

SAFETY NETS TO PROTECT AGAINST FATIGUE

by Jean-Jacques Speyer



Introduction

We can easily imagine the extent of the challenges faced by the lone Solar Impulse 2 Pilot André Borschberg during his recent trans-pacific journey of nearly 118 hours in the air. Working alone in his single-seat cockpit, he could rest for no more than 20 minutes at a stretch – and then only at lower altitudes where an oxygen mask was not needed in the unpressurised cockpit. Monaco's Control Centre was keeping a careful watch over the failed autopilot monitoring system to protect the flight against critical stability upsets during his occasional 'catnaps'. Narrow margins indeed, with only 15 seconds to react in case of trouble – 6 to 8 seconds for the pilot to wake up and take over with a 4 to 8 data transmission time to Monaco. A reliable safety net to protect against fatigue, would have come in handy to protect the Solar Impulse and its pilot at rest.

With the advent of the FRMS, pilot fatigue is now clearly recognised as one of the major hazards that can impair safety, crew performance and pilot situational awareness. Back in the early 1990's, physiological recordings made during 156 long-haul flights in a project sponsored by the French DGAC and performed jointly by Airbus and the University René Descartes in Paris had shown that reductions in alertness were frequent during flight, including the descent & approach phase. But most decreases in alertness were happening during the monotonous part of cruise and could even occur simultaneously for both pilots at the controls. Specific recommendation cards were designed as a function of number of time zone crossings, day or night-time departure, length of stay, crew augmentation. This underlined the positive impact of operational guidelines on pilot alertness and wellbeing. The findings of the project were eventually gathered together in a comprehensive report published by Airbus in French, English¹ and Chinese to help manage long haul fatigue.

One of the main recommendations promoted in these guidelines is based on the alternation of crew rest and activities, including cockpit napping. The efficiency of cockpit napping was first emphasised by NASA about thirty years ago. However, one of the main drawbacks of cockpit napping in two person crews is that it could contribute to increase cockpit monotony (reduced communications, lower light intensity...) and hence decrease alertness of the sole pilot remaining at the controls.

Monitoring Pilot Alertness

Overall, it was considered that a safety net was needed to cope with these various phenomena. Fail-safe monitoring of both pilots could both help manage the risk of simultaneous sleepiness encounters by protecting the alertness of the remaining pilot when their colleague was engaged in a cockpit nap. The Electronic Pilot Activity and Alertness Monitor (EPAM) was intended to provide exactly this support using a concept that could certainly be replicated to the case of ATC Controllers working in pairs.

The activity monitor included two modes. In the first mode, pilots' interactions within the flight deck were continuously monitored. It was based on the assumption that a pilot who is dozing off will, at some point, tend to interact less with their aircraft systems. Connected to different systems of the aircraft (Flight Management System, Electronic Centralised Aircraft Monitor, Radio Management Panel, etc...) the device tracked tactile Human Machine interactions. In a first mode of use (the ALERT function), if no interaction was detected with at least one of these flight systems after a pre-set period of 5, 10 or 25 minutes depending on the flight phase (or at pilot discretion), a precautionary visual alert would be generated. Then, after a further minute of inactivity, an aural warning activated. A second mode (the TIMER) could be considered as an alarm clock or egg timer which the pilot who

planned to nap would activate. When the alarm sequence in this mode would occur could be programmed but could not be longer than 45 minutes to avoid sleep inertia². Here, the EPAM was seen as a means to help manage rest-activity cycles that involve naps.

The second part of the device tracked alertness using in-flight video monitoring of pilot eye movement. The reason for this was that pilot inactivity alone would not be sufficient to effectively detect all decreases in alertness, since some pilots could still have some interaction with aircraft systems even in low alertness phases. It is a method of dealing with a problem found in other modes of transport and comparable to the function of the dead man's handle found in train drivers cabs... Using specialised image processing software, various parameters such as eye movement and eyelid closure can be automatically analysed. Initial studies in car driving in the late 1990's had already shown that just a few measurements were enough to detect low alertness stages with the nature of these stages depending on the extent of loss of alertness.



JEAN-JACQUES SPEYER

MS EI & Mech Eng, VUB, Brussels, Belgium, MS Aero & Astro, MIT, USA, DU HF's & Ergonomics, Univ René Descartes, Paris, France. After an airline start as B707 Flight Engineer, JJ Speyer moved on to Flight Operations Engineering & Certification at Airbus from where he retired as Senior Director Airline Consulting, Fuel & Flight Efficiency at the end of 2009. He is currently Professor in Aircraft Specification & Certification at the Vrije Universiteit Brussel.

1- a copy of "Coping with Long Range Flying" is available at <http://www.skybrary.aero/bookshelf/books/3214.pdf>
2- Sleep inertia refers to a feeling of grogginess after awakening typically lasting 15-30 min's. During this period, levels of capacity are reduced even to perform simple everyday actions.

Early drowsiness is more associated with strabism³ and long-duration eye fixations while sleepiness is mainly characterised by increased eyelid closures and slow eye movements.

The EPAM device was subjected to operational evaluation during long-range A340 airline flights in the late 1990's and early 2000's. Some 22 round trips were performed on the Brussels-New York route working with volunteer pilots from the former Belgian airline SABENA on rosters known for their significant fatigue effects: early evening flights departing and late evening flights heading back to base.

Physiological parameters such as: electro-encephalograms (EEG), electro-oculograms (EOG) and Heart Rate Variability (HRV) were continuously recorded to evaluate the impact of the EPAM both in terms of its sensitivity to fatigue effects and in respect of its ability to maintain alertness. Simultaneously, detailed observations of operating crew-members were carried out to monitor their activity patterns using dedicated Aircrrew Data Logging (ADL) software and to re-launch the system's timed ALERT function after crew physical tasks.

- The inactive time which would yield EPAM warnings for the different selectable periods: 10, 15, 20 or 25 minutes.
- The alpha/delta ratio from the EEG – when the pilot is supposed to be alert, an increase of this ratio represents an alertness decrement (i.e. an increase of alpha power) but during in-flight naps, a decrease of this ratio corresponds to deeper sleep (i.e. an increase of delta power). Increases of this ratio mean lighter sleep.

Figure 1 shows that potential alerts would have occurred around micro-sleeps after at least 15 minutes of inactivity. The very first micro-sleep is not related to any significant increase of inactivity time. This finding confirms the need for additional information related to the pilot's 'internal state', which it was considered could best be traced by monitoring eye movement.



Airbus flight trials were also held using an A340-300 test-bed in 1999 during a FANS flight around the globe and the usefulness of the device was monitored over 5 very long sectors. Finally, an A340-600 route-proving return flight was conducted to Hong-Kong in April 2002 to test the concept in terms of HMI with a 'Wizard of Oz' experiment. This consisted of a research experiment in which subjects interacted with a computer system that they believed to be autonomous, but which was actually being operated (or partially operated) by an unseen researcher in the aircraft cabin. This technique enabled an evaluation of the usability of the device whilst recognising that it may not yet have reached technical maturity. Usefulness & usability got high marks from this.

Data processing initially focused on sleep quantity and quality during in-flight naps, on in-flight alertness decrements and on EPAM alert warning occurrences. Figure 1 shows the hypnogram during scheduled in-flight nap with an example of results for a New York - Brussels leg with 3 types of data:

- The occurrence of sleep stages 1 to 4⁴ (no REM sleep was observed during these flights). When the pilot is supposed to be alert, some stage 1 sleep can occur – this corresponds to "micro-sleeps".

3- Strabism is the inability of both eyes to focus on one object producing the effect of cross-eyes often linked to a discrepancy between accommodation and convergence.

4- The constituents of the EEG trace being:
 alpha (7.5-14Hz): Deep Relaxation Wave
 delta (0.5-4Hz): Deep Sleep Wave
 beta (14-40Hz): Waking Consciousness & Reasoning
 theta (4-7.5Hz): Light Meditation & Sleeping
 gamma (above 40Hz): The Insight Wave with Rapid Eye Movement Sleep

Figure 2 shows an example of two parameters derived from eye movement video recordings, the duration of eye closures and the duration of eye blinking. First results suggested that an increase in the prevalence of these two parameters could reliably predict occurrences of micro-sleep. Analysis was also conducted on other parameters such as eye fixation and strabism to aid the derivation of the best algorithm.

The initial results of this work confirmed that the EPAM concept was feasible finding:

- that reductions of pilot interactions with cockpit interfaces are often related to decreased alertness which can be detected by physiological observation.
- that the measurement of pilot-system physical interaction alone is not sufficient to predict loss of alertness.
- that loss of alertness detection should employ alternative means such as eye movement tracking.

Further R&D indicated that revived alertness following EPAM cautions & warnings could induce increased situational awareness when pilots performed a systematic flight parameter review procedure as typically required after an absence from the cockpit.

It can be concluded that if pilot in-seat napping is supported, it should better be backed up with a device similar to the tested concept. However, no such systems have yet been developed. And we didn't get through the ten steps towards technical maturity. Somehow, the EPAM concept was ahead of its time since the pilot community was quite worried at the time that this would be a tool to be used to extend flight time & duty limitations as ULR was coming of age. It was indeed well before the heydays of FRMS.

In retrospect, aircraft manufacturers - who had already their plate full at the time - should have teamed up with other industries manufacturing cars, trucks and monitoring facilities in an effort to reach technical maturity and hence dampen costs. Back in 2002, a student team from Brussels'VUB University did their Master's Thesis with me at Airbus on "eye seeing machines" and we even received an award from an electronic display manufacturer that considered this work to be the most innovative of the year.

Thinking about it, this concept should certainly not be restricted to flight crews but could be extended towards Air Traffic Control where difficult rosters do exist for a fact. With today's safety culture we also have the evidence to believe in the need for such protection nets. But it would only work with a solid safety culture not even thinking of identifying any personnel origins of the traces. Only then! With full confidentiality... 

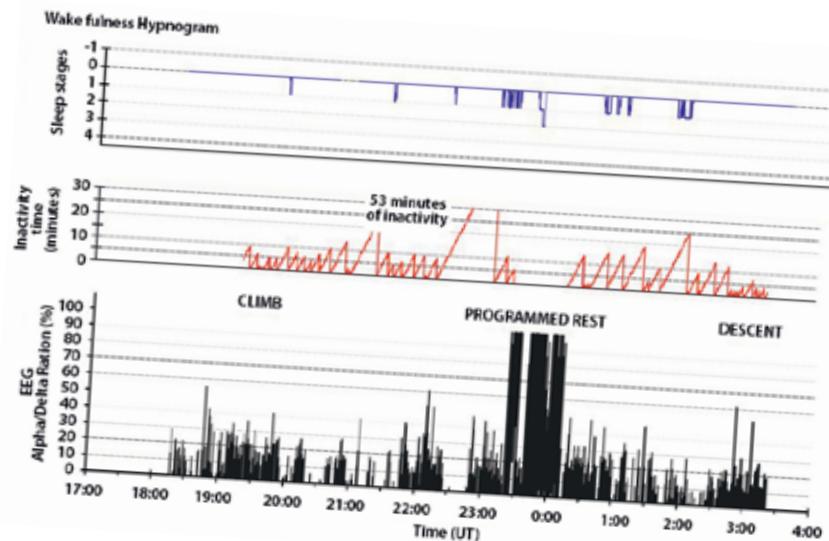


Figure 1. Microsleep occurrences and sleep (A) inactivity time (B), alpha/delta ratio (C) on Atlantic return

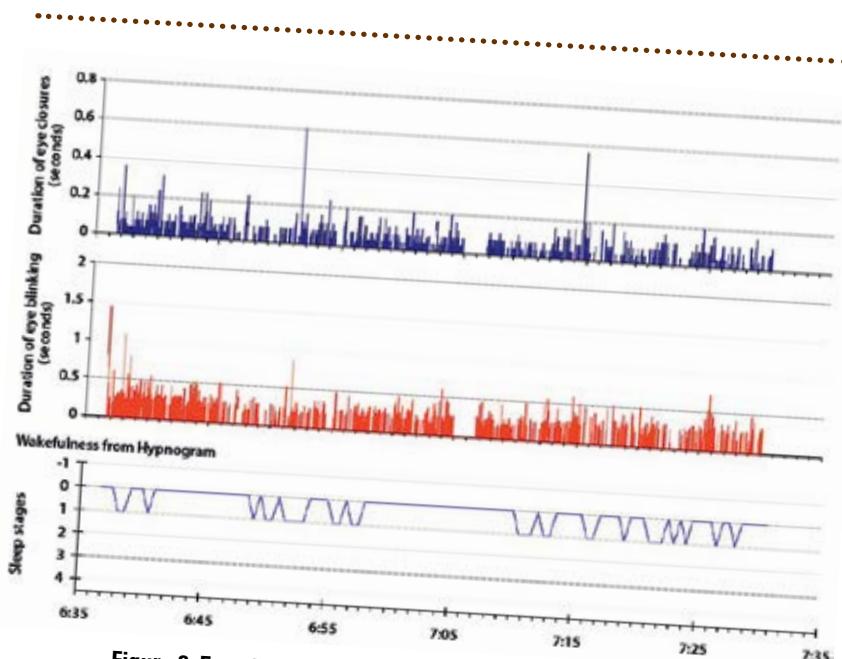


Figure 2. Eye closures duration (A), eye blinks duration (B) and microsleep onsets during 1 hour flight periods

