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Preliminary Analysis of Impacts from Future Potential FTL Regulatory Changes for Air Taxi and Single Pilot Operations

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Preliminary analysis of impacts from future potential FTL regulatory changes for Air Taxi and Single Pilot Operations
for

EASA

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Contents

Executive Summary

Introduction

A rulemaking task (hereafter referred to as RMT.0429) will begin in the third quarter of 2012 for the development of Flight Time Limitations and rest requirements (FTL) for Air Taxi and Single Pilot operations by aeroplane. As part of this task a Regulatory Impact Assessment (RIA) has to be developed. Under framework contract EASA.2010.FC06, EASA has requested that DNV/Circadian conduct some preparatory data collection and preliminary impact analysis to assist the future work on the RIA.

The focus of this report has been on the safety, economic and social impacts of potential future rule changes for Air Taxi and Single Pilot operations.

Method

For the safety impact analysis the approach has been as follows:

- Relevant fatigue hazards have been identified for Air Taxi and Single Pilot operations (preliminary – this will need to be reviewed during the related rulemaking task process);
- Key issues relating to the hazards which may form part of future FTL regulatory changes have been considered from a safety perspective; and
- These considerations have been based on scientific literature, if available, and the use of Circadian's CAS model to see how key parameters (e.g. FDP duration) impact on fatigue levels.

For the economic and social impact analyses, we have:

- Identified what are considered likely to be potential FTL changes with the most significant economic and social impacts;
- Described the effects qualitatively and listed factors which are likely to affect the size of the economic and social impact; and
- For selected impacts illustrated a process that would allow estimates of the scale of the impacts once more robust data have been gathered.

Conclusions

Air Taxi Operations (ATXO) have certain characteristics that can potentially create challenges to managing fatigue hazards. These characteristic include:

- On demand operations with the majority at short notice;
- Large amount of standby at home with a relatively low chance on average of being called out;
- Frequent change of schedule/routing; this can include duty start times being put back or brought forward;

- Many of the flights (especially on the small and light jet segments) leave in the morning and come back in the evening. In between, pilots are often waiting in crew rest facilities or on the aircraft on split duty;
- Passenger requirements can lead to planned on-ground breaks being curtailed or alternatively ad-hoc split duties being needed;
- Considerable use is made of positioning of crew and aircraft relative to scheduled flights; and
- Significant time zone (TZ) crossings occur for long range ATXO.

A survey of eight European States has showed that there is a range of national provisions addressing split duty, additional rest for TZ crossings, reduced rest, in-flight rest and standby at the airport and elsewhere.

Single Pilot Operations (SPLO) occur in the Air Taxi, scheduled airline and Aeroplane Emergency Medical Services (AEMS) sectors. They have the potential for leading to additional workload relative to multiple crew and hence could impact fatigue. Thus long duration flights/ FDPs are addressed in some national provisions in a variety of ways.

Given the range of national FTL provisions for ATXO and SPLO, European harmonisation of these FTL provisions is likely to have safety, economic and social impacts. These are investigated at a preliminary level in this report.

This report provides information and preliminary analysis to be considered for the RIA development for RMT. 0429 on FTL for Air Taxi and Single Pilot operations with a view to assist in an overall balanced assessment of safety, social and economic impacts.

1.0 Introduction

1.1 Background

In December 2010 the European Aviation Safety Agency (EASA) published the Notice of Proposed Amendment (NPA) No. 2010-14A on 'Implementing Rules on Flight and Duty Time Limitations and Rest Requirements for Commercial Air Transport (CAT) with Aeroplanes'. Following extensive consultation the Comment Response Document (CRD) to NPA 2010-14A was published in January 2012. Within the CRD is a Draft Opinion of EASA, Annex III, PART-ORO (ORGANISATION REQUIREMENTS) covering Subpart — Flight and duty time limitations and rest requirements. Section 1 of this contains General FTL requirements and Section 2 is for Commercial Air Transport Operators. Also within the CRD is a Certification Specification (CS) for Commercial Air Transport by Aeroplane — Scheduled and Charter Operations, designated FTL 1.

The CRD has placeholders for Certification Specifications FTL 2, 3 and 4 covering Emergency Medical Services (EMS) by aeroplane and by helicopter, Air Taxi and Single Pilot Operations by aeroplane and other CAT operations by helicopters respectively.

A rulemaking task has started at the beginning of 2012 for the development of FTL for EMS. The rulemaking task for Air Taxi and Single Pilot will begin in the third quarter of 2012 and the one for other CAT operations by Helicopters is to follow in 2013.

To support the development of these rules EASA procedures require the preparation of Regulatory Impact Assessments (RIAs) similar to the one published in NPA 2010-14A. These RIAs will be undertaken with the support of the respective Rule Making Groups (RMGs).

Under framework contract EASA.2010.FC06 EASA has requested that DNV/Circadian conduct some preparatory data collection and preliminary impact analysis to assist the future work on the RIAs. Prior to the current report DNV/Circadian have produced Deliverable D1, which was a survey from eight European NAAs of FTL provisions used for EMS in their States, and D2 which was a preliminary analysis of impacts from future potential FTL regulatory changes for EMS.

1.2 Objectives of D3 Report

The main objective of this report, Deliverable D3, is to produce a preliminary analysis of the impacts of potential future FTL regulations concerning Air Taxi and Single Pilot Operations. This analysis is intended to assist in future RMT discussions, the development of potential regulatory options and the preparation of the RIAs. As part of this task a survey of eight European States was undertaken concerning national FTL provisions relevant to Air Taxi and Single Pilot operations.

1.3 Scope of D3 Report

The scope of this preliminary analysis is to study, in the context of future potential FTL rule making proposals:

- Safety impacts;
- Economic impacts; and
- Social impacts.

In the future RIAs other impacts including environmental, the degree of proportionality of the proposed measures and regulatory harmonisation will also need to be taken into account.

It is not the purpose of this report to develop options for regulatory changes – this will be undertaken by the RMG. Hence, rather than analyse the impact of defined options, in this report we look at key issues/ parameters and analyse how safety, economic costs and social impacts will vary if this issue/ parameter is changed. This will assist the future choice and analysis of options.

No attempt is made in this report to combine the analysis of different impacts (e.g. safety and economics) via one of the accepted RIA methods such as multi-criteria analysis. This is to be completed as part of RMT.0429 activities.

This report addresses Air Taxi and Single Pilot Operations. Other reports cover:

- Emergency Medical Services (EMS) – Deliverables D1 and D2 as described above.
- Other Commercial Air Transport Operations by Helicopters – future Deliverable D4.

The combination of Aeroplane EMS and Air Taxi operations are not analysed in this report.

1.4 Structure of this Report

The rest of this report is structured as follows:

- Section 2 provides an overview of how the preliminary impact analysis has been conducted.
- Section 3 identifies and classifies relevant hazards.
- Section 4 is a literature review covering aviation references and general industry references where relevant.
- Section 5 analyses the key Air Taxi and Single Pilot hazards and the main issues related to these hazards.
- Section 6 presents conclusions.
- Sections 7 and 8 provide references and acronyms.
- The Appendices contain supporting data namely:
    - Appendix 1 – Air Taxi and Single Pilot Safety Data, descriptions of fatigue aspects of relevant accidents.
    - Appendix 2 – Circadian Alertness Simulation (CAS) modeling description.
    - Appendix 3 – FTL survey data from eight European States on ATXO and SPLO.

- o Appendix 4 – details of the scenarios modeled in CAS.

1.5 Acknowledgements

Large amounts of information were provided by representatives of the European Business Aviation Association (EBAA) and the eight surveyed NAAs, i.e. Czech Republic, France, Germany, Norway, Poland, Spain, Switzerland and the UK. We would like to thank all these people for their time and assistance.

2.0 Methods for Analysing Impacts

2.1 Analysing Safety Impacts of FTL Changes

A direct method for analysing safety impacts from FTL regulatory changes would be:

- To estimate current safety risk levels in European Air Taxi and Single Pilot operations from appropriate accident/ incident data.
- To analyse how potential changes to FTL regulations would affect this historical risk estimate either based on relevant data or expert judgement.

A problem with this direct approach, as revealed in the NPA 2010-14 RIA (EASA, 2010) is that:

- The data are statistically insufficient to directly deduce potential impacts of rule changes;
- The data are statistically insufficient to detect current and future safety risks, especially as fatigue related events may be masked under "human factor-related incidents" or they are not reflected at all in these data.

EASA's Safety Analysis Section conducted a search of the EASA copy of the ICAO ADREP data base. This data base contains 215 air taxi operations occurrences between March 2, 1998 and March 21, 2012. Only one accident could be associated to pilot fatigue, i.e. in 0.5% of air taxi occurrences pilot fatigue was involved.

With regards to aeroplane single pilot operations EASA's copy of ICAO ADREP data base contains 32046 occurrences registered until March 21, 2012. Pilot fatigue is indicated as a contributory factor of an occurrence in 139 events. Expressed as a percentage, 0.4% of single pilot aeroplane occurrences can be related to pilot fatigue. The same percentage is obtained if occurrences only in EASA Member States are considered. However, EASA's Safety Analysis Section notes the following caveats:

- Data derived from the EASA copy of the ICAO ADREP data base does not mean that fully comprehensive information on fatigue incidents and accidents in air taxi and single pilot aeroplane operations is obtained. From past experience, it is known that often the investigations into light aircraft accidents do not go into such comprehensive and deep analysis as for large aircraft accident investigations. Therefore, it is very likely that fatigue issues in single pilot operations accidents are hidden under other human factors related causes of occurrences.
- Few operators have introduced fatigue management systems as a part of their operations. Pilots are not always aware of the principles of fatigue management. Therefore, there are reasonable grounds to believe that occurrences in some cases were not classified as fatigue when fatigue may in fact have been a contributor.

The narratives for several pilot fatigue related occurrences identified by EASA's Safety Analysis Section and by DNV-Circadian are presented in Appendix 1. These descriptions show the impact of:

- Cumulative fatigue from working a long pattern of consecutive days.

- Time zone crossings and Circadian time of day.
- Night flying with little prior sleep.
- Long flying hours during a day for a single pilot.
- Pilots on home standby inadequately managing their rest so that they become excessively fatigued when they are called out, particularly at night.
- Cumulative fatigue due to high workload activity such as intensive single pilot operations.

Because of this lack of data relating to the exact contribution of fatigue a similar approach to that adopted in the NPA 2010-14 RIA has been adopted in this report, i.e.:

- Relevant fatigue hazards have been identified for Air Taxi and Single Pilot Operations (preliminary – this will be reviewed during the RMT.0429 process);
- Key safety issues relating to each hazard which may form part of future FTL regulatory changes have been considered from a safety perspective;
- These considerations have been based on scientific literature, if available, the use of Circadian's CAS model (see Appendix 2) and Circadian's expertise in the field of fatigue.

The CAS software models alertness based on three physiological processes:

- circadian time of day;
- sleep-wake balance and sustained wakefulness; and
- sleep inertia.

Based on the hours worked, the CAS model estimates sleep duration and placement around these restrictions. Within the hours worked CAS can apply varying degrees of alertness decrease to emulate varying workloads. For fixed wing operations CAS assumes higher workload during the take-off and landing phase of the flight.

CAS then provides simulation results as either direct alertness averages per given time period (usually duty periods) or an aggregate Fatigue Score which summarizes the entire pattern into one number.

To establish a consistent basis for comparison between the multiple diverse duty-rest and scheduling options considered in this study the following assumptions have been made in the CAS settings used for this analysis.

1. The settings are based on the average working age person, and individual variations in circadian chronotype (e.g. morningness-eveningness, unrestricted sleep duration, sleep quality, adaptive flexibility of circadian sleep-wake pattern and napping propensity) are not considered. Thus actual fatigue scores and alertness levels may be higher or lower than estimated in this CAS analysis depending on the individual chronotype of each individual. Much of sleep science research has been based on college students, as a matter of convenience; but this population has a significantly different circadian sleep profile compared to the majority of working age (25-65 year

old) subjects. We have based our modeling on data from this post-college age population.

2. It is assumed that no active fatigue risk mitigations are in place, and the individuals modeled act as a person not trained in nor practicing sleep-alertness management. Thus with populations of individuals who are actively practicing fatigue risk management, this CAS analysis will overestimate the fatigue score and underestimate the levels of alertness.

The safety impact analyses are described in Section 5.0.

2.2 Analysing Economic Impacts of FTL Changes

2.2.1 Scale of Air Taxi Operations in Europe

2.2.1.1 Overall Economic Contribution to Europe

In a recent presentation (EBAA, 2012) it is noted that in 2011 there were 654,514 movements of Business Aviation (BA) in Europe based on EUROCONTROL data. In order to estimate the proportion of BA traffic that could be classified as Air Taxi reference is made to EUROCONTROL's analysis of 2009 BA data (EUROCONTROL, 2010). In this reference 45% of BA traffic was found to be "non-scheduled commercial" and all this traffic involved aircraft with 19 or less passenger seats. EASA's proposed definition for Air Taxi is "*Non-scheduled, on demand commercial operations with an aeroplane with a passenger seating configuration of 19 or less*."

Thus it is estimated that in 2011 there were 654,514 x 0.45 = 295,000 air taxi movements in Europe. It is estimated that this represents approximately 3% of all movements in the EU; BA traffic in total represents just over 7% of all movements (EBAA, 2012). EUROCONTROL expects business aviation to pass 8% of total movements around 2015 (EUROCONTROL, 2010).

A PwC report (PwC, 2008) commissioned by the EBAA concluded that the BA sector contributed a total of €19.7bn in annual gross value added (GVA) to the European economy in 2007, accounting for approximately 0.2% of the combined gross domestic product (GDP) of the European Union (EU), Norway and Switzerland. This overall value was made up of:

- Direct impact – which corresponds to the contribution to the European economy created by business aviation aircraft-related manufacturing, operations and maintenance. This reflects the industry's visible presence in Europe. This contributed €5.6bn.
- Indirect impact – which is created by the purchase of goods and services by firms directly involved in the business aviation industry. These are the benefits that accrue 'up-stream' in the business aviation supply chain, such as when aircraft manufacturers buy metal and plastic for their product. This contributed €4.8bn.
- Induced impact – this is the additional contribution to the economy resulting from increased expenditure by the workforce employed directly and indirectly by the business aviation industry. The income earned by these employees is spent on

various goods and services, leading to further economic activity and employment. This contributed €9.3bn.

In approximate terms the air taxi part of BA might be expected to have an economic footprint about half that of the values above given that 45% of BA movements is made up air taxi operations.

The PwC report further determined that the BA sector represents 164,000 jobs in aircraft manufacturing and operations and maintenance generating salaries of €5.7bn.

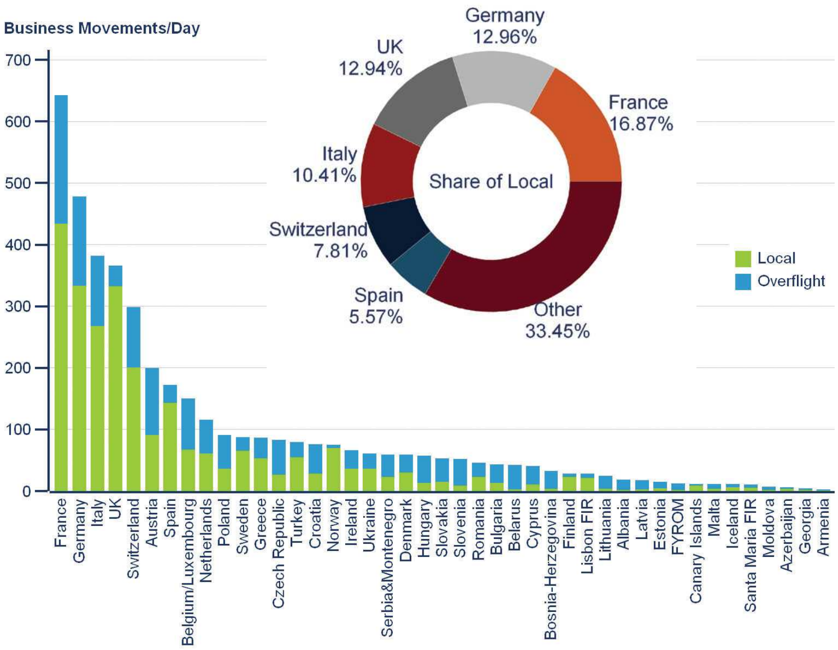
For this project, EBAA has supplied the following estimates relating to BA as a whole:

- Number of European Operators — 850 approximately
- Number of aircraft — 4300 approximately
- Number of pilots — 10 750 (based on an average of 2.5 pilots per aircraft)

2.2.1.2 Analysis by States

In terms of breaking down the European number of movements by States, EUROCONTROL provides an analysis of BA traffic by State for 2009 (EUROCONTROL, 2010). Figure 2.1 provides graphs of these data.

Figure 2.1: Breakdown of Daily BA traffic by European State (from EUROCONTROL, 2010)



There is no equivalent set of graphs purely for air taxi, but similar patterns are expected.

As part of the survey of FTL provisions during this project some States have also been able to provide information on the volume of air taxi operations.

Table 2.1: Air Taxi Operational Data from States

State	Air Taxi Operational Data			
	Flights/ Flight hours	**No. of Operators**	**No. of Aircraft**	**No. of Pilots**
Poland	6697 flights/ 8230 flight hours	5	27	61
Spain	71 631 flight hours	27	102	Not available
UK	Not available	60 approx.	Not available	Not available

2.2.1.3 Size of Operators

The EBAA commissioned Alertness Solutions to examine fatigue factors in European Business Aviation Operations (Alertness Solutions, 2011). As part of that study a survey of several hundred Business Aviation pilots was conducted. One of the background questions asked was how many pilots are employed by your company. The responses are shown below which provide an indication of the distribution of operator sizes in Europe.

Table 2.2: Distribution of Pilot Numbers for Business Aviation Operators

	Number of pilots employed by BA operator				
	10 or less	**11-30**	**31-60**	**61-100**	**More than 100**
Number of pilot responses	160	239	117	88	52
% of pilot responses	24%	36%	18%	13%	8%

2.2.2 Single Pilot Operations

Based on responses from the surveyed NAAs, single pilot operations are associated with Air Taxi operations, scheduled operations, AEMS and flights landing at the same airfield where they took off.

2.2.2.1 Air Taxi

EBAA has no specific data on single pilot operations within air taxi or BA operations. It was considered a marginal activity by EBAA within their membership.

Some of the NAAs were able to provide estimates on single pilot operations within Air Taxi.

Table 2.3: Operational Data on SPLO for Air Taxi

State	Single Pilot Air Taxi Operational Data			
	Flights/ Flight hours	**No. of Operators**	**No. of Aircraft**	**No. of Pilots**
Poland	Approx. 1560 flights/ 950 flight hours	4	15	35
Spain	Only one operator is authorised for conducting single pilot operations. However, it has not operated air taxi services up to now. It has been conducting aerial services.			
UK	Not available	Approximately: 15 operators have aircraft that only require a single pilot for CAT work 5 operators only have aircraft that need a single pilot	Not available	Not available

In Poland about half the aircraft and pilots involved in air taxi are involved in single pilot operations. In Spain there are no current air taxi single pilot operations. In the UK, about 25% of air taxi operators have aircraft capable of single pilot operations. Thus, based on the limited received data the picture is varied in different European States. Further data collection on single pilot operations would be desirable.

2.2.2.2 Scheduled Operations

In France, single pilots are involved in some scheduled operations. Examples include:

- Finist'air an airline providing scheduled passenger flights between Brest and Ouessant as well as air taxi operations and freight transport. The airline operates Cessna 208 Caravans.
- St. Barth Commuter an airline based in the Caribbean operating Cessna 208 Caravans and Britten-Norman Islanders.

In the UK single pilot operations apply to scheduled services around the Highlands and Islands (e.g. Loganair and Hebridean Air Services) and the Channel Islands.

No other data on scheduled single pilot operations were obtained during the survey of NAAs and relevant associations.

2.2.2.3 AEMS

During the preparation of report D2 on EMS, data were received from France and UK that single pilot AEMS operations take place in those States and that relevant FTL provisions are in place. Poland stated that single pilot AEMS operations did not occur in that State. No other specific information on single pilot operations in AEMS was obtained during the EMS survey.

2.2.2.4 Other Services

France and Germany have noted that flights landing at the same airfield where they took off take place as single person operations in addition to the services above.

2.2.3 Crew Cost Estimates

The main impacts of FTL and rest regulatory changes are likely to be on crew costs. Crew costs cover salary and non-salary such as pensions, social security, benefits such as medical insurance and expenses. Any changes in crew numbers will also impact costs associated with recruitment, training and checking of crew.

None of the NAAs nor the EBAA were able to provide specific Air Taxi data on crew costs as a proportion of total operator costs. One of the States provided an estimate for a combined AEMS/ Air Taxi provider of 15% of total operating costs relating to crew costs. In the absence of further data a range of 10% to 30%, similar to that for AEMS in D2 is considered reasonable.

It should be noted that there could also be other more subtle economic impacts on operators associated with changes to FTL and rest requirements, e.g.:

- Air Taxi or Single Pilot jobs could become less or more attractive, for example, by changing the number of rest days available, affecting the number of flying hours or leading to changes in salary.
- In areas where there is competition for crew, this could affect the availability of crew for Air Taxi with a consequent knock-on impact on service viability.
- If there is a need for more crew arising from FTL changes it may be a challenge to find such crew from the immediate locality. It may be difficult for crew to travel from further afield depending on FTL constraints regarding travel times.
- The impact on the number of flying hours can also affect job satisfaction and how motivated/ bored personnel become.

In the absence of more robust data, these impacts are not considered explicitly in the sections below.

In addition to direct economic impacts on Air Taxi operators, there could also be indirect or induced economic impacts as indicated in Section 2.2.1.1.

2.2.4 Analysis Method for Air Taxi and Single Pilot Operations

It is not possible to analyse all possible economic impacts of all conceivable future FTL regulatory changes. Therefore the subsections in Section 5.0 have, for the safety issues identified under each hazard:

- Identified what are considered likely to be those FTL changes with the most significant economic impacts;
- Described the effects qualitatively and listed factors which are likely to affect the size of the economic impact; and
- For selected impacts illustrated a process that would allow estimates of the scale of the impacts once more robust data have been gathered.

2.3 Analysing Social Impacts of FTL Changes

The types of social impacts considered in the report are:

- Working conditions for crew;
- Employment impacts (job creation/ curtailment), closely linked to economic impacts;
- Need for relocation or more/ less travelling as a result of FTL changes; and
- Impact on social life and work/ life balance.

The analysis method for social impacts has been analogous to the one above for economic impacts.

3.0 Hazard Identification

3.1 General Fatigue Factors

Fatigue is an impairment of mental and physical function manifested by a cluster of debilitating symptoms, usually including excessive sleepiness, reduced physical and mental performance ability, depressed mood and loss of motivation, which may result from a variety of causes including:

- **Sleep deprivation/circadian phase effects**: Fatigue develops as the result of an extended time awake (acute sleep deprivation), or reduced time asleep, or disrupted or poor quality sleep (partial sleep deprivation), time awake in the Window of Circadian Low (WOCL) or from the cumulative effect of multiple days with shortened or disrupted sleep such as may occur in jobs with extended work hours, irregular schedules or with night duty (chronic sleep deprivation).

- **Heavy stressful physical or mental effort:** Fatigue occurs as the result of extended hours of work with heavy muscular activity (e.g. marathon runner), continued stress or danger (e.g. combat fatigue) or intense mental exertion which occurs either during the task or as a rebound effect after the task, in proportion to the relative fitness (and/or prior training) of the individual.

- **Sleep disorders:** Fatigue manifested as excessive daytime sleepiness is the most common presenting complaint in sleep disorders, such as obstructive sleep apnoea, restless legs syndrome, narcolepsy or most of the other 85 different sleep disorders listed in the International Classification of Sleep Disorders (2005).

- **Illness or disease:** Fatigue is common in many diseases and illnesses (ranging from flu to cancer) which may occur as a direct result of the metabolic or other systemic pathophysiological disturbances of that disease, as a secondary consequence of sleep disturbances caused by other symptoms such as pain, nausea etc., or as the primary presenting complaint (e.g. chronic fatigue syndrome).

- **Therapeutic side-effect**: Fatigue is a commonly listed side-effect of prescription or over-the-counter pharmacological drugs, or may occur as the result of other therapeutic interventions (e.g. surgical procedure).

- **Stimulant drug usage:** Fatigue often occurs as a person rebounds after the initial euphoria, increased energy or “high” induced by illegal, over-the counter (e.g. Redbull, NoDoz etc.) or prescription stimulant pharmacological substances.

Unlike the engineering use of the word “fatigue” which is used to describe irreversible failure of a material as a result of stresses over an extended period of time, the medical definition of “fatigue” usually refers to a loss of physiological and psychological function as a result of extended wakefulness, heavy work, excessive stimulation, illness or stress which can usually be reversed in whole or in part by rest, sleep, treatment or recovery from the condition that caused it.

For this report we use the ICAO definition of fatigue:

A physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental or physical activity) that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety related duties.

In this report we have not considered sleep disorders, illness and disease, therapeutic side effects or stimulant drug usage. Workload is considered in terms of its direct effects on fatigue.

During sleep the human brain cycles through distinct stages, each characterized by changes in the electrical activity of the brain. When we are awake and alert, the electrical brain waves measured by electro-encephalography[1] (EEG) are fast (13 to 35 cycles per second) and random, but as we become drowsy the brain waves start to slow into a regular "alpha" pattern (of 8 to 12 cycles per second), which is exaggerated when we close our eyes. The first stage of sleep is when we start slipping into a semiconscious state, called stage 1 sleep, characterized by a further slowing of the brainwave rhythm to the "theta" range of 3 to 7 cycles per second, but in which we remain vaguely aware of our surroundings. We may even convince ourselves that we are still awake and in control of our consciousness - a dangerous misperception if we are on duty in a critical job.

From stage 1 we progress unknowingly into stage 2, a light level of sleep in which bursts of electrical activity called K-complexes and sleep spindles intrude into the EEG. Finally, after 30 to 40 minutes, we sink into the deepest stages of sleep (called stages 3 and 4) in which the brain waves slow down to 0.5 to 2 cycles per second and are magnified in their amplitude. These deep slow waves are called delta waves.

We do not linger for long in delta sleep. In fact, we tend to oscillate in a 90- to 100-minute cycle between the lighter and deeper stages of sleep interspersed with bouts of dreaming in which the brain waves suddenly speed up to an awake-like pattern and the eyes start moving rapidly from side to side. This stage, called rapid eye movement (REM) sleep, may occur four or times a night, building in duration as dawn approaches. Thus one may have four or five distinct dreams per night.

The stage of sleep from which you awake determines your condition on arousal. If you are in the deepest stages of delta sleep, you will feel groggy and disoriented on awakening, and suffer significant "sleep inertia" or impaired functioning for ten or twenty minutes or more. If you are in stage 1 or 2 sleep, you are much more likely to wake up alert and refreshed. Likewise you are more likely to remember a dream if you awake during a REM sleep stage.

Those factors which are most likely to affect sleep deprivation and circadian phase effects include:

[1] the recording of electrical activity along the scalp

1. Time of day according to the individual's own circadian phase

An individual's level of alertness and sleepiness varies over the course of the 24–hour day in a predictable circadian (approximately 24-hour) pattern with the greatest sleepiness in the early hours of the morning before dawn (typically 1AM-6AM), and a second lesser period of sleepiness in mid-afternoon (often referred to the "post-lunch dip" or the "siesta hour"). Numerous studies have shown that transportation and other accidents caused by fatigue have a peak time of risk relative to circadian phase around 1-6 AM and secondary time of risk approximately from 1-4 PM (Horne, 1995; Langlois, 1985).

It is not the clock time on the wall that determines these daily biological cycles of sleepiness and alertness. The time of day according to a person's circadian pacemaker (biological clock) is called the "circadian phase", which is shifted by exposure to light in other time zones or to a lesser extent during night duty activities. Even in people who are not travelling across time zones, an habitual early bed time and early arising time on both work days and weekends/rest days is associated with an earlier (or "advanced") circadian phase, and a pattern of maximum sleepiness and alertness that is shifted to earlier hours, as compared to someone who habitually stays up and sleeps in late, who will have a late (or "delayed") circadian phase.

2. Chronotype of the individual

Individuals vary considerably in their orientation to day and night on a morningness-eveningness scale and in their required sleep duration for recuperation (Duffy, 1999; Horne, 1976; Aesbach, 1999). Morning types tend to rise early and they feel and perform best during the morning hours. Evening types tend to rise late in the morning and they feel at their best late in the evening. It has been shown that these characteristics are genetic in nature, and independent of age, sex and ethnic heritage (Katzenberg, 1999). As discussed earlier we have used default settings representing the average person in this analysis and have not simulated individual chronotypes.

3. Length of time since awakening from last sleep episode

When a person first wakes up from sleep there is a period of grogginess or sleepiness that resolves typically in less than half an hour. This is referred to as "sleep inertia". Once a person has fully recovered from the residual sleep inertia from his or her last sleep period the drive for sleep builds with time until the next sleep period occurs. Eventually the extended time spent awake results in a strong sleep pressure. This is referred to as the homeostatic drive to sleep. However, sleep propensity, or the likelihood of falling asleep, is determined by a combination of the homeostatic drive and the other factors listed here. As a result sleep propensity does not simply relate to the length of time awake which drove the original FDT regulations. In reality, the circadian and homeostatic drives to sleep interact. This produces peaks in relative alertness in mid-morning and early evening, separated by an early afternoon "post-lunch" dip in alertness or siesta hour. This circadian-homeostatic interaction also causes the precipitous drop in alertness after midnight when an employee begins his first night duty period following several days of night-time sleep and daytime wakefulness.

4. Duration of the previous consolidated sleep period

The effectiveness of a sleep period in quenching the level of sleepiness that an individual has accumulated over the previous day(s) is determined by the sleep period's duration, as well as by the quality of sleep obtained (see factor #6 below). The average adult needs 7-8 hours of sleep per day to maintain average levels of daytime alertness. However, there are considerable inter-individual differences, with some individuals needing as much as 9 hours per day, while others only need 6 hours. Significant increases in daytime sleepiness are found for most people when the nocturnal sleep length is reduced below 5 hours, or when reduced sleep duration occurs for two or more successive nights. In the CAS analysis we have used default settings representing the average person.

5. Timing of sleep episode

In addition to the duration of sleep, the timing of the sleep episode is a key factor. Due to the influence of circadian phase, sleep is more effective and its quality better at some times of the day than at others. As noted above, it is also important to consider the time of day according to a person's biological clock, (i.e. his or her "circadian phase") not only in predicting or assessing the level of sleepiness, but also in judging the duration and quality of sleep that is obtained by sleeping at a particular time of day.

Because of the strong effect of the circadian system, sleep duration is also highly dependent on the circadian time of day. For example, there are certain times of day when it is difficult to obtain more than four hours sleep, even under ideal conditions, after extended periods of time awake, and with the most highly motivated individual.

The studies of Akerstedt and Gillberg (1986) are particularly instructive. They studied working age subjects (comparable to flight crew personnel) who were given an opportunity to sleep under ideal conditions (quiet comfortable bedroom) during rest periods which started at various times of day or night. When the rest period began at 11PM at the end of a normal day of 16 hours continuously awake, they slept on average for 8 hours, as one would expect given the unlimited sleeping opportunity. However the later the rest period began after 11PM, the shorter was the sleep duration as a result of the strong circadian time of day effect. Thus when the rest period began at 3 AM (after 20 hours continuously awake) they achieved only 6.5 hours sleep, when rest began at 7 AM (after 24 hours continuously awake) they obtained only 4.5 hours sleep; when rest began at 11 AM (after 28 hours continuously awake) they got only 4 hours sleep.

6. *Quality of sleep in the previous sleep period*

The quality of sleep at night also influences the sleepiness level on the subsequent day. When sleep is disturbed by deviations from typical sleep characteristics, this results in increased sleepiness the following day.

Many factors may influence these characteristics of sleep quality, including the time of day or night that sleep is attempted, the environmental conditions in which one is sleeping, and the existence of any clinical sleep disorders or other medical conditions.

To ensure adequate sleep, the sleeping environment should be both physically comfortable and psychologically conductive to sleep. People usually sleep better in their own bedroom than in an unfamiliar environment. One of the most important challenges many transportation employees face is the requirement to sleep away from home. In other words a transportation employee sleeping in their own bed on their regular nightly schedule and routine will have significantly higher sleep quality than the same person sleeping away from home in unfamiliar circumstances at an unusual time of day. In this analysis CAS takes into account the timing of sleep. It does not consider the effect of sleep disorders.

7. *Cumulative effect of sleep duration and quality over the past week*

A person's sleepiness level on a given day is most strongly influenced by the quality and duration of the last sleep episode. However, the sleep pattern during the preceding week will also affect sleepiness level. It is also well recognized that days-off, where there is no substantial restriction on the opportunity for unrestricted sleep, allow a person to recover fully from all accumulated sleep debt. The number of days required depends on the level of sleep deprivation, but in most circumstances two consecutive nights of sleep has been determined to be sufficient.

When a person follows a regular sleep-wake schedule, that is, going to bed and waking up at approximately the same hour every day, this helps to synchronize his or her sleep/wake and other circadian rhythms to that regular schedule.

Thus a regular daily pattern of bedtime and awake time, and a regular routine of exposure to light and dark will cause a person's circadian sleep-wake rhythm to become optimally synchronized to the time of day that they are going to bed – even if that time of day is not a typical or traditional time. This synchronization will promote optimal sleep quality and consequently minimize sleepiness at the time of the day the crew member wishes to be most alert.

3.2 Air Taxi Operational Data and Characteristics

3.2.1 Operational Data Relevant to FTL

Data were received from the EBAA and 3 States that help characterise Air Taxi operations in Europe. These data are summarised in Table 3.1 below.

The EBAA data are for Business Aviation as a whole rather than specific to Air Taxi and are drawn from the Alertness Solutions report (2011).

Table 3.1: Air Taxi Flight and Duty Characteristics

Issue	Survey Responders			
	EBAA	Poland	Spain	UK
Average duty hours per year	1188	820	717	-
Average flying (block) hours per year	339	630	285	-
Home Standby	Contactable: 98d/yr Standby: 73d/yr 25% chance of callout	70d/yr	144d/yr	-
Daily Duty Durations	9h average 20% reported that 12h+ was typical	FDP max of 11h for medium ac and 13h for long range	FDP 8h average	-
No. of sectors per duty	2.4 average	3-4 for medium ac 1-2 for long range	3 average	-
Average sector duration	-	2-5h for medium ac 2-11h for long range	3h average	-
Time zone crossings	0-3 typically, 1 flight per month crossing 4-6 TZs 13% reported TZ crossings >6 in last month	2-5 for medium ac 2-11 for long range	For 5 operators may have TZ changes of 4-6 hours	-
Frequency of split duty	53% reported split duty in last month – average of 3 split duties in that month	-	-	-
Duration of split duty	Typical length of ground break – 5.3h Mean typical total duty time – 12.9h (4 hours longer than average non-split duty) – standard deviation of 5.8h about the mean	-	-	-

Issue	Survey Responders			
	EBAA	Poland	Spain	UK
Airport standby	Very rare	Not much used.	Not much used.	Not much used.
In-flight rest	For long range flights	Yes for long range	Not much used.	Only a couple of operators have in-flight rest facilities
Consecutive nights or consecutive earlies/lates	Very rare as on-demand operations	No	-	No
Reduced rest	Rarely. It happens when Air-Taxi operations include a late positioning at the end of the day in preparation for a morning start the following day.	Yes	No	No provision in CAP 371
Travel time	Average travel time from home to home base of 1.5 hours	-	-	-
Positioning	65% of responders said that their company pre-positioned crew.	-	-	-

3.2.2 Air Taxi Characteristics

The general characteristics of Air Taxi operations in Europe of relevance to fatigue and FTL are considered to be:

- On demand operations;
- Majority at short notice;
- Large amount of standby at home with relatively low chance on average of being called out;
- Frequent change of schedule/routing; this can include duty start times being put back or brought forward;
- Many of the flights (especially on the small and light jet segments) leave in the morning and come back in the evening. In between, pilots are often waiting in crew rest facilities on split duty;
- Passenger requirements can lead to planned on-ground breaks being curtailed or alternatively ad-hoc split duties being needed;

- Air taxi pilots on average fly significantly fewer flying hours per year than scheduled airline pilots;
- Considerable use is made of positioning of crew and aircraft relative to scheduled flights;
- Generally aircraft used for Business Aviation may be considered to have higher levels of comfort (e.g. with respect to noise and pressurisation) than scheduled airliners; and
- Time zone crossings are an issue as can be seen from Table 3.1.

As well as these characteristics the EBAA survey (Alertness Solutions, 2011) found that 18% of responders held jobs in addition to Business Aviation flying. They recorded a mean of 48 hours per month conducting these other jobs.

In broad terms these characteristics can lead to peaks in workload and pressures on rest times which combined with the potentially unpredictable/ disruptive nature of the work could lead to transient fatigue. Cumulative fatigue, on average, will be less of an issue than for scheduled airline pilots, but obviously still needs to be considered in FTL rule making.

Table 3.2 identifies hazards that appear relevant to Air Taxi operations. Potential mitigations have been identified. Comments based on the information supplied by NAAs and associations about the characteristics of Air Taxi have been included where relevant. These hazards and mitigations are preliminary and will be reviewed during the future RMT .0429 process.

3.3 Single Pilot Specifics

Based on the limited amount of data received, the distinctive characteristics of single pilot operations relate to the generally shorter flights and duties. This applies to all types of operations, not just air taxi. SPLO will mainly be domestic or intra-European flights. Some single pilot air taxi operations do entail multi-day trips as far as the Middle East and hence TZ crossings can still be relevant. The other hazards identified in Table 3.2 below are also considered relevant apart from in-flight rest/ augmented crew. Mitigations and comments specific to SPLO are highlighted with bold underlined text.

Table 3.2: Preliminary Air Taxi and Single Pilot Operations Hazard Identification

Grouping	Hazards and Description	Potential Mitigations	Comments
A. Time Awake/ Duration of Duty (relating to homeostatic process principally) See Literature Review in Section 4.2.	A1. Duration of FDP too long leading to fatigue (including extensions)	a. Limits on maximum duration of FDP (including extensions) b. Modifying FDP according to number of sectors and/ or limits on daily flying time c. Not allowing reduced rest before an extended FDP d. Extended rest after a long duration FDP (after the event) e. Limiting the frequency of long extended FDPs per week or per month (cumulative fatigue control) f. FRMS (general – applicable to all hazards) g. Napping and relaxation during any ground breaks h. Ensuring that the most strict limits apply when extensions are used for mixed operations (e.g. air taxi and AEMS) i. Records to NAA of extensions and NAA oversight measures j. For **single pilot operations** specific requirements for FDP limits, maximum daily block hours, maximum single flight/ sector time and restrictions on extensions k. Relief pilot for **single pilot operations** when an extension is invoked	Long (extended) FDPs can occur in air taxi operations (see Table 3.1) and are likely to be a potential peak fatigue issue. The impact of FDP duration and WOCL encroachment have been analysed in Section 5.1.

Grouping	Hazards and Description	Potential Mitigations	Comments
	A2. PIC reacts to circumstances on the day to extend FDP excessively leading to fatigue	a. Maximum limits on PIC extension b. A non-punitive process for a PIC to reduce a FDP duration and/or increase rest in the case of fatigue c. Reporting to the NAA when the extension is above a certain threshold d. Guidance to the NAA on this subject e. Training on fatigue to support PIC in the decision process, e.g. the potential risks of PIC extensions, techniques for self-evaluation of fatigue, pressures likely to be encountered, etc. f. FRMS including awareness training for commanders	PIC discretion can be used to extend FDPs, to finish a trip or return the aircraft to base. Could potentially lead to long duration FDPs. Considered in Section 5.11.

Grouping	Hazards and Description	Potential Mitigations	Comments
	A3. Extended FDP due to in-flight rest (augmented crew) leads to fatigue	a. Maximum duration of FDP with augmented crew (including extensions) dependent on type of onboard rest facilities and number of additional crew carried b. Setting minimum standards for in-flight rest facilities c. Minimum rest period onboard required d. Setting a minimum continuous duration for in-flight rest e. Limiting Pilot Flying (PF) time in one FDP f. Specifying minimum rest durations at destination and home g. Additional compensation time at home over and above the standard rest time h. Sleep opportunities at home base after long missions (to mitigate home travel risks) i. Promote and pay for use of public transport after long missions j. Limiting the frequency of such extended FDPs with augmented crew k. Limiting the number of sectors.	See Section 5.2. **N/R for single pilot operations**.

Grouping	Hazards and Description	Potential Mitigations	Comments
	A4. On-ground break (split duty) used to extend the FDP excessively leading to fatigue	a. Establish minimum consecutive number of hours for break b. Establish how hours of the break contribute to FDP c. Placing limits on the extension time and total FDP with split duty d. Establishing limits for the duration of FDP before and after the break e. Specifying standards for the rest facilities/ accommodation during the break (including aircraft facilities if break taken on-board, e.g. noise levels, temperature, activities occurring on and around the aircraft, etc.) f. Numbers of breaks in one FDP g. Restriction on combining split duty with augmented crew rules or reduced rest h. Impact of travel time during break on FDP extension i. Time difference/ non-acclimatisation restrictions j. Frequency of extended FDPs due to split duties (e.g. in one week) k. Whether a crew member can be pilot flying after a certain FDP duration l. Take account of split duty for subsequent rest calculation m. Pre-plan breaks	See Section 5.3. For air taxi operations could have ad-hoc breaks rather than planned split duties, might be in aircraft and hence quality of rest may be reduced + could be customer pressures to reduce/ change break. This applies also for **<u>single pilots</u>** conducting ATXO, but not those conducting scheduled operations where such breaks are easier to plan.

Grouping	Hazards and Description	Potential Mitigations	Comments
	A5. Standby (generally at home for AT, but could be elsewhere) followed by FDP leads to excessive time awake Unpredictability of home standby can cause difficulties in being fully rested before FDP	a. Take account of standby time in maximum FDP b. Limit on standby duration c. Establish minimum rest after standby d. Establish different levels of readiness e. Standby management procedures so operator avoids placing crew on repeated 24 hr duration standbys, and preferential use of persons on standby who should be better rested. f. FRMS and crew's individual management of rest during standby – a FRMS can help raise crew's awareness of the importance of napping, avoiding heavy home working tasks, etc.	See Sections 5.1 and 5.8. Air Taxi (AT) pilots spend high proportion of time on standby at home. This applies also for **single pilots** conducting ATXO, but not those conducting scheduled operations. On demand nature of Air Taxi Operations (ATXO) makes rest planning difficult – could lead to lack of rest prior to an FDP (particular issue with FDP at night) Focus is on short call standby as presenting most significant potential fatigue issues. Airport Standby also considered in Section 5.8
	A6. Ground duties in addition to flight duties extend day's duties excessively.	a. Limitations on combined flight and ground duties	ATXO pilots generally called out from home standby. However, EBAA survey shows that BA pilots do have non-flight duties that can extend duty time.
B. Time of Day Effects (relating to circadian	B1. WOCL encroachment	a. Limiting maximum FDP duration based on WOCL encroachment	See Sections 5.1 and 5.4.

Grouping	Hazards and Description	Potential Mitigations	Comments
process principally) See Literature Review in Section 4.3.	B2. Circadian disruption – mixing duty transitions between early/ late/ night duties	a. Extended and recovery rest b. Limiting mixing of night and day flights	See Section 5.5.
	B3. Time Zone de-synchronisation	a. FDP restrictions and rest (home and away) based on number of time zones crossed b. Limit max FDP according to day time and degree of acclimatization c. Minimum time set before a crew would be considered time zone acclimatized d. FRMS of particular importance to take account of time zone specifics and specific route patterns of a long range ATXO operator e. Limiting number of alternating east-west rotations per month f. Providing additional rest when alternating east-west rotations happen g. Trying to schedule flights to take account of TZ desynchronisation (difficult for an on-demand service such as ATXO) h. Use of augmented crew to allow in-flight rest (**N/R for single pilot operations**)	See Section 5.6. Can get large time zone changes with Air Taxi and even long multi-sector trips for Single Pilot (SP).

Grouping	Hazards and Description	Potential Mitigations	Comments
C. Cumulative See Literature Review in Sections 4.4 and 4.8.	C1. Cumulative fatigue / sleep debt builds up Includes effect of FDPs on consecutive days/ nights (even though unlikely to extend to several days due to on-demand nature of service)	a. Limitations on consecutive days b. Limitations on weekly duty hours c. Longer term cumulative limits d. Minimum number of days off per month e. Rest periods periodically extended f. Spreading out duty as evenly as possible – difficult for on-demand AT service g. Providing additional rest if frequency of FDPs encroaching WOCL exceeds a certain limit h. Limiting the frequency of WOCL encroached FDPs – again potentially difficult for on-demand AT service i. Limit frequency of consecutive split duties	See discussions in Section 5.7. Although annual hours for AT pilots are generally significantly lower than for scheduled airline pilots, could still have cumulative fatigue building over shorter time periods.
	C2. Home/hotel standby not considered adequately in cumulative duty and rest calculations	a. Take account of home/ hotel standby time in cumulative duty and rest calculations	See Section 5.8.

Grouping	Hazards and Description	Potential Mitigations	Comments
D. Rest and Sleep Off Duty (relating to homeostatic process principally but affected by circadian process) See Literature Review in Section 4.5.	D1. Lack of rest opportunity and rest at sub-optimal periods (in relation to basic rest and reduced rest)	a. Set minimum rest period and sleep opportunity between duties b. Setting different minima for rest period at home base and out of base to cover travelling time and protect sleep opportunity c. Set minimum duration for reduced rest (if used) d. Augmentation of rest and/or reduction in max. FDP following reduced rest e. Limit frequency of reduced rest occasions f. Limiting the length and number of sectors after reduced rest g. Ensuring reduced rest encompasses entire WOCL h. Specifying minimum accommodation requirements for reduced rest i. Not allowing rest reduction when FDP is extended by in-flight rest or when there is crossing of multiple time zones j. Special rules if reduced rest is combined with split duties k. FRMS if reduced rest used	See discussions in Section 5.9.
E. Relaxation and Naps On Duty (relating to Sleep Inertia process principally) See Literature Review in Section 4.6 and 4.7.	E1. Overlong nap and insufficient time awake could lead to sleep inertia during flights	a. Awareness training about effect of length of nap on sleep inertia	Role as a mitigation and potential hazard considered in Section 5.10 **In-flight rest N/R to SPLO**

Grouping	Hazards and Description	Potential Mitigations	Comments
F. Positioning and Travelling (related to time awake and cumulative effects and homeostatic process principally) See Literature Review in Section 4.9.	F1. Positioning before an FDP causing lack of rest and excessive time awake and hence fatigue	a. Inclusion of positioning immediately before flight duty in the FDP	See Section 5.12. ATXO involves more positioning than scheduled – see Table 3.1.
	F2. Positioning immediately after an FDP leading to excessively long duty periods with potentially a cumulative effect	a. Post-FDP positioning should be limited to prevent excessive duty day b. FDP and post-FDP positioning to be taken into account for subsequent rest period	See Section 5.12. ATXO involves more positioning than scheduled – see Table 3.1.
	F3. Excessive travelling time	a. Nomination of a home base for each crew member b. Ensuring a protected 8 hour sleep opportunity c. Counting travel time in excess of a limit (e.g. 60 minutes) as duty time (or positioning) d. Napping during ground breaks to reduce fatigue at the end of long days created by long duration FDPs and travel	See Section 5.12.

4.0 Fatigue Literature Review

4.1 Overview

This section reviews the peer-reviewed research literature in fatigue with an emphasis on aviation and on single pilot and air taxi operations where relevant studies are available. The literature search did not identify many peer-reviewed studies on fatigue risk specifically in single-pilot operations excluding single-pilot EMS operations (already covered in D2). However, single-pilot operations face many of the same physiological and operational contributors to pilot fatigue as other sectors of aviation. The main contributors to pilot fatigue and their interactions are discussed in the following sections.

4.1.1 Air-Taxi Operations

The characteristics of air taxi operations set out in Section 3.2 can present fatigue management challenges. Similar to commercial airline pilots, and the general shiftwork population, air taxi pilots suffer from fatigue due to operational factors. A survey of European business aviation pilots on behalf of EBAA (Alertness Solutions, 2011) found that 30% of responding pilots experienced fatigue on a weekly basis and 46% on a monthly basis in flight operations. Almost half admitted to nodding off in the cockpit. While these pilots are generally successful at mitigating the effects of fatigue by using naps, caffeine, and other countermeasures, over two thirds stated that they had received no formal training on how to manage fatigue. Another survey of corporate/ business pilots found that 71% of pilots admitted to nodding off in the cockpit during a flight (Rosekind et al., 2000).

In the United States, most research on air taxi operations has been done in Alaska. Alaska is a unique environment with a less developed road infrastructure, rough terrain, unpredictable weather, and a busy summer tourism season that requires a considerable number of air taxis to connect the state. Surveys of Alaskan pilots show that fatigue is an issue – 22% of pilots working for large air taxi operators and 13% of pilots working for small air taxi operators admit to wanting to refuse to fly because of fatigue at least monthly (Conway, 2006).

In Europe, a survey of charter pilots for passenger operations and cargo operations (similar in scope in some ways to air taxi operations) found that sleep quantity, quality, and alertness was affected by scheduling practices including early starts, night duties, and shortened rest periods, etc. (Spencer and Montgomery, 1997).

4.1.2 Single-Pilot Operations

Single-pilot operations are generally considered to be more challenging than multi-pilot operations. Single-pilots often operate under high workload conditions, since the pilot assumes multiple roles, e.g. navigator, radio operator, systems manager, meteorologist, record keeper, etc. (AOPA Safety Advisor, 2006). A single-pilot must multi-task and has no-one to assist him/ her under conditions of unexpected weather, high-density traffic, or other circumstances that can quickly cause them to become overwhelmed. Some of the problems that pilots face that are made more challenging in single-pilot operations include following and completing all pre-flight and in-flight checklist items, dealing with multiple tasks that may lead to distraction and/or increased time pressure (which increases accident risk), missing small pieces of knowledge that may be useful in a given circumstance, monitoring errors, making and catching errors of omission, and missing automatic situational alerts from the flightdeck (Deutsch and Pew, 2005).

These challenges have the potential for increasing workload and hence fatigue and also can make single pilots more vulnerable to fatigue. While there are data looking at general single pilot safety levels, there is a lack of data considering the relative fatigue related accident rates between single and dual pilot operations. For example in a study investigating 25 years of IFR accident data, the single-pilot crash rate was only slightly higher than the dual-pilot crash rate (7.27 vs. 6.48 crashes per 100,000 takeoffs), however, the crash rate for single-pilots during more challenging night-time flying was over 8 times higher (Bennett and Schwirke, 1992). However, no direct link to fatigue was made in that study.

4.2 Duration of Duties and Time Awake

4.2.1 Overview

The relationship between duty length and fatigue is complex, and cannot be reduced to a simple formula, as it is complicated by circadian phase, time awake since last sleep, chronotype and the other factors discussed in Section 3.1.

The length of duty directly impacts the accumulation of fatigue whilst on duty since it goes along with "time awake" which is directly related to fatigue. This "time awake" also explains that the length of duty has to be looked at in conjunction with "time of day" since for night duties sleep often ends hours before the duty start, whereas for day duty pilots usually start with "freshly charged batteries" in terms of recent sleep. The length of duty also determines at what time of day the opportunity for rest and sleep occurs. This is important since sleep outside the window of circadian low (WOCL) is usually of lower quality and less beneficial.

When evaluating duty or shift duration, it should be noted that longer duty periods not only affect consecutive hours on duty, but also may reduce the amount of time off between duties, and impact sleep duration and recovery.

There are a series of factors that should be taken into account when analysing duty period duration in aviation operations, including the influence of length and number of sectors (section 4.2.4), time of day effects (section 4.3), and augmented crews and the possibility of in-flight rest (section 4.7). Although air taxi and single pilot operations are not typically based around shift schedules, their pilots can work long duty periods, and are subject to the same types of risk with increasing duty/FDP length as shiftworkers in other industries. Thus, a general discussion of relevant shiftwork research is provided, along with a review of duty/FDP lengths in aviation.

4.2.2 Shift Duration Literature Across All 24/7 Industries

The main issue with shift duration is whether fatigue risk (and the associated risk of incidents and injuries) increases with increased shift length. A review of the scientific literature shows that most studies found increased fatigue with longer duty periods, and a number of studies have shown an increased risk of accidents at the end of the shift. However, the increase is not linear, and usage of breaks within a shift has been shown to be effective in decreasing accident risk during that shift as described below in section 4.2.2.2. Moreover, other studies have found that there is also increased risk at the beginning of the shift, and within 2-4 hours of the start of a shift.

4.2.2.1 8-Hour versus 12-Hour Shift Comparisons

Most of the scientific literature on shift duration is focused on the comparison between 8-h and 12-h shifts, since these shift lengths are the most common in shiftwork environments. While in some studies shifts up to 12 hours have been shown not to affect performance negatively (Smith et al. 1998), most studies have found an increased level of fatigue and sleepiness, especially during the final few hours of the shift (Rosa and Bonnet 1993; Rosa 1995; Fischer et al. 2000; Son et al. 2008).

However, there is agreement that in most circumstances, shift durations up to 12 hours do not represent a significant risk increase, compared to 8-h shifts provided the total hours worked per week is the same. This is because the completion of weekly work hours in a fewer number of days means that there are more off-duty days per week on 12 hour shifts, and this allows more time to recover from any accumulated sleep debt as compared to the fewer number of days off-duty on 8 hour shifts.

4.2.2.2 Accident Risk and Shift Length

Some scientific studies have indicated that there is an increased risk of industrial incidents in the 9th to 12th consecutive hour of work (Spencer et al., 2006). However, other studies have found that the relative frequency of incidents does not increase linearly from the first to the last hour of the shift. Furthermore, often there is an increased risk not only at the end of the shift, but also during the first or second hour (Hanowski et al., 2009; Folkard, 1997) until the operator becomes focused. A review of shiftwork studies analysing the relative incident risk over time on duty found a slight increase from the second to the 5th hour, a decrease in the 6th hour and then risk increased in an approximately linear fashion with time on duty, and in the 12th hour was more than double than during the first eight hours (Folkard and Tucker, 2003). The authors suggested that a more comprehensive evaluation of the risk associated with time on duty should take into account the effect of breaks. Their study analysed the effects of breaks on injuries in an industrial setting and found that breaks reduced accident risk, and that risk increased substantially and almost linearly between successive breaks, both during day and night shifts. The authors concluded that different factors need to be considered in combination when evaluating risk associated with night work, and for example, a 12-h night shift that included frequent rest breaks might be safer than an 8-h shift with only a single, mid-shift break (Folkard and Tucker, 2003).

4.2.2.3 Shifts Exceeding 12 hours

Schedules with shifts longer than 12 hours are less common across a range of industries (except in the trucking industry, where drivers are allowed to be on duty up to 14 hours per day, and a 10-hour rest before the following shift is enforced) and generally not recommended on a regular basis.

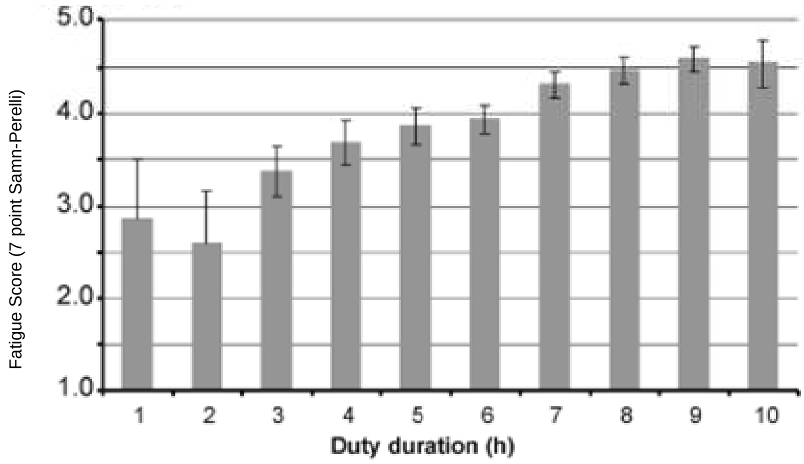
The safety of 14 consecutive hours on duty in a safety-critical position was endorsed by the Federal Motor Carrier Safety Administration (FMCSA) in the trucking Hours of Service regulations (Department of Transportation Report 2003). After much research (US Federal Register, 2005) and consultation, these U.S. trucking industry regulations introduced in 2004 allow drivers to be on duty a maximum of 14 consecutive hours per day. However it should be noted that these regulations also enforce a minimum of 10 hours rest after each 14-hour duty period. This is also the pattern for FTL in the US for CAT operations.

Shifts of 16 hours or longer are unusual, except in emergency situations. For instance, the U.S. Nuclear Regulatory Commission (2001) sets the limit at 16 h in a 24-h period, provided that this is an occasional event. The international FRMS standard for the oil industry (American Petroleum Institute, 2010) states that extended shifts (greater than 14 hours) shall occur only to avoid unplanned unmanned safety critical positions or accomplish unplanned safety critical tasks. It also states that in the case of 14-16 hour shifts, a minimum of 8 hours off before the next shift is required, and for shifts greater than 16 hours, a minimum of 10 hours off before the next shift. It also requires that extended shifts shall in no case exceed 18 hours and that that there should be not more than 1 extended shift longer than 14 hours per work set. Some studies have found that 16-hour shifts may be worked without significantly increasing fatigue, provided that adequate countermeasures are taken during and after the shift, such as allowing a nap during the shift and scheduling at least one day off after the shift (Takahashi et al., 1999).

4.2.3 Review of Aviation Scientific Literature: Duration of FDP in Non-Augmented Crews

Many studies in the aviation industry (e.g. Samel et al (1997a), Spencer and Robertson (1999), Goode (2003)) have found that extended duty periods in non-augmented operations are associated with elevated fatigue levels and increased accident risk at the end of the duty period. Powell et al. (2007) found that fatigue levels in short-haul pilots (flying as a 2-pilot crew) increase with duty lengths up to 10 hours (Figure 4.1). Fatigue was self-reported using the Samn-Perelli scale of sleepiness (with 1 being the lowest, and 7 being the highest).

Figure 4.1: Fatigue increases with duty duration in short-haul pilots. Reference: Powell et al., 2007

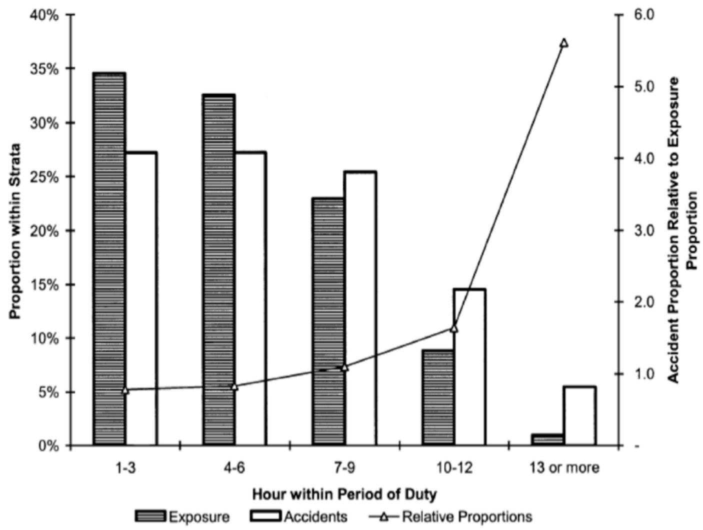


The risk of aviation accidents increases with time of duty. A large U.S. study analysed human factors related accident data over a period of 21 years for which a 72-hour history of pilot activities prior to the accident was available. The distribution of these pilot work schedules was compared to a large reference sample of all pilot work patterns. The data showed that for duties of 10-12 hours the relative risk of an accident was 1.7 times higher than for all duties, and for duties of 13 hours or more, the relative risk was over 5.5 times higher (see Figure 4.2). In addition, while 20% of human factors accidents occurred to pilots who had been on duty for 10 hours or more, only 10% of pilot duty hours occurred during that time (Goode, 2003). As noted in Section 4.1.1 the relationship between duty length and fatigue risk is complex; in particular in the context of the Goode 2003 paper the rest requirements under Part 121 will have influenced the fatigue risk as well as the duty lengths and hence the relationships derived in this paper need to be treated with caution when the rest requirements are significantly different from those applicable to this study.

NTSB investigations have found that long duty days (over 13 hours) are associated with a disproportionate amount of accidents, compared to duty periods of less than 13 hours. The longer the crews are awake, the more errors they commit, especially cognitive errors such as decision making (NTSB, 1994).

Accident rate may also be linked to FDP length in air taxi operations. A survey of 153 air taxi operators in Alaska categorized the operators by high or low fatal accident rate to determine what factors contributed to a high fatality risk. The authors found that in addition to other factors (age, experience, willingness to fly into unknown weather conditions), pilots for high risk operators were flying more hours per day (approximately 13), and working more hours per week (approximately 81) than low risk operators – more than 1 hour per day and 10 hours per week extra (Conway, 2006).

Figure 4.2: **The risk of having an accident increase with duty on time. Reference: Goode, 2003**



There is some agreement that FDP limits should be 12-14 hours, with recommendations for specific situations. An early study (Dinges et al., 1996) recommends that an extended cumulative flight duty period should be limited to 12 hours within 24 hours (in the context of a 10-hour max FDP recommendation) and that it should be accompanied by additional restrictions and compensatory off-duty period. The Paper for the European Transport Safety Council (ETSC) states that there is no objection to an FDP of 12 hours during the day, but does not support FDPs as long as 14 hours for early starts (Akerstedt, 2003). The Moebus Aviation report (Moebus, 2008) recommends based on the Goode, 2003 paper that a single maximum daily FDP should never exceed 13 hours (and then only under specific favourable conditions) and that extension provisions above this should be excluded. However, in the report there is no account taken of the increased rest period required by Subpart Q in case of an extension of 1 hour to an FDP (2 hours before + 2 after or 4 hours after the extended FDP) and the generally more robust rest requirements and limitations for cumulative duty.

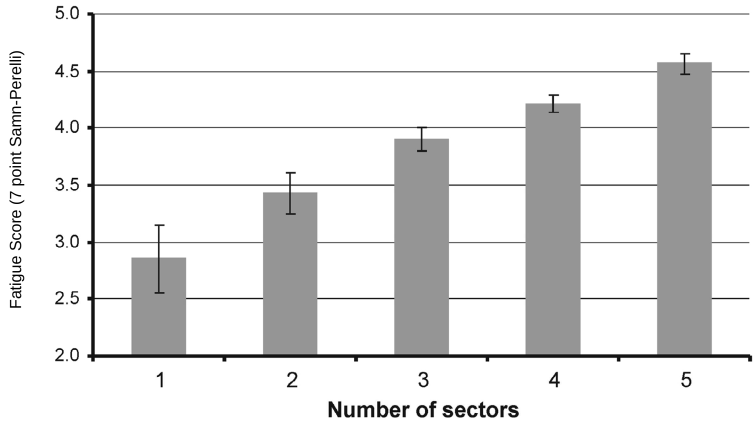
4.2.4 Influence of Number of Sectors

There is consensus that multi-segment flights are a major contributor to fatigue. However, there is still controversy on when fatigue countermeasures, such a reduction of maximum FDP, should be implemented and what should be the magnitude of the reduction.

A number of studies have shown that fatigue increases with the number of sectors (Powell et al., 2007; Spencer and Robertson, 2000; Bourgeois-Bougrine et al., 2003). Prolonged duty periods (multi-segments flights over a sequence of 4 to 5 days) was cited as a major contributor to fatigue by 53% of short-haul pilots completing a questionnaire assessing perceived causes of fatigue (Bourgeois-Bougrine et al., 2003). In a study that evaluated fatigue in two-pilot short-haul operations with no overnight duties, pilots were asked to complete a questionnaire and validated fatigue and sleepiness scales at top of descent on the last sector of the duty. The most important factors affecting fatigue were length of duty and number of sectors, which increased fatigue in a linear fashion (Powell et al., 2007).

Air taxi pilots for European business aviation operations report that they fly an average of 2.4 sectors (see Table 3.1). Interpolating from results from the Powell 2007 study, the pilots would experience the equivalent of a fatigue score of 3.5-4 on the Samn-Perelli scale of sleepiness at the top of the descent period (Powell et al., 2007) (see Figure 4.3).

Figure 4.3: Fatigue increases linearly with the number of flight sectors flown at the top of descent in short-haul pilots. Reference: Powell et al., 2007.



The need to decrease the FDP if there are a significant number of sectors is confirmed by many scientific studies. The Subpart Q requirement on maximum allowable FDP is based on a 30-minute reduction after the second sector.

However, the scientific literature does not give a uniform answer to the question of at which sector number should the reduction begin. For example, while Spencer and Robertson (2000) find no difference with respect to fatigue between one and two sectors, Powell (2008) states that fatigue increases from the second sector.

There is no agreement on how large should be the reduction. While some studies have recommended a reduction of 45 minutes per sector (Spencer and Robertson, 2002), other studies recommend shorter reductions.

4.3 Time of Day Effects, Early Starts and Night Duty

4.3.1 Overnight Flights and Night Duty

There is extensive data on the increased risks associated with night duty shifts across multiple industries. For example, the relative incident risk across different shifts increased in an approximately linear fashion. Compared to the morning shift, the increased risk was 18.3% for the afternoon shift and 30.5% on the night shift (Folkard and Tucker, 2003).

There is consensus that overnight flights and night duty are especially vulnerable to severe fatigue, since flying time occurs during the WOCL, the circadian phase with lowest alertness and performance. In addition, these effects are compounded by the sleep deprivation associated with working during the night and sleeping during the day. The detrimental effects of sleep deprivation, time since sleep, and the WOCL can lead to severe fatigue with increasing time on task. Furthermore, fatigue during homebound flights is often exacerbated in un-acclimatised crews, who had a sleep shorter and of poorer quality during layovers than at home.

EUROCONTROL data (shown in Section 5) shows fewer night departures for business aviation than other aviation sectors. However, flying during the night hours does occur for air taxi and single pilot operations and so is considered below.

4.3.1.1 Increased Fatigue and Accident Risk During Night Duty

Field studies of single-sector two-crew operations have shown that some crews were having difficulty remaining awake during overnight duties of 11 hours or more (Samel et al., 1997b; Spencer & Robertson, 1999). A survey of long-haul pilots found that 59% of pilots reported night flights as a major contributor to fatigue, especially schedules involving overnight outbound and inbound flights with daytime layovers (Bourgeois-Bougrine et al., 2003). Another study assessing pilots' fatigue using a validated scale found that fatigue ratings were greater on long-haul versus short-haul flights (except where mitigated by adding an extra pilot) and on overnight versus daytime sectors on long-haul flights (Powell et al., 2011). Based on a review of scientific studies, the Moebus Aviation report (Moebus, 2008) notes that during night hours fatigue increases and vigilance decreases more markedly with ongoing duty hours than during the day.

4.3.1.2 Night Operations and Pilot Error

The negative impact of night duties was clearly demonstrated in a study analysing the hours of the day when pilots working in a commercial airline made the most errors (de Mello et al., 2008). Errors were analysed using data from flight operation quality assurance systems, including the following errors: operational deviations and/or errors, procedural errors and maintenance faults and mistakes in procedures. The data showed that the risk of pilot errors increased by almost 50% in the period from 0000 to 0559, relative to the morning period 0600-1159.

Night approaches were found to increase the risk of single-pilot instrument flight rule (IFR) crashes in three separate studies (Forsyth, 1978; Mortimer, 1995; Bennett and Schwirke, 1992). Bennett and Schwirke found that the single-pilot IFR crash rate was 8 times higher during the night than during the day under IFR conditions (35.4 vs. 4.5 crashes per 100,000 takeoffs).

Based on scientific data, some experts have suggested that FDP limits could be different for daytime and night-time duties, with longer duty period during daytime than during overnight duties, depending on the start time and the amount of sleep obtained and acclimatization to local time (Samel et al., 1997b, Spencer and Robertson, 2007). An early study (Dinges et al., 1996) recommended that there be no extended flight duty period that encroached on any portion of the WOCL. Spencer and Robertson (1999) strongly supported that non-augmented duty overnight should not exceed 10 hours, and suggested that 12 hours is acceptable for 2-crew operations during daytime. A 13 hour FDP was also identified in this reference as feasible if it occurred at a favourable circadian time. In an attachment to CRD 2010-14 (Spencer, 2011) Spencer states that a one-hour extension from 13 to 14 hours for morning departures after 08:00 would be supported by fatigue data collected during The Haj operation.

4.3.1.3 Factors Contributing to Increased Fatigue During Night Duties

Longer periods of wakefulness before duty: One of the factors contributing to increased fatigue in overnight flights is an increased period of wakefulness before duty, especially if crews are not able to take an afternoon nap, or if they are on standby and are called out to fly, as is often the case with air taxi pilots. A study of a simulated ULR flight found that pilots who had been awake for 13.5 hours before departing for nighttime flights had significantly slower reaction times compared to pilots who departed during the morning hours after about 3.5 hours of wakefulness. Pilots in the overnight flights were especially impaired during the first half of the flight, due both to sleep and circadian factors that promote sleep. However, towards the end of the flight, with increased hours of continued wakefulness, performance decrements were seen in both morning and night departure groups (Caldwell et al., 2006).

Consecutive night duties: The risk associated with overnight flights may increase with recurrent night duties because studies show that shift workers seldom obtain the same amount of sleep during the day they would normally obtain when sleeping at night (Folkard et al., 2005). Consecutive night duties are rare for air taxi pilots, with the exception of cargo pilots.

Duration of duty period and number of segments: A study evaluating fatigue in two-pilot operations flying 1-2 sectors duties that ranged from 3 to 12 hours total duty time asked pilots to complete a questionnaire and validated fatigue and sleepiness scales at top of descent on the last sector of the duty. The strongest influence on fatigue was time of day, with the highest levels during the WOCL (0200-0600). Fatigue also increased with length of duty and number of sectors. Moreover, the study found that time of day also affected level of fatigue at start of duty and the rate at which fatigue levels increased. For example, fatigue level after 12 hours for duties starting between 0600 and 1200 was already exceeded after 3 hour on duty for duties starting between 0000 and 0300 (Powell et al., 2008).

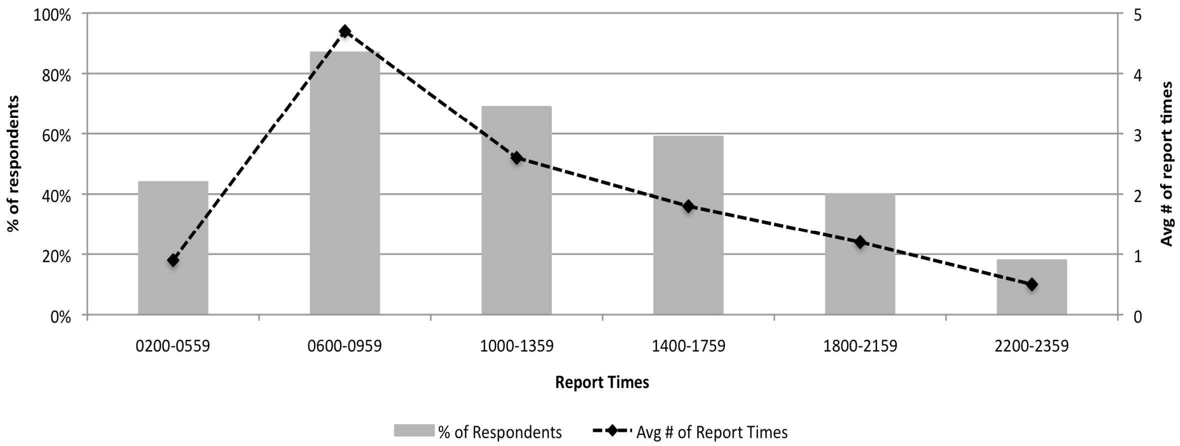
Thus the scientific literature strongly supports the need for reducing the maximum FDP for WOCL encroachment. This supports the approach taken in Subpart Q and in the CRD 2010-14.

4.3.2 Early Start Flights

Time of day effects due to early start flights present a challenge, since they usually result in shorter sleep before the flight, mainly due to the fact that pilots do not advance bedtime to compensate for the early wake up time. There is agreement that early starts are associated with sleep deficit and increased fatigue, especially in the case of consecutive early starts.

Early starts are common for air taxi pilots. The most common report for duty time for European business aviation pilots is the window between 0600-0959 (80% of respondents), and 40% of pilots report arriving for duty between 0200 and 0559 at least once a month (Alertness Solutions, 2011; Figure 4.4).

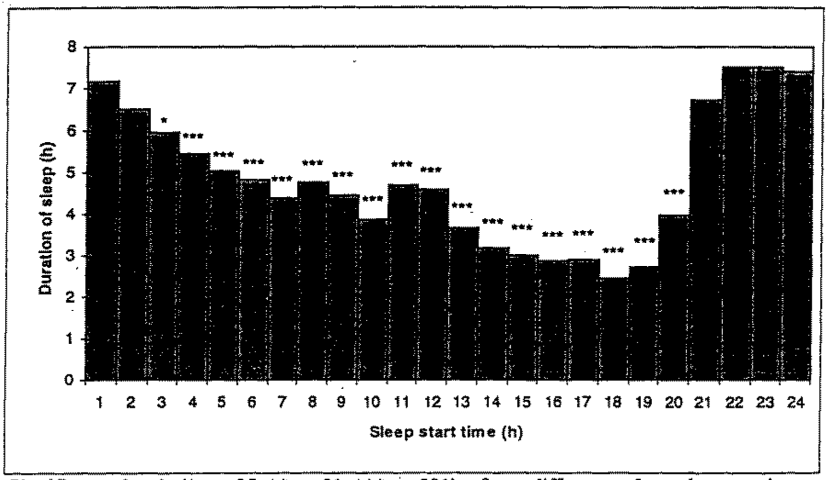
Figure 4.4: Duty report times for European business aviation pilots during the last month. Reference: Alertness Solutions, 2011.



With shift start times before 0600, achieving the required seven to eight hours of sleep can be difficult for most people, and these shifts have great potential to contribute to pilots' sleep deprivation (Kecklund & Akerstedt, 1995). This results in increased fatigue and consequently increases the risk of errors and accidents during the morning shift. One reason for reduced sleep before an early morning shift is that, irrespective of what time the shift starts, many people go to bed at their usual bedtime (Moores, 1990). However, the main reason is that it is difficult to fall asleep in the early evening. Lavie (1986) described a “sleep forbidden zone,” during the evening, related to the circadian rhythm of alertness, which makes it very difficult to fall asleep at that time.

The effect of early start times on sleep and alertness in short-haul pilots has been confirmed by several studies. For example, a survey found that for short-haul pilots, successive early wake-ups was cited as a major contributor to fatigue by 41% of pilots (Bourgeois-Bougrine et al., 2003). Spencer and Montgomery (1997) found that time of day was the most important factor affecting sleep duration (see Figure 4.5) and quality. The mean duration of sleep episodes starting between 2100 and 0100 was greater than 7 hours. As start of sleep was progressively delayed, its duration decreased to 2.5 hours with starts between 1700 and 1800. When a duty period started before 0900 the duration of the preceding sleep period was reduced. The sleep loss amounted to approximately 30 minutes for every hour that the duty period advanced between 0900 and 0500. Subjective sleep quality was also reduced for duty periods starting before 0700. During schedules involving consecutive early starts, the sleep deficit accumulated and alertness tended to deteriorate (Spencer and Montgomery, 1997).

Figure 4.5: **Relationship between sleep duration and sleep start time. Reference: Spencer and Montgomery, 1997**



Significance levels (* p< .05, ** p<.01, *** p<.001) refer to differences from sleep starting between 22:00 and 01:00.

Another study conducted on 476 British Midland Pilots based at London Heathrow and East Midlands airport showed that the duration of sleep prior to an early start was reduced by almost one hour for report times between 0700 and almost two hours for report times between 0500 and 0600. The subsequent sleep deficit had a clear effect on fatigue. Duties starting before 0900 were associated with increased fatigue throughout the following duty period, and that fatigue also increased during schedules that included several consecutive duties starting at 08:00 or earlier (Spencer and Robertson, 2002). A recent study on 70 short-haul pilots from Australian researchers found that the lowest amount of sleep was obtained prior to duty periods starting between 0400 and 0500 (5.4 hours), and the greatest for duty periods starting between 0900 and 1000 (6.6 hours). The data indicate that approximately 15 minutes of sleep are lost for every hour that the start of duty is advanced prior to 0900. Moreover, self-rated fatigue at the start of duty was highest for duty periods starting between 0400 and 0500 and lowest for duty periods starting between 0900 and 1000 (Roach et al., 2012).

4.3.3 Day-Night Duty Transitions

Another important factor is the number of day-night transitions, that is, from sleeping at night and being active during daytime to sleeping during the day and being active at night.

The underlying issue is that physiological rhythms do not shift immediately when transitioning from day to night shift and vice versa. Research studies have shown that circadian rhythms can shift approximately one hour per day when working night shifts, but coming back to the daytime routine the adjustment is faster, about two hours per day. During the transition, there is a misalignment of the circadian rhythms, which translate into malaise and increased fatigue. Earlier studies found that the change from night to day shift may cause as much discomfort as a change in the other direction (Akerstedt et al 1977). Recent studies have confirmed these results. For example, a study conducted on off-shore oil rigs evaluated adaptation and re-adaptation to night shifts and day shifts, and found that the return to day shift led to an increase in sleepiness and worsening of sleep, but they improved gradually during the week (Bjorvant et al. 2006).

Several research studies have studied the transition from day to night shift without rest days in between and found that in these circumstances, the first night shift is the most difficult shift in a sequence of consecutive shift. The studies showed that the impairment in the ability to sustain focus, decrease in subjective alertness and decrease in visual search sensitivity were more pronounced during the first night shift than in subsequent shifts (Santhi et al 2007). Thus, increasing the number of transitions may result in increased frequency of problems.

4.3.4 Time Zone Crossings and Circadian Desynchronization

An additional source of fatigue for air taxi pilots, particularly those who fly long-haul routes is circadian desynchronization caused by rapid travel between multiple time zones, or “jetlag”. Long-haul pilots cite flying night duties (59%) and jetlag (45%) as the two major contributors to fatigue (Bourgeois-Bougrine, 2003). For these pilots, a single return flight can be as tiring as a series of consecutive short-haul flight duties. The Moebus Report (2008) considers a significant time zone crossing as one that covers more than 2 time zones within a single FDP. European business pilots report that most flights cross 0-3 time zones, with about 1 flight per month crossing 4-6 time zones (Table 3.1).

4.3.4.1 Eastbound vs. Westbound Flights

The general consensus is that Eastbound flights are more fatiguing for pilots than Westbound flights. This reflects the natural state of the circadian clock, which runs slightly longer than 24hrs. Flying East shortens the day by several hours, whereas flying West lengthens it, making it easier to fall asleep later than earlier for most people.

51% of European business aviation pilots report that fatigue is more of an issue on Eastbound flights, compared to Westbound (8%) (Alertness Solutions, 2011).

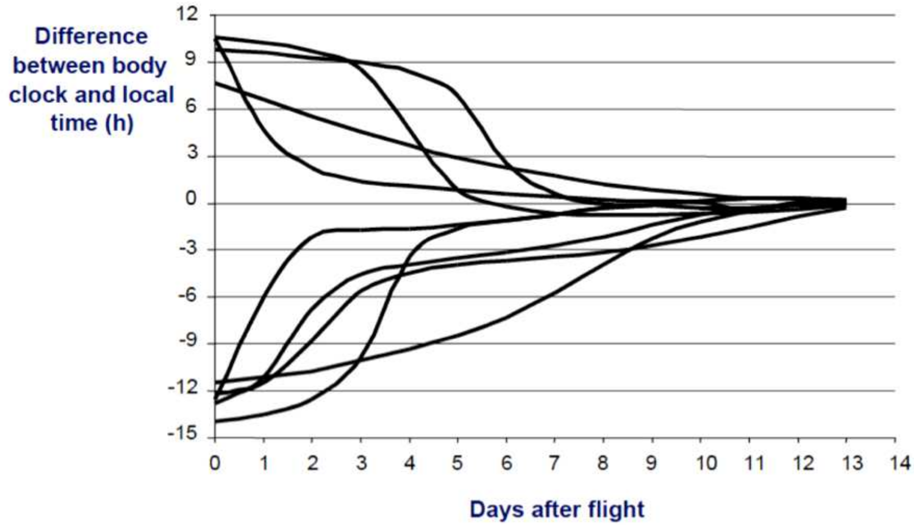
Another survey of long-haul pilots flying 3 day round trips between the UK and the East Coast of the United States found similar results – pilots found it difficult to fly East with a short layover, citing that early departures truncated sleep and made the inbound flight more fatiguing (Spencer and Montgomery, 1995). Similarly, pilots flying from Australia to Los Angeles and back found eastbound flights more fatiguing. A short layover (<40h) with truncated sleep was unable to dissipate the effects of fatigue from the eastbound flight. As a result, pilots slept more on the return flight, and performance on a vigilance task was impaired (Lamond, 2006).

4.3.4.2 Recovery from Circadian Desynchronization

Pilots who cross multiple time zones in a single trip can take several days to recover after returning. Some pilots find that while more fatiguing, trips with 5 or more time zone transitions with shorter layovers only take approximately 3 days to recover from, since the pilots' circadian clock does not have a chance to adjust from local time to the new time zone (Spencer and Montgomery, 1995). For example, charter flights from the UK to either the Caribbean or the East coast of the United States that encompassed fewer than 3 layover nights took pilots 3 days to return to baseline levels of alertness (Spencer and Montgomery, 1997).

Longer trips, such as the 5-7 day "Polar Route" between London and Tokyo, with a 24hr layover in Anchorage Alaska, can dramatically alter the circadian clock. In one study, pilots were pre-positioned in Tokyo for 1-3 days, but were unable to sleep well – only 28% of all sleep periods were between 6-9hr long. After flying the polar route and returning to London, measurements of the circadian body temperature rhythm showed that circadian phase was altered in many of the pilots. In some pilots, it took five days for the circadian clock to realign with local time (Stone, 1993; Spencer, 1991). Many similar experiments have been done to assess the length of recovery after long international trips. For instance, one group of pilots based in London were pre-positioned in Hong Kong (7hr time zone transition) for 9 days before returning to London. Circadian temperature rhythms revealed that some pilots took 7 days for their clock to realign with London local time (Rogers, 1996). A similar experiment with a 10hr time zone transition (London to Sydney Australia) found that pilots' body clocks were not in synch with local time (Figure 4.6) and took between 3-8 days to recover. In this experiment they also showed that after returning to London, sleep duration and quality was reduced and performance was reduced for up to 6 days after the return flight to London (Spencer 1995).

Figure 4.6: Difference between circadian phase of body temperature rhythm and local time, and time of recovery after a 10hr Eastward transition. Reference: Spencer et al, 1995



The Moebus Report (2008) includes specific recommendations for rest periods following trips with significant time zone crossings (>2 within an FDP). It recommends that the minimum rest period during a layover should be 14hrs. If the return flight overlaps the WOCL, pilots should receive two nights free of duty. The range of time off should also vary depending on how long the layover is. The report recommends that pilots should receive rest with 1 local night if the layover is <36hrs, and the number of time zone transitions is 5 or less. The amount of rest increases with increasing layover length and time zone transitions to a maximum of rest with 6 local nights to allow adjustment/recovery after a layover of >132hrs and an 8-12hr time zone difference.

4.4 Cumulative Effects of Multiple Consecutive Duties

4.4.1 Overview

There is contradictory data on the effects of consecutive duty shifts on fatigue and performance. The results of the studies are not conclusive: while some studies found increased accident risk over consecutive nights, other studies found lower risk and improved performance over the first few days, and some did not find any significant changes across consecutive nights. There are multiple factors that explain the divergent results including the amount of sleep individuals obtain between shifts, the time on task (length of shift), and the time of day of the shift.

With some exceptions (e.g. pilots during a busy spring/summer tourist season) air taxi pilots are less likely to work multiple consecutive FDPs than commercial airline pilots. However, the effects of consecutive FDPs on fatigue will be discussed here, since the fatigue risks can become significant under some circumstances.

4.4.2 Review of Cumulative Fatigue Across All Industries

The effects of consecutive day and night shifts on fatigue involve different sets of factors and are therefore considered separately.

Day shifts: An early study (DERACHS, 1999) showed a gradual increase in subjective fatigue that occurs over seven consecutive work days. The increase in fatigue was much more pronounced with an early starting time (6 am) than with a late start (9am) (75% increase compared to 40% increase). Workers reported that they needed 1 day off to recover from working 3 consecutive shifts with an early start, and 2 days off to recover from 5 consecutive early shifts. However, other studies suggested that risk is not substantially greater with up to seven consecutive 12-h day shifts (Persson et al. 2003, 2006a&b). The results from these studies suggest that for day shift, an early shift start has more impact on fatigue than time on duty. In addition, early starts, which are likely to be associated with greater sleep deprivation, require longer rest periods (days off between blocks of shifts) to recover from the cumulative fatigue.

Night shift: A more significant concern relates to the number of consecutive night shifts, since they are usually associated with higher levels of fatigue than day shifts (Akerstedt, 1995). Working too many consecutive night shifts can cause an accumulation of sleep deficit, which can cause both health and safety issues (Knauth, 1997). This accumulation of sleep debt over consecutive periods of shortened day time sleep is counterbalanced by the adaptation of the sleep/wake cycle after working several consecutive night shifts. The adjustment of the circadian physiological rhythms to night work among individuals working consecutive night shifts is seldom complete, and permanent night shift systems are unlikely to result in sufficient adjustment in most individuals to benefit health and safety (Folkard, 2008).

This counterbalance between accumulated sleep debt and partial circadian adaptation either results in an increased risk over successive night shifts if sleep is not well managed, or decreases risk if good sleep management practices are followed. As a result the literature contains data which reaches apparently contradictory sets of conclusions. To avoid the cumulative effects of sleep deprivation the best practice is to train the employees on optimal sleeping strategies and provide opportunities for sleep (appropriate time and facilities for sleep). In this way the accumulated effects on performance can be minimised.

1. Studies showing increased risk over successive nights. A series of studies have found increased risk over consecutive night shifts. A review of seven studies (mainly of 8-h shifts) found an increased risk from the first to the fourth night. One study found a continuous deterioration of performance during five consecutive night shifts (Tilley et al., 1982). Another study showed that overall, there was a gradual increase in fatigue over 5-6 nights (DERACHS, 1999). A review of shiftwork studies analysing the relative incident risk over successive shifts found that, compared to the first night shift, on average, risk was 6% higher on the second night, 17% higher on the 3rd night and 36% higher on the 4th night. Studies evaluating the risk on day/morning shift also found an increased risk over consecutive shifts, but the increase was substantially smaller than over night shifts (Folkard and Tucker, 2003).

A meta-analysis of several studies of operations without an FRMS indicated that accident and injury risk can increase over consecutive night shifts (Folkard & Lombardi, 2006).

2. Studies showing decreased risk over successive nights. However, under optimal sleep conditions, the sleep debt that accumulates during consecutive night shifts is relatively small and does not exacerbate decrements in night-time performance resulting from other time-of-day factors. Based on laboratory studies, as well as field studies, it has been reported that for employees with diurnal patterns (active during daytime, sleeping at night), the first night shift after days off is the most difficult (Santhi et al., 2007; Lamond et al., 2004; Baker, 1995), and that alertness and performance is increased on subsequent nights. One study, evaluating four consecutive 11-h shifts, found three different patterns of fatigue on consecutive night shifts, reflecting the loads of the reticular activating system, musculoskeletal, and central nervous system respectively. While the musculoskeletal fatigue increased over consecutive night shifts, the other two patterns showed significant improvement over consecutive night shifts (Kubo et al., 2008). When sleep loss is minimised, employees' performance adapts as their circadian rhythms adapt (Lamond et al., 2003). One study found that performance in the night shift increased from the first to the third night shift, probably reflecting an adjustment of circadian rhythms. However, there was a decrease of productivity toward the 5th shift, which is most likely due to an accumulation of sleep deficit. A different study found an increase on production quality from the first to the 5th night shift, while another found an increase in human error from the first to the 6th night shift, and a lower error rate on the 7th shift (Knauth, 1995). Other studies (Vinogradova et al. 1975, Wagner 1988) analysing longer spans of consecutive night shifts reported a decrease in risk from the 4th to the 5th night, which was maintained until the 7th and final night shift.

4.4.3 Review of Aviation Literature on Cumulative Fatigue

The same opposing conclusions on the effects of cumulative fatigue have been shown in aviation studies.

For instance, in contrast to an earlier study that did not find a cumulative fatigue effect of early starts, Spencer and Robertson (2002) found an increase in cumulative fatigue over consecutive early starts (prior to 0900). Intriguingly, less cumulative fatigue was seen after a consecutive run of very early starts (prior to 0600). Also, while Spencer and Robertson (2002) found an increase in fatigue over consecutive duty days – equivalent to an extra 40 minutes of duty per day, an earlier study found no evidence of cumulative fatigue in charter pilots after 4 consecutive days of working a daytime schedule (Spencer and Montgomery, 1997).

After a sequence of night duties in cargo pilots, Spencer and Montgomery (1997) found that sleep quality and alertness decreased, suggesting cumulative fatigue, but overall sleep quantity increased. One of the few studies so far carried out of cargo operations where aircrew is experienced at routinely operating at night found that fatigue levels on the first night were higher than on nights two, three and four (Spencer MB et al 2004). This was in contrast to the results of a study on passenger charter flights, which showed a slight increase in fatigue over three consecutive nights (Spencer MB & Robertson KA, 2000).

Despite the sometimes conflicting results of studies on cumulative fatigue in aviation, the Moebus Aviation report (Moebus, 2008) takes the view that the development of cumulative fatigue tends to increase during consecutive periods of duty, especially for long duties or when early starts, late finishes or overnight duties are involved that disrupt the normal pattern of sleep. It suggests that it is sensible therefore to limit the number of duties and/or reduce the maximum FDP of these duties when they run consecutively, especially where they are close to maximum FDP limits. Following a sequence of consecutive duties, mitigating strategies could involve scheduling a rest day including one local night. The author proposed additional limits to those in Subpart Q, i.e. a duty hours limit over 14 consecutive days and a block hours limit per 12 consecutive months. Limits on these (slightly modified from those proposed in the Moebus Aviation report) are included in CRD 2010-14 although, as noted in NPA 2010-14 (EASA, 2010) there is a lack of scientific evidence and the limits are rather based on judgements of what appears "reasonable".

4.5 Sleep and Rest

4.5.1 Rest Between Consecutive Duty Periods in the General Working Population

Research studies have found a high correlation between the duration of the rest period and the amount of sleep obtained during it. This is important because one of the key factors to mitigate fatigue is to obtain adequate sleep during time off.

Scientific data demonstrated that shortened sleep every day (less than 7-8 hours) for one or two weeks (Belenky et al., 2003; van Dongen et al., 2003) produced significant cognitive decrements. Limiting sleep to six hours or less over successive nights resulted in a cumulative dose-dependent deficit in performance. Individuals who obtained less than four hours of sleep per night showed increased lapses in performance and reduced speed and accuracy when completing performance tasks, while those who obtained seven or more hours of sleep were able to maintain adequate levels of performance over 14 consecutive days. Other studies have documented the negative impact on health, mood, and safety of chronic sleep deprivation (Oginska & Pokorski, 2006; Leproult et al., 2003; Garbarino et al., 2002).

A single day with a shortened sleep in a person who otherwise has been obtaining adequate sleep can be tolerated without excessive fatigue risk. However, the number of days when these short sleep episodes occur must be strictly limited because shortened sleep episodes over consecutive days results in chronic sleep deprivation. Four hours of sleep has been suggested as the minimum amount of sleep required to sustain adequate performance levels during a single day (Belenky et al., 2003), although performance levels are lower than in people able to sleep for eight hours. Insufficient sleep, poor sleep quality and long work hours have been found to be both independently and synergistically associated with workplace injury risk (Nakata, 2011). An epidemiological study (Lombardi et al., 2010) showed the impact on health and safety of the combination of chronic sleep deficit and extended working hours. Using 7-8 hours of sleep as reference, the adjusted injury risk increased gradually with shorter sleep duration (from an odds ratio of 1.4 for 6-7 hours of sleep to an odds ratio of 2.7 for less than 5 hours of sleep).

The rest period between shifts should provide enough time for obtaining adequate sleep. A series of studies have shown that rest periods of 10 hours or less between consecutive shifts result in short sleep episodes, sometimes only 3-5 hours of sleep. It should be taken into account the time of day of the rest period, since breaks between work periods that occur during daytime result in less sleep than breaks at night (Kurumatani et al., 1994; Wylie et al., 1997).

Roach et al (2003) evaluated the effects of duration (12, 16 and 24 hours) and timing of rest periods between consecutive shifts, as well as the interaction between these two factors. The study participants (locomotive engineers) worked irregular rosters, with work episodes having an average duration of 8.4 hours. 44% of work periods started between 04:00 and 12:00, 34% between 12:00 and 20:00, and 22% between 20:00 and 04:00. Overall, the results showed that total sleep increased with longer rest periods. For 12-h and 16-h rest periods more sleep was obtained during rest periods that occurred during nighttime. For 24-h rest periods, longer sleep was obtained for rest periods starting 04:00-06:00 and 10:00-12:00. This is because individuals who finished a shift in the morning and started another shift the following morning (that is, that changed from night to day shift) often were able to fit two sleep episodes in the 24-h rest period (one after the work shift and another before the day shift).

4.5.2 Rest between Consecutive Duty Periods in Pilots

One means of mitigating the effects of a long (extended) FDP post-event is to provide a longer rest afterwards. Clearly this does not help during the extended FDP, but it can mitigate subsequent effects. An early study (Dinges et al., 1996) recommends that the required off-duty period should be extended by the same duration of the flight duty period extension.

There may be occasions when air taxi and single pilot crew require reduced rest. However, the Moebus Aviation report (Moebus, 2008) notes that any reduced rest arrangement is likely to result in increased fatigue levels.

The report (2008) recommends that reduced rest is only allowed as part of a comprehensive FRMS, and that the FRMS would need to take account of a wide range of factors including both the time spent travelling and the influence of the body clock on sleep duration. In addition, it recommends that any reduced rest that is less than 12 hours long should include the entire WOCL period, and that consideration should be given to ensuring that the subsequent flight duty is not too onerous and to specifying an absolute minimum reduced rest period, even in presence of an FRMS.

4.5.3 Split Duty

Split duty is commonly used in air taxi operations (see Table 3.1), which could enable pilots to take on-ground naps when they are not performing additional ground duties (including Aeronautical Information updating, baggage handling, and administrative and documentation duties).

No research specifically examining fatigue and risk in pilots working a split duty was identified during the literature search, however as discussed in section 4.2.3, any circumstance that increases FDP length may result in increased fatigue. Long duty days caused by split duty periods are more likely to encroach on the WOCL, extend into the late evening, or reduce the rest period between consecutive duty periods.

The Moebus Report (2008) recommends that under these conditions:

a) the ground break should be no less than 1/3 the length of the FDP

b) sleeping facilities should be provided during the break

c) the split duty period should start after 06:00 and end before 22:00

d) a minimum 10hr rest period is required between consecutive split duties

e) consecutive split duties with less than 10hr rest periods between should only be attempted in crew who have received comprehensive fatigue risk training.

4.5.4 Rest During Layover

Little information is available on sleep quality during layover, whether the pilot sleeps in a hotel, "crash pad", or crew lounge. European business aviation pilots report that overall, they receive 20 minutes less sleep in hotels than at home. While most report their sleep as being "good" quality, 26% of pilots receive less than 6 hours of sleep (only 13% get this little sleep at home), and 22% report their sleep during layovers as being "poor" or "very poor", double the number of pilots who report poor/very poor sleep at home (Alertness Solutions, 2011).

4.6 Standby

4.6.1 Standby at Base/Airport

There are differing approaches to how airport standby should be treated with respect to FDP and duty time contributions. Moebus (2008) notes that there is no scientific evidence to suggest that airport standby should be considered as any less fatiguing than flight duty and that further research is needed in this area. It concludes that time spent in airport standby should normally count 100% as flight duty when calculating the maximum FDP. It further recommends that standby count as 50% FDP if adequate rest facilities are provided, and an FRMS is in place. However, detailed scientific justifications are not provided in this report on this issue and there is a general lack of scientific evidence about the impact of different airport standby facilities.

The Principles and guidelines for duty and rest scheduling in Commercial Aviation 'NASA Study' (Dinges et al., 1996) recommends that airport standby should be considered as duty but does not provide a rationale for this.

This uncertainty is reflected in the range of European States' national provisions covering standby in Appendix 3.

4.6.2 Standby at Home and Elsewhere

The nature of air taxi operations is that flights are available on an as needed, unscheduled basis. This leads to a significant amount of standby for air taxi pilots (see Table 3.1). Long periods of standby time can make it difficult for pilots to plan their sleep/rest appropriately. A 24 hour call window especially can make it challenging to decide when to sleep – does the pilot stay up the night before and try to sleep during the day to prepare for an unlikely, but possible night flight call? In the event of a day flight, the pilot would have truncated sleep. Or does the pilot sleep at night and stay awake all day, which would benefit a day flight call, but increase the probability that the pilot will be fatigued if called in for a night time flight?

Crew Factors in Flight Operations XI: A Survey of Fatigue Factors in Regional Airlines Operations (Co, E., 1999) notes that the nature of flying on reserve means that crewmembers must respond when called for duty, thus creating unpredictability in their schedules. This unpredictability can lead to sleep loss. As evidence that sleep loss occurred, crewmembers reported getting 5.6 h of sleep before duty on average - 2.3 h less than their normal average sleep.

The majority of research into sleep and on-call issues has focused on the decrease in sleep quantity and quality while on-call compared to non-call nights (e.g. in a hospital environment) (Nicol and Botterill, 2004). One study investigated sleep quality *in anticipation* of being woken in on-call ships' engineers, which is more relevant to pilots on standby. This study found that the anticipation of being called out for an emergency was enough on its own to reduce sleep quantity and quality, increase heart rate, and increase sleepiness the following day (Torsvall and Akerstedt, 1988).

The Principles and guidelines for duty and rest scheduling in Commercial Aviation 'NASA Study' (Dinges et al., 1996) does not consider 'on call reserve status' as duty, but recommends that 'a …. 8 hour sleep opportunity' should be protected from interruption by assignment to a flight duty period. The Moebus Report (2008) acknowledges that not enough is known about sleep while on standby to make a specific recommendation for how to account for standby time in FDP limits and minimum rest period.

4.7 In-flight Rest and Flightdeck Napping

This section evaluates separately in-flight rest and controlled napping in the cockpit.

4.7.1 In-flight Rest

Some air taxi operations have aircraft capable of flying long, international flights. Augmented crews allow pilots to use in-flight rest and obtain sleep in order to maintain alertness and reduce fatigue. Numerous studies have shown that both objective physiological measures and subjective ratings of alertness demonstrate improvement following an in-flight rest taken during periods of sustained wakefulness, and that in-flight rest can also reduce or delay expected performance decrements.

A number of other studies have evaluated frequency and duration of in-flight sleep, and the effectiveness of napping as a fatigue countermeasure. For example, a study of in-flight napping during trans-Atlantic flights compared two and three-pilot crews. It found that sleep duration was longer in augmented crews: 38 minutes in outbound flights, and 1 h 06 minutes in homebound flights, compared to 26 min and 54 minutes respectively in non-augmented crews. The difference in sleep amount was directly related to the time allowed for the pilots to obtain in-flight rest. Shorter in-flight sleep was associated with lower performance at top-of-descent for 2-pilot crews (Eriksen et al., 2006).

There is some debate on the quality of sleep obtained while on duty. Based on scientific research, “sleep quality” ratings have been assigned to sleep in different facilities. Depending on the aircraft, sleeping facilities could include

a) Class I: sleeping bunk/ fully reclining (lay-flat) first class seat

Sleeping in a bunk is thought to lead to the best sleep quality. Bunks are separate from the main cabin and flight deck and include light, sound, and climate controls. Roach and colleagues estimated that in-flight sleep in bunks provides pilots with 70% as much recovery as duration-matched bed sleep (Roach et al., 2010). In a subsequent study, they evaluated frequency of in-flight sleep. Their data showed that pilots obtained 1.8 hours of sleep (27% of rest time) during duty periods with low fatigue likelihood and 3.7 hours of sleep (54% of rest time) during duty periods with extreme fatigue likelihood. The results indicated that pilots obtain more sleep during periods when fatigue is likely to be high (Roach et al., 2011). Other studies support the finding that sleep efficiency will be best during a time that the pilot is normally asleep (Simons et al., 1994; Valk and Simons, 1998; Pascoe et al. 1994). In well-equipped aircraft, sleep of six hours or longer is possible under the right conditions (Signal et al., 2003). A study of pilots flying Haj pilgrims to and from Indonesia and Saudi Arabia found that 82% of pilots were able to sleep in a bunk. They obtained 1.2hrs of sleep with a sleep quality of 4.52 (out of 7) (Spencer and Robertson, 2000).

There seems to be some controversy in how much of the time spent in the bunk is actually sleep. For example, while the TNO report “Extension of flying duty period by in-flight relief” (Simon, 2007) considers that 75% of the time spent in a bunk may be counted as actual sleep, an FAA report (AC No: 120-100 Basics of Aviation Fatigue AFS-200, 2010) states that flight crews who had a 7 hour sleep opportunity obtained, on average, only 3 hours 25 minutes of bunk sleep.

A fully reclining business class seat is expected to provide as much sleep quality as a bunk. This is provided that the seat is separate from other business class travellers and can be fully darkened (Simon, 2007).

b) Class II: a normal, semi-reclining business class seat

A normal business class seat that does not fully recline is expected to provide 75% of the sleep quality possible in a bunk or lay-flat first class seat (Simon, 2007). In one study, sleep was reduced 25% in a business class seat compared with sleep in a bunk (Spencer et al., 2004). In a business class seat the pilot will be subject to noise and lights (unless they wear eye shades and earplugs). Pilots may only choose this option if they are completely separated from other passengers by a curtain.

c) Class III: flight deck seat (40 degree angle)

Sleep in a flight deck seat is expected to provide 66% of the sleep quality possible in a bunk (Simon, 2007). Seats in the back of the flight deck are separated from passengers and may be quieter than business class seats in some circumstances. A study comparing sleep quality in a horizontal bed, a "sleeperette" reclined to 49.5 degrees, a chair reclined to 37 degrees, and a chair that reclined to 17.5 degrees found that sleep could be obtained only in chairs reclined to about 40 degrees (Nicholson and Stone, 1987). A study of pilots flying pilgrims to the Haj found that 65% of pilots were able to sleep in a flight deck seat. They obtained almost an hour of sleep, with a sleep quality of 5.41 (out of 7) (Spencer and Robertson, 2000).

d) Class IV: economy class seat

Economy seats are the least recommended for good quality sleep. The TNO report (Simon, 2007) proposes to give no credit to rest in an economy seat, although no data are available concerning onboard sleep in a normal economy class seat. However, based on laboratory data and ergonomic considerations, sleep in an economy seat is considered to be degraded to 0% of bunk because these seats do not recline to 40 degrees, have poor foot/leg room, and are closely spaced to other passengers.

The TNO report "Extension of Flying Duty Period by In-Flight Relief" (Simon, 2007) recommends allowing an extension of the FDP based on the duration of the rest period available to the pilot and on the environment that is available for rest. The recommendations assume the pilot is acclimatized to the local time zone (they suggest 3 days acclimatization period). These conclusions are reflected by the Moebus Aviation report (2008).

a) Class I: Increase FDP length by 75% of the rest period (50% if not acclimatized)
b) Class II: Increase FDP length by 56% of the rest period (40% if not acclimatized)
c) Class III: Increase FDP length by 25% of the rest period (20% if not acclimatized)
d) Class IV: No extension of FDP

The TNO report (Simon, 2007) also recommends that if augmentation is only by one additional pilot, the maximum FDP should be 16 hours.

4.7.2 Napping

Brief structured nap breaks during extended-hour work duties have been shown to be an effective operational strategy. Timing and duration of naps can be designed for optimal impact on alleviating fatigue. As with in-flight rest, napping will be most efficient when sleep occurs during the WOCL. An important consideration in terms of scheduling is the duration of the beneficial effects obtained. Studies suggest that a nap can maintain or improve subsequent performance and physiological alertness from 2 to 12 hours following the nap. Experiments have examined naps of varying lengths, and there seems to be a dose-dependent effect: more sleep is associated with greater beneficial effects.

However, some studies suggest that shorter naps can be just as or more effective than longer ones; recommendations range from 20- to 60-minute duration. Shorter naps (10-20 minutes) are also less likely to be associated with the phenomenon of sleep inertia (a short period of impaired alertness upon awakening). This is because in this amount of time, the individual will usually remain in light sleep and would not reach deep sleep. It is easier to wake up from light sleep and the individual will regain full alertness faster than waking up from deep sleep. In the case of long naps, sleep periods of approximately 90 minutes allow the completion of a full sleep cycle, and the individual wakes up from light sleep or REM sleep, which minimizes sleep inertia. On the other hand, naps of 40-60 minutes would result in the individual waking up from deep sleep, and that will result in more severe and long lasting sleep inertia. Sleep inertia can be associated with a performance decrement lasting for a few minutes to 35 minutes, though effects usually seem to dissipate in about 10 to 15 minutes (Robertson and Stone, 2002, Rosekind et al 1994).

A series of studies have proved the effectiveness of napping as a fatigue countermeasure in the aviation industry, and ICAO has stated that controlled napping is a valuable mitigation strategy that can temporarily relieve the symptoms of sleep loss (ICAO, 2011).

A joint study by the National Air and Space Administration (NASA) and the Federal Aviation Administration (FAA) examined the effect of controlled napping during long-haul flights. Two crews flying the same sequence of four scheduled flights were compared. One group was allowed a 40-minute nap opportunity (one crew member at a time), whereas the other group followed their normal activities. Pilots slept on 93% of the opportunities, falling asleep in 5.6 minutes on average and sleeping for 25.8 minutes on average. Crew assigned to the nap group showed better performance and higher physiological alertness on objective measures during the last 90 minutes of the flight (critical descent and landing phases of the flight) than did the control group (Rosekind et al, 1994).

The FAA authorises in-flight rest for flight crews if there is an augmented crew, so that two pilots are on the flight deck when the augmented crew is resting. The FAA does not authorise naps in the cockpit, however, other carriers and authorities do.

4.8 Periodic Extended Rest

4.8.1 Rest After Multiple Consecutive Duty Shifts in the General Working Population

How much rest an individual needs between blocks of working days is related to the number, timing, and length of consecutive shifts he or she has worked. Allowing more time off after extended blocks of night shifts is important because night shifts are more fatiguing, and sleep debt more prevalent, than with day shifts. There is agreement that a 24-h period including one single night is usually not enough to fully recover from a series of consecutive work days, and that the number of consecutive days off should increase with consecutive work days.

Several studies have found that two full nights of sleep are usually enough to recover from sleep deprivation and return to baseline levels of sleep structure and waking performance and alertness (Carskadon & Dement, 1979). Shiftwork researchers have shown that at least two sleep episodes are needed to recover after a series of shifts and that at least 3 days, including 3 overnight sleep episodes, are necessary to recover from 7 consecutive night shifts (Knauth, 1997). Another study (Totterdell et al., 1995) showed that alertness and performance were more impaired on the first three days back at work following a single rest day, as compared to two or three rest days.

It is thus usually recommended that time off between blocks of work days should allow two days with nocturnal sleep (Health and Safety Executive, 2006; Knauth, 1997). This is due to the fact that night-time sleep occurs at the time when circadian rhythms are conducive to sleep, and thus sleep episodes are longer and more restorative. An off-duty period of 36 hours after daytime shifts and 48 hours after night shifts are required to allow shiftworkers to obtain these two nocturnal sleep episodes.

Folkard (2000) recommends that staff be able to have sufficient sleep to fully recover after working two or three consecutive night shifts. This requires two full nights' sleep after the consecutive night shifts, without an early start after the second night. In order to ensure this is achieved (and commuting time does not leave too short a period for rest), it is considered optimum that 54 hours or more should elapse between the end of the consecutive night shifts and the next shift.

4.8.2 Rest after Multiple Consecutive Duties in Aviation

Few studies have specifically investigated how much rest should be allowed after consecutive FDPs in aviation.

One study examined sleep and alertness in a charter flight crew after a return flight from the UK to the East coast of the United States. The layover period between legs lasted from 12 hours to three local nights. After returning to the UK, alertness levels took three recovery nights to return to normal (Spencer and Montgomery, 1997). This study suggests that duty periods involving time zone desynchronization may require more recovery time than multiple consecutive duties within the same time zone (already addressed in section 4.3.4).

Despite a lack of specific research on rest periods in aviation, recommendations exist for rest after consecutive duties. One potential mitigation strategy is additional rest after consecutive night duties (Spencer, 1997). The Principles and guidelines for duty and rest scheduling in Commercial Aviation 'NASA Study' (Dinges et al., 1996) recommends that if two or more flight duty periods within a 7-day period encroach on all or any portion of the WOCL, then the standard off-duty period (36 continuous hours within 7 days) be extended to 48 hours recovery.

4.9 Travelling and Positioning

4.9.1 Overview

Travelling and positioning are two factors that may influence pilot fatigue. Travelling involves commuting (by car, train, bus, or airplane) from the pilot's domicile to their home base airport. This is considered to be non-duty time. The average travel length for European business aviation pilots is 1.5hr – suggesting a range of much higher travel times (Table 3.1). Positioning involves transporting the pilot from their home base (usually by air as a passenger) to an airport further away for duty. Time spent flying while positioning is considered duty, and is part of the FDP limits unless it occurs after flight duties are completed. European business aviation pilots report that 65% of their companies use positioning as part of their business (Table 3.1).

4.9.2 Travelling

Pilot travelling has become a source of controversy in aviation. Airlines report that pilots might live hundreds of miles away from their home base and travel for duty via commercial airline. The practice of travelling for hours before duty raised the issue of additional pilot fatigue, since their time since awake could be extended by several hours. This issue was brought to international attention after the crash of Colgan Air Flight 3407 to Buffalo NY, killing all 49 passengers and crew. While the NTSB board reviewing the case did not agree to list fatigue as a contributing factor, the Chairman Deborah Hersman issued a five page report lamenting this exclusion, and argued the case that fatigue due to travel time was a probable factor contributing to the crash.

Recently, the National Research Council (NRC) Committee published a special report on the "Effects of Commuting on Pilot Fatigue" (2011) to investigate pilot travelling practices. The NRC found that;

"…*there are no comprehensive data on the frequency of pilot commuting, the lengths of commutes, or such trip characteristics as the transportation modes used in commuting. There are also no systematic data on the timing, duration, or quality of pilots' sleep before or during their commutes. Furthermore, changes in airports to which the pilots' report for the start of their duty (their domicile) may alter commuting patterns, but the committee was unable to obtain any systematic information about how frequently individual pilots experience domicile changes or how such changes affect pilot commuting behaviour*."

Based on the lack of objective data, the committee concluded that while travelling may influence pilot fatigue and safety risk, there is no way to be certain. In the meantime, they recommend that pilots should avoid planning any pre-duty activities, including travelling, that will result in their being awake for 16 consecutive hrs by the end of the FDP. They also suggest that pilots receive no less than 6hrs of sleep prior to duty, and consider how long they have slept and been awake when they are deciding whether or not to fly.

4.9.3 Positioning

As with travelling, no controlled experiments have examined the effect of positioning on pilot fatigue. Positioning is considered duty and is already accounted for in determining FDP limits when prior to a FDP. However, depending on when the positioning flight occurs, how long it takes, and whether the pilot is able to sleep or not, in theory positioning flights can be as disruptive as if the pilot was flying themselves. For example, if the positioning flight has an early departure, all of the drawbacks of early departures apply. If the pilot has the ability to nap during the positioning flights, some of the fatigue effects may be mitigated, but if not, the potential exists for the pilot to begin their FDP already fatigued.

5.0 Hazard Analysis

The following hazards from Table 3.2 are addressed in this section:

Duty Duration/ Time Awake

5.1 Hazard A1, duration of FDP too long leading to fatigue, (implicitly includes other causes of overlong FDP, A2, A5, A6)

5.2 Hazard A3, extended FDP with augmented crew/ in-flight rest leads to fatigue

5.3 Hazard A4, on-ground break (split duty) used to excessively extend FDP leading to fatigue

Time of Day Effects

5.4 Hazard B1, WOCL encroachment

5.5 Hazard B2, circadian disruption due to mixing night and day duties

5.6 Hazard B3, Time Zone desynchronisation

Cumulative

5.7 Hazard C1, cumulative effect of multiple consecutive FDPs

5.8 Home/ hotel standby – how the unpredictability of home/ hotel standby can contribute to long periods awake, hazard A5, and how it could contribute to cumulative fatigue, hazard C2

Rest and Sleep Off Duty

5.9 Hazard D1, lack of rest opportunity

Relaxation and Naps During Ground Breaks

5.10 Relaxation and napping relating to hazard E1, sleep inertia, and as a mitigation to hazard A1

Others

5.11 Pilot in Command (PIC) discretion – hazard A2, PIC discretion leading to too long an FDP

5.12 Positioning and travelling – hazards F1, F2 and F3 from Table 3.2 leading to excessive time awake and/or cumulative fatigue.

For each of these hazards the safety, economic and social impacts associated with potential FTL changes are analysed.

5.1 Hazard A1, Duration of FDP Too Long Leading to Fatigue

5.1.1 Safety Impacts of Changes of FDP Duration and Extensions

The key issues associated with hazard A1 from Table 3.2 are considered to be:

i. Length of FDP and fatigue level
ii. Length of extended rest after a long duration or extended FDP
iii. Encroachment of WOCL (see section 5.4)
iv. Impact of number of sectors
v. Other potential mitigations.

5.1.1.1 Length of FDP and Fatigue Level

Literature Review and States' Survey

The relationship between duty length and fatigue is complicated by circadian phase, time awake, chronotype and the other factors discussed in Section 3.1. The literature in Section 4 from across industries indicates that shifts up to 12 hours are not necessarily higher risk than 8 hour shifts if appropriate mitigations are put in place. From the airline industry there is a range of proposed limits for daytime FDPs between 12-14 hours beyond which there is likely to be increasing fatigue and risk. The number of sectors in an FDP and WOCL encroachment will be important fatigue contributing factors.

For air taxi operations adherence to the maximum daily FDP requirements in Subpart Q OPS 1.1105 are expected in Europe[2]. For single pilot operations see Appendix 3 – there are specific national requirements for FDP limits, maximum daily blocks hours, maximum single flight/ sector time and restrictions on extensions.

CAS modeling

FDPs in the range 11 to 20 hours have been considered with a two person crew. The scenario specific assumptions are:

- Two sectors of 5 hours each, first flight starting 30 minutes after start of FDP and second flight ending at end of FDP
- Pilots assumed to stay awake during break in 2 sectors
- No time-zone complications for this scenario

Three different finish times for the FDP have been selected, 0600 (worst case in terms of alertness), 1300 and 2100. The graph below shows alertness at the end of the last flight for these 3 different finish times with the different FDP durations.

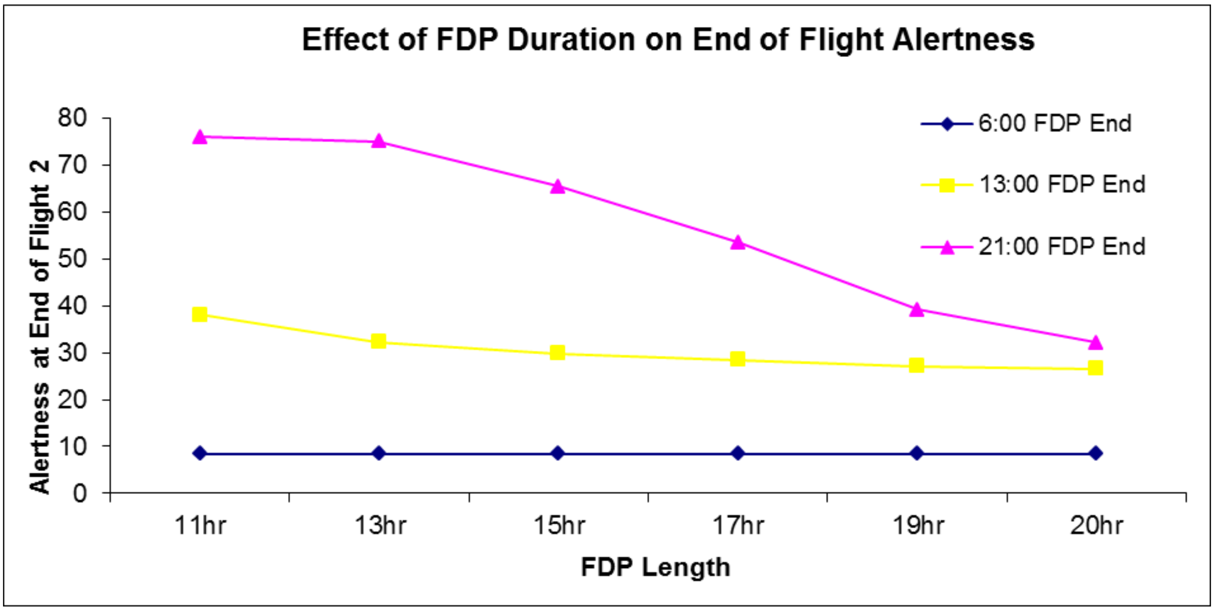
Figure 5.1 indicates that:

[2] CAP 371 applies for the UK

- Alertness at the end of the last flight is heavily dependent on circadian time-of-day as expected.
- For the finish time where alertness is highest (2100) there is a large variation in alertness depending on FDP length between 11 hours (score of 76) and 20 hours (score of 32). Above 13 hours FDP duration the alertness score starts to decrease steadily.
- For the other two end times of 0600 and 1300 there is less variation with FDP duration. In the case of 0600 the alertness is very low (<10 "bottomed out") for all the durations modeled. A combination of FDP greater than 11 hours flown with an unaugmented crew and ending at 0600 will lead to low levels of alertness. Additional mitigations may be applied by crew in such circumstances, such as controlled napping when sanctioned. For 1300 the alertness varies from 38 to 27.

These findings seem broadly consistent with the literature in Section 4 indicating significant increases in risk as FDP begins to exceed 12-14 hours. The combination of literature and modeling shows that if extensions are granted beyond 13 hours, flight safety risks are likely to increase.

Figure 5.1: **Alertness at end of FDP depends on FDP length and time-of-day of FDP end**



With respect to **single pilot operations** it is to be expected that on average flightdeck workload may increase relative to operations with two or more crew. The complexity of the flightdeck and the nature of the operations will also influence the relative workloads and hence it is difficult to determine how large the workload differences will be. To address this preliminary CAS modeling was undertaken with the whole flight with a single pilot set at the same workload as that used during take-off and landing for multi-crew operations. This assumption models higher levels of fatigue over the course of each FDP and leads to lower alertness levels. Most of the States surveyed (see Appendix 3) have additional mitigations in terms of maximum FDP and flying time limits for single pilot operations to counter this potential for extra fatigue. These mitigations are summarized in Section 5.1.1.4 below.

5.1.1.2 Length of Extended Rest After an Extended FDP

One means of mitigating the effects of a long (extended) FDP, post-event, is to provide a longer rest afterwards. Clearly this does not help during the long FDP, but it can mitigate subsequent effects.

In terms of the scientific literature, The Principles and guidelines for duty and rest scheduling in Commercial Aviation 'NASA Study' (Dinges et al., 1996) recommends that '*the ….. required off-duty period should be extended by the same duration of the flight duty period extension'*. Other literature in Section 4 notes the importance of two nights sleep to recover from peak fatigue.

5.1.1.3 Impact of Number of Sectors

The need to decrease the FDP if there are a significant number of sectors is confirmed by many scientific studies (see Section 4.2.4). The Subpart Q requirement on maximum allowable FDP is based on a 30-minute reduction after the second sector. Air Taxi (AT) and single pilots can fly multiple sectors and it is reasonable to believe that this will have at least a similar effect on them as for multi-crew scheduled and charter pilots. For **single pilots** the impact may be greater as they have to conduct the turn-around alone.

5.1.1.4 Other Potential Mitigations

In addition to limits on FDP duration, extended rest and modifying maximum FDP depending on the number of sectors, other potential mitigations for long duration FDPs could be incorporated into the RIA options. These may include:

- Requiring full rest before the extended FDP (assumed in the modeling above)
- FRMS (general for all hazards)
- Ensuring that the most strict limits apply when extensions are used for mixed operations (e.g. air taxi and AEMS)
- Limiting the frequency of extended FDPs
- Controlled napping and relaxation during any ground breaks between sectors
- Records to NAA of FDP extensions and NAA oversight measures.
- For **single pilot operations** specific requirements for FDP limits, maximum daily block hours, maximum single flight/ sector time and restrictions on extensions (see Appendix 3)
- Relief pilot for **single pilot operations** when an extension is invoked.

5.1.2 Economic and Social Impacts of FTL Changes for FDP Duration and Extensions

Those economic and social impacts which are judged likely to be most significant following proposed regulatory changes are tabulated below (Table 5.1).

Table 5.1: **Economic and Social Impacts Associated with Potential Changes to FDP Duration Provisions**

Potential change	**Reference situation in Europe**	**Identification of generic economic and social impacts**	**Factors which will affect size of impacts**
Harmonisation of basic max. FDP duration and extensions	Air taxi operations already well harmonized around Subpart Q. Maximum FDP for single pilot operations (SPLO) vary from 8 to 11 depending on State, FDP start time and number of sectors. Hence impact analysis focusses on SPLO.	If change effectively reduces maximum FDP this could impact service provision, e.g. prevent a single pilot operation being able to provide the required combination of flights to a customer. This could have economic impacts and social impacts in terms of job security. Changes could lead to requirement to switch from single pilot to multi-crew operations with associated crew cost impacts.	Size of impact will depend on how close to FDP limits single pilot operators currently fly. If close to the limits and limits change then could be significant impacts.
Harmonisation of flight time for single sector for SPLO Harmonisation of flying hours per FDP for SPLO	Flight/ sector times for single pilots are restricted to various limitations including 5 hours, 4 hours (with autopilot), and 2 hours (without autopilot) in different States. One State restricts FDP block hours to less than 6 hours for IFR operations or operations at night for single pilots.	As above	As above – depends on how close operations are to harmonised flying hours limits.

An indication of the process for determining the economic impacts of proposed changes is illustrated by the following example relating to daily block hours for single pilot operations:

- Assume that a regulatory change leads to a new daily block hours limit of X hours.
- Assume that a single pilot operator operates at greater than X flight hours for Y% of FDPs.
- Assume that for these Y% of FDPs, two person operations need to be introduced.

- From this extra crew numbers can be estimated and combined with estimates on the percentage of operating costs due to crew costs (see Section 2.2).

5.2 Hazard A3, Extended FDP with Augmented Crew/ In-Flight Rest Leads to Fatigue

5.2.1 Safety Impacts of Changes for Extended FDP due to Augmented Crew

The key issues associated with this hazard are:

i. Length of FDP and fatigue level
ii. Availability and quality of in-flight rest facilities and other potential mitigations.

5.2.1.1 Length of FDP and Fatigue Level

Literature Review and States' Survey

Some issues with extended duration FDP's can be avoided by augmenting the crew during long flights with an additional crew member(s). Augmented crews allow pilots to take in-flight rest and obtain sleep in order to maintain alertness and reduce fatigue.

Numerous studies have shown that both objective physiological measures and subjective ratings of alertness demonstrate improvement following an in-flight rest taken during periods of sustained wakefulness and that sleep can also reduce or delay expected performance decrements (Simon, 2007). Timing and duration of rest/ sleep can be designed for optimal impact on alleviating fatigue.

Appendix 3 summarises the national provisions regarding in-flight rest from the survey of States. They show FDP extensions that are a function of the number of augmented crew, the on-board rest facilities, minimum in-flight rest hours and the number of sectors. In France the minimum rest at home base requirements can be changed for air taxi operations as explained in Appendix 3. For the other States there are no air taxi specifics.

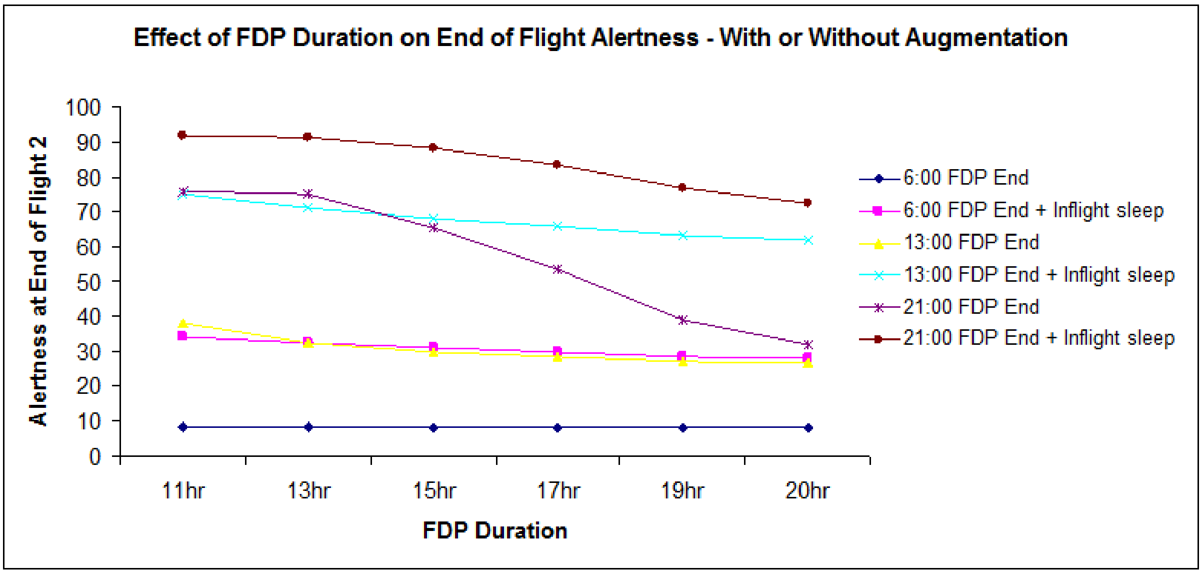
CAS modeling

FDPs in the range 11 to 20 hours have been considered with 3 person augmented crews. The scenario specific assumptions are:

- Two sectors of 5 hours each, first flight starting 30 minutes after start of FDP and second flight ending at end of FDP
- 90 minute sleeps as part of inflight rests were placed in the middle of each flight
- No time-zone complications for this scenario

As in section 5.1.1.1 three different finish times for the FDP have been selected, 0600 (worst case in terms of alertness), 1300, and 2100. Figure 5.2 shows alertness at the end of the last flight for these 3 different finish times for augmented and non-augmented crew.

Figure 5.2: **Impact of FDP duration on alertness at end of Augmented Crew FDP**



The graph indicates that:

- For the end time where alertness is highest (2100) crew augmentation is effective in maintaining alertness at the end of the second flight (compared to Figure 5.1 with non-augmented crew).
- In the case of 0600 end time the alertness is low even with augmentation (although augmentation does raise alertness to an equivalent level with a 1300 FDP end time without augmentation) and at this finish time the alertness shows only weak dependence with FDP duration.
- Alertness is at intermediate levels with an afternoon (1300) end time and augmentation shows clear benefits.

5.2.1.2 Other Potential Mitigations

As well as providing limits to FDP extensions with in-flight rest other potential mitigations could be incorporated into the RIA options. These may include:

- Technical criteria for in-flight rest facilities
- Minimum duration of rest period onboard required
- Setting minimum continuous duration for in-flight rest
- Limiting the number of sectors
- Limiting the FDP time over which a crew member can be Pilot Flying (PF)
- Specifying minimum rest durations at destination and at home
- Additional compensation time over and above the standard rest time (used in AEMS)
- Sleep opportunities at the airport after long missions
- Promote and pay for use of public transport after long missions which mitigates the risk of car accidents for flight crew
- Limiting the frequency of such extended augmented FDPs.

5.2.2 Economic and Social Impacts of FTL Changes for Augmented Crew Duty Duration and Extensions

Those economic and social impacts which are judged likely to be most significant following proposed regulatory changes are tabulated below (Table 5.2).

Table 5.2: **Economic and Social Impacts Associated with Potential Changes to Augmented Crew FDP Provisions**

Potential change	Reference situation in Europe	Identification of generic economic and social impacts	Factors which will affect size of impacts
Harmonising FDP hours for augmented crew and/ or requirements for onboard rest facilities	FDPs are a function of the number of augmented crew, the on-board rest facilities, minimum in-flight rest hours and the number of sectors. Up to 20 hours in Switzerland with 4 pilots, bunk beds and 3 sectors. 18 hours is the maximum in other States.	If a change requires 4 crew instead of 3 to fly an FDP of a certain number of hours this will clearly lead to increased crew costs. Alternatively operators may choose to upgrade onboard rest facilities (if practical) to achieve desired FDPs with available crew with consequent capital costs.	Size of impact will depend on how close to FDP limits operators currently fly. If close to the limits and limits change then could be significant need for more/ less crew.
Harmonising extended rest after an augmented FDP	The required rest after an extended FDP can vary from = FDP up to 48 hours depending on State.	Changes to the amount of rest following an extended FDP may affect crew availability. If a new requirement for extended rest following an augmented FDP is introduced then extra crew may need to be made available to cover such an event.	The percentage of FDPs that get extended using augmented crew. How much spare crew capacity operators currently have to cover such events.

An indication of the process for determining the economic impacts of proposed changes is illustrated by the following example relating to additional extended rests following extended augmented FDPs:

- Assume that a regulatory change leads to an additional 12 hours rest being allotted whenever an extended augmented FDP beyond X hours is flown.
- Assume that each crew member experiences an augmented FDP beyond X hours Y times per year.
- The change will lead to an average of 12Y hours extra rest per year per crew member.
- This can be used to assess the impact on crew costs and overall operating costs as per the other illustrative example above.

5.3 Hazard A4, On-Ground Break (Split Duty) used to Excessively Extend FDP Leading to Fatigue

5.3.1 Safety Impacts of FTL Changes Relating to On-Ground Breaks (Split Duty)

5.3.1.1 Literature and States' Survey

Table 3.1 indicates split duty is relatively common for ATXO. Folkard and Tucker (2003), reviewed in Section 4.1.2.2, found that breaks in shifts reduced accident risks. Moebus Aviation (2008) noted the lack of scientific studies on the impact of split duty on aircrew but made a number of recommendations (see Section 4.5.4).

Related to this lack of clear scientific evidence there is a range of national provisions in place in Europe on split duty. Seven out of the eight States surveyed have national provisions covering split duty and Appendix 3 indicates that there is a significant degree of variation. In six of the eight States there is a minimum period of 3 hours for a break before it can influence FDP duration. In France and the UK the FDP can be extended by half of the break minus 30 minutes. In other States there is a sliding scale where longer breaks can contribute to proportionally longer FDP extensions. In Poland for example with a break between 7 and 10 hours, the FDP can be extended by 1.5 times the break time provided the break is between 20.00 and 08.00 local time. The national provisions in Appendix 3 have a wide range of conditions and caveats associated with the possible extensions. These are summarised below under Potential Mitigations.

In France there are specific provisions for Air Taxi related to taking a break inside the aircraft. Conditions for taking the break inside the aircraft are the following:

- Minimal noise, temperature, light, ventilation conditions are included in the operations manual
- Temperature and ventilation can be adjusted
- No passengers are on board
- No interference with on ground operations (catering, etc.) that might compromise the rest during the break. Otherwise, the possible extension is decreased by half the duration of said operations.

5.3.1.2 CAS Modeling

A number of scenarios have been modelled in CAS to investigate the influence of a ground break on fatigue.

Day FDPs

Three scenarios have been modelled:

1. No ground break – 13 hour FDP starting at 07.00, with two six hour sectors
2. Ground break – 13 hour FDP starting at 07.00, with two 4 hour sectors at either end of the FDP and a 5 hour ground break in between
3. Ground break and sleep – as for #2 but with a 90 minute sleep on the ground

Fatigue/ Alertness Measures	**Day FDP Scenario 1**	**Day FDP Scenario 2**	**Day FDP Scenario 3**
Fatigue Score[3]	6.8	6.7	5.7
Average Alertness during FDP	81.5	82.5	86.2
Alertness at end of FDP	78.2	80.4	86.7

These results indicate that for all these FDPs in isolation, fatigue is low and alertness high. The unground break and afternoon sleep have little effect. If the break was used to extend the FDP later than 20.00, time of day effects would become important combined with the long duration FDP impacts illustrated in Figure 5.1.

Night FDPs
Three scenarios have again been modelled:

1. No ground break – 11 hour FDP starting at 20.00, with two five hour sectors
2. Ground break – 13 hour FDP starting at 20.00, with two sectors and a 4 hour ground break in between
3. Ground break and sleep – as for #2 but with a 3 hour sleep on the ground

Fatigue/ Alertness Measures	**Night FDP Scenario 1**	**Night FDP Scenario 2**	**Night FDP Scenario 3**
Fatigue Score	46.4	48.5	23.0
Average Alertness during FDP	35.2	32.4	56.1
Alertness at end of FDP	9.7	21.6	74.8

For the night FDP, the ability to sleep during the ground break has a much larger effect on reducing fatigue and increasing alertness. A break without a sleep does not show significant benefits on average fatigue/ alertness across the FDP. Alertness at end of the FDP is also affected by the different times of day at which the FDP ends.

Thus the degree to which an on-ground break can justify FDP extensions will be dependent on a number of factors including time of day (which influences the ability to sleep and the benefit of the break) and the rest facilities available to crew.

[3] The fatigue score is calculated as a weighted sum of 11 individual factors including the average alertness on duty, number of recovery breaks per week, hours on duty per week, number of time zone crossings and others. It is based on a 0-100 scale, with 100 the most fatigued.

5.3.1.3 Potential Mitigations

As well as specifying how the duration of the on-ground break contributes to FDP and placing limits on the extension time and total FDP with split duty other potential mitigations include:

- Establishing the minimum consecutive number of hours for break
- Specifying standards for the rest facilities/ accommodation during the break (including aircraft facilities if break taken on-board)
- Establishing limits for the duration of FDP before and after the break
- Establishing limits for the numbers of landings/ sectors after the break
- Limiting numbers of breaks in one FDP
- Restriction on combining split duty with augmented crew rules or reduced rest
- Impact of travel time during break on FDP extension
- Time difference/ non-acclimatisation restrictions
- Frequency of extended FDPs due to split duties (e.g. in one week)
- Whether a crew member can be pilot flying after a certain FDP duration
- Taking account of split duty for subsequent rest calculation
- Pre-plan the break.

5.3.2 Economic and Social Impacts of FTL Changes Relating to On-Ground Breaks (Split Duty)

The main economic and social impacts are judged to be associated with the following potential changes:

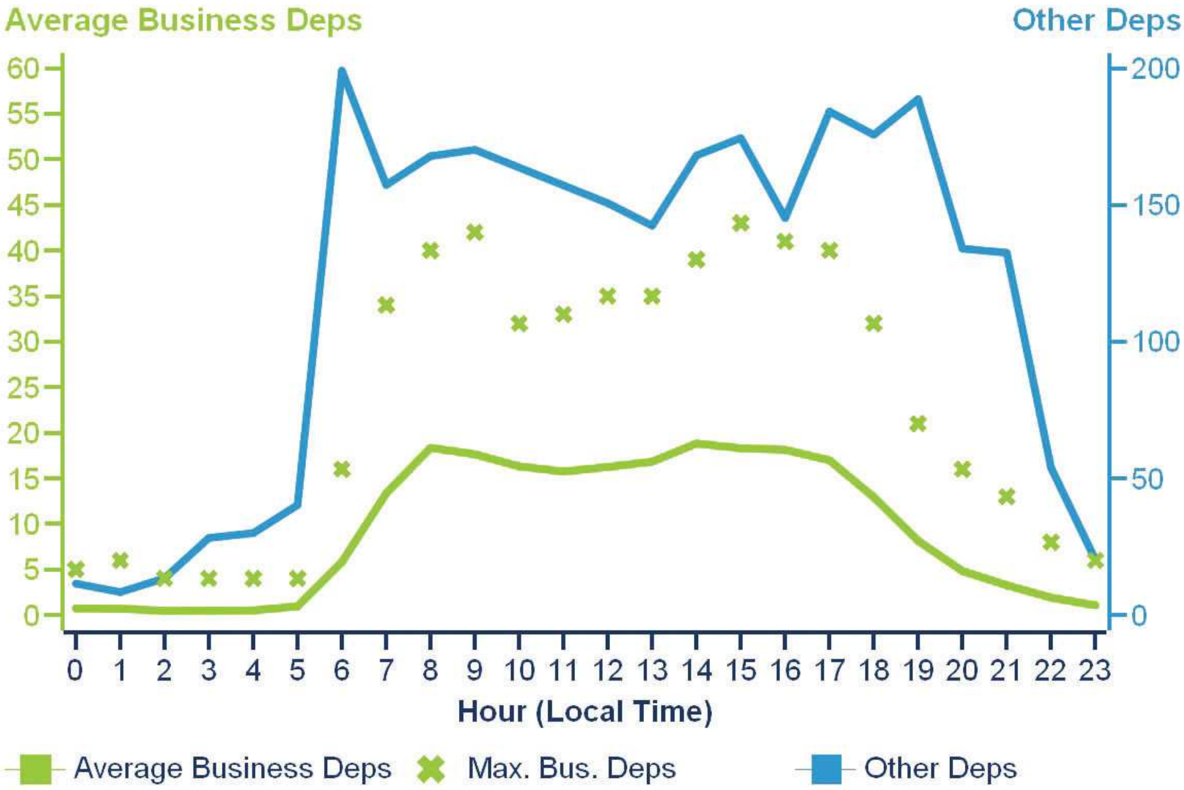
- Harmonised rules for determining FDP extension based on break duration and accommodation – this will effectively change FDP duration for some States and hence the economic and social impacts will be as in Table 5.1 above.

- Harmonised rules for rest facilities/ accommodation – including on aircraft. This could mean that some operators may not be able to take benefit for on-ground breaks in terms of FDP durations or they have to spend money upgrading facilities. See Table 5.2 above for similar impacts.

5.4 Hazard B1, WOCL Encroachment

The traffic patterns for Business Aviation (BA) are different from the overall European traffic picture in terms of hourly departures. EUROCONTROL (2010) shows the hourly pattern of BA departures for Germany in the graph below (a similar pattern is also shown by EUROCONROL for France). The busy hours for Business Aviation begin later and end earlier than is the case for the rest of the traffic. There is a relatively low percentage of flights beginning in the WOCL or soon after the WOCL.

Figure 5.3: Hourly pattern of departures in Germany (from EUROCONTROL, 2010)



However, Business Aviation (and hence air taxi) flights do encroach the WOCL and hence this source of fatigue requires consideration.

5.4.1 Safety Impacts of FTL Changes Relating to WOCL Encroachment

There is consensus within the scientific literature and from operational experience that the length of the FDP should be reduced if sleep is restricted, e.g. if a crew member cannot sleep during the WOCL and then finds it difficult to sleep at other times of the day. The CAS modeling in Section 5.1.1.1 shows low alertness for FDPs ending at the end of the WOCL. Subpart Q sets out requirements for reducing FDP for WOCL encroachment which is a mitigation for transient effects.

Other potential mitigations aimed at cumulative fatigue include:

- Providing additional rest – e.g. if two or more FDPs encroach the WOCL during a week, the weekly rest could be extended from 36 hours to 48 hours. This could include other periods of extended rest not necessarily weekly.
- Limiting the frequency of such WOCL encroached FDPs.

Mitigations aimed at both transient and cumulative fatigue are:

- Planning to optimize sleep opportunity (a Subpart Q provision) – this is hard to guarantee for an on-demand service such as ATXO.
- Personnel trained to recognize fatigue and respond appropriately.

5.4.2 Economic and Social Impacts of FTL Changes Relating to WOCL Encroachment

The major potential impacts are judged to be any future rule changes affecting:

- Additional rest to compensate for WOCL encroachment – the economic impact will be the equivalent of that described in Table 5.2 for Extended Rest after Extended FDP and the illustrative calculation of impacts of extra rest time after Table 5.2.
- Changes in the manner that FDP is adjusted if WOCL is encroached – the economic impact will be equivalent to changing the maximum FDP duration shown in Table 5.1.

5.5 Hazard B2, Circadian Disruption due to Mixing Day and Night FDPs

5.5.1 Safety Impacts of FTL Changes Relating to Day/ Night Transitions

As noted in Section 4.3.3 transitioning from day to night duties and vice versa can cause problems. During the transition there is a misalignment of the circadian rhythms which leads to malaise and increased fatigue. Research studies (Santhi et al., 2007) have studied the transition from day to night shift without rest days in between and found that the first night shift is most problematic with impairment in the ability to sustain focus, decrease in subjective alertness and decrease in visual search sensitivity more pronounced than in subsequent shifts.

Subpart Q notes that "*Operators shall allocate duty patterns which avoid such undesirable practices as alternating day/ night duties*…". The provision of rest in between these transitions is an important mitigation for this cause of circadian disruption. Providing at least one full local night between transitions provides some protection against a late night FDP being followed by an early starting in the WOCL the following night. CAP 371 recommends avoiding rest periods between 18 and 30 hours to avoid such disruption.

Limiting the frequency of such transitions may be difficult to achieve depending on operational factors and crew resources.

5.5.2 Economic and Social Impacts of FTL Changes Relating to Day/ Night Transitions

Providing extended rest between transitions and minimizing their frequency may be more difficult for smaller operators with less resource flexibility. However the economic impacts would not be expected to be large given that these mitigations are good practice already built into Subpart Q.

Minimising such disruption by applying adequate rest between transitions will have a positive social impact in terms of promoting the wellbeing of crew.

5.6 Hazard B3, Time Zone Desynchronisation

5.6.1 Safety Impacts of FTL Changes Relating to Time Zone Desynchronisation

5.6.1.1 Literature and States' Survey

The literature reviewed in Section 4.3.4 indicates that it can take several days for people's body clock to align with the local time following long haul flights. The direction of travel and the length of layovers will influence the impact as well as individual factors.

As noted in Table 3.1, crossings of several time zones are relatively common for ATXO. Six out the eight States surveyed had specific national provisions concerning time zone crossings. These are described in Appendix 3 and vary widely. In Switzerland for example, for time zone differences of 3 hours or more the subsequent rest period must be increased by 30 minutes for every hour of difference. In the UK, CAP 371 has a table for guidance showing that the number of days for Minimum Base Turn Around (MBTR) is a function of Return Sector Length, Duration of Trip and Time Zones Crossed; at the upper end, the MBTR is 5 days for a return sector length of 14 hours +, a trip length of 96 - 216 hrs, and 7 plus hours time zone difference. In Germany after return to home base the rest in hours is determined by multiplying the time zone difference by 8 up to a maximum of 12 time zones. It should be noted that the provisions above are not specific for ATXO, but are general CAT rules.

In France there are specific provisions for air taxi operations. Under general CAT rules when returning to the home base, if the preceding FDP took the crew more than 3 time bands away, then rest = 36h including 2 local nights. For air taxi operations, these provisions may be changed as follows:

- Rest = maximum of either the preceding FDP or 10h + 1 additional hour for every time zone crossed. Rest shall include at least one local night.
- If rest <36h or rest does not include 2 local nights, then the periodic rest referred to in OPS 1.1110 §2.1 shall include 3 local nights and be granted at the home base.
- These changes may be implemented only under FRM.

The national provisions also cover rest provisions away from home base and rest between Eastward-Westward and Westward-Eastward TZ transitions (see Appendix 3).

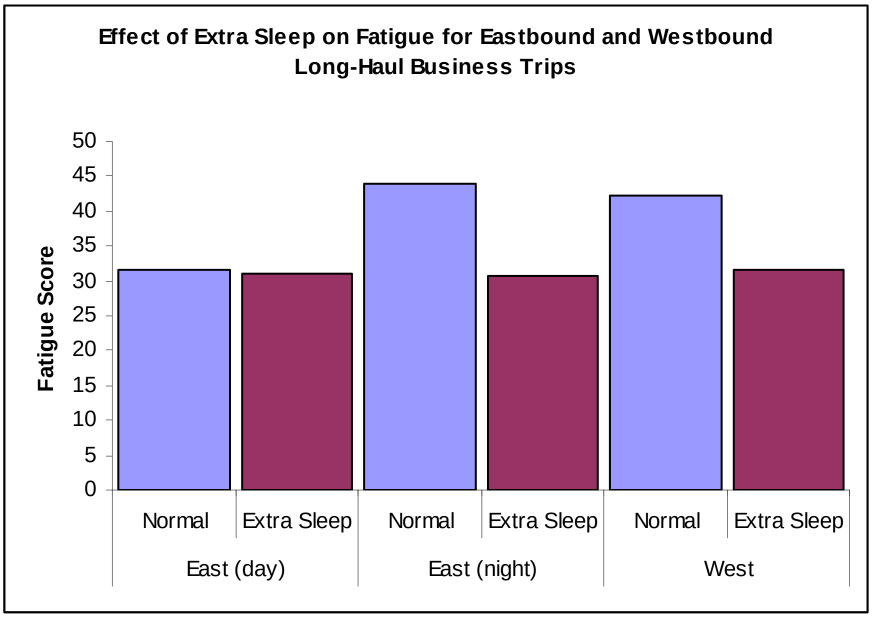
5.6.1.2 CAS Modeling

In order to understand this hazard better the following scenarios have been modeled with CAS:

1. Flying East (flights during pilot's subjective daytime): London, UK > Delhi, India > Sydney, Australia > Tokyo, Japan > London, UK
2. As for #2 but flying during the pilot's subjective night-time
3. Flying West: London, UK > New York City, USA > Miami, USA > Rio de Janeiro, Brazil > London, UK

For each of these three sequences augmented crews were assumed enabling in-flight rest of either 90 minute sleeps (termed "normal" in graph below) or 3 hour sleeps (termed "extra sleep" below).

Figure 5.4: Fatigue for Eastbound and Westbound Long Haul Air Taxi Flights



For the sequences creating increased fatigue, the extra in-flight rest shows benefits in terms of reduced fatigue and increased alertness (see Appendix 4 for detailed alertness graphs). It should be noted that while generally eastbound flights cause more problems (as noted in the literature review), this particular westbound schedule involves erratic flight times relative to the crew's body clocks. The schedules above are considered realistic from the viewpoint of long range air taxi flights, but clearly cannot represent the wide range that could actually be encountered.

5.6.1.3 Potential Mitigations

In addition to trying to schedule flights to take account of TZ desynchronisation (difficult for an on-demand service such as ATXO) and use of augmented crew to allow in-flight rest the following mitigations are relevant:

- Duty restrictions and rest (home and away) based on number of time zones crossed
- Limit the maximum FDP according to day time and degree of acclimatization
- Set a minimum time before a crew would be considered time zone acclimatized
- FRMS of particular importance to take account of time zone specifics and specific route patterns of a long range ATXO operator
- Limiting number of alternating east-west rotations per month and providing additional rest when these happen.

5.6.2 Economic and Social Impacts of FTL Changes Relating to Time Zone Desynchronisation

The main economic and social impacts are judged to be associated with harmonised rest provisions at home and away from home base following TZ crossings. Changes in these provisions compared to a State's current provisions could impact the availability of crew (see Table 5.2). Whether this leads to additional crew being required will depend on how often a pilot is required for an FDP soon after another FDP involving TZ crossings. In terms of social impacts changes in rest provision after TZ crossings will affect crew's ability to recover and hence their overall feeling of wellbeing.

5.7 Hazard C1, Cumulative Fatigue due to Consecutive FDPs

Although AT pilots generally fly significantly fewer hours per year than scheduled airline pilots, cumulative fatigue could still build up over shorter timeframes if workload is unevenly spread. Single pilots, if flying scheduled operations (see Section 2.2.2.2), could accumulate sleep debt in a similar manner to multi-crew scheduled and charter pilots.

5.7.1 Safety Impacts of FTL Changes Related to Cumulative Fatigue

5.7.1.1 Literature Review and States' Survey

The scientific research on the links between fatigue and the subsequent risk of accident and injuries over consecutive work days is reviewed in Section 4.4. The development of cumulative fatigue tends to increase during consecutive periods of duty, especially for long duties, early starts, late finishes and overnight duties, when the normal pattern of sleep is disrupted (Spencer and Robertson 2000, Spencer and Robertson 2002).

How much rest an individual needs between blocks of working days is related to the number, timing, and length of the consecutive days he or she works. Allowing more time off after consecutive night FDPs is important because night flights are more fatiguing, and sleep debt more prevalent, than with day flights. There is agreement in the literature that rest including just one night's sleep is usually not enough to fully recover from a series of consecutive work days. Two consecutive days and nights rest (48hrs) with unlimited sleep opportunity is usually enough to dissipate any cumulative sleep debt (see Section 4.8).

Monthly and annual limits are generally built up from weekly limits with rest days added in. It is very difficult to relate cumulative fatigue to longer term limits either from scientific literature or modeling.

Moebus Aviation's report (Moebus, 2008) proposed additional limits to those in Subpart Q, i.e. a duty hours limit over 14 consecutive days and a block hours limit per 12 consecutive months. Limits on these (slightly modified from those proposed in the Moebus Aviation report) are included in CRD 2010-14 although, as noted in NPA 2010-14 (EASA, 2010), there is a lack of scientific evidence and the limits are rather based on judgments of what appears "reasonable". Operational experience with respect to ATXO and single pilot operations will be important to allow filling in the gaps from the scientific literature and modeling on cumulative fatigue.

Based on the States' survey, there are no special requirements for single pilot operations and hence both Air Taxi and single pilot operators are assumed to adhere to Subpart Q requirements for cumulative duty hours and block times.

5.7.1.2 CAS modeling

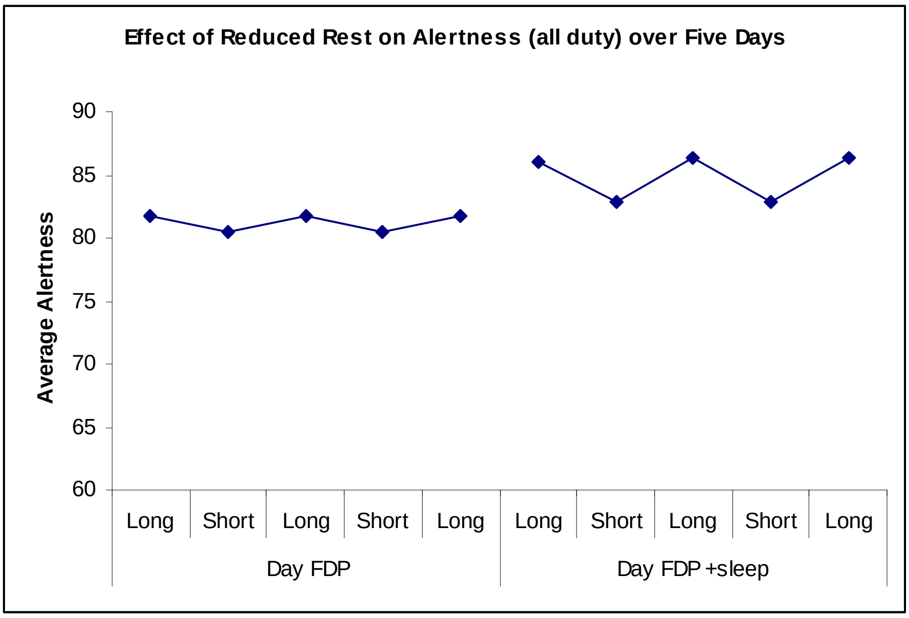
To investigate the potential buildup of cumulative fatigue over a week, the following sequences of FDPs have been modeled with CAS:

Day FDPs – 5 consecutive days:

- FDPs starting at 0900 and ending 2200 with a 4 hour ground break, 2 sectors for Days 1, 3 and 5 ("long" days) followed by travel, allowing just 6 hours sleep
- FDPs starting 0900 and ending 2000, 2 sectors for Days 2 and 4 ("short" days) followed by travel allowing 8 hours sleep

This sequence has been considered with and without short sleeps during the on-ground breaks in the long days.

Figure 5.5: Alertness over a 5 day sequence of Day FDPs



Even in the case of no on-ground afternoon sleeps, average alertness over the FDP remains high through the 5 days with no sign of cumulative fatigue even with the reduced rest. Adding the sleep does increase alertness, so it suggests that even though average alertness scores are high, there is still some benefit of napping, particularly for the long days.

A similar sequence of FDPs was also modeled for 5 consecutive nights. While average alertness was lower than day FDPs (as expected) rather than show a deterioration over the sequence of duties indicating cumulative fatigue, average alertness improves showing adaptation to the sequence (see Appendix 4).

The modeling indicates that the Subpart Q limit on duty hours within a 7 day period appears as an effective mitigation for shorter term cumulative fatigue. It should be noted that such sequences of 5 consecutive day or night FDPs are unlikely to occur for on-demand air taxi services.

5.7.1.3 Other Potential Mitigations

As well as limits on cumulative duty/ flying over weekly/ monthly and annual periods, other potential mitigations could be incorporated into the options for managing cumulative fatigue. These may include:

- **Minimum number of days off per month** – there is a lack of scientific evidence regarding the impact of this measure on cumulative fatigue. The Working Time Directive requires a minimum of 7 days off per month.
- **Spread out duty as evenly as possible** – good practice but difficult to apply in ATXO.
- **Rest period increased periodically** – Subpart Q requires a weekly rest period of 36 hours including 2 local nights. National Authorities may decide that the second of those local nights may start from 20.00 hours if the weekly rest period is at least 40 hours. The survey of eight States (Appendix 3) shows that about half of the National Authorities do allow this.
- **Cumulative fatigue mitigations related to WOCL encroachment and split duty** – see Table 3.2.

5.7.2 Economic and Social Impacts of FTL Changes Related to Cumulative Fatigue

Those economic and social impacts which are judged likely to be most significant following proposed regulatory changes are tabulated below.

Table 5.3: Economic and Social Impacts Associated with Potential Changes to Cumulative Limits

Potential change	Reference situation in Europe	Identification of generic economic/ social impacts	Factors which will affect size of impacts
Changed harmonised limits on weekly, monthly, annual duty/ block hours	Subpart Q cumulative duty hours and block hours limits	New regulations on cumulative limits, if different from current practices, will lead to crew reaching limits more quickly/ slowly and impacting the productivity and costs of crew.	Depends on how current hours compare to whatever new limits are proposed. For smaller operators with less crew, effects are likely to be proportionally larger.
Harmonisation of weekly extended rest	Subpart Q OPS 1.1110 para. 2.1 allows for National Authority acceptance of changed hours for second night rest	Existing flexibility in Subpart Q allows some operators to begin operations at 06.00. Removing this flexibility could impact some of the services that ATXOs currently provide with economic impacts.	Percentage of operator's flights currently based on flexibility provided by Subpart Q OPS 1.1110 para. 2.1.

5.8 Standby Related Hazards

The use of short call home standby is used by many European AT operators (see Section 3.2). Long call home standby (at least 10 hours before start of an assigned duty) is not considered below as safety impacts are not considered so significant and is not so relevant to AT on-demand operations.

5.8.1 Safety Impacts of FTL Changes Relating to Standby

The key issues associated with this hazard are:

i. Maximum duration of standby
ii. Taking account or not of standby time in FDP hours and duty hours and subsequent rest calculations
iii. Other potential mitigations.

5.8.1.1 Maximum Duration of Standby

In terms of the scientific literature the Principles and guidelines for duty and rest scheduling in Commercial Aviation 'NASA Study' (Dinges et al., 1996) does not consider 'on call reserve status' as duty, but recommends that 'a protected 8 hour sleep opportunity' should be protected from interruption by assignment to a flight duty period.

Crew Factors in Flight Operations XI: A Survey of Fatigue Factors in Regional Airlines Operations (Co, E., 1999) notes that: '*The nature of flying on reserve means that crewmembers must respond when called for duty, thus creating unpredictability in their schedules. This unpredictability can lead to sleep loss, for example, when a call for duty occurs when a sleep period was planned. As evidence that sleep loss occurred,* *crewmembers reported getting 5.6 h of sleep before duty on average—2.3 h less than their normal average sleep*.'

The survey of national FTL provisions in Appendix 3 revealed maximum short call home standby durations of 12 hours, 14 hours and 24 hours renewable. The degree to which crew can obtain 8 hours sleep during a 24 hours standby is unclear.

If an operator is using different standby types it can be possible to use the crew on 24 hours standby as a "last resort" and hence minimize the chance that their sleeps will be disturbed (see below under "Other potential mitigations"). Hence the scale of safety significance and the impact of changing maximum standby duration is uncertain.

Thus this is an issue where operational experience will have a large input in future RMT discussions rather than the scientific literature or modeling. A key question is – does operational experience (and any outputs from FRMSs) show that AT pilots and single pilots on other services are able to get 7-8 hours sleep when on 24 hour standbys?

5.8.1.2 Taking Account of Standby Time in FDP Hours, Duty Hours and Subsequent Rest Calculations

There is very little scientific research covering this topic. However, Torsvall and Akerstedt (1988) showed that sleep quality is affected in ships' engineers based on whether they are on-call or not. Changes in sleep quality were noted before any alarms went off, suggesting that sleep was disrupted in anticipation of being called out for duty.

The survey in Appendix 3 revealed wide variation in this issue. Clearly reducing the allowable FDP length to allow for some/ all of the standby time before a callout will, on average, reduce the chance of crew fatigue. However, it will also reduce the ability of the AT operator to provide a service to their customers and/ or have economic impacts (see below).

CAS modeling

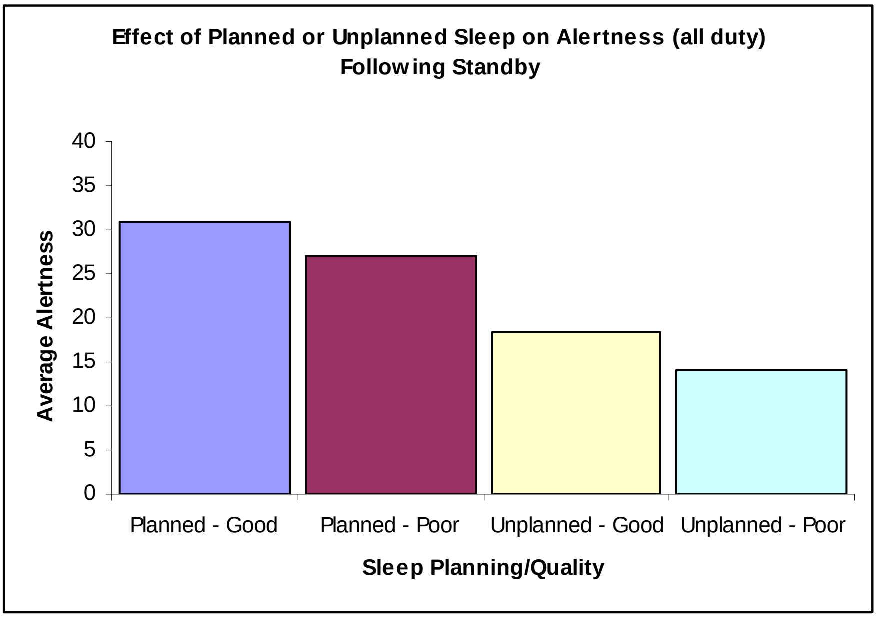
To investigate the potential impacts of home standby on subsequent FDPs if called out the following scenario has been modeled:

FDP starting at 22.00 and finishing at 09.00 following a call out from home standby with the following features of the home standby:

1. A good night's sleep preceding the FDP (8 hours) and fatigue planning in terms of 2 naps mid-afternoon and prior to leaving for the FDP (termed "Planned – Good" in graph below).
2. A poor night's sleep preceding the FDP (6 hours) and fatigue planning in terms of 2 naps mid-afternoon and prior to leaving for the FDP (termed "Planned – Poor" below).
3. A good night's sleep preceding the FDP (8 hours) and no naps prior to leaving for the FDP (termed "Unplanned – Good" below).

4. A poor night's sleep preceding the FDP (6 hours) and no naps prior to leaving for the FDP (termed "Unplanned – Poor" below).

Figure 5.6: Alertness during a night FDP following home standby



The graph indicates that the measures taken by crew during home standby and the circumstances that could arise during home standby can have a significant impact on the fatigue and alertness during a subsequent FDP. Awareness training and guidance to crew as part of FRMS is clearly important (see below).

Accounting for home standby hours in duty hours (either in full or in part) would affect the time it takes to reach cumulative limits with economic impacts, reviewed below. In terms of safety the impacts are less easy to predict. In general AT crews fly less annual hours than other types of pilots and cumulative fatigue is less of an issue than peak fatigue after long, disrupted missions. New provisions that lead to extra rest requirements and fewer flights per year might affect pilot competence and hence flight safety if crew hours drop too low. These various safety impacts will need to be considered.

Thus this is an issue where operational experience will again have a large input in future RMT discussions rather than the scientific literature or modeling. Key questions include – does operational experience (and any outputs from FRMSs) show that AT and single pilots are able to manage time at home so they do not arrive fatigued for FDPs, what fatigue training and awareness do they receive concerning home standby and do they obtain sufficient overall rest to manage cumulative fatigue? Fatigue training and awareness could cover use and quality of pre-FDP naps, effect of meal and drinks, effects of home based tasks on fatigue, etc.

The focus of the analysis above has been on home standby – however, the broad issues also apply for hotel standby. For airport standby, Subpart Q requires this to count in full for the purposes of cumulative duty. However, the issues of what relationship there should be between the time on airport standby and any subsequent FDP and what rest period should follow an airport standby not leading to an FDP are applicable.

5.8.1.3 Other Potential Mitigations

Other potential mitigations include:

- FRMS and crew's individual management of rest during standby – a FRMS can help raise crew's awareness of the importance of napping, avoiding heavy home working tasks, etc.
- Establish different levels of readiness
- Management of standby so operator avoids placing crew on repeated 24 hr duration standbys, and preferential use of persons on standby who should be better rested.
- Developing harmonized FTL requirements for standby other than at home, i.e. hotel, airport and elsewhere.

5.8.2 Economic and Social Impacts of FTL Changes Relating to Standby

Those economic and social impacts which are judged likely to be most significant following proposed regulatory changes are tabulated below.

Table 5.4: Economic and Social Impacts Associated with Potential Changes to Standby Provisions

Potential change	Reference situation in Europe	Identification of generic economic/ social impacts	Factors which will affect size of impacts
Harmonised limit on standby duration	Varied national provisions up to a maximum of 24 hours (see Appendix 3).	If limit on standby duration is reduced (e.g. 24 hours to 12 hours) this is likely to increase crew costs although this may vary depending on how the standbys are organised. 24 hour standby can have a negative social effect for crew relative to 12 hour standby as it does not allow relaxation time, e.g. going out in the evening. On the other hand having to conduct 12 hour standbys twice as often as 24 hour standbys can also have social impacts for crew.	The extent will depend on what standby patterns operators are currently using and how much reliance is being placed on longer home standbys.

Potential change	**Reference situation in Europe**	**Identification of generic economic/ social impacts**	**Factors which will affect size of impacts**
Harmonisation of the contribution of standby to FDP, duty hours and subsequent rest calculations	Varied national provisions for contribution of home standby to FDP and cumulative duty hours can vary from 100% to 0%, depending on State and associated factors (see Appendix 3).	If available FDP duration is effectively changed by inclusion/ exclusion of a contribution from home standby time this will have similar impacts to those potential FDP changes set out in Table 5.1. If home standby which does not lead to a duty is proposed to be followed by a rest period (e.g. in accordance with ORO.FTL.235) and no rest has been accorded before, there will be a reduction in average crew availability and a need for higher crew costs to maintain service level to customers. Reaching cumulative duty hour limits earlier or later due to potential changes in the manner in which standby hours are counted in cumulative duty time could also impact service provision and/ or impact crew costs.	Frequency of standbys. Duration of extra rest periods following standby based on proposed change. Degree of proposed contribution of standby hours to FDP and duty hours.

An indication of the process for determining the economic impacts of proposed changes is illustrated by the following example relating to additional rests following home standby that does not lead to duty:

- Assume that a regulatory change leads to a new requirement for X hours rest following a Y hour home standby.
- Assume an average of Z days home standby per crew member, with average of Y hours per standby.
- New requirement would introduce Z × X hours of extra rest per year.

In addition operational data would be needed on how often a mission occurs immediately after a standby period and hence whether the extra rest would necessitate an increase in the operator's crew numbers.

5.9 Hazard D1, Lack of Sleep Opportunity

5.9.1 Safety Impacts of FTL Changes to Basic and Reduced Rest

5.9.1.1 Literature Review and States' Survey

How much rest an individual needs between duties/ FDPs is reviewed in Section 4.5. A single event of shortened sleep in a person who otherwise has been obtaining adequate sleep can be tolerated without excessive fatigue risk. However, the number of days when these short sleep episodes occur must be strictly limited because shortened sleep episodes over consecutive days results in chronic sleep deprivation. Performance levels decrease and the chance of errors and accidents increase as sleep reduces below 7-8 hours per night.

The minimum rest requirements in Subpart Q OPS 1.1110 (applicable to Air Taxi and single pilot operations) for home and away from home base enable an 8 hour sleep opportunity. Some States in the survey (see Appendix 3) allow reduced rest between duties with certain mitigations in place. These mitigations include those listed in Section 5.9.1.3. The STARE project (Air Transport Safety – Fatigue Risk) found that predictive models indicated that fatigue risk levels for morning duties following a reduced rest varied widely from one schedule to another. For rosters including a reduced rest, the STARE project (summarised in EASA, 2010) found that the average sleepiness level during morning duties after a reduced rest is close to that observed on the last flights of the day, prior to reduced rest, indicating low recuperation during the rest. CAS modelling has been conducted to complement the existing literature.

5.9.1.2 CAS Modeling

The sequence of FDPs used to investigate the potential for cumulative fatigue in section 5.7 (see Figure 5.5) included reduced rest between consecutive FDPs allowing only 6 hours sleep. These did not lead to low alertness averaged across the FDPs nor the development of cumulative fatigue as predicted by the modeling. However, scientific evaluation of helicopter pilots working 7 consecutive days where sleep was dropping below 6 hours per night did show clear signs of cumulative fatigue (Samel et al., 2004).

5.9.1.3 Other Potential Mitigations

In addition to setting minimum rest periods and limits on reduced rest, other potential mitigations for lack of rest that could be considered are:

- Setting different minima for rest period at home base and out of base to cover travelling time and protect sleep opportunity
- Augmentation of rest period following reduced rest
- Reduced maximum FDP following reduced rest
- Limiting the frequency of reduced rest occasions
- Limiting the length and number of sectors after reduced rest
- Ensuring reduced rest encompasses entire WOCL
- Specifying minimum accommodation requirements for reduced rest
- Not allowing rest reduction when FDP is extended by in-flight rest or when there is crossing of multiple time zones

- Special rules if reduced rest is combined with split duties (see French regulations in Appendix 3)
- The identification via a FRMS of factors that can reduce the quality of sleep, e.g. a noisy or uncomfortable hotel room, and resulting preventive actions.

5.9.2 Economic and Social Impacts of FTL Changes to Off-Duty Rest

Those economic impacts which are judged likely to be most significant following proposed regulatory changes are tabulated below.

Table 5.5: Economic and Social Impacts Associated with Potential Changes to Off Duty Rest Provisions

Potential change	**Reference situation in Europe**	**Identification of generic impacts**	**Factors which will affect size of impacts**
Removing possibility for reduced rest	Minimum reduced rest in different States varies from: • Sufficient to allow 10 hours at accommodation • 10 hours out of home base, 12 hours in base. Minimum of 9 hours at accommodation • Minimum of 10 hours • 7.5 hours including 2 hours at least within WOCL + mitigations	May need extra crew to provide services currently being provided by crew after reduced rest. Alternatively service provision to customers may be reduced. Both have potential economic impacts.	Frequency with which reduced rests are currently taken.
Harmonising minimum hours for reduced rest	As above.	If the proposed regulatory minimums are significantly different from current national rules, the impacts could be similar to row above.	As above.

5.10 Relaxation and Naps During On Ground Breaks

5.10.1 Safety Impacts of FTL Changes to Relaxation and Naps during On Ground Breaks

Sections 4.6 and 4.7 review the literature related to napping between flights. If taken between flights, a brief nap can benefit alertness and performance. The nap should be limited to 15-20 minutes, or 90 minutes. Shorter naps (10-20 minutes) are less likely to be associated with the phenomenon of sleep inertia (a short period of impaired alertness upon awakening). This is because in this amount of time, the individual will usually remain in light sleep and would not reach deep sleep. It is easier to wake up from light sleep and the individual will regain full alertness faster than waking up from deep sleep. In the case of long naps, sleep periods of approximately 90 minutes allow the completion of a full sleep cycle, and the individual wakes up from light sleep or REM sleep, which minimizes sleep inertia. On the other hand, naps of 40-60 minutes would result in the individual waking up from deep sleep, and that will result in more severe and long lasting sleep inertia. Sleep inertia can be associated with a performance decrement lasting for a few minutes to 35 minutes, though effects usually seem to dissipate in about 10 to 15 minutes (Robertson and Stone, 2002, Rosekind et al 1994).

Another potentially negative consequence is that the nap can theoretically disrupt the duration or quality of a later sleep period.

The CAS modeling in sections 5.3 and 5.7 above indicate that sleeps during on ground breaks, especially during the night, can provide significant benefits in terms of managing fatigue. In addition, providing fatigued employees with an opportunity for a nap before driving home at the end of a long FDP will theoretically decrease the risk of accidents while driving fatigued.

The main mitigation for the hazard of sleep inertia (E1 from Table 3.2) is awareness training and the provision of guidance. There are no obvious FTL regulatory changes of relevance to this hazard.

5.10.2 Economic and Social Impacts of FTL Changes to Relaxation and Naps during Ground Breaks

The provision of awareness training and guidance as part of FRMS are not considered to have significant economic or social impacts. If upgraded rest facilities are required to facilitate napping between flights, this is addressed in section 5.3.2.

5.11 Hazard A2, Pilot in Command Discretion

5.11.1 Safety Impacts of FTL Changes to PIC Discretion

The facility for the PIC to extend an FDP is considered in the ranges of FDPs modeled in Section 5.1. As well as providing maximum limits on this extension other potential mitigations could be:

- A non-punitive process for a PIC to reduce a duty duration and/or increase rest in the case of fatigue
- Training on fatigue to support PIC in the decision process (part of FRMS)
- Reporting to the NAA when the extension is above a certain threshold
- Guidance to the NAA on this subject.

5.11.2 Economic and Social Impacts of FTL Changes to PIC Discretion

The main impact would be related to the duration of the extension period that is under the PIC's discretion. The impacts of changing extended FDP limits are considered already in Section 5.1.

Other economic impacts will be related to the setting up and administration of any new or updated processes related to training, reporting and guidance.

5.12 Positioning and Travelling Related Hazards

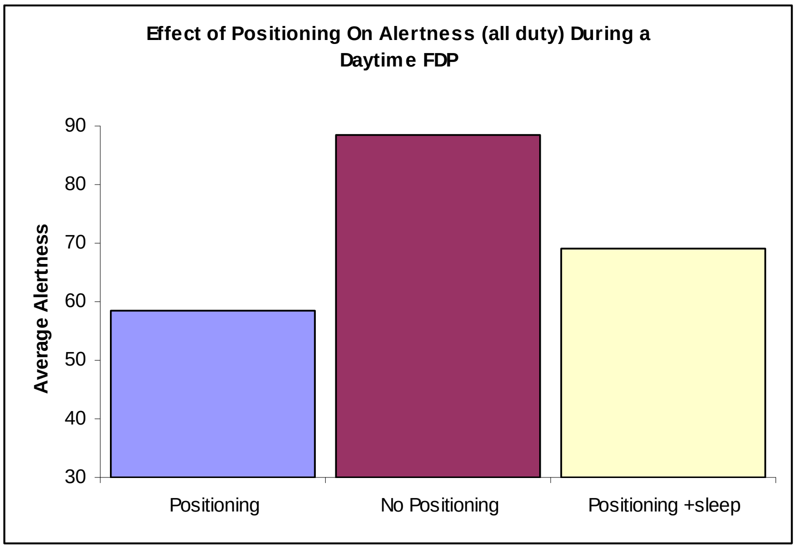
The relevant hazards are:

- Positioning before an FDP which could lead to excessive time awake towards the end of a mission (F1, Table 3.2)
- Positioning immediately after an FDP which could lead to excessively long duty periods with a cumulative effect (F2, Table 3.2)
- Excessive travelling time contributing to transient and cumulative fatigue (F3, Table 3.2)

5.12.1 Positioning

CAS modeling has been used to investigate positioning prior to a day FDP. The scenarios involved an FDP from 07.00 to 20.00 with "No Positioning" prior to FDP, Positioning involving a flight during the night with no sleep and Positioning during the night with some sleep. The results in terms of average alertness during the FDP are shown below. Further details of the scenario modeling are included in Appendix 4. The extra time awake caused by pre-FDP positioning increases fatigue and this is only partially offset if sleep can be taken during the night positioning.

Figure 5.7: Effect of Positioning on Alertness



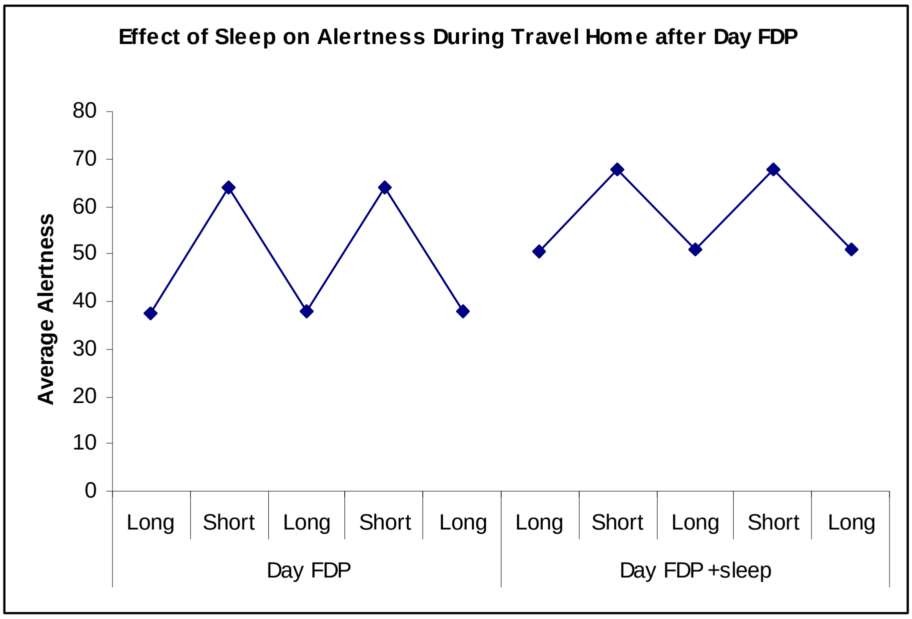
The following mitigations from Subpart Q (applicable for air taxi and also applied for single pilot operations based on the survey in Appendix 3) are relevant for positioning:

- Counting position duties as FDP when immediately prior to FDP (supported by results above)
- Rest being based on the duty hours which counts positioning in full.

5.12.2 Travelling

The potential for excessive traveling times contributing to fatigue is relevant to AT as for other operations. As noted in section 4 there is a lack of literature and knowledge about the impact of travel on fatigue risk. Long travel durations prior to an FDP could lead to excessive times awake by the end of the FDP. In section 5.7 where sequences of day FDPs are modeled it is noticeable that the alertness during the travel home is noticeably lower for the "long days" (see Figure 5.8 below). Figure 5.8 shows that the alertness during the travel home can be low as long travel times push this into the late evening hours and extend the time awake. Providing facilities for crew to nap after long FDPs can reduce road accident risk.

Figure 5.8: Alertness during Travel Home After FDPs in Section 5.7.1



The following mitigations are likely to be relevant in terms of flight safety:

- Nomination of a home base for each crew member (part of Subpart Q)
- Ensuring a protected 8 hour sleep opportunity (part of Subpart Q)
- Counting travel time in excess of a limit (e.g. 60 minutes) as duty time (or positioning)
- Napping during ground breaks to reduce fatigue at the end of long days created by long duration FDPs and travel.

The EBAA survey data (see Table 3.1) on crew travel times from home to home base showed a mean time of 1.5 hours based on almost 750 responses. Thus introducing a limit such as 60 minutes over which travel counts as duty time or positioning could have significant economic impacts. If this causes movement of crew closer to bases there could also be social impacts. Further data collection and analysis would appear worthwhile on this topic.

6.0 Conclusions

Air Taxi operations (ATXO) have certain characteristics that can potentially create challenges to managing fatigue hazards. These characteristic include:

- On demand operations with the majority at short notice;
- Large amount of standby at home with a relatively low chance on average of being called out;
- Frequent change of schedule/routing; this can include duty start times being put back or brought forward;
- Many of the flights (especially on the small and light jet segments) leave in the morning and come back in the evening. In between, pilots are often waiting in crew rest facilities or on the aircraft on split duty;
- Passenger requirements can lead to planned on-ground breaks being curtailed or alternatively ad-hoc split duties being needed;
- Considerable use is made of positioning of crew and aircraft relative to scheduled flights; and
- Significant time zone (TZ) crossings occur for long range ATXO.

A survey of eight European States has showed that there is a range of national provisions for addressing split duty, additional rest for TZ crossings, reduced rest, in-flight rest and standby at the airport and elsewhere.

Single Pilot operations (SPLO) occur in the Air Taxi, scheduled airline and AEMS sectors. They have the potential for leading to additional workload relative to multiple crew and hence could impact fatigue. Thus long duration flights/ FDPs are addressed in some national provisions in a variety of ways.

Given the range of national FTL provisions for ATXO and SPLO, European harmonisation of these FTL provisions is likely to have safety, economic and social impacts. These are investigated at a preliminary level in this report.

This report provides information and preliminary analysis to be considered for the RIA development for RMT. 0429 on FTL for Air Taxi and Single Pilot operations with a view to assist in an overall balanced assessment of safety, social and economic impacts.

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8.0 Acronyms/ Abbreviations

Term	Description
AAIB	Aircraft Accident Investigation Board
ADREP	(ICAO's) Accident Data Reporting system
AEMS	Aeroplane Emergency Medical Services
API	American Petroleum Institute
ATXO	Air Taxi Operations
BA	Business Aviation
CAA	Civil Aviation Authority
CAP	Civil Aviation Publication
CAS	Circadian Alertness Simulator
CAT	Commercial Air Transport
CM	Crew Member
CRD	Comment Response Document
CS	Certification Specification
CVR	Cockpit Voice Recorder
d/yr	Days per year
DNV	Det Norske Veritas
EASA	European Aviation Safety Agency
EBAA	European Business Aviation Association
EEG	Electro-encephalography
EMS	Emergency Medical Services
ETSC	European Transport Safety Council
EU OPS	European Union (Safety Regulations) Commercial Air Transportation Operations
FAA	Federal Aviation Administration
FDP	Flight Duty Period
FDT	Flight Duty Time
FMCSA	Federal Motor Carrier Safety Administration
FRM(S)	Fatigue Risk Management System
FTL	Flight Time Limitations
GA	General Aviation
GDP	Gross Domestic Product
GVA	Gross Value Added
h or hrs	hours
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
IR	Implementing Rules
JAR OPS	Joint Aviation Requirements on Commercial Air Transportation Operations
MSLT	Multiple Sleep Latency Test
MWT	Maintenance of Wakefulness Test

Term	Description
NAA	National Aviation Authority
N/A	Not Applicable
NASA	National Air and Space Administration
NM	Nautical Miles
NPA	Notice of Proposed Amendment
N/R	Not Relevant
NTSB	National Transportation Safety Board
PF	Pilot Flying
PIC	Pilot In Command
REM	Rapid Eye Movement
RIA	Regulatory Impact Assessment
RMG	Rule Making Group
RMT	Rule Making Task
SPLO	Single Pilot Operations
SRG	Safety Regulation Group
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organisation for Applied Scientific Research)
TZ	Time Zone
ULR	Ultra Long Range
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
WOCL	Window Of Circadian Low

Appendix 1 – Air Taxi and Single Pilot Safety Data with Fatigue as a Causal Factor

1. Data from EASA's Safety Analysis Section

EASA's Safety Analysis Section conducted a search of the EASA copy of the ICAO ADREP data base. The EASA copy of IACO ADREP data base contains 215 air taxi operations occurrences between March 2, 1998 and March 21, 2012. Only one accident (in the US) could be associated to pilot fatigue, meaning that in 0.5% of air taxi operations occurrences pilot fatigue was involved.

With regards to aeroplane single pilot operations EASA's copy of ICAO ADREP data base contains 32046 occurrences registered until March 21, 2012. Pilot fatigue is indicated as a contributory factor of an occurrence in 139 events. Expressed as a percentage, 0.4% of single pilot aeroplane operations occurrences can be related to pilot fatigue. EASA's Safety Analysis Section have supplied narratives to 13 European occurrences; in 5 cases the narratives specify useful information about the circumstances leading to fatigue and are reproduced below.

<u>Single Pilot – 5 occurrences</u>

Occurrence 1 – 1986, UK, Britten – Norman – BN – 2A MK3 Trislander, CAT, 0 fatalities

THE PILOT TOOK OFF AT 0030 HRS FOR A NIGHT FLIGHT TO AMSTERDAM, WHICH WAS COMPLETED WITHOUT INCIDENT. **HE THEN HAD 2 HRS SLEEP** AND DEPARTED AT 0500 HRS FOR A VFR FLIGHT TO STANSTED AT 1000 FT. WHILE OVER THE SEA, HE BRIEFLY FELL ASLEEP, DESPITE FEELING WELL RESTED. HE FELL ASLEEP AGAIN AND THE A/C HIT THE SEA SUSTAINING SUBSTANTIAL DAMAGE TO ITS LANDING GEAR, INCLUDING COMPLETE LOSS OF THE RIGHT GEAR. THE A/C BECAME AIRBORNE AGAIN AND THE PILOT NOTED THAT ALL THREE ENGINES WERE DELIVERING REDUCED POWER DUE TO CARBURETTOR ICING. THE FLIGHT WAS CONTINUED AND THE PILOT LANDED WITH LITTLE ADDITIONAL DAMAGE TO THE A/C. >THE CAA HAVE INSTRUCTED THAT TWO PILOTS ARE TO BE EMPLOYED ON ALL NIGHT FLIGHTS UNDERTAKEN BY THE OPERATOR.

Occurrence 2 – 2004, France, Piper – PA – 31T Cheyenne, GA Pleasure, 3 fatalities

The pilot was on a flight from Ben Gurion Airport (Israel) to Toussus-le-Noble (France) with a stopover at the airport in Kerkyra Corfu (Greece). He filed an IFR flight plan with a scheduled departure at 5 am for an estimated 3hr 50min flight to Corfu. After refuelling, it took off again from Corfu at 10.41 on an IFR flight to Toussus-le-Noble. During the VOR-DME approach to runway 07L at Toussus-le-Noble at around 15.25, the pilot lost control and the aircraft fell in the middle of a forest along a nearly vertical trajectory.

Probable Causes

The loss of control probably resulted from significant airframe icing inadequately or belatedly addressed by the pilot. The possible contributing factors to the accident were:

1) Pilot fatigue caused by 8h 30min flying single pilot operations and being faced with quick icing phenomenon while the workload required by the approach was already high.
2) A desire to reach the destination field approach so that the pilot was excessively focused on his objective and encouraged to continue the approach without taking sufficient account of external phenomena.

Occurrence 3 – 2004, France, Gulfstream Aerospace – G V, GA Business, 0 fatalities

At 18:31:57, the pilot of a private business flight from New-York - La Guardia (KLGA) to Geneva, was handed over by Marseille Control to Geneva and called on the ARRIVAL sector control frequency. The aircraft was in the region of La Tour-du-Pin (LTP/VOR), at flight level FL 160. The pilot was cleared by the radar controller direct to point INDIS for a straight-in approach on runway 05, at flight level FL 160. The pilot asked the ARRIVAL radar controller to repeat the point to which he was cleared, without reading back the flight level. The ARRIVAL radar controller then gave him a heading of 025 degrees and the pilot read back this clearance.

At 18:32:07, the pilot of a scheduled flight between Lyon-St-Exupéry and Rome called the Geneva Initial South control sector (INS). The pilot was cleared by the radar controller to change to flight level FL 150 on the route PENAR - RISOR. The pilot informed him of traffic just above him. This was the GA business flight. The routes followed by the two aircraft intersected perpendicularly in the region of the La-Tour-du-Pin VOR.

According to his statements, the pilot of the GA business flight thought he was cleared to descend to flight level FL 130 and began his descent. He repeated the clearance to maintain flight level 160. At 18:32:27, the ARRIVAL radar controller issued essential traffic information to the pilot of the business flight, who replied that he had contact with the traffic. The pilot received the confirmation to maintain flight level FL 160. He then asked for confirmation that he was in fact to maintain flight level FL 160 and the radar controller again confirmed this clearance.

Despite these urgent instructions and during their transmission, the pilot of the business flight began a descent to flight level FL 130, to which the pilot, according to his statements, believed he was cleared. When the two aircraft were at a lateral separation of 4.7 NM and an altitude difference of 700ft, on converging headings, the Short Term Conflict Alert (STCA) was activated on the controller's radar screen. According to the radar plot, the private flight was at flight level 156. The INS radar controller immediately issued essential traffic information to the pilot of the scheduled operator, who replied that he was following his TCAS. Less than ten seconds later, when the routes of the two aircraft were still converging and the separation reducing, the ARRIVAL radar controller instructed the pilot of the private business flight to climb immediately to flight level FL 160, issuing him with further essential traffic information. The ARRIVAL radar controller asked the pilot of the private business flight if he had the traffic in sight. The pilot replied that he was at flight level FL 160, adding that he was obeying a TCAS resolution advisory.

The private flight then carried out a steep climb, passed flight level FL 160 for which he was cleared and continued to climb to flight level FL 171.

CAUSE
The incident is due to the fact that the pilot of the private business flight left the flight level cleared by ATC. The crew stated as the reason of this error the **effect of the circadian cycle (time difference) and fatigue.**

Occurrence 4 – 2005, Scotland, Britten-Norman Islander, AEMS, 2 fatalities (also appears in D2 report for EMS)

http://www.aaib.gov.uk/cms_resources.cfm?file=/Summary%20%20AAR%202-2006%20Pilatus%20Britten-Norman%20BN2B-26%20Islander,%20G-BOMG.pdf

On 15 March 2005, a Britten-Norman Islander aircraft crashed into the sea while descending toward Campbeltown Airport in western Scotland. The aircraft was operating an air ambulance flight on behalf of the Scottish Ambulance Service. The pilot and paramedic both died in the crash. Given the relevance of this accident to the current study quotes are taken from the UK AAIB report below.

AAIB Report No: 2/2006 Report on the accident to Pilatus Britten-Norman BN2B-26 Islander, G-BOMG, West-north-west of Campbeltown Airport, Scotland, on 15 March 2005

Abstract/ Summary

"*The Glasgow based Islander aircraft was engaged on an air ambulance task for the Scottish Ambulance Service when the accident occurred. The pilot allocated to the flight had not flown for 32 days; he was therefore required to complete a short flight at Glasgow to regain currency before landing to collect a paramedic for the flight to Campbeltown Airport on the Kintyre Peninsula.*

Poor weather at Campbeltown Airport necessitated an instrument approach. There was neither radar nor Air Traffic Control Service at the airport, so the pilot was receiving a Flight Information Service from a Flight Information Service Officer in accordance with authorised procedures. After arriving overhead Campbeltown Airport, the aircraft flew outbound on the approach procedure for Runway 11 and began a descent. The pilot next transmitted that he had completed the 'base turn', indicating that he was inbound to the airport and commencing an approach.

Nothing more was seen or heard of the aircraft and further attempts at radio contact were unsuccessful. The emergency services were alerted and an extensive search operation was mounted in an area based on the pilot's last transmission. The aircraft wreckage was *subsequently located on the sea bed 7.7 nm west-north-west of the airport; there were no survivors.*

The investigation identified the following causal factors:

1. The pilot allowed the aircraft to descend below the minimum altitude for the aircraft's position on the approach procedure, and this descent probably continued unchecked until the aircraft flew into the sea.

2. A combination of fatigue, workload and lack of recent flying practice probably contributed to the pilot's reduced performance.

3. The pilot may have been subject to an undetermined influence such as disorientation, distraction or a subtle incapacitation, which affected his ability to safely control the aircraft's flightpath."

AAIB Section on Pilot rest

"The pilot was rostered for a night standby duty on 14 March 2005, to be conducted from home and commencing at 2300 hrs. He had finished a two week leave period on 12 March, and had been rostered for a day off on the 13 March. During his leave he had gone on holiday to Italy with his family, returning to the UK on 9 March and travelling home on 12 March. He spent the remainder of the weekend at home with his family. On the evening of 13 March he had retired at about 2245 hrs and had an uninterrupted night's sleep. On the day of the 14 March the pilot awoke at about 0645 hrs and spent the day attending to domestic tasks. He was called at 2136 hrs by the operations officer and notified of the intended flight. He dressed and drove to work, arriving at about 2220 hrs. There was no indication that the pilot attempted or achieved any sleep during the day or early evening."

The aircraft took off about 23.30 after a short currency flight. The crash happened 15 March 2005 at 0018 hrs.

AAIB Section on Pilot fatigue

"The pilot was well rested prior to the day of the accident flight, and had achieved a normal sleep pattern for the 72 hours prior to the accident. He reportedly achieved about seven hours 45 minutes of sleep during the night and was not known to have suffered from any sleep disorders that may have reduced the quality of his sleep. The average human adult physiologically requires about eight hours of sleep for optimal performance and alertness, so the pilot was probably close to maximum 'sleep credit' at the start of the day.

Although he had been rostered a night standby duty, the pilot was called only infrequently on such duties and did not normally aim to achieve any sleep during the day. Such seems to be the case on the day of the accident. The difficulty of achieving sleep during the day preceding an initial night duty is well recognised, and for many individuals the best that can be achieved is a period of rest.

How long an individual remains awake is a physiological factor that can affect performance and alertness. Generally, performance and alertness can be maintained up to 12 hours of *wakefulness, after which some reduction in performance occurs. Sixteen to 17 hours of continuous wakefulness can be associated with significantly reduced performance and alertness. At the time of the accident the pilot had been awake for 17 hours 15 minutes and is therefore likely to have been suffering from fatigue to some extent."*

Occurrence 5 – 2005, UK, Reims – F172, GA Pleasure, 1 fatality

The pilot and aircraft had been involved in two consecutive days of banner-towing operations. The accident occurred on a positioning flight towards the end of the second day. Shortly after takeoff the aircraft was seen to turn left, with an increasing angle of bank, until it stalled and impacted the ground after turning through approximately 310º. Although the banner hook installation showed evidence of interference with the rudder, it was considered that this was not a factor in the accident. The most likely cause was a stall following the turn to the left with an increasing bank angle. This may have resulted from an attempt to maintain visual contact with a point on the ground, and would have been exacerbated by an increasing tailwind. It was also considered that the pilot may have been affected **by fatigue after the two intensive days of banner-towing**. Recommendations have been made relating to the banner hook installation and on fatigue associated with banner-towing operations.

2. Data from Sources Other than EASA

Air Taxi

Report on the accident to Bombardier CL600-2B16 Series 604, N90AG at Birmingham International Airport, 4 January 2002
www.aaib.gov.uk_cms_resources.cfm_file=_5-2004 N90AG.pdf

This accident on take-off caused five fatalities, two crew, two passengers and one non-flying observer. The investigation identified the following causal factors:
1. The crew did not ensure that N90AG's wings were clear of frost prior to take-off.
2. Reduction of the wing stall angle of attack, due to the surface roughness associated with frost contamination, to below that at which the stall protection system was effective.
3. Possible impairment of crew performance by the combined effects of a non-prescription drug, jet-lag and fatigue.

Flight Details and Fatigue Related Timings

N90AG was based at Dekalb Peachtree Airport (PDK), Atlanta, Georgia, USA. On 3 January 2002, the crew came on duty at 0900 hrs (0400 hrs local time in Atlanta) at PDK in preparation for a planned flight to the UK. The aircraft and crew departed PDK at 1015 hrs for a flight to Fort Myers Airport (FMY) in Florida to pick up a passenger. After landing at FMY at 1135 hrs, N90AG departed at 1200 hrs for a flight to West Palm Beach Airport (PBI) to pick up a second passenger. The aircraft landed at PBI at 1230 hrs and departed at 1259 hrs.

After an uneventful flight, N90AG arrived at Birmingham Airport at 2039 hrs.

The aircraft was parked on the Western Apron while at Birmingham. There was no precipitation while the aircraft was on the ground at Birmingham. Over the night of 3/4 January 2002 the air temperature remained below zero, with a minimum temperature of minus 9℃ at 0550 hrs.

The two pilots and the observer spent the night in a local hotel. Records indicated that they checked in at approximately 2115 hrs and had a meal and some alcohol between 2144 hrs and 2315 hrs, before retiring to bed. The handling pilot for the return to the USA made a phone call home at 0200 hrs.

The next morning, the handling pilot and the observer arrived at the aircraft together at approximately 1040 hrs. Aircraft refuelling commenced at about 1105 hrs and the aircraft fuel tanks were reported full at about 1140 hrs. Then, following the arrival of the two passengers, the aircraft doors were closed. The occupants were the same as on the arrival flight. During the morning, various witnesses had seen frost/ice on the wing surfaces of N90AG. Other aircraft had been de-iced during the morning, with associated reports of severe to moderate ice accumulation. Evidence from the Cockpit Voice Recorder (CVR) indicated that the operating pilots discussed the presence of frost on the leading edge prior to engine start. However, neither requested deicing and N90AG was not de-iced.

Following ATC clearance, engine start was at 1156 hrs and N90AG was cleared to taxi at 1201 hrs. At 1207 hrs, N90AG was cleared for takeoff and the crash occurred shortly after.

Single Pilot Events from the USA

USA Event 1, 2004

Reference: National Transportation Safety Board. 2006. *Special Investigation Report on Emergency Medical Services Operations.* Special Investigation Report NTSB/SIR-06/01. Washington, DC.

Dodge City, Kansas

On February 17, 2004, about 0256 central standard time, a Beech BE-B90 twin engine airplane, N777KU, operated by Ballard Aviation, Inc., was destroyed when it impacted terrain about 5 nautical miles (nm) northwest of Dodge City Regional Airport (DDC), Dodge City, Kansas. The single pilot, flight nurse, and flight paramedic were killed. The 14 CFR Part 91 positioning flight departed Wichita Mid-Continental Airport (ITC), Wichita, Kansas, about 0210 and was en route to DDC. Night VMC prevailed. The flight was on an IFR flight plan, but the pilot cancelled the IFR flight plan about 37 miles east of DDC and proceeded under VFR.

The Safety Board's investigation revealed that the pilot had been awake for as long as 21 hours at the time of the accident. Additionally, the accident occurred 14.5 hours after his duty day began. Recorded radar data indicate that the airplane initiated a gradual, straight-line descent toward the airport but flew past the airport before descending into the ground. No communications from the airplane were made during this descent, which suggests that the pilot was fatigued.

The Safety Board determined that the probable cause of this accident was the pilot's failure to maintain clearance with terrain due to pilot fatigue (lack of sleep).

USA Event 2, 2010

NTSB Identification: CEN10MA367

Nonscheduled 14 CFR Part 135: Air Taxi & Commuter operating as air ambulance

Accident occurred Sunday, July 04, 2010 in Alpine, TX

Aircraft: CESSNA 421B

Injuries: 5 Fatal.

The airplane impacted terrain shortly after takeoff. The extended landing gear and flaps degraded the climb performance of the airplane. The single pilot held an airline transport pilot certificate and had recent night flight experience. According to family members, the pilot normally slept from 2230 or 2300 to 0700; the accident occurred at 0015. Although the investigation was unable to determine how long the pilot had been awake before the accident or his sleep schedule in the three days prior to the accident, it is possible that the pilot was fatigued, as the accident occurred at a time when the pilot was normally asleep. The company did not have, and was not required to have guidance or a policy addressing fatigue management.

The National Transportation Safety Board determines the probable cause(s) of this accident as follows: The degraded performance of the airplane due to the pilot not properly setting the flaps and retracting the landing gear after takeoff. Contributing to the accident was the pilot's fatigue.

Appendix 2 – CAS Modeling Description

Introduction

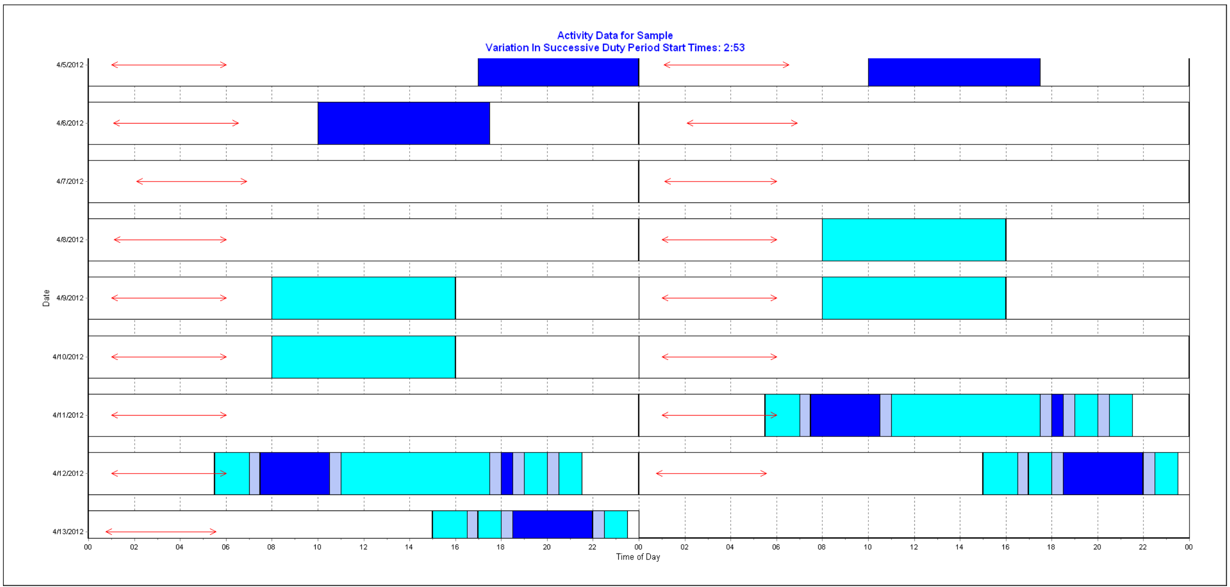
Circadian Technologies, Inc. has developed a Circadian Alertness Simulation (CAS) model that allows the assessment of fatigue risk based on sleep-wake patterns. Since the model includes an algorithm that predicts the most likely sleep pattern given a specific work pattern, it allows the evaluation of duty patterns for fatigue-related risk.

The impact of duty patterns on the alertness level and the resulting fatigue risks of an individual pilot are relatively uncertain and difficult to calculate analytically, especially if the individual sleep characteristics of the employee are not known. Here, the application of a simulation tool is particularly useful. Simulation models help us to understand when situations of extreme fatigue risk occur and why.

CAS – Model Concept

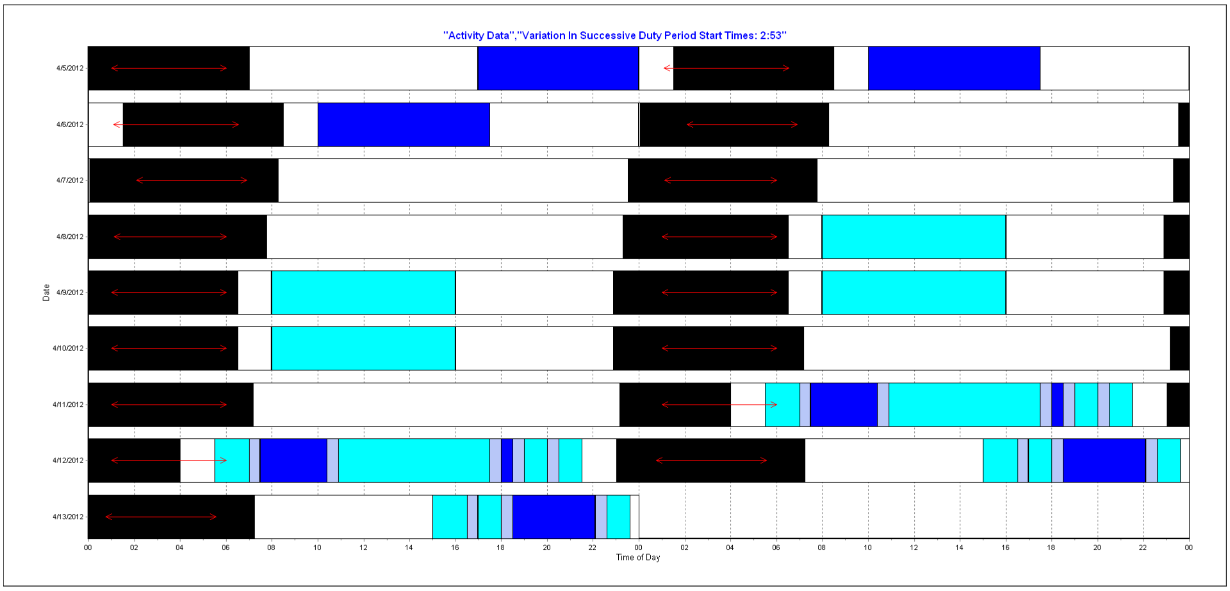
The CAS concept is based on the Three-Process Model of sleep regulation. A homeostatic component, a circadian component, and a sleep inertia component are combined to calculate an alertness curve. Figure 1 through 3 show the steps in the process between activity data (horizontal bars), the alertness calculation and the results output. Alertness at any specified point in time is entirely a function of all preceding data points. It therefore includes the effects of acute and cumulative fatigue.

Figure 1: Duty-Rest data without sleep



Based on the calculation of alertness, CAS5 predicts a sleep/wake pattern by triggering sleep when alertness reaches a certain lower threshold. The algorithm assumes sleep and calculates the subsequent data points assuming sleep until an upper wake-up threshold or an activity block (e.g., work, commuting) is reached. This capability was used for the model validation and it allows the analysis of data where there is no information about the person's actual sleep pattern (e.g. duty logs, time and attendance data, proposed work schedules).

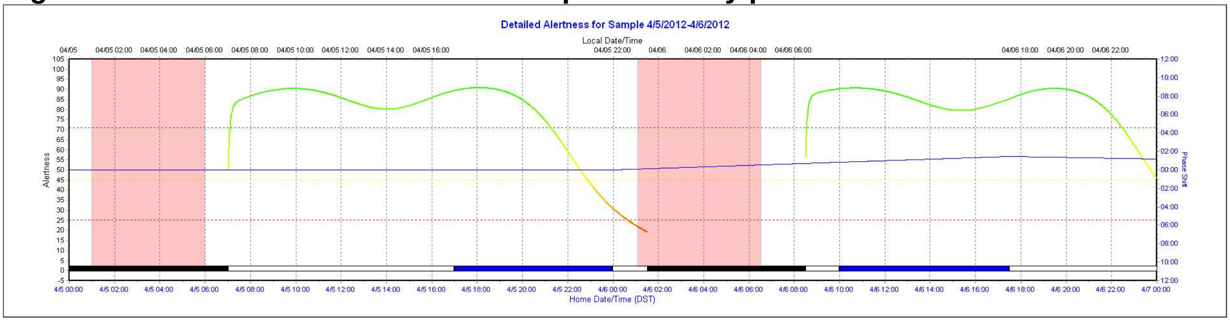
Figure 2: Duty-Rest data with sleep (black blocks)



After CAS5 has added sleep into the duty pattern, the model can now calculate an alertness value based on the three processes mentioned before:

- Alertness decreases during duty and non-sleep and increases during sleep (homeostatic component)
- Alertness fluctuates throughout the day (circadian component)
- Alertness is temporarily lowered after sleep depending on length of sleep and level of alertness on wake-up (sleep inertia component).

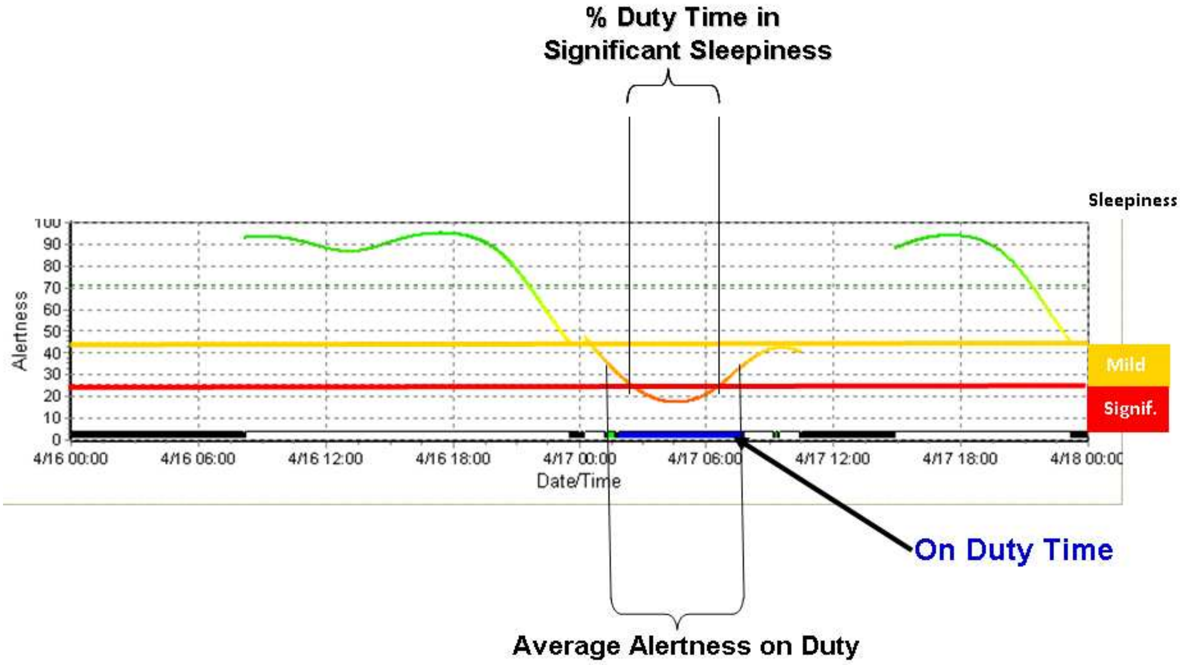
Figure 3: Alertness curve based on Sleep-Wake-Duty pattern



The CAS5 model can adjust various parameters of the model to reflect individual sleep profile properties (morning vs, evening type, long sleeper vs. short sleeper, habitual wake-up time, napping propensity, etc.). These adjustments affect the alertness calculation. However, at a planning stage there cannot be an individual profile since it is not known which specific person will work any of the simulated patterns.

The calculated alertness can then be used to analyze specific moments or periods in time, i.e. alertness at the end of a duty period, alertness during a scheduled flight/sector.

Figure 4: Sleepiness During a Specified Duty Pattern



Appendix 3 – Survey of National FTL Provisions

Air Taxi

The survey of the eight states focused on the Article 8.4 issues. These are preceded by a table of the definitions used in different states for "Air Taxi".

Definitions of Air Taxi (if different from EASA proposal)	
UK	Air Taxi/Sole Use Charter - in the context of CAP 371, Annex B which addresses Air Taxi/ Sole Use Charter, this term is applicable when the operator utilises an aircraft which contains 19 or less passenger seats, and: a) flights are confined to an area within which the local time does not vary by more than 2 hours, and b) the application of in-flight relief to extend an FDP is not used.
Switzerland	No information received
Spain	The Spanish national regulation neither provides a definition of Air Taxi Operations nor specific requirements for them.
Germany	There is no legal definition.
France	The French FTL regulation does not refer to "air taxi operations", but implements specific requirements for operators using : - aircraft with a MCTOM of less than 10t or - aircraft with MOPSC of 19 seats or less The "non-scheduled" or "on demand" criteria are not used.
Norway	EASA proposed definition used. No specific rules for Air Taxi though.
Poland	EASA proposed definition used.
Czech Republic	The legislative framework for the operation of aircraft in the Czech Republic does not specify Air Taxi category. This type of operation is not conducted under any special requirements and operators hold a certificate for commercial air transport only. Requirements for CAT (Aeroplanes) operators are defined in Subpart Q of Annex III to Regulation (EEC) No 3922/91. There are no additional national provisions.

Split Duty	
UK	**CAP 371 applies to all air taxi operations (Section B, Para 16)** When an FDP consists of two or more sectors - one of which can be a positioning journey counted as a sector - but separated by less than a minimum rest period, then the FDP may be extended by the amounts

<table>
<tr><th colspan="2">Split Duty</th></tr>
<tr><td></td><td>indicated below.

Consecutive Hours Rest — Max. FDP Extension
Less than 3 hours — NIL
3-10 hours — A period equal to half the rest taken

The rest period shall not include the time allowed for immediate post flight and preflight duties, a minimum total of 30 minutes. When the rest period is 6 hours or less it will suffice if a quiet and comfortable place, not open to the public, is available. Rest may be taken in the aircraft on the ground only when the crew has adequate control of the temperature and ventilation within the aircraft, and the passengers are not on board. If the rest period is more than 6 consecutive hours, then suitable accommodation will be provided.</td></tr>
<tr><td>Switzerland</td><td>Below is a standardized sample for the application of a split duty model as accepted by the Swiss NAA:

A split duty must be defined and announced to the crew before the beginning of the FDP.

Consecutive hours break — Increase in FDP
0-3 hours — NIL
3-7 hours — ½ length of break
7-10 hours — 2/3 length of break or full length if 7 hours of the break fall between 2000-0800 local time

• Parts of the FDP before and after the break may not be longer than 10 hours.
• The total length of the increased FDP must not be more than 20 hours including the break.
• Only one break may be used for applying split duty rules.
• Split duty rules may not be combined with augmented flight crew rules.
• Suitable accommodation must be provided if planned break is 6 hours or more or when the break is covering 3 hours or more of the period 2200-0600. Otherwise adequate facilities must be provided.
• If during a break for split duty the traveling time in both directions between place of rest and airport exceeds 1 hour, any travelling time in excess of 1 hour shall be deducted from the break for the purposes of calculating increase in FDP.
• The time difference between where the duty starts and where it ends shall not exceed two hours.
• No reduced rest period shall be applied immediately prior to or after a split duty.</td></tr>
</table>

Split Duty	
Spain	Extended FDP due to split duty = + 50% of the rest time in suitable accommodation if, -Minimum rest 3 hours -Max FDP increase due to split duty of 4 hours or 50% of the time in the rest facility, whichever is most restricted, is allowed - Number of extended FDP due to split duty is limited to 3 times in 7 days - Further extension not allowed; e.g. by in flight rest. For more information, see article 5 Real Decreto 1952/2009.
Germany	**1. DvLuftBO, §11 Split flight duty time** If the flight time in OPS 1.1105 or § 10 schedule is interrupted by a pause of at least three hours and a secluded room with sleeping accommodation is available for the member of the crew during a break in the immediate vicinity of the airfield the related service period could be extended up to 18 hours. Extra conditions associated with this extension include: • Not being PF after 10 hours • No more than two landings planned after the break • No more than 2 split duties within 7 consecutive days • No more than 2 extensions within 7 consecutive days arising from split duties + in-flight rest
France	Same as for CAT operations, i.e: a. Minimum consecutive number of hours for the break : 3h ≤ break ≤ 10h b. Maximum Flight Duty Period (FDP) based on the length of the break : FDP< FDPmax +0.5 (break-30min) c. Suitable accommodation for the break: - Break <6h : comfortable and quiet place with no public access +…(minimum conditions to be included OPS manual) - Break ≥6h : suitable accommodation d. Take account of non acclimitisation: crew must have spent at least 48h in the time zone where the split duty begins, if a preceding duty was more than 3 time zones away from home base. For Air Taxi operations, it is of utmost importance to maintain the possibility to take the break inside the aircraft (accommodation may not be available for all destinations). Conditions for taking the break inside the aircraft are the following : - Minimal noise, temperature, light, ventilation conditions are included in the ops manual - Temperature and ventilation can be adjusted - No pax is on board - No interference with on ground operations (catering…) that might compromise the rest during the break. Otherwise, the possible extension is decreased by half the duration of said operations.

Split Duty	
	See provisions concerning combination of split duty and reduced rest below.
Norway	The following is valid for all operators that are using Subpart Q. Provisions for split duty are 1) break on ground counts 50%towards max FDP provided a rest facility with bed is available 2) if break is planned to be >4hrs then time is = 0 towards max FDP.
Poland	Regulation of the Minister of Infrastructure, 2002 - Journal of Laws, § 13 1. If the working time is divided by a planned ground break which is included in the timetable, the time for carrying out aviation activities, shall be extended as follows: 1) a break of 3-6 hours and 59 minutes – extending by ½ of the break time; 2) a break of 7-9 hours and 59 minutes – extending by 2/3 of the break time or 1 ½ of the break time, provided that the break was between 20:00 and 8:00 local time 2. Extending the time of carrying out aviation activities, referred to in par. 1, before and after the break, shall not exceed 8 hours, and the working time extended in this way shall be no longer than 18 hours. 3.Only one break is allowed in the course of one period of carrying out aviation activities. 4.Provisions of par. 1-3 shall not apply to working time in an augmented aircraft crew.
Czech Republic	No additional national provisions to Subpart Q.

Additional Rest due to Time Zone Differences	
UK	Although Annex B of CAP 371 assumes time zone differences less than 2 hours, Annex E of CAP371 contains a table on rest used as guidance for all operations. The number of days for Minimum Base Turn Around (MBTR) is a function of Return Sector Length, Duration of Trip and Time Zones Crossed and is given for flight crew and cabin crew separately. At the upper end the MBTR is 5 days for a return sector length of 14 hours +, a trip length of 96 - 216 hrs, and 7 plus hours time zone difference.
Switzerland	For time difference of 4hours or more - the subsequent rest period must be increased by 30 min. for every hour of time difference.
Spain	**SubpartQ-OPS 1.1110 + Article 6, Real Decree to 1952/2009;** Rotation; FDPs starting and finishing at home base, or in a place where time difference is no more than one hour compared to the home base, and including at least one flight crossing 4 or more time zones . Additional rest will be achieved following the rotation and at home base

	Additional Rest due to Time Zone Differences
	or in a place with time difference no more than one hour compared to the base. Additional rest + basic minimum rest (due to previous duty) will include 2 local nights and will be as follows: a)When time elapsed between departure and arrival to the home base is less or equal to 60 hours= max (36, 4 time the time difference between the home base and the location with the greatest local time difference). b) When time elapsed between departure and arrival to the home base is greater than 60 hours= max (36, 6 time the time difference between the home base and the location with the greatest local time difference). c)With FDP extension by in flight rest, the rest defined in a) and b) will not be in any case less than 48 hours. Before a FDP crossing 4 or more time zones a minimum 14 hours rest shall be respected. Rest according to a), b) and c) could be reduced (respecting OPS 1.1110) when: prior FDP finishing at home base a rest including 3 local night had been provided and subsequent flight duty less than 11 hours and its following rest includes 3 local nights as well. Period rest between Eastward-Westward and Westward-Eastward time zone transitions, or vice-versa, shall be at least 3 local nights. This rest could be reduced to 2 local nights if the rest following both rotations includes 4 local nights. **Article 12,Circular del Director General de aviación Civil, 17/12/2010**; In the computation of time differences, seasonal time corrections will not be taken into account. The number of rotations in 28 consecutive days or in one month is limited to 5 for each crew member being not applicable split duty.
Germany	**1. DvLuftBO, § 12 Taking into consideration resting periods between time zone differences** If there exists between the place of commencement of the air service and the location of the termination of air service a time zone difference of four or more time zones, the minimum rest period is increased to 14 hours. After return to home base, the rest in hours is determined by multiplying the time zone difference by 8 up to a maximum of 12 time zones.
France	For CAT operations : a) Away from home base : if the preceding FDP takes the crew more than

Additional Rest due to Time Zone Differences	
	3 time bands away for the time zone of departure, then rest = max (FDP,14h) b) At home base: if the preceding FDP took the crew more than 3 time bands away, when returning home base, rest = 36h including 2 local nights. For air taxi operations, provisions in b) may be changed : • rest _1 = max (preceding FDP;10h+time zone crossing). Rest shall include one local night. • if rest_1 <36h or rest_1 does not include 2 local nights, then periodic rest referred to in OPS 1.1110 §2.1 shall include 3 local nights and be granted at the home base. • These changes may be implemented only under FRM.
Norway	No national provisions stated.
Poland	Regulation of the Minister of Infrastructure, 2002 - Journal of Laws, § 19. Member of the flying staff who carries out the flight in the changed time zone may start work outside home port, provided that the rest period uninterrupted with any duties was at least as long as the time of aviation activities, however no less than 14 hours – when the time difference was at least 4 hours, and no less than 16 hours – when the time difference was at least 6 hours.
Czech Republic	No additional national provisions to Subpart Q.

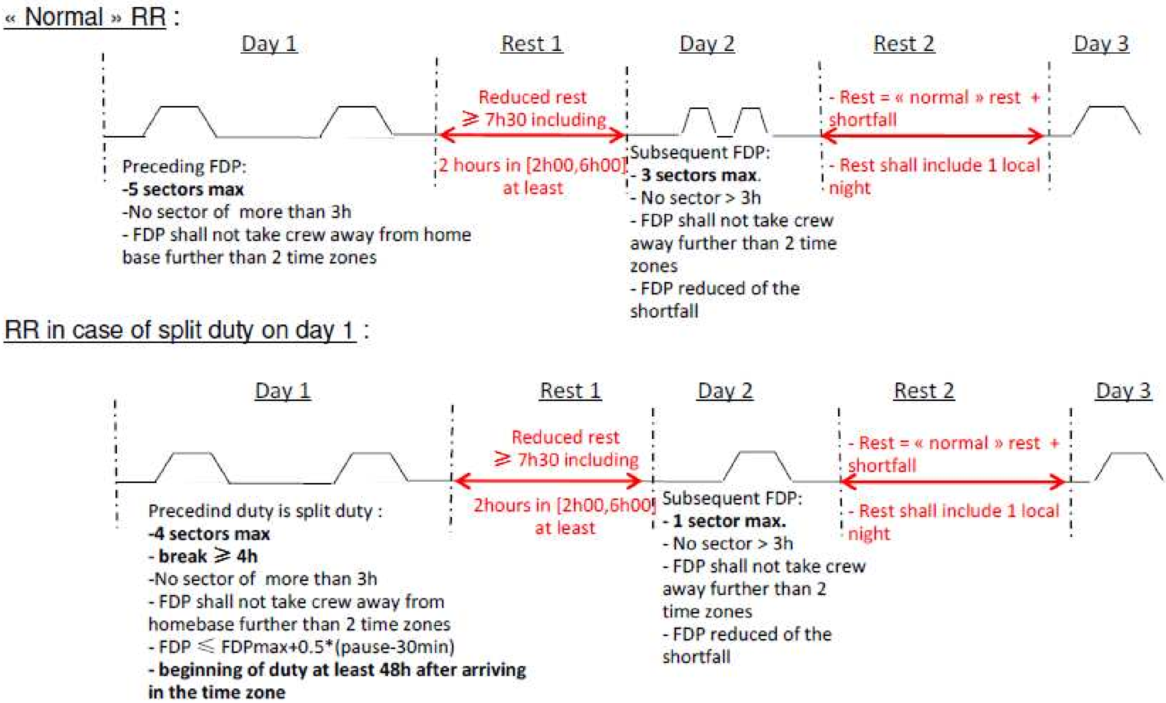
Basic (Reduced) Rest	
UK	**CAP 371 Annex B Air Taxi, section 17** An aircraft commander may, at his discretion, and after taking note of the circumstances of other members of the crew, if carried, reduce a rest period, but only insofar as the accommodation allocated to the crew member must be available for occupation for a minimum of 10 hours. The exercise of such discretion, must be considered exceptional and must not be used to reduce successive rest periods. If the preceding FDP was extended, the rest period may be reduced, provided that the subsequent allowable FDP is also reduced by the same amount. In no circumstances may a commander exercise discretion to reduce a rest period below 10 hours at accommodation. When away from base and where an individual crew member separates from the crew, or the crew as a whole splits up, then any use of discretion to reduce rest becomes a decision for an individual crew member. The decision to continue with the next flight and the submission of an associated discretion report is the responsibility of the relevant commander after the crew member, and operator if in a position to do so, has informed the commander that a reduced rest period has been taken.

Basic (Reduced) Rest	
Switzerland	Rest may not be reduced below basic rest of 10 hours or as long as previous duty whichever longer.
Spain	**OPS 1.1110 and Article 7, Real Decreto 1952/2009;** Rest reduction limited to 3 hours. Minimum duration of reduced rest = 10 hours out of home base or 12 hours in base. Minimum of 9 hours at the suitable accommodation. Subsequent rest shall be augmented by the shortfall. FDP following reduced rest shall be reduced by the shortfall. Number of reduced rest occasions is limited to 3 times scheduled in 90 days. Reduction not allowed when: pre or post-FDP is extended by in flight rest and/or time zone crossing at the previous or next FDP.
Germany	**1. DvLuftBO, §13 Shortened rest periods in special cases (OPS 1.1110 Nr.1.4.1 and 2.1)** The supervisory authority may, upon written request grant deviations from the requirements of § 12 and in accordance with OPS 1.1110 permit No. 1.4.1, if there are important reasons for shortening the rest period. The minimum rest periods may be shortened by no more than two hours. A minimum rest period of ten hours must not be reduced.
France	There are French national provisions for reduced rest under CAT operations (see Figure 1 below). All these provisions can also be used under so called Air Taxi operations. Yet, there are some possible variations : - Combination of split duty and reduced rest • if break <6h, reduced rest = max [10h; FDP-0.5*break duration] E.g. for a 4 sectors FDP not encroaching the WOCL and a 5h30 break, max FDP =13h-1h+1/2*(5h30 –0h30) = 14h30 If planned FDP = 13h45, then minimum rest = 13h45-0.5*5h30=11h • if break >6h, reduced rest = max [10h; FDP-3h-0.75*(break duration-6h)]

Basic (Reduced) Rest	
	- Max 2 reduced rest between two periodic rests as per OPS 1.1110 §2.1 - If shortfall = nominal rest – reduced rest, then subsequent rest (or alternatively , next periodic rest as per OPS 1.1110 §2.1) = minimum rest + shortfall E.g. with same example as above : let us assume reduced rest = 11h15, then shortfall = 13h45-11h15=1h30 Then the rest after the reduced rest should be = normal rest+1h30 (alternatively 36h+1h30) as a minimum
Norway	No national provisions stated.
Poland	Regulation of the Minister of Infrastructure, 2002 - Journal of Laws, § 17. § 16. If members of the flying staff comprising aircraft crew start their work: 1) outside their home port – the employer shall provide them with rest time which is at least as long as the previous working time, or amounting to 10 hours, depending on which of the two is longer; 2) in their home port - the employer shall provide them with rest time specified in point 1, however: a) after work with a break – rest time should be at least as long as the previous working time including break. b) After a flight in a changed time zone – rest time should be at least 48 hours starting from 24:00 local time on the arrival day. ***§ 17.1 Rest time specified in par.16.1 may be reduced by a maximum of 3 hours, provided that rest is no shorter than 10 hours and:*** ***1) Previous rest time was at least as long as rest time specified in par. 16.1.*** ***2) Number of hours by which rest was reduced is added to the next rest time which cannot be shortened;*** ***3) Rest time may not be reduced before or after work with a break.*** 2.Rest time specified in par.16.1. a) should be increased to: 1) 36 hours – over the next 7 days, or 2) 60 hours – over the next 10 days. 3. member of the flying staff be entitled to: 1) as many days free from duties in the home port, as there are days off in the adopted settlement period, including at least 1 free day each month falling on a Sunday or holiday; these days can include rest periods; 2) the allocated days off shall be notified at least 24 hours in advance and shall be planned to make sure that they can be used in home port. 4. if over 7 subsequent days one of at least three planned work timetables falls between 01:00 – 06:00 local time and time difference

Basic (Reduced) Rest	
	between two rest locations is less than 4 hours, than the rest period of 36 hours referred to in par. 2.1. shall be extended to 48 hours.
Czech Republic	No additional national provisions to Subpart Q.

Figure 1 – French Provisions for Reduced Rest and Combining with Split Duty



Weekly Rest – Adjusted Second Night Allowed (OPS 1.1110 para. 2.1)	
UK	No – a single day off shall include 2 local nights and be at least 34 hours long. (CAP371, Section B, Para 20.2)
Switzerland	No information received
Spain	Yes.
Germany	Yes.
France	Weekly rest : no difference with CAT operations except for extended FDP due to in-flight rest. The possibility to start the second local night as per OPS 1.1110 §2.1

Weekly Rest – Adjusted Second Night Allowed (OPS 1.1110 para. 2.1)	
	exists for air taxi operations.
Norway	No provision on this.
Poland	No provision on this.
Czech Republic	No additional national provisions to Subpart Q.

Duty Extensions due to In-Flight Rest	
UK	CAP371 – Minimum 3 hours, 50% of time in bunk can be added to FDP (maximum FDP permissible shall be 18 hours for flight crew) or 33% of time in suitable seat (40 degree recline, leg and foot support, screened from pax and crew) can be added to FDP up to maximum of 15 hours for flight crew. (Section B, Para 15)
Switzerland	Standard limit 3 landings: with C.Bunk: 3 Pilot: 18 hrs FDP 4 Pilot: 20 hrs With Rest seat: 3 Pilot: 16 hrs 4 Pilot: 18 hrs With 4 landings. Values must be reduced by 2 hrs. No more than 4 landings allowed with augmented crew rules.
Spain	**Article 9 and 10, Real Decree to 1952/2009** Flight Crew; ≥ 70º pitch seats, augmented → +5h, max 16h30min ≥ 70º, double crew→ +7h, max 18h30min ≥ 45º, augmented→ +4h30min, max 16h15min ≥ 45º, double crew→ +6h30min, max 18h ‹ 45º, augmented, additional rest requirements→ +4h, max 16h ‹ 45º, double crew, additional rest requirements→ +5h30min, max 17h30min Passenger Cabin Crew; 33% in flight-rest, max 18h30min 25% in flight-rest, max 16h30min

Duty Extensions due to In-Flight Rest	
	1h in flight-rest, max 15h
Germany	**1. DvLuftBO, §13** NAA may grant FDP extensions up to 18hrs max twice within 7 consecutive days - providing crew is augmented and there is suitable sleeping arrangement in-flight. Cannot be pilot flying if served over 12 hours. **Attachment to 1. DvLuftBO "Design, Equipment and Installation Criteria for Flight Crew Sleeping Quarters" (includes definition of facilities)** The maximum FDP may be extended: With one additional flight crew member: (i) up to 15 hours with class 3 rest facilities; (ii) up to 16 hours with class 2 rest facilities; (iii) up to 17 hours with class 1 rest facilities; (iv) up to 18 hours with class 1 rest facilities, if a bunk is installed; The FDP shall be limited to 2 sectors, where 1 sector shall be over 9 hours continuous flight time. The minimum in-flight rest period shall be a consecutive 90-minute period for each crew member and two consecutive hours for those crew members at control during landing. The cruise phase of the flight above FL 200 shall be used to maximise the inflight rest period of those crew members at control during landing. The whole period of time spent in the rest facility shall be counted as FDP. The minimum rest at destination shall be at least as long as the preceding duty period, or 14 hours, whichever is the greater. All flight crew members shall commence their FDP at the same reporting place if they are part of an augmented crew. No single crew member may start a positioning sector to then augment a crew on the same flight.
France	Same as for commercial air transport a. Flight crew : - 1 additional pilot : • bunks (90°): FDP up to 18h • reclinable seat (not precisely defined) : FDP up to 16h • minimum consecutive rest of 90 minutes b. Cabin crew (no additional cabin crew member required): • bunks (90°): FDP up to 18h • reclinable seat : FDP up to 16h (near bunks for the NPA) • minimum rest of 90 minutes c. Sectors requirements : 4 max (-30 minutes/sector from the third) for FDP of 16h or less and 2 sectors max for FDP of more than 16h (which need bunks)

<table>
<tr><th colspan="2">Duty Extensions due to In-Flight Rest</th></tr>
<tr><td></td><td>d. Minimum rest at home base following extended FDP is 48h with 2 local nights

Requirement d. above may be changed for air taxi operations :
rest _1 = max (preceding FDP;10h+time zone crossing; 14h). Rest shall include one local night.
if rest_1 <48h or rest_1 does not include 2 local nights, then periodic rest referred to in OPS 1.1110 §2.1 shall be at least 60h, include 3 local nights and be granted at the home base.
These changes may be implemented under FRM</td></tr>
<tr><td>Norway</td><td>No national provisions stated.</td></tr>
<tr><td>Poland</td><td>Regulation of the Minister of Infrastructure, 2002 - Journal of Laws, § 15
§ 15.1. If the composition of multi-person aircraft crew is enlarged with another complete crew which comprises members of the flying staff the time of carrying out aviation activities may be extended to 18 hours, and the uninterrupted flying time to 15 hours.
2.If the aircraft crew is enlarged with one pilot who is authorized to perform the role of aircraft commander in a given aircraft type, the name of carrying out aviation activities shall not exceed 15 hours, and the uninterrupted flying time shall not exceed 12 hours.
3.the enlarged aircraft crew shall not carry out more than 2 landings in the event referred to in par. 1 and 2.
4.if the planned time for carrying out aviation activities by members of the flying staff comprising a multi-person aircraft crew referred to in par.1 and 2, in enlarged crew:
1) does not exceed 16 hours – the crew which temporarily does not carry out any activities should be provided with a reclining chair separated from crew cabin and the passengers;
2) is 16 or more hours – the crew which temporarily does not carry out any activities should be provided with berth separated from crew cabin and the passengers.</td></tr>
<tr><td>Czech Republic</td><td>No additional national provisions to Subpart Q.</td></tr>
</table>

<table>
<tr><th colspan="3">Airport Standby & Standby Elsewhere</th></tr>
<tr><td></td><td>Airport Standby Time</td><td>Standby Elsewhere</td></tr>
<tr><td>UK[4]</td><td>100% of Airport Standby counted towards the FDP, FDP calculated from report time of the standby. (CAP 371</td><td>Home standby and contactable duties. Max duration 12 hours.</td></tr>
</table>

[4] CAP 371 has variations from Subpart Q involving the maximum FDPs as a function of duty start times and sectors (see tables below)

Airport Standby & Standby Elsewhere		
	Airport Standby Time	**Standby Elsewhere**
	Section B, Para12) Minimum rest period of 12 hours if not called out (Section B, Para 12)	Up to 6 hours on home standby any time spent on standby beyond 6 hours reduces the allowable FDP by the same amount. 100% towards cumulative duty when on immediate readiness during the day and 50% between 2200 – 0800 or if the notice period from call to report is 3 hours or more (long call pre-notified). Contactable – 10 hours' notice to report, does not count towards cumulative duty but contactable periods must be notified in advance and not be longer than 2 ½ hours in one day. Hotel standby follows home standby rules. (CAP 371,Section B, Para 12 and Para 22.3)
Switzerland		Standby at Hotel or home does not count as duty.
Spain[5]	**SubpartQ-OPS 1.1125 + Artículo 9, Circular del Director General de aviación Civil, 17/12/2010;** When a FDP is immediately followed by a standby and during this standby a new flight duty begins, the previous FDP as well as the standby will be part of the last FDP. However, when a rest period is followed by standby and during this standby a new FDP begins, the FDP counts from the reporting time. **Article 2, Real Decreto 1952/2009;** Standby shall be provided in a	**Hotel Standby;** **Subpart Q-OPS 1.1125+Article 1a), Real Decreto 1952/2009**; Hotel standby; is defined as the standby performed in the hotel designated by the operator, providing a suitable accommodation to the crew for adequate resting **Article 9, Circular del Director General de aviación Civil, 17/12/2010;** When a FDP is immediately followed by a standby and during this standby a new flight duty begins, the previous FDP as well as the standby will be part of the last FDP.

[5] Spain's regulations have variations from Subpart Q involving the maximum FDPs as a function of duty start times and sectors (see tables below)

Airport Standby & Standby Elsewhere		
	Airport Standby Time	**Standby Elsewhere**
	suitable accommodation ("suitable accommodation" is defined in the article 3 Real Decreto 1952/2009) **Article 11.3 Real Decreto 1952/2009;** Airport standby period is limited to 12 hours **Article 11.8 Real Decreto 1952/2009;** When standby period goes over 8 hours and is not followed by flight duty a minimum rest period shall be provided according to OPS 1.1110.	**Article 11.3, Real Decreto 1952/2009;** Hotel standby period is limited to 12 hours **Article 11.4, Real Decreto 1952/2009;** % of Hotel standby vs FDP (and DP); 0% < 6 hrs, 0% FDP > 6 h, 100% DP > 6 h **Article 11.5, Real Decreto 1952/2009;** The rest period following a hotel standby with FDP shall be increased by the time elapsed between the sixth standby hour and the beginning of the FDP **Article 11.8 Real Decreto 1952/2009;** When standby period goes over 8 hours and is not followed by flight duty a minimum rest period shall be provided according to OPS 1.1110 **Home Standby;** **OPS 1.1125+ Article 1b), Real Decreto 1952/2009;** Home standby; standby other than airport and hotel standby **Article 9, Circular del Director General de aviación Civil, 17/12/2010;** When a FDP is immediately followed by a standby and during this standby a new flight duty begins, the previous FDP as well as the standby will be part of the last FDP **Article 11.3, Real Decreto 1952/2009;** Home standby period is limited to 24 hours **Article 11.6, Real Decreto 1952/2009;** % of Home standby vs FDP (and DP); 0% < 12 hours, 0% FDP > 12 h, 50% DP > 12 h

Airport Standby & Standby Elsewhere		
	Airport Standby Time	**Standby Elsewhere**
		Article 11.7, Real Decreto 1952/2009; When standby begins at home and then changes to hotel or airport, or vice-versa, 50% of the home standby time will contribute as hotel or airport standby, depending on the place where the previous or subsequent standby takes place. **Article 11.8 Real Decreto 1952/2009;** When standby period goes over 8 hours and is not followed by flight duty a minimum rest period shall be provided according to OPS 1.1110
Germany	**As per Subpart Q-OPS 1.1125.** **1. DvLuftBO §15 Standby** 1) Standby time shall be counted as flight duty time if flight duty time not separated by a rest period in accordance with OPS 1.1110 and either 1. the crew member during the standby time has no secluded space with sleeping accommodation available, 2. or the crew member during the standby time has a secluded room with sleeping accommodation available, but the standby time is less than two hours, unless the standby time is spent following a rest period. (2) If a secluded room with sleeping accommodation is available to the crew member, the Standby time will be counted as a break.	(3) Standby time following a rest period in which the crew member is in their own home or an appropriate accommodation at a particular place where he may have the opportunity to sleep shall be counted as rest time. The same applies to a corresponding standby time before a rest period. No maximum duration.
France	Same as for CAT operations : At airport (or at a place required by the operator): - Standby is considered as duty	Same as for CAT operations: - No impact on Duty and FDP (max FDP fully available whatever the time when crew members are called out) - Limit on standby duration : 24h

Airport Standby & Standby Elsewhere		
	Airport Standby Time	**Standby Elsewhere**
	- Reduction of the subsequent FDP corresponding to the standby period spent beyond 6 hours - Limit on Standby duration : 12h - Minimum rest after standby with no FDP : 11h	renewable
Norway	Subpart Q - OPS 1.1125 applies. In addition: 1) if standby is immediately followed by a FDP then 100% of previous standby time counts towards max daily FDP & 2) if standby period is not followed by duty period then minimum rest in accordance with OPS 1.110 applies.	Subpart Q applies & maximum standby duration shall not >14hrs. **(Valid for all operators that are using subpart Q)** FOR 2008- 02-21 § 11. Norway. 1) All activities shall be planned ahead and/or the crew shall be informed beforehand. 2) The time of start and end of the standby period shall be defined and the crew informed beforehand. 3) The standby time must not exceed 14 hours. 4) The flight crew shall have access to rest in a bed during the standby period. 5) Not counting the exceptions below, the standby time outside the airport shall count as 50% towards cumulative duty hours (OPS 1.1100 1.1) and daily FDP. 6) If the standby period is preceded by a rest period, the first 4 hours of the standby period shall not count towards cumulative duty hours (OPS 1.1100 1.1) and daily FDP. If called for flight duty, item 8) below is still valid. 7) If there is no call for flight duty between 22.00 and 06.00, the time in this period shall not count towards cumulative duty hours (OPS 1.1100 1.1) and daily FDP. 8) By the time being called for flight duty, 50% of the time from the call until start of the flight duty will count towards cumulative duty hours (OPS 1.1100 1.1) and daily FDP. 9) If being called in the time period 06.00-22.00 with early enough

<table>
<tr><th colspan="3">Airport Standby & Standby Elsewhere</th></tr>
<tr><th></th><th>Airport Standby Time</th><th>Standby Elsewhere</th></tr>
<tr><td></td><td></td><td>warning that the time between the call and reporting time for flight duty is at least 5 hours, the time between the call and reporting shall not count towards cumulative duty hours (OPS 1.1100 1.1) and daily FDP.</td></tr>
<tr><td>Poland</td><td>Subpart Q-OPS 1.1125 - 1.2. Airport standby will count in full for the purposes of cumulative duty hours.
1.4. Where the airport standby does not lead to assignment on a flight duty, it shall be followed at least by a rest period as regulated by the Authority.
1.5. While on airport standby the operator will provide to the crew member a quiet and comfortable place not open to the public.

Regulations are being prepared by the Ministry of Transport, Construction and Maritime Economy.</td><td>Regulation of the Minister of Infrastructure, 2002 - Journal of Laws, § 21.1. Standby can be executed at the home port, in a different local determined by the employer or by phone. Member of the aircraft crew should be capable of taking up work.
2.Duty time limits have been specified in table No. 4:

<table><tr><td>Notification time</td><td>Maximum standby time</td></tr><tr><td>Up to 5 hours 59 minutes</td><td>12 hours</td></tr><tr><td>from 6 hours and more</td><td>18 hours</td></tr></table>
§ 22 - 1. If duty is carried out outside the mother port, when it exceeds 6 hours or when more than 4 hours fall between 22:00 – 06:00 local time, the employer shall provide respective accommodation conditions.
2. If duty is carried out at the airport, the employer shall provide respective conditions for carrying out duty.
3. Time of telephone duty shall be included in working time as 50 % of the duty time, excluding the first 4 hours.
4. If the flight is delayed, the time between the planned take-off hour and the new take-off hour shall be included in the time of carrying out duty.</td></tr>
</table>

Airport Standby & Standby Elsewhere		
	Airport Standby Time	**Standby Elsewhere**
		Also regulations are being prepared by the Ministry of Transport, Construction and Maritime Economy.
Czech Republic	No additional national provisions to Subpart Q.	

Special Single Pilot Provisions

<table>
<tr><th></th><th>Single Pilot Provisions</th></tr>
<tr><td>UK</td><td>See FDP tables – single pilot FDPs less than two flight crew.

CAP371 Section B, Para 13, Table C
<table>
<tr><th rowspan="2">Local time of start</th><th colspan="5">Number of Sectors</th></tr>
<tr><th>4</th><th>5</th><th>6</th><th>7</th><th>8+</th></tr>
<tr><td>0600-0650</td><td>10</td><td>9:15</td><td>8:30</td><td>8</td><td>8</td></tr>
<tr><td>0700 - 1259</td><td>11</td><td>10:15</td><td>9:30</td><td>8:45</td><td>8</td></tr>
<tr><td>1300 - 1759</td><td>10</td><td>9:15</td><td>8:30</td><td>8</td><td>8</td></tr>
<tr><td>1800 - 2159</td><td>9</td><td>8:15</td><td>8</td><td>8</td><td>8</td></tr>
<tr><td>2200 - 0559</td><td>8</td><td>8</td><td>8</td><td>8</td><td>8</td></tr>
</table>

Otherwise provisions same as tables above.</td></tr>
<tr><td>Switzerland</td><td>No information received</td></tr>
<tr><td>Spain</td><td>Article 4.2 , Circular operativa 16B;

Maximum interrupted flight time (single pilot) = 5h (+ 10% to complete stage)

Maximum FDP function of report time and number of sectors worked in passenger operations = Table n1 in Article 5.3.1.1, Circular Operativa 16B (see below)

Maximum FDP function of report time and number of sectors worked in cargo operations = Table n1 in Article 5.3.1.2, Circular Operativa 16B (see below)

Article 3, Circular Operativa 16B;

Position duties shall be counted as FDP when immediately prior to an FDP

Article 5 Circular del Director General de Aviación Civil, 17/12/2010;

After 18 hours of duty (FDP+Post-FDP positioning) crew members will be able to choose if they want to proceed to positioning or take minimum rest.

Other provisions the same as for multi-pilot crew in tables above.</td></tr>
<tr><td>Germany</td><td>For single pilot (VFR) ops, maximum basic daily FDP is 10 hours and extensions according to 2.1 to 2.7 of OPS 1.105 are not applicable.
Otherwise all provisions are same as multi-pilot crew.</td></tr>
<tr><td>France</td><td>Same as for CAT operations described above except for the following:</td></tr>
</table>

<table>
<tr><th></th><th>Single Pilot Provisions</th></tr>
<tr><td></td><td>For IFR operations or operations at night, total block hours of each FDP shall be less than 6h

Maximum block hours for each sector shall be :
- 4h or less if the aeroplane is equipped with a full autopilot
- 2h in all other cases</td></tr>
<tr><td>Norway</td><td>Max. FDP for single pilot operations is reduced by 3 hours related to ops 1.1105 1.3

Max. FDP is reduced by 30 mins. per sector from the third sector.

No other special provisions.</td></tr>
<tr><td>Poland</td><td>Regulation of the Minister of Infrastructure, 2002 Journal of Laws, - §9 time for carrying out aviation services by an aircraft single-person crew

<table>
<tr><td rowspan="2">Time of reporting for flight (time of local Take-off port)</td><td colspan="4">Maximum amount of landings and time of carrying out aviation activities</td></tr>
<tr><td>1-4 landings</td><td>5 landings</td><td>6 landings</td><td>7 landings and more</td></tr>
<tr><td>06^{00}-06^{59}</td><td>9 hours</td><td>8 ¼ hours</td><td>8 hours</td><td>8 hours</td></tr>
<tr><td>07^{00}-13^{59}</td><td>10 hours</td><td>9 ¼ hours</td><td>8 ¼ hours</td><td>8 hours</td></tr>
<tr><td>14^{00}-17^{59}</td><td>9 hours</td><td>8 ¼ hours</td><td>8 hours</td><td>8 hours</td></tr>
<tr><td>18^{00}-21^{59}</td><td>8 ½ hours</td><td>8 hours</td><td>8 hours</td><td>8 hours</td></tr>
<tr><td>22^{00}-05^{59}</td><td>8 hours</td><td>8 hours</td><td>8 hours</td><td>8 hours</td></tr>
</table>

Otherwise same as for multi-pilot crew.</td></tr>
<tr><td>Czech Republic</td><td>No additional provisions to Subpart Q.</td></tr>
</table>

Spain

Table n1 in Artice 5.3.1.1, Circular Operativa 16B – Single Pilot, Passenger Operations

TRIPULACIONES TÉCNICAS CON UN SOLO PILOTO

Hora de Presentación	Número de aterrizajes			
	1 a 4	5	6	>= 7
0700 - 1159	1030	0945	0900	0830
1200 - 1359	1000	0915	0830	0830
1400 - 1559	0930	0845	0830	0830
1600 - 1759	0900	0830	0830	0830
1800 - 0359	0830	0830	0830	0830
0400 - 0459	0900	0830	0830	0830
0500 - 0559	0930	0845	0830	0830
0600 - 0659	1000	0915	0830	0830

Table n1 in Artice 5.3.1.2, Circular Operativa 16B – Single Pilot, Cargo Operations

OPERACIONES CON UN SOLO PILOTO

Hora de Presentación	Número de aterrizajes			
	1 a 4	5	6	>= 7
0700 - 1159	1030	0945	0900	0830
1200 - 1359	1000	0915	0830	0830
1400 - 0559	0930	0845	0830	0830
0600 - 0659	1000	0915	0830	0830

Cabin Crew Provisions if different for Air Taxi

	Cabin Crew Provisions
UK	No special provisions. If cabin crew are required to be carried they must comply with all the regulations. Where they are not required by the regulations but are carried then the Operator is encouraged to comply with all safety training requirements.
Switzerland	No information received
Spain	No special provisions for cabin crew involved in air taxi operations.
Germany	No data provided.
France	Provisions for cabin crew are the same as for pilots.
Norway	No information received
Poland	No information received
Czech Republic	No additional national provisions to Subpart Q.

Appendix 4 – CAS Model Scenarios

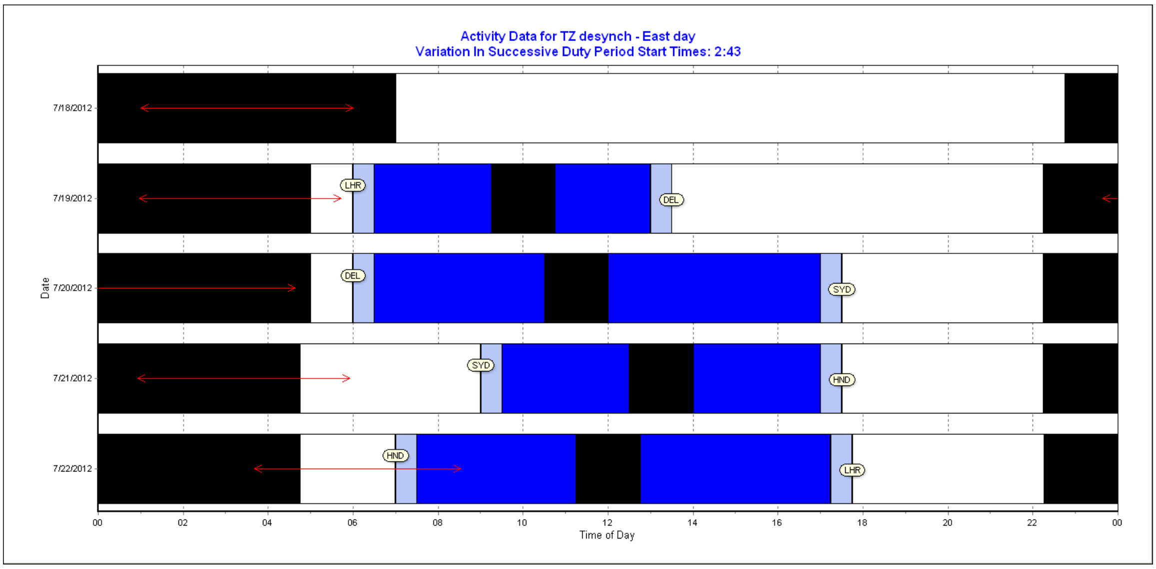
Colour code:
Black = sleep
White = awake
Light blue = ascent/descent
Dark blue = cruising
Teal = ground duty
Green = positioning OR travelling (depending on context)

Additional notes on CAS graphs:
Red arrow = WOCL
Time of Day = Pilot BODY time, not LOCAL time

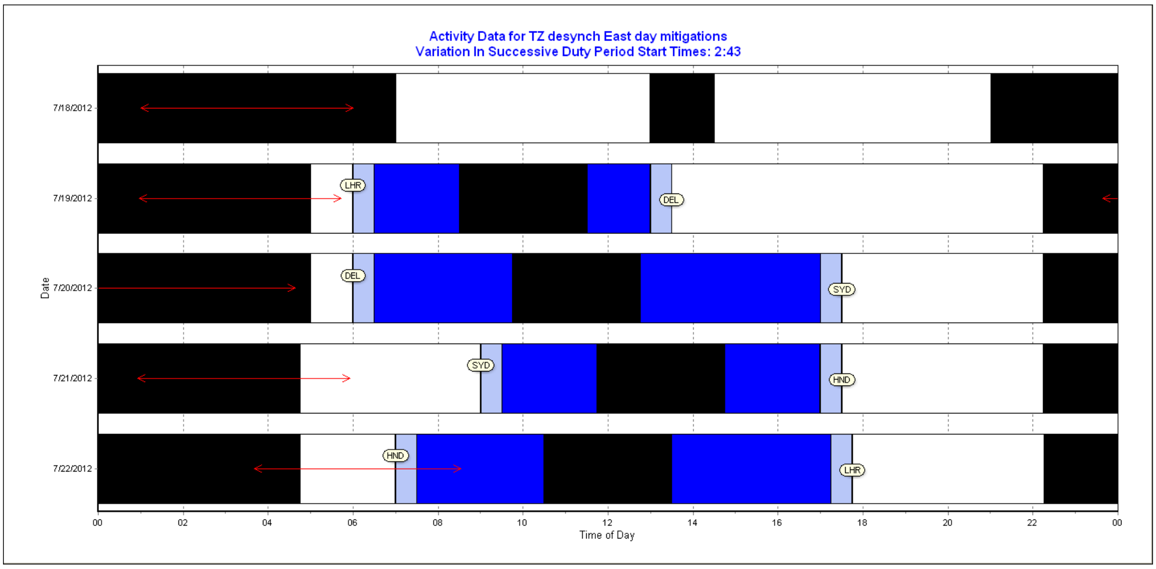
Main report Section 5.6 - Time Zone Desynchronisation

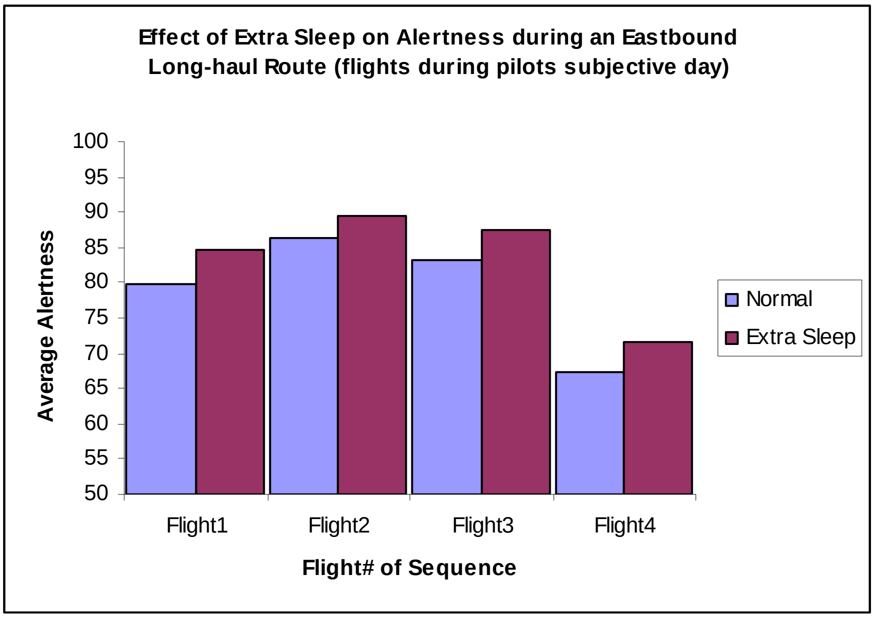
Assuming a 3 pilot augmented crew for flights >8hr, pilots can take 90min or 3 hour in-flight sleeps.

Flying East (flights during pilot subjective daytime): London, England > Delhi, India > Sydney, Australia > Tokyo, Japan > London, England, Fatigue Score: 31.60



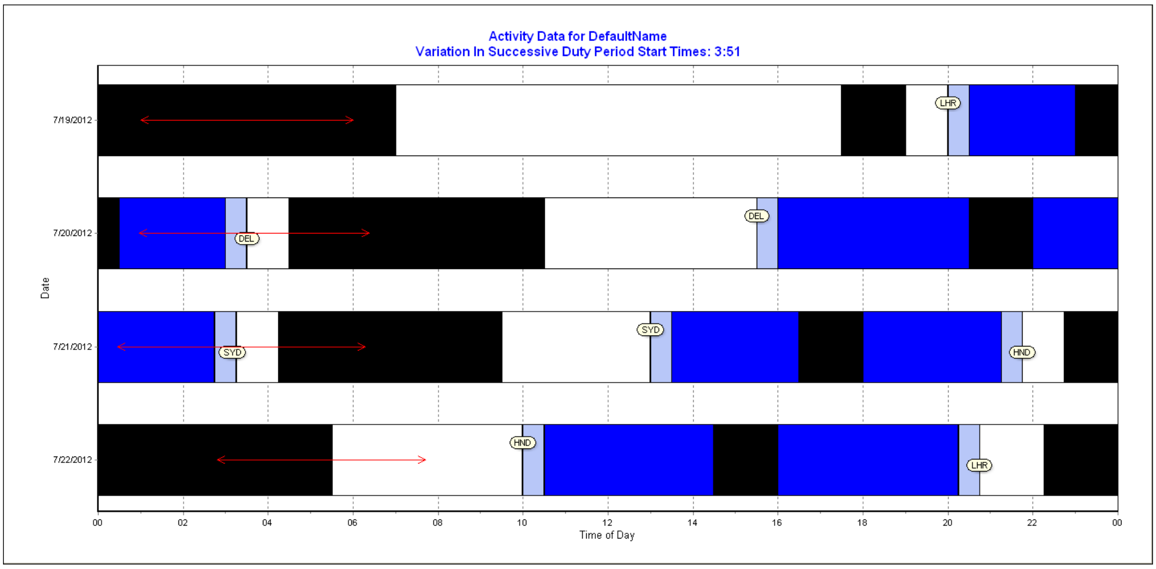
Flying East with mitigations (extra sleep on first day, longer in-flight sleep). Fatigue score: 31.09



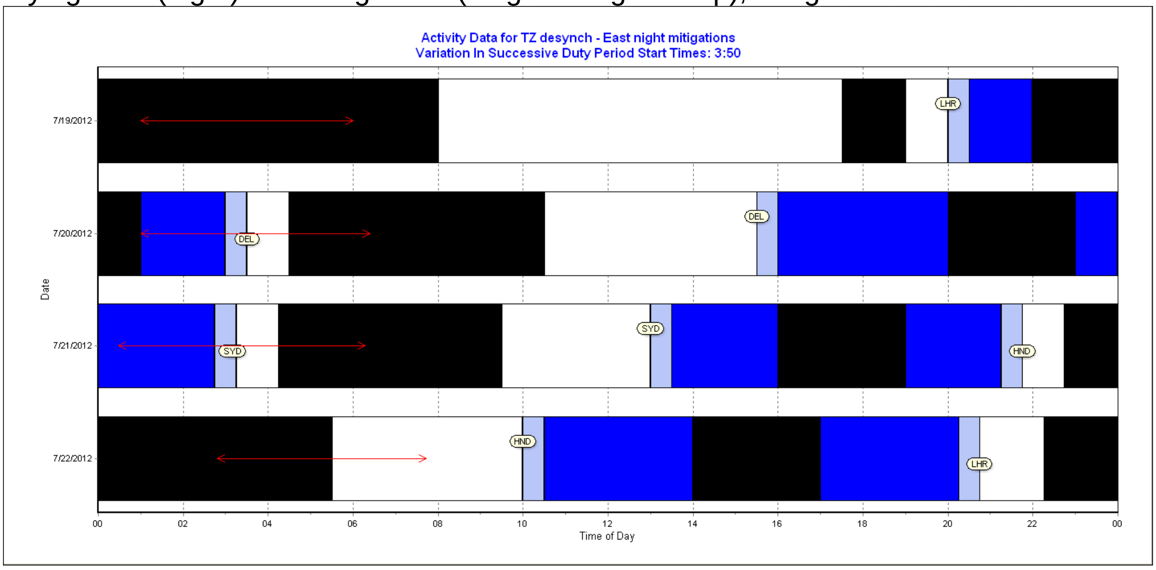


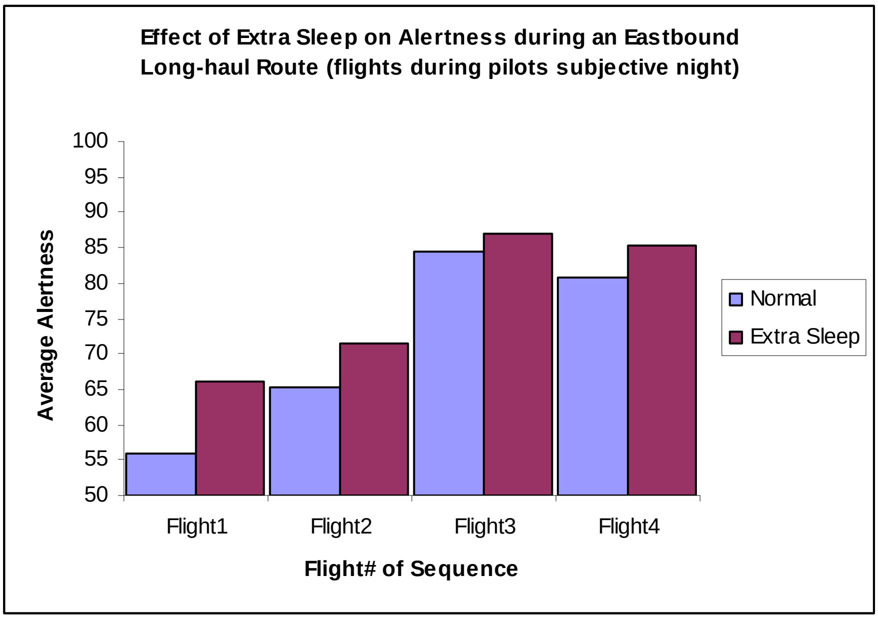
Average alertness while flying four flights on an Eastbound business trip is improved by obtaining extra in-flight sleep. Average alertness during flights 1-4 with a short (90 minute) in-flight sleep (blue bars), versus a long (3 hour) nap plus extra sleep pre-trip (mauve bars). Flight 1: London, England > Delhi, India, Flight 2: Delhi, India > Sydney, Australia, Flight 3: Sydney, Australia > Tokyo, Japan, Flight 4 (return) Tokyo, Japan > London, England. All flights occur during the pilot's subjective day.

Flying East (flights during pilot subjective night-time): London, England > Delhi, India > Sydney, Australia > Tokyo, Japan > London, England, Fatigue Score: 43.85



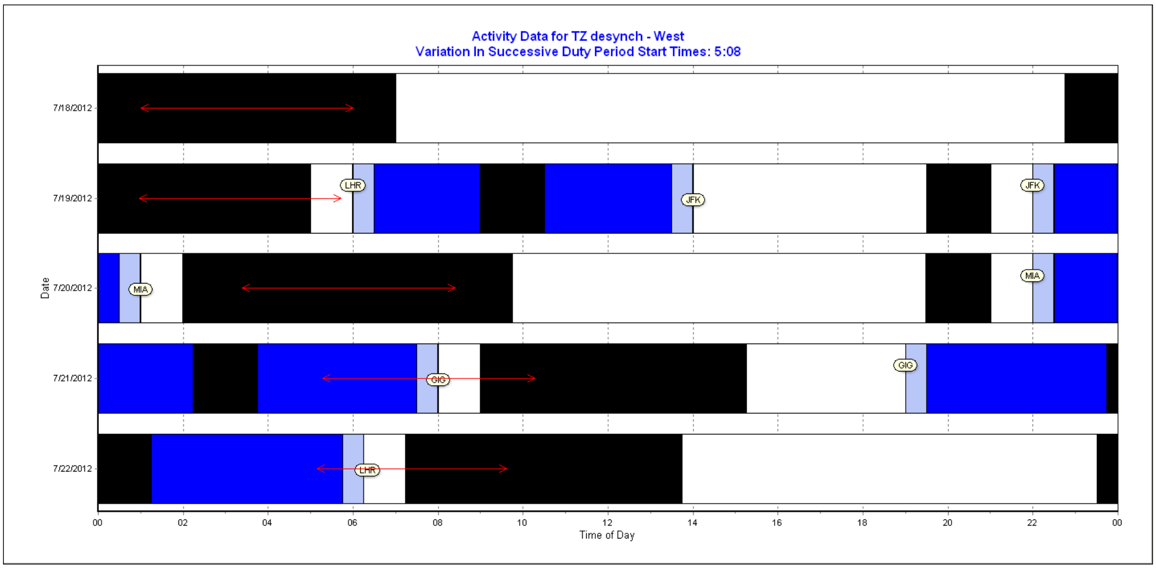
Flying East (night) with mitigations (longer in-flight sleep), Fatigue Score: 30.68



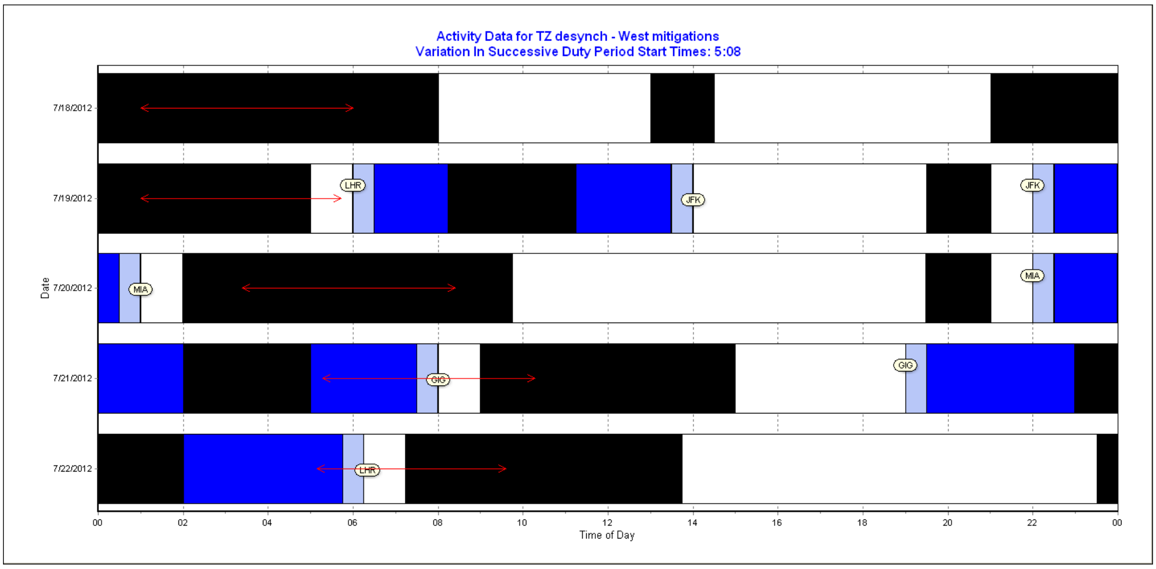


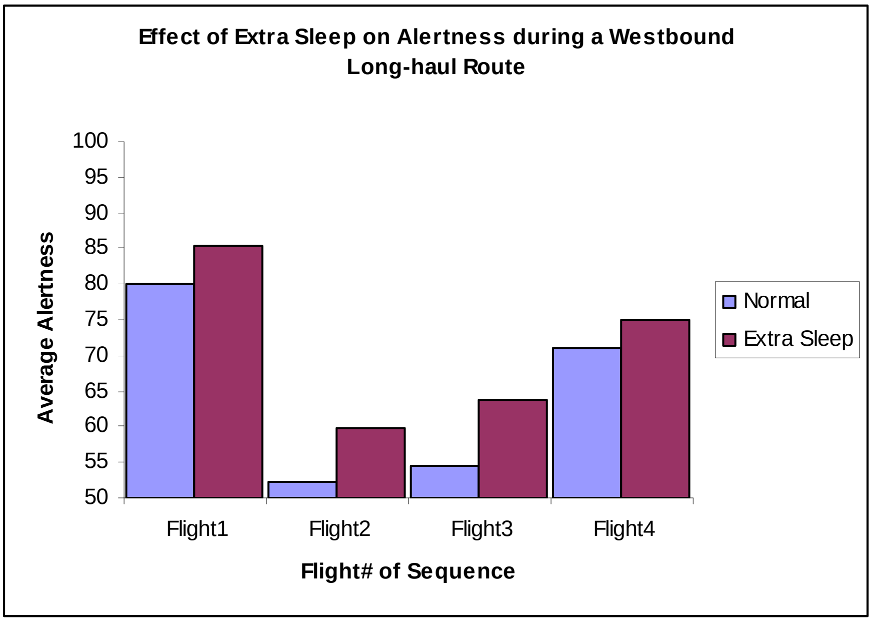
Average alertness while flying four flights on an Eastbound business trip is improved by obtaining extra in-flight sleep. Average alertness during flights 1-4 with a short (90 minute) in-flight sleep (blue bars), versus a long (3 hour) in-flight sleep plus extra sleep pre-trip (mauve bars). Flight 1: London, England > Delhi, India, Flight 2: Delhi, India > Sydney, Australia, Flight 3: Sydney, Australia > Tokyo, Japan, Flight 4 (return) Tokyo, Japan > London, England. Flights occur during some portion of the pilot's subjective night.

Flying West: London, England > New York City, USA > Miami, USA > Rio de Janeiro, Brazil > London, England, Fatigue Score: 42.25



Flying West with mitigations (extra sleep first day, longer in-flight sleep), Fatigue Score: 31.66



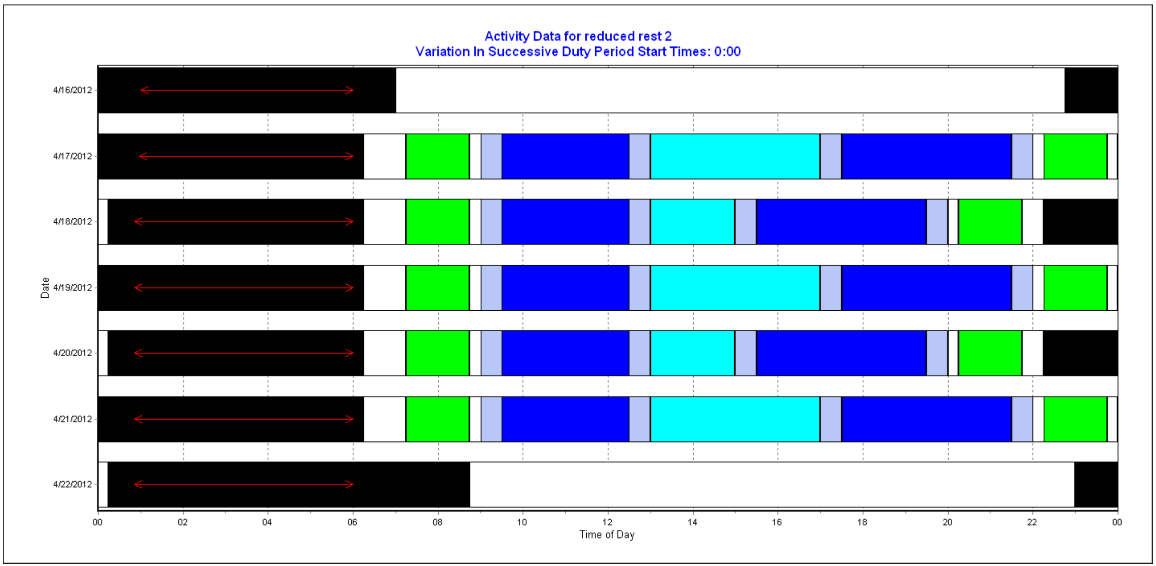


Average alertness while flying four flights on a Westbound business trip is improved by obtaining extra in-flight sleep. Average alertness during flights 1-4 with a short (90 minute) in-flight sleep (blue bars), versus a long (3 hour) in-flight sleep plus extra sleep pre-trip (mauve bars). Flight 1: London, England > New York City, USA, Flight 2: New York City, USA > Miami, USA, Flight 3: Miami, USA > Rio de Janeiro, Brazil, Flight 4 (return): Rio de Janeiro, Brazil > London, England.

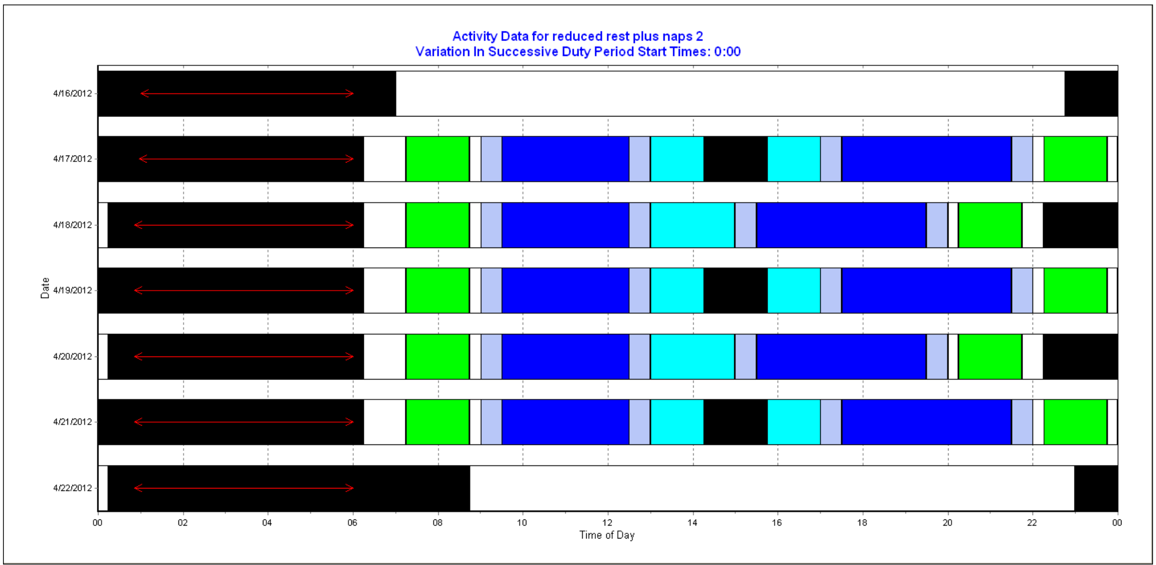
Main report Section 5.7 - Modelling of Cumulative Fatigue, Rest and Reduced Rest

Scenario: Pilots sometimes have to fly on reduced rest, due to long FDP (13hr), long commutes (1.5hr each way), and early starts. These scenarios are intended to compare nights with reduced rest to those with reasonable amounts of rest.

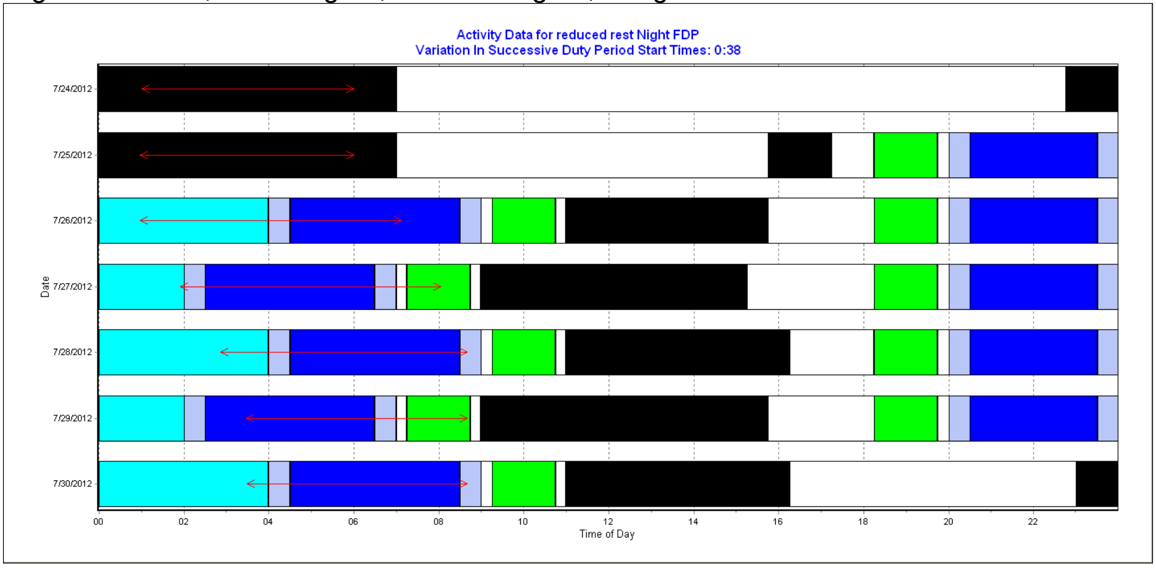
Daytime FDP, 3 late nights (6hr sleep), 2 earlier nights (8hr sleep), Fatigue Score: 26.09



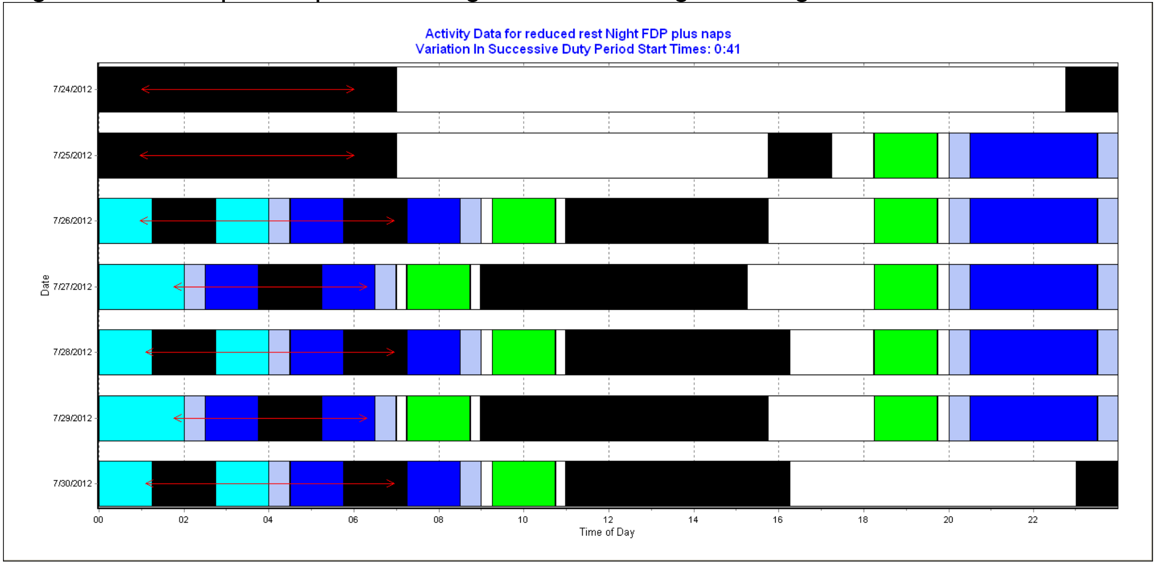
Daytime FDP, plus naps, 3 late nights (6hr sleep), 2 earlier nights (8hr sleep), Fatigue Score: 24.37

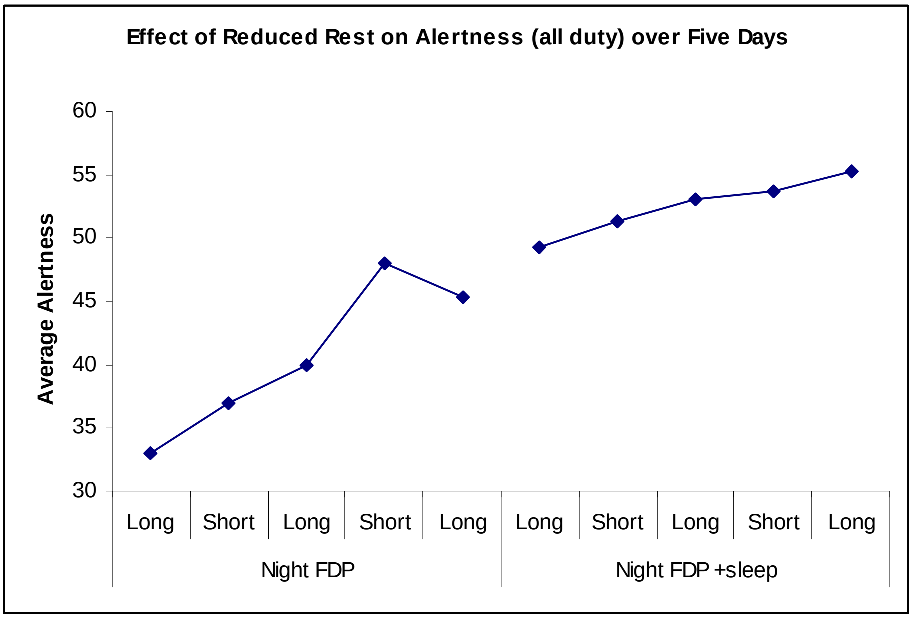


Night-time FDP, 3 late nights, 2 earlier nights, Fatigue Score: 62.04

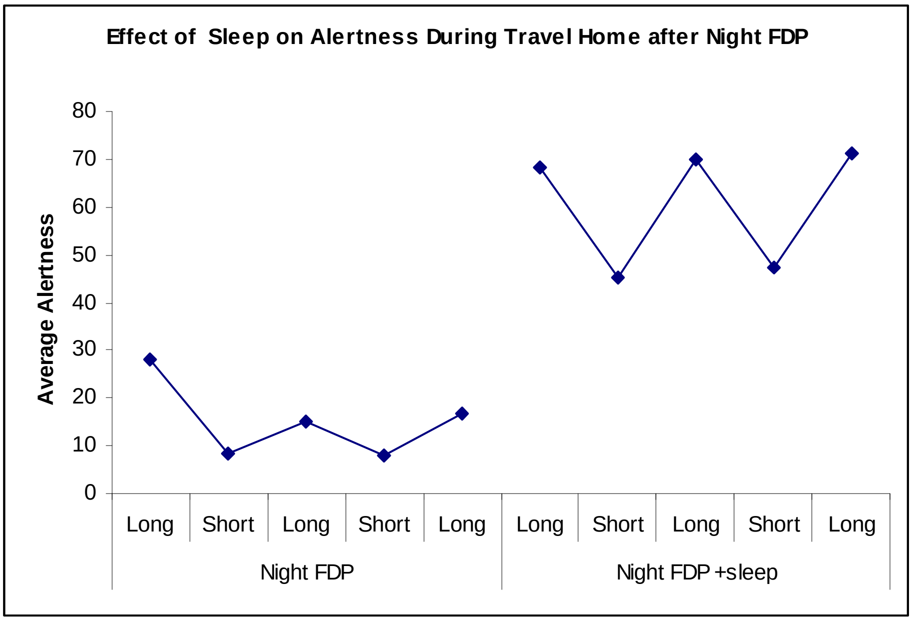


Night-time FDP, plus naps, 3 late nights, 2 earlier nights: Fatigue Score: 44.13





Reduced rest does not obviously alter alertness following a long vs. short night-time FDP. Average alertness increases over time between "Long" days (13hr FDP, 2000-0900 – 9hr flight time) and "Short" days (11hr FDP, 2000-0700 – 9hr flight time). A 90 minute nap during ground break improves alertness on both Long days and Short days.



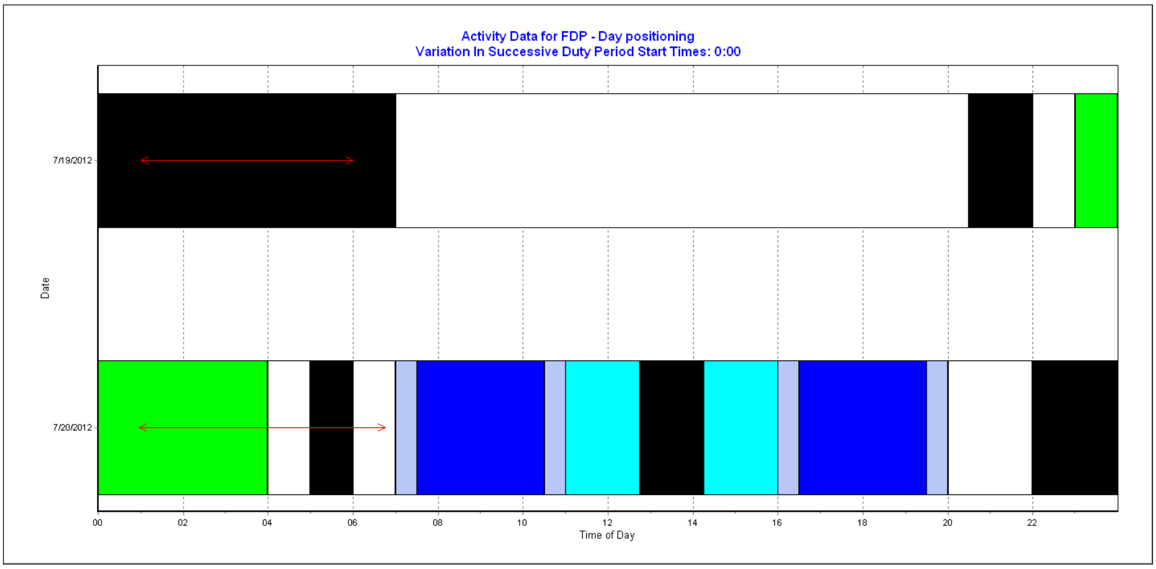
Reduced rest alters alertness during a 90 minute travel home for long and short night-time FDP. Average alertness is reduced during travel home on "Long" days (13hr FDP, 2000-0900 –9hr flight time) and Short days (11hr FDP, 2000-0700 –9hr flight time) and is improved by a 90 minute nap during ground break.

Summary: Overall Fatigue Score and alertness improved with naps included for long nights/reduced rest. When looking at travel home, naps dramatically improve alertness on both short and long days. No sign of cumulative fatigue, in fact the pilots appear to adapt to the schedule and alertness improves over the five days

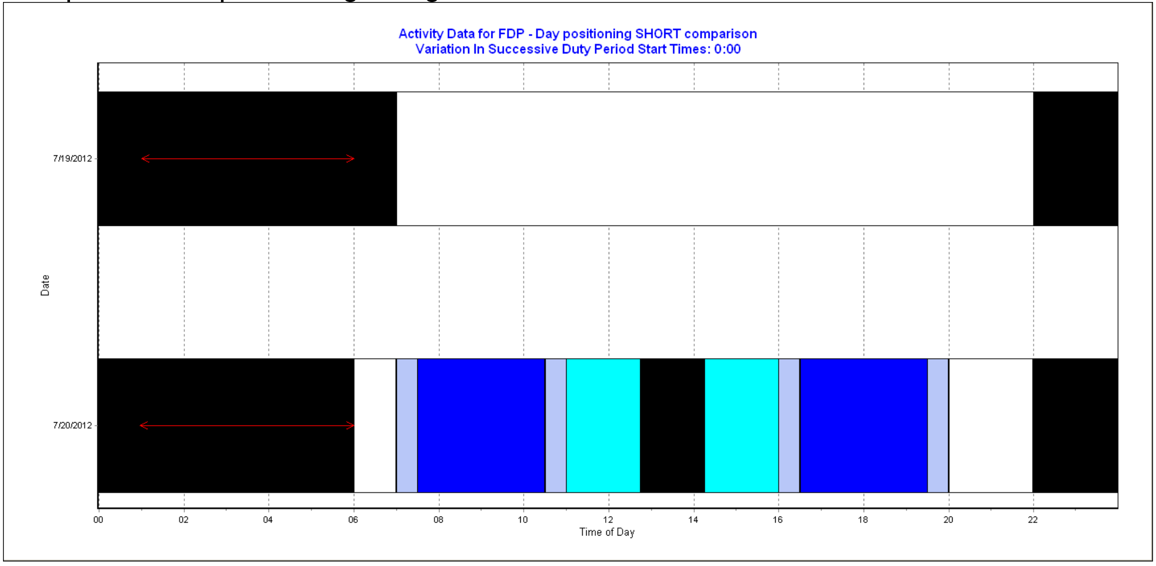
Main report Section 5.12 - Positioning

Scenario: Pilots sometimes have to be positioned to an airport before they can begin their FDP. This scenario examines how positioning could affect fatigue levels, depending on whether the pilot is able to sleep or not during the positioning flight.

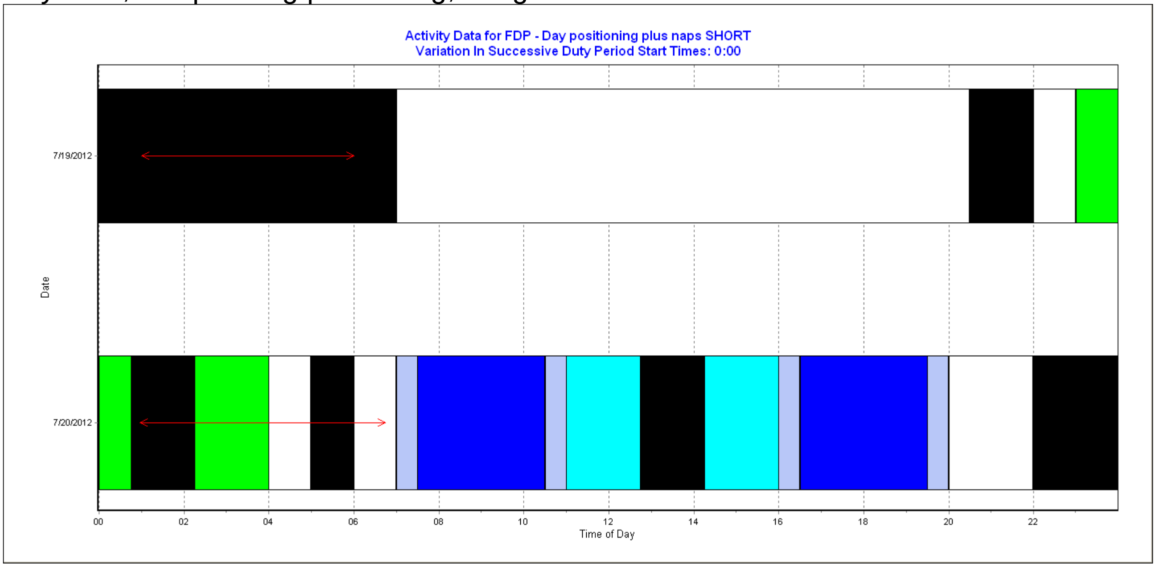
Day FDP, no sleep during positioning, Fatigue Score: 21.76



Comparison, no positioning, Fatigue Score: 7.3



Day FDP, sleep during positioning, Fatigue Score: 14.61



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