APPENDIX 7: Study of Fatigue

Plateforme d'Evaluation, de Prototypage et de TeSts d'UsageS

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ASSISTANCE ON HUMAN FACTORS ANALYSIS

1 STATE OF CURRENT SCIENTIFIC KNOWLEDGE ON FATIGUE

1 USE OF A PREDICTIVE MODEL TO AVALUATE SLEEP: ANALYSIS OF THE A330 5A-ONG ACCIDENT

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1 – STATE OF CURRENT SCIENTIFIC KNOWLEDGE ON FATIGUE

Before considering the probable state of fatigue of the pilots of the A330, it seems useful to prepare a synthesis of the current state of scientific knowledge about fatigue, particularly in aeronautics. This presentation is based on the syntheses carried out during recent work in France under the STARE project (Mollard et al., 2006, Cabon et al. 2009 a, b, Cabon et al., 2010, Cabon et al ,. 2011). This state of knowledge is built around four axes:

- Definition and installation of fatigue mechanisms,
- Acute fatigue versus chronic fatigue,
- Fatigue and safety,
- Fatigue risk management systems.

a) Definition and installation of fatigue mechanisms

Crew fatigue is widely recognized as a safety risk. This risk has been classified by the NTSB as one of its seven "most wanted" improvements and identified as the cause of several accidents and serious incidents. Although there is no real consensus in defining fatigue (we can identify more than one hundred definitions in the literature!), mainly because of the multidimensionality of the concept, it can generally be defined as a physiological and psychological state reflecting a need for recovery (Figure 1). This recovery process corresponds to two distinct types of manifestations of fatigue:

- Events associated with drowsiness or tendency to sleepiness. These events are generated mainly by three processes:
  - the C or Circadian process, regulated by the biological clock that induces a time variation at the arousal level, mainly with a reduction between zero and six hours,
  - the S process, or Sleep pressure that increases with the duration of wakefulness,
  - the W process, which corresponds to a state of sleep inertia (transient state of drowsiness after waking that dissipates gradually).
- The recovery process associated with the drowsiness corresponds to the start of sleep. These processes are affected by many internal factors (individual "morning" or "Evening", "light" or "heavy sleeper", personal concerns, or external (ambient temperature, noise, ..).
- The manifestations of such mental fatigue, physical and muscle associated with the magnitude of service and workload. The recovery process occurs by stopping the activity.

In most situations, these two forms of fatigue coexist. However, most scientific studies, including those conducted in air transport, have mainly concerned the somnolence dimension in fatigue. Recent developments in this work have enabled the development of tools for predicting fatigue (fatigue predictive models).

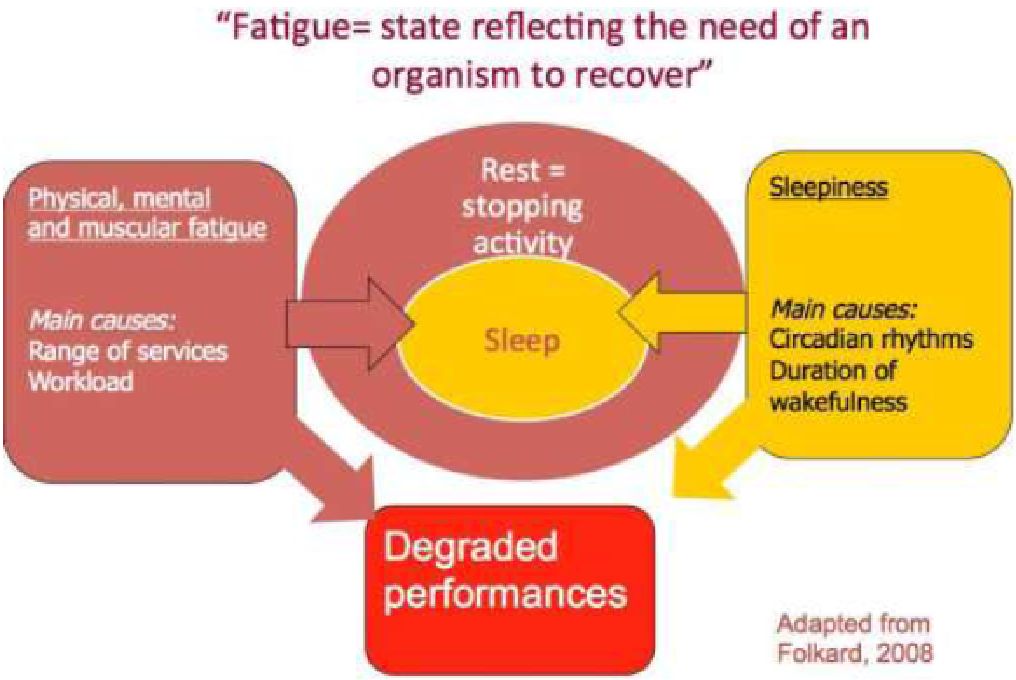


Figure 1. General definition of fatigue

b) Acute fatigue versus chronic fatigue

Another distinction is also made in the manner of installation and recovery from fatigue over time:

- Acute, over 24 hours, such deprivation of all or part of sleep. Depending on the extent of sleep debt, it will be recouped in one or more nights,
- Chronic, over a week or month. It is recovered more slowly and requires several days of rest.

Recent studies suggest that chronic fatigue can have similar effects on cognitive performance as fatigue acute. And repeated sleep deprivation over several days leads to the same performance degradation as a night of sleep deprivation (Van Dongen et al., 2003).

It is essential to remember that fatigue is, in most cases (apart from states of fatigue-related diseases), a normal and reversible physiological phenomenon that reflects a need for recovery (such as hunger, which reflects the need for food intake). However, sleep deprivation or shifts in biological rhythms, repeated over several years, are likely to lead to pathological conditions within the scope of occupational medicine.

c) Fatigue and Safety

The relationship between fatigue and safety is one of the central issues in the recent implementation of the Fatigue Risk Management System (FRMS). Several scientific studies suggest that this link is not completely linear: an increase in the level of fatigue does not systematically and proportionately increase risk. Folkard and Akerstedt (2004) postulate that low levels of fatigue could create a high level of confidence in the operator which would tend to control safety performance less well. This seems especially true in so-called complex systems such as aerospace where team work and automation are likely to "lessen" the impact of fatigue on performance. One critical element that seems to impact the relationship between fatigue and safety is the degree of awareness of one's own fatigue (Cabon et al., 2008). Indeed, when an individual is aware of his/her fatigue, he/she tends to develop strategies to either reduce the level of fatigue, or to ensure this level of fatigue does not degrade his/her performance. Of course, these strategies are effective only for intermediate levels of fatigue. At high levels, fatigue presents a safety risk because of poor performance (increased response times, degradation of situational awareness, deterioration of mood, reduction of communication within the crew , ...).

Although fatigue constitutes a "danger" to safety - in the sense of the French Decree of 22 December 2008 on Safety Management Systems - it cannot be fully assimilated with other risk factors. To summarize, four properties are considered:

Sources of fatigue, both professional and extra-professional: travel time between home and base are particularly likely to be factors favoring fatigue, The sources of occupational fatigue are multidimensional, affecting both work schedules that the nature and context of the activity,

The existence of individual differences in susceptibility to fatigue and the ability to manage fatigue,

That link between fatigue and safety is not linear at high levels of fatigue, and a pilot may need to develop strategies for managing safety that he/she would not need at a lower level of fatigue.

d) Fatigue Risk Management Systems

Traditionally, prevention of fatigue in airlines involves a prescriptive approach governing limitations on service time and calculating minimum rest periods. This approach has its origins in the early 20th century and was adapted to the physical fatigue that tends to become fixed and to decrease linearly. It seems to be much less dominant for "cognitive" activities. Indeed, the establishment and recovery from mental fatigue exhibit nonlinear dynamics (McCullough and Dawson, 2004). Changes related to our biological rhythms mean that an equivalent period of rest does not represent the same potential recovery in daytime. We note that these regulations set criteria level where these variations are rarely taken into account (Cabon et al., 2002). Overall, very few are based on chrono-biological criteria. It is also though that the simultaneous consideration of all the scientific criteria would make the regulations over-complex or inapplicable.

Prescriptive approaches also have limits in that they are generally not adapted to consideration of the high diversity of situations encountered in airlines and the flexibility to design rotations in a highly competitive industry. Moreover, working time is a major issue in social relations within an airline. To cope with these pressures, the system makes use of exceptions leading to reductions of rest periods or extensions of service time without the impact of such measures being checked, despite any negative impact on safety.

From these findings the idea of SMS-RF emerged, which are intended to replace part or all of the limitations of prescriptive duty time and rest requirements. In other words, the limits are set either from universal regulatory criteria, though based on risk-assessed tiredness case by case. For a history and a review of SGS-RF, see Gander et al (2011).

In air transport, the Civil Aviation Authorities of New Zealand were pioneers in this field. Since 1995, they have offered airlines either to apply the duty and rest time rules in force or to implement a much more flexible approach in terms of limits, but with an obligation to take into account the risk of fatigue, a system akin to SGS-RF.

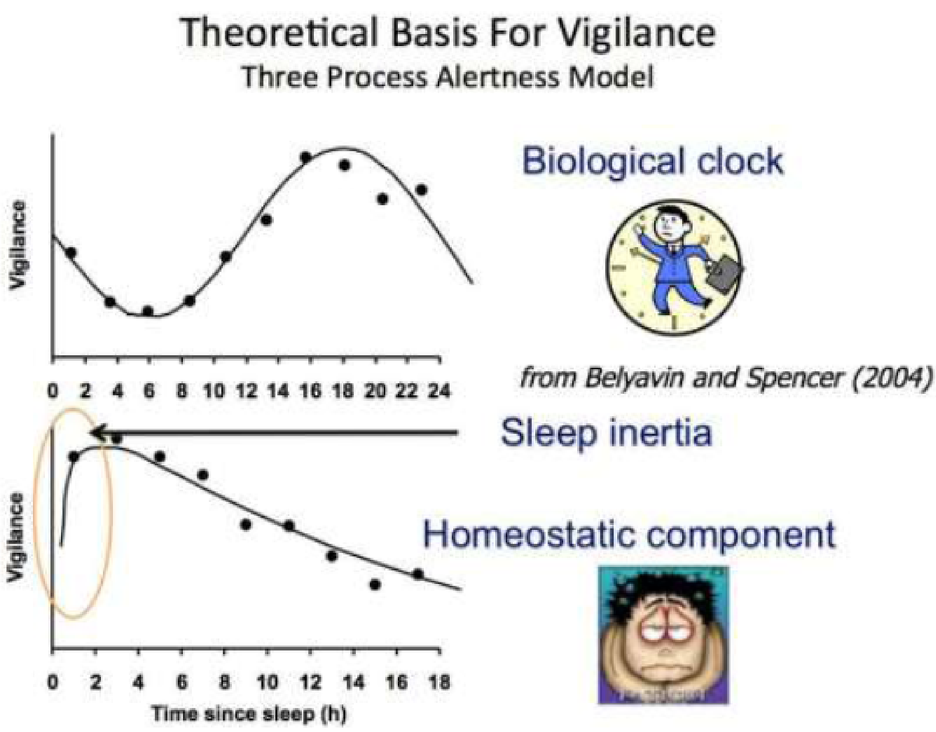
To date, the principles of SGS-RF have also been applied by two airlines: Singapore Airlines, for the introduction of Ultra Long Haul flights that exceeded regulatory limits (Spencer and

Robertson, 2007) and then by Easy Jet for the introduction of new short-haul rotations (Steward, 2006). The common point in these systems is that they use predictive models to assess upfront the risk of fatigue associated with service hours and a continuous or periodic monitoring of safety indicators and fatigue assessments (questionnaires, observations). On an international level, in 2009 ICAO created a "Fatigue Risk Management System Task Force" comprised of operators, authorities and experts to guide the future development of SGS-RF.

2 - USE OF A PREDICTIVE MODEL FOR EVALUATION OF SLEEP: ANALYSIS OF THE A-330 5A-ONG ACCIDENT

The use of predictive models on drowsiness or fatigue is increasingly common in studies of the effects of work schedules on the management of rest for personnel assigned to shift work or unsociable hours, which is the case for pilots of long-haul flights at night. This use is also now common for airlines that have adopted the principles of SGS-RF or FRMS (see previous §).

Simulations were performed using one of the most common models to assess the risk of sleepiness: the Sleep Wake Predictor or SWP. This model accounts for variations in alertness and sleepiness over time. The predictions of this tool are based on the TPMA model (Three Process Model of Alertness) developed by Simon Folkard in the late 80's and integrates the three components mentioned above: the C process which represents the influence of circadian processes, where S represents the homeostatic sleep pressure during wakefulness, and the W process which corresponds to sleep inertia (Figures 2 and 3).



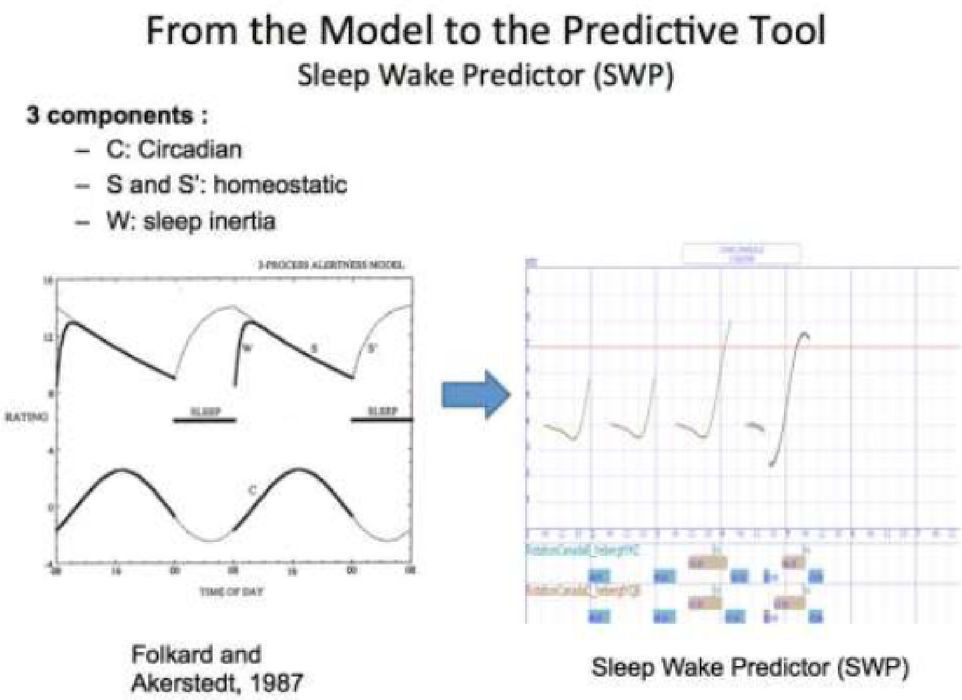


Figure 3. Components of SWP and predictions of sleepiness

The fatigue index is obtained on the KSS (Karolinska Sleepiness Scale). This scale consists of 9 points starting at "extremely alert" corresponding to a score of 9. From a score of 7, the objective signs of drowsiness began to appear, so this value of 7 is conventionally used. Fig 4 presents the levels of sleepiness predicted by SWP for different durations of continuous wakefulness. It was found that level 7 is reached after 21 hours of continuous wakefulness.

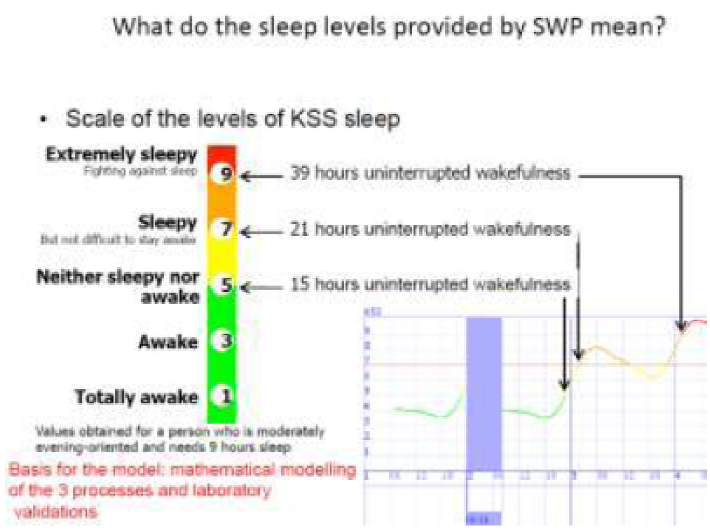


Figure 4. the levels of sleepiness predicted by SWP for different durations of continuous wakefulness

The parameters required as input to the SWP software to plot the curves correspond to the sleep hours in work and sleep schedules.

Since we did not have data on pilots' sleep, we used a software function that can generate, automatically and optimally, these periods of sleep. The sleep durations thus evaluated also take into account certain individual characteristics of sleepers: sleep need and circadian typology.

Two configurations were selected for the simulations:

- Pilot with a need to sleep eight hours and "evening" type profile
- Pilot needing to sleep 10 hours and in the "morning" type profile.

Flight schedules for rotations of 09, 10 and 11 May were taken as input into the software, adding 1 h 30 before and after the end of the flight for the calculation of opportunities for sleep. Opportunities that were incorporated included naps before night flights and during the rest day from night flights and an evaluation of the effect of postprandial sleepiness early in the afternoon. For sleep during the night flights, they were placed according to selected types of sleep for the simulations. It is assumed that the pilots were without sleep debt when they started their duty on May 9. With this input data, SWP calculates the maximum sleep and nap opportunities, then sleepiness levels during periods of wakefulness.

Simulation results for the two selected configurations are shown in Figure 5. One can see that the day flight on May 9 had no effect on the level of sleepiness, identical to that on May 8 On the other hand, the night flights on 10 and 11 May induced partial sleep deprivation, of the order of 40-50% of normal time, it was the same for the daytime rest after the night flights. These findings are not surprising, and there is abundant scientific literature on this subject.

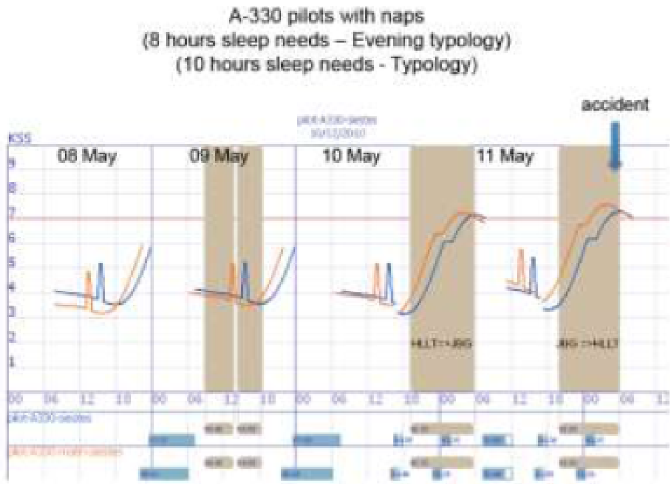


Figure 5. Simulation results for the two selected configurations

Because of the durations of wakefulness and repeated partial sleep deprivation, levels of sleepiness become critical at the end of late night flights (KSS > 7), which again is not surprising.

Altogether, these results lead to a conclusion of a possible contribution of fatigue for both pilots in the accident occurrence.

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