

# Fatigue in air traffic control

By Professor Philippe Cabon

## Introduction

Fatigue is known to be a major risk for safety in aviation. Even if an accurate quantification of the contribution of fatigue in accidents is currently impossible because fatigue is not systematically investigated by a standardised procedure, it is classified as one of the "most wanted" factors by the National Transportation Safety Board (NTSB): "The Safety Board has long been concerned about the effects of fatigue on persons performing critical functions in all transportation industries including flight crews, aviation mechanics, and air traffic controllers". Since the ini-

tial statement from NTSB recommendations, it is clear that little progress has been made by the industry to address this critical safety issue despite the large amount of available scientific knowledge. The reason is probably because fatigue is a complex concept raising issues beyond safety such as productivity and social aspects. Therefore, fatigue cannot be simply prevented by the application of scientific knowledge but needs a case-by-case approach. This paper summarises the main available scientific knowledge on fatigue, and from this body of knowledge provides some practical recommendations.

## Basic knowledge on fatigue

Although widely recognised as a hazard, there is surprisingly no consensus on what fatigue is exactly, even among

scientific experts. However, Williamson et al proposed to define fatigue as "a biological drive for a recuperative rest." In this perspective, fatigue covers a range of manifestations (physical and cognitive) that results from the absence of rest. One viewpoint could be that fatigue is like hunger and thirst, a signal that alerts us that we need to take a rest. This means that just as for hunger and thirst, it is a normal, physiological state that cannot be totally suppressed. We might just consider preventing it or mitigating its effect to avoid adverse safety outcomes.

Looking at rest, two main aspects should be considered: rest as defined as the end of a given task and rest as the production of sleep. The first type of rest is associated with specific and task-dependent fatigue (muscular, sensorial, mental, etc.). The second type of rest is linked to a more general fatigue manifestation, namely sleepiness. The present paper will focus on this last aspect of fatigue as it is particularly important for ATCOs.

Sleepiness is known to be mainly related to 3 processes (Figure 1):

- the process C for circadian, regulated by the so-called biological clock
- a homeostatic process, the process S associated with the amount of prior wake and amount of prior sleep
- a process W (waking) which reflects sleep inertia, i.e. "a transitional state of lowered arousal occurring immediately after awakening from sleep and producing a temporary decrement in subsequent performance" (Tassi and Muzet, 2000).

This model predicts that at least two conditions are needed for sleep to

## Alertness components

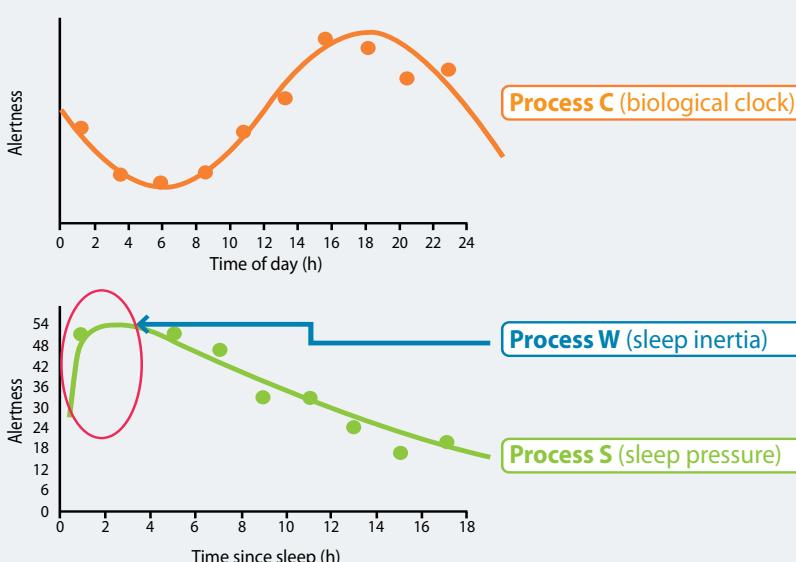


Figure 1. The three-process model of alertness.

## Fatigue in air traffic control (cont'd)

be triggered: a certain level of sleep pressure (homeostatic factor) and an appropriate timing (circadian factor). Under some circumstances, only one condition is met, e.g. during daytime sleep after a night duty, the sleep pressure is maximum but the timing is not appropriate, leading to a disturbed and shortened sleep.

Process W is also an important factor to be considered as it might have a safety impact when considering napping during duties (see next section). Two important features of our biological clock have to be kept in mind when considering the effects of hours of work on ATCOs.

## From an organisational point of view, two levels should be considered in air traffic scheduling: the organisation of the duty cycles ... and the organisation of breaks within the duties.

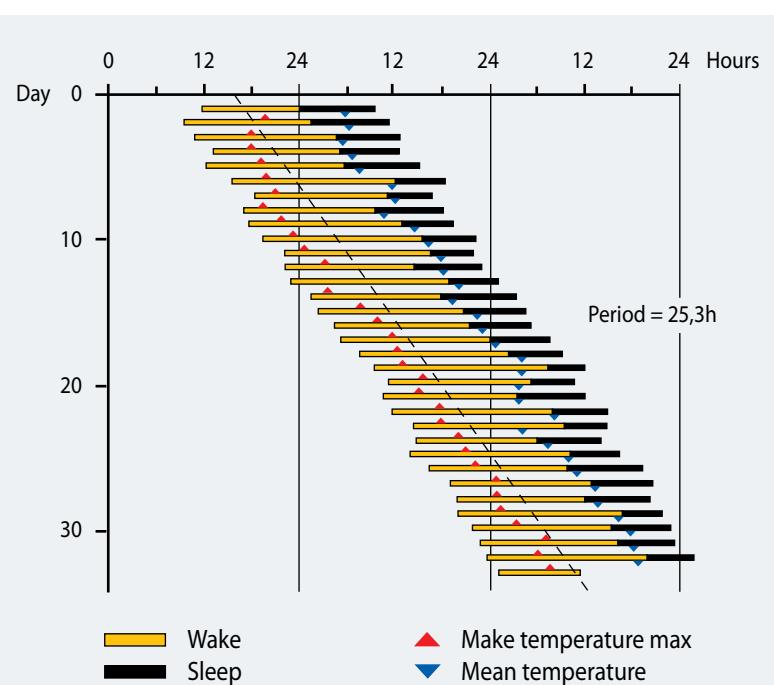
The first of these is that we have a natural trend to delay our sleep-wake cycle. This is particularly clear during days off or holidays, with a spontaneous tendency to delay our sleeping time. This natural trend is essentially due to the fact that the internal period of our biological clock is not 24 hrs but rather 25 hrs. This was discovered in the famous experiment on temporal isolation where subjects were kept for weeks in a cave totally isolated from external time cues (Figure 2). After a few days, the period of the biological clock increases (indicated by the body temperature and sleep-wake cycle). This natural trend explains why it is so difficult to go to bed early the evening

before a morning shift. It also shows the importance in our daily life of exposure to time cues, especially bright light!

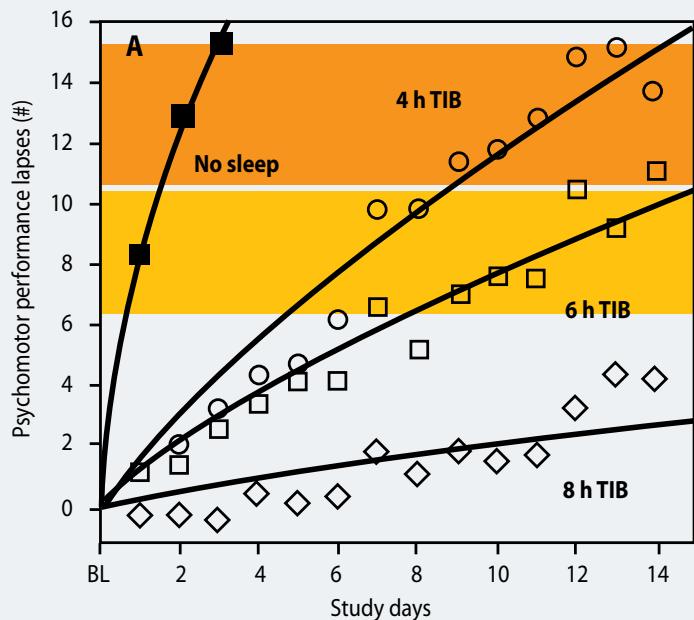
The second important feature of our biological clock is its inertia to change. Therefore, any shift in the work-rest cycle (e.g. shift work) does not induce an immediate adaptation of our biological clock. That is why after days off, when it's time to return to work we have difficulties to advance our sleep-wake cycle leading to fatigue and a decreased performance.

Therefore, the primary effect of irregular hours of work is sleep deprivation. Sleep deprivation is known to produce several detrimental effects on cognitive functions and interpersonal communication. It has been demonstrated in laboratory research that moderate sleep deprivation produces

impairments in cognitive and motor performance equivalent to legally prescribed levels of alcohol intoxication. Even though alcohol and sleep deprivation produce different behavioural effects, this experiment strongly suggests that sleep deprivation can seriously affect safety. Two aspects should be distinguished when addressing sleep deprivation: acute and chronic sleep deprivation. Several researchers suggest that chronic sleep deprivation has the same effects as acute sleep deprivation. This means that slight sleep deprivation cumulated over several days produces an effect equivalent to that of acute sleep deprivation over one period (Figure 3). This result is critical when considering shift work where slight reductions in sleep are repeated duty after duty. This raises the importance of a shift pattern that allows sufficient time off to prevent the accumulation of sleep loss.



**Figure 2.**  
Free running of biological rhythms during temporal isolation experiment (Wever, 1979)

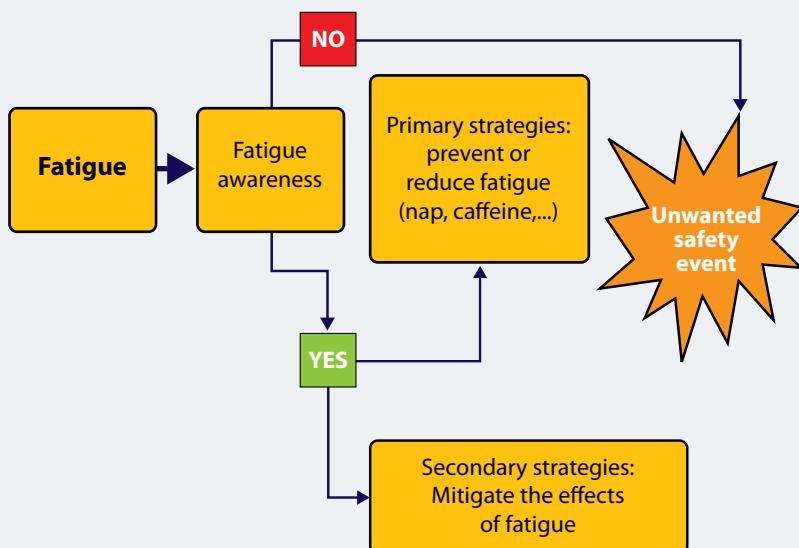


**Figure 3.**  
Chronic sleep deprivation produces the same effects as acute sleep deprivation

It is clear that sleep deprivation has a significant effect on a wide range of cognitive and motor performance. However, does this mean that sleep deprivation has a demonstrated effect on safety?

It seems that the answer to this question is more complex than one would intuitively think. In fact, several findings suggest that the link between sleep deprivation and safety is complex and influenced by many factors. One of the key factors that could explain this complex link is fatigue awareness. On the one hand, being aware of fatigue would lead to the development of strategies to either reduce fatigue or to protect performance (Figure 4). On the other hand, being unaware would not lead to the development of these strategies, which in turn would impact performance and consequently safety. This level of awareness would be probably low at intermediate levels of fatigue, leading to an increased risk for safety. Therefore, it shows the importance of fatigue training to improve awareness and the development of personal and collective strategies.

## From fatigue to safety



**Figure 4.** A model of fatigue and safety

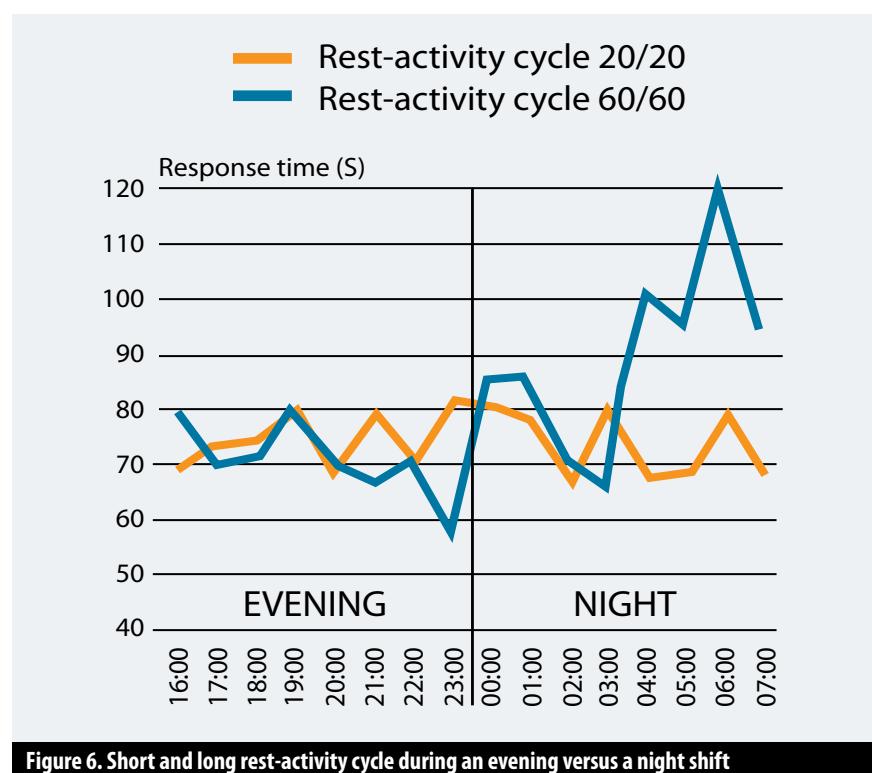
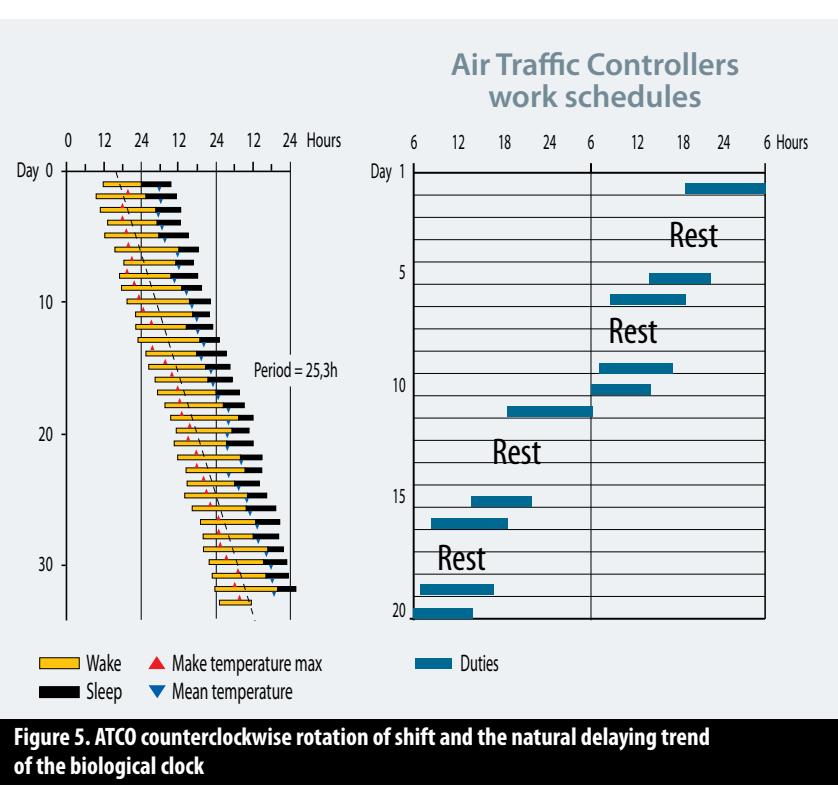
## Fatigue countermeasures for ATCOs

When applied to ATC, the body of scientific knowledge has practical implications both from an organisational point of view and for the development of personal strategies intended to cope with fatigue.

From an organisational point of view, two levels should be considered in air traffic scheduling: the organisation of the duty cycles (i.e. the sequences of duties) and the organisation of breaks within the duties.

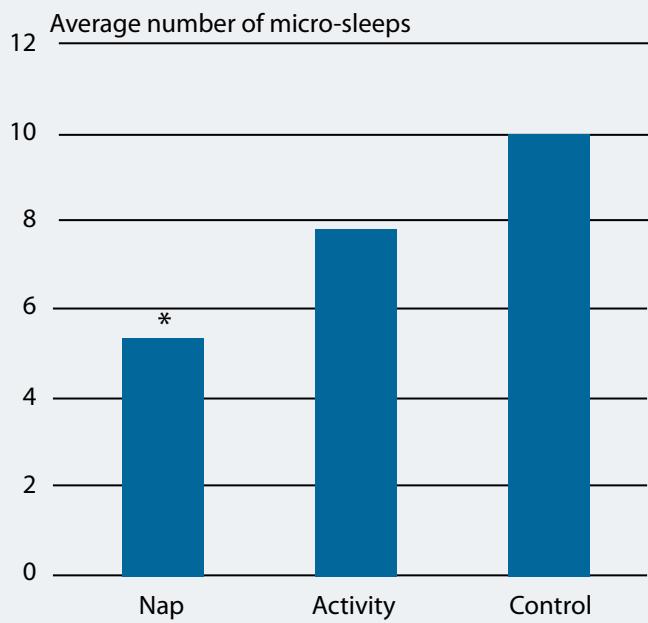
## Fatigue in air traffic control (cont'd)

Organisation of duty cycles is a difficult issue as there is no ideal scheduling. Scheduling is always a compromise between safety, health requirements, productivity and social acceptance. One of the first aspects to consider is the direction of shift, i.e. clockwise (delayed rotation) or counterclockwise (advanced rotation). From a physiological point of view, most shift work experts argue that clockwise rotations are better than counterclockwise rotations because of the dynamics of the circadian cycle, which has a natural delaying trend (Figure 5). However, from the ATCO's perspective these delaying schedules are often unpopular as they tend to compress the weekend. Therefore, if a clockwise schedule is adopted it is necessary to find a way to keep sufficient time off for the weekend period. Another critical aspect is the scheduled time off between shifts, which should not be less than 10 to 13 hours to avoid sleep loss. Of course, the best compromise will



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be reached if ATCOs are consulted in the scheduling change, as it will increase social acceptance. Furthermore, scheduling design can now be supported and improved by the use of a predictive model of fatigue.



**Figure 7. Reduction in the average number of microsleeps by ATCOs during the nightshift after a 20-min nap.**

\* Statistically significant difference between the nap group and activity and control group

Organisation of breaks during shifts is also a critical aspect because of the continuous level of attention that is required in ATC tasks. In a simulated ATC experiment, Pigeau et al (1995) demonstrated that the frequency of breaks should be adapted to the hours of work. Figure 6 shows that a quick work-rest cycle (20 min on/20 min off) produces the same performance (measured as the reaction time to detect aircraft) as a long cycle (60 min on/60 min off) during an evening shift. A reversed tendency was observed, during the night shift, when a significant increase in reaction time was seen for the 60/60 cycle in the circadian low (between 03:00 and 06:00).

One of the important issues concerning breaks is whether these breaks should contain sleep. Napping is probably one of the most popular countermeasures adopted by many employ-

ees in night and shift work. Although various research has demonstrated the beneficial effects of napping on alertness and performance, including in ATC (Figure 7), it is also a controversial issue because of the potential "side effects". These are linked to sleep inertia, i.e. the state of reduced alertness and performance that follows sleep. The duration of sleep inertia is usually measured as the time taken for performance to recover to pre-nap levels. This period can last from a few minutes to several hours depending on various factors, in particular in which sleep stage the waking up occurred (Tassi and Muzet, 2000). Sleep inertia is known to impact a wide variety of cognitive functions, especially an impairment of performance and reaction times and a reduction in memory ability.

Sleep inertia is greater the higher the quantity of deep sleep during the nap.

Therefore, napping during shifts should be implemented carefully by taking into account the timing of naps. When napping is scheduled close to the circadian low or in the case of a previous sleep deprivation, it is preferable to limit the duration of naps to 20 min to avoid sleep inertia.

## Conclusions

Fatigue is a physiological drive for a recuperative rest resulting from internal processes that cannot be naturally suppressed. ATCO working hours led to various cognitive performance degradations associated with sleep deprivation and working at times for which humans are not biologically programmed. However, when considering safety, the impacts of fatigue are less clear as they are influenced by our own awareness of our state and by our ability to develop strategies to overcome the detrimental effects of fatigue. Therefore, the prevention of the negative safety outcomes linked to fatigue should make it possible to reduce the occurrence of fatigue with appropriate scheduling, but also by providing ATCOs with the means to detect and mitigate its effect. **S**



## Professor Philippe Cabon

is currently Assistant Professor in Human Factors at Paris Descartes University (France) and Human Factors consultant in Dédale S.A.S. His main research interests include fatigue, workload and stress in Civil Aviation, Air Traffic Control and industry. He is a member of the ICAO task force on Fatigue Risk Management Systems.