

A FRAMEWORK FOR INVESTIGATING FATIGUE

CONTENTS

1	INTRODUCTION	3
2	FATIGUE-RELATED INCIDENT OR ACCIDENT INVESTIGATION	4
2.1	FATIGUE IN INCIDENTS OR ACCIDENTS	4
2.2	THE NEED FOR A FRAMEWORK FOR INVESTIGATING THE ROLE OF FATIGUE	5
2.3	THE SIX LEVELS OF FATIGUE INVESTIGATION	7
2.4	SLEEP/WAKE TIMINGS	10
2.5	THE USE OF BIO-MATHEMATICAL MODELS	11
3	INVESTIGATING FATIGUE REPORTS	13
4	CONCLUSIONS	15
	REFERENCES	17

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1 INTRODUCTION

ICAO defines fatigue as 'A physiological state of reduced mental or physical performance capability resulting from sleep loss, extended wakefulness, circadian phase, and/or workload (mental and/or physical activity) that can impair a person's alertness and ability to perform safety related operational duties.'

(ICAO, 2015, page xiii)

Fatigue is increasingly considered as one of the most significant hazards to aviation safety and other safety-critical industries. As an illustration, the term 'fatigue' has appeared in the NTSB 'Most Wanted' list for over two decades. Both the academic community and industry have focused on understanding the phenomenon of fatigue and the factors that contribute to it in order to prevent it, but also to mitigate its possible consequences. As a result, procedures and regulations have been developed for operators to comply with and there is now a requirement for operators to demonstrate that they are actively managing fatigue.

While tools and methods have been developed that enable safety professionals to identify whether a crew member or an operator may have been suffering from fatigue, it is considerably more challenging to determine whether fatigue played a role in the sequence of events that led to an accident. This is partly why investigating fatigue remains a challenge, despite the extensive knowledge developed through scientific research and operational experience.

One of the problems faced by aviation investigators is that fatigue cannot be directly measured in the same way that alcohol levels can be tested with a breathalyser. Measuring fatigue involves an element of subjectivity that cannot be ignored. However, research has enabled practitioners to determine limits of time awake after which the likelihood of an individual being fatigued is much higher. This information is key to the investigation of a fatigue-related accident or incident.

While investigating incidents or accidents where fatigue may have been a contributory factor is often considered to be a reactive means of managing fatigue, it can also be considered as having proactive elements, namely through the development of safety recommendations.

The aim of this white paper is therefore to provide safety practitioners with a better understanding of the process of investigating fatigue.

Importantly, investigating fatigue can broadly cover two areas; conducting an investigation of fatigue-related incidents or accidents, and the investigation of fatigue reports submitted by crew members. These are two very different processes that operators need to dissociate in order to efficiently and effectively run investigations and use their resources adequately. This white paper will mostly focus on the investigation of fatigue-related accidents or incidents by providing an investigation framework. It will nonetheless demonstrate the importance of distinguishing the two types of 'fatigue investigation' and provide guidance on how to conduct each of these investigations.

2 FATIGUE-RELATED INCIDENT OR ACCIDENT INVESTIGATION

2.1 FATIGUE IN INCIDENTS OR ACCIDENTS

Fatigue could occur at any time and to anybody. The challenge is that fatigue is not confined to roster, shift, or work-related factors, but also involves personal factors such as home sleep environment and family issues. Effective management of fatigue therefore requires both companies and individuals to have responsibilities for fatigue management, which can be more difficult to monitor and control.

Fatigue has been implicated in a number of incidents and accidents, and directly linked to impaired human performance. Whether it is being considered as a root cause or as a contributory factor, the thorough investigation of fatigue should involve looking at higher levels of management and at broader organisational factors rather than being confined to the individual crew member. The process should also enable the investigation team to discover any underlying reasons why fatigue was a factor in a specific event and therefore understand why an incident occurred.

Because it is difficult to provide evidence that an individual suffered from fatigue at a specific point in time and that this resulted in a mishap that contributed to an accident, fatigue has never been listed as the 'main' and only cause of an accident. However, it has been listed as a likely contributory factor in numerous incidents or accidents. For example, on January the 14th, 2011 Air Canada Flight 878 experienced a pitch excursion and an altitude deviation of +/- 400 feet resulting from the action of the first officer, causing injuries to crew and passengers. Among the causes and contributory factors identified by the TSB Canada were sleep inertia, inadequate fatigue management training, interrupted sleep and circadian phase:

'The first officer was experiencing a circadian low due to the time of day and fatigue due to interrupted sleep which increased the propensity for sleep and subsequently worsened the sleep inertia'

(TSB Canada report, Aviation Investigation Report, A11F0012, p17)

In such investigations, where the role of fatigue is being explored, it is first necessary to identify whether or not the crewmember was fatigued at the time of the event, and second, whether this potential fatigue resulted in the crewmember taking specific actions that played a role in the occurrence.

In common with any other investigation, the initial task is to identify the data to be collected. Since the first step is to investigate the crew or operator's level of fatigue at the time of the event, obtaining sleep data is a priority. This involves collecting a sleep history

from the crew member for the days preceding the event, as well as the usual sleep need of the individual, so that the investigator is able to identify whether the crew may have been suffering from any sleep loss. In addition to the sleep history of the crew member, other sources of evidence include interviews with the crew and/or next of kin, and the use of CVR (Cockpit Voice Recorder) and ATC (Air Traffic Control) tapes in order to identify potential signs of fatigue in the crew or operator's behaviour.

2.2 THE NEED FOR A FRAMEWORK FOR INVESTIGATING THE ROLE OF FATIGUE

Because it can be difficult to measure fatigue accurately, the investigation of the role of fatigue would benefit from the use of a systematic process, based on scientific evidence. This would also permit the classification of fatigue events, which could in turn enable the organisation to develop appropriate countermeasures and/or mitigations.

Over the past 60 years, the body of research on sleep and fatigue has led to significant developments in our understanding of the effects of fatigue on performance and alertness. As a result, tools have been developed which could be employed to design such a process.

One such approach is Dawson and McCulloch's fatigue-risk error trajectory framework (Dawson and McCulloch, 2005). Based on extensive experience working with operators, and assisting safety investigators dealing with the issue of fatigue, Baines Simmons has adapted this approach to provide a framework for fatigue investigation (see figure 1).

INVESTIGATING FATIGUE

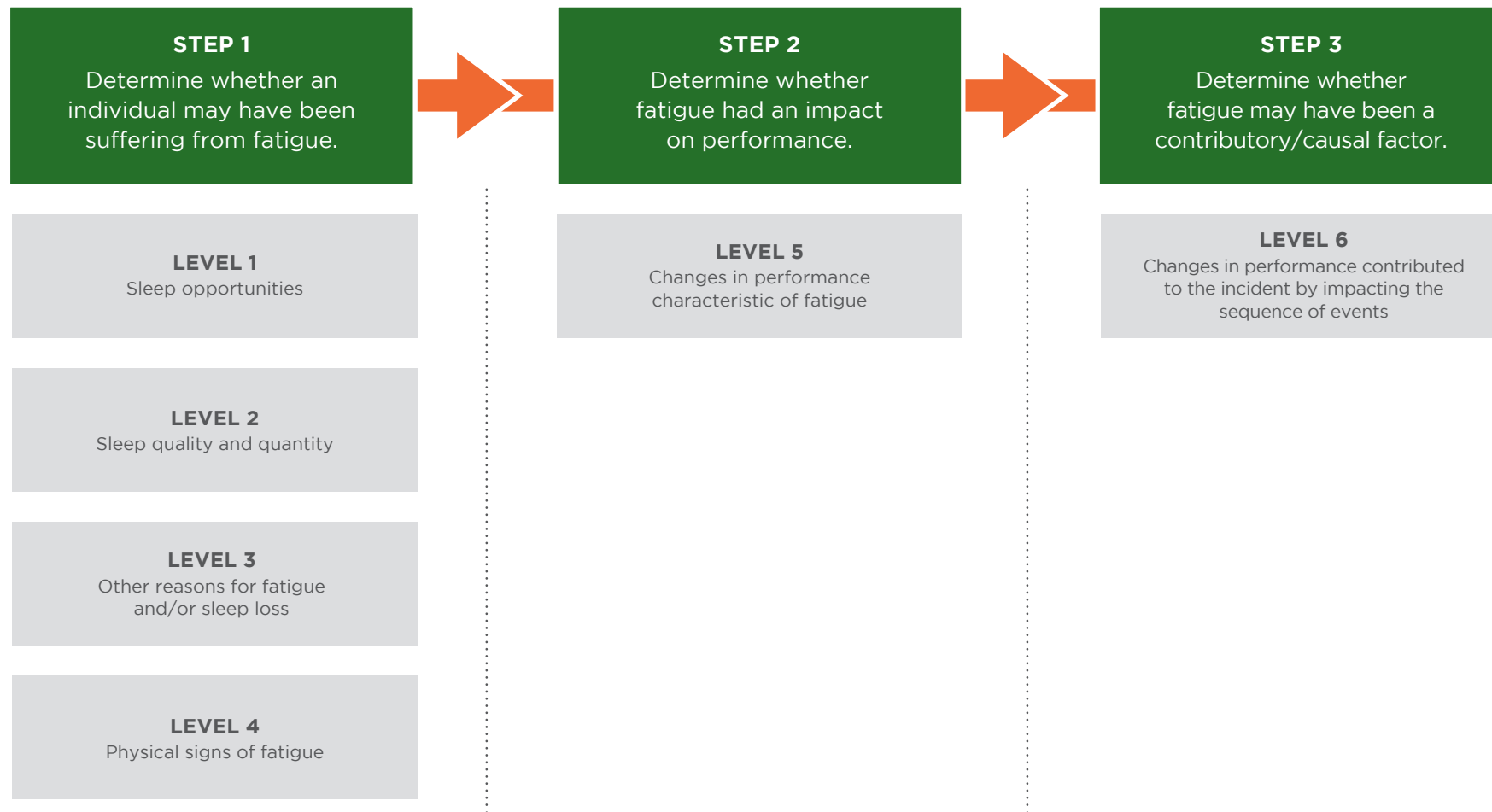


Figure 1: Fatigue investigation framework

2.3 THE SIX LEVELS OF FATIGUE INVESTIGATION

Our approach is designed to enable the investigator to take a step-by-step approach to a fatigue investigation and breaks the process down as follows:

- **Step 1** consists of determining whether an individual may have been suffering from fatigue at the time of the event;
- **Step 2** is to determine whether that fatigue had an impact on the operator's performance; and
- **Step 3** is to determine whether or not fatigue was a contributory factor to the accident or incident.

This approach is based on the premise that there are six levels at which fatigue could be examined to determine whether or not fatigue was a contributory factor to an incident. Each level represents a different layer leading to a fatigue-related incident or accident, as illustrated by the arrow representing an error trajectory. As each level is considered, and information is identified that supports fatigue, the likelihood that fatigue contributed to the incident increases.

- The first 4 levels identify the operator's fatigue level (Step 1);
- The fifth level (Step 2) identifies a change in the operator's performance due to fatigue; and
- The sixth and final level enables the investigator to draw conclusions on the involvement of fatigue in the incident or accident.

Each of these levels contains areas of focus to identify fatigue hazards, and an organisation can manage fatigue and mitigate those hazards by implementing controls at these different levels.

In keeping with Dawson and McCulloch's original model, the framework is based on the understanding that **when a fatigued individual is involved in an incident it does not necessarily mean that fatigue contributed to the incident**. Rather, for fatigue to be a contributor to the incident, the following two conditions must be met:

- At the time of the incident the individual was fatigued: determined by levels 1 to 4;
- A change in performance consistent with fatigue contributed to the incident: determined by levels 5 and 6.

Level 1 explores whether the person was provided with an adequate opportunity to obtain the sleep necessary to perform effectively.

For pilots and cabin crew during a block of duties, sleep opportunity is largely determined by the regulatory flight and duty limitations and contractual limits. Therefore, analysis of a crew member's roster, examination of duty patterns, overnight durations and flight and rest timings, should be undertaken. Other factors such as roster stability should also be considered.

This level mainly considers organisational factors such as policies and procedures and emphasises company responsibilities in providing adequate sleep opportunity to their crew/employee. Examples of controls at this level include Working Time Limitations at the regulatory and organisational levels, as well as fatigue modelling (e.g. using a bio-mathematical model at the roster development stage to highlight potentially fatiguing duties).

Level 2 considers how much sleep was actually obtained during the sleep opportunity. This level focuses on the individual's responsibility to use the sleep opportunity provided to obtain as much sleep as is practicable.

Sleep duration is influenced by a range of factors, most importantly the time of day and quality of the sleep environment. Naps should also be included.

At this level, investigators could take the opportunity to interview the operator who may have been fatigued (if possible) as well as the next of kin, in order to obtain sleep duration and quality during the 48 hours prior to the incident or accident.

As a good indication, most adults need on average between 7 and 9 hours of sleep to be fully alert. Obtaining less sleep increases the probability that the operator was suffering from acute fatigue.

Any sleep disruption or sleep loss should be recorded at this level, and the timing of the incident is also relevant particularly if it occurred during the Window of Circadian Low (WOCL)¹ of the individual.

The role of cumulative fatigue can be determined by considering the sleep pattern during the weeks preceding the incident, and establishing whether repeated sleep loss has occurred over a prolonged period. Factors to consider might include the presence of a new baby, successive early duties requiring an early morning wake up, and excessive commuting. Environmental factors that may impact on sleep quality and quantity (e.g. whether the sleeping environment was dark, quiet and cool) should also be taken into consideration.

The number of time zones crossed during the days leading up to the incident/accident and the impact this may have on the circadian phase of the individual can also have consequences for fatigue and should therefore be included in the examination of level 2.

¹ Window of Circadian Low (WOCL): the period between 02:00 and 05:59 hours in the time zone to which a crew member is acclimatised

Level 3 is concerned with identifying other causes of fatigue, including workload (e.g. number of sectors operated, hassle factors, consecutive duties, duty duration, overtime, working on days designated as rest days), and health difficulties.

Factors such as caffeine intake, alcohol consumption, the use of illicit drugs, prescription and over-the-counter medicines, the possibility that the individual has an undiagnosed sleep disorder, stress, sickness or chronic health conditions that might impact on sleep, should also be considered at this level.

Level 4 evaluates whether the individual displayed any of the physical or cognitive signs of fatigue. For example, physical signs of high levels of fatigue include difficulty keeping eyes open and head nodding (i.e. symptoms of a microsleep – a brief, uncontrollable period of sleep). Other physical signs of fatigue that occur earlier in the process of falling asleep include frequent blinking and repeated yawning.

The extent to which fatigue will be evident in the cognitive performance will depend on the nature of the tasks in which the individual was engaged, but typically the first skills to be affected include communication (the individual becoming more withdrawn and not engaging with colleagues), and mood control (the individual being uncharacteristically irritable, or failing to control their emotions). This information is most likely to be elicited via interviews with friends, relatives and work colleagues. CVRs could help identify whether an individual mentioned feeling fatigued or indeed were sleeping prior to the accident (e.g. Air India Express, Flight 812, 22nd May 2010).

Level 5 describes the changes in performance that research has linked to fatigue.

Fatigue reduces alertness, increases response times and can impair performance, which in turn can lead to errors. If an operator's situation awareness or short term memory were impacted, it could be due to fatigue.

Other characteristic signs of fatigue include impaired decision-making or problem solving, failure to conduct an appropriate risk assessment, tolerance of higher levels of risk, inefficient or ineffective communication, or the use of short cuts and the acceptance of lower standards.

These can be identified if, for example, an individual displayed signs of flawed logic, or failed to react at all, or to react appropriately to external stimuli.

Level 6 is the stage at which the investigator concludes whether or not fatigue was a cause and/or a contributory factor in the incident or accident, by determining whether the change in performance had an impact on the events leading up to the incident or accident.

If levels 1 to 5 identified that the individual was likely to have been fatigued, displayed signs of fatigue, made errors (however minor) characteristic of fatigue, and that those errors had an impact on the sequence of events, then it is likely that fatigue was either a cause of the incident or a contributory factor.

2.4 SLEEP/WAKE TIMINGS

Considering the importance of prior sleep to one's levels of alertness and fatigue, it is easy to understand that sleep/wake duration of an individual is essential evidence to support a fatigue investigation.

In order to effectively investigate fatigue, it is therefore recommended to build a work/rest/sleep timeline for the 3 days leading to the accident. Wherever possible, such information should be obtained via open-ended interview questions as opposed to directly asking the personnel involved how much sleep they obtained the night before the incident. The latter can often be difficult to answer, particularly in the aftermath of an incident or accident. A more fruitful approach is to build up a picture of the individual's activities prior to their last sleep period, (e.g. asking what time they arrived home, how much time was spent eating, socialising with friends/family, preparing for bed etc.) culminating in asking what time they put the light out to go to sleep and then what time they woke, and whether that sleep was disturbed. A comparison between this information and their normal sleep pattern will also help to establish whether the sleep obtained was sufficient given the individual's sleep need.

When gathering this information, it is fundamental to record everything in 'body clock' time, that is to say the time zone to which the individual is acclimatised. This is particularly important when crossing time zones and considering the individual's WOCL.

Finally, bearing in mind that the aim of an investigation is to avoid a similar occurrence in the future, the product of an investigation where fatigue is likely to have been a contributory factor should be the identification of possible mitigation strategies and countermeasures to avoid fatigue. Following the process described in figure 1 should help identify the different organisational levels at which such recommendations could be implemented, whether it consists of amending or adding a safety barrier to reduce the likelihood of fatigue occurrence, or strategies to address the effects and consequences of fatigue.



2.5 THE USE OF BIO-MATHEMATICAL MODELS

Bio-mathematical models are software programmes that enable safety practitioners to estimate an individual's fatigue level and performance degradation based on the length of each work period and days off, the amount and quality of sleep obtained, their circadian rhythm and the time of the day, while considering biological limitations of sleep and recovery. Whilst models are a valuable addition to the safety team's toolkit, it is important to recognise that all bio-mathematical models have limitations. For example, models only make predictions about fatigue, based on the average human being. That is to say they do not take into account individual differences, for example in sleep need. Important factors such as mitigations, workload and environment are also largely ignored by models, and most do not consider the impact of countermeasures such as strategic caffeine intake.

For these reasons bio-mathematical models should not be used in isolation. Moreover, whilst most models have a function that automatically predicts likely sleep based on opportunities between duties and the predicted position of an individual's circadian rhythm, this sleep is always a prediction, and therefore should not be used as a part of the investigation process. When undertaking an investigation, **actual sleep data should always be used** in order to be as accurate as possible.

Despite these caveats, used appropriately bio-mathematical models are a powerful predictive tool in a fatigue risk management system. Together with operational experience, models enable the identification of fatigue hazards by considering crew schedules, hours of wakefulness, sleep opportunities and circadian rhythms.

In some instances, the likelihood that the crew were suffering from fatigue, and/or that fatigue acted as a contributor, cannot be identified due to a lack of sleep data. For example, in the case of Comair Flight 5191, which crashed on take-off in August 2006, the NTSB was unable to identify whether fatigue contributed to the accident and instead concluded that the pilots' non pertinent conversation and failure to use available cues were the causes of the accident:

'The Safety Board concludes that, even though the flight crewmembers made some errors during their preflight activities and the taxi to the runway, there was insufficient evidence to determine whether fatigue affected their performance.'

(p71, NTSB report)

In this specific accident, the crew attempted take-off from the wrong runway and then both crew members and the Air Traffic Controller (ATC) failed to identify the error.

Pruchnicki et al. (2011) used a bio-mathematical model (SAFTE-FAST) to analyse the circumstances of the accident. Using actual sleep/wake data, the model was used to calculate the circadian phase of the ATC on duty during the accident (the investigators were unable to retrieve enough information for the two pilots to reconstruct their sleep/wake history). Duration and quality of sleep were entered into the model, using the information retrieved from the NISTB report. SAFTE-FAST presents fatigue in terms of 'performance effectiveness scores', which are reported using a threshold of 77%². The analysis found that, at the time of the accident, the ATC's predicted performance effectiveness was 71%, indicating a likely elevated level of fatigue.

At a 71% level it can be expected that the performance of the controller would be similar to that of a person with more than 20 hours of continuous wakefulness and that their reaction time was degraded by more than 40%. This suggests that the ATC's performance could have been impaired due to fatigue at the time of the event. Pruchnicki et al. also identified and analysed a number of errors and behaviours displayed by the ATC that were characteristic of fatigue-related errors and behaviours, for example task-fixation.

'... the ATC made fatigue-related performance errors and showed behaviours consistent with fatigue in the 30m prior to the crash and immediately after the crash. These data do not definitively link fatigue from sleep loss and adverse circadian phase to the accident. They do, however, suggest that had the ATC been less fatigued, he might have detected the error in time'

(Pruchnicki et al., 2011, p1060)

This demonstrates the potential usefulness of such tools when real sleep data has been obtained. By entering Pruchnicki's findings and conclusions into the fatigue investigation process developed in section 1, investigators would have been likely to consider the ATC's fatigue as having had an impact on the sequence of events of that accident. In turn, they could have concluded that fatigue was likely to have been a contributory factor.

² A threshold of 77% was selected because research has established that at this level an individual will be performing at a similar level to someone with a blood alcohol concentration (BAC) of 0.05% (50mg alcohol per 100ml blood), the legal limit for drink driving in most countries in Europe.

3 INVESTIGATING FATIGUE REPORTS

Thus far, this paper has focused on the collection of data as part of an investigation of a potentially fatigue-related accident or incident. However, another distinct part of the fatigue investigation process involves the collection and analysis of data from fatigue reports.

As part of the management of fatigue, operators need to encourage crew to report fatigue hazards or instances of fatigue they have experienced via the use of a reporting system. Fatigue reports are a way for crew to self-report any fatigue hazards, or fatigue risks, prior to, during or after a duty. Crew should be encouraged to report unfit for duty if they believe they are too fatigued to conduct their duty, but also to submit a report when they believe they have experienced fatigue-related performance issues.

A functional fatigue reporting system is an essential tool for an operator to manage fatigue and measure the extent to which fatigue has an impact on the operation. It also provides an opportunity for crew to share any concerns that they may have, or may have had regarding their or other's level of fatigue during any stage of the operation.

To facilitate honest and open reporting the organisation needs in place a just culture:

“An atmosphere of trust in which people are encouraged, even rewarded, for providing essential safety-related information, but in which they are also clear about where the line must be drawn between acceptable and unacceptable behaviour.” Reason (1997), p.195

Just culture is therefore a prerequisite of an effective fatigue reporting system. This means that, a crew member submitting a fatigue report should not be worried about the consequences of reporting unfit for duty due to fatigue or when informing the operator that they operated fatigued. This will encourage crew to provide true and accurate information, which in turn will be useful for the analysis. Clear reporting procedures and analysis processes, including timely, individual feedback, should also be put in place and these procedures communicated to the workforce.

Fatigue reports do not systematically require a full investigation, and this is why it is important to differentiate the analysis of fatigue reports from investigations conducted after an incident or accident involving fatigue. Data should be collected from individual fatigue reports, as a part of the analysis process, from which metrics can be calculated which should be periodically reviewed and analysed by the operator's Fatigue Safety Action/Advisory Group (FSAG). Metrics could include trends of sleep history, time of day, type of duty, leave history and subjective fatigue rating amongst reporting crew. If the analysis undertaken by the Fatigue Analyst, and/or the FSAG's overview of the metrics identifies a specific pattern within reports, for example a repetition of a particular route, then more in-depth analysis by the Fatigue Analyst might be required to allow the FSAG to undertake a risk assessment on the identified fatigue hazard and put in place possible mitigations.

The two types of fatigue investigation are however not entirely independent. There are situations where a fatigue report analysis could prompt a full investigation. These can be identified through a thorough risk assessment of the fatigue report analysis outcome: if the risk assessment identifies potential risks to safety then a full investigation should be conducted in order to identify potential countermeasures to mitigate those risks. If on the other hand the risk assessment does not identify a high level of risk, the data from the fatigue report analysis should nonetheless be logged into a database to enable the analysis of trends.

In both situations, the crewmember should be provided with timely feedback: failure to acknowledge receipt of an individual's fatigue report is a sure way to discourage that individual from submitting future fatigue reports.



4 CONCLUSIONS

Fatigue is a major human factors issue that safety-critical industries such as aviation have to manage effectively in order to reduce the risk associated with its occurrence, and to limit its effects. Fatigue can result from work (e.g. roster, work design, workload) and non-work factors (e.g. health, personal, lifestyle, social, economic), which is one of the reasons why reliance on prescriptive rules, in isolation, is not an effective fatigue management strategy.

A number of methods are employed by operators and safety practitioners to identify, assess and manage the risks associated with fatigue, amongst which is fatigue investigation. Investigating fatigue can mean two very different things; namely, analysis of fatigue reports submitted by crew, and investigating occurrences where fatigue is likely to have been a contributory factor.

The former does not generally require a full investigation, whereas the latter necessitates a more thorough process to first identify whether fatigue was present, then whether it was the reason for any observed impaired performance, and finally to identify whether these potential errors had any causal role in the event.

The framework proposed in this paper enables the safety practitioner to investigate, step-by-step, whether or not fatigue was involved in an incident or accident, by considering the different levels where fatigue should be examined, and by asking the right questions.

This approach highlights the importance of considering both individual and organisational responsibilities in the management of fatigue and in turn, in the making of safety recommendations in the aftermath of a fatigue-related accident or incident.

The investigation framework outlined above is not restricted to commercial aviation flight crew fatigue, but instead could be applied to other safety-critical operations, such as helicopter operations, and Air Traffic Control as well as in the wider transport industry, health, mining and oil and gas industries.

Differentiating between the analysis of fatigue reports and the investigation of fatigue events is essential for an organisation. If one were to run a complete investigation of every fatigue report, it would use valuable resources such as time and money and place intolerable demands on the workload of the safety team, as well as delaying individual feedback.

It is, however, fundamental that the data from all reports is collated and analysed, and that the resulting metrics are reviewed by a dedicated fatigue safety group on a regular basis to identify trends and potential hazards, as well as taking appropriate actions when necessary.

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- Baines Simmons is a London-based company established to help organisations to manage the risks associated with fatigue and workload. Baines Simmons specialises in delivering fatigue risk management solutions for companies whose employees are involved in safety critical work, such as aviation, the petrochemical industry, road transport and the emergency services. Our work provides organisations with the evidence needed to ensure that the business is operating within an acceptable risk threshold.



REFERENCES

Dawson, D. and K. McCulloch (2005) Managing fatigue: it's about sleep, *Sleep Medicine Reviews*, 9, 365-380.

ICAO (2015) *Fatigue Management Guide for Airline Operators*, 2nd Edition.

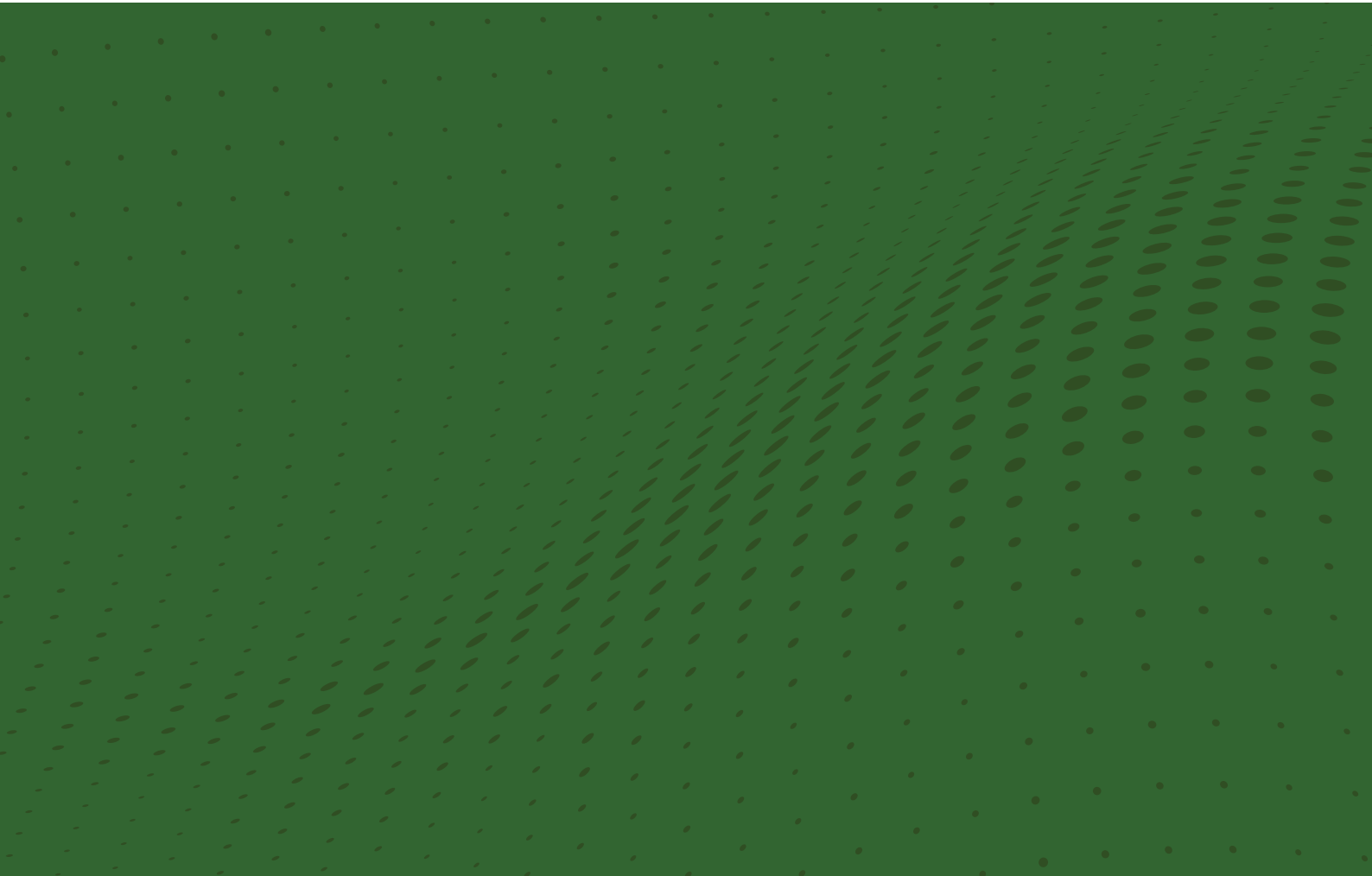
NTSB ACCIDENT REPORT NTSB/AAR-07/05 PB2007-910406: Attempted Take-off From Wrong Runway Comair Flight 5191 Bombardier CL-600-2B19, N431CA Lexington, Kentucky August 27, 2006.

Pruchnicki S.A., Wu, L.A. and G. Belenky (2011) An exploration of the utility of mathematical modelling predicting fatigue from sleep/wake history and circadian phase applied in accident analysis and prevention: The crash of Comair Flight 5191, *Accident Analysis and Prevention*, 43, 1056-1061.

Reason, J. (1997) *Managing the Risks of Organizational Accidents*, Ashgate Publishing Limited, England.

TSB Canada report, Aviation Investigation Report, A11F0012: Pitch Excursion Air Canada Boeing 767-333, C-GHLQ North Atlantic Ocean, 55°00'N 029°00'W 14 JANUARY 2011.





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