: 2:30 h for unacclimatized crew and 3:00 h (= 3:25 cut off at the 16 h limit) for acclimatized crew.
   - Class II seat: 1:50 h for unacclimatized crew and 2:15 h for acclimatized crew.
   - Class III seat: 0:40 h for unacclimatized crew and 0:55 h for acclimatized crew.
   - Class IV seat: no extension.
2. augmentation with *two pilots* and availability of a rest facility that is a:
   - Sleep bunk or Class I seat: 4:20 h for unacclimatized crew and 5:00 h (= 5:55 cut off at the 18 h limit) for acclimatized crew.
   - Class II seat: 2:45 h for unacclimatized crew and 3:50 h for acclimatized crew.
   - Class III seat: 1:10 h for unacclimatized crew and 1:35 h for acclimatized crew.
   - Class IV seat: no extension.

Recommendations concerning the maximal permissible extensions of a maximum basic FDP of 11 hours are presented in Table 2.

Recommendation concerning Class IV seat (Economy class)
Scientific data concerning in-flight sleep in an economy class seat are lacking. Based on ergonomic principles and lack of adequate separation of such seat from the passengers, we assume the probability of obtaining recuperative sleep in a normal economy class seat to be minimal. Therefore, we recommend to permit no extension of the basic FDP for an economy class seat until a study is carried out on sleep and alertness of pilots resting on a Class IV seat. In case the use of an economy seat for relief crew is further considered by the Authority, such study is recommended.

6.2 Comparison with requirements from other European countries

The recommendations in the present report are the product of applied scientific knowledge that is generally accepted by scientists dealing with sleep and alertness issues in the context of FTL requirements. It is not known whether scientific knowledge has been used to construct the requirements of the Czechoslovakian and UK requirements (see Section 3), or that these were made using operational experience and knowledge, which are also important considerations.

When comparing the recommendations of the present report with the Czechoslovakian and UK requirements, it can be seen that:

- the present recommendations are more detailed (also consider max. FDPs shorter than 13 hrs) and allow for calculation of the additional allowable duty time for every hour the FDP may wished to be extended;
- the present recommendations compare well with the UK requirements, but are somewhat less restrictive concerning the extent of extension when a seat is used by the relief crew;
- the present recommendations compare well with the Czechoslovakian requirements, but are somewhat more restrictive where unacclimatized crew are considered and where a seat is used by the relief crew.

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