Aviation

NON-TECHNICAL SKILLS

NTS

GUIDEBOOK

INTRODUCTION

It has long been recognised in aviation that it's not just technical knowledge and skill that makes an individual a great performer. Great performers have something more — an understanding of how humans work, their abilities and limitations, and how to use these to get the best from themselves and others.

The term non-technical skills (NTS) encompasses attributes including the ability to recognise and manage human-performance limitations, to make sound decisions, communicate effectively, lead and work as a team and maintain situation awareness. When coupled with strong technical skills, NTS is the difference between performance that is acceptable and performance that is outstanding.

The nature of military operations — complex, dynamic and often conducted in challenging environments — warrants increased emphasis on NTS. As our platforms and operations become increasingly complex, standardised NTS training becomes critical to an agile, adaptive and networked force.

Defence aviation has a well-deserved reputation as a leader in the field. Targeted human-factors and crew/maintenance resource management programs have been well established for many decades and involve a range of occupations, including aircrew, engineers, maintainers and joint battlefield airspace controllers. The current evolution of human-factors training focuses on the NTS of individuals and teams and emphasises the need to integrate both technical and non-technical performance in the training continuum.

This guidebook is designed to introduce the reader to human-factors considerations such as human performance, error and violation, safety culture and specific NTS such as situation awareness, decision-making, communication, leading and working in teams and managing stress and fatigue.

It has been designed to complement the Defence Aviation NTS Foundation and Continuation training courses and support NTS trainers and other Defence members to strengthen their knowledge of aviation human factors.

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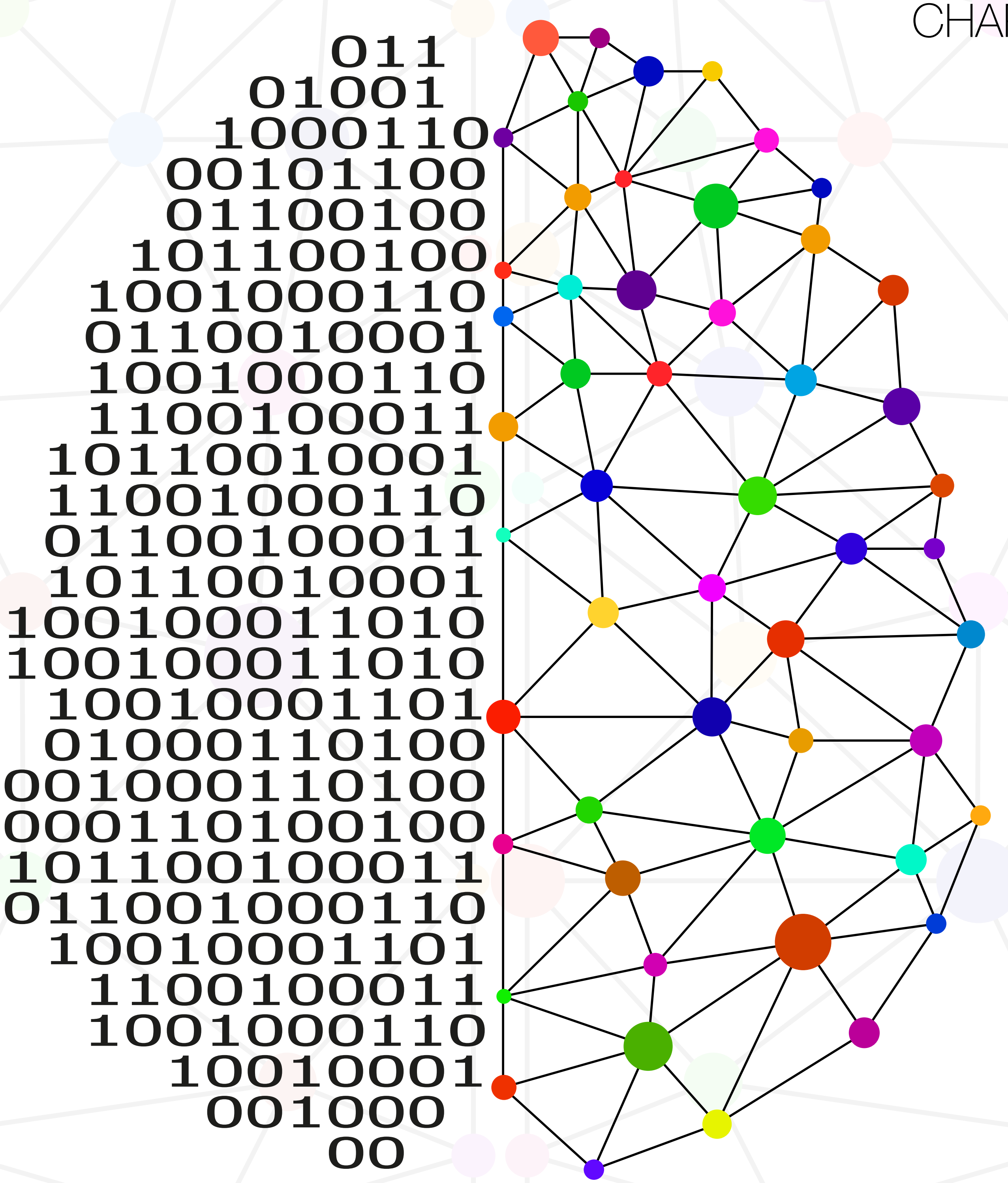


CHAPTER 1 History and development of non-technical skills training

Aviation is an industry that has long been preoccupied with technical excellence. However, time and time again, safety-occurrence investigations reveal the critical nature of non-technical skills (NTS), such as communication, situation awareness, decision-making and teamwork. NTS are sometimes referred to as 'soft skills', but this diminishes their importance. In fact, irrespective of technical-skill level, without well-developed NTS the pilot, maintainer or air traffic controller is likely to be an adequate operator at best. An analogy might be the genius who has little common sense or social skills and cannot relate to others and; therefore, functions poorly in a co-operative environment. This genius may have little or no ability to influence others despite having quality contributions to make. In Defence aviation every task you undertake will be reliant on a number of individuals coming together to achieve a mission.

In a world where improvements in training technologies and training techniques have facilitated the acquisition of technical knowledge and technical skills, individual differences in performance are increasingly due to NTS, which have not traditionally been trained or developed to the same degree.

Aviation is a field that does recognise the importance of NTS. We have learnt this lesson the hard way through aviation accidents, where NTS were identified as key contributing factors, or as potential defence systems that failed to prevent them.

For example:

- A crew, distracted by the failure of a landing gear indicator light, failed to notice the automatic pilot was disengaged and allowed the aircraft to descend into a swamp.
- A co-pilot, concerned that take-off thrust was not properly set during a departure in a snowstorm, failed to get the attention of the captain so that the aircraft stalled and crashed into the Potomac River.
- A crew failed to review instrument landing charts and the aircraft's navigational position with respect to the airport, and further disregarded repeated Ground Proximity Warning System (GPWS) alerts, before crashing into a mountain below the minimum descent altitude.
- A crew, distracted by non-operational communications, failed to complete checklists and crashed on takeoff because the flaps were not extended.

- A breakdown in communication between the captain, co-pilot, and air traffic control (ATC) regarding fuel state resulted in the aircraft crashing following complete fuel exhaustion.
- A crew crashed on takeoff because of icing on the wings after having enquired about de-icing facilities. In the same accident, a flight attendant did not communicate credible concerns about the need for de-icing expressed by pilot passengers.

Defence is not immune — consider the following:

- A helicopter crashed into a ridgeline on approach to landing after conducting night tactical-formation operations. The captain had been awake for nearly 18 hours and had conducted 10 take offs and landings during the three-hour flight. The three crew members and two passengers were all killed.
- An aircraft caught fire during maintenance operations on the oxygen system — the task was carried out without reference to the publications and the high-pressure oxygen system had not been bled from 1800 psi to 500 psi as required. This likely exacerbated the rate and severity of the fire. The aircraft was written off with category 5 damage.
- A mid-air collision during air combat training killed the lead pilot and destroyed the lead aircraft. The investigation noted errors of judgement, distraction, inexperience and fatigue among the contributory causes.
- An aircraft crashed during a night TACAN approach killing both pilots. The investigation identified a number of human-factors issues, including: loss of visual cues, distance judgement at night and disorientation.

These are just a small selection of military accidents that have identified NTS deficiencies during the investigation. This guidebook will cover some of these and others in more depth as we progress.

NTS don't just prevent accidents, they aid in enhancing performance and reaching our maximum potential. The US National Association of Colleges and Employers regularly publishes a list of the attributes that are most valued by potential employers. In a recent publication (NACE, 2015), of the top 10 most valuable attributes, technical skills come in at number 10. The top five spots were occupied by NTS that will be covered in this guidebook: leadership, ability to work in a team, verbal-communication skills, problem-solving skills and written-communication skills. Spots five through nine are also highly relatable: strong work ethic, initiative, analytical/quantitative skills and flexibility/adaptability.

The aim of this guidebook is to introduce individuals to some of the main categories of NTS, to demonstrate their value in aviation through case studies, identify where deficient NTS have led to accidents, and to explain techniques that will help individuals develop their own non-technical skills.

Human factors, crew resource management, and non-technical skills.

These three terms are all frequently heard in Defence aviation where there is concern about the role of human factors in an increasingly technological environment.

Human factors (HF)

Human factors refers to the wide range of aspects that affect how people perform tasks in their work and non-work environment. The study of human factors pools knowledge from psychology, medical and engineering disciplines to develop an understanding of human capabilities and limitations, and to minimise human error by optimising the relationships within systems between people, activities and the work environment. In Defence aviation we use the C-SHELL model (adapted from Edwards, 1972), shown in Figure 1–1, to help us identify and manage those interactions.

C-SHELL stands for culture, software, hardware, environment, and liveware and presents different categories of factors that can affect human performance.

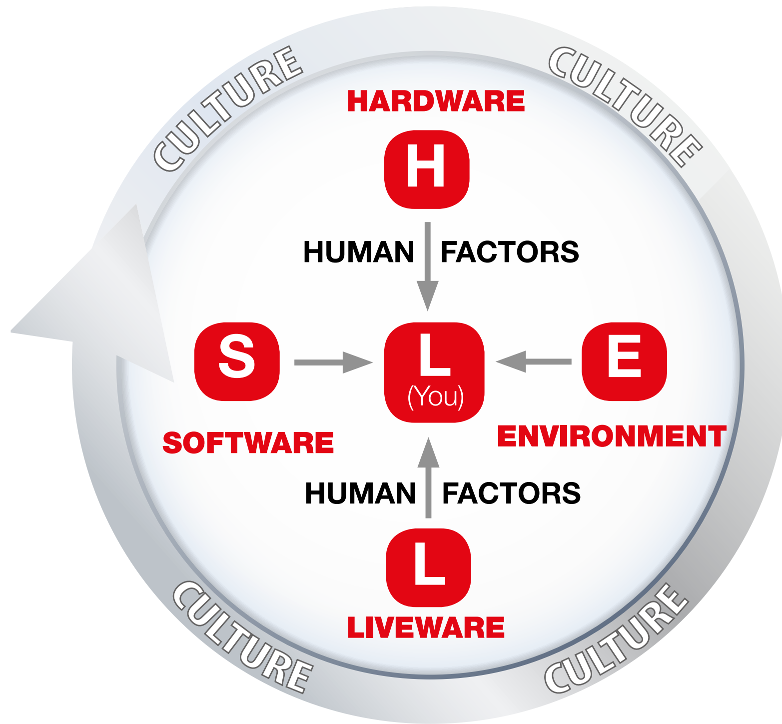


Figure 1–1. Capturing human factors in the C-SHELL model

Culture refers to the shared beliefs, values and norms that individuals and groups develop to make sense of the organisation in which they work. An organisation's culture provides a powerful influence on the way members think, feel and behave.

Software includes documentation such as procedures, policies, rules, and manuals that specify how we are to do things, and the maps, charts, checklists and documents that we use to support our task.

Hardware refers to all physical aspects of the aircraft and associated equipment. It includes the things we work with: tools, the aircraft, equipment, our physical workspaces and buildings. The design of hardware can determine how effective we are at our jobs and can contribute to error.

Environment refers to the physical characteristics of the workplace, including elements such as light, temperature, vibration and weather conditions. These conditions can impact our ability to sense information (for example, if the environment is noisy we may not hear an instruction), our ability to complete a task safely, or contribute to stress and fatigue that in turn affects our performance.

Liveware refers to the other people in the system, including their physical characteristics, knowledge (as affected by training or experience), their attitudes and cultures. All these factors affect how well they perform. Stresses they bring with them from home or encounter on the job can also affect their performance. Liveware also refers to how people act in groups. Issues of teamwork, communication, group leadership, and group norms affect how well the group performs.

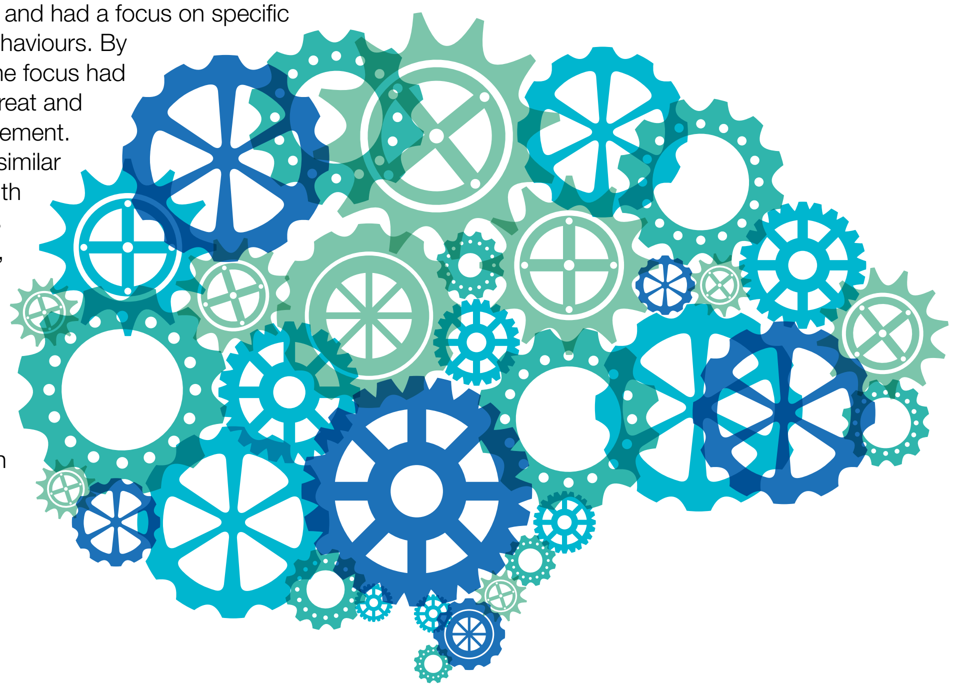
The components of this model do not act in isolation. Rather, they interact with each other and with the central human component to shape performance. Any combination of these elements can contribute to human-performance problems. Where problems are encountered, HF solutions involve changes to the design of the system (software, hardware, environment) or to the selection and training of the personnel (liveware).

Crew resource management

Aircrew in particular have always been aware of the importance of NTS, but they haven't always approached training in a systematic way. For many years, experience and gut feel were more often used to train and assess NTS. Early programs, initially called Cockpit Resource Management, and then Crew Resource Management (CRM), began to emerge in the late 1970s and early 1980s. The first formal military CRM program was introduced in the US in the late 1980s.

CRM has continued to evolve over the years. In the early days, the focus was in the cockpit and on individual management styles and interpersonal skills. In the mid 1980s, CRM programs expanded to include teams outside the cockpit and focused on more aviation-specific concepts including teamwork and team management.

By the mid 1990s, CRM had expanded beyond the aircraft to include air traffic controllers and maintainers, and had a focus on specific skills and behaviours. By the 2000s the focus had moved to threat and error management. While other similar programs with similar focus existed prior, formal, systematic CRM training was initially introduced in Defence in 2000.



CRM is defined as the optimal use of all available resources — equipment, procedures and people — to promote safety and enhance the effectiveness of operations (Lauber, 1986). CRM and Maintenance Resource Management (MRM) programs have been standard elements of training courses and safety stand down days for many years.

Non-technical skills (NTS)

Like CRM, NTS is a branch of human factors. In Defence aviation, the term 'non-technical skills training' is used to denote targeted HF training designed to promote reliable and effective task performance by personnel in safety-critical positions. It may be treated as synonymous with CRM or MRM. They are all performance based, and do not focus on teaching specific technical skills. This exclusion of the technical element is simply an acknowledgement that training in this important area is already occurring.

After many generations of CRM, Defence is joining other sections of the aviation industry and shifting the focus of its foundation training in HF towards NTS. The training contains many of the subjects found in the CRM course but the emphasis is clearly different with a focus on NTS at both the individual and group levels.

How do non-technical skills affect performance?

It can be difficult to demonstrate the effectiveness of CRM and NTS training because safety performance is difficult to measure and safety occurrences, when they do occur, usually have multiple contributing factors. Accident reports and ASRs can help to establish whether factors such as communication and situation awareness were involved in an occurrence (see van Haren, 2015) but these occurrences are not frequent enough to judge the effectiveness of training directed at communication and situation awareness.

Techniques such as Line Operations Simulation (LOS) and the Model for Assessing Personnel Performance (MAPP; Mavin & Dall' Alba, 2010) are better suited for this purpose. Even here; however, the difference between simulated and actual environments can compromise the measurement and evaluation. For example, flight simulators can never fully capture the impact of subtle weather changes on flight controls, or prepare flight crew for completely novel and unexpected safety-critical scenarios.

Fortunately, we can refer to other areas that have a longer tradition of investigating and evaluating non-technical elements of performance. The field of sport psychology, for example, has always kept separate the technical and non-technical elements of performance.

A sport psychologist working with an athlete to improve performance will not even venture into the technical area. The coach takes care of that side of things and the exercise physiologist or personal trainer takes care of fitness. The sport psychologist will help the athlete to acquire skills in confidence, self-talk, debriefing, visualisation, goal setting, anxiety management, motivation, fatigue management and personal self-care. These are all non-technical skills that have an unchallenged role in achieving sporting success. Once athletes have reached a certain level of technical skill and fitness, it is the NTS that often determine the outcome.

Aviation follows the same principles — classroom-based NTS training must be transferred to skilled practice. Throughout an individual's Defence aviation career they will be exposed to a range of NTS training and assessment in the classroom, the lecture theatre and while undertaking practical training. These skills aren't just about safe and efficient performance, but have the potential to improve performance and bring out a person's best abilities.

Key points

- It is easy to fall into the trap of focusing only on the technical requirements for good performance.
- Technical and non-technical skills are important influences on performance.
- Training in both areas is an essential step in an individual's career path in Defence aviation.

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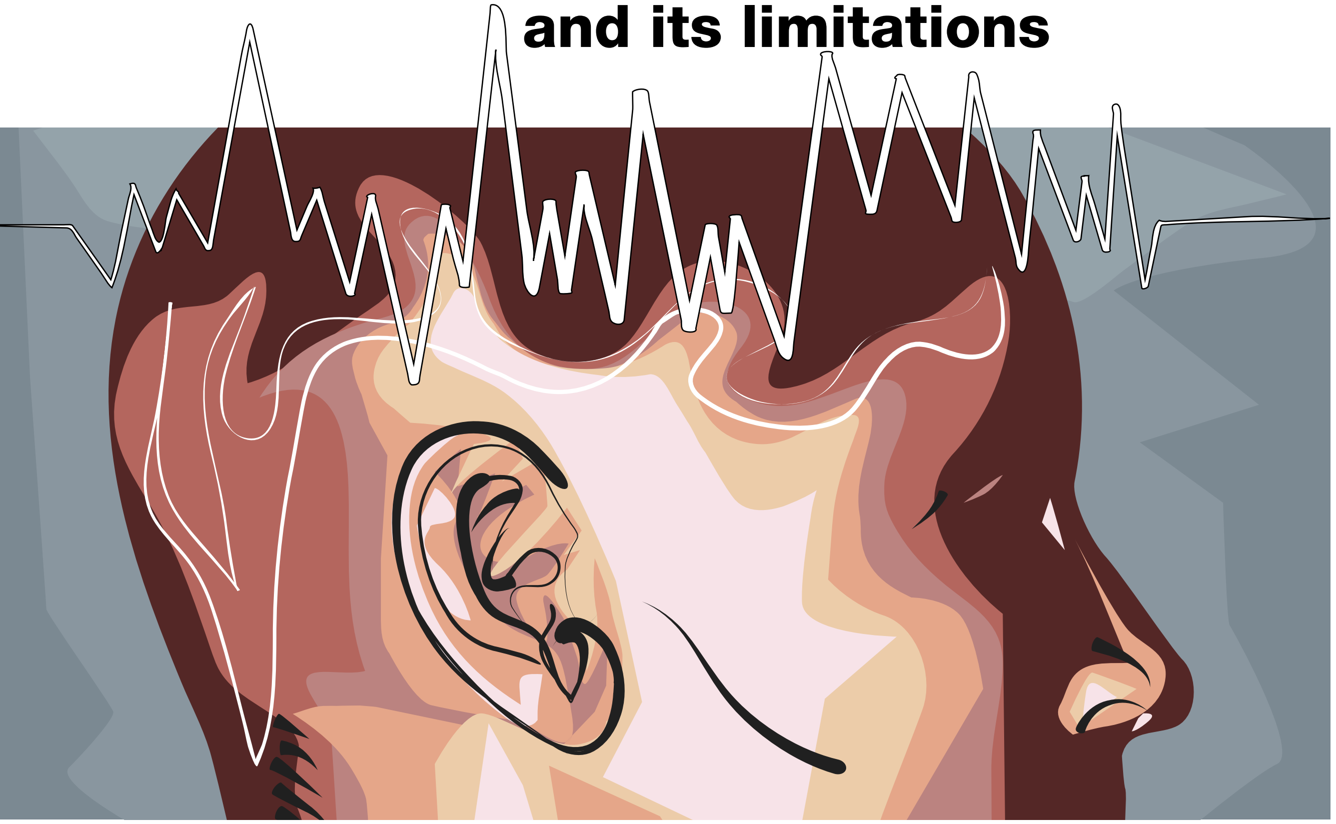
CHAPTER 2 **Human performance and its limitations**



Overview:

- The human information-processing system
- Influences on human behaviour
- Effects of physiological factors such as hypoxia, medications, alcohol, and caffeine
- Behaviours and characteristics of an emotionally intelligent person
- Emotional-intelligence skills can be applied in aviation
- Ways to improve your socio-emotional skills

A model of human performance

There are many factors that influence behaviour. A representation of some of these influences is shown in Figure 2–1. Although overly simplistic, it is compatible with the human-factors and aviation-psychology approaches and will serve as a useful vehicle for discussing some of the factors that shape human behaviour.

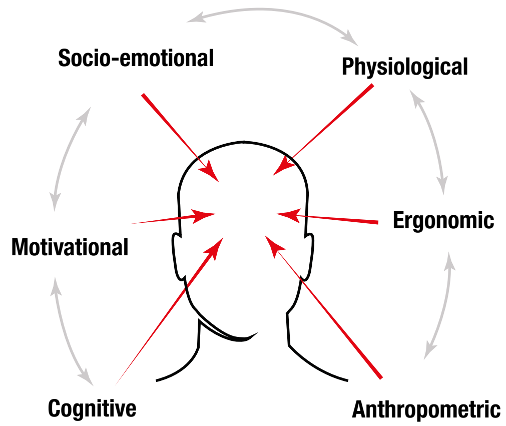


Figure 2–1. Influences on human behaviour

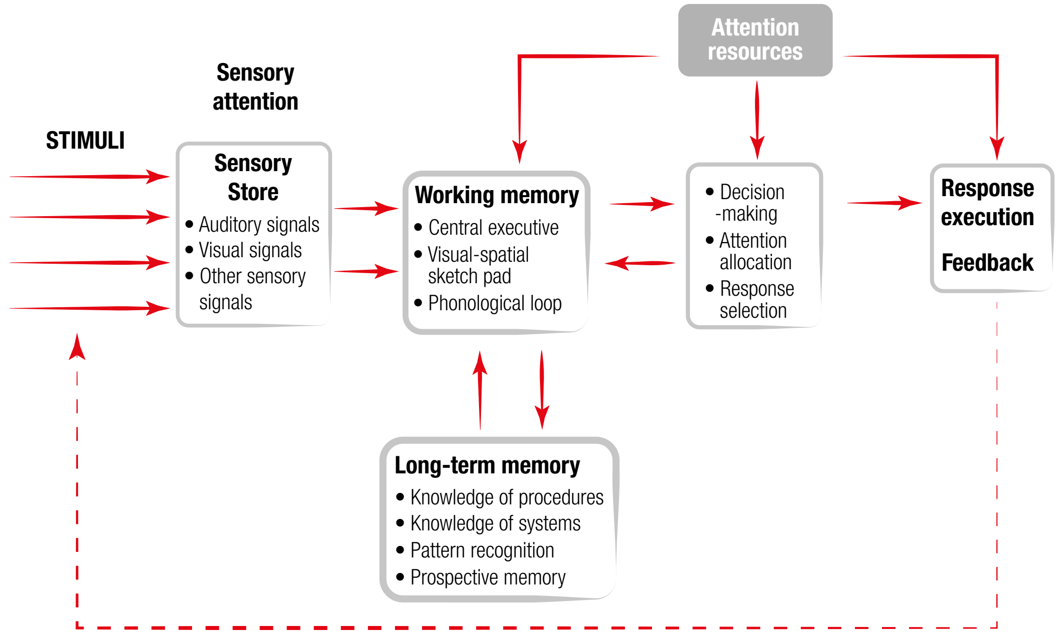


Figure 2–2. A model of information processing

The first three elements in the model capture the three traditional areas of mental activity. Cognition refers to processes such as attention, memory, decision-making, reasoning, and responding.

Motivation is the mental faculty of purpose, desire, or will to perform. It is the source of motivation, confidence, and resilience. The socio-emotional domain is where emotions come into play, influencing the way we see ourselves and how we interact with others.

The physiological, ergonomic, and anthropometric (that is, job-design elements concerned with the dimensions of the human body; for example whether flight controls are in reach of a pilot) influences represent different kinds of performance-shaping variables and they belong to the broader human-factors domain rather than non-technical skills.

Cognition: a model of information processing

For most people, work does not involve vigorous physical effort. Rather, it involves attending to the stimuli in our environment, making decisions about what to do next, executing responses and monitoring the effectiveness of those responses.

Although the responses may involve physical actions, most of what a person does happens at the cognitive level. A model of this sequence adapted from Wickens & Flash (1988) is shown in Figure 2–2.

The first element in this model is the act of being aware of what is going on around us. We are constantly bombarded with sensory information. If we don't attend to it, this information is lost. If we do attend to it, the information is moved into working memory where it can be held while it is matched against information stored in long-term memory (pattern recognition). We may recognise patterns in the information or we may not. In either case, we make a decision about what to do next, execute the selected response, and continue to survey the environment.

This is a very stripped-down version of what happens every second of our waking lives. It isn't completely accurate because at a subconscious level there must be some degree of awareness of everything that is out there, else we would not hear our name mentioned in a crowded room and would not automatically attend to changes in the environment that have profound meaning for us (smelling smoke, for example). It is also likely that there is some processing of the stimuli at an emotional level. The model will suffice for a brief discussion of the limitations in our information-processing system.

Limitations in our information-processing system

Every element in the model shown in Figure 2–2 has limitations that can have a severe impact on performance.

- Our sensory registers cannot pick up a lot of stimuli because they are outside the range of our sensory systems or the environment is masking them (for example, noise, poor light).
- The information in the sensory store fades very quickly, within a second, if we do not attend to it. If our sensory store did not behave this way, we would be overwhelmed by stimuli in a most unpleasant way.
- Attention is also limited in scope. It can be broad and diffuse, or it can be narrow and concentrated. It can be directed internally or externally but it cannot be all of these things at once. There is no guarantee that we will see the things we need to see, hear the things we need to hear, and so forth. That's why visual alarms use flashing lights and auditory alarms use loud, discordant sound patterns. It can require some effort to capture our attention. There are other limitations associated with attention. It is difficult to divide it between two or more tasks and it is difficult to sustain attention for long periods when there is little change in the environment. Some of the most common errors are due to failures to pay attention to what we are doing.
- Working memory has a limited capacity, both in terms of how many bits of information it can hold at any one time and how long it can hold them. As a general rule, we can hold about seven bits of information in our working memory. Some people can hold up to 10 bits, others struggle to hold as few as five bits. Unless we rehearse what is in our working memory, all traces of the information disappear within 10 to 15 seconds. Working memory begins to decline around middle age (Wang et al., 2011).
- Happily, the long-term memory system is virtually unlimited and is resistant to the effects of age. We can keep adding to it as we grow older, which helps to balance our declining working memory so that, overall, we are able to maintain high cognitive performance standards as we age. A limitation is that we cannot always quickly retrieve information and routines that are stored there (Park et al., 1996).
- Pattern recognition involves matching incoming sensory information with knowledge structures or routines that are stored in long-term memory. If a match is found, we have a basis for action. If, on the other hand, we are faced with a truly novel situation, we have little option but to work things out from first principles.
- Decision-making and response selection is relatively straightforward if the situation has been encountered before and we know what to do and how to do it. However, there will be many occasions when the situation is either unfamiliar or no dominant pattern emerges and we have to engage in a cyclical process that involves both working and long-term memory. What we are doing, in effect, is searching for the right rule to apply. Our selection can be affected adversely by various decision-making gremlins that are described in Chapter 5 (for example, heuristics, biases).
- The response execution stage looks straightforward but things can go wrong here too if attention is taken away from the task. The most common error at this stage being a slip, where we end up doing something that we didn't intend to do. For example, putting sugar into the teapot.

Addressing limitations in information processing

Limitations at the front end of our information-processing system are often handled through design change — an option that has more to do with human factors than non-technical skills. Thus, maintainers work in well-lit environments, non-destructive testing methods are used in maintenance inspections to detect material failures that may not be visible, pilots and air traffic controllers rely on radar. With those sensory limitations overcome, training then helps to maintain performance at an acceptable standard.

Memory problems can also be addressed through design changes. Checklists, for example, are a way of overcoming the fact that people will omit steps if they commit standardised sequences to memory. Maintainers are required to work from documentation, not from memory.

We can also do a lot to improve our own memories. To take a trivial example, pay attention when someone is introduced to you, rehearse the person's name in working memory, and you won't have as much trouble recalling it later because it will have been transferred to long-term memory. What often happens is that you either pay very little attention to the name or you don't rehearse it in working memory, in which case the name will not enter your long-term memory store and will not be there when you need it.

The best way to improve memory is by processing information, retrieving it, associating it with other information already in memory, and repeating this cycle as often as you can [see loop in Figure 2–2]. Simply saying something over and over to yourself (rehearsing) is a much less effective memory technique, unless you just want to keep the information in your immediate span of awareness until you can use it.

Rehearsing may just keep the information in working memory without moving it to long-term memory. There are some quite sophisticated memory techniques that involve the use of imagery. These methods work for most people but they have to be learnt.

For more information on memory, see the article in additional reading by Codey (2016).

Attention limitations are an obvious target for design solutions, as can be seen in the constant attempts to improve the design of displays so that they are noticed and their contents absorbed.

Distractions are the major hazard to maintaining attention. In the annual *Snapshot* survey administered to all Defence aviation personnel, there is an item that asks respondents why they make errors. Ten different possible causes are listed. The most common cause is too much to do. The second most common cause is distractions.

Knowing where to direct your attention is something that comes with experience and training. It is perhaps the single biggest difference between novices and experts in emergencies. Experts know where to direct their attention while novices are overwhelmed by the possibilities. Tennis coaches urge their charges to "watch the ball" during a rally. Sometimes coaches put coloured dots on the balls and ask the players to call out the colour as the ball approaches. That's how they train for the degree of selective attention required by this task.

At a different stage of the game, some other aspect has to be the focus of the trainee's attention, such as the position of the opponent's feet when preparing to serve or the precise location of the ball toss. None of these attentional skills come naturally, they have to be learnt. It's the same in aviation. A pilot is taught to fly the plane, regardless of whatever else is going on.

Consider the case study, 'Crash of Eastern Flight 401, December 1972' [see page 14], that could also be used as an example of situation awareness.

Situation awareness is a skill that requires you to perceive information, make sense of it and anticipate future events. Learn more in Chapter 6.

CASE STUDY CRASH OF EASTERN FLIGHT 401, DECEMBER 1972

Background

Eastern Flight 401 was diverted from Miami International Airport due to a malfunction in the nose landing gear.

The autopilot was set to 2000 feet to reduce workload. The crew was preoccupied with a landing gear problem and was trying to replace the landing gear light while on autopilot and in a holding pattern.

As the captain got up to help, he inadvertently pushed on the yoke releasing the autopilot. With no ground reference and under night-time conditions, the aircraft gradually descended until it crashed into the Everglades, 18.7 miles west-northwest of Miami killing 101 out of 176 aboard.

The failure of the crew to monitor the flight instruments during the final four minutes of flight, and to detect a descent soon enough to prevent impact with the ground.

What follows is an abbreviated account of the dialogue:

Miami Tower	*Eastern 401 heavy, roger. Pull up, climb straight ahead to two thousand. Go back to approach control, one twenty six.*
First Officer	*We're up to two thousand. (To Captain: You want me to fly it, Bob?)*
Captain	*What frequency did he want us on, Bert?*
First Officer	*One twenty eight six.*
Miami Tower	*Eastern 401, roger. Turn left heading three six zero and maintain two thousand, vectors to nine. Left, final.*
Captain	*Left three six zero.*
Captain	*Put the …….. auto pilot here.*
Second Officer	*Alright*
Miami Tower	*Eastern 401 turn left heading three zero zero*
Captain	*Okay, three zero zero Eastern 401*
Captain	*Hey, hey, get down there (in the nose wheel well) and see if that damn nose wheel's down. You better do that.*
First Officer	*You got a handkerchief or something so I can get a little better grip on this (warning light)? Anything I can do with it?*
Captain	*Get down there and see if that, see if that damned thing….*
First Officer	*The light won't come out, Bob. If I had a pair of pliers, I could cushion it with a Kleenex.*
Second Officer	*I can give you pliers, but if you force it, you'll break it, just believe me.*
Captain	*To hell with it, to hell with this. Go down and see if it's lined up with the red line. That's all we care.*
First Officer	*Bob, this (light) just won't come out.*
Captain	*Alright, just leave it there.*
Second Officer	*I don't see (the wheel) down there.*
Miami Tower Approach:	*Eastern 401, turn left heading one eight zero.*
Captain	*Huh, we did something to the altitude,*
Captain	*What?*
First Officer	*We're still at two thousand, right? Hey, what's happening here?*
	… SOUND OF IMPACT

Source: PlaneCrashInfo.com. Retrieved from http://www.planecrashinfo.com/cvr721229.htm

The information-processing system and human error

The model shown in Figure 2–2 can be used to explain some of the non-technical skills that will be described in more depth in later chapters, especially error management. Errors by individuals and teams often have their roots in human cognitive limitations, memory restrictions, and finite information-processing capacity. An understanding of the different stages of skill acquisition can help to explain why errors occur in each of these stages.

People pass through three stages of learning in their journey from novice to expert. The three levels of performance correspond to increasing levels of familiarity with the environment or task. The knowledge-based level of performance is required in unfamiliar situations and in tasks for which no training was given or no procedures exist, such as reversing a trailer for the first time.

Actions must be thought through using conscious analytical processes and stored knowledge. This conscious mode requires effort and is slow, sequential, restricted in capacity, and error-prone. This stage requires paying attention; and attention is a limited resource that necessitates withdrawal of mental focus from other areas.

The rule-based level of performance is used when stored rules are recalled to solve known but not routine problems; for example, if this situation happens, then do these actions. This situation will likely be one that has been encountered before or is at least covered by procedures.

The skill-based level of performance is applied to well-known and routine activities and is governed by stored patterns of pre-programmed instructions. Routine, highly-practised tasks are carried out unconsciously with occasional conscious checks on progress. This level of functioning is automatic, fast, and requires little conscious effort.

The military often uses such 'over training' to foster instinctive reactions and stress inocculation — such as weapon-handling drills and emergency boldface.

Training is linked with these levels of performance in predictable ways:

- if a person is trained in normal operating and error-recovery procedures, most cognitive processing will be at the skilled level
- diagnostic training usually promotes rule-based processing (for example, learning to diagnose an engine malfunction based on a series of criteria or symptoms)
- lack of training usually results in knowledge-based reasoning.

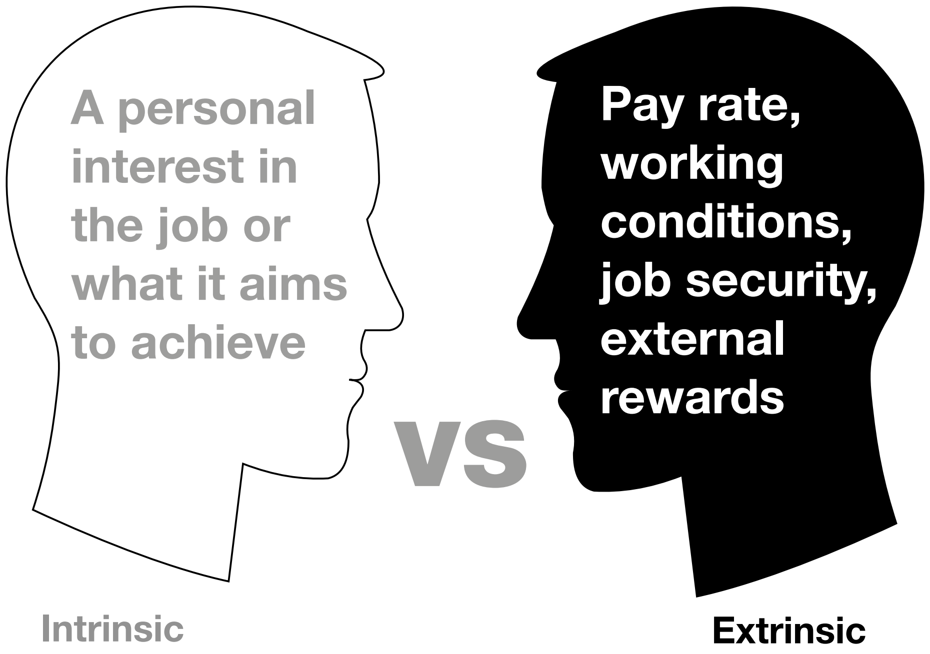
An appreciation of these skill-acquisition stages and their links with the information-processing system helps to understand the different forms that human error can take.

Summary comments on information processing

The model shown in Figure 2–2 is just one of many that have been used to represent human information processing. It is useful because we can see in the model the foundations of situation awareness and the origins of different types of errors that have their roots in the part of our cognitive architecture that deals with information processing. Another part of this architecture deals with the motivations for behaviour.

Motivation: the drivers of performance

Figure 2–2 represents the systems involved in processing information and making decisions. It is like the control panel in a vehicle. The motivational system is the power unit that propels the vehicle.



Intrinsic and extrinsic motivation

There are complex models of human motivation and there are simple ones. A very simple model states that the main drivers of performance can be classified as either intrinsic or extrinsic. In the case of intrinsic motivation, you do the job because it is interesting and you like doing it. In the case of extrinsic motivation, you do the job because of the external rewards it brings, mostly in the form of pay, good working conditions, convenience, and so forth. Intrinsic motivation is more strongly linked to job satisfaction but both forms of motivation are effective in driving performance.

Self-confidence

Another powerful driver of performance is self-confidence. Success breeds confidence but the converse is also true: confidence increases the chances of success. We see that in all walks of life and it hardly needs elaboration or demonstration. While lack of confidence is a limiting factor in performance, over-confidence leads to people attempting tasks that are beyond their own capabilities or beyond the capabilities of their team, their equipment or their aircraft. The can-do attitude that is encouraged in Defence aviation needs to be tempered by a strong sense of what is safely achievable. A large body of research has shown that people in all walks of life tend to overestimate their knowledge and skills (Dunning, 2011).

Overconfidence has been identified in Defence aviation as a cause of violations, particularly when it comes to following documentation and devising different ways of doing things. What we need in Defence aviation is personnel who are neither underconfident nor overconfident but well-calibrated.

Calibration can be achieved by setting performance goals that are neither too easy nor too difficult, by accepting feedback (both positive and negative), and by increasing competence through training.

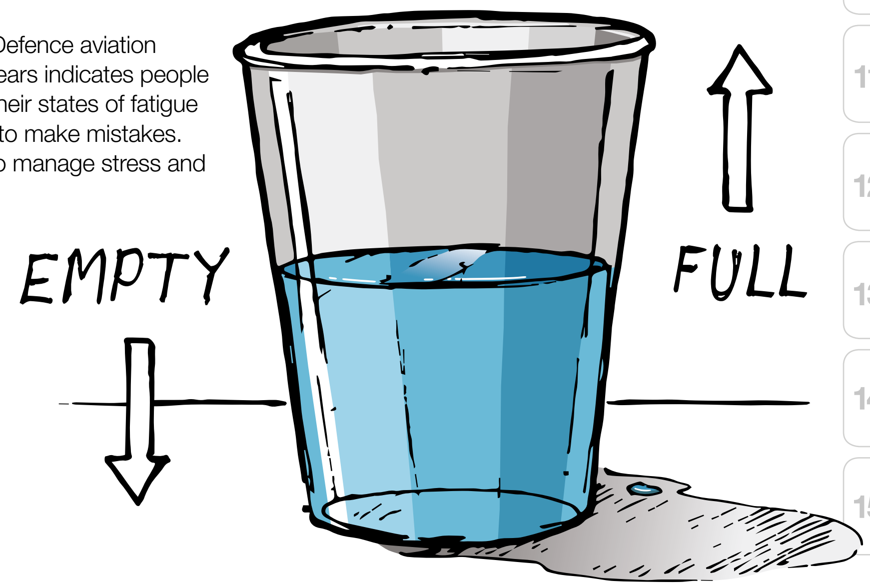
The socio-emotional domain

The third component of our mental machinery is affect, representing the feelings and emotions that guide and accompany our thoughts and actions, particularly regarding our interactions with others. Salovey and Mayer introduced the term emotional intelligence (EI) or emotional quotient (EQ), as it is sometimes called, to refer to this aspect of intellect. The set of skills associated with EI can be summarised as follows:

- being aware of one's emotions
- being aware of another person's emotions
- being able to control one's emotions
- being able to manage the emotions of others.

EI skills are helpful in the following ways:

- Being aware of your own emotions and the emotions of others is an important aspect of situation awareness. We have all been taken by surprise at times by the strength and suddenness of our emotional responses. We use the term 'brain snap' to describe such outbursts.
- If you are not sufficiently aware of how you are feeling or how others are feeling, it is easy to misread a situation and react inappropriately.
- An important evolutionary role for emotions is to direct our attention to things that are important in the environment. If an object arouses fear, we are much more likely to attend to it.
- Being able to control your emotions is an important aspect of interpersonal relations. Stay calm yourself and others are likely to stay calm too. Calmness in stressful situations is a valued trait in leaders.
- Research conducted in Defence aviation environments in recent years indicates people who are more aware of their states of fatigue and stress are less likely to make mistakes. Learn more about how to manage stress and fatigue in Chapters 8 and 9.
- However, just being aware of your emotions is not sufficient. Athletes who struggle under pressure know exactly what is going on but they are not able to manage their emotional states. So, being aware of one's emotions is a necessary but not sufficient condition for effective action. We need to be able to control and manage them as well.



People who are skilled at controlling and managing emotions:

- Tend to maintain more positive, stable emotions. They are more resilient — they bounce back after disappointments.
- Make better leaders because they build rapport with colleagues and have a stabilising influence on them.

When faced with a stressful situation, for example, a person possessing well-developed EI is likely to adopt an optimistic thinking style and demonstrate cognitive flexibility and resilience. For example, they will tend to take a planned, careful approach to problem solving, will generate alternative solutions and be motivated to persist at a task until it is mastered.

In contrast, people who have low EI tend to adopt a pessimistic thinking style, which causes them to disengage from their goals and leaves them feeling depressed, inadequate, and prone to failure.

Research on leadership (Cherniss, 1999) has found that the primary causes of failure in executives involve deficits in emotional competence. The three primary ones are difficulty in handling change, not being able to work well in a team, and poor interpersonal relations.

CASE STUDY

Aloha Airlines Flight 243, Maui, Hawaii, 28 April, 1988

Maintenance staff failed to detect small fatigue cracks on this aircraft fuselage before it departed on a routine passenger flight. Once airborne, a section of the fuselage peeled off. One flight attendant lost her life. The remaining crew and passengers were extremely lucky to survive.

Could it happen again?

Yes, in December 2000 and again in April 2001, the Australian airline carrier, Ansett, had its fleet of 767s grounded by Australia's Civil Aviation Safety Authority. The reason? On inspection of the fleet in December, four of the jets were found to have cracks in the rear fuselage near the tailplane. Then, in April, four jets were found to have cracks in the engine mountings.

Why were the cracks missed in routine inspections? Was it a failure to attend during the inspection task? A failure to recognise a pattern? A failure in the sensory (visual) system itself? A failure to anticipate the possible consequences of a crack (situation awareness)?

The NTSB report into AA Flight 243 suggests that there are several possibilities why the inspectors, despite being in compliance with inspection regulations, failed to find the detectable crack. The human element associated with the visual inspection task is a factor — a person can be motivated to do a critical task very well; but when asked to perform that task repeatedly, factors such as expectation, boredom, task length, isolation and environmental conditions all tend to influence performance reliability.

This case study illustrates the importance of considering the whole system when attempting to account for human performance. What at first glance might seem like a simple case of failure of our visual system, could end up involving our cognitive, motivational, and affective systems.

Clearly, EI is something we would all want to have. How can we develop it and how can we use it to improve our own chances of success and life in general?

EI conclusions

The various facets of emotional intelligence can be improved. You can develop your awareness, your understanding, your control, and your strategic use of emotions to improve work performance. Clinicians have always been aware of the influence of emotions on behaviour. We are only just starting to find out about their contributions to work performance.

Physiological limitations

This section covers a small range of the possible physiological influences on performance. The main interest here is the impact of certain physiological conditions on cognition.

Sensory limitations

Compared with many other animals, our sensory system is limited. We don't see as well as cats. We don't hear as well as dogs. Our sense of smell is weak. If we ever tested it, we would discover that our sense of touch is not as good as we think it is. We don't know we are getting sunburned until it is too late. As all-rounders; however, humans don't do too badly.

We get around the part of the world that we know without bumping into too many things or doing too much damage to ourselves. A description of our sensory systems is more properly the domain of human factors or aviation psychology and certainly beyond the scope of this guidebook.

The single case study (left), involving a visual inspection task will be presented to illustrate the strong links between our physiological and cognitive systems.

Hypoxia

The atmosphere comprises approximately 80 per cent nitrogen and 20 per cent oxygen. The ratio stays the same with increasing altitude but there is less of both elements at high altitudes, with the result

that the lungs are not able to supply sufficient oxygen to the brain. Hypoxia is covered in more detail in aviation medicine training.

Medication

In the operational environment, the main difficulty associated with medication relates not to the primary effects, but to secondary, or side-effects that may occur. The secondary effects of drugs can differ markedly between individuals and between environments. For example, taking antihistamines generally results in drowsiness and physicians recommend against operating machinery. However, these effects may be exacerbated if an individual is already drowsy before ingesting the medication. Likewise, the effects upon one person may be considerably less severe than the effects upon another.

The uncertainty associated with the effects of medication is such that it is often impossible

MANAGING EMOTIONS

Note these exercises are also useful for stress management.

The following set of psychological skills assist with emotional control and management.

- Reducing anxiety. Take three deep breaths. Doing this slows everything down and gives you an opportunity to regain control of your emotions. Taking three focusing deep breaths is the single, most effective thing you can do to reduce anxiety.
- Stopping negative self-talk. Positive self-talk enhances performance through increases in self-confidence and anxiety control.
- Using mental imagery to calm yourself, to motivate yourself, to build confidence. Picture yourself being the person you want to be, doing the things you want to do. One of the greatest golfers of all time, Jack Nicklaus, has repeatedly said that he never hit a shot without first visualising a successful outcome.
- Making emotional management one of your goals. Your goal is to manage negative thoughts and emotions and to create more situations where you are experiencing positive thoughts and emotions. Goal setting is the foundation of successful self-regulation.
- Preparing for any important events. Elite athletes use what are called pre-performance routines. A pre-performance routine is a systematic sequence of motor, emotional, and cognitive behaviours that are performed immediately before the execution of self-paced tasks.
- Taking breaks when they are due. If you have lost control of your emotions, breaks give you an opportunity to recover. If you haven't lost control, breaks are still useful for topping-up your emotional reservoir.

to ensure that an operator will be capable of operating within a highly complex operational environment.

Alcohol

Defence has a zero alcohol tolerance policy. Alcohol and aviation can have some very subtle interactions such as the persistence of alcohol in the vestibular system long after it has left the bloodstream. In safety-critical areas you must have zero blood-alcohol content and no affect of hangover.

Caffeine

Caffeine is a stimulant. If you drink caffeinated beverages, you are probably aware that caffeine can perk you up. If you are low on sleep and need to remain alert, caffeine can assist by blocking adenosine reception in the brain. Adenosine causes blood vessels to dilate and nerve cell activity to slow down, causing drowsiness.

Caffeine intake therefore results in increased nerve activity in the brain. The pituitary gland senses this activity and interprets it as an indication of an emergency, triggering the release of hormones that signal the adrenal glands to produce adrenaline.

It takes caffeine about 20 to 30 minutes to enter your system and its physiological effects peak after about an hour after the drug reaches the bloodstream. The noticeable effects of caffeine usually last for four to six hours.

A handy factsheet on nutrition entitled 'Eating for brain health and cognitive performance' is available at the end of this chapter.

Research (Winkelmayer, Stampfer, Willet & Curhan, 2005) suggests that more than six cups of coffee (or an equivalent caffeine source) a day can put one's health at risk. Further, research also shows that if you are a regular user of caffeine, you may actually require it for your brain to function normally (O'Keefe, et al., 2013). Such drug dependence clearly is not desirable in personnel who are in security- or safety-sensitive occupations.

Lowered performance because of the effects of addiction may also explain why some researchers believe that caffeine is not an effective alertness management tool in people who normally ingest three or more cups of coffee each day — these people need coffee just to get back to baseline mental performance levels.

On the other hand, a light caffeine user or caffeine abstainer may benefit from as little as 20 mg of caffeine if an improvement in alertness is the goal.

Circadian rhythms

Circadian rhythms are also known as body rhythms and relate to the cycle of both psychological and physiological dimensions within the body. The impact of circadian rhythms is most noticeable following trans-meridian flight where the physiological and psychological responses of the body are not synchronised with the environment.

Of all aviation personnel, flight crew and shift workers are likely to be most susceptible to circadian dysrhythmia because of the effects of trans-meridian flight (travelling across multiple time zones) and the lack of consistency between duty shifts. This combination of factors may lead to an increase in the potential for error and an overall reduction in human performance. The impact of circadian rhythms on fatigue is explored in Chapter 8.

Age

Age restrictions apply to all Defence roles: 60 years of age for full-time personnel and 65 years of age for reservists. Outside Defence, there used to be a rule that required pilots and co-pilots to retire at the age of 60 or at least to cease work in the pilot role. The International Civil Aviation Organisation (ICAO) retirement age limit standard for pilots involved in international air transport operations was increased in 2006 from 60 to 65.

Air traffic controllers are also forced to retire early in some countries but not in others — such as Australia.

The reason for the early retirement rule was concern about in-flight incapacitation in older pilots and deterioration in psychomotor and cognitive performance. However, although certain abilities (for example, working memory) are known to deteriorate from as early as age 30, there are compensatory mechanisms that continue to strengthen past the age of 80, provided people maintain a healthy lifestyle. There is no evidence that older people are involved in more accidents. Nor do older Defence personnel report making more errors.

Additional reading

For more information on attention and memory, consult the following resources:

Directorate of Defence Aviation and Air Force Safety (DDAAFS) (2009). Dangerous distraction: an examination of accidents and incidents involving pilot distraction in Australia from 1997 to 2004. *Aviation Safety Spotlight*, *3*, 12–30.

Rash, C. E. (2013). Attention on deck. *Aviation Safety Spotlight*, *1*, 19–22.

Codey, R. (2016). Memory-based fails. *Aviation Safety Spotlight*, *2*, 3–17.

Key points

- The model of information processing [Figure 2–2] becomes an important vehicle for explaining skills such as situation awareness, decision-making, pattern recognition, and response selection.
- The model of information processing also helps to explain some classes of human error.
- The motivational aspect of performance is equally important when it comes to achieving high standards. Confidence, competence, and commitment together are key components of effective performance in aviation.
- The affective element was neglected for many years but is now being addressed under emotional intelligence or, more recently, the socio-emotional skills label. This element is especially important for successful interpersonal relations and is therefore an essential element of team building.

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Wickens, C. D., & Flach, J. M. (1988). . In E. L. Wiener & D. C. Nagel (Eds.), *Human factors in aviation* (pp. 111–156). San Diego, CA: Academic Press.

Winkelmayer, W. C., Stampfer, M. J., Willett, W. C., & Curhan, G. C. (2005). Habitual caffeine intake and the risk of hypertension in women. *Journal of the American Medical Association*, *294*(18), 2330–2335.

Eating for brain health & cognitive performance

Aviation personnel, including aircrew, ATC, maintenance, ground support, and other staff, need sustained cognitive performance to perform at their best. The complexity and fast pace of operations, and the need for accuracy and safety, requires everyone to be on their game. Nutrition is a vital part of the equation.

Fast facts

- **A balanced diet** promotes optimum brain health and cognitive performance.
- **regular physical activity** aids in a healthy mind and body.
- **staying hydrated** supports cognitive and physical performance.

To achieve a balanced diet eat a wide variety of foods from each of the five food groups each day: grains (cereals), vegetables, fruits, lean meat (including poultry, fish and alternatives) and dairy and/or alternatives. 'Eight daily steps for brain health' provides more information on how to achieve a balanced diet. Maintain hydration at all times.

Carbohydrate foods = glucose for the brain

Foods containing carbohydrate are the primary source of glucose in the diet. When carbohydrate foods are broken down in the gut, glucose units are released and enter the bloodstream. Glucose is then transported to the brain, other organs and muscles, where it is used as the preferred source of energy.

Nutrient-rich carbohydrate foods for peak cognitive performance

Foods containing carbohydrate may be nutrient-rich or nutrient-poor. Nutrient-rich carbohydrate foods provide a sustained release of glucose, because they take longer to digest, resulting in a steady rise in the level of glucose released to the blood. They are nutrient-rich because they contain other energising nutrients such as protein, vitamins, minerals, fibre and antioxidants.

Nutrient-rich carbohydrate foods

- Wholegrain breads and cereals such as multigrain bread and muesli
- grains such as rice, pasta and quinoa
- fruit
- starchy vegetables such as potato and corn
- legumes such as lentils and red kidney beans
- flavoured low-fat milk and yoghurt (dairy and alternatives), for example, banana and honey smoothie.

Nutrient-poor carbohydrate foods

Nutrient-poor carbohydrate foods (simple carbohydrates) are high in carbohydrate and often fat, with little or no other nutrients, for example lollies, cakes and pastries. These foods are not essential to the diet and should only be eaten occasionally. They provide a quick release of glucose due to being easily digested, resulting in a rapid rise in blood glucose levels. A rapid drop in blood glucose levels often follows resulting in feelings of lethargy, fatigue and poor cognitive performance. Maintaining a stable level of blood glucose can be achieved by eating nutrient-rich sources of carbohydrate at meal and/or snack times.

Low blood glucose levels

A decrease in blood glucose levels may be the result of:

- prolonged exercise, due to a depletion in the amount of glucose stored in muscles
- not eating in the past two or more hours
- stress and illness, which can also increase the body's demand for glucose, making it particularly important to eat well.

When mental performance is critical, you should be aware of the following symptoms:

- feeling hungry
- a drop in concentration
- mental fatigue.

CAUTION

If you experience any symptoms like these in flight it may be due to hypoxia or other physiological threats. Always manage these first. If physiological threats are absent and symptoms persist, consume a high carbohydrate snack. In time-poor situations, a simple carbohydrate snack will quickly raise blood glucose levels and reduce mental fatigue. This should be followed up with a nutrient rich carbohydrate snack or meal as soon as time permits, to help maintain good blood glucose levels for longer.

Did you know: Aircrew must TMUFF themselves if they have not consumed an adequate meal and fluid within the previous six hours of flight duties.

Nutrients and their benefits

Some individual nutrients may be particularly important to brain health and cognitive performance. Table 1 provides a list of some of these nutrients, their potential benefits and some foods rich in these nutrients.

Nutrient	Possible Benefit	Food Sources
Omega-3 fatty acids	Improve brain function and structure	Oily fish (for example, salmon and tuna), nuts, seeds
Antioxidants (including vitamin E, vitamin C, selenium)	Reduce risk of cognitive impairment and age-related deficits	Blueberries, citrus fruits, nuts, seeds, orange/red coloured vegetables, herbs and spices, for example, turmeric
Vitamin D	Protective of cognitive function	Oily fish, mushrooms, fortified dairy and alternative products
B vitamins (thiamin, folate, B6 and B12)	Improve brain function, including memory and learning ability. Reduce age-related cognitive decline.	Wholegrain breads and cereals, red meat, green leafy vegetables

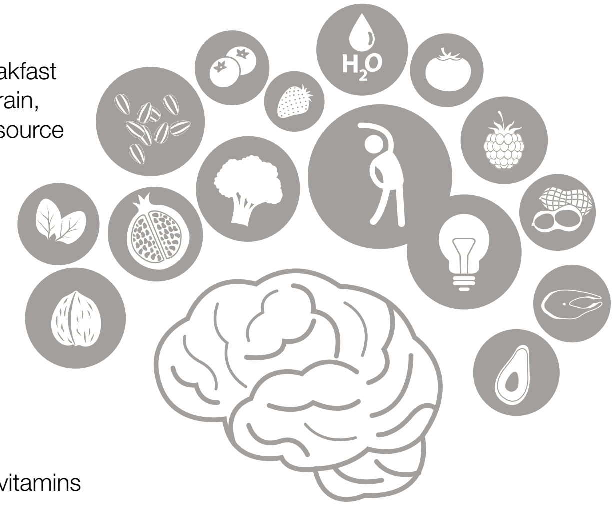
Table 1: Nutrients to support brain health

Not everything is known about the foods we eat and their nutritional impact on brain health. More scientific research on the benefits of individual nutrients for brain health and cognitive performance is required.

Suffice to say, consuming three meals and/or between meal snacks consisting of a range of nutrient-rich sources of carbohydrate will enable you to maintain blood glucose levels for peak cognitive performance.

Good hydration and nutrition benefits physical endurance and stamina, especially for high-G flying and G-tolerance or long hours working in cramped conditions.

Eight daily steps for brain health



1. Eat a variety of grain foods — bread, breakfast cereals, rice and pasta — mostly wholegrain, multigrain or high-fibre varieties — great source of energy food for the brain.
2. Eat plenty of vegetables and legumes of different types and colours and beans and legumes — variety is the key to providing a wide range of energising nutrients.
3. Eat fruit — aim to eat two whole pieces of fruit each day, including a variety throughout the week. Choose fresh, in season varieties where possible — fruit is packed with nutrients, such as vitamins and minerals, needed for brain health.
4. Eat lean meat and poultry (with visible fat removed), fish, eggs, tofu, nuts and seeds — excellent sources of protein, vitamins, minerals and essential fatty acids vital to brain health.
5. Eat milk, yoghurt, cheese and/or alternatives — great source of sustained release energy, calcium and protein.
6. Avoid foods that contain saturated fat, added salt and added sugar, such as pastries, processed meats, packaged foods, soft drink and confectionary — making more room for brain food.
7. Drink plenty of water — aim for minimum of two-to-three litres per day for peak cognitive performance!
8. Aim for at least 30 minutes of moderate physical activity (for example, brisk walk, cycling, swimming) — a healthy body leads to a healthy mind.

Eating a wide variety of nutritious foods and drinking plenty of water every day provides all the nutrients needed for good brain health.

More information on how to achieve a balanced diet can be found at www.eatforhealth.gov.au and military specific information in the ADF Educators Guide to Healthy Eating (ADF EDGE) http://www.dst.defence.gov.au/publication/adf-educators-guide-healthy-eating-adf-edge.

Additional reading

Feldman J & Barshi I (2007) Effects Of Blood Glucose Levels On Cognitive Performance: A Review Of The Literature. NASA/TM-2007-214555. Retrieved from http://adhd-npf.com/wp-content/uploads/2009/07/NASA_The_Effects_of_Blood_Glucose_Levels_on_Cognitive.pdf

AAP 8000.011 DASR MED, AMC to MED.15, Paragraph 21.

Australian Government
Department of Defence
Science and Technology

Directorate of Defence
Aviation & Air Force Safety

Institute of Aviation
Medicine

CHAPTER 3 **Error and violation**

Overview:

- Error
- Cognitive origins of human error
- Violation behaviour
- Psychological basis of violations
- Systems approach to errors and violations
- Models of accident causation
- Measuring and managing errors and violations

Introduction

In the past 20 to 25 years there has been an increasing interest in, and recognition of, the importance of human error as a contributing factor in workplace accidents. In fact, human error attracts more attention than any other topic in human factors, crew resource management or non-technical skills literature. Errors are the cause of most accidents, and accidents are the main reason for the emergence of the field of human factors.

While we should pay equal attention to the positive side of human performance, it is only natural that the loss of lives in accidents such as Chernobyl, Bhopal, and Tenerife draws the most interest. It's this interest that has led to the more general appreciation of the impact of human error and the fact it is a major factor in personnel accident and injury, lost time and production.

This chapter will trace the development of theories of human error, ways of managing errors, and techniques used in Defence aviation to monitor progress in our efforts to minimise workplace errors.

The history of error investigation

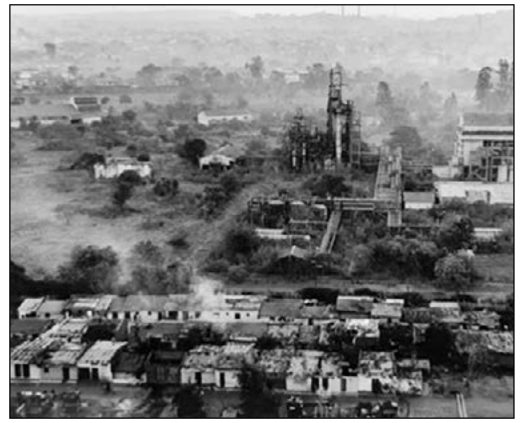
The topic of human error was slow to attract the attention of psychologists, although English psychologist James Reason (1990) in his book *Human Error* noted the following early references to it in the literature:

- In 1881 James Sully, Grote Professor of Mind and Logic at University College London, published a book entitled *Illusions* in which he proposed a system for classifying errors.
- William James, sometimes called the Father of Psychology, did not explicitly address the topic of human error in his 1890 book *The Principles of Psychology* but James Reason noted that James' chapters on habit, memory, and will (motivation) contain nearly all the necessary elements of a theory of human error.
- Freud wrote extensively about errors in his 1904 classic, *The Psychopathology of Everyday Life*, and the term Freudian slip — as in slip of the tongue — is still with us.
- Ernst Mach (1905) argued that: "Knowledge and error flow from the same mental sources, only success can tell one from the other". We know that's true because all actions flow from the information-processing system as discussed in an earlier chapter.
- In 1905, Joseph Jastrow published an analysis of 300 lapses of consciousness collected from his students. Reason credits Jastrow with being the first researcher to look at slips of action, as opposed to slips of the tongue.

Despite these promising beginnings, human error was not a popular topic among early psychologists. By 1928 we find Charles Spearman, an English Army officer who developed the first credible theory of human intelligence, lamenting the lack of interest shown by psychologists in the subject of error.

Spearman attributed errors to memory, interference, and confusion among response options. He was writing in the early days of the discipline of psychology; however, and the terms he used would not be familiar to human-factors specialists today. What is interesting is his association of errors with failures of what we would now call the information-processing system.

Chernobyl disaster (1986)
Event: Catastrophic nuclear event
Location: Pripyat, Ukraine **Fatalities:** est. 4000



Bhopal tragedy (1984)
Event: Gas leak **Location:** Bhopal, India
Fatalities: est. 16,000+

Tenerife Catastrophe (1977)
Event: Aeroplane collision **Location:** Tenerife, Canary Islands
Fatalities: 583

Three Mile Island accident (1979)
Event: Partial nuclear meltdown
Location: Dauphin County, USA **Fatalities:** 0

Blackhawk tragedy (1996)
Event: Helicopter collision
Location: Townsville, Australia
Fatalities: 18

Sea King crash (2005)
Event: Helicopter crash
Location: Nias, Indonesia
Fatalities: 9

Not everyone shared his view — some other early psychologists thought that personality might be the culprit. Some examples follow:

- Munsterberg (1913) attempted to develop better selection techniques to reduce accidents among tram drivers and ships' officers. This attempt was obviously based on the assumption that some people are more likely to have accidents than others. [Cited in Reason (1990)].
- The term 'accident proneness' appeared in English and German psychological literatures in 1926.
- In 1929 two English psychologists, Farmer and Chambers developed a battery of tests that attempted to identify accident proneness. [Cited in Reason (1990)].

This approach peaked in the 1930s; however, it has always been controversial. It was totally unsuited to dealing with the magnitude of the problem thrust upon psychologists as advancing technology resulted in human errors causing catastrophic consequences for large numbers of people.

Major accidents where human error of some kind was clearly involved include:

- A major airline disaster involving Pan Am and KLM at Tenerife in 1977 saw 583 people killed.
- Three Mile Island in 1979, no fatalities reported but consider among the first major civilian nuclear disaster.
- The thousands of people killed in the Indian city of Bhopal in 1984 when lethal gas leaked from a pesticide plant.
- Chernobyl in 1986.
- In our own backyard, the Blackhawk accident in 1996 and the Sea King in 2005.

Today, the topic of error is familiar in many areas, but the field of psychology that has been most concerned with error in recent times is human factors. The initial concern in this field was to develop a taxonomy of errors that suited an industrial context.

The development of error taxonomies

Slips, lapses, and mistakes

There are various methods of classifying errors. Reason (1990) used three broad categories: slips, lapses, and mistakes.

Slips occur when an intention is executed in an inappropriate manner, and lapses are the failure to perform some required action (Norman, 1988; Reason, 1990). Slips are potentially observable as they are external actions and are often caused by factors such as haste and divided attention (Hudson, 2000). Most slips do not cause harm because they are often quickly detected by the individual.

Lapses, on the other hand, refer to more covert memory failures and are often apparent only to the person. Lapses can be missed as it is harder to detect an omitted behaviour (Hudson, 2000). For this reason, they are considered more dangerous than slips.

Slips and lapses occur at the skill-based level of performance (Rasmussen, 1982). Skill-level errors include failures from lack of attention and misallocation of attention. External causes are interruptions, distractions, and unpredictable events. Many events happening simultaneously can cause information overload and task failure (Sutcliffe & Rugg, 1998).

Mistakes are errors in the formation of an intention or in the choice of a strategy for achieving a goal (Reason, 1990). They involve deficiencies in the judgmental and/or inferential processes concerned with the selection of an objective, or of the means to achieve it, or both. Mistakes are considered more dangerous than slips or lapses because the person making the mistake thinks he or she is doing the right thing. Evidence to the contrary may be ignored because the person is so sure of himself/herself (Hudson, 2000).

Mistakes can occur at Rasmussen's (1982) rule-based or knowledge-based levels. At the rule-based level, mistakes involve misapplication of normally good rules, applying an inappropriate rule, or the failure to apply a good rule. Good rules may be misapplied because of recognition problems; for example, when information overloading prevents normal recognition. Rule-based mistakes may be triggered by new variations to known problems and/or poor training (Sutcliffe & Rugg, 1998).

Time stress, in particular, is a powerful cause of mistakes at the rule-based level when people have a tendency to use recently-memorised or frequently-used rules even if they are wrong for that situation (Reason, 1990). At the knowledge-based level, no problem-solving rules are available and the individual has to resort to resource-limited reasoning as a result of a new situation. This can be a highly error-prone situation (Reason, 1997). Knowledge-based mistakes occur because people are faced with a novel, possibly emergency situation which requires conscious analytic processing and stored knowledge (Leape, 1994).

These three forms of error — slips, lapses, and mistakes — are a major focus of safety-culture interventions and have been incorporated into a number of incident databases.

In addition to these categories, Defence aviation also classifies errors according to the stage of information processing within which the error occurred. This classification system overlaps with the slips, lapses, and mistakes taxonomy.

Information errors, decision errors and action errors

Information errors result from not perceiving something correctly, perceiving something incorrectly, or not understanding the current situation correctly. This type of error includes

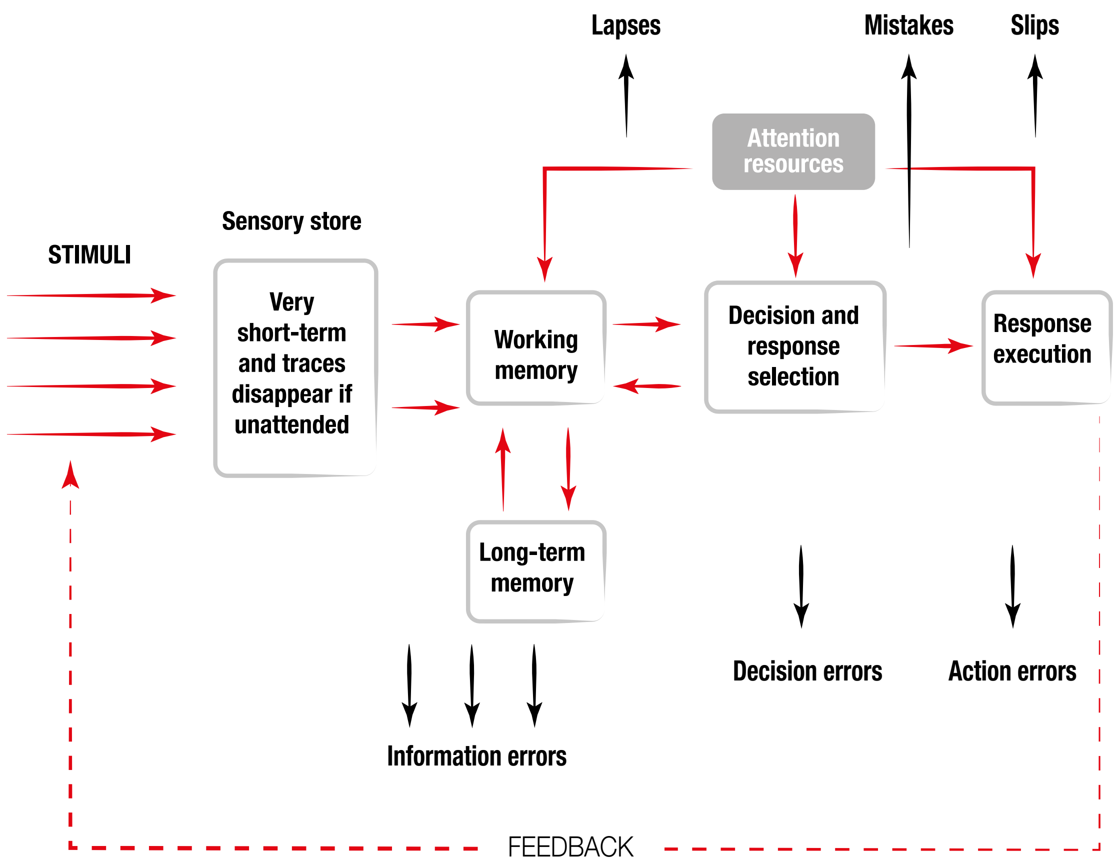


Figure 3–1. Information-processing model with error taxonomies superimposed

situation-awareness problems or errors caused by visual or perceptual illusions.

Decision errors come from the middle part of the information-processing model shown in Chapter 2. The person carries out the actions as planned, except that the planned action was not right for the situation. Mistakes are decision errors.

Action errors occur when the actions themselves deviate from an individual's plans. Action errors tend to occur during highly routine activities, or when attention is diverted from a task, either by thoughts or external factors. Action errors are like slips and lapses.

Information processing and errors

The difference between the two taxonomies described above is that the second system is more directly linked with the information-processing model shown in Figure 3–1. As can be seen in Figure 3–1, both taxonomies are based on the information-processing model and assume a cognitive path to accident causation, the second taxonomy more obviously so.

The second taxonomy also recognises the many errors that arise in the initial stages of information processing (for example, inspection errors for maintainers, visual illusions for pilots).

However, there is a second pathway to unsafe behaviours that must also be taken into consideration: the social-behavioural path, which involves attitudinal and group-norm factors.

This path can lead to the deliberate deviation from safe working practices, that is, violation behaviours, which are direct causes of errors (Fogarty, Murphy, & Perera, 2017; Lawton & Parker, 1998).

Violations

Definition

Violations are defined as behaviours that involve the deliberate deviation from rules that describe the safe or approved method of performing a particular task or job (Fogarty, Cooper, & McMahon, 2016; Reason, 1990).

The conceptual boundaries between errors and violations are not always clear as both involve a deviation of action from some required standard of performance. The question of intentionality is what differentiates errors and violations and it is what makes them more dangerous than slips, lapses, mistakes, and other forms of information-processing errors.

A taxonomy of violations

As was the case with errors, the development of a taxonomy of violations has proved to be useful for incident investigation and for monitoring the safety status of an organisation.

The seven-category taxonomy that supports the Defence just-culture initiative [see Chapter 4] is described below.

Routine violations are frequent, also committed by others in the workgroup, and often condoned by management. These violations usually reflect the practices within the workgroup (that is, the norm).

Situational violations occur when there is a gap between what the rules require and what the person thinks is available or possible. For example, workarounds that help to make up for resource constraints or limitations in the workplace.

Exceptional violations are rare and happen in abnormal situations or emergencies. They usually occur when something goes wrong and the person believes that the rules no longer apply, or that applying a rule will not correct the problem.

Organisational-optimising violations are committed to meet performance goals. They are usually a result of a 'can-do' attitude rather than resource constraints.

Personal-optimising violations are committed for personal gain or benefit. For example, finishing a shift earlier, taking shortcuts to reduce personal effort, thrill-seeking, or playing practical jokes.

Serious carelessness reflects a disregard of an obvious risk or a profound failure of professional responsibility. It may also reflect a general disregard for rules and procedures.

Possible sabotage/criminal act describes actions where the person intended harm, either to an individual, an asset, a workplace, or the organisation.

Why people break rules

If they are so dangerous, why do workers commit these violations? Violation behaviour is directly related to how people adapt to the situations that arise in their workplace where behaviour is regulated by procedures, codes of practice, and rules. Violations occur for many reasons, and are seldom wilful acts of sabotage or vandalism. Most stem from a genuine desire to perform work satisfactorily given the constraints and expectations that exist.

Focus-group interviews were conducted (Fogarty, 2004, 2005) with Defence aviation maintenance personnel that confirm this impression: they see themselves as often forced to work outside strict procedural guidelines because of resource shortages, work pressures, and the like. Interestingly, the interviews revealed they do not see themselves as working unsafely when using these shortcuts, relying on their knowledge and skill level to achieve a safe outcome using non-standard procedures.

Reducing violations requires an investigation of the motivational and attitudinal precursors to accidents. In the chapter on culture, we examine some of the causes of violations that have been revealed through Defence surveys. Those causes were inadequate documentation, belief that the approved procedure or process is inefficient, time pressure to complete a task, lack of proper equipment, conflicting goals, group norms that favour shortcuts, the nature of the maintenance job, overconfidence, and lack of documentation.

We see the same causes in other industries. For example, in a study of railway workers in the United Kingdom, Lawton (1998) found that time pressure, high workload, and a more efficient way of working were strongly endorsed reasons for not working to the procedures. She argued that the benefits to workers in terms of saved time, energy, and effort are common motivational reasons for violating procedures. Van Vuuren (2000) examined the cultural influences on incident causation and risk management in the Dutch steel industry and also in medical environments.

Findings indicated that there was a poor attitude towards following safety procedures in both domains. For example, risks were taken in the steel industry in order to save time, and the use of personal protective equipment was considered inconvenient especially when working conditions were hot. These violations of safety procedures were accepted by both employees and many team leaders and had become the norm in this group. In a study conducted in 13 industrial plants located throughout Europe, the USA, and Canada, Rundmo (2000) found that acceptance of rule violations as the norm was the strongest predictor of unsafe behaviour.

Accidents can often involve both errors and violations in combination (Lawton & Parker, 1998). Although an error may appear to be the immediate cause of an incident, the necessary condition in the accident sequence may have been a violation of a safety rule. Violations tend to take people into an area of greater risk, thereby making the situation less forgiving of subsequent errors. In addition, organisational precursors such as inadequate training, incorrect procedures, and/or poor task allocation may contribute to accidents by creating the kind of workplace that invites unsafe behaviour, both errors and violations, by individuals or teams (Reason, 1997).

In summary, the literature suggests that errors are mainly associated with cognitive factors, while violations originate in social behavioural factors (Fogarty, Murphy, & Perera, 2016; Lawton, 1998; Lawton, Parker, Stradling, & Manstead, 1997). Because of this difference in psychological origins, remedial strategies required for each would benefit from taking these cognitive/motivational distinctions into account. By way of example, while skills training may be able to reduce errors, it will not significantly affect violation behaviour. Furthermore, it is unrealistic to expect compliance with procedures if compliance results in inefficient work practices. To reduce violations and errors, a range of organisational interventions may be required.

Organisational contributors to human error

Error taxonomies have proved to be very useful. A downside of these taxonomies; however, is that they can have the effect of putting the individual in the spotlight. Psychology moved away from this view of some individuals being, by nature, somehow more-or-less accident prone to a position where accident proneness was seen as a temporary state, caused by such things as stress, fatigue, illness, cognitive overload, or poor mental attitude.

This shift in emphasis from permanent states of accident proneness to more temporary states was a welcome change but it still left the individual operator right in the spotlight. This view of accident causation was reflected in accident investigation reports across a range of industries where phrases such as pilot error, driver fatigue, and failure to follow procedures were a common explanation for accidents.

In the last 20 years, spurred by the work of Reason and a handful of other prominent researchers, the emphasis has switched to the more encompassing view of error. Identifying human error as the ultimate cause of a system failure is of limited use unless the context in which the error occurred is well understood. For example, fatigue, stress, and interruptions are frequently vital contributing factors to cognitive failures.

These states can be induced by organisational factors such as poor workload planning, resulting in long working hours or an excessive workload in peak times. Environmental factors such as unusual events, excessive workload, and stressful situations put pressure on people and increase the probability of error. Time pressure in particular is a powerful cause of rule-based mistakes as people under time pressure have a tendency to use recently memorised or frequently used rules even if they are wrong (Reason, 1990).

Reason argued that organisational failures such as lack of management commitment to safety, unclear safety responsibilities, and poor training contribute to accidents by creating the kind of workplace conditions (for example, fatigue, time pressure, low morale) that provoke unsafe behaviour by the individual or team, or by creating deficiencies in system defences. The people in the workforce are the final defensive filter and often inherit organisational defects, for example those created by inadequate design, conflicting goals, and poor management decisions.

In addition, social- and organisational-level failures can occur when the organisation has not created a safety-conscious culture (Reason, 1997). For example, normal operational procedures may be well-designed and documented but never enforced due to cultural deficiencies. Group dynamics and the culture of the organisation play a role in determining how effectively safety is managed (Neal & Griffin, 2002, 2006; Sutcliffe & Rugg, 1998).

In summary, it is clear from the literature that the psychological causes of error are attributable to a range of variables, ranging from cognitive factors at the individual level to cultural factors at the organisational (and beyond) level. The interactions of these variables are captured in a handful of popular models of accident causation.

Accident causation: the systems approach

Reason's Occupational Accident Model

Reason (2000) suggested that the human-error issue could be viewed in two ways: the individual or person approach, and the system approach. The individual approach focuses on the unsafe behaviour, that is, the error or violation by the individual in the workplace. Using this approach there is a tendency to view most unsafe behaviour as attributable to forgetfulness, inattention, or incompetence on the part of those identified with this behaviour.

The individual approach has proven ineffective since errors are inevitable and part of the human condition. Although it is true that some unsafe acts in any field are due to negligence, the vast majority are not. Most people who make even serious errors are conscientious and dedicated professionals who usually do their jobs well. The individual approach isolates the person and the unsafe behaviour from their system context (Reason, 1997).

The system approach looks at unsafe behaviour in a different way. According to this approach, the most important cause of error within an organisation is faulty systems or design rather than the individual. Individuals are seen as fallible and errors are expected, even in the best organisations.

This approach concentrates on the conditions under which individuals work and tries to build defences to prevent unsafe behaviour and errors or to diminish their effects. Errors are seen as consequences rather than causes, having their origins not so much in the fallibility of the individual as in contributing systemic factors.

Based on the assumption that though we cannot change the human condition, we can change the conditions under which humans work. From this perspective, an adverse event is seen to result from faults in system design that allow unsafe behaviour by the individual in the workplace that may result in an adverse outcome.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

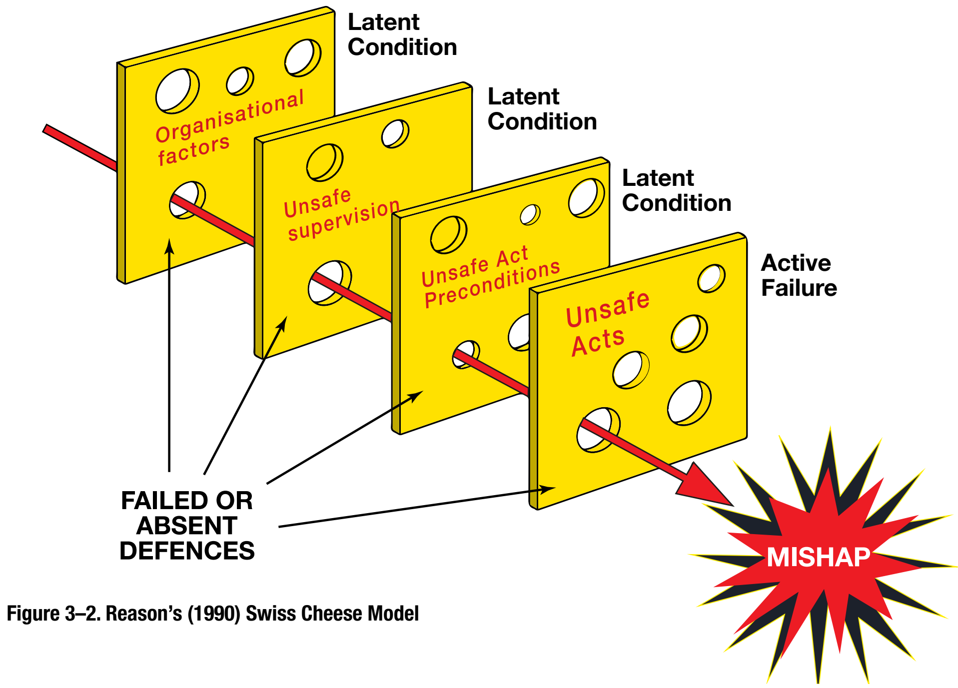


Figure 3–2. Reason's (1990) Swiss Cheese Model

Although different accident causation models exist, there is no question that Reason's (1990) model, based on theories by Rasmussen (1982) and Norman (1988), is the most popular. It has been widely adopted in complex industries such as aviation, nuclear power, and medicine as the method of choice to investigate the way in which threats penetrate the extensive defensive barriers that characterise those industries.

The model can be applied to Defence aviation because it is a high-risk environment that is complex, internally dynamic, interactive, and often time-pressured. The model is shown in Figure 3–2.

The concept of defences and weak spots in those defences is the key to Reason's model. High technology systems have many defensive layers. Some are engineered; for example, alarms, physical barriers, and automatic shutdowns. Others rely on people, and yet others depend on procedures and administrative controls. Mostly these defences are effective but there are always weaknesses. These weaknesses may arise for two reasons: active failures and latent conditions.

Active failures are unsafe behaviour by people who are in direct contact with the system. They take a variety of forms: action slips or failures, such as failing to identify a defect in a component; cognitive failures, such as memory lapses; mistakes through ignorance or misreading a situation; and violations, that is, deviations from safe operating practices, procedures, or standards.

Active failures have a direct and usually short-lived impact on the integrity of the defences. The individual approach looks no further for the causes of an adverse event once the proximal unsafe behaviour has been identified. However, virtually all such behaviour has a causal history that extends back in time and up through the levels of the system (Reason, 2000).

Blaming the individual for adverse events that are not due to negligence or lack of care does not lead to permanent change in the safety status of the system. To move beyond blame requires that the underlying contributing factors — that is, the latent conditions that provoke unsafe behaviour — be identified.

Latent conditions/failures stem from fallible decisions, often made by people not directly involved in the workplace, such as designers, writers of policies and procedures, and senior management (Reason, 1997). Latent failures provide the conditions under which unsafe behaviour occurs. Reason referred to these as errors waiting to happen arising from poorly designed processes and systems. They can have two kinds of adverse effects: producing error-provoking conditions within the workplace (for example, time pressure, understaffing, inadequate equipment, fatigue, and inexperience), and/or creating long-lasting holes or weaknesses in the defences (for example, unworkable procedures and design deficiencies).

Latent conditions may lie dormant within the system for many years before they combine with active failures and local triggers to create an accident opportunity. Unlike active failures, whose specific forms are often difficult to anticipate, latent conditions can be identified and remedied before an adverse event occurs (Reason, 2000). Whereas organisations that follow the individual approach direct most of their management resources at trying to make individuals less fallible, advocates of the system approach strive for a more holistic management program aimed at several different areas, that is, the individual, the team, the task, the workplace, and the institution as a whole (Reason, 2000).

Reason's model therefore distinguishes between the immediate situation surrounding the accident or error and the various organisational layers that should have acted as barriers to the accident. To give an example from the military context, at the organisational level it is important for proper resource planning to occur. If this does not happen, a hole is created in that particular slice of cheese.

However, that's not likely to cause an accident by itself. Even if senior management is not providing the resources that are required, it is more than likely that experienced supervisors will still ensure that work is carried out to a high standard. If; however, there is a shortage of trained supervisors, then holes are created in the second slice of cheese as well.

This is still not sufficient to cause an accident because there are other layers of defence. The maintenance engineers themselves are well-trained and generally capable of working to a high standard with or without supervision. However, if the maintenance engineer is tired or stressed, holes appear in this layer as well. But even then it is unlikely that an accident will occur; most of the time the work is still completed on time and at a satisfactory standard. What you have now; however, is a series of defences, all of which have been breached in some way. Every now and then, the holes in the slices line up, and an accident occurs.

To give some idea of how this model works in practice, consider the following case study.

CASE STUDY

American Airlines Flight 191, May 1979

At 3 pm on 25 May, 1979, American Airlines Flight 191, A McDonnell-Douglas DC-10 crashed into an open field just after departing Runway 32R at Chicago-O'Hare International Airport, Illinois. All 271 people on board were killed. The following information was gleaned from the NTSB's accident investigation.

The immediate cause of the accident was the separation of the left engine and pylon assembly and about three feet of the leading edge of the left wing. The plane rolled to the left and crashed to the ground.

The separation resulted from damage caused by improper maintenance practices which led to failure of the pylon structure. In terms of Reason's model, we are talking about an active failure. So where were the defences?

First of all, let's look at the improper practices. Engines and pylons need to be removed periodically for scheduled maintenance. The aircraft manufacturer's specifications state that the engine (which weighs about 5 tons) and the pylon (which weighs about 1 ton) are to be taken off separately. Engine first, then pylon.

American Airlines and Continental Airlines devised a procedure whereby a forklift was positioned below the engine with a special cradle to take the weight of the whole structure, the pylon was then disconnected and the whole assembly lowered so that access could be gained to bearings located in the wing structure. When this task was completed, the forklift moved the assembly back into position again and the attaching hardware was reinstalled.

This was a very efficient procedure and was actually part of approved maintenance procedures within American and Continental Airlines. It was a procedure that had been carried out many times without incident. The problem was that tolerances were very low and mechanics had to be extremely cautious when moving the assembly back into position. A minor error by the

(cont)

(cont)

forklift operator could result in damage to the wing structure. Damage that would be difficult to detect.

McDonnell-Douglas, the manufacturer, was aware of the precision that would be required to fit a 6-ton assembly to the wing and specified in its original maintenance procedures and subsequent service bulletins that the engine be separated from the pylon before the pylon is removed from the wing.

We can see already that the problem extends some way back into Reason's error chain: how is it that an airline was able to establish procedures that contravened those published by the manufacturer?

American Airlines is a designated alteration station, as are the other major carriers that conduct heavy maintenance programmes. It has the authority to establish its own procedures and document these in its maintenance manuals. It is not at all unusual for a carrier to develop procedures which deviate from those specified by the manufacturer if its engineering and maintenance personnel believe that the task can be accomplished more efficiently using an alternate method. Three major carriers had developed alternative procedures to deal with this particular maintenance task. From almost any perspective, the alternative procedures made good sense.

The facts indicate that in this particular instance, the manufacturer was right and the engineering sections were wrong. A potential defence had been breached and an opportunity for human error was created.

Let's go further back up the chain, should the manufacturers or the regulators, or the government bear some responsibility too?

Continental Airlines, the other major carrier that used this procedure, had damaged two aircraft in the same way. The aviation industry is very open and publishes most of its mistakes for anyone to scrutinize, so this incident was published as an Operational Occurrence Report in January 1979. A second incident was reported in February 1979. American Airlines was on the distribution list for these reports.

However, the main requirement of these reports was that they indicated how the damage was repaired so that the FAA could ascertain that the aircraft was indeed airworthy. Continental Airlines was not required to describe how the damage occurred and in both of these cases the cause was simply noted as personnel error. Neither McDonnell-Douglas nor the FAA chose to investigate these identical incidents any further.

Source: US National Transportation Safety Board (NTSB) investigation

This case study illustrates the complexity of most accident scenarios. The point is not to shift the blame up the ladder but to understand the tight couplings that exist in any high-tech system.

Operators are fallible but their fallibility is often unnecessarily exposed by weaknesses elsewhere in the organisation. Scenarios like the one described above are found in all areas of aviation, both civilian and military, and they are found in almost all industries.

Another key aspect of this case study is that it illustrates the concept of active and latent failures: a system can operate for many years with inbuilt flaws that do not actually cause an accident until a particular combination of circumstances arises.

Shappell and Wiegmann's 2001 Cascade Model

The Cascade model developed in 2001 by former US Naval psychologists Scott Shappell and Doug Wiegmann to capture the main components of Reason's famous Swiss Cheese model, illustrates the systems approach very well.

This model shows very clearly how management decisions and policies affect the actions of individual workers. It also recognises the influence of supervisors and the physical and mental limitations of the workers themselves. The model served as the basis for the Human Factors Analysis and Classification System (HFACS: Shappell & Wiegmann, 2001), which provided the taxonomy for the US Navy's incident database.

Updating Reason — the Defence Aviation Safety Analysis Model

The systems approach is now widely accepted in aviation, health, the nuclear power industry, offshore oil, and various other high-risk industries and Reason's model has provided a useful guide for accident investigation.

In recent years; however, practitioners have become aware of various limitations of the model. The Australian Safety Transport Board (ATSB), for example, was concerned that the model did not deal with technical problems. An example of a technical problem would be a component that failed to perform according to its specifications. In order to provide a more

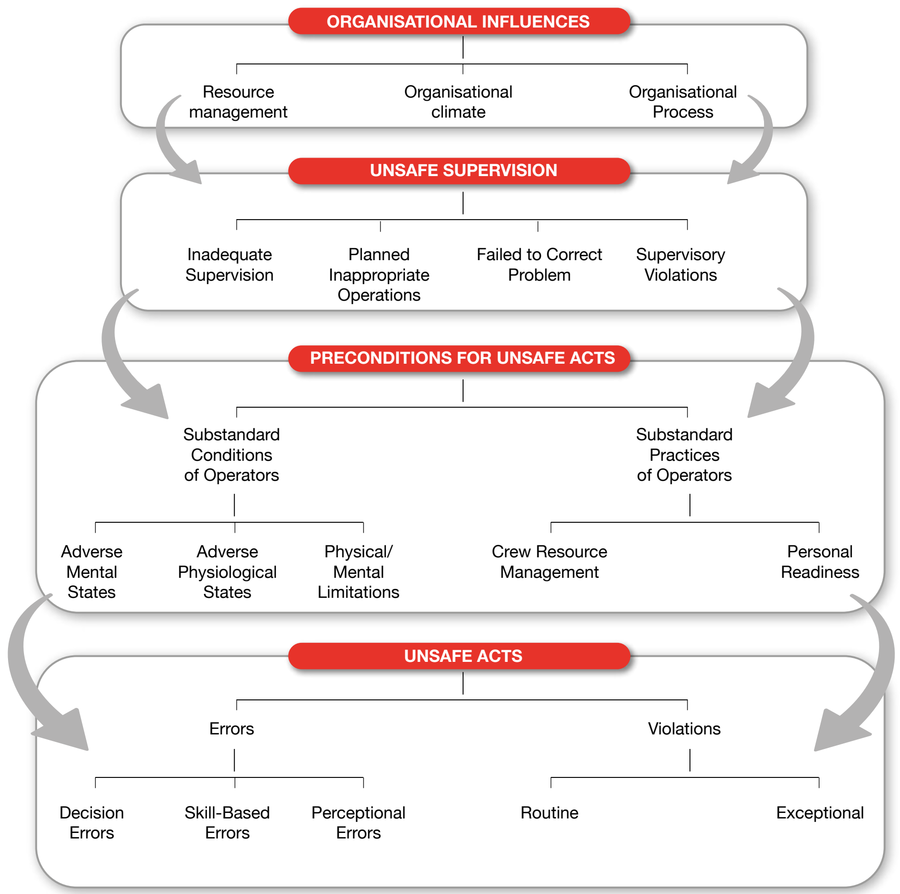


Figure 3–3. The Cascade Model (Shappell & Wiegmann, 2001)

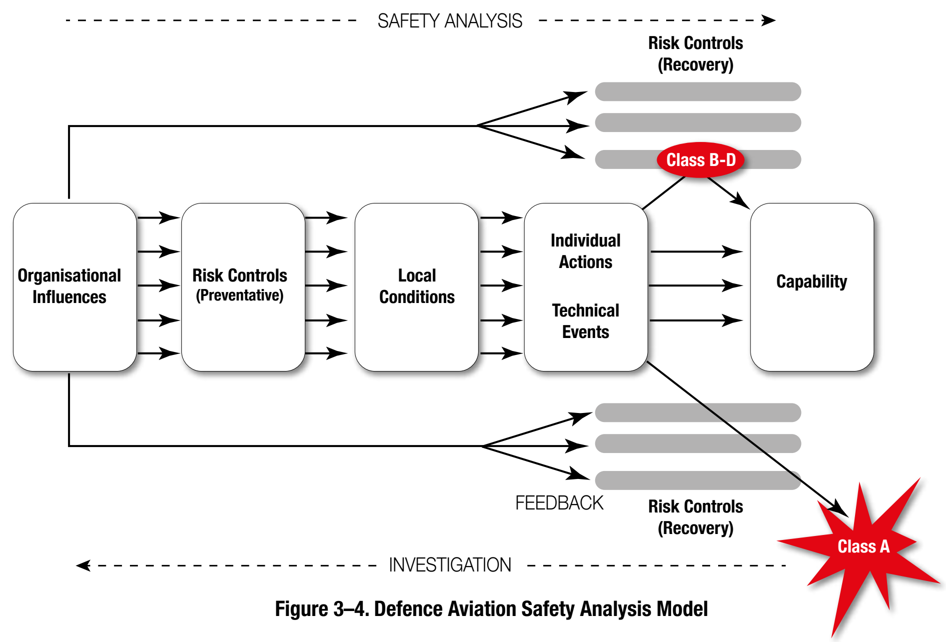


Figure 3–4. Defence Aviation Safety Analysis Model

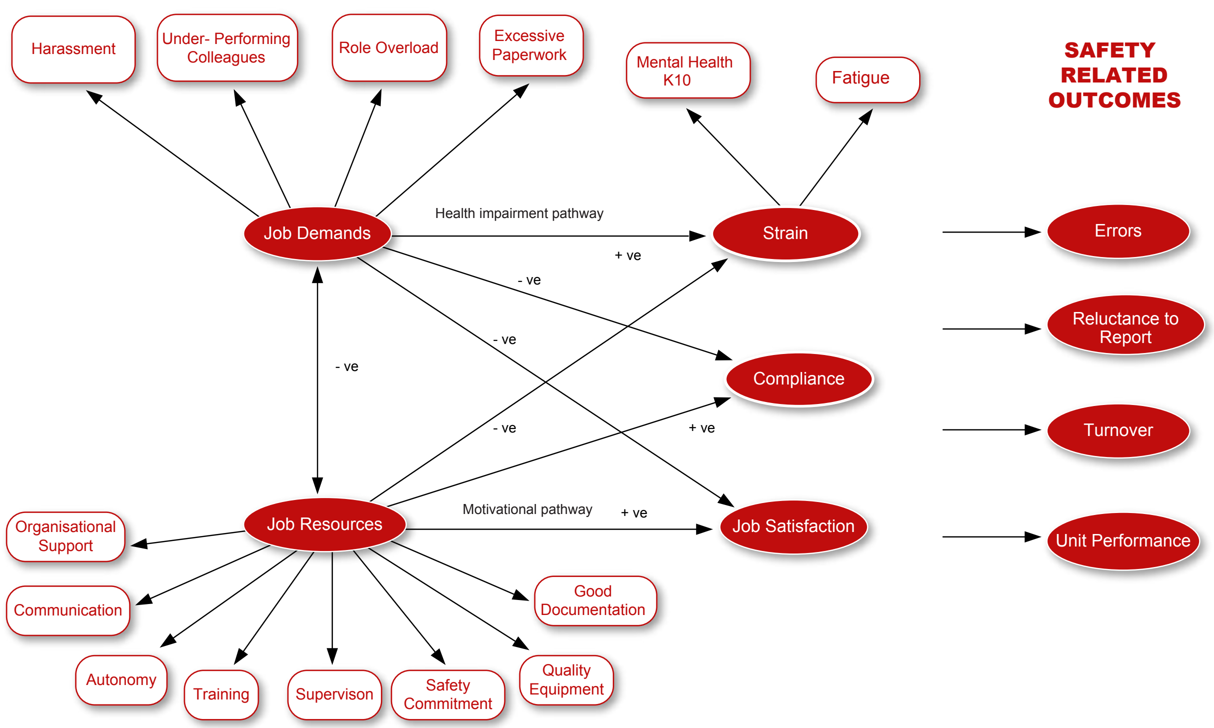


Figure 3–5. Model underlying the *Snapshot* (from the Technical Manual for the *Snapshot* Survey)

generic model that would be more applicable to a wider range of investigations, and better fulfil the role of identifying potential safety factors, the ATSB has modified some aspects of the Reason model. The Defence Aviation Safety Analysis Model is based on the ATSB model and is shown in Figure 3–4.

Figure 3–4 provides a broader view of the work situation, one that captures the system as a whole, including the organisation, the individual, technical issues, the production process, risk controls (defences in Reason's language), incidents, and accidents. Within the Defence Aviation Safety Analysis model, we can also see scope for error management (risk preventive) and error recovery (risk controls), thus acknowledging the ever-present threat of something going wrong in complex systems and the need to recover to maintain production goals.

The *Snapshot* Model

The previous three models discussed have been descriptive, in that they represent in graphic format highly plausible relations among factors that are present in all high-risk industries. One can look at these models, find the elements one expects to find, and use the arrows embedded in the models to trace the direction of influence. Thus, in all three one can see that organisational factors influence local conditions, which influence individual workers, who are most closely connected with the system outputs. These accident-based models have been highly influential on safety management, especially in relation to accident investigation.

However, another type of model exists that examines cultural and motivational aspects of the workplace and human performance. The first of these culture-based models in Defence was reported to the international aviation community in 1999 (Fogarty, Saunders, & Collyer, 1999). It has been updated many times since then and is now linked with the annual *Snapshot* survey. The model is shown in Figure 3–5.

Influenced by Bakker' and Demerouti's Job Demands Resources (JD-R) model (2007) the *Snapshot* model illustrated on page 38 shows a complex web of organisational factors and how they relate to one another. The direction of influence is shown by the arrows: the workplace affects the individual workers, who are responsible for performance.

The JD-R (and *Snapshot*) model proposes that there are two basic sets of forces acting on individuals within a work setting; job demands and job resources. If demands exceed resources, individuals may experience negative individual outcomes such as poor health and wellbeing (health impairment pathway), non-compliance (compliance pathway) and low job satisfaction (motivational pathway).

This, in turn, can lead to negative organisational outcomes such as reduced unit performance and increased tendency to make errors. Conversely, if resources outweigh or meet demands, individuals are likely to become more engaged and therefore more effective.

The *Snapshot* model is not incompatible with the Reason, Cascade, or ATSB models. It is just different, with different origins and a different purpose. In the *Snapshot* survey, there are groups of items that measure all of the constructs shown in boxes in Figure 3–5. The *Snapshot* survey is a key part of Defence aviation's attempts to measure, manage and enhance safety performance. Other techniques are described in the next section.

Managing errors and violations

In Defence aviation, the many techniques used to control error are set out in the *Defence Aviation Safety Manual* (DASM). In this section, we present a simplified view that involves developing an understanding of: a) error- producing conditions; b) classic human-factors approaches to managing error; c) violation-producing conditions; and d) managing violations.

Error-producing conditions

We know from many years of safety-climate (*Snapshot*) research in Defence aviation that, in rank order, the main causes of errors are as follows:

1. having too many things to do
2. interruptions
3. time pressure
4. fatigue
5. lack of concentration
6. stress
7. forgetfulness
8. lack of knowledge
9. poor teamwork
10. lack of equipment.

Most of these causes are what we might call proximal, meaning that they are often the immediate cause of the accident. The systems approach recognises that these 10 proximal causes are themselves potentially driven by many factors. Through investigations of safety events and annual *Snapshot* surveys, Defence aviation attempts to identify and address the causal factors and, by so doing, reduce the flow of errors near to the production end of the system.

Managing errors

Errors can be managed using classic human-factors techniques: a) changing the design of the equipment; b) changing how the task is done; c) changing the work environment; d) changing the state of the human doing the task; e) changing the individual doing the task.

> “Nobody really cares about safety! As long as the job is done then that’s what everybody cares about. If you do a job correctly, then you shouldn’t bend the rules but everyone does to get it done — you can’t not dodge it.
>
> If we were to follow every proper procedure each time we do a task, not much would get completed. Bosses say that doesn’t matter, but guess what happens if nothing gets done: planes don’t fly!”

DDAAFS *Snapshot* survey respondent, 2014

Changing the design of the equipment

Consider the following case study which came from World War II and which was perhaps one of the very first human-factors investigations of error.

Accounts of flight experiences frequently contain descriptions of mistakes in the use of controls which might have been prevented by better control design. The following experience of an AAF pilot in WWII is an example: “The mistake of which I am speaking was made on the way from Gander Lake, Newfoundland, to Marrakech, North Africa”. “Our B-29s were on their way over. We had been out from Gander Lake about two hours when we encountered fuel-pressure trouble in number-one engine.

“The gage was reading about 4 pounds per square inch and the motor was backfiring. I told the engineer to try to clear it out and bring the pressure up. In trying to do so in a hurry, he pulled off number-four engine, the wrong one. For a while we sat up there with just two engines while he was trying to get number four started again. Eventually we had to feather number one and go on into Marrakech on three engines. I believe that the reason why our engineer, who was a green man, made this mistake was because the engineer on the B-29 faces aft. In an emergency he got excited and pulled the engine control which, if he had been facing forward, would have been the number one control (Fitts, 1947).”

Changing how the task is done

There are some tasks that are error-prone when done by humans because of limitations in the human-processing system. A possible solution is to change the task. Some examples are:

- automate or partially-automate the task
- use technology to assist with the task (for example, borescopes for visual inspections)
- use checklists to reduce memory load
- build error traps and error redundancies into the task (for example, additional inspections).

Changing the work environment

There are many ways of changing the work environment. Examples of changes that could improve safety performance follow:

- physical changes such as better lighting, temperature control, noise reduction
- design duty/rest schedules that prevent the accumulation of fatigue
- design shift rosters that are compatible with circadian rhythms
- increase the resources and reduce the workplace stressors.

Changing the state of the human carrying out the task

The most obvious way of doing this is through training. The training can occur at three levels:

- awareness training (for example, knowing there is a relationship between stress and errors)
- knowledge-based training (for example, knowing why there is a relationship between stress and errors)
- skills-based training (for example, knowing how to use relaxation techniques to manage stress levels).

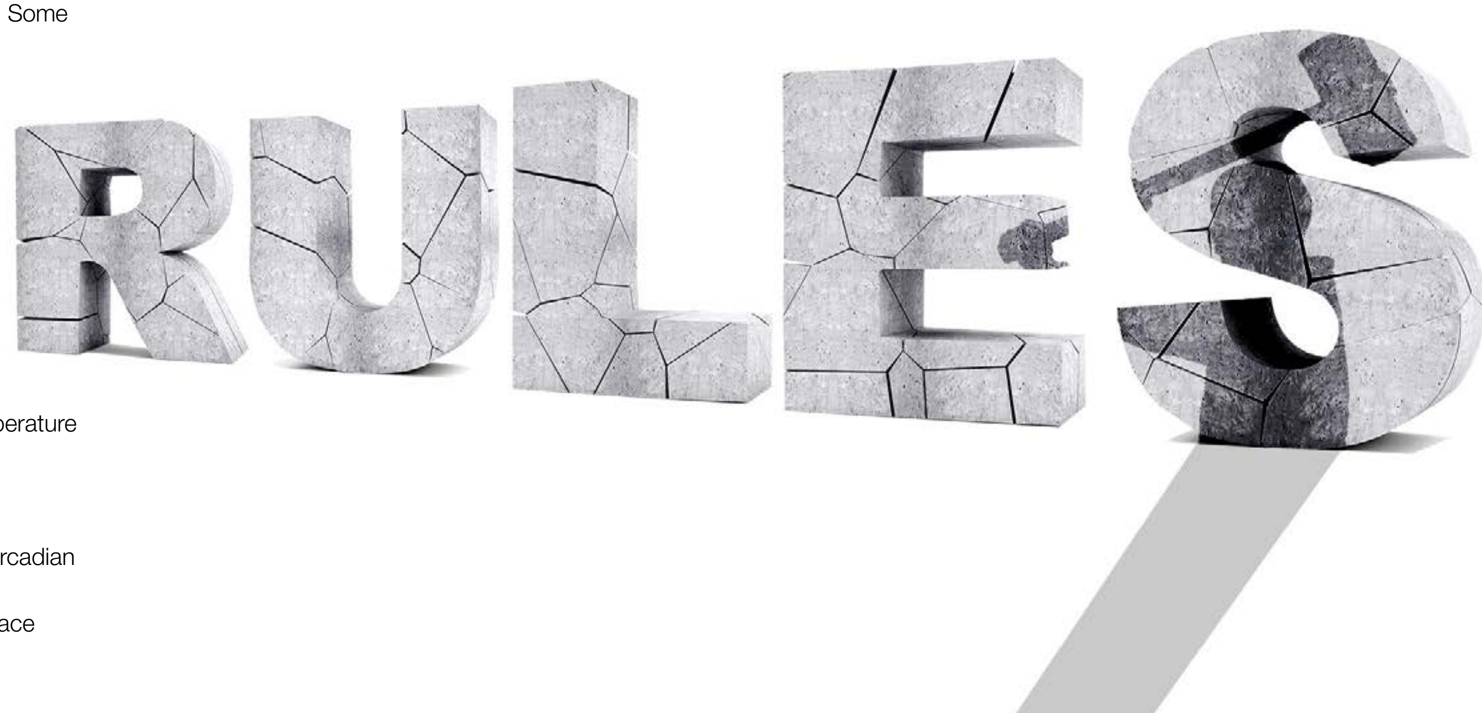
Changing the individual doing the task

This is perhaps the most complicated of the error-management techniques. Jobs change, new jobs emerge, and it can be difficult to work out who should be doing what. For example, should drone operators be pilots?

Common types of violations

We will return to the topic of violations in Chapter 4 when we look at the causes of violations. The first step in the management of violations is to know what types of violations are occurring. They are listed in rank order below (from *Snapshot*):

1. doing a task a “better” way
2. doing a task without the right tools
3. taking risks in order to complete a job
4. using an informal source of documentation
5. not using any documentation at all
6. using an unserviceable piece of equipment (for example, obsolete test equipment)
7. correcting someone else’s mistake without documenting the correction
8. taking shortcuts in order to complete a task on time
9. signing off without checking.



> "Shortcuts start creeping in when workload is high, people's morale is low, and the tempo gets going. That's when the holes start to line up."

DDAAFS *Snapshot* survey respondent

> "You can't manage what you can't measure."

Peter Drucker, management consultant and author

Managing violations

The key to managing violations is to understand that they are driven by attitudinal rather than cognitive factors. Workers believe that they can get the job done using non-standard procedures.

And they are able to rationalise their actions afterwards:

- Everyone knows that there are safety margins built into regulations.
- Rules are simply there to protect inept operators from themselves.
- Military aviation is over-regulated.
- I can't push the envelope and improve if I have to follow all these rules.
- Everybody else is following the rules, so it won't matter if I don't.
- If no one knows and nobody gets hurt, what's the problem?

Such rationalisations must be challenged and shown to be wrong. Supervisors are instrumental in this process. The American Airlines DC-10 crash is a classic example of what seemed like a perfectly acceptable workaround that turned out to be fatal for a large number of people.

Additional reading

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The importance of measurement

Being aware of the types of errors and violations that are occurring in Defence aviation and why they are occurring is an important step towards management. It is also very important to monitor the extent of these unsafe behaviours.

Snapshot plays a role in this monitoring process, so do incident databases and accident investigations, which not only record the types of occurrences but also the reasons for the occurrences and remedial actions.

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Key points

- Error taxonomies tend to be based on the cognitive processes involved.
- Error taxonomies are useful but they put too much emphasis on the immediate circumstances surrounding an incident.
- A systems approach identifies all the elements in an accident sequence and describes relations among the elements.
- Error management relies upon basic human-factors principles such as task redesign, workplace redesign, training, and selection.
- Violations can also be presented in terms of a taxonomy. Violations tend to be distinguished according to motivations, behaviours, and severity.
- Because of their different origins, errors and violations must be managed in different ways.
- Measurement is a fundamental requirement for the management of both errors and violations. Surveys, accident investigations, and incident databases are important in this regard.

> **"If you are convinced that your organisation has a good safety culture, you are almost certainly mistaken. A safety culture is strived for, but rarely attained. The process is more important than the product."** JAMES REASON

CHAPTER 4 **Culture**

Overview:

- Goals and attributes of high-reliability organisations
- The terms organisational culture and safety culture
- Organisational culture versus organisational climate
- Safety culture and climate influencing performance
- Leadership in safety
- Organisational resilience
- Strategies for building and maintaining safety culture

Introduction

The organisational dimension of the systems approach to safety is the focus of this chapter. In systems theory, errors are regarded as consequences rather than causes; having their origins not so much in the fallibility of the individual as in a range of contributing systemic factors (recall the C-SHELL model). This chapter will explore the role of organisational culture, organisational climate and leadership in influencing safety and impelling both safe and unsafe behaviour.

The organisational dimension of safety is often overlooked in training and education courses. For example, most crew resource management/non-technical skills courses neglect to study organisational behaviour and its facets. This is despite — as we shall see — numerous accident investigations having identified problems in organisational culture, psychological climate and leadership as contributing factors to adverse safety events.

High-reliability organisations

A common definition of the high-reliability organisation (HRO) has focused on the safety record of organisations. HROs are considered to be organisations that have avoided serious safety incidents in operating environments characterised by a high level of inherent risk or danger and/or operational complexity.

The US Navy nuclear fleet is a prime example of a HRO that has had an exemplary safety record without a known significant safety accident. In more than 60 years of operations, the US Nuclear Navy has logged over 5400 reactor years of accident-free operations and travelled in excess of 200 million kilometres (Conca. 2014). This is perhaps the best safety record of any industry.

The concept of HROs originated in the 1980s when some researchers moved away from the preoccupation with incidents of failure/catastrophe that characterised the safety management literature, to focus on organisations with successful safety records. A similar approach proved popular in the general management literature with the release in 1982 of *In search of excellence* by Tom Peters and Robert Waterman. It was time to accentuate the positive.

The theory of HROs asserts that accidents can be prevented by organisational systems and management practice with at least five characteristics:

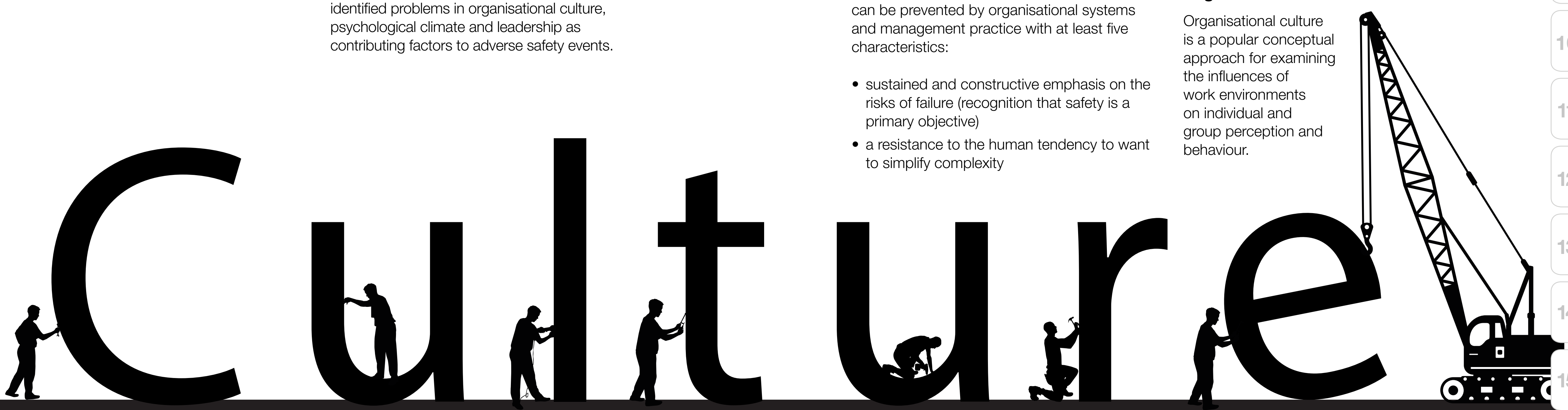
- sustained and constructive emphasis on the risks of failure (recognition that safety is a primary objective)
- a resistance to the human tendency to want to simplify complexity
- a pragmatic understanding of challenges experienced during operations at the 'sharp end'
- commitment to building organisational resilience in terms of adaptability and the ability to bounce back from setbacks and failure
- genuine respect for (safety) expertise.

In contrast to Normal Accident Theory (Perrow, 1984), which claimed that accidents are virtually inevitable in sufficiently complex systems, the theory of HROs has a positivistic approach that emphasises factors such as proactive culture, in-built redundancies, well-defined organisational roles and structures, genuine learning from mistakes, rigorous training, and integrated processes across the various areas and levels of an organisation. This sounds a lot like the generative culture espoused in the *Defence Aviation Safety Manual* (DASM).

Another perspective on HROs is that, rather than defining a HRO by its actual safety record, any organisation whose operating environment has inherent high risk and/or complexity can be regarded as a high-reliability/high-consequence organisation, and therefore has an ethical responsibility to ensure safety. Irrespective of definition, it is clear that Defence aviation and its people should aspire to be a HRO.

Organisational culture

Organisational culture is a popular conceptual approach for examining the influences of work environments on individual and group perception and behaviour.



Culture has been especially useful in providing a conceptual foundation and a language for the analysis of the social architectures within organisations.

Culture is a powerful force. When applied in the context of aviation safety, culture is the set of shared attitudes, beliefs, and values that drives behaviour in an organisation or a section of an organisation. In its simplest form, culture reflects "how we do things around here".

The culture of an organisation may be driven by a statement of values, such as with Defence, where officers, soldiers, sailors and airmen and airwomen are expected to live by the values of professionalism, loyalty, integrity, courage, innovation, and teamwork.

Interestingly, each of the Services has its own values statement comprising different sets of values; for example, Army's values are courage, initiative, respect and teamwork, while Navy's values are honour, honesty, courage, integrity and loyalty.

Culture can also be captured in slogans, images, or mottos. The motto of the Royal Australian Air Force: per ardua ad astra — "through struggle to the stars", aptly captures the culture of the pursuit of excellence, often in challenging conditions. The Defence Aviation Safety Authority (DASA), with safety as its primary concern, captures its mission in a four-word motto: Capability first, safety always.

Safety culture

The commercial aviation industry has a very low accident rate of about 1.6-in-a-million flight operations (IATA, 2017). The dramatic decline in the airline accident rate from the 1930s to the 1980s was attributed largely to improvements in technology.

Since the 1980s, it has been suggested that further improvements in the aviation accident record will be largely in response to improvements in organisational aspects such as policies, processes, and practice as well as enhanced non-technical skills.

An outcome of the focus on these organisational and human factors has been an increasing emphasis on the study of safety culture.

This interest in safety culture is associated with the need to transform "the way people do business" to more desirable, safety-friendly practices.

In aviation, the International Civil Aviation Organisation (ICAO) has mandated that all member states must implement safety management systems. Further, these safety management systems must include a component aimed at improving safety culture.

It is interesting that many other high-risk industries (for example, rail, shipping, surgery) are following aviation's lead by seeking to assess and improve safety culture. Safety culture is a relatively new area of research so our understanding of it is still evolving, as are the tools used to assess it.

A simple definition of safety culture is the dynamic interplay of workplace factors at multiple levels in an organisation that influence safety performance. The term 'safety culture' seems to have first appeared in a 1987 report on the Chernobyl nuclear disaster. The errors and violations of operating procedures that contributed to that accident were regarded as being evidence of a poor safety culture at the plant.

Since then, the concept of safety culture has been central to investigations into other major accidents, including the Piper Alpha oil platform explosion, several aviation accidents, and the twin space shuttle tragedies. As a result, safety culture has become a focus within organisations that appreciate the human and organisational dimensions of safety.

It is fascinating how differently safety is defined by different professions. For example, psychologists often refer to safety in terms of individual, group and organisational factors that lead to errors or failures. Engineers tend to refer to safety in terms of failure modes. Systems theorists view safety as a product of multiple forces across different levels of the entire system. Most recently, resilience engineering and systemic adaptability have been the focus of safety theorists (for example, Hollnagel, Woods & Leveson, 2006). We will briefly examine organisational resilience later in this chapter.

Concerns about safety culture in Defence aviation

On the evening of 12 June, 1996, two Blackhawk helicopters engaged in a live-fire counter-terrorism/special recovery training exercise near Townsville, collided in mid-air. Fifteen members of the Special Air Service Regiment lost their lives along with three members of the 5th Aviation Regiment. A further 12 servicemen were injured — some critically. Equipment worth $37 million was destroyed.

The Board of Inquiry set up after the Blackhawk crash identified 16 directly causative factors and a further 26 contributing factors. It found linkages between many of these factors, although it did not place a separate weighting on each of them.

Of relevance here, the Board identified a number of longer-term, systemic factors that contributed to the accident, including a 'can-do' culture (where pilots were flying close to the limits of the aircraft and human capability, thereby reducing or eliminating their margin for error), and lapses in safety supervision.

Ten years later in 2006, a similar outcome was found by the Board of Inquiry into the crash of a Blackhawk onto the deck of HMAS *Kanimbla*, killing the pilot and an SAS trooper.

A recurring theme in literature regarding culture in aviation organisations is that of 'can-do'. The 'can-do' culture within Defence is explored by Falconer and Murphy (2005). While a military organisation without a 'can-do' outlook would be a lame duck, 'can-do' can, nonetheless, be a double-edged sword if not balanced by realistic risk assessment, pragmatic risk management and proper oversight.

On 2 April, 2005, Royal Australian Navy Sea King helicopter, Shark 02, crashed on the Indonesian island of Nias while participating in a Defence humanitarian aid operation following the devastation caused by a recent tsunami. This accident resulted in the deaths of nine Defence members and two were seriously injured.

The Sea King Board of Inquiry identified that the primary cause of the accident was a failure of the flight control system caused by separation

“They were going for, gunning for, the best possible outcomes to satisfy the mission and at the same time as that was happening over a period of years, the safety margin gradually reduced until they’re flying on the absolute limit.

What happens then if you make a mistake, well, there’s no margin to look after you.”

ANGUS HOUSTON, CDF, *THE 7:30 REPORT*, BLACKHAWK CRASH RESULT OF COWBOY CULTURE, 15 JULY 2008

of the fore/aft bell crank from the pitch control linkages. This separation was, in turn, the result of a series of errors and violations with the Maintenance Regulations.

“The extent of regulation violations within the 817 Squadron environment surprised the Board. Many violations, especially with regards to aircraft maintenance documentation were accepted shortcuts, which appear to have developed in high-workload, low-supervision environments.” (Nias Island Sea King Accident, Board of Inquiry Report, executive summary, p. 6.)

In all three of these fatal accidents in Defence, organisational culture was found to be a significant contributor, paralleling the conclusion in the preceding section that further improvements in the commercial aviation accident record will be largely driven by improvements in organisational and human-factors aspects.

Further similarity between the general aviation and Defence safety record is demonstrated by Figure 4–1. It shows a dramatic reduction in Defence aviation hull losses and fatal accidents during the period from 1950 to 2010. Nevertheless, even one loss or fatality is one too many. Defence aviation has accepted that it must also look to improve the organisational and human elements of its safety management system.

Hull losses/fatal accidents (per decade)

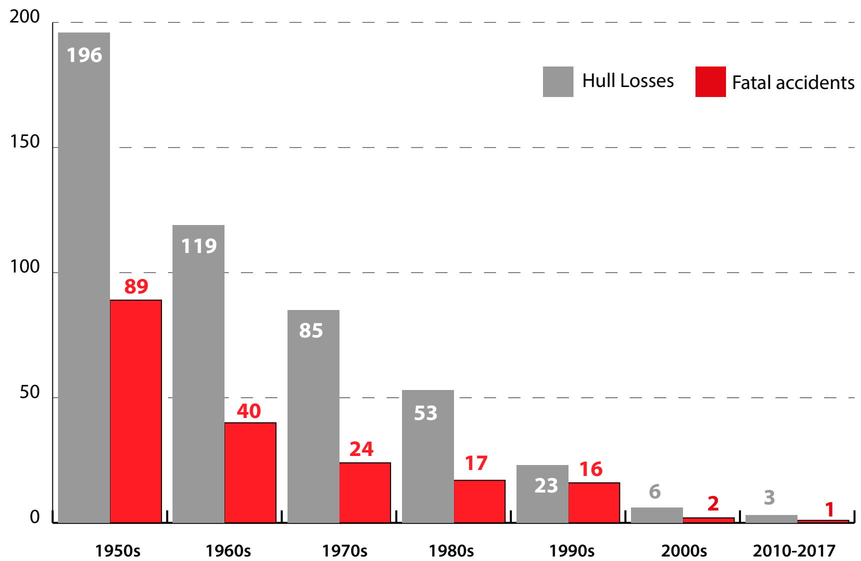


Figure 4–1. Defence aviation hull losses and fatalities 1950–2010

Figure 4–2. Piper Alpha Oil Platform after the July 1988 accident

Safety culture — learning from other industries

Piper Alpha: what happened

On 6 July, 1988, the Piper Alpha oil platform experienced a series of catastrophic explosions and fires. This platform, located in the North Sea approximately 110 miles [176 km] from Aberdeen, Scotland, had 226 people on board at the time of the event, 165 of whom perished (in addition, two emergency response personnel died during a rescue attempt). The platform was totally destroyed.

The disaster began with a routine maintenance procedure. On the morning of 6 July, a backup propane condensate pump in the processing area needed to have its pressure safety valve checked. The work could not be completed by 1800 and the workers asked for and received permission to leave the rest of the work until the next day. The tube was sealed with a plate.

Later that evening during the next work shift, the primary condensate pump failed. None of those present were aware that a vital part of the machine had been removed and decided to start the backup pump. Gas products escaped from the hole left by the valve, ignited and exploded, blowing through the firewalls.

The fire spread through the damaged firewalls, destroyed some oil lines and soon large quantities of stored oil were burning out of control. The automatic deluge system designed to spray water on such a fire in order to contain it or put it out was never activated because it had been turned off.

The accommodations were not smoke-proofed, and the lack of training that caused people to repeatedly open and shut doors only worsened the problem. Most of the 167 who died had suffocated on carbon monoxide and fumes in the accommodation area. The whole accident took place in 22 minutes.

Piper Alpha: lessons learnt

The Cullen Report (1990) into the Piper Alpha catastrophe included the following findings:

- Procedures were not followed and were often flagrantly disregarded. For example, signatures for things like gas-test results were often omitted. Paperwork was not where it should have been at the end of a shift. Inspections were not conducted as directed in the written procedures.
- The system on Piper Alpha had become too relaxed. Employees relied on too many informal communications and communication between shift changes was lacking. If the system had been implemented properly, the initial gas leak never would have occurred.
- The report was highly critical of management in the company. Managers had minimal qualifications, which led to poor practices and ineffective audits. The company also knew about the risk that a gas fire could pose to the safe evacuation of the platform because it had received an engineering report warning about this very problem one year before the fire occurred.
- There were deficiencies in equipment and facilities. The firewalls on Piper Alpha were not built to withstand an explosion. The initial blast blew the firewalls down, so that the fire spread unimpeded.
- Communication was inadequate. During shift turnover, the status of critical ongoing work was often not recorded. In this case, the incoming shift did not know the pump was left in a condition where it should not have been started.
- Inadequate attention was paid to safety procedures. Some survivors reported that they did not even know where the life rafts were located, let alone how to launch them.

In summary, the safety culture on Piper Alpha and within the management of its operator, Occidental, was complacent and non-compliant. Safety procedures and design were also inadequate, presumably a function of the lack of commitment to safety.

Piper Alpha: transferring the lessons to aviation

In many ways, Piper Alpha was a typical accident. What seems at first glance to have been an isolated example of poor communication or failure to follow procedures by a handful of workers turns out to have been just two indicators of a mass of underlying safety issues.

The nuclear disasters at Three Mile Island and Chernobyl were of much the same character — people making errors under pressure, multiple breeches of safety standards, poor communication, complacency, and so on, fostered by a weak safety culture. The disastrous flight of the space shuttle *Challenger* is another case in point, with the significant addition of political pressure to launch by a given date.

As noted earlier, the Defence Boards of Inquiry reports on the Blackhawk accidents and Sea King crash identified a wide range of issues above and beyond those that were the immediate cause of the accidents. No single accident contains all of the ingredients that are found in the voluminous safety literature but they all share one feature in common — people working alone or in teams as part of organisations that develop their own over-riding cultures.

Drivers of safety culture

There is no agreement among researchers as to what the main drivers of safety culture are, but the following dimensions feature prominently in the literature (Guldenmund, 2000) and have been shown to be related to safety outcomes in Defence research.

- **Management/command commitment to safety.** That is, the extent to which senior supervisors are perceived to place a high priority on safety by communicating about, and acting upon, safety issues genuinely and effectively. This dimension consistently emerges as the most important factor in the development of an effective safety culture. Importantly, commitment has to be in a form that creates room for individual workers to make their own commitment to safety.
- **Communication.** A positive safety culture requires effective channels for top-down, bottom-up, and horizontal communication on safety matters. Effective communication is a network that can connect all the elements of the organisation. Elements that fail to receive or absorb essential information, perhaps because of faulty handover procedures, inadequate briefings or simple disinterest, are more likely to behave in a manner that threatens the safety of the system.
- **Supervision support.** The extent to which supervisors are perceived to place a high priority on safety, respond to safety concerns, and provide support and encouragement for subordinates who comply with safety procedures and participate in safety activities.
- **Safety responsibility.** Workers' attitudes toward safety are underpinned by their sense of individual responsibility and the culture within the work environment.
- **Training.** Lack of knowledge usually ranks very highly in analyses of human causes of safety incidents.
- **Workload.** That is, the extent to which workload is perceived to exceed employees' capacity to perform their tasks safely. High workload has been implicated in decreased safety performance in all industries, usually because production concerns take precedence over safety. In the annual aviation safety *Snapshot* surveys, having too many things to do has always been ranked among the top three causes of error.
- **Personal health and wellbeing.** Stress and fatigue are major contributors to errors. They can become part of the culture if job demands are consistently high and/or organisational support consistently low.

Safety culture: components and types

There is some consensus that safety culture comprises four components:

- underlying values and implicit assumptions (often expressed in slogans)
- safety leadership strategies, including the organisation's stated mission, norms, history and ethos
- a defined safety climate, including attitudes, perceptions and opinions
- formal measures of safety performance, that is, the actual behaviours that result in safe outcomes, such as

"Safety is such a complex issue. Managers need to be seen showing a strong intent pushing safety as a priority. The reality is that intent isn't always shared at the coalface due to time constraints, expectations, double standards and the human nature of wanting to get the job done."

DDAAFS *SNAPSHOT* SURVEY RESPONDENT

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

successful error recoveries and systematic safety improvements in response to feedback.

It is generally accepted that some form of safety culture exists in every organisation or industry, although safety culture is rarely well understood. Further, any large organisation is likely to have a number of safety subcultures that will complicate the executive's ability to understand the organisation's culture.

Nevertheless, the dominant state of safety culture is often characterised as positive or negative. There is a dynamic interplay between safety culture and the organisational, psychosocial and technical elements of the organisation. A range of issues such as values, confidence in leadership, leadership effectiveness, attitudes, morale, cohesion, level of profit motivation, reputation and performance are closely linked to safety culture.

There is considerable consensus that safety culture can be improved through planned interventions — as long as safety climate can be measured and therefore monitored.

The safety literature has postulated different types or levels or stages of safety culture in large organisations that help to explain prevailing safety behaviour. A popular model of safety cultures (Hudson, 2007) that can be tracked along a developmental line is:

- **secretive or pathological culture** — where errors and mistakes are hidden or not disclosed, thereby inhibiting the organisation's ability to learn from its mistakes and improve safety
- **blame or reactive culture** — where individuals are blamed and punished when things go wrong, and safety is only addressed after things have gone wrong
- **calculative** — where safety is driven by a top-down approach using formal management systems
- **proactive** — where personnel at all levels look for opportunities to improve safety performance
- **generative or learning culture** — where safety is a core value and information is actively sought to understand safety-related events and levels of risk.

More than 8000 aviation personnel responded to a *Snapshot* item asking where Defence aviation sat on the safety-culture stage continuum. As Figure 4–3 shows, most respondents placed Defence aviation somewhere in the calculative-proactive-generative region. That indicates Defence aviation still has some way to go as we strive for a generative culture.

Let's take a closer look at the features of a generative safety culture.

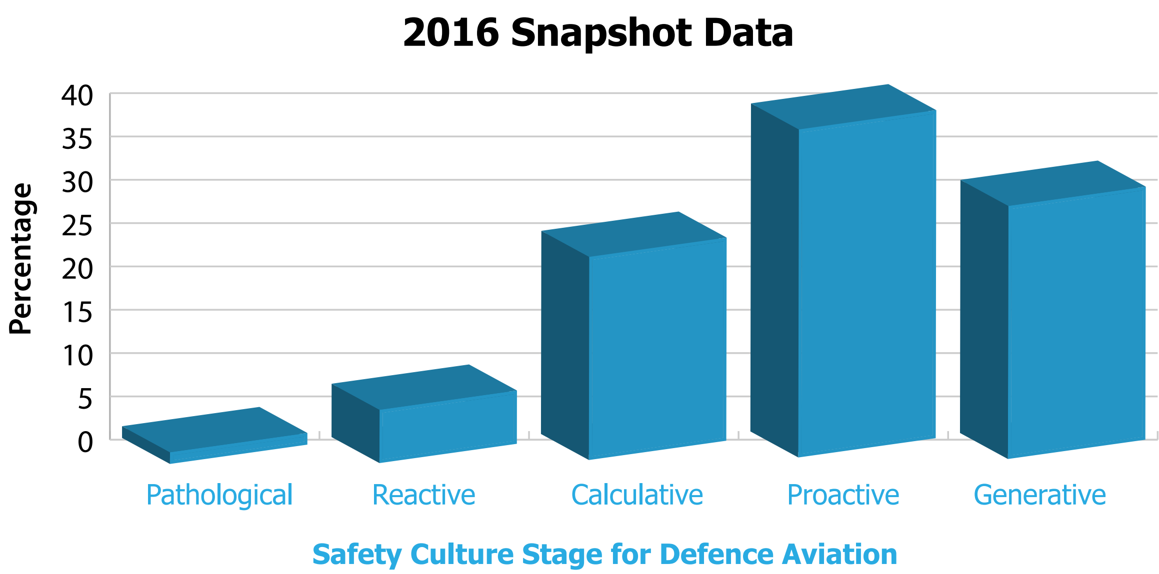


Figure 4–3. Perceptions of safety culture stage in Defence aviation

Generative safety culture

The generative safety culture has a number of sub-elements, including just culture, reporting culture, 'healthy wariness' culture, learning culture, compliance culture, and adaptive culture.

Just culture

A just culture acknowledges that human error is unavoidable and must; therefore, be managed. Just culture refers to the way that both errors and violations are treated.

For a just culture to exist we need a collectively agreed and clearly understood distinction between acceptable and unacceptable behaviour. All personnel must understand the difference between intentional departures from the rules and honest errors.

In a just culture, members of an organisation are not punished for actions, omissions or decisions taken by them that are commensurate with their experience and training, but gross negligence and wilful violations are not tolerated.

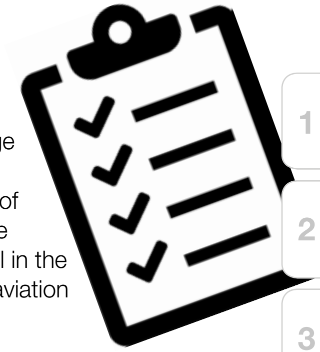
Just culture affects not only the willingness to report unsafe behaviours but also the tendency to engage in unsafe behaviours in the first place. A just and fair culture lies at the heart of an effective safety management system and is essential to maintain and improve safety performance.

However, the notion of a just culture does not imply complete freedom from blame. In 1997, James Reason argued that a no-blame culture was neither realistic nor desirable, as some people commit errors and violations that warrant punishment. In fact, a blanket amnesty would lack credibility with employees.

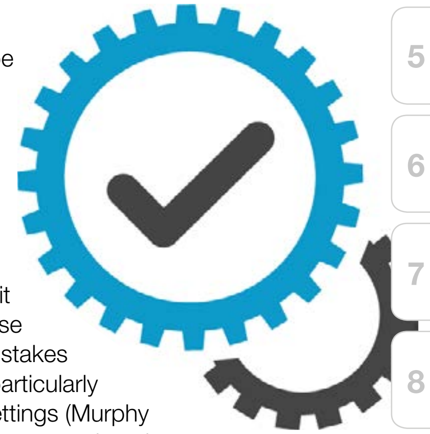
The Safety Behaviour Management Tool (SBMT) can help commanders determine acceptable and unacceptable safety behaviours and commensurate action. The SBMT is based on the principles of a just culture and deals with errors as well as instances of violation.

Reporting culture

James Reason argued that a reporting culture is a crucial component of a good safety culture. Incident-reporting systems constitute a rich source of information regarding successful error discovery (Sarter & Alexander, 2000) and often involve errors that have already breached one or several lines of defence. Information gleaned from incident data is used to change procedures, policies, and processes so that recurrence of errors is reduced. As such, the reporting of incidents is crucial in the management of safety in the aviation industry.



However, in order to develop an effective reporting culture, the issue of how an organisation deals with blame and the punishment of errors and violations must be openly examined.



There appears to be a human tendency to assign blame because it mollifies their own or the public need for retribution. Blame is generally unhelpful because it induces guilt in those who have made mistakes and erodes trust, particularly in organisational settings (Murphy & Jones, 2005). Scape-goating also prevents organisations from properly learning from past incidents.

Wariness and learning cultures

Healthy wariness refers to a culture where all personnel actively look for hazards and safety issues within their environment. Always asking what have we missed? What will catch us out? In a learning culture we learn from our previous errors and incidents and are always looking at ways to improve safety (continuous improvement).

Compliance culture

A compliance culture, as the name implies, is one wherein rules and procedures are followed rigorously. As illustrated in Figure 4–4, Fogarty, Murphy, Cooper, and McMahon (2016) traced the reasons for violations in aviation maintenance across a 17-year period in Defence aviation. They came up with a list of the 10 main reasons why rules are broken.

1. **Inadequate documentation.** In the maintenance environment, documentation plays an important role in guiding and recording the completion of tasks. Poor quality (ambiguous/ repetitive), excessive (too wordy) or absent documentation can contribute unnecessarily to workload. Furthermore, if written procedures are unworkable or unrealistic, they can induce violations.
2. **Inefficient or incorrect procedures.** Procedures have to be modified to suit the Defence environment, especially when new types of aircraft are introduced or modifications are made to aircraft to suit local conditions. Maintainers know there is a settling-in period for all new aircraft and can come to distrust the official procedures.
3. **Time pressure.** Shortcuts are usually a response to time pressure.
4. **Resource/equipment shortages.** There is a tendency for maintainers to cut corners when there is a lack of proper equipment.
5. **Practical drift.** Perhaps the biggest single cause of rule breaking is an unconscious, gradual movement away from written procedures over time. Dekker (2005) called this phenomenon practical drift or drift into failure. Practical drift is the slow, incremental movement of systems operations towards the edge of the safety envelope. When change occurs incrementally, it rarely attracts attention. If a small step away from written procedure appears to work and to be more efficient, it is not long before that change is considered normal operations. This new, unwritten, standard then becomes the stepping-stone for further incremental changes. To an outsider looking at the gap between actual and ideal practice, usually after an accident, the deviation from approved procedures appears reckless and culpable. To an insider, the gap may have opened so slowly that it was not even noticed.
6. **Conflicting goals.** Often at the heart of practical drift is a perennial tension or conflict. This conflict is common in safety-critical systems where people are constantly trying to reconcile what are often irreconcilable goals. For example, the need to generate business or optimise production is often in conflict with the need to minimise exposure to risk or potential hazards. If the balance of this tension swings towards production, practical drift can involve all levels in an organisation. Sometimes the deviation from approved procedures will have approval from people above the tradesperson/supervisor/ manager level. We know from survey data dating back more than a decade that supervisors sometimes turn a blind eye to routine violations (Fogarty, et al., 2016).
7. **Nature of the job and 'can-do' attitude.** Defence aviation personnel are faced with the challenge of building a bridge between the reality of work demands and rules and regulations that cannot possibly cover every work challenge that can arise. Part of the reason why individuals and supervisors take it upon themselves to decide that there is a more efficient way of doing things lies in the 'can-do' attitude that typifies most Defence aviation organisations. Working successfully under pressure and resource constraints is a source of professional pride.

   While the benefits of encouraging a 'can-do' culture are numerous, it must be acknowledged that some safety-management strategies can be impeded because of a strong sense of not wanting to let the team down. Deviation with standard procedures enables tasks to be achieved, and reputations as capable operators to be maintained. We know; however, from experience and the wider literature, that departures from approved procedures increase the risk of accidents. Individuals can misunderstand or underestimate the wider effects of decisions that made perfect sense in the local context in which they were made.
8. **Supervisors and co-workers.** In maintenance, as in other walks of life, people are influenced by those around them and, most of all, by their supervisors. Fogarty and Shaw (2010) used Defence aviation data to examine the influence of group norms on the intention of employees to not comply with the safety procedures. They found that supervisor commitment to safety was the primary driver of group norms. In turn, norms emerged as the primary driver of maintainer intentions to follow or ignore safety procedures. Fogarty and Shaw argued that the results of the study provided further justification for the importance placed on the role of supervisors given their direct effect on the attitudes of their work teams.
9. **Overconfidence.** Overconfidence in their own knowledge can also contribute to rule breaking among maintainers. Psychological research on metacognition (knowing what you know) has shown repeatedly that people tend to be overconfident when asked about factual information (Moore & Healy, 2008). Unfortunately we don't know as much as we think we do.
10. **Lack of feedback.** Lack of immediate feedback about the consequences of poor maintenance is another factor that can lead to rule breaking. We learn best when we get immediate feedback but that doesn't always happen where maintenance is concerned. In 1985, the world's worst single-aircraft accident claimed the lives of 520 people when Japan Airlines Flight 123 crashed into a mountain. The cause of the accident was faulty maintenance carried out years earlier. The aircraft flew more than 12,000 flights before the faulty maintenance caused it to crash. In 2002, China Airlines Flight 611 disintegrated in mid-flight, resulting in 225 deaths. The aircraft disintegrated because of faulty repairs carried out 22 years earlier.

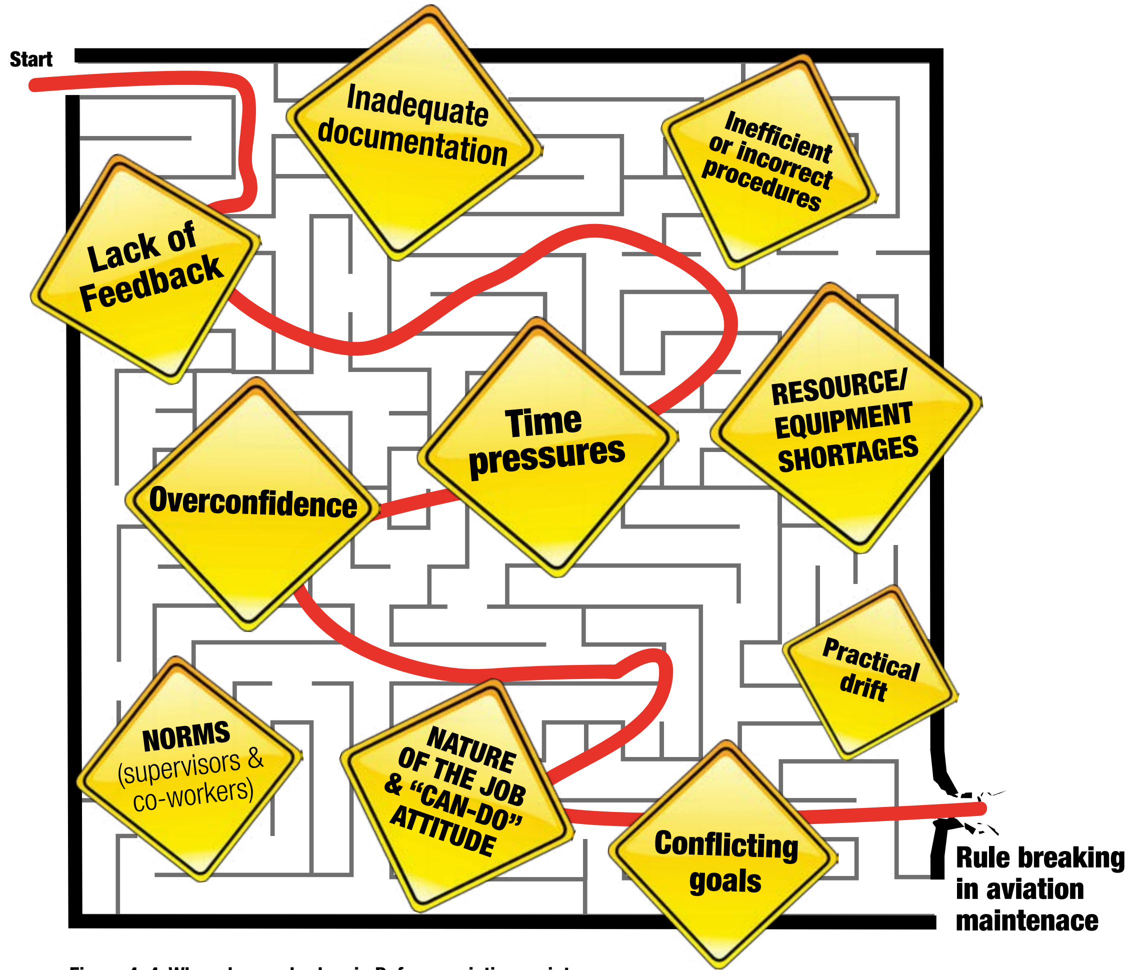


Figure 4–4. Why rules are broken in Defence aviation maintenance

In both cases, faulty maintenance remained undetected for a long time. Nearer to home, in 2005 the incorrect fitting of a nut and split pin during maintenance on an RAN Sea King helicopter two months earlier, caused it to crash on the Indonesian island of Nias, resulting in the loss of nine lives. The report from the Board of Inquiry criticised an embedded culture of shortcuts in the RAN's maintenance practices, leading to a defect that remained dormant for 57 days until the time of the accident.

Adaptive culture

An adaptive culture seeks to balance the need for compliance with the need to adapt to cope with the complexities of the real world. It involves a willingness to recognise the diversity and unpredictability that exists in life and the impossibility of devising rules to cope with all eventualities.

Having established processes that enable individuals to report ineffective and inefficient rules to the rule-makers (designers, managers, commanders and subject matter experts) is central to an adaptive culture. Such processes can lead to basic assumptions being challenged and changes being made where warranted.

As part of an adaptive culture, wherever possible, individuals are also required to seek and obtain pre-authorised approval for exceptions. At the same time, an adaptive culture allows for some individual discretion when confronted with exceptional circumstances.

Safety climate

The construct of climate has featured in the organisational psychology and management literature for many decades. This interest in climate perceptions was spurred by efforts to understand the effects of the work environment on individual and group motivation and behaviour.

The concept of climate was intended to explore how people in a given work system made sense of their experience of the processes and behaviours in organisational life.

From an applied perspective, interest in climate has been related to the desire to foster or reliably predict a range of individual, group and organisation-level outcomes. These outcomes have included job satisfaction, work performance, retention, personal growth, and even accident rates. Climate perceptions are also used diagnostically to evaluate organisational interventions such as major changes.

Several definitions of organisational climate exist. Most regard climate in organisations as characteristics of the work environment, perceived directly or indirectly by employees, which influence employee attitudes and behaviour with respect to factors such as satisfaction and commitment.

Safety climate is considered a subset of organisational climate. By extension, safety climate refers to employee perceptions of the organisation's policies, procedures and rewards related to safety that influence safety attitudes and behaviour within the workplace (Guldenmund, 2000).

Distinguishing climate from culture

The term safety culture is often confused with safety climate. Safety climate refers to the individual's perceptions of the organisational policies, procedures, and rewards relevant to safety in the organisation. This definition sets it apart from safety culture, which is usually regarded as a stable, deep-seated aspect of an organisation.

In simple terms, culture can be described as the personality of the organisation. Safety climate, on the other hand, is the external manifestation of safety culture, and is more malleable than culture. So if culture is the personality, then climate can be thought of as the prevailing mood within an organisation.

This approach has obvious synergies with issues of measurement and research design. For example, climate perceptions would be the focus of interventions designed to measure the short-term impact of events such as accidents, the initiation of major projects or change programs, and unexpected changes in important staff positions.

Organisational culture would be a more appropriate focus of research attempting to define the normal behaviours and shared values of members of an organisation.

As noted previously, safety climate represents a subset of organisational climate. Safety climate can be considered as the overt or surface manifestation of safety culture. In other words, safety culture is a stable, deep-seated aspect of an organisation that is expressed through safety climate.

Safety culture underpins safety climate, but safety climate is believed to be much easier to measure.

Measuring safety climate

It is difficult to measure culture directly but we can assess it indirectly through climate surveys in the same way that we can assess physical health by checking a number of external indicators such as temperature and blood pressure.

There is considerable consensus that culture can be improved through planned interventions — as long as climate is measured and monitored.

Safety-climate surveys gather information about employees' attitudes, opinions, and feelings regarding safety and how safety is managed within an organisation.

This information can be used to indicate aspects of the overarching safety culture of the organisation. In addition, such surveys are used to:

- increase safety awareness among aviation personnel
- involve personnel in safety initiatives
- benchmark safety standards across sections of the workforce, and
- monitor improvements in safety performance.

A number of characteristics of climate surveys make them potent agents for change. For example, climate surveys are easily administered, the resulting data are quantitative, benchmarks can be established, and feedback can be provided to management and the workforce. Furthermore, climate surveys (not just safety-climate surveys) are a familiar part of the methodology used by organisations to assess employees' perceptions of a wide range of organisational initiatives. Defence makes regular use of climate surveys, including the annual, aviation-specific Safety Pulse or *Snapshot* survey.

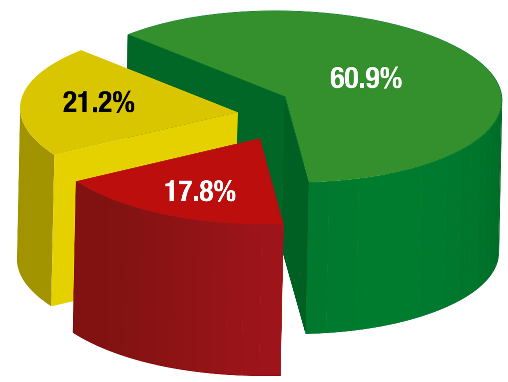
Evaluation items

Of course, safety culture should not and cannot be assessed by safety-climate measures alone but these measures have been used successfully in many industries to monitor levels of safety awareness and attitudes towards safety in the workforce.

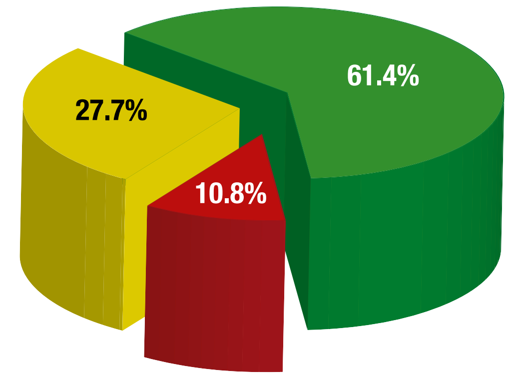
Dimensions of safety climate

There is a proliferation of safety-climate measures across the aviation domain. Among dozens of dimensions, five features are commonly found:

Snapshot safety survey evaluation



I can see the value of contributing to this survey



This survey covered the main issues in my workplace

Disagree Neutral Agree

Figure 4–5. Summary data from the *Snapshot* survey

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

- quality of management/supervision
- attitudes towards the organisation's safety management system
- attitudes and behaviours related to risk
- the range and experience of work pressures
- issues related to training and competence.

The *Snapshot* survey covers a wide range of safety-climate/culture dimensions that have developed over the last 20 years of dedicated safety research within Defence aviation.

They include:

- management commitment to safety
- communication
- workplace stressors
- supervisor support
- documentation
- occupational training
- safety training
- autonomy (the degree to which one is free to use one's initiative)
- resources and equipment
- personal commitment to safety
- just culture
- group compliance
- individual compliance
- reporting culture
- job satisfaction
- morale
- individual strain
- individual fatigue
- errors.

Groups of items are normally included in *Snapshot* to measure each of these dimensions of safety climate. The rationale is that by summing groups of scores we can gain a good idea of the status of that particular cultural facet and by summing all the scores, we can judge the status of the overall safety culture.

Looking through the list, it is apparent that some of the safety-climate dimensions are very close to an underlying cultural facet. For example, just culture, reporting culture, and group and individual compliance are measures of safety behaviour.

Other climate measures — such as documentation, training, and resources and equipment — together might reflect the degree to which safety is effectively resourced.

There is another way of assessing overall safety culture in a safety-climate survey that involves providing a description of various levels of safety culture and asking survey respondents to rate their organisation against these descriptions. *Snapshot* uses this technique, as shown in the next section.

Does climate influence safety behaviour?

Another line of enquiry has attempted to establish the mechanisms by which safety climate influences safety behaviours. In an Australian health industry study, Neal, Griffin and Hart (2000) tested a model examining the effects of general organisational climate on safety climate and safety performance in hospital staff.

Organisational climate measured aspects of the work environment such as leadership, professional interaction, decision-making processes, and role clarity. These factors were found to have a significant impact on safety climate, that is, perceptions of safety within the hospital environment such as management values, communication, training, and safety systems. Safety climate, in turn, was related to self-reports of compliance with safety regulations and procedures, as well as participation in safety-related activities.

Fogarty (2005) developed a conceptual model to predict aircraft maintenance performance and to investigate the role of individual and organisational factors in aviation maintenance in Defence. His model was based on Reason's theory in that it highlighted background variables that induce unsafe behaviours.

It was found that safety climate predicted personal health variables, which in turn predicted self-reported maintenance errors. A further study discovered that the link between safety climate and workplace errors was mediated by the psychological health of individual workers and the extent to which they were prepared to use non-standard working procedures.

Safety climate influenced both health and violation behaviour which, in turn, influenced errors.

These studies are a small selection of a substantial body of empirical support from the safety literature demonstrating the impact of individual and organisational factors on safety outcomes as proposed by James Reason.

Safety leadership

Everyone has their own experience and views with regard to leadership. The military has always understood and developed leadership as a priority, more than perhaps any other organisation. (Although this leadership is most often about leadership on operations.) Leadership styles are, to a certain extent, derived from an organisation's history, culture, mission, and task characteristics. This may explain why customary leadership styles can be dramatically different in different organisations.

There is also the chestnut issue of confusing management with leadership. It is claimed that some effective organisations function without leadership — they are simply skilfully managed.

Martinussen and Hunter (2010) make the point that relatively little research has been directed at discerning the influence of leadership on safety, inside or outside the military. Research within Australian Army aviation (Murphy, 2004) has demonstrated differences in safety climate across units that are strongly associated with perceptions of unit leadership.

Put simply, units with commanders who were perceived by their subordinates as being genuinely committed to safety had more positive safety-climate profiles, including lower reported rates of violating behaviours.

Despite the lack of research evidence, there is a strong belief that leadership is critical to safety. This point was underscored when CASA released a guidance booklet for aviation industry chief executives. Although entitled *Safety Management Systems*, the booklet emphasised a range of leadership issues including legal responsibilities for safety, practical reasons for leaders to be involved in safety, the importance of safety culture and case studies.

Organisational resilience

Resilience has been flavour of the month in many domains, particularly mental health. With the rise of positive psychology, there has been a focus on positive coping and the performance of high achievers.

This is in contrast to the traditional focus of many areas in health on pathology and other negative outcomes.

Put simply, units with commanders who were perceived by their subordinates as being genuinely committed to safety had more positive safety-climate profiles, including lower reported rates of violation behaviours.

Most of you will be aware of the tremendous interest in post-traumatic stress disorders among victims of crime, road accident survivors, and military veterans. In contrast, positive psychology focuses on issues such as post-traumatic recovery and growth in the 90 per cent or more of people who are exposed to crime, road accidents, and warfare and who do recover reasonably well from the experience. It is quite a paradigm shift for many health professionals and human scientists.

The concept of resilience suffers from the same lack of consensus associated with many behavioural science theories. Much of the research on resilience has been focused at the individual level. More recently, the topic of organisational resilience has begun to flourish. Fundamentally, resilient organisations are posited to:

- have the ability to prevent disruptions from occurring, and, if struck by trouble, have the ability to respond quickly and to recover from such an event
- be adaptive, prepared for risks and disruptions
- be encouraging of autonomy and innovation
- be skilled in working via distributed teams and locations
- have extensive networks and strong leadership that builds a sense of purpose, empowerment, trust and accountability.

Resilience is essentially about the ability of an organisation to deal with undesired and unexpected events.

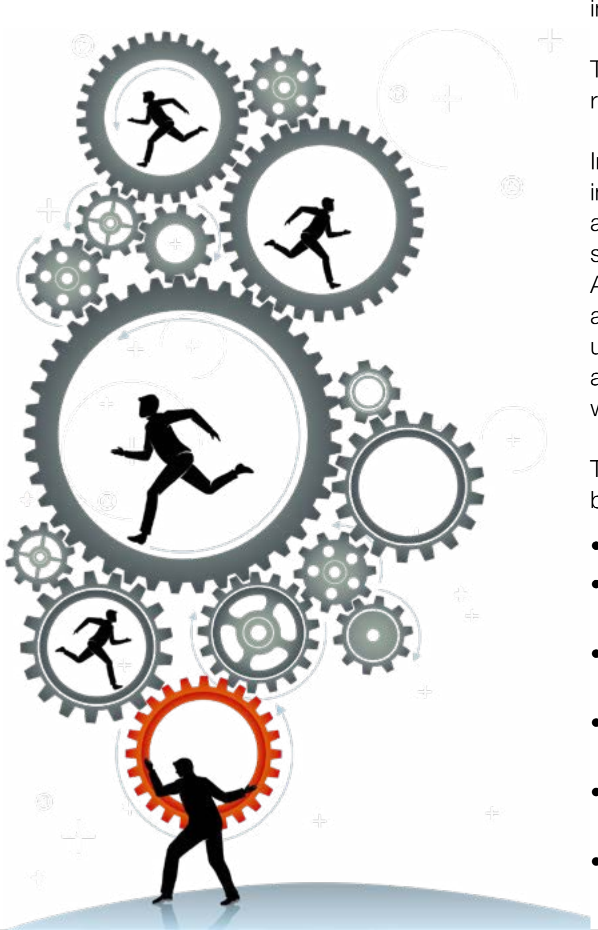
We can link resilience back to high-reliability organisations.

According to Weick and Sutcliffe (2001), a feature of HROs is not that they are error-free, but that errors are not disabling. HROs assume that errors will occur and develop systems to catch and correct errors. A commitment to resilience is a commitment to learn from error.

How can we develop a generative culture?

Figure 4–3 suggests that Defence aviation is on the way towards a generative safety culture — though in some people's minds there is still some way to go. How easy is it to change culture and how long can it take to affect a total change within the organisation?

Unlike some organisations that were slow to recognise the need for improvements in safety performance, Defence aviation is not trying to add a new culture to its profile. Safety has always been part of the backdrop in Defence aviation. It is now in the foreground and through our own research we know the drivers of safety culture in Defence aviation and we can measure progress towards the goal of a generative culture. A systems approach is required.



From the highest to the lowest levels in the organisation, we need commitment to safety performance. The Defence Aviation Safety Authority (DASA) is a significant organisational unit established to oversee matters of aviation safety.

We need the policies, procedures, and administrative systems to manage safety performance. Most of the guidance is to be found in the DASM.

We need to be able to measure our progress towards the goal of a generative safety culture. The annual safety-climate survey — *Snapshot*, the incident database, and accident investigation teams all help in this regard.

Training, delivered by DASA, is regularly being refreshed and updated.

In the final analysis; however, it is the individuals at the centre of the system who are most responsible for achieving the highest standards of safety performance behaviour. All personnel must understand that there is a clear line between what is professional and unprofessional behaviour; that is, what is acceptable and what is unacceptable in the workplace.

To close, a six-pack of precepts to guide behaviour is offered:

- complete all required documentation
- where appropriate procedures exist, follow them
- if a better procedure is known, change the system formally
- report all safety-related deficiencies and incidents
- take responsibility and accountability for your work
- support and maintain a just culture.

Additional reading

Fogarty, G. J., Murphy, P.J., Cooper, R., & McMahon, S. (2016). Maintenance human factors: Are rules made to be broken? *Aviation Safety Spotlight*, *3*, 5–12. (This reading provides an in-depth exploration of the reasons why maintainers continue to work outside the rules. It also contains pointers to resources that can be used by commanders to develop strong compliance and reporting cultures.)

Hall, J.L. (2003). *Columbia and Challenger: Organizational failure at NASA*. Space Policy, 19, 239–247. Retrieved from https://josephhall.org/papers/nasa.pdf (This reading examines shortcomings in organisational culture in the National Aviation and Space Administration in relation to the two space shuttle accidents.)

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Key points

- Safety culture is one of the most powerful drivers of safety behaviour.
- Culture is a multi-faceted construct, safety being just one of those facets. Within the safety-culture domain, there are further sub-facets, such as just culture, reporting culture, and compliance culture.
- There are ways of measuring the safety culture in Defence aviation, particularly through the annual safety-climate survey, currently called *Snapshot*.
- Individuals can be influential in changing organisational safety climate and culture for the better.
- By being part of a culture where safety is integral to all operations and by being professional in everything they do, an individual can make a significant and positive difference to their personal safety and the safety of those around them.

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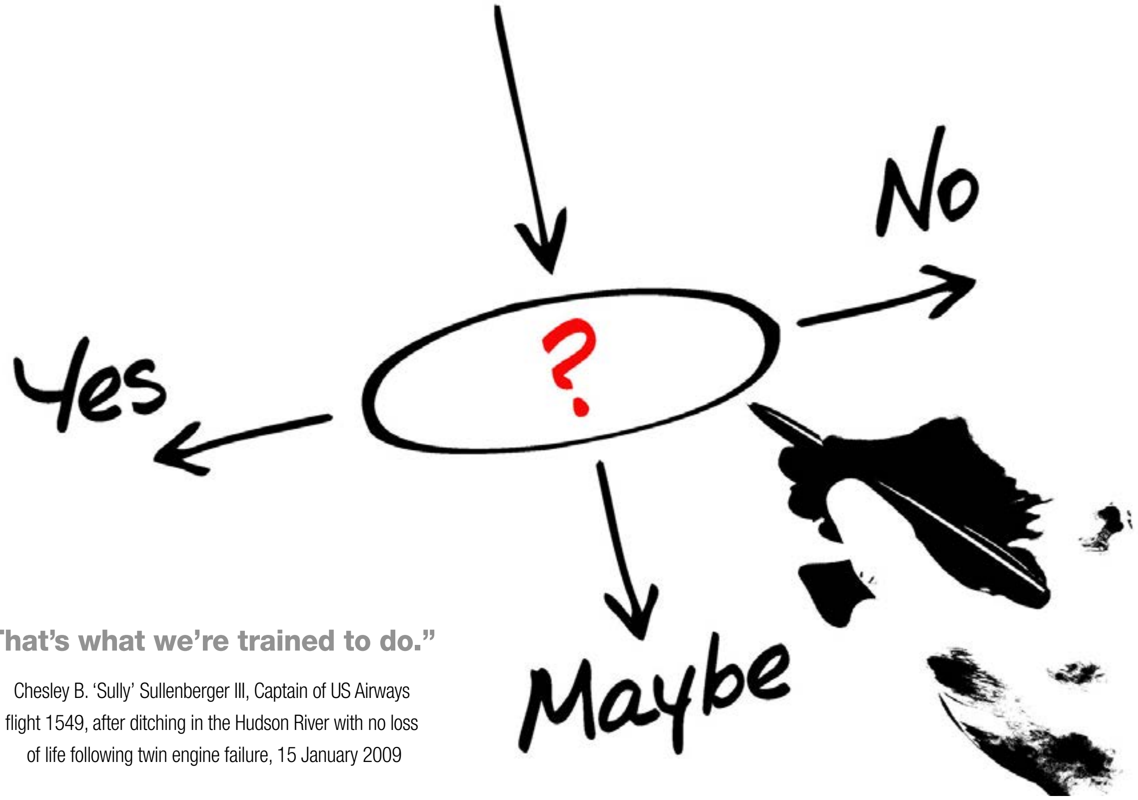
CHAPTER 5 **Decision-making in aviation**



"That's what we're trained to do."

Chesley B. 'Sully' Sullenberger III, Captain of US Airways flight 1549, after ditching in the Hudson River with no loss of life following twin engine failure, 15 January 2009

Overview:

- Suboptimal decision-making in military aviation
- Models of decision-making
- Heuristics and cognitive biases
- Complexity of decision-making in the work context
- Factors that influence decision-making (including specific factors that affect novices/trainees)
- Strategies to enhance or support decision-making

Introduction

Decision-making is pervasive in our lives and therefore might be considered mundane. In aviation operations; however, decision-making has added importance due to the level of inherent risk and the potential for catastrophic outcomes. The opening quote relates to a positive decision-making case study that is woven into the content of this chapter. Despite the drama injected into Hollywood's *Sully*, the ditching of US Airways flight 1549 is widely considered to have been exemplary aviation decision-making under extreme, unanticipated stress.

On the other hand, analyses of aviation accidents — both military and civil — consistently conclude that poor decisions are implicated in about half these events. For example, Shappell and Wiegmann (2004) reported that decision errors contributed to 45 per cent of accidents in the US Air Force and 55 per cent in US Naval Aviation. A National Transportation Safety Board (NTSB) study released in 1991 found that poor crew judgement and decision-making were contributory causes in nearly half of the aircraft accidents in the USA over a five-year period. In Taiwan, decision errors have been found to have occurred in 53 per cent of military aviation accidents and 71 per cent of commercial aircraft accidents (Li, Harris & Yu, 2008).

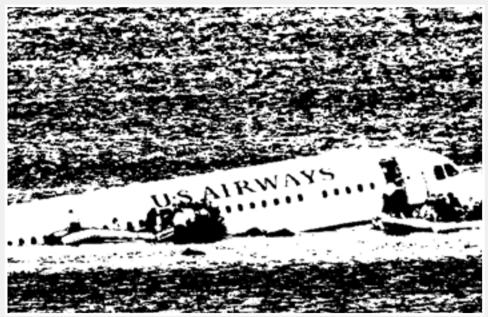
This chapter briefly examines some basic issues related to decision-making; before exploring the two major paradigms underpinning research into decision-making (that is, classical decision-making and naturalistic decision-making), a selected model of decision-making, characteristics of effective decision-making, effective decision-making in teams, and guidance for training for, and improving decisions in the aviation context. The focus across the chapter is on real-time decisions made by personnel at the coal face of aviation operations.

Fundamental issues

CASA defines decision-making as "a process for reaching a judgement or selecting an option to address or resolve a situation" (2009, p. 138). The FAA refers to aeronautical decision-making as a systematic approach to the mental processes used to consistently determine the best course of action in response to a given set of circumstances. A human-factors definition is "the process of reaching a judgement or choosing an option, sometimes called a course of action, to meet the needs of a given situation" (Flin, O'Connor & Crichton, 2008). Most simply, decision-making in the aviation context is what the operator determines to do, based on the information he or she has.

Decision-making should be understood from a systems perspective, rather than considered in isolation as the action of an individual operator. Aviation decision-making is a function of the features of the operational tasks (the mission) and the operator's knowledge and experience relevant to those tasks (the human in the loop). Hardware and software components of the aviation system can either support or inhibit decision-making. The cognitive processes of decision-making can be affected by situational, environmental and cultural factors. While much of the academic research on decision-making has focused on the mental processes of individuals, decision-making in military aviation is normally the result of team/crew interaction (liveware to liveware).

Effective decision-making is intricately linked to other non-technical skills, notably



CASE STUDY

US Airways flight 1549, Part 1

On 15 January, 2009, about 15:27 eastern standard time, US Airways flight 1549, an Airbus Industrie A320-214, was ditched on the Hudson River about 8.5 miles [13.7 km] from LaGuardia Airport, New York City. The 150 passengers, including a lap-held child, and five crewmembers evacuated the airplane via the forward and overwing exits. One flight attendant and four passengers were seriously injured, and the airplane was substantially damaged.

The National Transportation Safety Board (NTSB) determined the probable cause of this accident was the ingestion of large birds into each engine, which resulted in an almost total loss of thrust in both engines. Contributing to the survivability of the accident was the decision-making of the flight crewmembers and their crew resource management during the accident sequence.

Source: Excerpted and adapted from the Executive Summary of the NTSB accident report

communication, stress management and situation awareness. For example, decisions are normally triggered by a change in the state of the work environment detected by ongoing situation awareness. Further, decision-making has been regarded as virtually inseparable from the study of human error (Harris, 2011).

It should be recognised that the cognitive and interpersonal processes underlying decision-making in aviation are little different to other high-reliability industries and organisations where complex, high-risk and high-tempo operations occur routinely; and where unexpected and ill-defined challenges arise.

It is also important to recognise and counter the human tendency, when examining decision-making in complex safety incidents, to blame individual decision-makers, particularly the person in the loop nearest the adverse outcome.

Examples of the blame game occurred in response to the operator who mistakenly turned off a safety valve in the Three Mile Island nuclear plant, the Captain of the USS Vincennes who deemed an Iranian airliner to be a hostile F-14, the Apache crew that attacked a friendly Bradley Fighting Vehicle during Desert Storm, and the F-15 pilots who destroyed two Blackhawks in the no-fly zone in Iraq, having visually identified them as enemy Hinds.

Thorough safety investigations almost universally reveal incredible complexity in accident pathways and the reasons for human error. You are encouraged to embrace this complexity rather than settling on simplicity: making decisions is just one component of an entwined bundle of causal and contributing factors when safety incidents occur.

Decision-making paradigms

A vast literature exists on the subject of decision-making and the allied fields of problem solving, judgement, information processing, risk taking, conflict resolution and experience and expertise. The seeds of modern decision-making theory were sowed in the field of economics and then expanded into statistics, engineering and the behavioural sciences. There are many ways to classify the numerous paradigms, models and techniques that have appeared. The two most common categories are known as the prescriptive and descriptive approaches: that is, what should happen versus what actually happens when humans make decisions.

CASE STUDY

US Airways flight 1549 — Part 2

Decision to use engine dual failure checklist. At 1527:23, about 12 seconds after the bird strike, the captain took control of the airplane. Five seconds later, the captain called for the Quick Reference Handbook (QRH) engine dual failure checklist, and the first officer complied. Even though the engines did not experience a total loss of thrust, the engine dual failure checklist was the most applicable checklist contained in the US Airways QRH, which was developed in accordance with the Airbus QRH, to address the accident event because it was the only checklist that contained guidance to follow if an engine restart was not possible and if a forced landing or ditching was anticipated (starting from 3000 feet).

However, according to post-accident interviews and (cockpit voice recorder) CVR data, the flight crew did not complete the engine dual failure checklist, which had three parts and was three pages long. Although the flight crewmembers were able to complete most of part 1 of the checklist, they were not able to start parts 2 and 3 of the checklist because of the airplane's low altitude and the limited time available.

Source: NTSB accident report, p. 87

Classical decision-making

The prescriptive approaches are often grouped under the term classical decision-making (CDM). This approach adopts the view that the decision process should be an intensive, analytical comparison of options. A common CDM metaphor is the chess master processing and evaluating all possible options for as many future game moves as their cognitive capacity allows.

The emphasis of CDM has tended to be on how to reach optimum decisions. Notions of rationality, human bias and probability pervade CDM research, as well as a focus on trying to explain deviations from expected (optimum) decision behaviour. CDM has been distinguished by four essential characteristics:

1. **choice:** decision-making as choosing among alternative options
2. **optimisation of outcome(s):** making the ideal decision
3. **comprehensiveness:** using an exhaustive, analytic process
4. **generic models:** ignoring the context of decision-making.

The military appreciation process (MAP) was founded on CDM precepts (Hoskin, 2009). The emphasis of the MAP is to formally generate and evaluate several possible courses of action. The MAP is meant to ensure that decisions are made in a very deliberate and sequential process:

1. **the situation is assessed**
2. **multiple potential courses of action to resolve the situation are generated**
3. **the outcome of each potential action is (mentally) simulated**
4. **the course of action with the perceived best outcome is normally chosen and implemented**
5. **outcomes are monitored by returning to step 1.**

However, research has found that the majority of decisions made under real-world conditions do not involve the development of multiple courses of action.

People, especially experienced operators, do not instinctively engage in systematic, methodical and complete decision-making processes, particularly when time pressures exist. Reasons why it may not be necessary or beneficial to do so include:

- there is no need to find an optimum decision, just a satisfactory one
- a satisfactory solution may already be known so there is no need to consider alternatives
- the situation is familiar so experience can be relied upon to make a decision
- in time sensitive situations, it may not be possible to develop and consider multiple courses of action.

The influence of CDM has declined, largely due to it having little relevance to real-world settings. In addition, CDM has done little to contribute to effective training regimes or to design decision aids.

Naturalistic decision-making

Naturalistic decision-making (NDM) has become the most accepted and generic term among the numerous descriptive models of decision-making that have evolved. NDM studies using experienced subjects in operational contexts have resulted in many thought-provoking findings [see sidebar 'The impacts of NDM research']. Real-world decision-makers use their experience and expertise to take incremental action to adaptively react to dynamic, challenging situations. Comprehensive analysis is rarely used; in fact, people generally prefer to use experience and intuition rather than rational-choice methods even when tasks are relatively simple (Lipshitz et al., 2001).

The goal of NDM research is to examine the way people use experience to make decisions under operational conditions characterised by time pressures, shifting conditions, unclear goals, degraded information quality, risk-laden consequences and, possibly, conflicted team interactions. No correct or optimum strategies are assumed; rather the focus is on discerning behaviour. By observing and understanding what strategies people actually use, training and support can be better tailored.

A fascinating series of Australian studies of decision-makers at work was conducted by Mary Omodei and her colleagues (Omodei et al., 2005). They had fire service commanders wear head-mounted cameras during real operations and used the resulting videotape for discussion, debriefing and analysis. A recurring finding was that people over-estimated their ability to deal with incoming information during critical incidents. Another strong finding was that people tended to trust information given by sources they knew or had a closer relationship with when making decisions. Recommendations from the research included focusing on the fire and not the plan, not relying solely on intuition during rapidly changing events, not getting to the stage of mental overload, and establishing relationships with direct contacts at all fire events.

The impacts of NDM research

We no longer claim that the only way to make a good decision is to generate several options and compare them to pick the best one (experienced decision-makers can draw on patterns to handle time pressure and never even compare options). We no longer believe that expertise is based on learning rules and procedures (it primarily depends on tacit knowledge). We no longer believe that projects must start with a clear description of the goal (many projects involve wicked problems and ill-defined goals). We no longer believe that people make sense of events by building up from data to information to knowledge to understanding (experienced personnel use their mental models to define what counts as data in the first place). We no longer believe that insights arise by overcoming mental sets (they also arise by detecting contradictions and anomalies and by noticing connections). We no longer believe that we can reduce uncertainty by gathering more information (performance seems to go down when too much information is gathered — uncertainty can stem from inadequate framing of data, not just from the absence of data). We no longer believe that we can improve performance by teaching critical thinking precepts such as listing assumptions (too often the flawed assumptions are ones we are not even aware of and would never list) (Klein, 2015).

Issues typically of focus in NDM studies are complexity, quality of feedback, feedback delay, rate of change, environment-operator interaction and impact, and extent of delegation. This complexity has been simplified to three key factors: degree of change, level of uncertainty, and amount of task distribution.

NDM research has been closely linked to, and has fostered interest in situation awareness and team decision-making. A number of themes inherent in decision-making in complex systems within naturalistic settings have been identified (Orasanu & Connolly, 1993).

- **Ill-structured problems.** Problems in the real world rarely present in neat and complete form. Instead, decision-makers need to generate hypotheses about the nature of the problem or challenge before they can determine if a decision is required and before they can generate options.
- **Uncertain, dynamic environments.** Problems in the real world are typified by incomplete, imperfect, ambiguous and/or unreliable information. Adding to this problem is the fact that information decay can be very rapid.
- **Shifting, ill-defined or competing goals.** In real-world settings there is rarely a single, well understood goal. Normally, decision-makers are confronted by multiple and complex goals, some of which may not be clear or may appear to be competing or contradictory.
- **Action/feedback loops.** In real life, problems are often solved by a series of decisions, not a single decision event. Iterative and adaptive decision-making requires the feedback loops as more information is uncovered or develops.
- **Time pressure.** Decisions in the real world are frequently made under significant time pressure, resulting in personal stress which can interfere with decision-making processes [see Chapter 8].
- **High stakes.** Making decisions in naturalistic environments can have high stakes attached. This can be a double-edged sword: potentially increasing stress but also fostering motivation and engagement in the task at hand.
- **Multiple agents.** Many problems in the real world involve more than just a single decision-maker. Agents contributing to decision-making may be members of a close-knit team or dislocated elements of the aviation system.
- **Organisational goals and norms.** Because decisions in the real world often take place in organisational contexts, the culture and objectives of the organisation can strongly influence the decision-making process.

Another term often used almost interchangeably with naturalistic decision-making is recognition-primed decision (RPD). RPD is a model within the broader NDM approach/perspective. RPD research tends to be conducted in high-risk or high-reliability industries such as aviation and emergency services.

The focus of this research is on the role of experience, especially in time-critical scenarios. RPDs are based on remembering responses to previous situations of the same or similar type. Training to deal with specific emergencies is a traditional way that aircrew are primed to use recognition to assist in their decision-making.

There is considerable evidence that many professionals use RPD; including firefighters, intensive-care health workers, anaesthetists, military personnel, offshore installation managers, and aircrew. In complex, dynamic domains like these, the initial responses of experienced personnel are often triggered automatically by existing mental schemas that have developed over time. Once a situation or event is recognised, a relevant response is identified within an existing repertoire of options. RPD is less satisfactory in unfamiliar situations and for novices who do not have experience to draw upon. In such cases, conscious deliberation and the application of standard operating procedures (SOPs) are most useful.

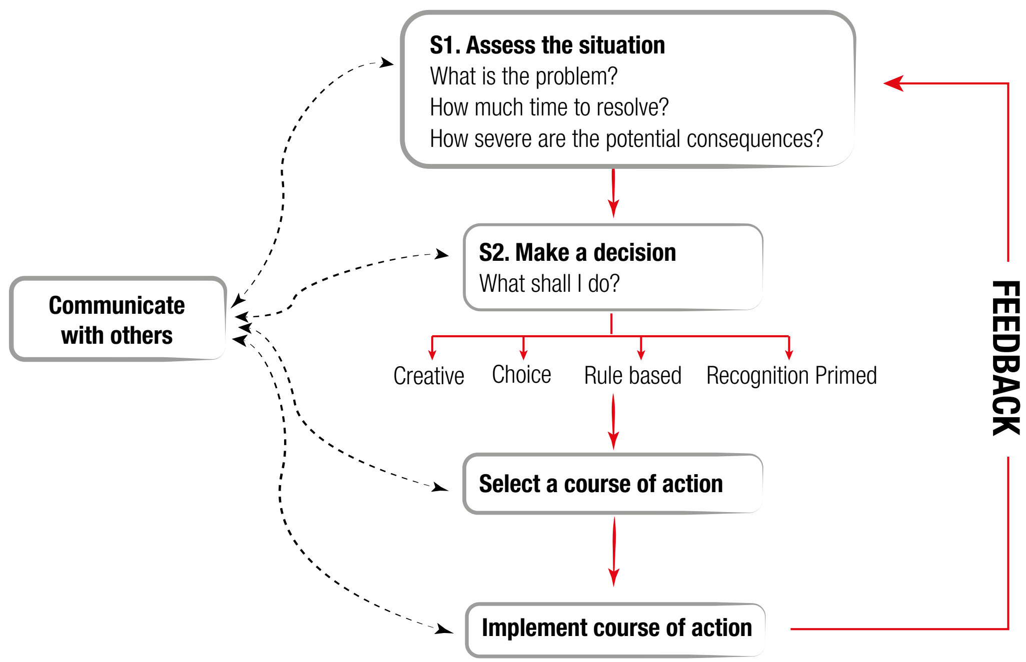


Figure 5–1. Simplified model of decision-making adapted from Flin, O'Connor & Crichton (2008)

A simplified model of decision-making

Figure 5–1 shows a simplified model of decision-making that can be used to describe the decision-making process. There are two primary stages to decision-making using this model. Firstly, a situation assessment is conducted, often with the assistance of a team, in order to build a mental model and diagnose the problem. Secondly the decision-maker chooses a course of action to meet the demands of the situation using one of the four methods — RPD, rule-based, choice or creative.

Recognition-primed decisions (RPDs). Research as shown that in 80 to 95 per cent of decisions made by people in high stakes occupations (for example, firefighters, first responders and pilots) were RPDs (Klein, 1998). Experience is the key to making an effective RPD. A study on chess players (Calderwood, Klein & Crandall, 1988) found good players made more poor choices during blitz games (only five minutes) than regular time conditions (40 moves in 90 minutes), whereas chess masters performed similarly under both conditions. The experience of master chess players allows them to calculate the right course reflexively and act.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Chess masters rely on experience to make critical decisions intuitively.

We can exploit this process in aviation safety by rehearsing the optimal course of action during different time-sensitive critical scenarios so that we can act immediately. This is especially important for pilots, who may have only a matter of seconds to address a malfunction with the aircraft. Before being certified to fly an aircraft, pilots must learn these steps intuitively, which are referred to as boldface actions as they are boldfaced in the aircraft SOP. The advantages and disadvantages of RPD are summarised in Table 5–1.

Including RPDs, also referred to as intuitive decisions as illustrated in Figure 5–1, there are four main decision-making methods.

Rule-based decision-making. Rule-based decision-making refers to a decision based on following a series of steps that are either committed to memory, or looked up in a set of instructions or a manual. The development of recognition-primed decisions (RPDs) often starts with rule-based rehearsal. Defence pilots for example are required to rehearse boldface: a series of steps to take in safety-critical scenarios that are time sensitive. With practice these steps become a reflex. In contrast, rule-based decision-making is a more conscious process of memory recall if not relying on a written document.

Whenever you are reading a manual for an aircraft, for either operational or maintenance purposes, you are using a rule-based decision method. Similarly, whenever ATC and aircrew communicate during various stages of flight (for example, departure clearance) there are a defined series of communication steps that must be followed by both parties. New Defence aviation personnel will rely heavily on rule-based decision-making before they can effectively implement more experience-based decision-making methods. The advantages and disadvantages of rule-based decision-making are summarised in Table 5–2.

Recognition-primed decisions

Advantages	Disadvantages
• Generates a course of action fast • Uses tried and tested actions based on past experience • Less workload than other strategies • Not as affected by stress as other strategies	• Requires expertise that can be time intensive to gain • Can promote confirmation bias (searching only for information that supports the mental model) • Only suitable for highly stable environments (doesn't work for unexpected or unpredictable scenarios) • May be difficulty to justify as decisions are more instinctive than planned

Table 5–1. (Flin, O'Connor & Chrichton, 2008)

Choice-based decision-making

Advantages	Disadvantages
• Allows for the comparison of viable options • It is more likely to lead to an optimal decision • Choices can be justified based on comparisons of options • Can be easily trained compared to the abstract thinking required for creative decision-making or the experience required for RPDs	• Can be time intensive • Can lead to indecisiveness • Can be difficult in stressful situations • Creates more workload than rule based or RPDs

Table 5–3. (Flin, O'Connor & Chrichton, 2008)

Rule-based decision-making

Advantages	Disadvantages
• Can be used by people lacking experience • Can also be fast if the rule is already known • Can be easy to justify the decision based on documents • Provides an evidence based course of action chosen by experts on the topic	• If the rule isn't known it can be time consuming to reference the rule in a document • If following the rule from memory steps could be forgotten or done in the wrong order • Without consideration, a person may apply a wrong or suboptimal rule

Table 5–2. (Flin, O'Connor & Chrichton, 2008)

Creative decision-making

Advantages	Disadvantages
• Produces a solution for an unfamiliar problem • Can lead to a rule being developed for future problems	• Can be time consuming • Creates a high workload • Difficult in stressful conditions • May be difficult to justify without precedent • Produces an untested solution

Table 5–4. (Flin, O'Connor & Chrichton, 2008)

Choice-based decision-making. Choice-based or analytical decision-making, refers to the traditional (that is, classical) decision-making method discussed earlier. Choice-based decision-making involves the generation of several possible courses of action and weighing up the merit of each possible course. This is important for pilots, who may need to consider different options when conditions change mid-flight, such as alternative flight paths because of poor weather. ATC is also required to consider placing aircraft on different flight paths or holdings to effectively co-ordinate aerodrome traffic. The advantages and disadvantages of choice based decision-making are summarised in Table 5–3.

Creative decision-making. Creative decision-making is the decision process adopted when faced with a completely unfamiliar problem, that is, where a solution needs to be devised and the decision-maker has to rely less on past experiences. Because you cannot rely on past experiences, creative decision-making is more time intensive. It should be reserved for only when an existing procedure or best course of action is not available. The advantages and disadvantages of creative decision-making are summarised in Table 5–4.

One of the most iconic examples of an aviation incident where a creative decision-making strategy was adopted was United Airlines flight 232.

Figure 5–2. Shrapnel damage during combat may need to be repaired without the usual tools or resources

Faced with a complete loss of hydraulics, the flight crew used differential engine thrusts of the two remaining engines to regain some control of the aircraft and crudely steer. The aircrew managed to land the aircraft and minimise loss of life.

While individuals will primarily rely on rule or choice-based decision-making during their Defence aviation career, they may be faced with unique challenges that require individuals or teams to use creative decision-making processes. For example, if an aircraft has diverted to an airfield in a hostile area, maintenance personnel may have to design a temporary fix using non-standard procedures or resources in order to get the aircraft to a more suitable location for repairs. It is important to remember that even in these exceptional circumstances, there are processes to seek approval for non-standard practices or operations through the chain of command.

To emphasise an important point, the model shows that the estimation of the available time and level of risk during the situation assessment phase is critical.

If the stakes are high and there is very little time available, a faster strategy such as RPD and rule-based decision (wherein only one response option is considered at a time) will likely be required. For example, in the case of an inflight engine stall, or rapid decompression, an action is prescribed in response to specific situation cues. In terms of time estimation, studies indicate that inexperienced individuals tend to underestimate the time available for decision-making and also tend to be less aware of strategies that they can use to buy time in a problem situation.

If there is more time, regardless of whether the risk is high or low, a more methodical strategy, such as choice-based, would be appropriate. While the most methodological approach would be to conduct a full evaluation of each possible option in terms of every variable relevant to the decision, this is very time consuming. In reality, people typically work toward the first workable (but not necessarily optimal) decision in the shortest time. Through a process of elimination, one course of action is chosen to match the constraints of the circumstances and perceived risks.

It is important for people to be mindful of their limited experience when making decisions and, where possible, rely on rule-based decision-making (orders, instructions and procedures, and manuals). Finally, it is important to remember to communicate with others during the decision-making processes. Communicating with others is especially important when learning a new task to confirm you are making the right decisions and during critical situations to use others as a resource in aiding your decision-making process.

Characteristics of effective decision-making

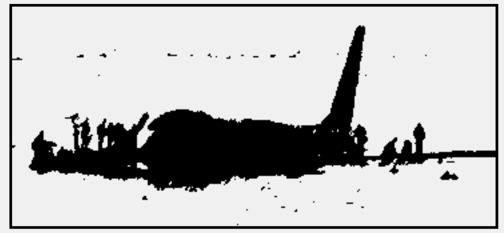
Factors influencing decision-making

The Westerner and the Japanese man mean something different when they talk of "making a decision". In the West, all the emphasis is on the answer to the question. Indeed, our books on decision-making try to develop systematic approaches to giving an answer. To the Japanese; however, the important element in decision-making is defining the question. The important and crucial steps are to decide whether there is a need for a decision and what the decision is about. And it is in that step that the Japanese aim at attaining consensus. Indeed, it is this step that, to the Japanese, is the essence of decision. The answer to the question (what the West considers the decision) follows from its definition.

Peter Drucker, *Management: Tasks, responsibilities, practices*, 1974

We have discussed how effective decision-making is strongly influenced by technical expertise, experience, familiarity with the situation, and practice in responding to challenging situations. Decision-making is a cognitive skill and is therefore potentially affected by factors such as fatigue, noise, distraction, diet, hydration, motivation, personality, interpersonal interaction, cultural differences, stress and bias. Personality characteristics associated with decision style include need for control, trust in others, assertiveness, openness to new ideas, and self-confidence.

The adverse effects of stress and fatigue on cognitive processes are examined in detail in Chapters 8 and 9 respectively. It is worth noting here that stress tends to lead to focused attention (tunnel vision), disruption to working memory, problems with long-term memory retrieval, impaired judgement, and changes in work performance particularly the speed/accuracy trade-off (people under stress tend to work more slowly in order to maintain their accuracy or standard of performance).



CASE STUDY

US Airways flight 1549 — Part 3

Decision to ditch on the Hudson River. At the time of the bird strike, the airplane was about 4.5 miles [7.2 km] north-northwest of the approach end of runway 22 at La Guardia Airport (LGA) and about 9.5 miles [15.3 km] east-northeast of the approach end of runway 24 at Teterboro Airport (TEB). During post-accident interviews, both pilots indicated that they thought the Hudson River was the best and safest landing option given the airplane's airspeed, altitude, and position.

About one minute after the bird strike, it was evident to the flight crew that landing at an airport may not be an option, and, at 1528:11, the captain reported to ATC that he did not think they would be able to land at LGA and that they might end up in the Hudson. At 1529:25, the captain told ATC that they would also be unable to land at TEB. Three seconds later, he stated to ATC that the airplane was going to be in the Hudson. During post-accident interviews, the captain stated that, "due to the surrounding area", returning to LGA would have been problematic and that it would not have been a realistic choice. He further stated that, once a turn to LGA was made, "it would have been an irrevocable choice, eliminating all other options", and that TEB "was too far away". The NTSB notes that a direct return to LGA would have required crossing Manhattan, a highly populated area, and putting people on the ground at risk. Simulation flights were run to determine whether the accident flight could have landed successfully at LGA or TEB following the bird strike.

The simulations demonstrated that, to accomplish a successful flight to either airport, the airplane would have to have been turned toward the airport immediately after the bird strike. The immediate turn did not reflect or account for real-world considerations, such as the time delay required to recognize the extent of the engine thrust loss and decide on a course of action. The one simulator flight that took into account real-world considerations (a return to LGA runway 13 was attempted after a 35-second delay) was not successful. Therefore, the NTSB concludes that the captain's decision to ditch on the Hudson River rather than attempting to land at an airport provided the highest probability that the accident would be survivable.

Source: NTSB accident report, pp. 88–89

Stress has the most impact on choice and creative decision-making styles because these expend more cognitive resources. RPD, which is more intuitive and relatively light on cognitive processing, is less affected by stress. Rule-based or procedure-based decision-making often recognises the potential impact of stress by incorporating checklists that can guide performance in emergency situations.

Cognitive bias

One of the biggest factors affecting decision-making is known as cognitive bias. A cognitive bias is a systematic tendency in thinking that affects the decisions and judgments that people make. Sometimes these biases are related to memory.

The way you remember an event may be biased for a number of reasons and that in turn can lead to biased thinking and decision-making. In another instance, cognitive biases might be related to problems with attention. Since attention is a limited resource, people have to be selective about what they pay attention to in the world around them. Another cause of cognitive bias can be engrained attitudes and opinions that shape how you perceive the world and your interactions with it.

The challenge of cognitive biases is that we are often unaware of how these biases affect our thinking and shape our judgement, behaviour and decisions.

A recent project defined 188 different cognitive biases and listed them in the 'cognitive bias codex'. A reduced version of the codex is provided in Figure 5–3.

By way of example, a few common cognitive biases are explained below.

- **Confirmation bias** involves favouring information that confirms previously held or existing beliefs. Confirmation bias can impact how people gather information and influence how they interpret and recall information.
- **Self-serving bias** refers to the human tendency to blame external forces when bad things happen and give ourselves credit when good things happen. Although self-serving bias can promote evasion of personal responsibility, it is also a defence mechanism that protects our self-esteem.
- The **halo effect** is a type of cognitive bias in which our overall impression of a person influences how we feel and think about his or her character; if you think someone is attractive, you may also think they must be intelligent and/or easy to get along with.
- The **availability heuristic** refers to how we use mental shortcuts to make fast, but sometimes incorrect, assessments. When we rely on information that comes to mind quickly, perhaps because it was a high-profile news story, or briefed in that morning's pre-flight, it is called the availability heuristic.
- The **anchoring bias** can occur when people are trying to make a decision or adopt a position. We often use information as an 'anchor' or starting point but there is a tendency to rely too heavily on the very first piece of information we learn, which can have a serious impact on the decision we end up making.
- **Overconfidence bias** occurs when you place too much faith in your own knowledge and opinions. You may also believe that your contributions to a decision are more valuable than they actually were.
- **Attentional bias** occurs when we focus on just a few of the available decision options while ignoring the rest. This tendency is postulated to have an evolutionary basis. In order to enhance survival, our ancestors paid greater attention to things in the environment that were perceived as potentially the most risky, and simply ignored the rest.
- **Functional fixedness** involves a tendency to see objects as only working in a particular way. This cognitive bias can prevent people from seeing the full range of uses for an object and impair our ability to think of novel solutions to problems.

Moderating cognitive bias

The keys to moderating the impact of cognitive biases are greater self-awareness, frank communication, honest feedback and a workplace climate of openness. Try the following:

- put yourself in the shoes of others
- do not foster "yes people" among your subordinates
- encourage and be receptive to frank and fearless advice
- discuss your thoughts candidly with others
- encourage diversity in your work team — including diversity in opinions

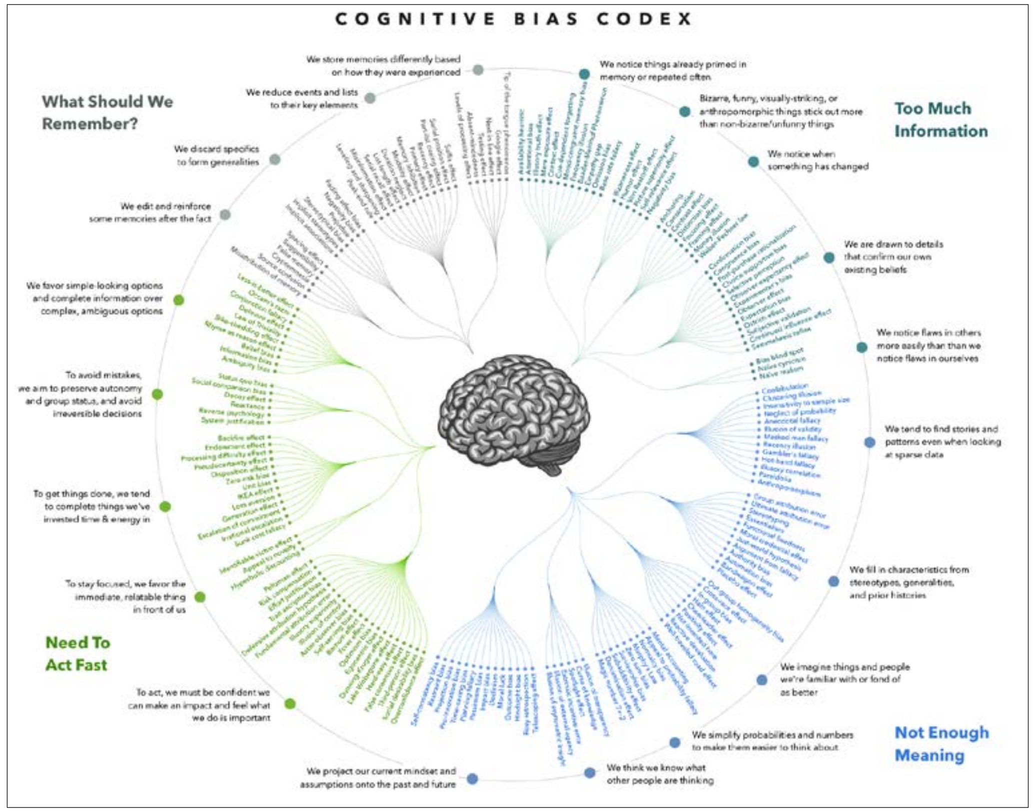


Figure 5–3. Cognitive Bias Codex

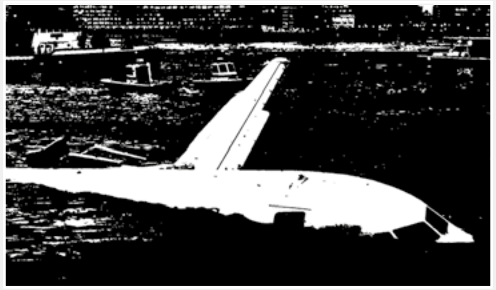
- take an emotional intelligence, cultural intelligence or personality test to gain more self-awareness
- assign someone to deliberately act as devil's advocate in group discussions
- introduce 360-degree feedback appraisals in the workplace
- gather information systematically from a wide range of sources
- take time every day to reflect on your performance and your thinking
- find yourself a mentor
- seek regular feedback (perhaps fortnightly or monthly) rather than settle for an annual performance appraisal
- be aware of the potential for cognitive bias that is generated by rank disparities and the cockpit authority gradient (for example, subordinates assuming your rank or position bestows infallibility or makes you unapproachable)
- read and listen widely and be open to the opinions of others
- read about or attend a workshop on cognitive bias.

Avoiding decision traps

A concept similar to cognitive bias is decision traps Walters (2002). These are decision styles or behaviours that are associated with poor decisions, and include:

- the tendency to plunge in and make impulsive decisions — aka, jumping to solutions
- not communicating
- being unwilling to challenge experts or supervisors/superiors
- solving the wrong problem
- complacency ("you worry too much"; "we can get through there")
- assuming you don't have the time to consider options
- failure to consult or ignoring feedback
- failure to evaluate or review.

Awareness of such traps in aviation can be fostered by activities such as including discussion



CASE STUDY

US Airways flight 1549 — Part 4

Decision to use flaps 2 for ditching. The Airbus and US Airways engine dual failure checklists indicated that only blue hydraulic power would be available and, therefore, that only slats would extend when configuring for landing. Although the dual-engine failure certification assessed this worst-case scenario, the possibility of having green and yellow hydraulic systems available was also considered.

Flight Data Recorder (FDR) data indicated that, during the accident event, all three (green, blue, and yellow) hydraulic systems were available and that the flight crew was able to extend flaps and slats. In the accident scenario, the NTSB notes that the selection of flaps 3 would have allowed the airplane to fly at a lower airspeed. At 1529:45, when the airplane was at an altitude of about 270 feet, the captain instructed the first officer to set the flaps. The first officer then stated that they were at flaps 2 and asked the captain if he "want[ed] more?" The captain replied, "no, let's stay at 2". About one minute later, the airplane was ditched on the Hudson River.

During post-accident interviews, the captain stated that he used flaps 2 because there were "operational advantages to using flaps 2". He stated that using flaps 3 would not have lowered the stall speed significantly and would have increased the drag. He stated that he was concerned about having enough energy to successfully flare the airplane and reduce the descent rate sufficiently. He stated that, from his experience, using flaps 2 provides a slightly higher nose attitude and that he felt that, in the accident situation, flaps 2 was the optimum setting. The NTSB concluded that the captain's decision to use flaps 2 for the ditching, based on his experience and perception of the situation, was reasonable and consistent with the limited civilian industry and military guidance that was available regarding forced landings of large aircraft without power.

Source: NTSB accident report, pp. 90–91

of potential decision traps in daily briefings, the analysis of safety incidents and accidents, and the inclusion of these decision styles and behaviours in training.

Decision errors

It is worth quoting Harris (2011) directly on this topic. He wrote: "there are two major ways in which a decision error may arise". "Decision-makers may make an error either in their situation assessment or in their action selection. Errors in situation assessment might arise through misinterpreting or ignoring cues. The root cause of errors in choosing a course of action can vary according to the type of decision strategy.

"Errors involving rule-based decisions might depend on failing to retrieve a response from memory (if indeed the correct action was actually known). Errors involving decisions where a choice is required among alternatives may be a product of failing to retrieve an appropriate response from memory, or alternatively, factors for determining the adequacy of the outcomes of the options derived may be unavailable.

"Creative decisions can be prone to error as a result of the absence of any support, requiring the decision-maker to develop a novel solution. It has been suggested the root of these errors could ultimately be either a lack of experience on the part of the decision-maker, a lack of information, or inadequate mental simulation (p. 81)."

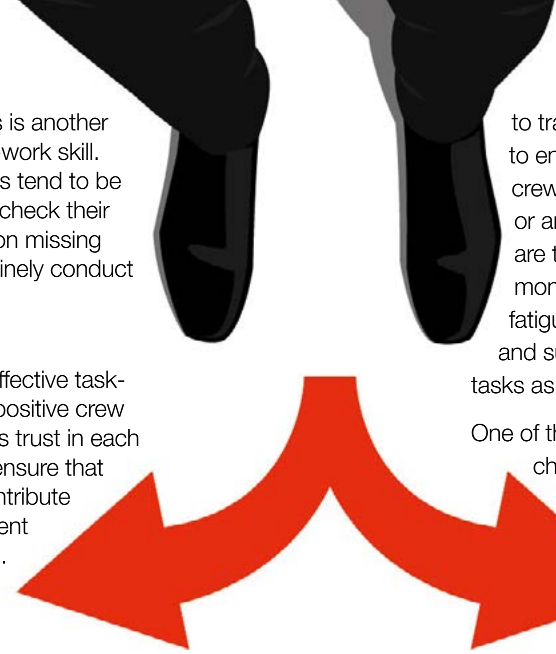
Effective decision-making in teams

A team should expand the cognitive resources at hand and can overcome some of the potential limitations of the single decision-maker. Several behaviours are associated with effective crew decision-making and these are often divided into 'task-work' and teamwork skills (Kanki, Helmreich, & Anca, 2010).

Task-work skills

Effective crews are vigilant and develop and maintain situation awareness [see Chapter 6]. They constantly monitor the environment for change and potential threat and monitor progress according to the task/flight plan. Proficient crews foster a shared mental model of their situation through regular communication and an understanding of each other's strengths, tendencies, preferences, and thinking styles.

Effective crews are also adaptive; typically by revising task priorities when required and reassigning tasks to manage workload. Evaluating the likely consequences of potential decisions is another important team task-work skill. Finally, effective crews tend to be analytical: they crosscheck their assumptions, question missing information, and routinely conduct risk assessments.



Teamwork skills

Teamwork enables effective task-work. Maintaining a positive crew climate where there is trust in each other is essential to ensure that all crewmembers contribute to situation assessment and decision-making. Communication, trust and openness help to recognise and correct errors before they become mishaps. Aviation has long acknowledged the importance of monitoring challenging behaviour among crews, although there is need to train for effective challenges to ensure they do not disrupt the crew climate if they are too strong or are ignored because they are too weak. Effective teams monitor each other for stress, fatigue and cognitive overload and support each other or reassign tasks as required.

One of the most consistent characteristics of highly effective teams is that team members know each other well, fostered by regularly training and operating together and socialising with each other to round out their mutual understanding of qualities and traits such as personality, thinking style, and motivation.

CASE STUDY US Airways flight 1549 — Part 5

Crew Resource Management (CRM) and Threat and Error Management (TEM) during the accident sequence. Both pilots indicated that CRM was integral to the success of the accident flight. The first officer stated that they each had specific roles, knew what each other was doing, and interacted when necessary. The captain indicated that, because of the time constraints, they could not discuss every part of the decision process; therefore, they had to listen to and observe each other. The captain further stated that they did not have time to consult all of the written guidance or complete the appropriate checklist, so he and the first officer had to work almost intuitively in a very close-knit fashion. For example, the captain stated that when he called for the QRH, about 17 seconds after the bird strike, the first officer already had the checklist out.

The captain stated that the US Airways CRM and TEM training, which was integrated into all aspects of US Airways training, including ground school and flight training, gave pilots the skills and tools needed to build a team quickly, open lines of communication, share common goals, and work together.

CVR data indicate that the communication and co-ordination between the captain and first officer were excellent and professional after the bird strike. Further, the flight crew managed the workload by making only pertinent callouts to ATC and the cabin crew as time permitted. In addition, CVR data showed that each pilot adhered to his role and responsibilities during the accident sequence.

The first officer progressed through the checklist while the captain was flying the airplane, communicating with ATC, and determining a suitable landing point. In addition, the captain used the first officer as a resource by requesting his input during the accident sequence. The NTSB concludes that the professionalism of the flight crewmembers and their excellent CRM during the accident sequence contributed to their ability to maintain control of the airplane, configure it to the extent possible under the circumstances, and fly an approach that increased the survivability of the impact.

Source: NTSB accident report, p. 91

Recognition-primed decisions

SHOR (Whol, 1981)	**FOR-DEC** (Hormann, 1995)	**DESIDE** (Murray, 1997)
• Stimuli (gather, filter, aggregate, store and/or recall data) • Hypotheses (create, evaluate and select response options) • Options (create, evaluate and select response alternatives) • Response (plan, organise and execute a response)	• Facts (what is actually going on?) • Options (what are the choices we have?) • Risk and benefits (what are the pros and cons of each option?) • Decision (what will we do?) • Execution (who will do what, when and how?) • Check (how are we progressing?)	• Detect change (are there serious risks if no action is taken?) • Estimate the significance (are there serious risks if the most feasible and safest action is pursued?) • Set safe objectives — beware hazardous attitudes (is there a realistic possibility of finding a better solution?) • Identify options (is there sufficient time to make a careful search for further information/advice gathering and evaluation?) • Do the best option • Evaluate the outcome and continue to apply DESIDE

Table 5–5. An outline of three popular decision-making training models/mnemonics

Improving decision-making in aviation

Effective decision-making is often considered to be a trait that individuals possess innately or as an ability required as a by-product of occupational experience without the need for targeted training and development. This may explain why there has been relatively little research aimed at improving decision-making. What attempts there have been to train or improve decision-making have yielded limited results.

Training models for decision-making

This dearth of results may be partly because most strategies to improve decision-making have developed mnemonics or acronyms that are supposed to be used by aviation personnel to guide and structure their decision-making. The aim of these techniques is to develop a systematic approach to decision-making that should be less affected by human tendencies such as cognitive bias and impulsive responses under stress, as well as to reduce cognitive workload. Three popular decision-making mnemonics are outlined in Table 5–5.

A significant limitation of this approach is that without the development of related skills —recall Table 5–2— mnemonics represent little more than memory-joggers. When a person is confronted by time pressure or other stressful situations, trying to recall and apply a mnemonic is likely to increase cognitive complexity — not reduce it — and therefore add further stress to the situation.

Nevertheless, there have been some modest findings in support of mnemonic-based methods and training. SHOR has been judged as best utilised in time-limited, critical situations; whereas DESIDE is superior for knowledge-based decisions requiring more comprehensive consideration (when sufficient time is available).

Simulation-based training

Rather than using and attempting to apply generic decision-making mnemonics, it has been suggested by human-factors practitioners that training should routinely include task performance under conditions of time pressure or stress in order to foster effective real-world decision-making. Simulator technology has enabled this suggestion to be implemented by many aviation operators.

Simulators can safely provide aviation training scenarios of varying complexity and likelihood of occurrence in the real world. Specific events requiring decisions under different conditions can be inserted into training and testing scenarios. These scenarios can be designed to foster the recognition of contextual patterns, which is the basis of recognition primed decision-making.

The ability to repeat scenarios and to provide immediate feedback aids in the positive transfer of training to real-world operations. There is evidence that simulator-based judgement training has produced significantly better decision-making in pilots (Buch & Diehl, 1984).

Training in non-technical skills associated with decision-making

Orasanu (2010) emphasised that training for decision-making in dynamic operating environments should include the following components:

- the development of situation assessment skills (pattern recognition, recognition of threat to use, risk assessment)
- evaluating a course of action (rather than multiple courses of action as in the military appreciation process (MAP)) that is premised on the goal of a workable rather than an optimal solution
- understanding that rule-based or recognition-primed decisions should only be generated when the situation is accurately assessed/recognised
- practice in using mental simulation in order to better evaluate likely outcomes of the chosen course of action
- an emphasis on evaluating one option at a time in most circumstances rather than generating and assessing multiple options, particularly when there is time pressure
- modifying the chosen course of action as required based on continuing situation assessment
- improving metacognition (thinking about thinking) to promote accurate recognition of relevant factors (such as time constraints, level of risk and the stakes involved, problem familiarity, validity and completeness of information), increased sensitivity to domain-specific cues, automatic self-assessment, critiquing and correcting of oneself and the team, and willingness to deal with complexity rather than seeking simple perspectives and answers
- processes for building shared mental models (effective, explicit and economical communication, contingency planning, explicit goals, comprehensive pre-briefings)
- fostering positive team relationships/crew climate (promoting trust, respect, acceptance of diversity, acceptance of responsibility, keeping commitments, open discussion of problems and errors, crediting team members for their contributions)
- monitoring skills (specified areas of vulnerability, prioritising, monitoring the environment, task status, crew member status, delegation)
- challenging skills (advocacy, assertiveness, obligation statements, preference statements, goal statements, and hints).

Conclusion

"One way of looking at this might be that for 42 years, I've been making small, regular deposits in this bank of experience, education and training. And on January 15, the balance was sufficient so that I could make a very large withdrawal." CHESLEY B. 'SULLY' SULLENBERGER III

The US Airways flight 1549 case study, peppered across this chapter, illustrates effective decision-making and crew resource management in a highly challenging situation. This is in contrast to much of human-factors training that uses catastrophic case studies to demonstrate the lack or failure of a particular non-technical skill or system defence.

US Airways flight 1549 makes one wonder how often aircrew, maintainers, air traffic controllers and other aviation personnel make valuable decisions that avert mishaps and accidents; decisions that are undocumented and essentially invisible.

Flight 1549 highlighted a number of key points from this chapter, as well as from the broader non-technical skills perspective. The multiple bird strikes immediately immersed the flight crew into an emergency situation where stress was extremely high, as were the risks and the sense of responsibility for the lives of those on board (as well as, potentially, people and infrastructure on the ground if the aircraft failed to find a clear place to land in what was a high density metropolitan landscape).

Captain Chesley Sullenberger and his co-pilot, First Officer Jeffrey Skiles, appear to have stayed within 'the zone' of optimum performance, controlling their stress, and maintaining their cognitive capacities and situation awareness to enable timely and effective decisions. They reached the decision to ditch in 35 seconds. The quote above is strongly reminiscent of the concept of recognition-primed decisions, so central to this chapter, and clearly at play during those critical moments of Flight 1549 following the birdstrikes.

While dual-engine failure is not an unexpected scenario for experienced aircrew, the subsequent investigation found that dual-engine failure training for A320 operators was conducted at high altitudes in accordance with Airbus recommendations and industry practice. In addition, this training was generally only completed during initial training, not recurrent training. No operators included training for a dual-engine failure at low altitude and there was a suggestion that the checklist for low-altitude, dual-engine failures was probably difficult to find. In addition, there was no data to determine height-loss, controllability and systems operation during a turn-back manoeuvre at such an altitude.

As a result, the situation that Sullenberger and Skiles faced also required a degree of creative problem solving, another type of decision that falls under the naturalistic decision-making paradigm. In what was largely an unfamiliar situation, some decision-making effort moved to a higher conceptual level in which performance was goal (minimise harm to passengers and bystanders) controlled and knowledge-based.

Sullenberger made the decision to ditch having commenced the relevant checklist. He and Skiles considered at least two feasible options — turn back to LaGuardia; ditching on the Hudson — which represents choice-based decision-making, another feature of Flin, O'Connor and Chrichton's model (Figure 5–1). Sullenberger stated that a turn back to LGA would have been an "irrevocable choice" and that option would have generated the need to consider the possibility of numerous outcomes including gear collapse (NTSB, 2010, pp. 54–55), considerations that would have taken up time in a tightly time-constrained situation.

Sullenberger did not complete the checklist being used, because once a go/no-go decision was made to ditch, he needed to focus his attention on flying the aircraft to a water landing. Thus he did not succumb to fixation in completing a checklist that was no longer required (what would be a 'plan continuation error') but moved 'off the decision ladder' once he committed to a path.

Simultaneously, Sullenberger and Skiles co-ordinated their efforts and distributed tasks, while being conscious of the time available with which to affect a landing. These resource-management decisions occurred largely instinctively, borne of experience.

The US Airways flight 1549 case study appears to demonstrate that the different postulated error types are not mutually exclusive. They can occur in parallel or in very close proximity. Decision-making, like other non-technical skills, can be very complex indeed.

A caveat

The NDM paradigm has advanced our understanding of decision-making in real-world contexts; however, it is not perfect. This is partly because of the difficulty in assessing the quality or correctness of decisions made in occupational settings. We tend to assess the correctness of a decision based on the outcome. What this tendency fails to appreciate is that good decisions can lead to bad outcomes and vice versa. Evaluating a decision should depend upon the stakes and the process, not on the outcome. The case study snippets regarding US Airways flight 1549 presented throughout this chapter nicely illustrate how the investigators in this case did focus on the processes involved in this incident — including situation assessments and risk management actions — rather than the outcome. You are urged to remember that in almost all safety incidents and accidents, adverse outcomes are not caused by the poor decisions of an individual or a team but by the collective failures of multiple components of the broader system.

This issue became a central dilemma into Snook's (2000) detailed examination of the friendly fire shoot-down of two U.S. Army Blackhawks by U.S. Air Force F-15 fighters over the no-fly zone in Northern Iraq in April 1994. In the concluding section of his book, he wrote:

"I could have framed the individual-level analysis as a problem of decision-making. I could have asked, 'Why did they decide to shoot?' However, such a framing puts us squarely on a path that leads straight back to the individual decision-maker, away from potentially powerful contextual features and right back into the jaws of the fundamental attribution error. 'Why did they decide to shoot?' quickly becomes 'Why did they make the wrong decision?' Hence, the attribution falls squarely onto the shoulders of the decision-maker and away from the potent situational factors that influence action.

Framing the individual-level puzzle is a question of meaning rather than deciding shifts the emphasis away from individual decision-makers toward a point somewhere 'out there' where context and individual action overlap. Individual responsibility is not ignored. However, by viewing the fateful actions of Tigers 01 and 02 as the behaviours of actors struggling to make sense, rather than as rational attempts to decide, we level the analytical playing field toward a more complete and balanced accounting of all relevant factors, not just individual judgement (pp. 206–7)."

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Key points

- The most useful theoretical approach to decision-making in real-world settings is known as naturalistic decision-making (NDM). This approach examines how operators use experience to make decisions under conditions characterised by time pressures, shifting conditions, unclear goals, degraded information quality, risk-laden consequences and perhaps conflicted team interactions.
- Most fundamentally, decision-making in the real world is often a two-stage cognitive process: situation assessment (working out what the problem is) and deciding what to do in response to the problem.
- Professionals in high-risk domains normally make decisions based on their experience, known rules or SOPs, and, if the situation is unfamiliar, through creative processes.
- Decision-making is shaped by the level of expertise or experience of the decision-maker, the level of risk, the degree of time pressure and stress, whether there are known rules and procedures, and the degree of familiarity with the situation.
- Decision-making is a continuous process, just as situation assessment, situation awareness and risk management require continuous attention and evaluation.
- A range of factors affect decision-making, particularly the plethora of cognitive biases that humans are prone to.
- Decision training with simulators using prepared decision scenarios has proven to be particularly beneficial in developing decision competence.

"You should never take your aircraft somewhere where your head hasn't already been." PILOT AXIOM

CHAPTER 6 Situation awareness

Overview:

- Situation awareness
- Situation awareness within aviation
- Endsley model of situation awareness
- Loss of situation awareness
- Lapses in situation awareness
- Factors that can affect situation awareness
- Techniques for confirming/maintaining/regaining situation awareness in the operational environment

Introduction

"War is the province of uncertainty: three-fourths of those things upon which action in War must be calculated, are hidden more or less in the clouds of great uncertainty.

Here, then, above all a fine and penetrating mind is called for, to search out truth by the act of its judgement."

KARL VON CLAUSEWITZ, *ON WAR*, 1832

It is believed that situation awareness was originally used by the military during the First World War and became mainstream during World War II, when its presence was seen as a significant asset in combat operations and its absence a serious risk. However, the construct is actually centuries old, albeit cloaked under different terminologies.

Many renowned military strategists and practitioners, such as von Clausewitz and Napoleon, referred to the vital importance of what we now call situation awareness.

The interest in situation awareness continues today. Most of this interest has been spurred by aviation, both military and commercial, where it has long been recognised that even momentary loss of situation awareness can lead to mishaps and disaster.

Most recently, interest in situation awareness has been driven by developments in technology that, paradoxically, often distance humans from the systems they are operating. The goal of improving situation awareness has become one of the major drivers in the development of aviation systems and aircraft design.

Not surprisingly, the aviation-accident record has also highlighted the importance of situation awareness. For example, two studies from the 1990s respectively concluded that:

- problems with situation awareness was the leading causal factor in a review 175 military aviation mishaps (Hartel, Smith, & Prince, 1991)
- limitations in situation awareness was a causal factor in 88 per cent of major commercial carrier accidents associated with human error over a four-year review period (Endsley, 1995a).

Investigations into incidents of both controlled flight into terrain (CFIT) and military aviation-related fratricide invariably identify a loss of situation awareness as a primary causal factor. Less tragic, but no less telling is the startling number of aircraft that land on the wrong runway or even the wrong airfield. Other aviation industry personnel, particularly air traffic controllers and maintainers, are no less prone to losing situation awareness in their duties.

The premise of this chapter is that if the basic requirements for the development and maintenance of situation awareness are understood, they can be measured, monitored and trained, with a consequent reduction in the range of incidents and accidents caused by problems with situation awareness.

This chapter presents definitions and a generic model of situation awareness, before discussing crew situation awareness, examples of situation awareness-related errors, threats to situation awareness, and strategies for maintaining and regaining it.

Terminology: situation versus situational awareness

There is some confusion about the exact terminology to be used when referring to the construct of focus in this chapter. Both situation and situational are used interchangeably within the literature. However, situation awareness means literally "awareness of the situation" whereas situational awareness means "a type of awareness relating to situations". The former meaning is simpler and clearer — situation awareness is therefore the advocated term.

Situation awareness — a systems perspective overview

C Cultural influences and experience shape our expectations about, and mental models of, the perceived situation, the expected situation and the inferred situation.

S Software components such as rules, instructions, regulations, policies, norms, SOPs, customs, habits and supervisor directions can shape our construction of a mental model of the situation.

H Situation awareness is a product of the quality of the hardware components of the aviation system, including design of displays, controls and tools, and even seating arrangements.

E Physical factors such as noise, ambient light levels and the design of facilities, and external environmental conditions such as weather, terrain and congested airspace, can adversely affect the ability to gather and interpret information and to anticipate future states.

L Attentional deficits and limitations in the working memory of the human operator are frequently associated with the loss of situation awareness.

L Interpersonal communication can contribute to misleading, ambiguous, inappropriate or poorly constructed understanding of the situation at hand.

Error is a second-order outcome of a lack of situation awareness.

Defining situation awareness

A selection of definitions of situation awareness, both formal and informal, are presented below to foster an appreciation of the different perspectives and hypothesised components of this cognitive skill. Situation awareness has been posited as:

- knowing what is going on around you
- knowledge about elements of the environment
- the cognitive processes for building and maintaining awareness of a workplace situation or event
- the up-to-the minute comprehension of task-relevant information that enables appropriate decision-making under stress
- a dynamic, multifaceted construct that involves the maintenance and anticipation of critical task performance events
- the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the future.

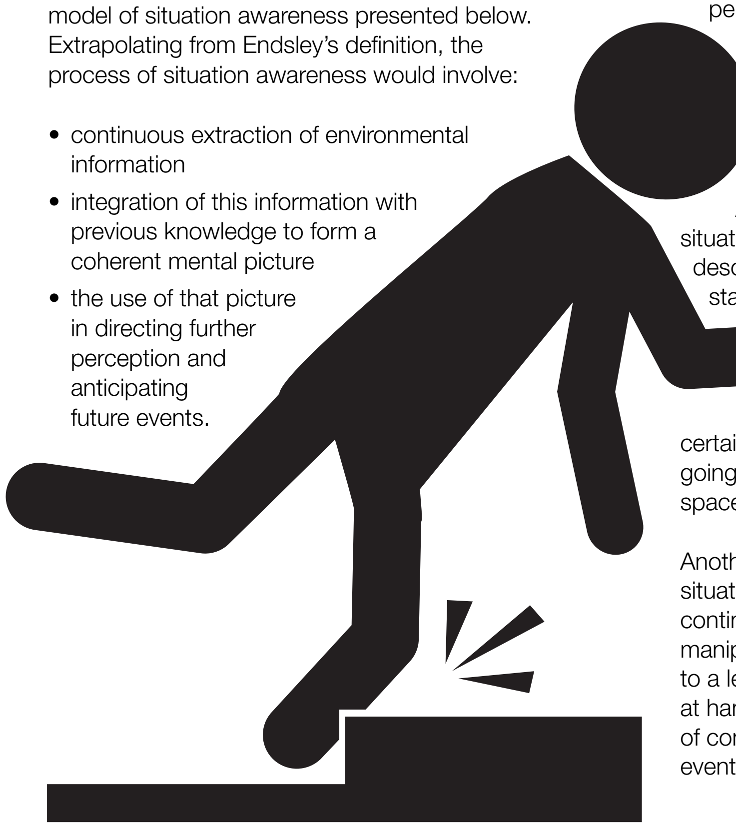
The final definition is by Endsley (1995b) and is perhaps the most influential in the literature on situation awareness. This definition underpins the model of situation awareness presented below. Extrapolating from Endsley's definition, the process of situation awareness would involve:

- continuous extraction of environmental information
- integration of this information with previous knowledge to form a coherent mental picture
- the use of that picture in directing further perception and anticipating future events.

Aviation personnel who are successfully doing these things are likely to achieve and maintain a high state of situation awareness. The activities underpinning the development and maintenance of situation awareness will include:

- constructing a structured, information-dense, mental representation of the task/workplace
- processing information continuously
- constantly interrogating the environmental data stream to detect missing, conflicting, updated, and novel information
- updating mental representations/models of the of the task/workplace/operational space
- generating and challenging expectations
- self-monitoring their performance and that of their crew/team
- self-directing their actions and decision-making.

Situation awareness can therefore be described as a cognitive skill that requires you to correctly perceive and make sense of your current state, use your existing knowledge to develop a mental picture, and then anticipate and look for future events and their potential impact on your task. Within a complex environment there are many dynamic elements that may affect your ability to perform tasks safely and effectively, which means that maintaining situation awareness is a constant process.



A point of confusion

A potentially confusing aspect of situation awareness is that it has been described as both a process and a state. Situation awareness is most often defined as an outcome or a state of knowledge where an individual or a team has a certain level of understanding of what is going on in the workplace or operational space.

Another, more complex, way of defining situation awareness is as a process — a continuous mix of perception, mental manipulation and insight — that leads to a level of understanding of the task at hand or the workplace and a degree of confidence about predicting future events.

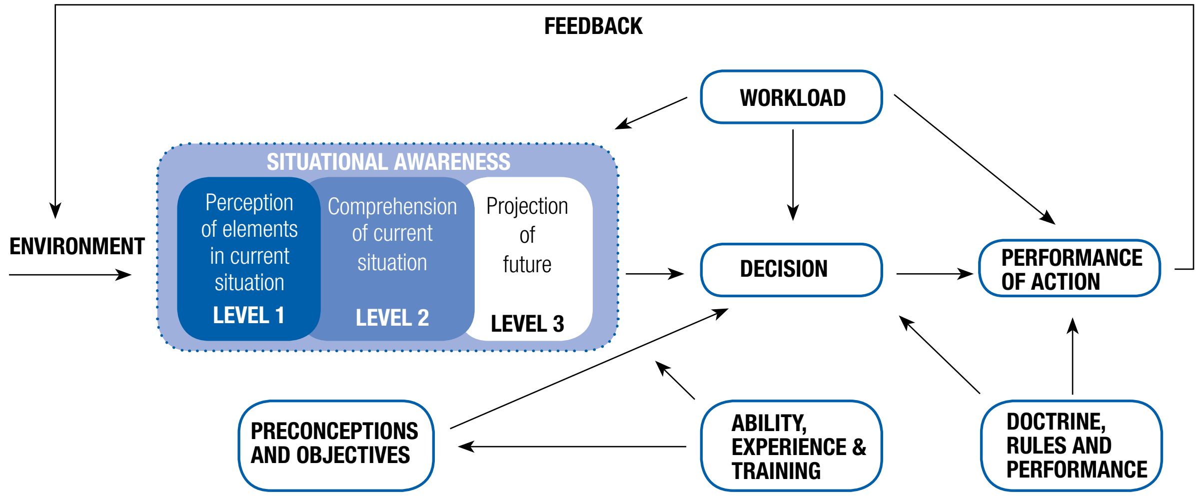


Figure 6–1. Endsley's model of situation awareness, from CASA's (2012) *Human Resource Guide for Pilots* (p. 127)

Some researchers prefer to distinguish the state and process aspects of situation awareness by giving them different labels: situation awareness for the state of knowledge achieved and situation assessment for the process by which that knowledge is achieved. Another confusing aspect of situation awareness is that it can mean different things in different environments, a fact that has led researchers to adopt varying definitions according to the context.

We will not further concern ourselves with the process/state distinction in this chapter. A generic definition will be used and the reader will need to keep in mind that at times we will be talking about situation awareness as a process and at other times as a state. The question of context; however, is extremely important because people in different roles will need to be aware of different features of the environment. We will touch upon this issue topic later in this chapter.

Endsley's model of situation awareness

There are various models of situation awareness but the most popular is the one proposed by Endsley (1995b). She identified three levels of situation awareness, each with its corresponding state.

Level 1: Perception

The first stage of situation awareness is perception. If we do not perceive important cues, then the subsequent two levels cannot follow and our mental picture is compromised. Pilots, for example, need to perceive important information outside the aircraft such as other aircraft, terrain, weather conditions, or inside the aircraft such as hearing radio calls or flight instrument alerts. An air traffic controller needs to be aware of the positions and movements of all aircraft within the controlled airspace. Maintainers need to be aware of the presence of other personnel when performing dangerous duties, such as engine tests. The fundamental premise at this level is that if you do not have the basic building blocks of awareness then you cannot become situationally aware.

Level 2: Comprehension

Once information has been perceived it needs to be fully and accurately comprehended to establish situation awareness. Comprehension encompasses our ability to relate separate pieces of perceived information to piece together an understanding of the situation, and relate that information to our existing knowledge. An individual must then use this integrated information to determine their relevance to their tasks and objectives. To use an analogy from your current situation, Level 1 situation awareness would allow you to be aware that you are seeing words on a page (if you are reading) or hearing the words of an instructor (if you are listening), Level 2 would allow you to extract meaning from the words and relate them to existing knowledge. To some extent, your level of situation awareness would be due to how much attention you are paying to the text or to the instructor but experience can also play a part. You have to know what you are looking for and why you are looking for it. In an aviation context, a novice may be capable of achieving the same Level 1 situation awareness as more experienced personnel but may fall short of being able to integrate various data elements to gain a complete understanding of the situation.

Level 2 situation awareness requires pieces of information to be combined so that they provide a bigger picture of the situation. The individual needs to form a holistic picture of the situation and understand the significance of its elements. Data points begin to become information.

Level 3: Projection

The highest level of situation awareness involves the ability to forecast future situations on the basis of the perception and understanding of current events. This ability to anticipate future situations allows for timely decision-making and depends on expertise more than attentional mechanisms. It is the domain of skilled experts. For example, upon seeing two aircraft with intersecting flight paths, an air traffic controller must forecast whether they will be within the same airspace at the same time. The controller will need to call upon his or her knowledge of the different aircraft and wind speeds to decide whether there is a need to redirect one of the aircraft. At this level, information has become knowledge.

Endsley's Model is illustrated in Figure 6–1, which describes the factors that influence situation awareness in complex and dynamic settings such as flying operations. The model illustrates that situation awareness is never really achieved; rather it is a continuous or cyclical process.

In terms of the information-processing model we discussed in Chapter 2, situation awareness spreads itself across the early stages of the model (Figure 2–2). It is what we call a metacognitive construct. (Metacognition is higher-order thinking that enables understanding, analysis, and control of one's cognitive processes, especially when engaged in learning; or more simply put: it is thinking about thinking.)

The Endsley model shows situation awareness as a precursor to decision-making and effective performance. The three levels of situation awareness result in a mental model of the state of the environment. Based on that cognitive representation, individuals can decide what to do about the situation and carry out any necessary actions. The accuracy and completeness of that representation is the main determinant of whether consequent decisions are appropriate and effective — or not.

Interrelationships among the three levels of situation awareness

It may be evident that, irrespective of available hardware and software supporting systems, situation awareness requires considerable mental capabilities. It is probable that as the level of situation awareness rises, more abstract and complex thinking is needed. Hence it is conceivable that an individual could achieve a high state of Level 1 situation awareness yet be unable to achieve satisfactory Level 2 or 3 awareness; or achieve high Level 1 and 2 situation awareness, yet be unable to make useful predictions of future state (Level 3). The inability to develop or maintain effective situation awareness may be due to a number of factors such as lack of sufficient or relevant cognitive aptitudes (such as visualisation, working memory and general intelligence) and transient difficulties such as stress and fatigue.

The importance of context

We know that situation awareness plays a major role in all aviation-related tasks but it will mean different things for different work roles. For example, for a fighter pilot, having good situation awareness may mean being aware of the state of the aircraft and other friendly aircraft in the area, as well as understanding the threats posed by enemy forces and how they may impact the mission.

For an ATC, it may involve knowing what aircraft are in the airspace, where they are, and the implications of their movements. For a maintainer, it means understanding the task at hand and being able to recognise and adjust to changes that could affect the successful completion of the task. For example, during a safety-critical task a maintainer must be able to recognise and effectively manage distractions.

Endsley (2010) defined a number of contextual factors or what she called classes of elements of situation awareness.

Geographic situation awareness. This would include the location of one's aircraft, other aircraft, terrain features, airports, cities, waypoints, and navigation fixes; one's position relative to designated features; runway and taxiway assignments; and climb/descent points.

Spatial/temporal situation awareness. For aircrew this would include attitude, altitude, heading, velocity, vertical velocity, G's, flight path; deviation from flight plan and clearances; aircraft capabilities; projected flight path; and projected landing time.

System situation awareness. This includes system status, functioning and settings; settings of radio, ultimate, and transponder equipment; ATC communications; deviations from correct settings; flight modes and automation entries and settings; impact of malfunctions/system degrades and settings on system performance and flight safety; fuel; and time and distance available on fuel.

Environmental situation awareness. Weather formations; temperature, icing, ceilings, clouds, fog, sun, visibility, turbulence, winds, microbursts; instrument flight rules (IFR) versus visual flight rules (VFR) conditions; areas and altitudes to avoid; flight safety; and projected weather conditions.

Tactical situation awareness. For military missions, this may include identification, tactical status, type, capabilities, location and flight dynamics of other aircraft; own capabilities in relation to other aircraft; aircraft detections, launch capabilities, and targeting; threat prioritisation, imminence, and assignments; current and projected threat intentions, tactics, firing, and manoeuvring; and mission timing and status.

Specific situation awareness requirements for a particular aircraft will be dependent on the goals of the aircrew in that particular role or for that particular mission.

Tactical situation awareness

Maintaining a high level of situation awareness has always been one of the most critical and challenging tasks for aviation personnel. In a general sense, situation awareness is a mental model of the current state of the task or operational area. This mental model forms the central organising feature from which ongoing decision-making takes place.

JUST WHEN I THOUGHT WE MIGHT MAKE IT THROUGH UNSCATHED

We were running silent now with all emitters either off or in standby … We picked up a small boat visually off the nose, and made an easy ten degree turn to avoid him without making any wing flashes …

Our RWR [radar warning receiver] and ECM [electronic countermeasures] equipment were cross checked as we prepared to cross the worst of the mobile defences. I could see a pair of A-10's strafing what appeared to be a column of tanks. I was really working my head back and forth trying to pick up any missiles or AAA [anti-aircraft artillery] activity and not hit the ground as it raced underneath the nose.

I could see Steve's head scanning outside with only quick glances inside at the RWR scope. Just when I thought we might make it through unscathed, I picked up a SAM [surface to air missile] launch at my left nine o'clock heading for my wingman … It passed harmlessly high and behind my wingman and I made a missile no-guide call on the radio …

Before my heart had a chance to slow down from the last engagement, I picked up another SAM launch at one o'clock headed right at me! It was fired at short range and I barely had time to squeeze off some chaff and light the burners when I had to pull on the pole and perform a last ditch manoeuvre… I tried to keep my composure as we headed down towards the ground. I squeezed off a couple more bundles of chaff when I realized I should be dropping flares as well! As I levelled off at about 100 feet, Jerry told me there was a second launch at five o'clock …

B. ISAACSON, *A LOST FRIEND*, 1985

Within military aviation, situation awareness is considered to be a key element of operational performance, especially in aerial combat. Captain Baron Manfred von Richthofen's success in the First World War has been attributed to his uncanny ability to monitor numerous factors relating to air combat: including flight control, air tactics, navigation, and the location and likely intentions of both enemy and friendly aircraft. It has been reported that after combat the 'Red Baron' could give accurate recreations and critiques of fellow pilots, despite being engaged himself in dogfights a considerable distance away (Gilson, 1995).

The relative success of American fighter pilots in the Korean War has been partly credited to a simple fact: U.S. aircraft had wrap-around cockpit canopies which enabled pilots to visually monitor a much wider perspective than their opponent pilots. It has been suggested that 90 per cent of all pilots killed during WWII never saw their attacker, and similarly a lack of situation awareness was involved in 80 per cent of all kills in combat between WWII and Vietnam (Wills, 2016). It is not remarkable, therefore, that situation awareness is now a major design factor in the development of all types of aircraft, especially military.

A modern combat example of how challenging it can be to monitor, recognise and understand what is going on around us is given in the sidebar 'Just when I thought we might make it through unscathed'.

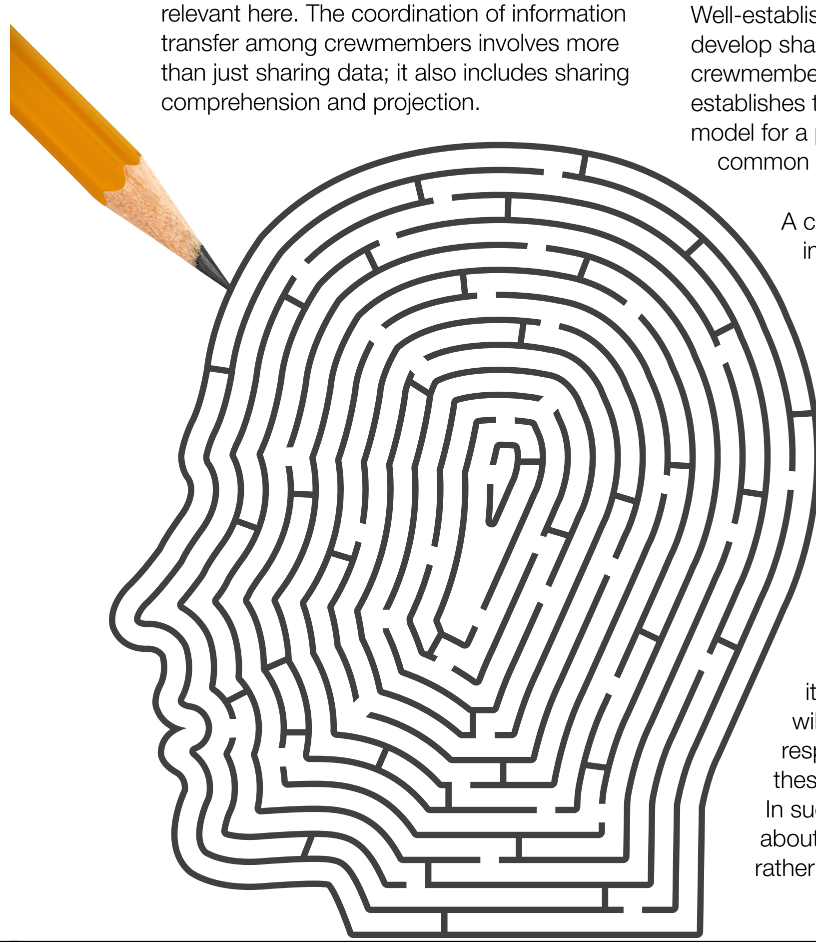
Poor situation awareness in tactical environments can lead to catastrophic error, such as the case of the United States Navy AEGIS cruiser U.S.S. Vincennes which shot down a civil airline Airbus 300 on 3 July 1988 with the loss of all her crew and passengers. Incorrect situation awareness was identified as a critical antecedent of this accident (Klein, 1996). Even the best trained commander will make incorrect decisions if he or she has inaccurate, incomplete or untimely awareness of the operational situation.

A major challenge for supervisors and commanders is developing and keeping individual and group situation awareness up-to-date in the constantly changing work/operational environment. As technology has evolved, many complex and dynamic systems have been created to assist aviation personnel. The goal of these systems is to support operational decision-making, but, as noted above, unless technology and technological systems are human-centred in their design, they can actually degrade the performance of the humans in the loop.

Shared or team situation awareness

While situation awareness is most often discussed at the level of individual, it is also relevant for aviation teams. In aviation, the development of situation awareness is rarely an individual process, and aviation personnel are generally mindful that they are part of a system. To be most effective, this system and its many subsystems must co-ordinate information flows and the sharing of knowledge.

Shared or team situation awareness has been defined as the degree to which every team member possesses the situation awareness required for his or her responsibilities. The three-level model of situation awareness is also relevant here. The coordination of information transfer among crewmembers involves more than just sharing data; it also includes sharing comprehension and projection.



The process of creating shared situation awareness can be enhanced by consistent mental models that provide a common frame of reference for all crewmembers and, to a certain extent, allows team members to predict each other's behaviours.

It is interesting that one study of team performance found that the best teams actually communicated less than poorer-performing teams (Mosier & Chidester, 1991). This result was partly explained by the better teams having common mental models.

Team situation awareness is improved by individual situation awareness being shared via four key process skills: planning, communication, leadership and adaptability (Prince & Salas, 1993). It appears that the quality of team situation awareness is strongly associated with other indicators of team effectiveness, such as trust, cohesion, strong interpersonal connections, and a positive group climate.

Well-established techniques also help to develop shared mental models among crewmembers. For example the crew briefing establishes the initial basis for a shared mental model for a particular work shift, providing common goals and expectations.

A common finding of research into group performance is that permanent teams which train or function together are much more effective than augmented teams unfamiliar with each other. Up to a point, experience has been shown to compensate for stress, fatigue and other performance-degrading effects.

Ideally, all crewmembers in the team will have a common mental model and a complete and shared understanding of the task or flight situation. However, it is likely that each crew member will be focused on their individual responsibilities and that elements of these responsibilities will not be shared. In such circumstances, we normally talk about overlapping situation awareness rather than shared situation awareness.

AVIATION SAFETY OCCURRENCE REPORT — A NEAR MISS

"During a low-level navigation syllabus sortie (2FTS Nav 7) from Geraldton to Pearce, the rear seat Qualified Flight Instructor (QFI) directed the front-seat student to carry out a practice diversion right of track around the town of Moora.

Passing abeam Moora to the left, the QFI pointed out the authorised landing area (Moora ALA) to the right and mentioned the possibility of aircraft in the area.

The student located the airfield to the right and when looking back to the front, the student saw a light aircraft slightly below and directly ahead.

The light aircraft was in a turn from left to right at a lateral range estimated to be 10 feet and 100 feet low. The student initiated a 6-Gbreak turn to the left to avoid the light aircraft and estimated missing the aircraft by 50 feet. The QFI did not see the light aircraft prior to the break turn."

For example, on a dual pilot flight deck, the 'pilot flying' is likely to be flying the aircraft, dealing with navigation and general aircraft operation; while the 'pilot not flying' is likely to be monitoring the flying pilot, monitoring aircraft performance, handling the radios, running the checklists, and monitoring the weather. Hence both pilots may be solely aware of many different elements of flight operations. It would be inefficient for flight crew to attempt to achieve complete shared situation awareness throughout the flight (Harris, 2011).

The major challenge to shared or overlapping situation awareness is the coordination of crew resources. This need to optimise the co-ordinated use of available human resources has long been a focus of crew resource management training. Recommendations for training to foster shared situation awareness within teams include:

- routinely specifying information requirements that need to be shared
- reviewing what communication devices and channels are available to enable sharing of information
- promoting an understanding and familiarity with situation awareness systems such as displays
- developing confidence in the available systems
- developing an ability to visualise the battlefield
- specifying what formal processes are to be used for sharing information, verifying understanding, prioritising tasks and establishing contingencies
- cross training staff to develop them into skilled operators capable of filling a number of work roles and capable of continued operation should parts of 'the system' crash
- practice, monitor and measure situation awareness until becomes it intuitive for the team.

Distributed situation awareness

A related concept, known as distributed situation awareness, has developed from the realisation that situation awareness can be held by various human operators within the aviation system as well as by technological components of the system. It is widely accepted that pilots of advanced aircraft have the role of an active supervisor coordinating a suite of human and automated resources in order to achieve the primary task of successful flight.

The concept of distributed situation awareness operates at the systems level, not at the level of the individual. A basic set of tenets underpinning the concept of distributed situation awareness has been proposed (adapted from Stanton et al., 2004).

- Situation awareness can be held by both human and non-human elements in the aviation sociotechnical system.
- There is likely to be multiple perspectives on situation awareness of the same scene, held by the different agents within the system.
- Non-overlapping and overlapping situation awareness depends on each agent's individual goals or roles — although part same system, each component can be focused on a different level or element of situation awareness.
- Communication between agents in the system may take many forms including non-verbal behaviour and ingrained practices (think software).
- One component in the system (be it human or machine) can compensate for degradation in situation awareness in another agent (although this likely would require Level 3 situation awareness to be achieved).

Situation awareness errors and their causes

A failure to maintain situation awareness is responsible for many of the accidents that are attributed to human error.

To help identify the reasons for these failures, Endsley (1995a) developed a taxonomy for classifying and describing errors in situation awareness. Her taxonomy is shown below.

Level 1 — Failure to correctly perceive situation

- data not available
- data difficult to discriminate or detect
- failure to monitor or observe data
- omission
- attentional narrowing/distraction
- high task load
- misperception of data
- memory loss or failure

Level 2 — Failure to correctly integrate or comprehend information

- lack of or poor mental model
- use of incorrect mental model
- over-reliance on default values in mental model
- other

Level 3 — Failure to project future actions or future state of the system

- lack of or poor mental model
- overprojection of current trends
- other

General

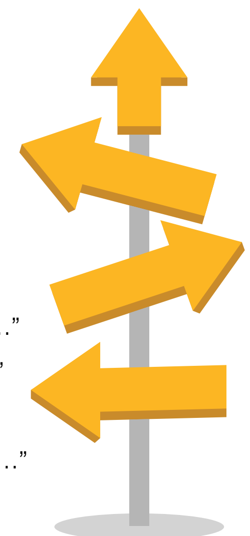
- failure to maintain multiple goals (memory limitations)
- habitual schema

Level 1 errors

We can see from Endsley's taxonomy that Level 1 errors are often due to lack of attention or poor quality information. To illustrate how failures can occur at this level, consider the case study 'Aviation Safety Report — a near miss'.

Telltale signs of lost situation awareness…

- "I didn't realise that …"
- "We were surprised when …"
- "I didn't notice that …"
- "We were so focused …"
- "I wasn't aware that …"
- "I was so busy that …"
- "We were so sure that …"
- "It certainly wasn't what I expected…"



Despite being an experienced pilot and instructor the QFI did not see the oncoming aircraft. How did this happen? One explanation is a process known as change blindness. Change blindness is the phenomenon where observers fail to notice a change in their visual field when presented with a momentary distraction. For a pilot, this distraction could be something as unavoidable as passing cloud cover, or dropping something in the cockpit and turning away from the windshield. Similarly, a maintainer may not notice someone entering a dangerous workspace after being distracted by a co-worker. Change blindness is therefore a major threat to situation awareness.

Level 2 errors

Level 2 errors in Endsley's taxonomy are due to the lack of mental models or the formation of poor mental models, fixation on incorrect values in these models, and memory failures. Developing a mental model is supported by experience and training but is heavily reliant on memory systems: short-term memory, which is limited in capacity and required to keep information within one's span of awareness; working memory, which is also limited in capacity and required for the manipulation of information; and long-term memory, which is unlimited and important for pattern recognition.

As discussed in Chapter 2; however, human memory is fallible and the wrong mental models will sometimes be constructed. If, for example, an operator matches the cues with an incorrect pattern, then the mental model will be wrong. This is true for both experienced and inexperienced people. Developing the wrong model can lead to a cognitive bias known as confirmation bias. Flin et al. (2008) describes confirmation bias as 'bending the facts' to fit — that is, incoming information is interpreted in a way that meets the model, and conflicting or ambiguous information is ignored.

Another way of looking at the process of forming mental models is through the lens of what is referred to as "sense making". [See 'Bending the map: An overview of the data/frame theory of sensemaking' at the end of the chapter.]

Level 3 errors

Mental models should include provision for future states. To take an example from the maintenance area, aircraft components must be serviced on a regular basis. These schedules are sometimes changed, usually by extending the interval between services. Sometimes the consequences are disastrous, as in the case of Alaska Airlines 261 which crashed because a service interval for a component that was originally set at 300 hours had been gradually increased to 2500 hours. In this case, there was a failure to project the consequences of maintaining the current state of the aircraft over a much longer period than specified by the manufacturer.

General

In addition, two general categories of causal factors are included in Endsley's taxonomy. Some people are poor at maintaining multiple goals in memory, which could impact situation awareness across all three levels. There is also evidence that people can fall into the trap of executing habitual schema; that is, doing tasks automatically. This automaticity renders such people less receptive to important environmental cues and changes.

The human factors of situation awareness

Cognition

It is clear that situation awareness is underpinned by cognitive or mental skills. To develop and maintain situation awareness, individuals must perceive and process a great amount of dynamic information. They must evaluate such information for relevance, importance, credibility and timeliness so that their mental picture of the situation is accurate. Cognitive skills critical to situation awareness include: logical reasoning, directed imagery (which allows visualisations of elements of the operational space), manipulation of symbols (as involved in mental arithmetic), understanding of language, the verbal expression of thought, and the integration of new information with existing mental models. A current catchword finding favour in the literature which is used to describe the set of mental processes and the associated cognitive task load which together lead to the attainment of situation awareness is "headwork".

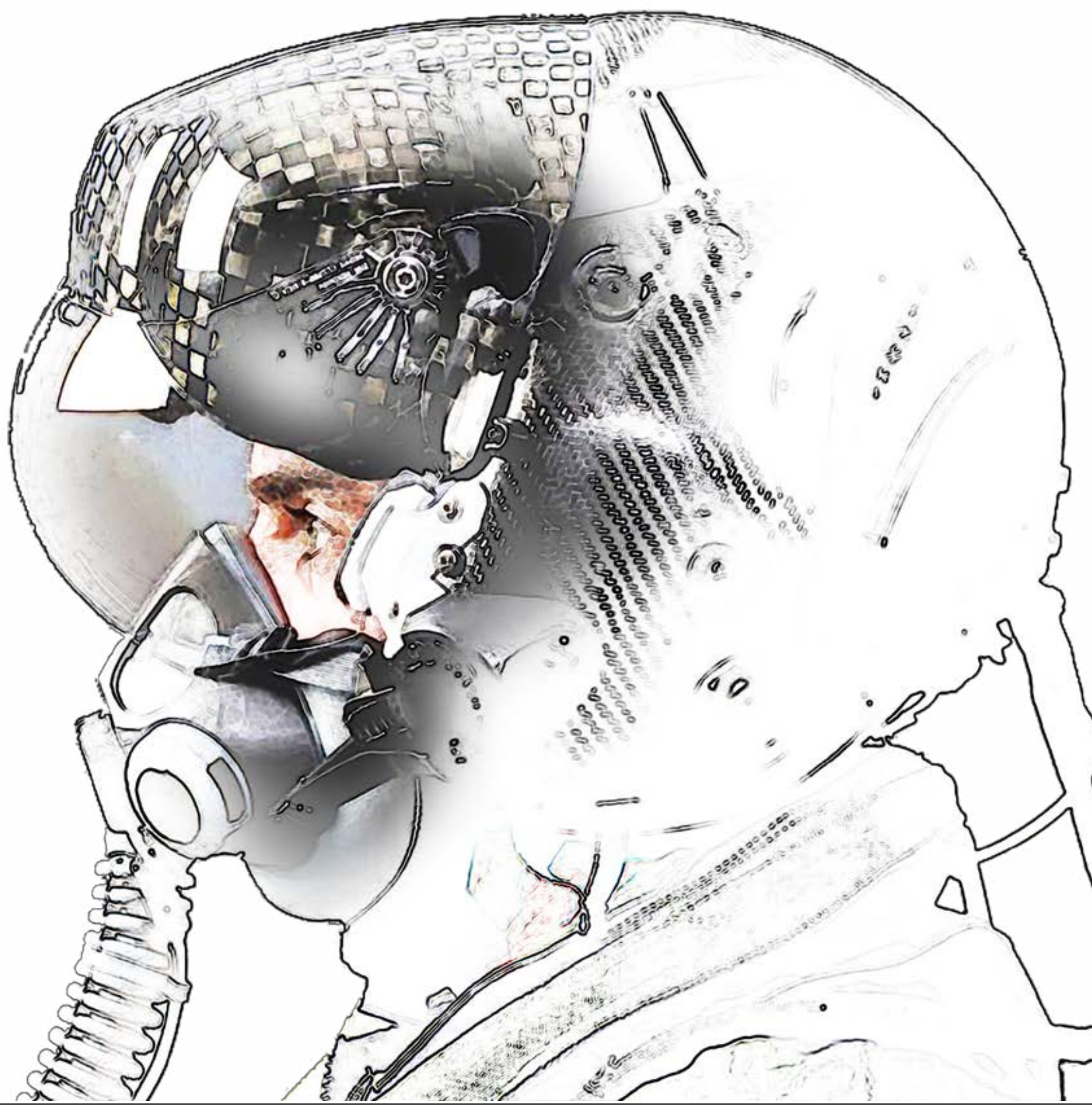
Memory

Memory is perhaps the most fundamental component of the cognitive processes vital to situation awareness. As examined in Chapter 2, the cognitive system receives information from the perceptual system, puts this into working memory, and incorporates long-term memory resources to decide on actions. Aviation operations are characterised by constant change which presents a continuous sequence of dynamic information that can overwhelm memory capacity.

You may recall that short-term memory capacity limits mental performance. A general rule of thumb is that working memory can contain about seven (plus or minus two) discrete information packets at once. Only when one of these packets is discarded or incorporated into long-term memory schemas, can new information be meaningfully absorbed.

Another important feature of memory is the 30-second decay rule. This refers to the fact that if the contents of working memory are not transferred to long-term memory; they will begin to be lost from working memory within about 30 seconds. Thus if a maintainer is distracted for more than 30 seconds after working from a checklist, he or she will be unlikely to be able to recall the step they were up to.

There is evidence that memory capacity can be improved by doing meaningful or familiar tasks. However, under conditions of stress and fatigue, working memory capacity can be significantly reduced. Memory retrieval can also be significantly impaired by stressful conditions.



Attention

Attention can act as a major constraint on the development and maintenance of situation awareness. Focused attention is required for both accurate perception and the processing of working memory. Yet in complex, dynamic environments, attentional demands can rapidly exceed human capacity in this ability. This is why attentional failures are common in dynamic environments.

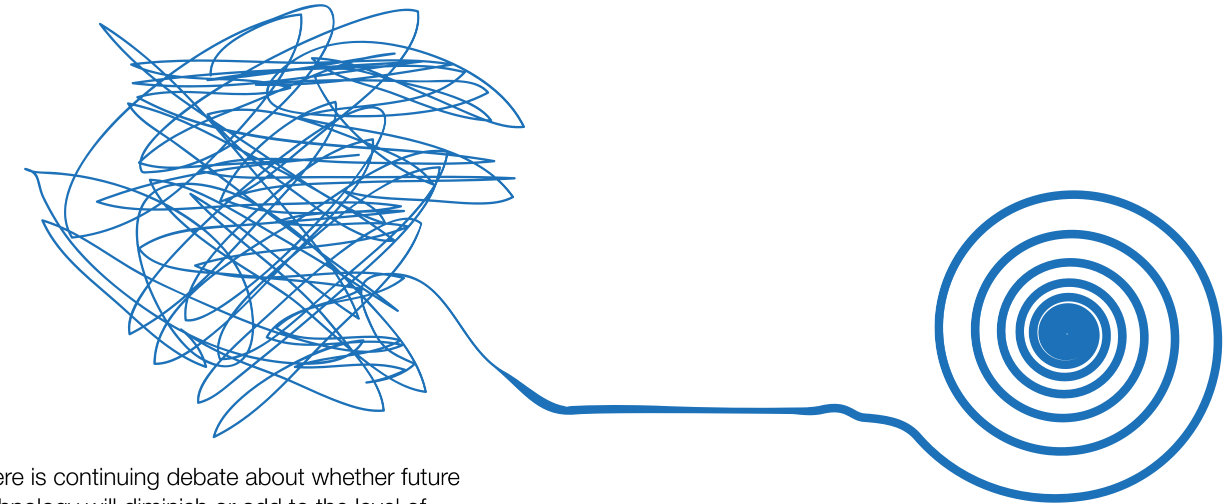
In order to cope with information overload, multiple tasking and complex decision-making, people generally adopt an environmental sampling procedure whereby they attempt to attend to a proportion of available inputs. However, such sampling procedures are rarely taught or formalised so that people adopt sampling strategies based on their own preferences or cognitive style. These can be little more than intuitive judgement, influenced by innate biases, faulty perceptions and inexperience.

There is potential for attention to be compromised by some human tendencies in perception. For example, most people have a bias towards information that is presented visually. This preference is called visual dominance. The implications of visual dominance are readily apparent. For instance, an air traffic controller may place more emphasis on information presented on a system display than communication from aircrew despite the timeliness and contextual relevance of direct communication.

There is a degree of variability among individuals in the capacity to divide their attention across multiple tasks — some people are inherently more capable of effectively and efficiently scanning the environment for appropriate information and cues. Attention is also vulnerable to the impact of stress.

Stress

The military aviation environment is one of the most risk-laden and hostile situations in which humans perform. The stressors inherent in aviation operations, particularly during combat and emergency response, can cause reactions that result in debilitating effects on performance in both individuals and teams.



There is continuing debate about whether future technology will diminish or add to the level of stress in aviation operations. Certainly, the future battlespace is likely to become more stressful as technology increases the demands on mental workload and weapons become more destructive.

The impact of stress on performance is well established and is examined in detail in Chapter 8. With respect to situation awareness, high levels of stress or high mental workload are likely to interfere with cognitive processes associated with accurate and timely situation awareness. These stress reactions include:

- narrowing of the perceptual field so that attention to salient and even vital factors is not maintained (cognitive tunnel vision)
- decreased search or scanning behaviour (less monitoring of the environment, information sources and the psychological status of subordinates due to fixation on just a few information sources or events)
- increased self-monitoring (personnel may become preoccupied with their thoughts or be drawn to attend to their internal physical stress reactions such as laboured breathing, heart palpitations and muscle tremors)
- decreased vigilance (alertness and responsiveness to relevant cues may decline)
- longer reaction times to peripheral cues and complex information
- rigidity in both thinking and behaviour (as perceptual field narrows and mental processes become confused, people tend to become constrained and inflexible)
- premature conclusions (arriving at a decision without exploring all pertinent information available)
- attentional focus on negative information (especially when under threat or time pressure)
- slowed performance (even routine tasks are likely to take longer to perform as decision and action pathways are disrupted by doubt, confusion and fear)
- degraded problem solving and decision-making (due to the collective impact of the above reactions).

It is apparent that stress can significantly affect the early stages of the decision-making process when people attempt to recognise and assess their situation. On the basis of these reactions, one should expect that high levels of stress will have a significant and adverse impact on the development and maintenance of situation awareness.

Human factors are fundamental

It is plausible that increasing automation and new procedures and technologies may have a dramatic impact on how work is performed across aviation. It is important that knowledge of human factors is integrated into the development of such systems so that aviation personnel are not too greatly challenged by the way information is presented or forced to change their natural ways of thinking and behaving.

Rather than concluding that the limitations of human thinking can undermine situation awareness, it is more fruitful to understand these limitations so as to develop appropriate procedures and support tools to optimise performance. The human operator is, and perhaps always will be, the primary information processor during aviation tasks and operations.

Enhancing situation awareness

General cognitive skills

Aviation studies (for example, Secrist & Hartman, 1993) suggest there are at least six general cognitive skills essential to maintaining situation awareness:

- heightened sensitivity to short-duration, low-intensity cues in the external environment (skilful recognition)
- rapid acquisition of relevant cues and patterns which are critical to defining the situation (refined acquisition)
- swift integration of environmental cues and patterns to reveal significant situational characteristics (prompt integration)
- rapid, automatic processing of acquired information, even under conditions of time-urgency and stress (efficient processing)
- timely situation assessment from minimal input information (sound judgement)
- direct apprehension of situation dynamics and trends (understanding or awareness).

Design of technology and systems

Many aspects of human cognition potentially can be incorporated in the design of systems and procedures that contribute to situation awareness. Memory, for example, is said to be supported by the use of sensory codes to help process and store stimuli. In a Defence Science and Technology (DSTO) study (Parker, 1999) showed that the way radar-warning-receiver information is displayed (colours, icons and audio cues) can have a significant impact on reaction time. Average response times to threats by the pilot participants varied by almost a second across four different display configurations. Given that attacking missile flight time is often a matter of five to seven seconds, the improvement in reaction time offered by one display prototype is impressive — and potentially life-saving.

A range of new technologies and tools aim to enhance situation awareness as an integral design consideration. Innovative avionics and sensors, datalink, crew station design, GPS, three-dimensional visual and auditory displays, voice control, cognitive modelling, helmet mounted displays, interactive display interfaces, virtual reality, decision support tools, sensor fusion, Traffic Collision Avoidance System (TCAS) and other advanced, adaptive automation are constantly enhancing the glass cockpit. Such technologies can provide numerous advantages, such as new types of information, more accurate information, novel ways of providing information, and reductions in crew workload, particularly mental workload.

However, technology can be a double-edged sword, especially if it is not based on human-centred design approaches. New technologies can affect situation awareness in unpredicted ways; three-dimensional displays, for instance, have been found to have quite negative effects on pilot situation awareness. While lack of information is generally a problem for situation awareness, too much information from increasingly complex technological systems also poses a serious problem.

Automation can reduce workload but can also reduce situation awareness by distancing aircrew from the current status of the aircraft — sometimes they are deliberately put out of the loop. In fact, there is growing concern that increasing automation is leading to widespread erosion of basic flight skills. [More information on human-factors considerations for automation are in Chapter 12.] Aviation maintenance shares similar concerns about the loss of fundamental skills and broad technical understanding due to black box component replacement practices and contracting out deep-maintenance tasks.

Aviation systems should be designed with an emphasis on providing relevant data for all three levels of situation awareness. A system which aims to deliver integrated information will foster Level 2 situation awareness. It is also possible to design systems to output information to support predictive needs, such as weather projection. Significant care should be taken to evaluate the impact of proposed and developing technologies on situation awareness. Direct measurement of situation awareness during design testing should be standard practice.

Training

Training can be tailored to the goal of developing situation awareness. The component skills of situation awareness for specific roles/tasks should be identified and formally taught in training. Topics could include how to best employ system components to promote situation awareness, efficient scan patterns, techniques for maximising the usefulness of limited information, the value of feedback in learning about situation awareness, and methods to foster shared situation awareness. Practical experience will assist in developing the skills, long-term memory structures and mental models which can lead to improved situation awareness at all the levels postulated by Endsley.

Measurement and assessment

Useful training outcomes are dependent on the ability to measure and assess the skills being taught. Situation awareness is no exception. Fortunately there are existing situation awareness measures, although to date they have been mainly used to evaluate the effectiveness of new equipment, such as tactical displays, that claim to enhance situation awareness.

There are two basic approaches to measuring situation awareness. The first involves experimentation using observations of behaviour. A common experimental technique uses a series of memory probes, developed by subject matter experts, and applied during simulation scenarios. This approach can tailor questions relating to each of the three levels of situation awareness proposed by Endsley. Responses are compared to the actual situation to provide an objective measure of situation awareness.

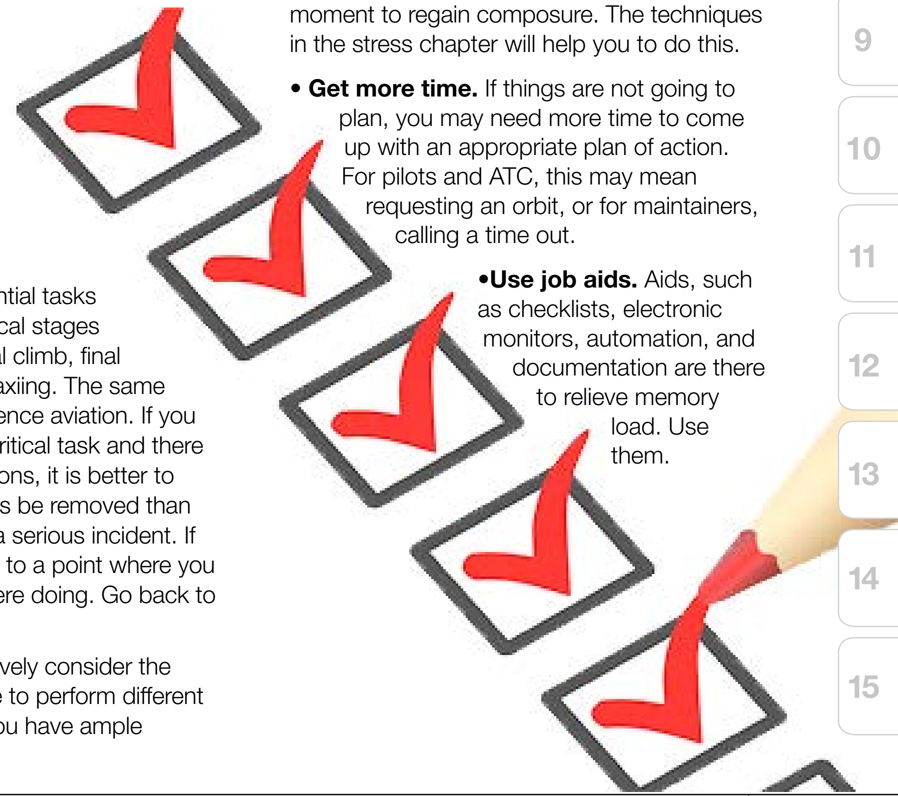
The second approach to measuring situation awareness uses subjective rating scales. Such scales typically measure a number of dimensions postulated to represent aspects of situation awareness. Respondents can be asked to rate their own situation awareness or that of their peers during simulated scenarios or after actual, on-the-job activities.

A collaborative mindset

A recurring theme in aviation situation awareness is the critical importance of speed in the processes involved in attaining it. Importantly, speed is not the only determinant of effective situation awareness, particularly in hangar tasks. In some situations, factors such as accuracy of assessment may assume greater importance. It is important for the different elements of the aviation workforce to consider the perspective of others in their dealings with them.

Managing situation awareness — tips

- **Learn to recognise the symptoms.** Learn the signs that you are losing situation awareness, which can include feelings of confusion, forgetfulness, and tiredness.
- **Be well-informed.** Make a conscious effort to identify all of the pertinent information in a situation, and that that information is being considered when deciding your actions. Being well-informed will also help you spot unexpected changes in your work environment.
- **Regularly evaluate your environment.** Periodically check your environment to see if anything has changed, especially if you are about to perform, or are performing, a safety-critical task.
- **Consider when and where to direct your attention.** During different tasks, or different stages of a task, you will need to direct your attention to different areas. When your task changes, take a moment to consider where you should be focusing.
- **Minimise distractions during critical tasks.** For pilots, the Federal Aviation Authority (FAA) endorses a sterile cockpit, where non-essential tasks are prohibited during critical stages of the flight: take off, initial climb, final approach, landing, and taxiing. The same advice goes for all of Defence aviation. If you are performing a safety-critical task and there are unnecessary distractions, it is better to ask that these distractions be removed than have them contribute to a serious incident. If you are distracted, return to a point where you were sure of what you were doing. Go back to the start, if necessary.
- **Manage your time.** Actively consider the amount of time it will take to perform different work tasks and ensure you have ample time to perform them throughout the day. This planning activity will help you avoid rushed work, which can lead to inattention and error. Planning your day will also help you remember what work you need to do and when to do it.
- **Work within your limits (and for pilots, the aircraft's performance limits).** Working over-capacity can affect your ability to notice changes in the work environment.
- **Communicate with your work unit.** As a team, your unit will develop a shared mental model of your environment. If you notice a change in the environment that may affect operations you should communicate this change to co-workers and supervisors in case they are not aware. This will help reduce the errors made by yourself and others.
- **Actively build your team.** Deliberate efforts to select and train cohesive teams with multi-disciplinary skills and an awareness of the value of shared situation awareness are likely to enhance situation awareness and consequently command effectiveness.
- **Remain calm.** Stress can affect both your ability to notice changes in your environment, as well as your decision-making during critical incidents. If you feel that you are becoming stressed or anxious, it is important to take a moment to regain composure. The techniques in the stress chapter will help you to do this.
- **Get more time.** If things are not going to plan, you may need more time to come up with an appropriate plan of action. For pilots and ATC, this may mean requesting an orbit, or for maintainers, calling a time out.
- **Use job aids.** Aids, such as checklists, electronic monitors, automation, and documentation are there to relieve memory load. Use them.

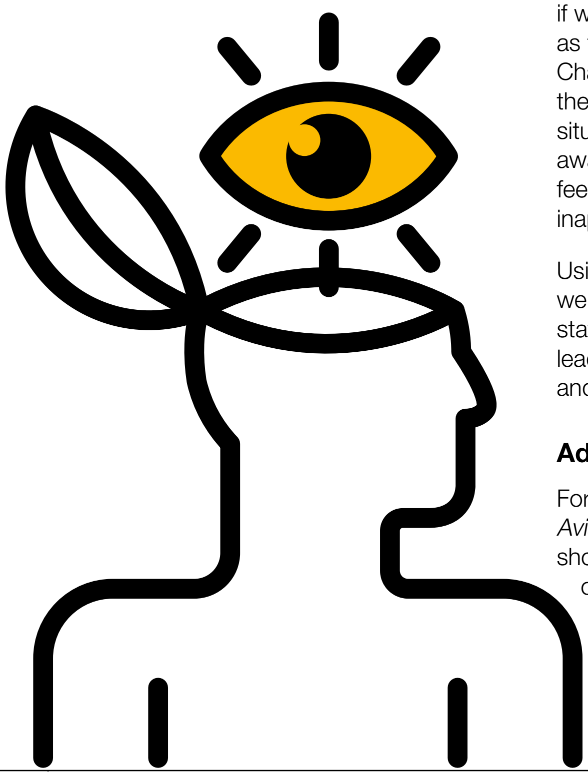


- **Share information, check with others, ask for help.** Communication is a vital part of maintaining situation awareness. [See Chapter 7.]
- **Adopt performance enhancement methodologies.** A variety of other generic performance enhancement techniques may contribute to the optimisation of situation awareness. These methodologies include memory-enhancement tools, decision aids, and formal situation-awareness measures.

The above list is just a sample of the strategies you may be able to use to maintain or restore situation awareness. Because it is such a broad topic, references to situation awareness will be found throughout this course and other strategies will be mentioned in those chapters.

Problems with the concept of situation awareness

It is not surprising that the ATSB study found that situation awareness was implicated in 85 per cent of human-factors incident reports because situation awareness is a metacognitive construct, embracing a large part of the information processing model shown in Chapter 2. Expressing this point in colloquial terms: situation awareness covers a lot of territory. That can be a problem. Saying that an incident was due to a loss of situation awareness may not take you much closer to the underlying issues.



An associated problem is that it is easier to say there was a loss of situation awareness than it is to say that situation awareness was present. That puts it into the same category as complacency; something we need to know about and guard against as best we can. There are warning signs — such as fatigue, stress, high workload, unfamiliarity, and complexity — but these warning signs are often missing. When present, they are too often ignored on the assumption that they apply to less-skilled operators. Situation awareness requires constant effort and vigilance.

A third problem with the notion of situation awareness is that the phrase itself directs attention to the external environment. We need to be aware of our physiological and emotional states too. Fatigue and stress are known causes of loss of situation awareness. Fatigue will eventually lead to a loss of any form of awareness and stress will often lead and a severe restriction of attention and a regression to familiar mental models. These internal states are both causes and aspects of situation awareness.

We need not be troubled by this inbuilt circularity if we remember to include the internal as well as the external environment. To quote from Chapter 2: "Being aware of your emotions and the emotions of others is an important aspect of situation awareness …. If you are not sufficiently aware of how you are feeling or how others are feeling, it is easy to misread a situation and react inappropriately."

Using the terminology introduced in this chapter, we would say that insufficient awareness of internal states such as fatigue, stress, and emotions can lead to the formation of incorrect mental models and lead to incorrect projections.

Additional reading

Ford, C. (2016). Momentary lack of awareness. *Aviation Safety Spotlight*, *1*, 8. This article is a short, first-hand account of an MRH90 flight that could have been compromised because of a temporary lack of situation awareness.

Joyce, K. (2015). Situation awareness in the Defence aviation maintenance workplace. In P. Murphy and P. Cross (Eds.), *Focus on human factors in aviation* (pp. 90–95). Directorate of Flying Safety — ADF, Campbell Park, Canberra, ACT. This article gives a good coverage of situation awareness from the point of view of maintainers but is recommended reading for all.

See also the article titled Situational Awareness in *Aviation Safety Spotlight*, *2,* 2015, 34–35. This short article presents an easy-to-read summary of situation awareness, including tips for preventing loss of situation awareness. Much of the same information can be found in the following Airbus Flight Operations Briefing Notes retrieved from http://code7700.com/pdfs/airbus_flight_ops_briefing_enhancing_sa.pdf

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Key points

- Gaining and maintaining situation awareness are critical components of each aviation worker's job.
- Without sound situation awareness, even the best trained individuals can make poor decisions.
- Situation awareness applies to everything we do because it relies on components of the basic information-processing model: memory, attention, pattern-recognition, and reasoning.
- Good situation awareness requires three elements: noticing information that is relevant to your task, incorporating that information in your mental model of your working situation, and being able to anticipate the impact of that information on the future state of your work situation.
- There are a number of factors that impact your ability to gain, maintain, or restore situation awareness. Inaccurate data/information, workload, inattention, distractions, and ignorance are perhaps the main threats to situation awareness.
- The more experienced you become, the easier the cognitive effort required to achieve situation awareness; but it will always require some effort.
- Good preparation, use of all resources, good communication and anticipating potential problems will help you to maintain situation awareness.
- Situation awareness is not just about the individual; team or shared situation awareness is the degree to which every team member possesses the awareness required for his or her responsibilities.

Bending the map: An overview of the data/frame theory of sensemaking

Conducting an unaided navigation sortie in close proximity to the ground requires pilots to extract the necessary cues that are from a continuous flow of events. This example provides a unique window into the underlying cognitive processes — often referred to as sensemaking. The data/frame theory of sensemaking (Klein, 2007) contends that the same processes that enable people to successfully navigate can also lead to pilots "bending the map" and becoming lost.

In the data/frame theory of sensemaking, understanding is achieved when the information gathered from the environment can be fitted into a mental frame such as a story, script, or map. That is to say, we use the information/data to retrieve or construct an appropriate explanatory frame.

For pilots conducting low-level unaided navigation, the fundamental principles of orientating the map, big-to-small, natural-to-man-made, and clock-to-map-to-ground are utilised to develop a frame of their current location and intended track. Individuals also use this frame to define new data and to identify relevant cues from the abundance of available information.

A frame is typically constructed using a small set of anchors which are considered to be firm cues that offer important information. The process of sensemaking is undertaken by combining new data with these anchors. Sometimes new data allows an individual to elaborate the richness of the frame. At other times individuals are required to make sense of inconsistency between the new data and the frame. In such instances an individual can either develop explanations for the discrepancies or accept them and either revise or replace the frame.

Regardless of the accuracy of the frame it is inevitable that some data will not fit and, as a result, explaining away discrepancies is frequently an effective strategy (Klein, Moon, & Hoffman, 2006). However, if one or more of the anchors that is being used to understand the situation is inaccurate, these explanations can lead to the corruption of sensemaking.

[If we were to stick to terms used in the situation-awareness model, we could say that the mental model has become distorted.]

When a pilot's frame of the current location is incorrect the inaccuracies will increase between new data and the frame. In this eventuality, the pilot may choose to bend the map by either twisting the frame to accommodate the data and/or twisting the data to match the frame. Sources of faulty explanations for discrepant data in navigation can be wide-ranging, from inferred map or weather anomalies to the belief that the sought-after turn point may be just over the next hill, or perhaps the one after that.

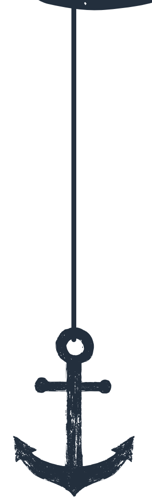
Persisting with a mistaken frame in spite of the opportunity to revise or replace it is called fixation. Researchers have argued that fixation is not a deliberate attempt to maintain a flawed frame but rather it is the natural result of the frame being used to direct attention. That is to say, faulty frames can result in undesirable fixation but the same process is labelled efficient attention management when the frames are accurate. Pilots may choose to persist with a frame until its increasing complexity becomes too much to handle or they encounter a frame-breaker; for example, the absence or presence of an unmistakable tracking feature.

One of the hardest parts of recovering from a faulty frame is realising that we are lost in the first place. What's more, the longer we persist with the frame the harder it is to recover. If individuals suspect their frame to be faulty they may choose to seek more information or increase their monitoring of the situation. However, on occasion these strategies may actually add to the confusion by resulting in more coincidental connection that may be misinterpreted as meaningful patterns.

Attempting to train pilots to keep an open mind and remain sceptical of their frames may also be counterproductive. Individuals who are more confident in the frames, such as experienced pilots, are more sceptical about contrary evidence and as a result are less prone to significant corruptions. In contrast, novice pilots who are less confident in their frames may readily explain away discrepancies. Accordingly, being committed to a frame is likely to be beneficial for sensemaking.

The early detection of corrupted frames is of paramount importance. To assist with early detection, individuals are encouraged to anticipate situations that might introduce corrupted beliefs (for example, elapsed time inconsistencies and relying on unsuitable anchors like man-made features) and remaining vigilant for potential signs of confusion along the way (for example, discrepancies between clock-map-ground). Undertaking navigation preparation which incorporates the identification of areas where one may become lost and how one would know they are lost is also likely to assist.

Once a pilot is uncertain of his/her location he/she is required to reorientate. Using the current frame to guide the process is fraught with danger. For example looking at the map and then attempting to confirm specific features may result in further corruption as the faulty frame is being used to interpret the new data.



A frame is typically constructed using a small set of anchors which are considered to be firm cues that offer important information. The process of sensemaking is undertaken by combining new data with these anchors.

It is essential that in such circumstances an individual begins again using only anchors and cues that he or she can trust. The practice of holding the map out of sight and identifying features using the principles of big-to-small and natural-to-man-made prior to seeking confirmation on the map is an effective approach to constructing a new frame. Only after a pilot has successfully recovered should he or she attempt to diagnose how the situation eventuated.

Source: Klein, G., Moon, B. & Hoffman, R.F. (2006). ***Making sense of sensemaking 11: a macrocognitive model. IEEE Intelligent Systems, 21*****(5), 88–92.**

Flying worse than blind:
Catastrophic loss of SA

Aeroperu, Boeing 757-200,
2 October 1996

Seven seconds after raising the landing gear, the first sign of trouble appeared. "The altimeters are stuck!" exclaimed the first officer. "All of them!" Just then a "wind shear, wind shear, wind shear" warning blared from the cockpit speakers. Surprised, the captain asked, "What's happening, we're not climbing?" Not only were the altimeters not responding normally to the airplane's climb, but the two airspeed indicators were erratic and in disagreement.

A warning appeared on the EICAS. "Rudder ratio!" the first officer called out, one minute after lift-off. "How strange," was the captain's reply, "turn to the right". Having taken off to the south from Lima in darkness, a turn to the right would take the aircraft out over open sea and away from mountainous terrain to the east.

"Go up, go up, go up!" implored the captain. "I am!" yelled the co-pilot, "but the speed…" The captain verbalised the first indication of the airspeed problem. "But it's stuck… mach trim, rudder ratio…"

Thirty seconds later, beginning to realise the seriousness of the situation, the pilots decided not to engage the autopilot. "The speed, let's go to basic instruments, everything has gone!"

With caution and alert alarms sounding in the background, Aeroperu 603 declared an emergency at 12:42:32 a.m., two-and-a-half minutes after take-off.

[Note: Throughout the remainder of the flight, the crew requested and received altitude information from ATC, using it to confirm what was shown on their altimeter. However, the altitude displayed on the controller's screen was not independently generated, but was electronically sent to ATC by the airplane's transponder, which read it directly from an aircraft altimeter. The altitude shown on the controller's radar screen was therefore always the same as that shown on the aircraft altimeter, whether accurate or not.]

Shortly thereafter, the captain took over all flying duties, but couldn't determine if the autopilot was on. "Autopilots have been connected", he stated. "No, no, they are disconnected!" argued the first officer, "…only the flight director is on."

Vectors were issued by ATC to keep the flight out over the ocean while the crew tried to understand the nature of the problem. The first officer made many attempts to find a remedy in the aircraft flight manual. In the confusion, procedures normally completed immediately after take-off were forgotten.

Eight minutes after departure the flaps were finally raised and climb power set. Several minutes later the air traffic controller called "Aeroperu six zero three, you are 40 miles from Lima and according to my screen are level at one two zero approximate speed over the ground is three hundred ten knots". Both crewmembers acknowledged the controller's statements, reinforcing the misconceptions of the airplane's true altitude. They also confirmed "maintaining speed, we have two thirty…" They had not noticed the discrepancy between their indicated airspeed and the ground speed reported by ATC.

Reading the flight manual provided no help. While being vectored to return to the airport at Lima, the captain's indicated airspeed increased to 320 knots and the overspeed warning sounded, startling the crew. Believing the alarm to be legitimate, engine thrust was reduced and the speedbrakes were extended in the mistaken attempt to slow the aircraft. Lima control again stated 603's position: "… Approximate speed is two hundred eighty over the ground."

"Yeah, but we have an indication of three hundred fifty knots here!" responded the first officer. The captain, his frustration complete, yelled, "I have speedbrakes, everything has gone! All the instruments have gone, all of them!"

Seventeen seconds after the overspeed clacker was heard, the stall warning stick-shaker activated. Shouting over the din of the simultaneous alarms, the first officer pleaded to the controller, "… Is there any aeroplane that can take off to rescue us? Any plane that can guide us?" The cockpit was filled with yet another aural warning, this one even more ominous: "Too low, terrain! Too low, terrain!"

"What happened?" demanded the captain in disbelief. "We have a terrain alarm!" screamed the first officer into the radio. Competing alarms continued to sound. "All of the computers are crazy here!" radioed the first officer. "We have a terrain alarm and we're supposed to be at 10,000 feet?". "According to the monitor you are at ten five (10,500 feet)" responded the controller.

Realising that the aeroplane had been in maintenance that day, the captain commented to no one in particular, "What the hell have those [mechanics] done?"

The confusion continued during the remaining minutes of the flight. A stall was avoided, the emergency procedures guide continued to be of no help, and the aircraft turned for Lima to attempt an approach and landing.

Less than a minute before the aircraft impacted the Pacific Ocean, the aircrew attempted again to verify their altitude with ATC. "You are still at nine seven hundred according to my presentation, sir" radioed the controller.

"Nine seven hundred? But it indicates 'too low terrain'! Are you sure you have us on the radar at 50 miles?" The first officer was now questioning their position, assuming the GPWS warning was due to proximity to mountainous terrain, not height above water. Seconds later the left wing and engine sliced through the surface of the ocean and the aircraft rolled into the sea 17 seconds later. At impact, the captain's instruments showed an altitude of 9500 feet and airspeed of 450 knots.

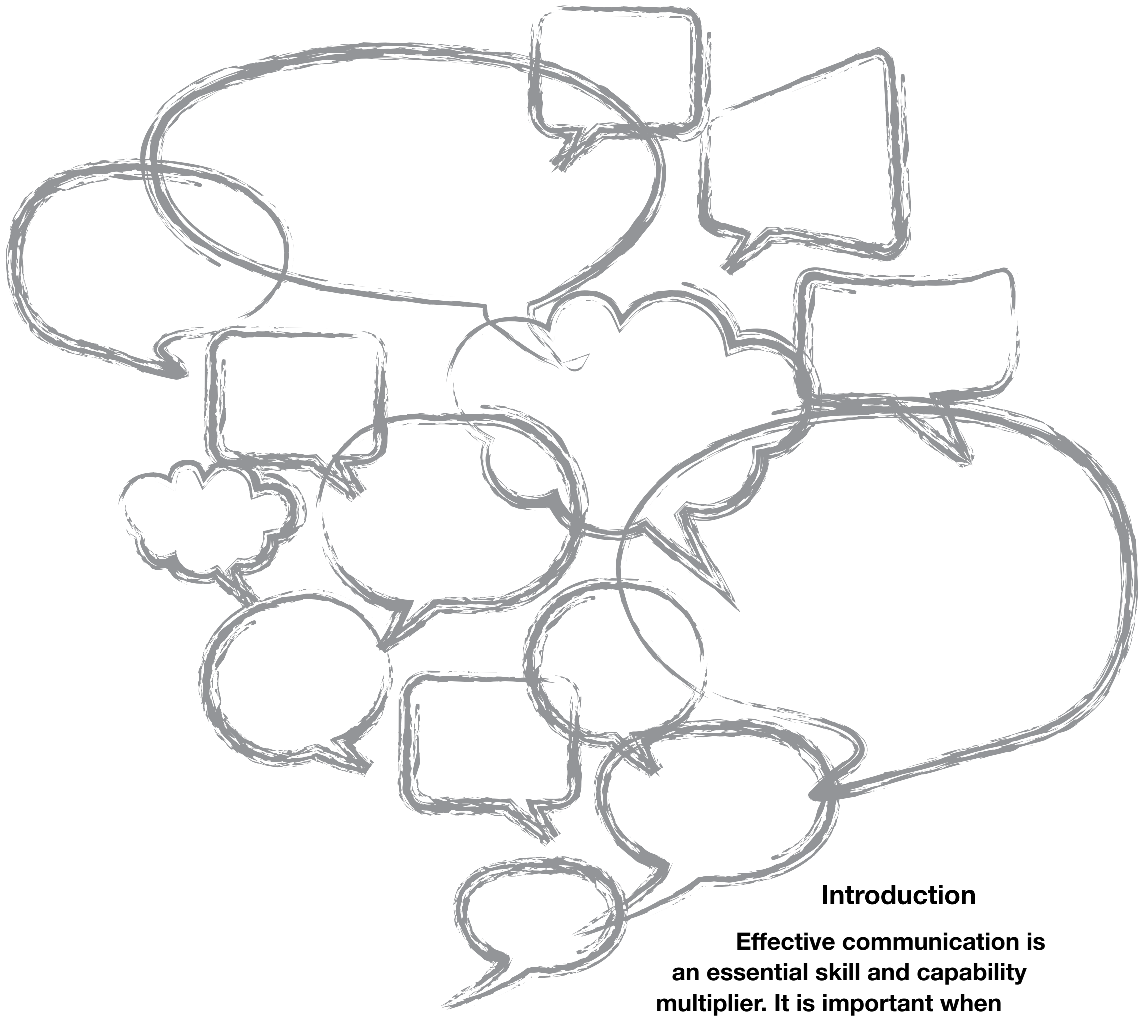
Postscript

Days later, photographic documentation of the wreckage on the ocean floor revealed a piece of masking tape covering all three static ports on the left side of fuselage. Blocked static ports can cause completely erroneous airspeed and altitude information to be displayed on the pilots' instruments. Partial obstructions can cause significant display delays.

The accident investigation revealed that during the washing and polishing of the aircraft on the day preceding the accident, masking tape was applied to the static ports to prevent the introduction of moisture and contaminants. The approved maintenance procedures call for the use of moisture resistant paper — not masking tape. A number of required maintenance inspections and reviews did not discover that the tape had not been removed after the polishing job was completed.

Source: Walters, J. M. & R. L. Sumwalt, R.L. (2000). *Aircraft accident analysis.* New York: McGraw-Hill.

CHAPTER 7 **Communication**



Introduction

Effective communication is an essential skill and capability multiplier. It is important when planning any communications to consider who the information is intended for, how you are going to transmit that information, the reason for communicating and, of course, the message itself.

Overview

- Effective communication
- Common communication errors
- Barriers to effective communication
- Barriers to assertiveness
- Strategies to overcome and manage communication barriers

In the context of Defence aviation, communication is a critical aspect of flight safety — ensuring coordination among aircrew, operators of unmanned aerial systems, ATC, maintenance technicians, and other groups within the aviation community. Numerous accidents have demonstrated the catastrophic consequences when vital communication links are compromised.

This chapter discusses communication as a critical non-technical skill and describes the different types of communication, barriers to effective communication, types of communication errors, and principles to improve communication.

Communication critical for safety

Communication is a fundamental part of good teamwork and is imperative in ensuring safety and efficient operations. The two essential features of successful communication are the transfer of both information and meaning from one party to another.

The transfer of information alone is not sufficient. The receiver must be aware of the content of the message, understand its meaning, and be able to project the consequences.

Consider the following case study, where ATC and the aircrew of Avianca Flight 52 did not share an understanding of the meaning of a message.

Basic communication framework

Communication is about sharing and using information to influence actions and behaviour to achieve desired outcomes. This information could be spoken or written; professional or social; personal or impersonal. Regardless of the form it takes or its content, communication needs to be effective. For communication to be effective it must follow a looped path — sender to receiver and then back to the sender via feedback.

Figure 7–1 displays the basic communication process in relation to task-related communication. While this is a simplistic framework, it provides a graphical depiction for use in a task-related context, recognising that in performing tasks, information transfer is the main aim of communication.

CASE STUDY

Avianca Flight 52 — failure to communicate

On 25 January 1990, during a flight from Bogotá to New York, an under-fuelled Avianca Flight 52 was required to go into a holding pattern over JFK International airport for an hour due to bad weather conditions.

This holding subsequently depleted the aircraft's reserve fuel, and the aircrew requested priority landing. Finally cleared to land, the aircraft executed a missed approach and during return the aircraft completely exhausted its fuel reserves, crashing 16 miles from the airport. Eight of the nine crew and 65 of the passengers died in the crash. Poor communication was cited as one of the major contributing factors to the accident. Language barriers and a failure to use the correct phraseology underpin the communication breakdown between ATC and aircrew. The following excerpt from the flight transcript highlights where some of the communication breakdown occurred:

Captain (to first officer): "tell them we are in emergency."

First officer (to tower): "…we're running out of fuel."

Tower (to first office): "okay."

Captain (to first officer): "advise him we are emergency."

Captain (to first officer): "did you tell him?"

First officer (to captain): "yes sir, I already advised him."

The first officer asked ATC for priority landing but failed to use the term "emergency". ATC was therefore unaware of the direness of the situation. It is also evident that there

was poor communication among the aircrew, as the captain requested the first officer tell ATC that they were experiencing an emergency. The failure of the first officer to include this significant term in his transmission to ATC meant that information was transferred but the meaning of the information was not. This case study not only illustrates failure to communicate the meaning of a message, it is also a good example of a failure to achieve the third level of situation awareness, projecting the consequences of a situation.

"Running out of fuel" was an expression with a wide range of meanings. It may even have been a common claim as pilots endeavoured to get their planes on the ground. We will expand on the use of common phraseology to aid in the sharing of meaning later in this chapter.

Poor communication was a major contributor to crash of Avianca Flight 52 and the loss of 73 lives.

Source: US National Transportation Safety Board (NTSB, 1990) investigation

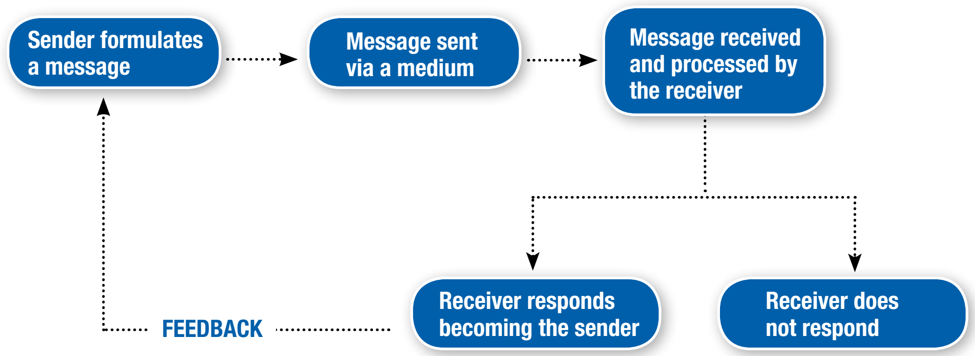


Figure 7–1. The communication loop, adapted from CASA's (2012a) *Human Factors Resource Guide for Pilots* (p.81)

Barriers to effective communication

Barriers in communication can occur at any point in the communication process. They can also be caused by external factors. A list of possible communication barriers that may affect safety is provided in Table 7–1.

In addition to these communication-related barriers, there are other factors that can hinder or prevent a message being received and understood. Examples include workload, fatigue, and stress.

- **Workload.** The efficiency of communication is sensitive to variations in the workload. An increased workload tends to shorten communications and reduce the number of exchanges, with a corresponding increase in communication errors. A person absorbed in a difficult or unfamiliar task is less likely to understand what someone is saying to them. It is always best to wait until the task is complete or stabilised before interrupting them.
- **Fatigue.** We know that fatigue has the potential to impact communication as it can negatively affect both our mood and cognition. The efficiency of every component of the information-processing system described in Chapter 2 is impaired to some extent. Our sensory system does not pick up as much information, we do not process the information we do receive very well, pattern recognition and decision-making are affected, and our response execution suffers.
- **Stress**. When we are stressed, we tend to focus on just part of the information that is coming to us from the world, a phenomenon known as "tunnelling". Communication suffers and situation awareness can drop dramatically.
- **Context.** Any message must have context. Context refers to the situation or environment in which the message is being delivered. Asking a person how he or she feels as part of a normal daily greeting and asking the person the same question after an accident will almost certainly elicit different responses. If you want to know how often a person suffers from headaches, the context will be set by the interval you use. Asking how many headaches a person has in a year will create an expectation in the person's mind that you are asking about really serious headaches. Ask how many headaches the person has in a week and the person will think that you want to know about the minor headaches as well. You will end up with different estimates of the number of headaches suffered in a year. Contextual factors that can influence the effectiveness of communication include international and organisational cultures.

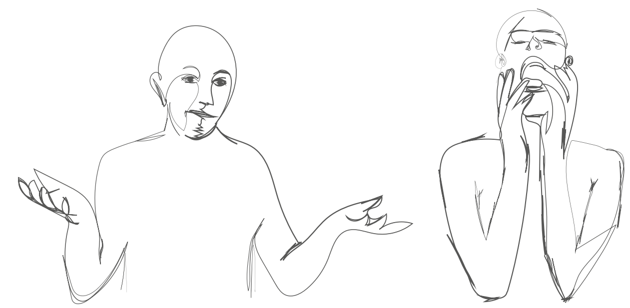
Types of communication

Communication is affected by the mode of speech employed as well as the linguistic context of the communication. In this context, people will adopt patterns of speech, grammatical styles, and body language which will all influence the communication. Considering the contextual and individual differences in the way we communicate, it is important to have an awareness and sensitivity for these communication modes. These modes can be expressed in speech, written word and non-verbal communications.

Written communication

Written communication can be in hard copy (paper) or soft copy (electronic) format. Written communications play an important role in Defence aviation, and will typically come in the form of one-way communications such as SOP manuals or two-way communications such as emails. The use of common phraseology is imperative in written communications. That is why we have Defence writing standards, and standard aviation phraseology and procedures.

When developing a written communication, also consider whether the person receiving the communication is familiar with the terms used. It is important that there is a shared understanding of the purpose of the communication. For example, a study on the use of aircraft logbooks found that pilots and maintainers perceived the use of logbooks differently. Pilots report making logbook entries to inform maintenance staff



TYPES OF BARRIER	EXAMPLES
Sender's errors	
Omitting communication	Clipping call signs. Inadequate detail in aircraft logbook, that is, describing a component as simply INOP.
Passing on incomplete/ ambiguous information	A pilot not adequately defining an abnormal situation to ATC.
Passing on incorrect information	Call-sign confusion. Providing the wrong part number.
Making assumptions	Assuming the receiver has prior knowledge of an incident.
Sender's/receiver's errors	
Failing to reach a clear and mutual understanding	Confusion about assigned runway Confusion over which team member is performing a given task.
Failing to follow recognised sequence for communication	Using non-standard phraseology or jargon.
Poor elocution/failing to communicate clearly	Rushing or mumbled speech Illegible writing in aircraft logbook.
Failing to read back messages	Failure of a pilot to read back mandatory pieces of information to ATC requiring further communication to resolve.
Receiver's errors	
Not responding correctly to communication	An aggressive response
Mis-recording information communication	Writing down an incorrect QNH. Incorrectly or inadequately labelling maintenance work conducted in an aircraft logbook.
Not listening (partial or total message)	Tuning out due to high workload.
External barriers	
Environmental noise	Engine noise. A loud nearby conversation among co-workers.
Visual obstructions	Describing an aircraft component at night. Referring to an aircraft or component across the hangar or tarmac.
Co-worker interference	A co-worker interrupting the conversation.

Table 7–1. Safety-related communication barriers, adapted from CASA's (2012a) *Human Factors Resource Guide for Pilots* (p. 86)

CASE STUDY

Garuda Airlines Flight 152 — was that left or right?

On 26 September 1996, Garuda Airlines Flight 152 flew into a mountain just before landing at Medan, Indonesia. An error from air traffic control (ATC) resulted in the aircraft being routed directly into mountainous terrain which, due to forest fires at the time, was obscured by smoke and haze.

None of the 234 passengers and crew survived the impact. This extract of conversation illustrates the confusion between the ATC tower and flight crew:

ATC: GIA 152, turn right heading 046 report established localiser.

GIA 152: Turn right heading 040 GIA 152 check established.

ATC: Turning right sir.

GIA 152: Roger 152.

ATC: Confirm you're making turning left now?

GIA 152: We are turning right now.

ATC: OK you continue turning left now.

GIA 152: A (pause) confirm turning left? We are starting turning right now.

ATC: OK (pause) OK.

ATC: GIA 152 continue turn right heading 015.

Ten seconds after this transmission, the accident occurred.

Source: CASA's (2012a) *Human Factors Resource Guide for Pilots* (pp. 80–81)

of maintenance work required, whereas maintenance staff report making logbook entries to inform regulators. Maintenance staff report wanting more information from the pilots in entries.

Verbal communication

The spoken word is the most common way of communicating. It is both social and functional and essential in building effective teams and networks; however, it is not without its limitations. It relies heavily on unspoken elements such as gesticulation, facial expression and voice characteristics to convey intent.

Verbal communication can occur as direct (that is, face-to-face) or transmitted (for example, radio or telephone) speech between multiple persons. Verbal communication is more prone to misinterpretation than written information, as the person may be misheard (for example, too quiet, mumbling, language barriers) or there may be interference (for example, radio static).

An important skill in improving verbal communication is paraphrasing, or reading back a message, especially if it is safety critical. Consider the case study of Garuda Airlines Flight 152, involving a simple but catastrophic miscommunication between left and right.

Non-verbal communication

Process is the way in which a message is delivered. This includes the non-verbal elements of language such as tone and modulation, body language, eye contact, hand gestures, emotion (for example, anger, fear, uncertainty, confidence) that can be detected by the receiver. Eye contact, for example, indicates attention, interest, and involvement. Gestures such as winking, or rolling one's eyes, communicate powerful messages. Non-verbal communication can assist communication in environments with high exposure to noise.

When there is compatibility between the verbal and non-verbal aspects of communication, the non-verbal aids understanding by complementing the spoken message. Examples include head shaking when saying no, frowning when saying you are angry, emphasising certain words and phrases, shrugging shoulders or raising an eyebrow to express doubt.

Non-verbal cues can also cause misunderstanding because people are more willing to believe in what they see rather than what they are being told. A popular research study found that only seven per cent of the meaning of spoken communication came from words alone, while 55 per cent was attributed to facial expression, and 38 per cent from the way the words were said. These figures have been debated by psychologists ever since Mehrabian (1971) published his '7-38-55 rule' in 1971 but no-one doubts the importance of the non-verbal component of communication.

Formal versus informal

Both formal and informal communication methods are adopted for various types of information. There are several different processes for communicating different sorts of information. Formal methods and documents such as user manuals, safety cases, and hazard logs are used routinely. However, other types of communication of a less formal nature may include:

- face-to-face briefings
- informal documents (such as newsletters, bulletins, electronic mail)
- audio-visual packages
- training.

Communication styles

There are several distinct styles of the communicator. Chief among these are; passive, aggressive and assertive. Of these the assertive style of communication is generally best for most situations. Assertive communicators can clearly and strongly articulate their position or opinion while respecting the opinions of others.

Safety-critical communication

In Defence aviation, safety-critical communication forms a special category. Within this category, specific types of communication have their own protocols and terminology to aid the transfer of content and meaning.

Examples of safety-critical communications

Some examples of special safety-critical communications are listed below:

- briefing and debriefing
- emergency communications
- handovers between shifts/crew
- communication of safety events and hazards
- labels on equipment and dangerous materials
- communications on changes to safety-related policies or procedures.

Note: Briefing/debriefing for aircrew and handovers for maintainers will be discussed in more depth in later.

Two other special safety-critical communication systems in Defence aviation are the safety reporting systems. Both systems are used for safety data collection, storage, management, analysis and protection of safety information.

Work health and safety events

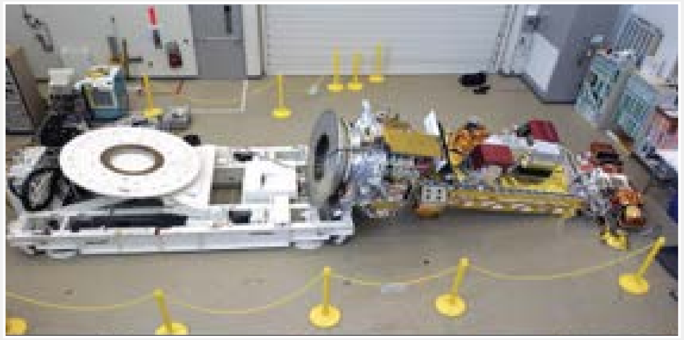
Every time there is a Work Health and Safety (WHS) event, whether it is a serious injury, a near-miss or a hazard, it is entered in the WHS database. WHS data is used to identify and address safety risks present within the workplace as well as track and project the risk of future events. Defence personnel, including cadets and contractors, have an obligation to file a report if they are involved in a WHS event.

Defence aviation safety reporting

Military aviation is a unique undertaking. Experience has shown that aviation accidents are often preceded by safety-related incidents and deficiencies that indicate the existence of safety hazards. Therefore all personnel involved in delivering Defence aviation capability have additional requirements for the reporting of specific safety events. These aviation safety events are entered into the Defence aviation safety database, enabling action to be taken to prevent recurrence, or more importantly, to anticipate and prevent other, potentially more serious outcomes, both locally and across Defence aviation.

If you are unsure of your obligations for reporting safety-related events, you should consult your aviation safety officer (ASO) or chain of command.

CASE STUDY Satellite worth $500 million dropped due to communication error



An aircraft falling off jacks is bad enough, but what if you dropped a satellite worth $500 million? In 2003, a weather satellite known as NOAA-N Prime was dropped from a work stand during pre-launch preparations in California. The satellite fell about a metre to the ground while it was being turned from a vertical to a horizontal position.

Workstands at the facility were shared between two different satellite projects, and were kept in a storeroom when not being used. A couple of weeks before the accident, workers from the other satellite program had decided to use the workstand because their own stand was red-tagged with a problem.

They went to the storeroom and began to prepare the stand by removing 24 bolts that held the special adaptor plate for the weather satellite, so they could fit an adaptor plate for their own satellite. After they had removed the bolts; however, they decided it would be easier to repair their own stand, and use it to work on their satellite.

The stand in the storeroom was then left with its adaptor plate in place, but not connected by any bolts. There was no requirement to attach a red tag to the stand as it was understood that all personnel had a responsibility to verify that ground service equipment (GSE) was properly set up for use.

Two weeks later, the weather satellite had to be attached to a workstand and rotated to a horizontal position to enable a piece of onboard equipment to be replaced. Almost all crew members thought this was 'just another routine operation'. The supervisor was required to conduct a pre-task briefing to make sure all team members understood their roles, that potential problems had been identified, and the equipment was set up correctly.

After the accident, some team members said a pre-task briefing had been held, others did not remember a briefing.

The workstand was retrieved from the storeroom and the weather satellite bolted to the adaptor plate. The fact the adaptor plate was not bolted to the workstand was overlooked.

The engineer in charge was required to check the workstand was in the correct configuration through a visual and physical check, but instead he referred to paperwork from a previous operation to confirm the stand was ready to rotate the satellite.

Finally, the lead technician and an inspector signed the paperwork to verify the satellite was ready to be rotated, without personally conducting or witnessing the operation.

Shortly before the satellite was rotated, one member of the team was overheard to remark that there were empty bolt holes on the workstand, but no-one seems to have paid any attention to the comment. In general at this organisation, there was a strong reluctance to speak up and hold up an operation unless an individual was absolutely sure something was wrong.

The crew then began to rotate the satellite, but as it reached 13 degrees of tilt from the vertical, it slipped off the workstand and fell approximately a metre to the floor, tipping over in the process.

Fortunately, nobody was injured.

Source: CASA's (2012b) *Human Factors Resource Guide for Engineers* (pp. 134–135)

Phraseology

The words we use can carry different meanings to different people and under different contexts, which can easily create ambiguity and confusion in communication. "Through the last door" could mean through the last door we discussed, or through the door on the end. To reduce ambiguity in aviation communication there are established protocol on the words and phrases we use. ICAO has standard phraseology, including the use of the word 'departure' instead of 'take-off' except for during the actual take-off. Terms such as 'runway', 'heading' and 'clearances' are also required to be read-back. Read-backs greatly improve the chance a message has been received correctly; however confirmation can still be given to an incorrect readback. Hawkins cites four major causes for a hearback error (Hawkins, 1993):

- confusing two similar sounding aircraft callsigns
- only one pilot working and monitoring the ATC frequency
- numerical errors, such as confusing 'one zero thousand' with 'one one thousand', and
- expectancy (hearing what we were expecting to hear).

Expectancy can be seen in the following transcript from the world's worst aviation disaster at Tenerife in 1977.

The positive side of communication

Up to this point in the chapter, we have spoken about the negative side of communication. The case studies have reinforced this emphasis. However, it is important to remember that good communication is a major driver of safety performance. The 1970 Apollo 13 mission may be cited as an outstanding example of successful communication under the most difficult of circumstances.

We have our own data demonstrating the power of good communication. In the annual *Snapshot* survey, we measure the quality of communication in a number of ways. The survey includes items about upwards, downwards, and sideways communication. It also asks a range of questions about documentation, reporting behaviour, supervision, and compliance; with compliance being perhaps the ultimate test of successful communication.

CASE STUDY

Tenerife — cleared for take-off?

AA: Third to the left, OK

PAA Captain: Third he said

PAA: Three

TOWER: …ird one to your left

PAA Captain: I think he said first

PAA First officer: I'll ask him again

PAA First officer: Must be three. I'll ask him again.

In the meantime, the KLM aircraft, waiting at the beginning of the runway, had reported "… now ready for take-off… we're waiting for our ATC clearance". The ATC Controller replied "… cleared to the Papa beacon … right turn after take-off, proceed'".

The most critical error at Tenerife centred on the word cleared. In an instance of expectancy bias [see Chapter 5], the KLM crew interpreted the word cleared as applicable to the airway's clearance and the take-off clearance, as both had been requested. However, ATC intended it to apply only to the airway's clearance. As a result of this misinterpretation, and the poor visibility due to fog, the KLM crew proceeded with its take-off roll and struck the Pan Am aircraft which had not turned off the active runway at either the first or the third taxiway.

The report by the Civil Aviation Authority Netherlands on the accident concluded that: a) the crew of the KLM aircraft took off in the absolute conviction that they were clear for take-off; b) the communication procedures and terminology employed were not perfect, but were those in normal daily use in civil aviation at the time; and c) the accident resulted from a breakdown in normal communication and from misinterpretations of verbal messages. Such breakdowns were known to have occurred a number of times on other occasions but were not acted upon because they did not have disastrous consequences.

Following this accident, ICAO undertook a systematic review, which resulted in changes to the standard phraseology in use at the time of the accident. One of the critical changes was to restrict the use of the words 'clear/clearance' and 'take-off' to avoid such accidents. Clear/clearance are no longer used for start-up, push-back and taxiing. The word take-off was replaced by depart/departure as mentioned previously.

Source: CASA's (2012a) *Human Factors Resource Guide for Pilots* (pp. 84–86)

APOLLO 13

Apollo 13 was launched on 11 April 1970 from the Kennedy Space Centre, but an explosion of the oxygen tank two days into the mission aborted the planned lunar landing. Despite significantly degraded systems, and the need to do makeshift repairs, the crew landed safely seven days later. Successful communication within the crew itself and between the crew and the ground controllers is considered a key factor in their safe return.

Good scores on communication are associated with lower error rates, higher job satisfaction, higher morale, lower turnover intentions, and higher ratings of unit performance.

Strategies for improving communication

General principles

There are certain communication principles common across all industries which should be adopted by the entire workforce. They are listed below.

- Everyone interprets messages differently so it is important to carefully choose the words and symbols — the language — we use in a message. Add to this the complexity of the English language — particularly when dealing with the spoken word — and the possibilities for confusion multiply rapidly.
- It is easy to fall into the trap of using complex vocabulary, jargon and acronyms. This may be alright when talking with peers but as a general rule target your language to the most common denominator when communicating with groups of people.
- Ensure your message does not contain incorrect pronunciation or spelling, too much or too little information, ambiguities or contradictory information.

General principles for safety-specific communication

- Communicate with all members of the workforce, both up and down the chain of responsibility, to help ensure that risk-management activities are sufficiently comprehensive and understood.
- Endeavour to raise awareness of potential hazards and risk issues amongst the workforce.
- Ensure that all those involved with a project are aware of any risks, such as limitations inherent in the design or operating procedures, and of any implications for their conduct.
- Discuss the reasons for incidents and near misses with the workforce so that lessons can be learned.

Steps for improving safety-critical communication

The following are some useful strategies in improving safety-critical communication, as outlined below:

- specify the critical information that needs to be communicated
- reduce or eliminate information that is unnecessary
- if unsure of information during communication, seek clarification
- ask for confirmation and repetition of critical information
- avoid slang, or non-technical terminology
- when providing instructions, don't overload the receiver with information because we know that read-back errors increase significantly when the instructions contain more than four elements
- use different mediums (for example, both written and verbal) to repeat key information.
- during safety critical moments or during handovers, allow sufficient time for communication
- remember the giver and recipient of the information have responsibility for accurate communication
- develop your communication skills and rehearse effective communication in your unit
- lead by example: encourage effective communication in your unit by exemplifies effective communication behaviours.

Listening skills

Listening is not the same as hearing. It involves paying attention to what is being said and trying to understand the message. A good listener:

- stays focused on what is being said and listens to the whole message and avoids making assumptions or drawing early conclusions
- consciously puts aside personal perceptions or prejudice towards the subject matter or the speaker

- uses congruent body language — eye contact and posture that shows interest, equal positioning (that is, all participants sit or stand) and uses considered facial expressions and gestures
- asks questions to clarify what is being said using open, impartial questions
- validates what is being said by acknowledging the speaker's feelings or thought, accepting but not necessarily agreeing with the speaker's opinions
- restates and paraphrases to check for understanding and demonstrate listening.

Asking questions

Questions provide a pathway to understanding situations, problems and issues and, while most people are used to asking simple questions, particularly in social situations, it is not always easy to formulate questions that will elicit the information you need.

Questioning is also a very important learning strategy. Effective questioning enables supervisors to find out more about how they can assist people to learn. It enables individuals to increase their knowledge, skills and confidence.

Open questions elicit a wide range of responses and open up discussion and two-way communication.

Closed questions tend to elicit single word responses such as yes or no. Questioning for understanding leans towards open questions as much as possible and often begin with what, who, where, when, why and how.

Specific communication faults and suggested remedies

Table 7–2 displays some possible communication faults and suggested remedies.

Communication stage	Possible communication fault	Remedies
Create the message	Message is incorrect • Incomplete or missing information • contains the wrong information • is badly worded or presented (for example, is ambiguous) • too much infomation given	• A second person checks the message • Make sure message sender is competent (give training if nccessary) • Have rules for presentation and content of messages
Send	• Fail to send message or send too late, message get losts • Use the wrong communication channel (email instead of conversation) • Send to wrong person	• Make sure sender and receiver understand timelines • Have procedures specifying how the information (especially sfaety-critical) should be presented • Ensure person receiving the message needs the information • Feedback follow-up on message sent
Receive	• Fail to receive message • Receive massage too late • Receive message in a unsuitable state • Partially received message (obsured by noise, damaged or only partial retreival • Receiver fails to understand message	• Feedack sender to ensre that the informion is eceived and understood, receiver to send acknowledgement • System in place for resending or reformatting messages

Table 7–2. Communication — creating, sending and receiving, from CASA's (2012a) *Human Resource Guide for Pilots* (p. 91)

Key points

- Information can be interpreted differently by different people, and under different situational contexts.
- There are barriers to effective communication that can be addressed through training.
- Effective communication skills are especially important in safety-critical industries such as aviation.
- History shows that communication errors and failures are a contributing factor in many aviation accidents .
- Defence research shows that good communication skills can lift the morale and performance of the organisation.
- Standard protocols and phraseology are an aid to effective communication in safety-critical industries.

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CHAPTER 8 Managing stress

Overview:

- Stress in the aviation environment
- The stress reaction
- Sources of stress
- Effects of stress
- Stress-management and coping strategies

Introduction

Stress has been described as the disease of the 21st century. The 2015 version of the Australian Psychological Society (APS)'s annual stress survey found that 35 per cent of Australians reported having a significant level of stress in their lives. The figure is rising every year and matches trends in other Western countries, including the UK and the US. Of greater concern is the finding that younger adults, who make up a sizeable proportion of our workforce, report higher levels of stress than older adults.

The top three causes of stress over the five years that the Australian Psychological Society survey has been run are personal finances (49 per cent), family issues (45 per cent), and personal health (44 per cent). Stress is not confined to home life, and costs the country's business sector more than $A10 billion every year, according to estimates published by Safe Work Australia (2010).

What stress is costing Defence aviation is unclear; however, *Snapshot* 2016 found that the levels of stress are generally much lower in Defence aviation than in Australian society (17 per cent compared to 35 per cent). The *Snapshot* survey uses the same measure of stress as that used by the APS.

There are two reasons why we should not be reassured by this comparison: first, Defence aviation is a select population and due to the nature of the job could be expected to be healthier and, second, looking back through previous APS surveys, it is evident the incidence of stress in the general population in 2011 was similar to what we find in Defence aviation today. It has grown quickly in the general population and may escalate in Defence aviation too unless the threat is recognised and dealt with.

Stress weakens the immune system, increases the risk of cardiac diseases, causes sleep disorders, causes mood changes, affects relationships and creates dissatisfaction and, when left uncontrolled, can result in long-term problems such as fatigue, depression, and exhaustion. Healthy, well-balanced diets help to combat stress, as can regular exercise and sufficient sleep.

In a safety-critical environment such as aviation, stress can have both acute and chronic effects. Stress has been identified as a contributing factor in accidents, so the ability to recognise and manage our own stress and that of others is important.

To better equip individuals to handle stress in aviation, this chapter will explain the physiology and psychology of stress, identify some of its common causes, discuss how to recognise symptoms and effects and suggest effective coping strategies.

The dynamics of stress

Definition

Stress is a state of unpleasant emotional arousal associated variously with overload, fear, anxiety, anger and hostility. It can threaten both individual performance and teamwork and quickly undermine the emotional climate in which personnel are operating.

MODELLING THE STRESS RESPONSE

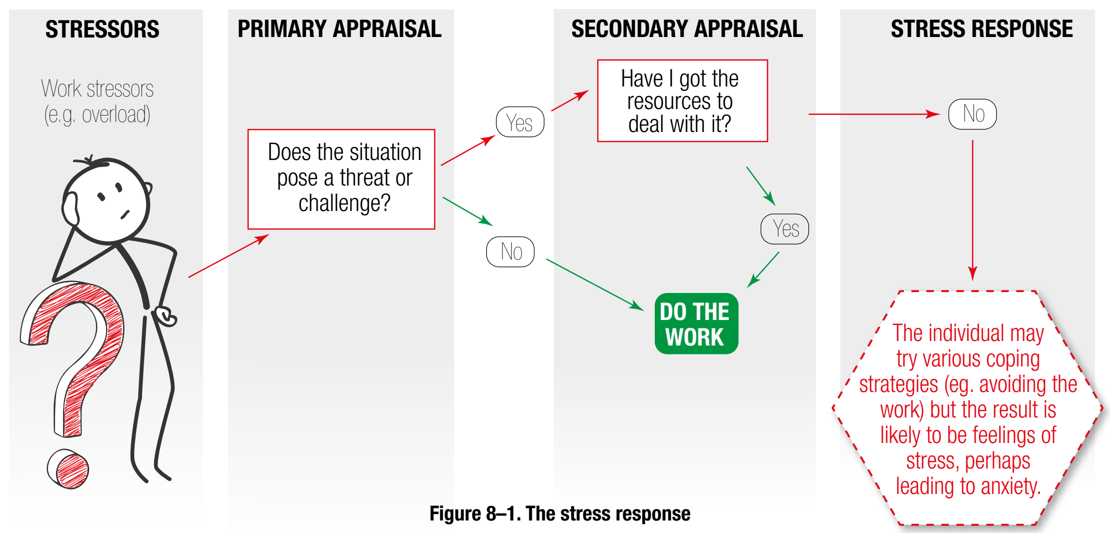


Figure 8–1. The stress response

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Change	Function
Dilated pupils	Increased light into the pupils for greater perception
Raised heartbeat	Increased blood circulation to muscles and vital organs
Increased blood-glucose levels	More energy in the blood circulated to muscles
Increased perspiration	Aids in cooling the body down to allow greater physical performance
Release of endorphins	Inhibits the feeling of pain from injury or physical exertion
Dilated bronchial tubes in the lungs	Increased oxygen intake

Table 8–1. Physiological changes and functions of stress

Stress often arises as a result of a perceived gap between the demands of a situation — which we refer to as stressors — and an individual's ability to cope with these demands. As stress involves both perception and evaluation, it directly affects the cognitive and interpersonal skills that form the basis of good technical and non-technical skills.

Terminology

The term stress is very popular and we will use it throughout this chapter but you will also hear the terms strain, distress, and anxiety to explain the ways in which people react to stress. These terms are often used interchangeably.

However, a negative stress reaction is not an inevitable consequence of experiencing stressors. As shown in Figure 8–1, stressors must pass through two appraisal processes (consciously or subconsciously) before they are in a position to cause stress. In the first place, they have to be judged as a threat and that appraisal process may have different outcomes for different individuals.

Flying, for example, is a pleasure for some but a serious stressor for others. For people with a fear of flying (aviatophobia), there is a secondary appraisal process that consists of an evaluation of whether or not they can deal with their fears for the duration of a flight.

There are calming strategies that athletes, actors, and performers use to help them cope with high-pressure situations. Some airlines help by playing soothing music as the plane comes in to land. The result for the stressed individual, as shown in Figure 8–1, may still be favourable because there are positive ways of approaching these situations, even if they are not immediately apparent or available.

Physiology of stress

A stress response is governed by the automatic nervous system (ANS) — a network of nerves that regulates bodily functions such as digestion, heart rate, and body temperature.

When a threat is perceived, a component of the ANS, the sympathetic nervous system (SNS), triggers the release of stress hormones (adrenalin, norepinephrine, and cortisol) into the bloodstream that rapidly prime the body to respond to that perceived threat. These hormones increase the heartbeat and rate of breathing, raise blood-sugar levels, increase perspiration, and slow digestion. Some examples of these physiological changes and their functions are listed in Table 8–1.

This rapid physiological change is referred to as the fight-or-flight response, as it primes an animal to be more physically prepared to fight a threat, or run from it. In this way stress can be a powerful tool for human performance. The fight-or-flight response was especially vital for our ancestors who faced danger from predators and other humans; however, can be disadvantageous when facing modern stressors, such as a difficult boss.

Life stressors

Although we no longer face the same physical dangers as our predecessors, modern society is associated with a new range of stressors that are commonly referred to as life stressors. They include such factors as domestic, social, emotional, environmental (for example, city driving), or financial pressures, which many people face on a recurring basis. Family arguments, death of a close relative, inability to pay bills, lifestyle and personal activities, smoking or drinking to excess, all contribute to life stress. Indeed, as we read in the opening paragraphs, these domestic stressors are the most commonly-reported stressors.

For some, new technologies are also an emerging source of stress — answering phone calls or emails late at night, having to learn challenging new work-related technologies, or the frustration that arises when technologies fail or are simply not performing efficiently.

The 2015 APS Stress Survey found that on an average day, adults were spending up to 2.1 hours and adolescents up to 2.7 hours on social media and that 25 per cent of the adult respondents and 60 per cent of adolescents reported feeling brain burnout (stress) from the constant connectivity of social media. A new term has entered the psychological lexicon to describe this phenomenon: it has been labelled Fear of Missing Out (FoMO). Technology has its benefits but it is also undoubtedly a potential stressor.

Pre-occupation with stressors outside of work can play on one's mind during the working day, distracting personnel from the working task and decreasing situational awareness. However, many of the stressors people experience come from the workplace itself and these are a major concern, for safe and efficient performance.

Different stressor categories

Challenge versus hindrance stressors

There are many ways to classify stressors. One popular method involves separating them into challenge and hindrance stressors. A challenge stressor is one that promises some benefit if people can deal with it, while a hindrance stressor is something that just has to be overcome.

Presenting a report to a large meeting, for example, would be classed as a challenge stressor for most people because it involves public speaking (which is very high on the all-time stressor index) but with significant favourable public exposure if handled well.

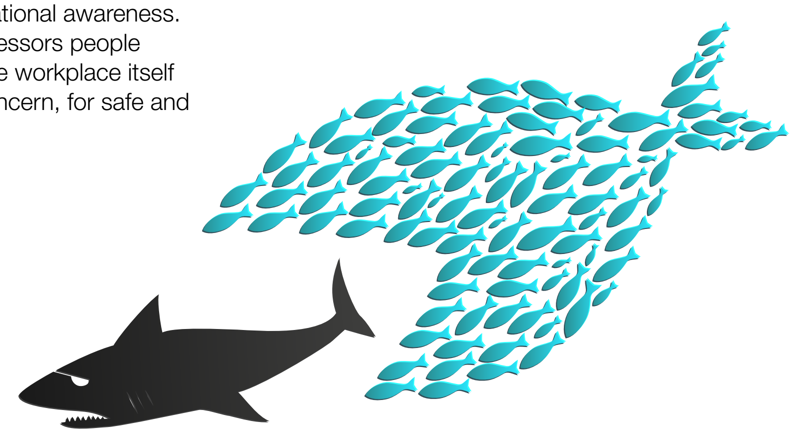
Dealing with an unjustified client complaint, on the other hand, is neither a pleasant experience nor is it likely to have any benefit for the person handling the complaint. Role ambiguity — that is, lack of clarity concerning one's duties, functions, and responsibilities — is one of the most common hindrance stressors in organisations.

Hindrance stressors tend to have a negative effect on team dynamics. They can decrease team motivation because they are viewed as obstacles to goal achievement.

Acute versus chronic stressors

Another way of classifying stressors is by their duration. When we talk of the fight-or-flight response, we typically refer to a response caused by acute stressors. Acute stressors are brief, intense, and infrequent.

Examples of acute stressors are being involved in a car accident or, in the case of defence personnel, training and military exercises. In these scenarios you will feel the full throttle



of the flight-or-flight response, which could save your life or the lives of those around you. In contrast, chronic stressors are typically less intense and occur over extended periods of time. When we talk about feeling stressed it is generally the stress that arises over prolonged exposure to one or more chronic stressors.

Military stressor categories

	Combat	Noncombat
Garrison	Stressor set A	Stressor set B
Deployed	Stressor set C	Stressor set D

Campbell and Nobel (2009) suggested that researchers interested in military stressors need a conceptual framework that captures the diversity of military sub-environments and the activities required in different sub-environments.

A simple framework described by these authors contains just four cells comprising two levels of deployment status (garrison [home base] versus deployed) and two levels of mission type (noncombat versus combat). The aim is to work out the stressors most often encountered in these four environments. These same authors proposed a more elaborate framework containing seven rows representing different types of stressor categories (work, social-interpersonal, family, self-identity, psychological environment, cultural environment, physical environment) and six columns representing the different phases of the deployment cycle (garrison, pre-deployment preparation, combat deployment, noncombat deployment, disengagement preparation).

This classification system yields 42 military environments with potentially different stressor profiles. That number may seem excessive but actually it is not large enough. Looking at the different deployments involving Defence in the early 1990s, Colonel Peter Murphy concluded: "It is readily apparent that each deployment had a different pattern of stressors that reflected the differing nature of these operations" (Murphy, Collyer, Cotton & Levy, 2003). The matrix grows even bigger if we include Australian Public Service employees and their many different work environments.

Interestingly, research has consistently found that the non-combat stressors of deployment are much more common and generate more stress and strain than combat-related stressors.

What stressors are you likely to encounter?

As is the case with any occupation, working in Defence aviation you may be exposed to a unique range of stressors in your workspace and when conducting your daily duties.

Organisational stressors

Various components of work organisation can contribute to stress. Defence aviation is engaged in constant improvement and you may experience changes in work policy and practices that, if mismanaged or poorly communicated, become stressors.

Defence aviation is also a high-paced and challenging work environment that requires much from its personnel. It may take new personnel time to adjust to the chain of command and associated organisational procedures.

Environmental stressors

Defence aviation personnel may be required to work under a range of environmental conditions that could include heat, cold, wind, rain, and noise. The temperature in an aircraft hanger lacks the regulation of air-conditioned offices. If deployed, you may also be required to work in regions that experience extreme temperature changes. Engine noise could also be a stressor for both pilots and maintenance staff.

Workspace stressors

Various roles in Defence aviation require working in movement-restricted or confined spaces. Pilots may be required to sit in a cockpit for extended periods of time, leading to discomfort. Maintenance personnel may be required to work in restrictive spaces in the aircraft while performing maintenance duties, which may also be exacerbated by heat, lighting or other stressors.

Duty-related stressors

Personnel may be required to work at an increased capacity or for extended periods to meet Defence aviation needs. Miscommunication within your team can lead to ambiguity over the assignment of duties, which can cause stress and frustration.

Absences may place strain on personal relationships. Defence members may be expected to spend time away from family and friends because of exercises and deployments. Postings to new locations can place strain on relationships.

What we know about stressors in Defence aviation

Defence has been collecting data on workplace daily stressors in Defence aviation since 2013 through the annual *Snapshot* survey. In a survey of more than 10,000 Defence aviation personnel in 2016, the four top workplace hassles were:

- manpower shortages
- paperwork
- having to perform tasks not obviously connected with real jobs
- workplace interruptions.

However, this list varies according to your role in the organisation.

- Junior officers, for example, reported major hassles connected with workload but they were not concerned about micromanagement, which was a major hassle for the junior NCO and other rank groups.
- Compared with aircrew, maintainers reported hassles associated with equipment shortages, micromanagement, and resolving the conflict between safety and production goals. Aircrew, on the other hand, were more concerned than maintainers about the pressures placed on their personal lives because of absences.

The point is, work hassles differ across organisational settings, often in predictable ways. Whatever the context, the process remains the same as that depicted way back in Figure 8–1 — people encounter the stressor, they evaluate it as a potential threat (primary appraisal), if it is perceived to be a threat, they then evaluate their ability to deal with it (secondary appraisal), and engage in some kind of coping process that may require further evaluation down the track.

Effects of stress

The effect on performance

The fight-or-flight theory demonstrates how a large stress response can increase our performance under dangerous scenarios. Similarly, a small stress response can improve our functioning in regular activities. However, our bodies can handle only so much stress and after a certain tipping point performance will start to decline. This curve in performance is known as the Yerkes Dodson Law (Yerkes & Dodson, 1908; Figure 8–2).

Stress will affect performance differently, depending on the nature of the task. When performing complex tasks, such as maintenance on, or learning to fly, a recently

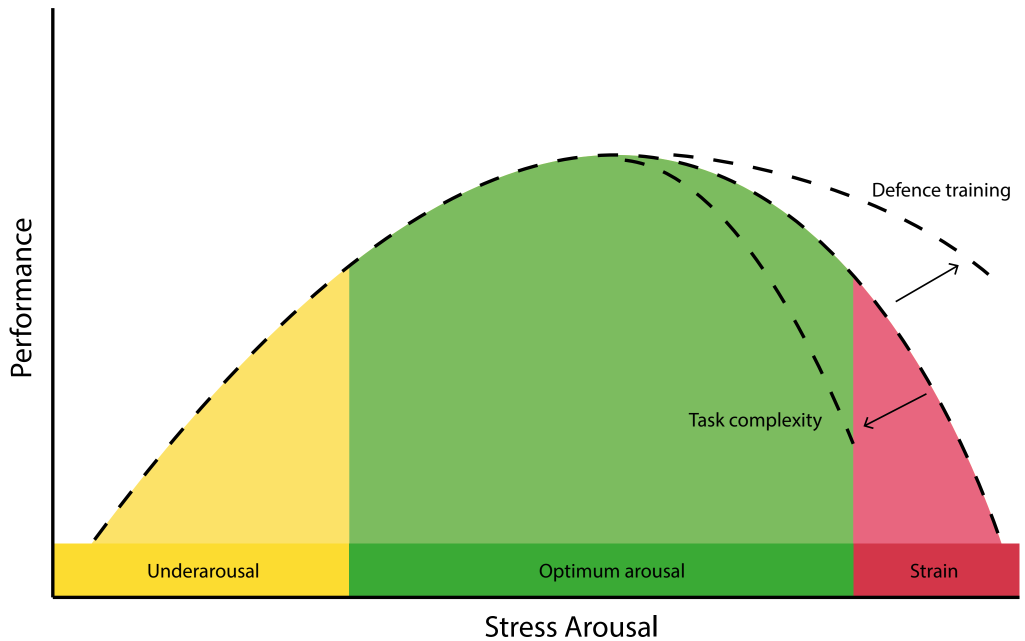


Figure 8–2. Yerkes Dodson Law

acquired military aircraft, performance will decline rapidly under pressure. Other activities that require less cognitive effort, such as some highly-learnt administrative tasks, may be less affected by stress.

How much stress affects performance will also differ from individual to individual. At times you will be required to do challenging tasks under stressful conditions; for example, working in operational areas. Defence training helps to condition personnel to be more resilient to stressful conditions beyond their normal limits.

The effect on wellbeing

Stressors, as we have already discussed, do not necessarily trouble an individual. Their effect depends on the appraisal process discussed earlier and the individual's coping resources. Their effect also depends on how many stressors the individual is experiencing.

One small workplace stressor can act like the proverbial straw that breaks the camel's back if an individual is under severe pressure from other sources. More often than not, it is the sheer number of stressors being experienced by an individual or the number of times that particular stressors are experienced — referred to as the dosage effect — that leads to that person actually feeling stressed.

In Figure 8–3, we see a graphical depiction of the cumulative effect of stressors in *Snapshot* 2016 data. On the left-hand side of the graph is a section of the K10 scale, a measure of psychological stress where scores above 20 indicate the likely presence of mild mood disorder and scores above 25 the likely presence of a moderate mood disorder.

On the horizontal (X) axis is the number of workplace stressors (all categories) currently being experienced by the aviation workforce who completed *Snapshot 2016*. The line represents the average K10 score across the 10,000 respondents for each point on the X axis.

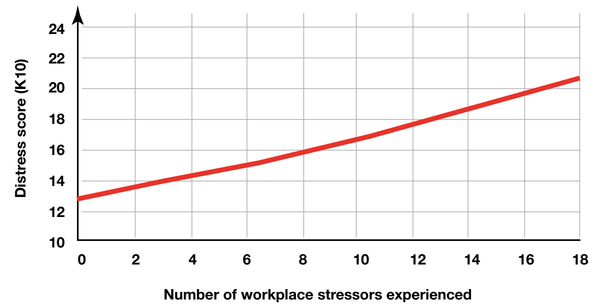


Figure 8–3. Relationship between number of stressors and stress response (distress)

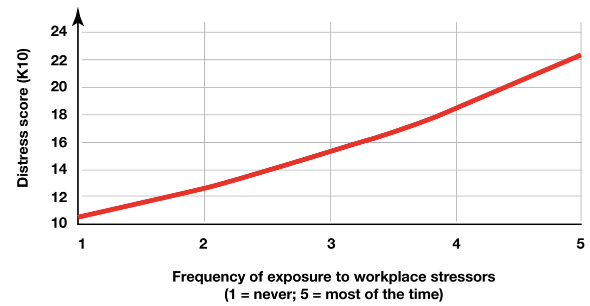


Figure 8–4. Relationship between frequency of exposure to stressors and stress response (distress)

Two things are apparent in this graph: first, the more stressors experienced, the higher the psychological stress score; second, the upward curvature of the line indicates that K10 scores are beginning to climb steeply by the time the number of stressors has reached 18.

A similar picture emerges when we examine the impact of the frequency of exposure to stressors on K10 scores. That relationship is shown in Figure 8–4. The difference between this graph and Figure 8–3 is that we don't know how many stressors are involved in producing the data for Figure 8–4, only how often they are occurring.

These are recent Defence data and they clearly show that if you are exposed to stressors on a frequent basis, you are more likely to report stress levels that are a concern.

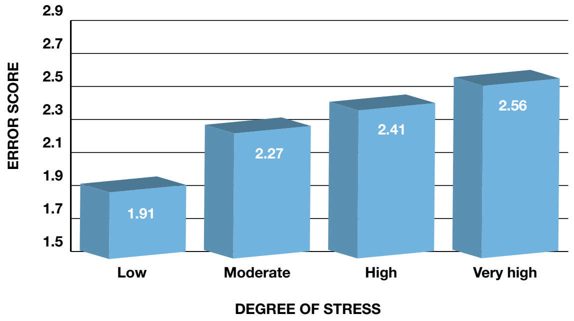


Figure 8–5. The impact of stress on errors

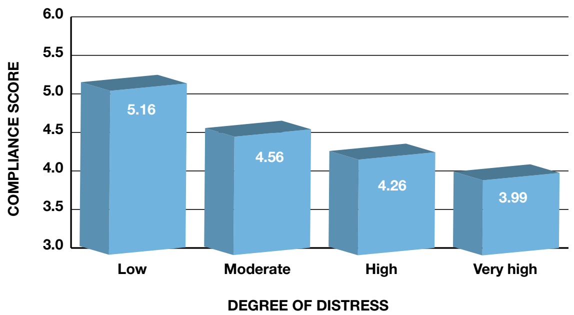


Figure 8–6. The impact of stress on compliance

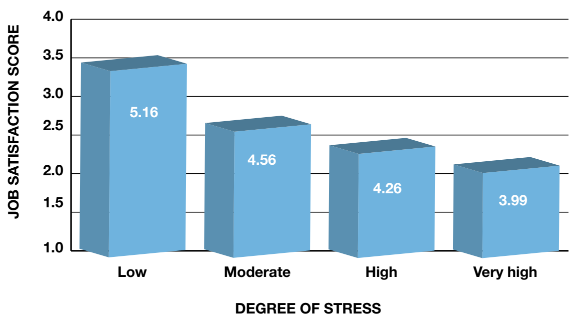


Figure 8–7. The effect of stress on job satisfaction

The impact of stress on team performance

It is important to remember that if one member of a team is stressed, others are also likely to be stressed. A compromised team member is likely to make a series of judgement errors and less likely to identify others' errors, as highlighted in the case study 'Flight 3378 — Running on Empty' on page 124.

The impact of stress on cognition

Individuals respond in different ways to high stress loads. Apart from the effects on behaviour — such as aggression, irritability, dogmatism and frustration — various psychological mechanisms may come into play in an attempt to cope with the situation. These make many of the human vulnerabilities discussed in other sections more likely, and include the behaviours below.

It can be seen that many of the above behaviours relate to factors such as workload, decision-making, and error. The impact of stress on errors can be seen quite clearly in Figure 8–5, which is based on data collected in the 2016 *Snapshot* survey.

As Figure 8–5 shows, there is a steady increase in the number of errors as stress levels increase. Figure 8–6 shows the impact of stress on compliance.

The impact of stress on wellbeing

Chronic stress can compromise the psychological wellbeing of personnel. This can manifest itself in different ways. A popular measure of wellbeing in workplace settings is job satisfaction. We can see evidence of the dampening effect of stress on job satisfaction in Figure 8–6.

While small amounts of stress may be beneficial as seen in the Yerkes Dodson Law, figures 8–5, 8–6, and 8–7 tell a consistent story — higher levels of stress are associated with more errors, lower compliance, and lower job satisfaction (and lower morale — not shown).

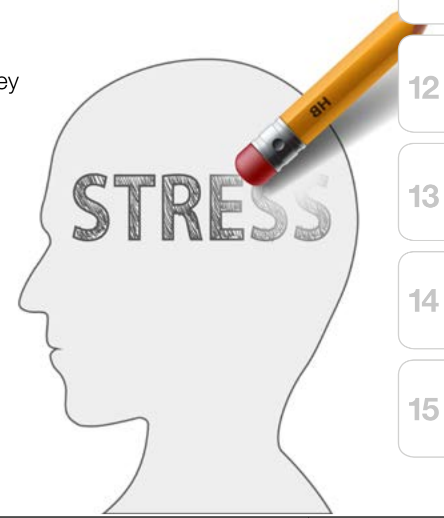
These graphs do not come from studies conducted elsewhere; they are based on data collected within Defence aviation and

EFFECTS OF STRESS ON BEHAVIOUR

Behaviours	Description	Aircrew	Maintainers
Slips	Doing something when you meant to do something else	Flicking the wrong switch on a control panel	Re-assembling a simple component incorrectly
Lapse/ omission	Forgetting to do a routine action	Failing to enter transponder code after receiving IFR clearance	Not replacing a split pin
Mistake	Incorrect action	Making the wrong response to an alarm	Using a bolt that is not the correct size
Queuing	Incorrectly prioritising actions	During an emergency, responding to ATC before going through the appropriate checklist	Failing to check for all tools before moving on to the next task
Filtering	Additional cues in your environment are unconsciously filtered out due to overload	Failing to see an oncoming flock of birds while talking to ATC and your co-pilot at the same time	Trying to finish maintenance quickly before close of business and tripping over an unnoticed cable
Coning of attention	Fixating on a single or limited number of tasks	In heavy cloud cover, fixating on certain instruments and neglecting others that have useful information	Focusing too much on one source of information during fault diagnosis
Regression	Under stress, behaviour may regress to the earlier, well-learned behaviours	Operating a control or selector in a manner that would have been appropriate to the previous type of aircraft flown but not the current one	Using a maintenance procedure that had been in place for many years but recently updated
Escape	Giving up completely on a task due to a build-up of stress		

Adapted from CAA's (2016) *Flight-crew Human Factors Handbook*

reflect the very real impact of stress on performance and wellbeing and they highlight the importance of stress-management programs.



Managing stress

Stress identification

An important process in stress management is stress identification. When working, you should be aware of your own stress levels and look for signs of stress among co-workers. The following symptoms could be signs that someone is under a lot of stress:

- agitation
- aggression
- absenteeism
- restlessness
- carelessness
- shaking
- social withdrawal
- less productive
- skipping meals.

> **If you believe that a co-worker is under a lot of stress, reach out and ask if they are okay. If you believe it could compromise safety let your supervisor know so that appropriate action can be taken as quickly as possible.**

Strategies for managing stress

The following strategies can be used to help manage stress.

- Learn to be attentive of the warning signs of stress (for example, agitating and shaking). When you have identified the symptoms you can take action before the stress escalates.
- Identify what factors are contributing to your stress. If time permits, address the causes of stress first (for example, complete stressful tasks first so that you are relieved of the stress for the remainder of the day).
- When a source of stress cannot be addressed, it can be beneficial to recognise and knowledge them and mentally put them aside.
- Identify all of the tasks required to be completed, and allocate an amount of time to each tasks to help you manage your available hours.
- If working on a large and overwhelming task, reduce workload by breaking the task down into smaller parts to focus your attention on one at a time. This is also a useful strategy of overcoming procrastination.
- When you are experiencing work overload, organise tasks to complete by their level of priority. Don't allow low priority problems to interrupt high priority tasks.
- If you are finding it difficult to concentrate or stay focused, rely on checklists and SOPs.
- Communicate with others. Other team members may be able to provide problem insights, or provide assistance in completing tasks.
- If your team have experienced a stressful event (for example, in-flight emergency or sustained, extended working hours due to high priority tasking) acknowledging that stress as a team can be cathartic and instigate the conversation for stress management as a team.
- Work within your limitations. Attempting something outside of your capabilities without assistance will exacerbate stress.
- Time permitting, take a break or hand over controls to another team member.
- Staying on top of your sleep, exercise and diet can make you more stress-resistant.

Summary

Stress is an inevitable part of human life and, in small quantities, necessary to achieve optimum performance. It is nature's way of keeping an individual keyed up for a task by helping concentration and making recognition of danger easier. Too many stressors; however, or prolonged exposure to stressors, can lead to anxiety and eventually to mental disorders such as depression.

The degree to which stress affects your performance will be contingent on the complexity of the task, your technical expertise, the number of contributing stressors, how often they occur and your perceptions of the stressors. Understanding how stress works will help you to manage stress so that you can perform at your best.

Failure to recognise and acknowledge your own stress can affect your ability to perform your job effectively, compromising your own safety and that of your team. It is your responsibility to manage your own stress and, where possible, identify and help manage stress in your team.

When it comes to stress-management training, some of the simplest strategies are overlooked because we are becoming stressed and overworked. Recognition and acceptance of the need for physical-maintenance strategies and good work-life balance (whatever you may wish to call it) is a really good start for anyone under stress.

Key points

- Stressors affect individuals differently, depending on their appraisal of those stressors and their ability to deal with them.
- Stress can benefit human performance but too much stress is harmful.
- Stressors can be classified in various ways, including hindrance or challenge, acute versus chronic, job-related versus home-related, and general versus contextual.
- A failure to cope with stressors can result in violations and errors, which may lead to accidents.
- The ability to recognise and manage stress in yourself and others is an important non-technical skill.
- There are methods to manage and cope with stress that, with a little practice, can be learnt by anyone.

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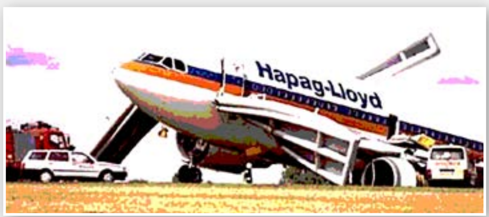
CASE STUDY FLIGHT 3378 — RUNNING ON EMPTY



Flight 3378 departed Khania, Crete, Greece, at 10:59 for a flight to Hanover. The flight crew encountered problems raising the right-hand main landing gear fully; however, they decided to continue the flight with the gear down and divert to München.

During the flight, the calculated spare fuel at Munich decreased on the flight management system (FMS). The flight crew now decided to divert to Vienna-Schwechat Airport instead. Approaching Vienna it appeared that there was not enough fuel on board. At about 4000 ft and about 12 nm short of the runway, both engines quit. The flight crew were able to restart one engine briefly, managing to reach the airport.

The aircraft landed in the grass some 500 m from the runway 34 threshold. The left main gear broke off and the no.1 engine and wing sustained substantial damage as the aircraft slid for 600 m before coming to rest. [From CASA's (2012) *Human Resource Guide for Pilots* (p.39)]

In this example, we see some of the features of a classic stress scenario unfolding. To begin with, the fact that the landing gear did not retract would have been appraised as a stressor but one that should have been well within the scope of the pilots' training and experience.

In the terminology we introduced earlier, it would have been a hindrance stressor, a major inconvenience but not something the flight crew couldn't handle.

The flight crew selected an alternative destination. The decision to divert would have caused discomfort of a different kind because a pilot feels pressured to get passengers to their destination.

The higher-than-expected fuel consumption during the continued journey would certainly have triggered some concerns for the flight crew but, again, not major ones because there were other destinations within reach. They didn't doubt their ability to get the plane down safely. Nevertheless, the pressures would have been compounding. They had now been forced to make two diversion decisions, passengers were not going where they thought they were going, and the aircraft was flying in an unusual configuration. As they thought about the situation they were in, and prepared for the cognitively-demanding landing phase of the flight, the flight crew did not pay sufficient attention to the fuel situation. The increased drag caused by the lowered landing gear consumed fuel at twice the normal rate.

The elaborate technology of the Airbus A310 did not help them because the FMS, which is capable of providing accurate fuel predictions, was not designed to be used when the undercarriage was deployed. Vine et al. (2015) found that when threatened, pilots tend to become more distracted with controls and to scan unnecessary instruments. In the end, the lack of fuel, not the undercarriage, was the cause of this near-catastrophe.

The investigation found that the continuation of the flight with a landing-gear problem until the engines failed due to fuel shortage caused the accident. A major contributing factor listed in the report was the flight crew's failure to comply with the company's rules on fuel reserves, caused by several human factors, the main ones being extreme workload and stress.

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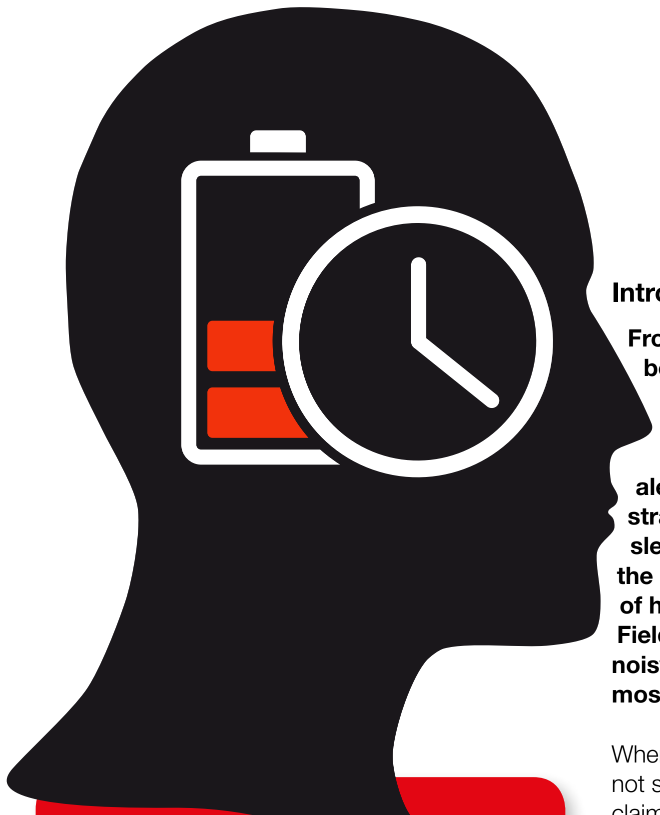
CHAPTER 9 Managing fatigue



Overview:

- Fatigue in high-reliability industries
- Basics of sleep, health and performance consequences associated with sleep loss, and attaining good sleep
- Potential causes of fatigue and how to minimise its effects
- Personal signs of fatigue and appropriate counter-measures
- Lifestyle choices that promote the effective, long-term management of fatigue
- Practices and countermeasures for managing fatigue at work
- Fatigue risk-management systems for preventing, identifying and managing the risks of fatigue at work

Introduction

From its earliest days, aviation has been in denial about fatigue and its impacts. Charles Lindbergh flew across the Atlantic in 1927 — a feat that required him to remain alert and piloting for 33 hours straight. The night before, he barely slept due to a combination of anxiety, the rain that pelted on the metal roof of his sleeping quarters at Roosevelt Field, near New York City, and the noisy newspapermen who played cards most of the night in the room next door.

When Lindbergh landed near Paris, having not slept properly for 57 hours, he initially claimed he had experienced "no trouble keeping awake". Yet in his subsequent published account of the flight he wrote: "My mind clicks on and off. I try letting one eyelid close at a time while I prop the other with my will. But the effect is too much, sleep is winning, my whole body argues dully that nothing, nothing life can attain is quite so desirable as sleep. My mind is losing resolution and control." (Lindbergh & Gould, 1956)

Despite the perennial challenge of fatigue in aviation and our ever-increasing understanding of how fatigue and sleepiness affect performance, the National Transport Safety Bureau (NTSB) did not identify fatigue as a major contributor to an airline crash in the United States until 1993. As recently as 2009, the NTSB was strongly criticised for not including fatigue as a causal or contributing factor in an accident that, according to a leading aviation-human-factors practitioner, showed the classic hallmarks of pilot fatigue [see sidebar 'Fails to acknowledge fatigue's role in the accident'].

Defence has acknowledged the challenges and dangers of fatigue and its obligations to manage the risks. As early as 1981, fatigue was formally recognised as a contributing factor to accidents [see case study 'Ground impact during low steep turn']. More recently, the Defence Fatigue Management Policy has been promulgated in the *Defence Safety Manual* (SafetyMan), prefaced by the following summary statements:

- Defence must eliminate or minimise the risk of workers experiencing fatigue in the workplace so far as is reasonably practicable
- The risks of workers experiencing fatigue arise from a variety of sources and for a variety of reasons and can be different for each individual worker
- Fatigue has predictable, adverse impacts on the workplace. Defence is committed to the proactive measurement, mitigation and management of the risks associated with fatigue.

[Source: SafetyMan Volume 2 — Defence WHS Policy Part 2, Chapter 10.]

The *Defence Aviation Safety Manual* (DASM) also provides guidance on managing fatigue-related risks in aviation operations. A point emphasised in the DASM is that the responsibility for managing fatigue is shared by everyone. The effective management of fatigue at all levels not only contributes to safety, it also ensures high levels of workplace performance and productivity. In addition, appropriate fatigue management helps to minimise the adverse impacts of challenging work schedules on the wellbeing of the employee and his or her family.

In transportation industries in Australia, including Defence aviation, the traditional approach to managing fatigue has been to prescribe maximum limits of duty hours and minimum breaks between duty periods. Such prescriptions are broadly designed to manage the risks of fatigue due to sleep loss, time awake, time on duty and the time-of-day effects.

However, the development of prescriptive limits is complicated by the number of fatigue-influencing factors (for example, 24/7 operations, shift work, time-zone transitions, complexity of operation and arduous living conditions). Further, traditional

An email to DDAAFS from an aviation safety officer…

Knowledge fosters informed decision-making at the coalface

I thought you might be interested to hear about something that happened yesterday at the squadron.

We'd had another long day, and our last maintenance test flight was due to launch at 1630 for about 1.5 hours in duration. As we were about to walk to the aircraft we had a phone call from a maintenance supervisor who said some of his team were showing symptoms of fatigue and had been discussing it with him.

His thoughts were that it was going to be a good 2.5 to 3 hours before their day was up, and they'd been working since 0630. As such he thought it might be jeopardising safety to go ahead with the flight as scheduled, and we subsequently knocked it on the head and programmed it for today instead.

I've not ever personally experienced this sort of thing happening at the squadron (not to say it's never happened, but I've never seen it originating from maintenance — they're very proud of their work and like to go the extra mile to get aircraft serviceable), so as you can imagine I was very pleased to hear the guys speak up and voice their very valid concerns.

I don't think it's a coincidence that this occurred shortly after your presentation [on managing fatigue], so thanks once again for giving some genuine legitimacy to the issue of fatigue in our workplace.

CASE STUDY

Fails to acknowledge fatigue's role in the accident

Shortly after 3 am on 21 August 2009, a plane approaching Teterboro Airport ferrying blood samples overshot the runway and crashed. Pope (2014) explored the causes and fallout of the accident.

Through the darkness across the Hudson River, New York City's dazzling all-night light show served as the backdrop for the Beech Baron's descent into Teterboro Airport. For the relatively inexperienced pilot in the left seat, this was a golden opportunity to sit beside the company's training captain and soak up knowledge from the veteran as he pointed out visual landmarks and described the unusual noise abatement procedure for the 3 am arrival.

Even though the younger pilot had been on duty for an exhausting 11 hours — and had worked about the same number of hours each of the previous two nights — the chance to fly to Teterboro for the first time with the company's chief pilot was worth the few extra hours of missed slumber.

As the Teterboro Tower controller cleared the Baron for the wide left base to set them up for landing on runway 1, the training captain continued to serve as New York-area tour guide. Neither pilot noticed their speed was still above 200 knots, too fast to configure the airplane for landing. According to an audiotaped interview with the young pilot from his hospital bed days later, the captain finally counselled him, you "had better slow down". The pilot recalled reaching up to bring the power to idle — but instead of grabbing hold of the throttles, according to the NTSB final accident report, he mistakenly put his hand around the propeller levers and pulled them all the way back. "What have you done?" the captain barked as the twin Continental IO-550s groaned in protest. "You've lost both your engines!"

What happened next was a blur, the young pilot said. As the captain repeated over and over that they had lost thrust in both engines, the Baron continued rocketing toward the runway at a ground speed of over 185 knots. The airplane sailed along the entire length of the runway, overshooting it and heading for the ominous speckled lights of the neighbourhood beyond. The pilots discussed their options, debated whether they should contact ATC, and finally began fighting over the controls before the Baron crashed on a street, hit a tree and burst into flames.

It turns out that the captain, who died from his injuries days later, knew something about this particular airplane that the less-experienced pilot perhaps did not. The Baron's propeller unfeathering accumulators, which provide oil pressure to the props to bring them quickly out of the feathered position, had been disconnected to make them easier to work on. With the props brought into the feathered position in flight, there was no way to remedy this stomach-churning error in the short amount of time available. The Baron's propellers were both found in the fully feathered position, just as investigators expected they would be. No other mechanical anomalies were uncovered that would suggest the accident was caused by anything other than what the young pilot had told them.

Strangely; however, nowhere in the probable cause statement did the NTSB list fatigue as a causal or contributing factor in the accident. This despite the fact that the accident pilot had flown for long periods over the previous three nights and the crash occurred at 3 am, when sleep research shows the circadian rhythm (the body's natural internal clock) exhibits its strongest sleep drive. The captain had also been on duty long hours flying at night, perhaps explaining why he didn't do a better job of monitoring the other pilot's actions.

The omission caused a minor rebellion within the NTSB as then Chairwoman Deborah Hersman and board member and noted sleep expert Dr. Mark Rosekind publicly issued dissenting statements in which they argued strongly that the crash showed the classic hallmarks of pilot fatigue. Training deficiencies and other factors undoubtedly played roles too, they acknowledged, but the errors made by the pilots were clear signs that both were overly tired. "Despite substantial indications of fatigue effects," Rosekind wrote in his dissenting brief, "the present accident report fails to acknowledge fatigue's role in the accident. Based on the factors identified, fatigue was a likely contributory cause."

Source: Stephen Pope, *Flying*, November 27, 2014

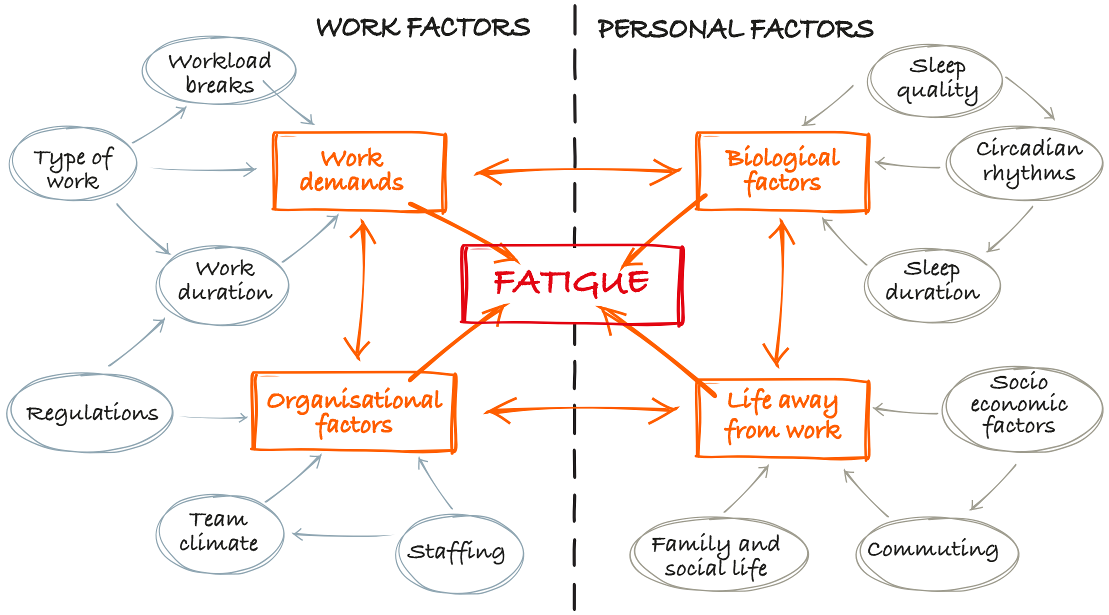


Figure 9–1. Workplace and personal factors that may contribute to employee fatigue (Adapted from Hobbs, Avers & Hiles, 2011)

prescriptive approaches lack operational flexibility, which can be counterproductive.

Importantly, it is now widely acknowledged that the use of prescriptive limits represents a single defensive strategy that, if used in isolation, is likely to be inadequate to address the fatigue-related hazards encountered in aviation operations. Instead, a multilayered approach utilising several defences is advocated because it provides greater depth and operational flexibility.

A fundamental principle of fatigue management is educating employees about the causes and outcomes of fatigue and how to prevent and manage them appropriately. This fosters adaptive risk management. This chapter has six main topics:

- the basics of fatigue including causes, signs, impacts on performance and the health consequences of chronic fatigue
- the need for sleep
- the circadian cycle or body clock
- sleep deprivation
- fatigue-prevention strategies
- fatigue-management strategies, including the risks of fatigue during shift handover and when commuting.

The basics of fatigue

What is fatigue?

Fatigue is a state of reduced physical and mental capacity as a result of loss of sleep, extended wakefulness, circadian phase and/or significant physical or mental workload.

Fatigue in the workplace can significantly impair a person's ability to perform tasks effectively, efficiently and in some cases, safely. Almost any type of task can be adversely affected by fatigue, but particularly duties that require sustained concentration, complex thinking, and manual dexterity.

Fatigue can also be described as acute, cumulative and circadian. Acute fatigue occurs in a relatively short time (hours or even minutes) after significant physical or mental activity. Cumulative fatigue develops gradually over several days or weeks and typically occurs when someone does not get sufficient sleep and/or respite from work over a prolonged period. Circadian fatigue refers to reduced performance during night-time hours when our body would prefer to be asleep or due to transmeridian travel that causes the circadian cycle to be out of sync (commonly referred to as jet lag).

Fatigue — the stop emotion?

Recently, some researchers have considered fatigue as a stop emotion. Fatigue is what influences an individual to withdraw from a task, either mentally (such as tuning out) or physically (stopping what you are doing). When individuals spend too much time on one task it tends to sap their motivation and/or cognitive resources. As a result, fatigued individuals either show a decline in performance or a change in how they manage their performance.

The classic example is the speed/accuracy trade-off. Tired individuals tend to slow their performance in order to maintain their accuracy. As such, fatigue can be seen as an adaptive mechanism that prevents the exhaustion of resources or an overly strong focus on one particular task. In this perspective, feeling tired can be seen as a protective mechanism that is warning us that we need to rest, recover, and/or avoid stress.

Causes of fatigue

Fatigue is normally the product of one or more of the following:

- adverse environmental conditions, such as extremes of temperature, low light levels, and confined spaces
- strenuous or sustained physical exertion
- inadequate food and fluid intake
- periods of monotony or boring activities
- mental workload: a function of cognitive processing demands and time on task
- emotional strain
- lost and/or disrupted sleep.

As shown in Figure 9–1, both work and non-work factors can contribute to fatigue. Work-related fatigue may be induced by early morning starts, long work hours, high work intensity, high levels of responsibility, pressing deadlines, long periods of concentration, interpersonal tensions, changing shift schedules, insufficient rest time between shifts, inadequate recuperation when fatigue develops, or some combination of such factors.

This list of factors is far from exhaustive. Examples of common non-work-related factors that generate fatigue include:

- disturbed sleep (for example, noisy neighbourhood, unsettled/noisy bed partner)
- disrupted sleep (for example, a sick child, infant feeding, phone calls)
- undiagnosed or untreated sleep disorders
- social pursuits that are given priority over sleep (for example, parties, watching television, computer-based activities).

The main causes of fatigue among Defence aviation personnel are summarised in Table 9–1. Both work and non-work factors are evident. Unfortunately, the survey did not include simple lack of adequate sleep as a given cause of fatigue.

Fatigue due to sleep loss is increasingly prevalent in contemporary Western society, with proven consequences on loss of productivity, risks to workplace health and safety, and reduced quality of life. Both the quantity and the quality of sleep are critical for maintaining normal alertness and performance, and to ensure recovery from fatigue when it develops.

Mental fatigue

The impact of fatigue on mental performance has attracted increasing interest among researchers. The effects of sleep loss and a challenging, continuous workload are most pronounced on simple cognitive tasks such as vigilance, working memory and psychomotor tasks. However, it is becoming more evident that sleep loss and high, sustained workload also degrade higher cognitive tasks such as creative problem-solving, judgement, and decision-making. Furthermore, the ability to judge how well or how poorly one is performing

Given cause of fatigue	% reporting this cause
Poor or disrupted sleep	48
Shift work (particularly night shift)	38
Work demands	31
Work-related stress	30
Family demands	25
Demanding mental work	23
Personal choices	19
Stress related to private life	18
Changing time zones or jet lag	18
Extended periods of constant work	15
Periods of boredom/monotony at work	13
Environmental conditions	10
Physical hard work or prolonged exertion	8
Lack of adequate food or water	2

Defence Aviation Fatigue Survey, 2011, > 1600 respondents

Table 9–1. Causes of fatigue for Defence aviation personnel

CASE STUDY GROUND IMPACT DURING LOW STEEP TURN

Kiowa A17-048, Weipa, 23 September 1981

While repositioning the aircraft to an adjacent passenger pick-up point, the pilot elected to complete a circuit, during which he performed a climbing right turn.

As the aircraft rolled out of this turn it had a nose-low attitude and a high rate of descent. The aircraft subsequently impacted the ground. The aircraft rolled several times suffering a main rotor strike to the ground causing mast separation and substantial fuselage damage. The pilot and the one passenger received minor injuries. The aircraft was damaged beyond repair.

Pilot's 72-hour history

- 20 September — the pilot flew half-an-hour before midnight, then from 0300 to 0400 hours. At 0900 hours he flew rehearsals for a display later in the day, and at 1400 hours performed the short display. At 1600 hours he flew a one-hour mission and then stood down until the following day.
- 21 September — the pilot flew 2.7 hours during the day, finishing mid-afternoon. He then rested until midnight, but was unable to sleep because of the oppressive conditions.
- 22 September — the pilot flew from midnight to 0030 hours; then slept under a hutchie, being on 10-minute standby. He was awakened at 0530 hours by another helicopter departing, then went back to sleep until 0630 hours when he was tasked for a one-hour flight. He completed this task, shut down at the airfield and was flown back to town in another helicopter at 0800 hours.
- He then stood down for a rest day, as he had been on duty for 10 days. He purchased some take-away food for breakfast and then retired in the single-person's quarters, where, for the first time in 10 days, he had a single room and a bed. He read a book during the day, occasionally dozing off. Take-away food was purchased for dinner and he went to bed about 2200 hours but got up shortly thereafter when some friends arrived. He eventually got to sleep at 2300 hours.
- 23 September — he woke at 0615 hours and went to the airport where he had a cup of tea (no food) then took off at 0700 hours for the sortie, which ended with the accident at 0727 hours.

Investigation outcome: The medical officer's report concluded that human factors played a major role in the accident. Pilot fatigue was compounded by the previous 10 days of duty, with nominally only six hours per day off, poor crew-rest facilities, monotonous diet leading to poor food intake, adverse environmental conditions (high temperatures and humidity), and the inability to share workload equally across all pilots (a third pilot was not cleared for night flying).

Source: Adapted from: *Sifting through the '80s: Australian Defence Aviation Accidents* 1980–89, pp. 14–17. Canberra: DDAAFS

Secret study says air traffic controllers are dangerously overworked

Air traffic controllers' demanding schedules can result in chronic fatigue and inhibit their ability to keep travellers safe, according to a previously unreleased study requested by the Federal Aviation Administration and conducted by NASA. The study has been kept secret for almost four years, despite dogged attempts by the Associated Press (AP) to extract it through Freedom of Information Act requests.

The study found that nearly 20 per cent of controllers had "committed significant errors in the previous year" and more than half of them blamed fatigue for the mistakes, according to the AP, which obtained a draft of the final report dated December 2011. Controllers averaged less than six hours of sleep each day, with less rest before time spent working at odd hours.

In one popular shift, called the "rattler", controllers squeezed five eight-hour shifts into four 24-hour periods in order to enjoy a three-day weekend, resulting in little recovery time between shifts.

The study recommended that controllers not be allowed to work six-day weeks, as 30 per cent of those who worked such a schedule admitted to committing significant errors. The AP reported that such schedules remain common today.

Source: Groden (2015)

on a given task is also impacted by sleep loss. We are generally unaware of our declining abilities during sleep deprivation. This is known as the insidious nature of fatigue and may explain why approximately one third of fatal motor vehicle accidents in Australia are linked to fatigue.

Attentional blinks

Another recent concept of relevance to aviation operations is known as the attentional blink. Mental fatigue is strongly associated with lapses of attention.

And in the complex, time-pressured and high-stakes environment characteristic of aviation operations, even the smallest of lapses in attention — attentional blinks — can generate errors and gaps in situation awareness. As we have seen in earlier chapters, aviation has low tolerance for errors and a need for exactness in attending and responding.

Aviation personnel need to be aware of the potential for attentional blinks by doing their best to monitor the level of fatigue in themselves and their team members and consider the potential for performance deficits related to tiredness.

Signs and symptoms of fatigue

Effective fatigue management requires a sound knowledge of the signs, symptoms and effects of sleep loss and fatigue. Fatigue-related signs and symptoms are often divided into three categories: physical, mental/cognitive, and emotional/social. Table 9–2 outlines some of the common signs in each category.

The more symptoms listed in the table that you experience at one time, the more likely it is that your performance is substantially impaired. Unfortunately, humans are generally unreliable judges of their own fatigue levels. Not only is it difficult to judge or measure the level of fatigue that indicates it is no longer effective or safe to work or drive, the impact of fatigue is often insidious — that is, we often do not realise how much it is affecting us.

Of course, fatigue is not the only cause of many of these symptoms, but when several occur together, it is likely to indicate fatigue is the main cause of the impairments.

Physical	Mental	Emotional/social
• Yawning	• Responsiveness and performance are slowed	• Being more quiet than normal
• Lack of energy or vitality, drowsiness	• Difficulty concentrating on tasks	• Reduced task motivation
• Slowed blinking	• Lapses in attention/vigilance	• Depressed mood, tendency to magnify grievances
• Bloodshot eyes, eye strain, sore, heavy or sandpaper eyes, dim or blurred vision	• Unintentionally failing to do the right thing	• Irritability or bad-tempered behaviour with colleagues, family, or friends
• Headaches	• Failure to communicate important information	• Despondency in response to challenge
• Slurred speech	• Increasing forgetfulness	• Argumentativeness
• Unstable posture, head droops	• Reduced ability for complex tasks	• Lowered sensitivity to the cues of social interaction
• Paleness of skin	• Failure to anticipate events or actions	• Loss of sense of humour
• Micro-sleeps	• Becoming easily confused	• Social withdrawal
• Lowered body temperature	• Unintentionally doing the wrong thing	• Difficulty controlling emotional reactions
• Intermittent loss of muscular strength, stiffness, cramps	• Narrowed perception (perceptual tunnelling)	• Decreased satisfaction with work
• Difficulty in fine motor movements (reduced dexterity)	• Cognitive slowness in general	• A sense of pessimism (even fatalism on deployment)
• Faintness, dizziness and nausea	• Deterioration in working memory	• Greater acceptance of risk

Table 9–2. Signs of fatigue

Impacts of fatigue on performance

Fatigue impairs performance. Often these performance impacts are subtle and fluctuating. For reasons of the circadian trough, night shift is particularly prone to decreased alertness, which consequently affects functioning in numerous ways. Other factors play a role in work performance as well, such as the type of task to be performed, motivational influences, individual differences in training, experience, and ability, and how well workers are adjusted to the current shift schedule.

Unlike most health effects, deterioration in performance can occur quite quickly after beginning to work non-traditional shifts. The negative effects on performance are exacerbated in jobs that require sustained attention and extended hours, or are characterised by high-reliability tasks where lapses or mistakes can have serious consequences.

Some specific effects of fatigue on performance are explained below.

- **Reduced attention.** People are slow to notice occurrences in their environment such as unusual congregations of people (in a headquarters) or the approach of an aircraft (in the field or at sea).
- **Communication difficulties**. As you become fatigued, it is increasingly difficult to decide what and how to communicate, especially if you are transmitting someone else's message. Signs of tired staff include an inability to formulate messages quickly and coherently, the omission of important information in messages or briefs, and speech that has become unintelligible.
- **Mood changes.** Significant changes in mood normally accompany performance degradation. These almost always include increased irritability and can entail depression, anxiety, and apathy.
- **Inability to concentrate.** Maintaining attention to the task at hand, for even a few seconds, is difficult when fatigue is extreme. As a result, personnel may not be able to follow even basic directions or perform simple numerical calculations. They can be easily confused.
- **Increasing omissions and carelessness.** Tired personnel begin to skip tasks, miss events, and make mistakes. Examples of omissions might include: failure to perform routine checks, to take time-zone differences into account, or to comply with normal security procedures.
- **Decreased vigilance.** As people become less alert, they may fail to detect errors and potential hazards, especially during monotonous tasks or in tedious environments. The monitoring of display screens is especially effected. Tasks requiring sustained attention (typical in air traffic management, signal monitoring) are the most adversely affected by fatigue.
- **Slowed comprehension and learning.** It takes longer to understand any form of information; for example, it may take an excessive amount of time to comprehend a communication, to locate a position on a map, or to find an electronic file.
- **Encoding/decoding difficulties.** It becomes more difficult to transform data or to process information; for example, co-ordinates are decoded slowly, or the phonetic alphabet becomes a challenge, and mistakes are made while doing tasks that are normally automatic.
- **Faulty short-term memory.** Recall of recent events becomes increasingly faulty when we are tired. The content of voice communications may be immediately forgotten or recalled incorrectly. The ability to assimilate new information is also degraded.
- **Muddled thinking.** Reasoning becomes slower and confused. Even simple and routine administrative and operational procedures and situations may stump the employee (albeit temporarily). This can deteriorate to irrational thinking/poor logic when fatigue is extreme.
- **Slowness in perception.** People are slow to understand things seen or heard, especially patterns; for example, the significance of changes in traffic signals or screen displays may be missed.
- **Slow and uneven responsiveness.** When tired, people are generally slower to respond to events, and some reactions degrade more quickly than others.
- **Differential impacts due to task complexity.** Uninteresting and complex tasks, as opposed to those that are interesting and simple, are more seriously affected by fatigue.

Quantifying the risks of fatigue

Employers are often dismissive of fatigue because it is difficult to quantify — there is no blood test or human speedometer reading to indicate when fatigue is definitely a problem.

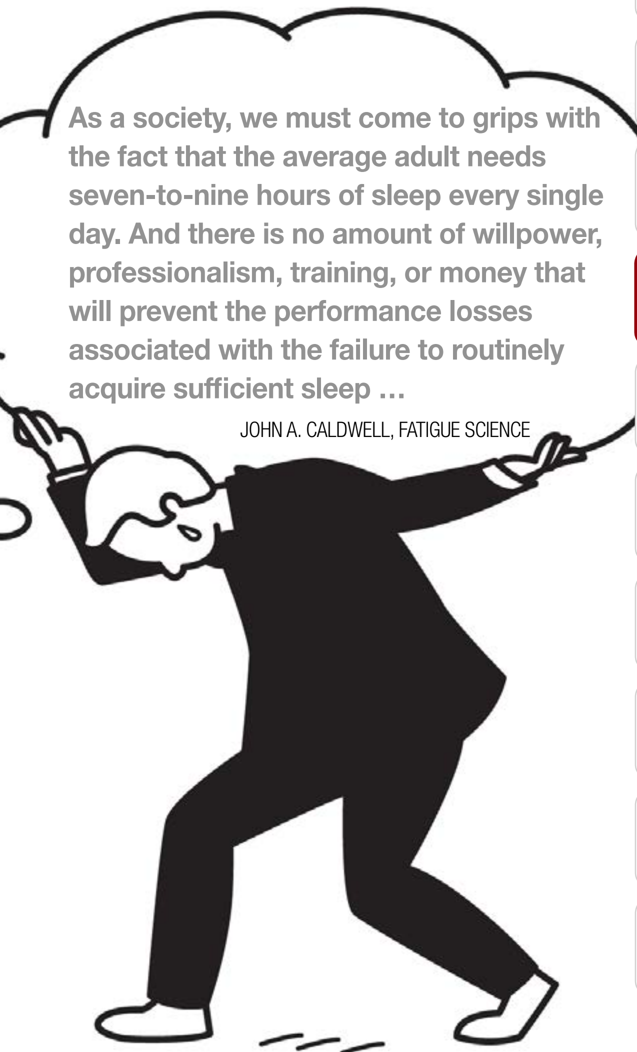
Researchers have countered this indifference by drawing comparisons between fatigue and alcohol in terms of their effects on performance. Because of long-standing public education campaigns (and perhaps personal experience), most people understand and accept that alcohol intoxication causes significant safety risks at work and especially on the roads. Drawing clear comparisons between fatigue and alcohol has tended to increase acceptance that fatigue at work deserves at least the same attention as alcohol.

The two main findings from these comparative studies are summarised below.

- The performance of a person who has been awake for 17 hours (for example, from 0700 hours until midnight) is likely to be as impaired by fatigue as someone with a blood-alcohol concentration (BAC) of 0.05 per cent — the legal driving limit in many countries.
- A person who stays awake for 23 hours (for example, from 0700 hours until 0600 hours the following day) is likely to have performance impairment similar to someone with a BAC of 0.10 per cent — twice the legal limit for fully licenced drivers in Australia.

Although there are differences between being fatigued and being drunk, this research has provided employers and employees with meaningful comparisons that send strong messages about the potential adverse effects of fatigue. For example, one night of lost sleep can leave you more impaired than would be acceptable for driving a vehicle.

Equating the impact of fatigue with the effects of alcohol intoxication has proven to be a useful approach for predicting performance impairment and informing commanders, policy-makers, and workplace supervisors about the importance of implementing fatiguemanagement programs.



Regular hours of continuous sleep	ADF %
3–4 hours	8
5–6 hours	34
7–8 hours	54
9–10 hours	4
More than 10 hours	1

Table 9–3. Reported hours of sleep for Defence members

The need for sleep

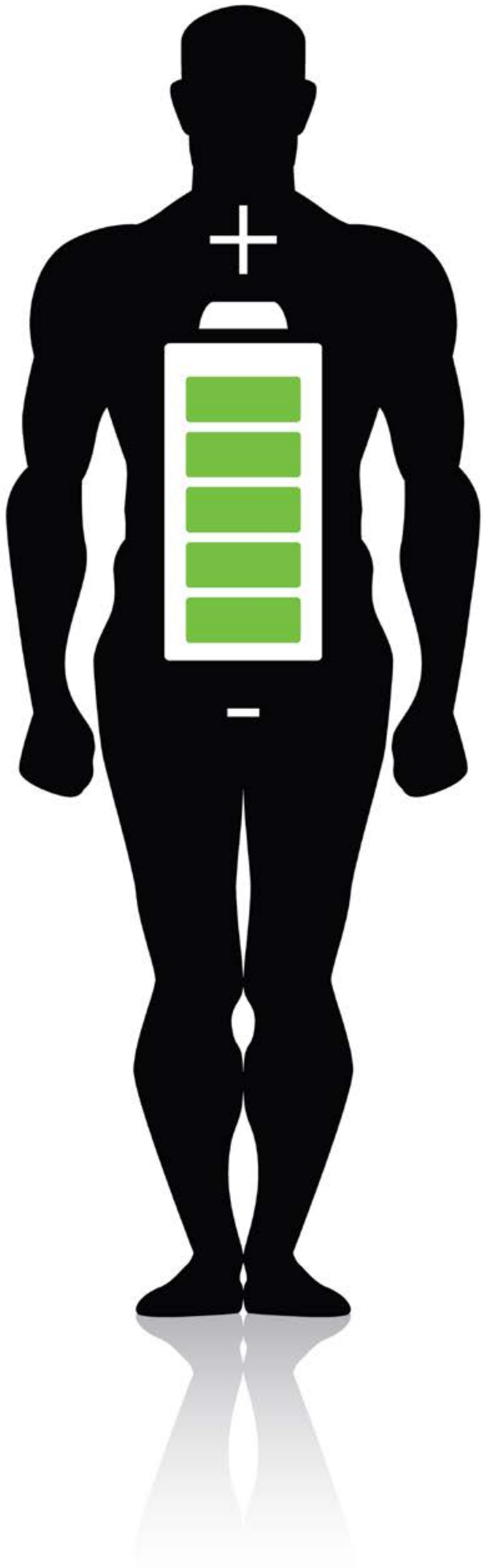
Sleep plays a vital role in memory and learning, in maintaining alertness, performance, and mood, and in overall health and wellbeing. Scientists and researchers continue to uncover ways in which sleep contributes to a range of other human functions.

How much sleep is required to avoid fatigue? It is telling that human science researchers rarely agree on anything, yet there is significant consensus that adult humans need at least seven to nine hours of quality sleep each 24-hour period in order perform effectively throughout the following waking period. In this light, the results of surveys of sleep habits among Defence personnel raises significant cause for concern. Table 9–3 summarises sleep achieved by 5200 Defence respondents.

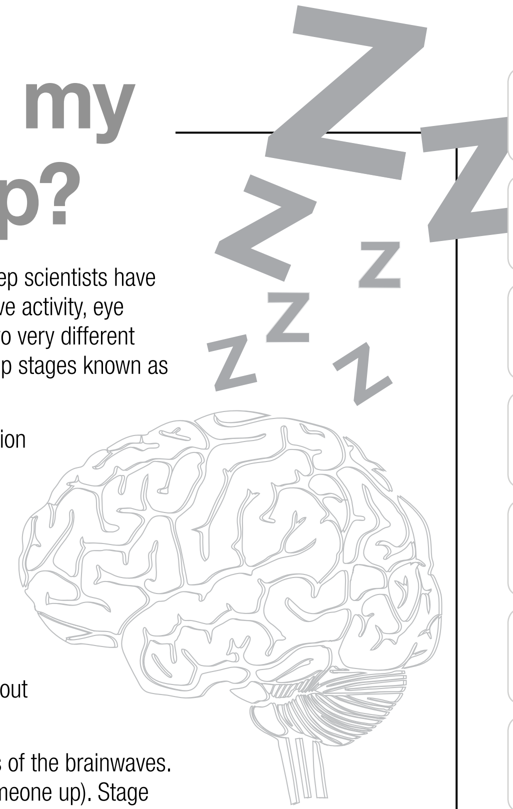
According to these results, four-out-of-ten Defence members are not getting the sleep they need to perform at their best each day. While there are individual differences in sleep need, the findings in Table 9–3 can probably be best explained by cultural factors (for example, the military's can-do attitude, and the prevailing myth of immunity to sleep loss) and the increasing prevalence in Western societies of people sacrificing sleep for other activities despite the documented adverse effects.

From the dual responsibility perspective of fatigue management, individuals need to understand and accept that they must arrive at work in a fit state to perform effectively for their duty period. The only reliable way to ensure such fitness for duty is to get seven to eight hours of sleep regularly. This is especially important; indeed it is an ethical responsibility for personnel involved in high-reliability occupations.

The quality of sleep is just as important as the amount of sleep because quality equates with restorative value. Sleep that is fragmented by multiple awakenings or disruptions to the sleep cycle's architecture (that is, deep



What happens to my brain during sleep?



A complex series of processes takes place in the brain during sleep. Sleep scientists have traditionally looked at sleep by monitoring electrical patterns in brain wave activity, eye movements and muscle tone. These measures indicate that there are two very different types of sleep: rapid eye movement (REM) sleep; and a collection of sleep stages known as non-rapid eye movement (non-REM) sleep.

REM sleep. During REM sleep, the brain is restoring itself and information from the previous day is being sorted and related to stored memories. People awakened from REM sleep can typically recall vivid dreaming. During REM sleep, the body cannot move in response to signals from the brain, so dreams cannot be acted out.

Non-REM sleep. During non-REM sleep, brainwave activity gradually slows compared to waking brainwave activity. Among other things, the body is being restored through muscle growth and repair of tissue damage. Across a normal night of sleep, most adults generally spend about three quarters of their time in non-REM sleep.

Non-REM sleep is divided into three stages, based on the characteristics of the brainwaves. Stages 1 and 2 represent lighter sleep (it is not very difficult to wake someone up). Stage 3 is also known as slow-wave sleep (SWS) or deep sleep. Basically, in SWS the brain largely stops processing information from the outside world and huge numbers of brain cells (neurons) start firing in synchrony, generating big, slow electrical waves. During SWS, consolidation of certain types of memory is occurring, so SWS is necessary for learning.

Across a normal night of sleep, non-REM sleep and REM sleep alternate in a cycle that lasts 60 to 90 minutes. Figure 9–2 summarises the non-REM/REM cycle across the night in a healthy young adult who goes to bed at 11 pm and wakes around 7.30 am. Real sleep is not as tidy as this — it includes more arousals (transitions to lighter sleep) and brief awakenings. Sleep stages are indicated on the vertical axis and time is represented across the horizontal axis.

Sleep is entered through Stage 1 non-REM and then progresses through Stage 2 non-REM (A in Figure 9–2) and eventually into slow-wave sleep (B). About 80 to 90 minutes into sleep, there is a shift out of slow-wave sleep (C). This shift is often marked by body movements, as the sleeper transitions briefly through Stage 2 non-REM and into the first REM period of the night (REM periods are indicated as shaded boxes). After a fairly short period of REM, the sleeper progresses back down again through lighter non-REM sleep (D) and into slow-wave sleep, and so the cycle repeats.

Waking up from sleep is a process, not an on/off switch, and various parts of the brain have to reactivate in sequence. People sometimes experience the transient grogginess and disorientation known as sleep inertia, when they are conscious but not fully awake. Sleep inertia can occur during waking from any stage of sleep and may be worse after longer periods of sleep.

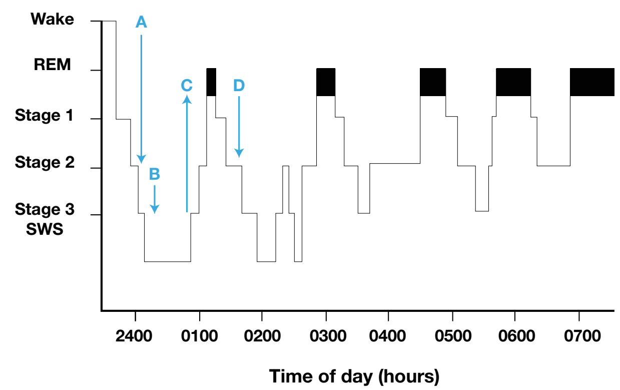


Figure 9–2. The non-REM/REM cycle across the night, for a healthy young adult

Source: Adapted from *ICAO Fatigue Management Guide for Airline Operators*

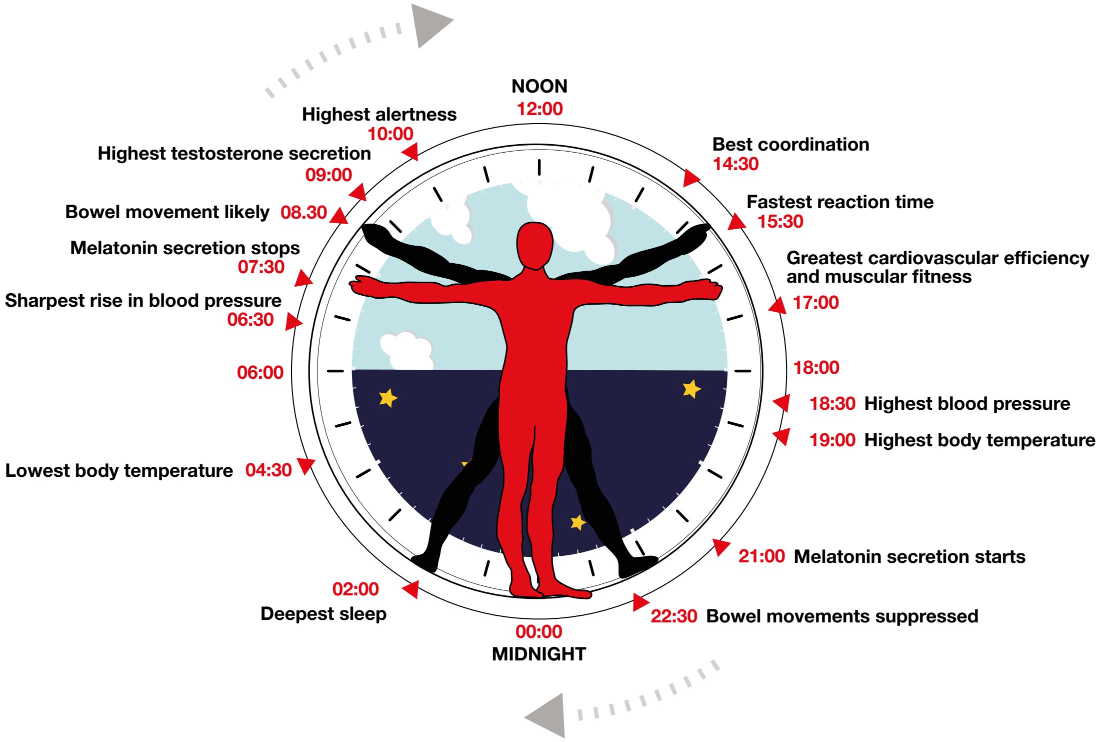


Figure 9–3. A selection of events in a representative circadian rhythm

sleep being disturbed) is less restorative. Poor sleep affects how you feel and function the next waking day.

The impact of drugs and alcohol on sleep patterns

Both the occasional use of sleeping pills and the consumption of alcohol effect sleep patterns by suppressing REM sleep. Overuse of sleeping pills significantly reduces both REM and Stage 4 sleep — the two most critical stages of sleep. Caffeine increases the time it takes to fall asleep and decreases time spent asleep. Alcohol results in more awakenings during sleep and more frequent shifts in sleep stages. The message is clear: drugs and alcohol should be avoided if getting quality sleep is important. Effective, non-drug approaches to sleep difficulties are addressed later in this chapter.

The body clock (the circadian rhythm)

One of the most predictable environmental variations to which the body must respond is the cycle of night and day. This cycle relates strongly to why we feel sleepy at night and awake during much of the day. Many physiological rhythms, such as sleepiness and wakefulness, the secretion of digestive enzymes, specific hormone production (such as testosterone and melatonin), and core body temperature operate very close to a 24-hour cycle. These are called circadian (about a day) rhythms that are controlled by a human body clock.

As the day begins, body temperature, alertness, and mental performance begin to rise. Best mental performance is usually mid-morning to early afternoon (0700–1400) and in some tasks (for example, vigilance and reaction time) between 1900 and 2100. Late night/ early morning work is a problem for most people because it requires overriding their body clock. Moods and willingness to work are also detrimentally affected during certain stages of the daily body clock. Figure 9–3 illustrates some aspects of a circadian cycle superimposed on a 24-hour clock.

CASE STUDY AVIATION ACCIDENTS INVOLVING FATIGUE

Even when fatigue is not the main cause of an accident, it is often recognised as a contributing factor that affects the crew's ability to react appropriately to a specific situation. Below is a selection of accidents/incidents where fatigue was formally recorded as a factor.

- **1981**, 23 September, Kiowa A17-048, Weipa. The medical officer's report concluded that human factors played a predominant role in the accident. Pilot fatigue was compounded by being on duty for the previous 10 days (with nominally only six hours per day off), poor crew-rest facilities, monotonous diet leading to poor food intake, adverse environmental conditions (high temperatures and humidity), and the inability to share workload equally across available pilots (a third pilot was not cleared for night flying). [See case study on page 130]
- **1993** Kalitta International, DC-8-61F at Guantanamo Bay. The flight crew had been on duty for 18 hours and flown nine, thereby experiencing sleep loss and a disruption of their circadian rhythms. The company had intended for the crew to ferry the airplane back to Atlanta after it was offloaded in Guantanamo Bay. This would have resulted in a total duty time of 24 hours and 12 hours of flight time. The NTSB concluded: "Probable Cause: The impaired judgment, decision-making, and flying abilities of the captain and flightcrew due to the effects of fatigue."
- **1994** Air Algerie, 737-200F at Coventry, UK.
- **1997** Korean Air, 747-300 at Guam. Before the accident flight, the captain had flown from Seoul to Australia, back to Seoul, to Hong Kong, and then back to Seoul, all with only a few hours of rest.
- **1999** American Airlines, MD-82 at Little Rock, USA.
- **2001** Crossair, BAe146 at Zurich, Switzerland. The accident investigation report stated "the commander's ability to concentrate and make appropriate decisions as well as his ability to analyse complex processes were adversely affected by fatigue."
- **2002** AgcoCorp, Challenger 604 at Birmingham, UK.
- **2004** MK Airlines, 747-200F at Halifax. One of the causal factors identified by the investigation was human error, caused by the crew being fatigued.
- **2004** Corporate Airlines, BAe Jetstream31 at Kirksville, USA.
- **2004** Med Air, Learjet35A at San Bernadino, California.
- **2005** Loganair, B-N Islander at Machrihanish, UK.
- **2006**, 11 April, Cessna 177B Cardinal, Cheyenne, Wyoming. Jessica Whitney Dubroff was a seven-year-old girl who died while attempting to become the youngest person to fly a light utility aircraft across the United States. The NTSB noted that Joe Reid, pilot-in-command, suffered fatigue from the first day's flight. That fatigue seems to have impaired his judgment, allowing him to depart into weather that other experienced pilots deemed worth a delay.
- **2006**, 27 August, Comair, CRJ100 at Lexington KY. Both controller and pilots were judged as being fatigued.
- **2007**, 25 June, Cathay Pacific 747F. Ground collision at Stockholm Arlanda — crews awake 18 to 20 hours; incident at 03:30 a.m.
- **2007**, 28 October, JetX, 737-800TF-JXF. Serious runway excursion at Keflavik airport, Iceland. Due to delays at the departing airport (Antalya), the flight duty period was extended until 17 hours 20 minutes, instead of a maximum of 16 hours and the crew did not get adequate rest between the two flights.
- **2009**, 12 February, Colgan, Dash8-Q400 at Buffalo, USA. Two pilots seriously fatigued, 50 killed.
- **2010**, 22 May, Air India Express, Boeing 737-800, Mangalore, India. Captain slept a large part of the flight, woke up shortly before landing and was unable to prevent a runway excursion.158 people were killed.

The circadian cycle has two periods of sleepiness, known as the circadian trough (the major slump in alertness) and the circadian lull or dip (a smaller slump). The circadian trough occurs typically between 0200 and 0600 hours (or until dawn). During the circadian trough, the body's temperature is at its lowest level and mental performance, especially alertness, is at its poorest.

The circadian lull has a smaller decline in alertness and performance that typically occurs between 1300 and 1600 hours (the post-lunch dip). Although relatively small, there are numerous indicators that demonstrate the impact of the circadian lull. For example, road accidents tend to spike during these hours.

These biological rhythms do not adjust easily to changes imposed by non-traditional work schedules. On the whole, people find working at night more difficult than working during the day. This is because night schedules disrupt sleep/wake patterns and other biological rhythms. At the start of a night-shift roster, workers find themselves trying to be alert, to sleep, and to eat when their body is not programmed to do so.

Night-shift workers normally have to work through the window of circadian low (WOCL). WOCL refers to a time on the circadian clock where the body is most primed for sleep; typically between 0200 and 0600 hours. During this time alertness levels are at a low, and the secretion of melatonin, a sleep-inducing hormone, is at a high. Not only can working during this time be uncomfortable, but it can also be more dangerous. This explains why long-term shift workers are more likely to make errors at work, to experience fatigue, and to suffer health complaints such as gastrointestinal disorders.

Circadian dysrhythmia (aka jet lag)

The body clock keeps time (that is, it synchronises its circadian rhythms to a 24-hour pattern) by attending to various cues related to our normal daily routine. These cues are known as zeitgebers (time givers). Light, sleep periods, and the timing of meals appear to be among the most powerful zeitgebers. Bright light can shift the phase of the human circadian clock when applied at particular times (by stimulating what is known as the dawn effect when much of our physiological increases in activity).

Interestingly, if zeitgebers are suppressed (for example, continuous, low-intensity, artificial lighting, continuous snacking), the free-running rhythm of the human circadian cycle tends to increase to a little beyond 24 hours (usually somewhere between 24.2 and 24.9 hours). This tendency to extend beyond 24 hours may explain why most people find it easier to get to sleep after staying awake late than it is to sleep earlier than usual.

Rotational shiftwork and international air travel involve unstable sleep/wake schedules, variable light exposure, and changing meal times. This explains why shiftwork and transmeridian air travel are the two main culprits for the body clock becoming confused and, if changes are prolonged, misaligned or desynchronised. This body clock confusion is known formally as desynchronosis or circadian dysrhythmia. Jet lag or shift lag are common terms for circadian dysrhythmia. Typical symptoms are fatigue, nausea, sleepiness, lack of motivation, mental confusion, adverse emotional states, and digestive system upset. Obviously, such symptoms can contribute to lowered performance and wellbeing.

With respect to readjustment after circadian dysrhythmia has occurred, there is a general rule of thumb that the body clock can adjust about an hour each 24-hour period. Therefore, an eight-hour difference in time zones or shift schedules will take about a week of adjustment before the body is back to normal. Different components of our physiology re-adjust at different speeds and in different directions, with core body temperature being one of the slowest to change. Of course, many shift workers do not stay on a particular shift long enough for full readjustment of the circadian cycle to occur. This is why many shift workers are in a perpetual state of circadian upheaval — they rarely have the opportunity to stabilise their body clock.

There is some evidence that the speed of circadian cycle readjustment can be enhanced by a number of proactive and reactive actions. In some cases, pre-emptive modifications to sleep and work patterns can assist. Planned exposure to bright light, and specific timing of meals and work shifts, can also be useful. Further information about understanding and managing jet lag is available at the end of this chapter.

Morningness and eveningness (larks and night owls)

Some people can be categorised as morning or evening types (chronotypes) depending on the period of the day when they perform at their best. Morning people will better adapt to early-morning hours but will have more trouble coping with night work. Evening types cope more easily with evening and night shifts. Evening types also tend to cope better with shiftwork overall since they generally have less rigid sleep habits and find it easier to catch up by sleeping late in the morning.

Some people have their biological clocks well ahead of the normal daily cycle, while others are considerably behind. People who prefer rising early (often before 0600 hours), enjoy working in the morning, and cope best with demands early in the working day are commonly referred to as larks or early birds. In contrast, the night owl can be very alert even late at night and well into the early hours of the new day (perhaps until 0200 or 0300 hours). Most people are not this extreme but do identify having a preference either for morning (known as the morningness type) or evening (eveningness).

Some people may not conform to any category (early bird, morning, evening, night owl) because they are either inconsistent (some days a lark, some days an owl) or simply do not identify their alertness or performance with a time of the day. However, beyond age 50, many people show a marked preference for morningness.

Sleep deprivation

When actual sleep obtained in a 24-hour period is less than an individual's sleep need, sleep deprivation has occurred. Sleep deprivation is also referred to as "having a sleep debt". Inadequate quality of sleep can also contribute to a sleep debt. Cumulative sleep debt occurs when there is reduced sleep over many nights. Sleep debt can only be repaid by obtaining adequate recovery sleep.

The results of studies into sleep deprivation are notoriously inconsistent. This is partly because some skills and abilities appear to be resistant to moderate levels of sleep deprivation (for example, reading comprehension) while others are clearly vulnerable (for example, planning and decision-making). Nevertheless, it is clear that even one night of sleep deprivation can have measurable impacts on overall performance. Furthermore, the adverse impact of sleep deprivation on mood is one of the most consistent findings from research. Tired people normally become irritable and find it more difficult to control their emotional reactions to unexpected and trying events.

While the most obvious debilitating effects of sleep deprivation are psychological rather than physical, there are two readily observable symptoms of sleep deprivation (characterised by a mix of physical and mental impairment): micro-sleeps and sleep inertia.

Micro-sleeps

When sleep-deprived, we are prone to drifting into short lapses of sleep (nodding off) that may last a matter of a few seconds. These micro-sleeps do little to overcome the effects of fatigue. Micro-sleeps are unavoidable when sleep loss is extreme and are a major contributor to degraded performance and lowered safety due to lapses in vigilance.

The first aircraft accident officially attributed to fatigue by the NTSB occurred when the sleep-deprived pilot experienced a micro-sleep during the approach to land. A less dramatic example of a workplace micro-sleep may result in a worker missing part of a voice transmission. In such circumstances, the worker may fill in memory gaps with distorted or made-up information.

If not aroused from a micro-sleep, people will progress into deep sleep. Micro-sleeps are most prevalent during the circadian trough hours. Sleep is the only safe and effective remedy for micro-sleeps.

Sleep inertia

After any period of sleep, there is a tendency to feel drowsy and disoriented, and mental abilities may be unreliable. This hangover effect is called sleep inertia and can last from a few minutes to perhaps an hour in cases of extreme sleep deprivation.

During a period of sleep inertia, a worker may forget instructions, be liable to overreact to alarms or uncertainty, and involuntarily fall back to sleep. To prevent sleep inertia affecting work operations, personnel who nap during a shift should be woken about 20 minutes before they are expected to work independently or as a fully effective member of a team. Hot drinks and food can help to alleviate sleep inertia. In security- or safety-sensitive work roles, it is wise to supervise personnel who have woken from sleep until it is clear they are properly awake.

Fatigue-prevention strategies

Dual responsibility for preventing fatigue

Effective prevention of fatigue requires a twofold commitment by both the individual worker and the organisation. Each has important responsibilities with respect to preventing and managing fatigue.

For the individual, the prevention of fatigue is fundamentally about satisfactory self-care. In high-reliability industries, occupations, and work roles, it is imperative the worker arrives for work in a fit condition to perform optimally throughout the expected shift. If the individual is not fit for duty, then they should formally notify their supervisor of this before commencing work. Of course, making such a self-assessment is not easy, and declaring it may be even more difficult in some work settings.

The organisation undertaking high-reliability tasks has its own responsibilities and obligations. At the very least, the employer should ensure that its shift-scheduling practices, workplace conditions, and the nature of the work do not generate insupportable levels of fatigue. Further, workers should have sufficient time between shifts to recuperate adequately and be fit for their next duty period.

Where the potential for fatigue is high, and the risks posed by this fatigue are substantial, an organisation has obligations to conduct fatigue-management training with its supervisors and staff and to monitor and manage fatigue through a formal fatigue risk-management program. If a formal safety management system is in place, the fatigue risk-management program normally becomes a component of that safety management system. Defence and civil aviation are good role models for sophisticated safety management.

Self-care

Self-care activities of relevance to fatigue include the following:

- sleep hygiene
- sleep difficulties and disorders
- napping
- understanding and managing jet lag
- aspects of nutrition
- hydration
- aspects of caffeine use
- responsible and informed use of alcohol
- the use of nicotine
- exercise
- informed use of sleep and alertness medications
- social and family life.

Supplementary information on self-care and fatigue — exploring each of the topics above — is in the supplement at the end of this chapter. You are encouraged to become acquainted with these activities, strategies and techniques.

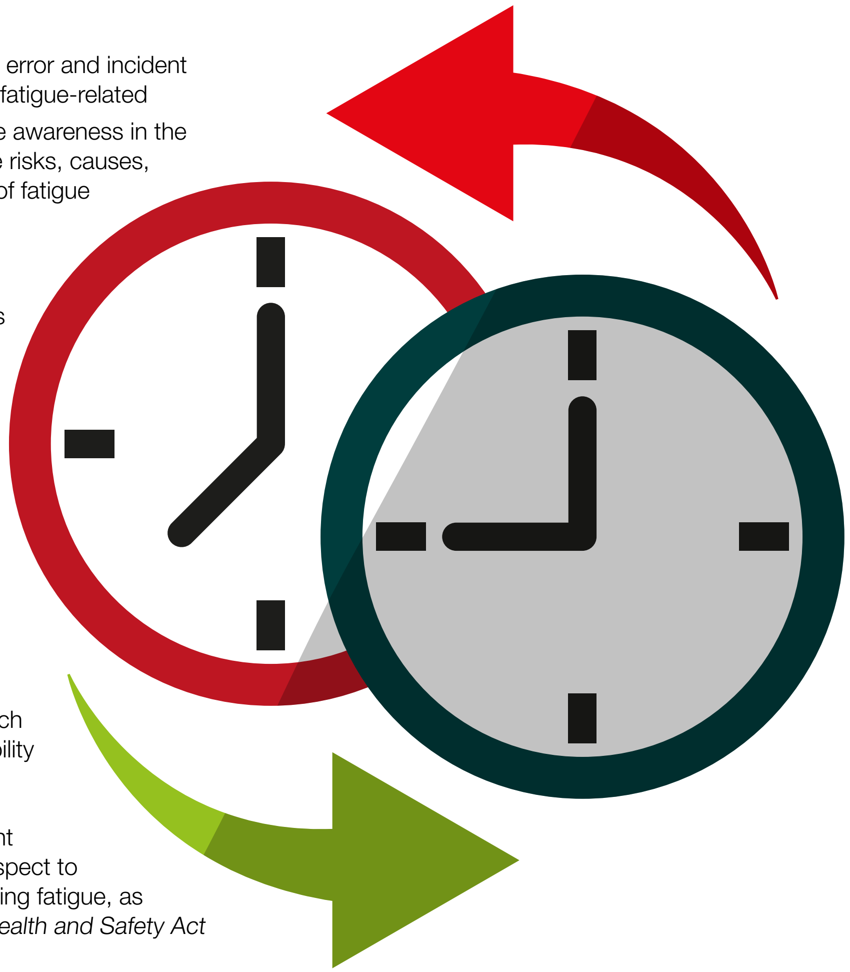
Organisational approaches to prevention

In the organisational context, it can be difficult to distinguish between preventative and management activities for fatigue because there is so much overlap in these actions and responsibilities.

Nevertheless, there are several discrete elements of fatigue prevention that the organisation is responsible for, as follows:

- proactively identify the fatigue risks related to your particular workplace
- ensure shift duration and the nature of the work and the work environment do not contribute routinely to unacceptable levels of fatigue
- demonstrate a genuine organisational commitment to the prevention and management of fatigue
- design shift schedules that should provide employees with adequate sleep opportunity
- comply with the wider Defence policies and procedures for the prevention of fatigue
- foster a safety culture that accepts and tackles the risks of fatigue
- educate employees and managers/supervisors about fatigue and its prevention and management
- define, document and promulgate specific responsibilities for both employers and employees for fatigue prevention
- provide fatigue sign and symptom checklists to managers/supervisors to assist in standardising the monitoring of fatigue

- monitor and analyse error and incident reports that may be fatigue-related
- consistently promote awareness in the workplace about the risks, causes, and consequences of fatigue
- ensure employees understand and can apply fatigue-prevention strategies (evaluate education and training)
- assess shift schedules for adequate sleep opportunity.



Fatigue-management strategies

As previously highlighted, fatigue management is as much an individual responsibility as a command/ management function, and each has important responsibilities with respect to preventing and managing fatigue, as outlined in the *Work Health and Safety Act 2011* and DASM.

Individual responsibilities

With respect to the management of fatigue, these include:

- arriving at work in a fit and rested state so that there is a reasonable expectation of being adequately alert
- communicating fatigue-related safety and performance concerns with peers and supervisors
- reporting all fatigue-related safety incidents
- being aware of fatigue and how to counter it in the workplace
- identifying and managing fatigue-related hazards.

Organisational responsibilities

Commanders' and managers' responsibilities with respect to the management of fatigue include:

- the assessment, monitoring and reactive management of fatigue-related hazards
- developing policies, procedures and practices that manage fatigue-related risks
- ensuring safe work practices, such as sensible work schedules
- encouraging and incorporating the participation of personnel in the development of workplace policies, procedures and practices
- providing tailored information and training in relation to the management of fatigue.

The previous section examined the self-care strategies that contribute to the prevention of fatigue. Several of these strategies, for example, napping, hydration, exercise, and caffeine intake, are also appropriate for the management of fatigue. Once fatigue occurs, additional, compensating strategies come into play.

Improving mental alertness at work

Night shifts, shifts following very early starts, long shifts, and sustained operations are notorious for reduced alertness due to acute or chronic fatigue. Lack of alertness can affect performance and increase the risk of errors, accidents, and injury.

The following strategies to enhance alertness have been reported as helpful and appropriate for some individuals.

- Take moderate exercise before starting work.
- Keep the light bright in the workplace during night shift (use desk lamps if it is not possible to brighten large workspaces). Exposure to sunlight or bright light can stimulate mental activity.
- Consider the broader purpose of your work — such reminders may increase incentive.
- Take frequent breaks to alleviate strain, boredom and complacency, if possible.
- When fatigue is due to sleep loss (rather than physical effort), use periods of mild exercise or short bursts of strenuous activity. At the very least, get up and walk around during breaks. Take the stairs rather than lifts.
- Plan to do more stimulating work at the times you feel most drowsy.
- Similarly, do not leave the most tedious tasks until towards the end of your shift when you are apt to feel most drowsy (for the nightshift this is often around 0400 hours).
- Increase social support; ensure personnel are paired up to provide companionship, support, and checks/double-checks for one another.
- Use teams rather than individuals to do tasks whenever possible. Social interaction tends to be mutually alerting.
- If possible, change routines and rotate tasks. To facilitate this option, cross-train personnel in a variety of tasks and skills.
- Where feasible and culturally appropriate, introduce novel background noises (such as a radio) — at least for personnel completing mundane or repetitive work.
- Go to the bathroom and freshen up.

Compensating for the effects of fatigue

When signs of degradation from fatigue begin to appear, close supervision is necessary. The following may help to alleviate the impacts of fatigue.

- Promote the mateship system where personnel team up to do tasks, check and double check each other, and permit napping. New personnel should be supported by experienced personnel.
- Let members most affected by sleep loss do tasks which are self-paced. Mental fatigue has less impact on these types of tasks as opposed to tasks that are work-paced.
- Encourage personnel to write down tasks or messages received and have others check that it has been written down clearly and correctly.
- Adopt "brief back" procedures to confirm understanding.
- Cross-check calculations, interpretations, and decision processes — especially for safety — and security-sensitive tasks.
- Where there is flexibility in the timing of tasks, undertake mentally demanding or safety-critical tasks at times of lowest fatigue risk, according to circadian cycle effects or time on duty.
- Develop written checklists for common procedures that can be utilised when levels of fatigue are expected to be high and memory and performance are likely to be degraded.
- Give priority for napping to personnel who have critical tasks, whose role or tasks make them more vulnerable to sleep loss, or who are showing that they are more severely affected by fatigue.

Organisational approaches to the management of fatigue

Errors by tired workers have caused or contributed to many major incidents, including the Three Mile Island and Chernobyl nuclear mishaps, the Bhopal chemical plant gas leak, and the ill-fated decision to launch the Challenger space shuttle. In each of these cases, systemic factors across the relevant organisation contributed to a failure to identify, prevent, and/or recover from fatigue-related errors.

This accident record helps to explain why it is now considered best practice for fatigue management to incorporate a systems approach to minimising fatigue-related incidents. Other components of fatigue management include workplace design, shift scheduling and design, safety reporting and investigation, training and education and risk management. The DASM provides detailed guidance on these and other factors that are to be addressed to eliminate or otherwise minimise the risk of fatigue so far as is reasonably practicable.

Leadership and fatigue

When a person is significantly sleep deprived, the desire to complete tasks conscientiously and to work collaboratively as part of a team normally will be eroded.

The impact of other stressors (for example, concerns about leadership, relationship issues, and conditions of service matters) may be amplified by fatigue. In such circumstances, the results are likely to be diminished effectiveness and lowered morale.

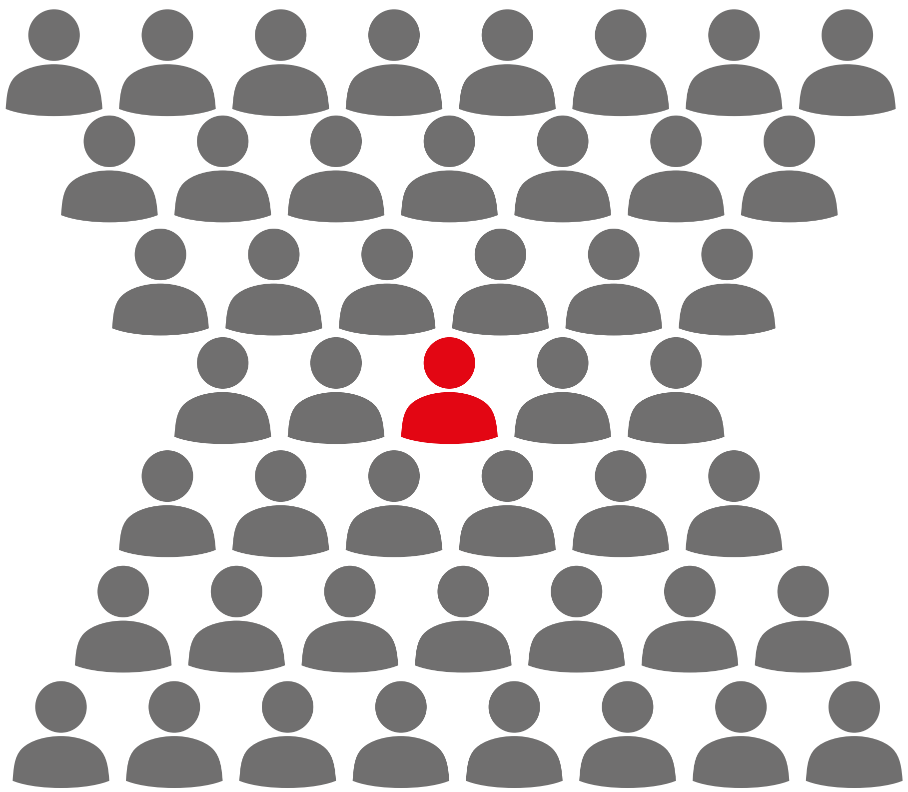
Strong and effective leadership, which fosters morale, can be a powerful antidote to fatigue. Skilful supervisors know the endurance capabilities of their team. They understand and respect how precious sleep is to a tired person. They can identify the early symptoms of fatigue and know when to rest their personnel so as to avoid exhaustion or serious mistakes.

Skilful supervisors also understand how to use motivational techniques judiciously to alleviate tiredness when it is important to do so. Defence members are renowned for working long and hard, but they do not appreciate unnecessary or unfair workloads or toiling for what they perceive are the wrong reasons.

It is important for leaders/supervisors to constantly manage the meaning of why we are working, especially when the nature of our work is likely to induce unusual levels of fatigue.

Culture

Culture is a critical ingredient in any safety system. Leaders at all levels across Defence are responsible for promoting a strong safety culture so that individuals will understand and accept the need to actively address the adverse effects of fatigue. Chapter 4 explores organisational culture in detail.



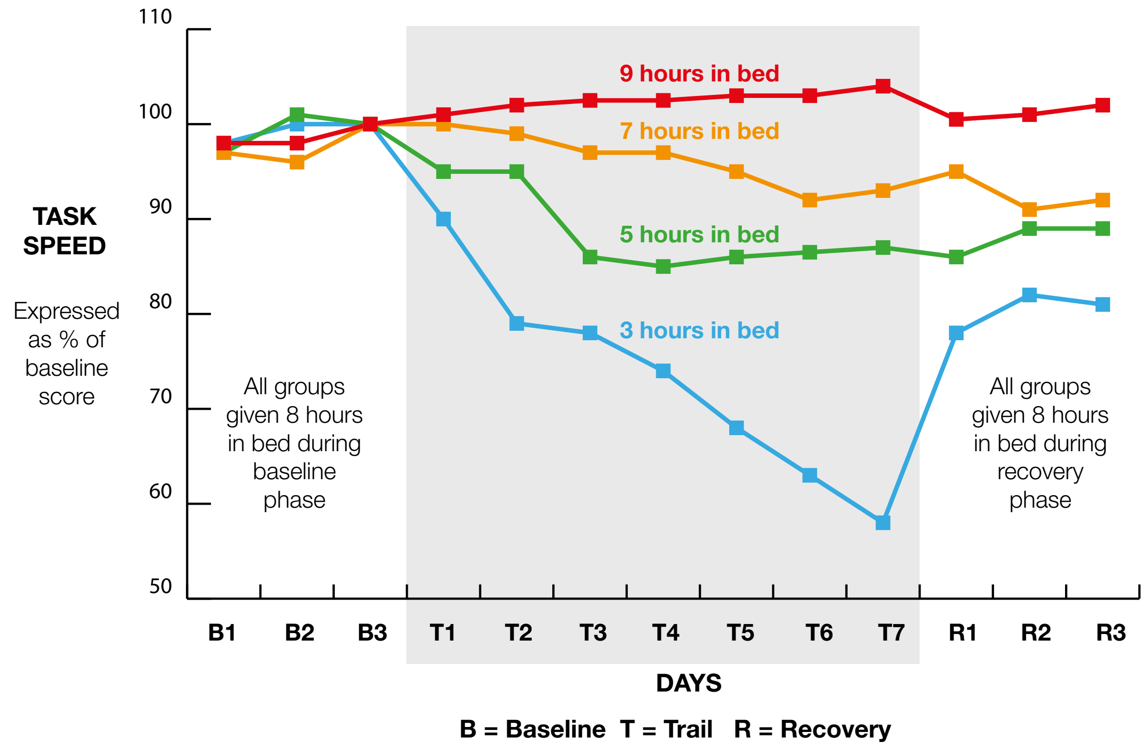


Figure 9–4. Average task speed across days for groups defined by time allowed in bed

Recuperating from fatigue

There are no universally accepted guidelines for recuperation from lost sleep, although a sleep-debt model is often advocated. Basically, this approach suggests that a person needs to repay any sleep debt that has been created. Sleep debt is difficult to determine precisely, due to individual differences in sleep need and the difficulty in assessing quality of sleep.

Common sense suggests that, if possible, recuperative sleep should proceed until spontaneous awakening occurs (not counting periods of wakefulness for toilet requirements). Just as sleep debt normally accumulates progressively over days as a result of getting less sleep than required, sleep recovery can also take time.

It has been recommended that recovery sleep be extended to about 10 hours. Any longer, and you may begin to unsettle your circadian cycle. Some people, of course, will find that just getting their normal period of sleep need is sufficient to promote recovery from fatigue compared to their usual sleep period.

An often referenced research study (Belenky et al., 2003), which clearly demonstrated the performance costs of acute and chronic sleep deprivation also provided remarkable information about recovery from sleep deprivation.

The study demonstrated how persistent the performance detriments of sleep loss can be — even after several days of recuperative sleep. Figure 9–4 shows how groups of subjects restricted to seven, five, or three hours in bed demonstrated a clear decline in performance over a week of restricted sleep.

Another group (a control group) allowed nine hours in bed actually improved performance above baseline. There was evidence of adaptation (levelling off in performance scores) in the seven-hour and five-hour sleep groups, although their performance levels were lower than baseline. However, the group with only three hours in bed continued a steep performance decline across the seven-day trial.

While the performance impact of sleep restriction was expected, the pattern of performance scores during the recovery phase of the study was surprising. During recovery, all groups were allowed eight hours in bed. None of the three groups that experienced sleep restriction during the preceding seven days returned to their baseline performance levels, even after three days of recovery. The implications for supervisors and shift schedulers is that they should expect lowered performance for several days after any shifts or operations that generate sleep debt. One or two days off duty may not be enough for full recuperation.

Note: The scores shown in the figure are for a vigilance task that is known to be sensitive to the effects of sleep restriction, and shows no learning effects over repeated administrations.

Commuting when tired

Driving tired can be as dangerous as drink driving. Fatigue can result in inattention, poor vehicle handling, slowed reaction times, and deficient situation awareness, all of which increase the risks of having an accident. A worst-case scenario for a tired driver is falling asleep at the wheel.

Fatigue crashes are often very severe as they typically involve high speeds — and a sleeping driver makes no attempt to avoid or prevent the crash. Loss of control and head-on crashes are the most common types of fatal crashes involving fatigue. Fatigue crashes are therefore particularly hazardous for the driver concerned, any passengers, and others (drivers and pedestrians) in the vicinity of a fatigued driver.

Tiredness, no matter the length of the journey, can lead to a serious or fatal accident. In fact, a majority of road accidents occur within the first 10 minutes of the journey or the last 10 minutes of the intended route, presumably because of distraction or switching off. While the danger of speed and drink driving are well understood, even the most careful and sober driver can be susceptible to the effects of fatigue.

Shift handovers

Shift work routinely involves a handover of duty from one individual or work group to another. Shift handovers are a particularly vulnerable time for communication failures. And, of course, the presence of fatigue adds to the risk that shift handover may not be fully effective.

Preventing and managing shiftwork fatigue

Preventing and managing shiftwork fatigue: A Workbook for Defence Members (Murphy & Fogarty, 2012) was designed for Defence personnel posted to units where shiftwork is the norm.

The workbook provides extensive guidance on fatigue and its management. It targets commuting from work and shift handovers as potentially high-risk activities when workers are tired and need to be especially alert to the risks of fatigue and how to effectively manage them.

A copy of the workbook can be provided on request. You can also download the workbook from the fatigue resources section of the DDAAFS website.

Additional reading

Four excellent publications about managing fatigue:

CASA (October 2016). CAAP 48-01 v2.0: *Fatigue management for flight crew members*. Retrieved from https://www.casa.gov.au/files/481pdf

ICAO (2015). *Fatigue management guide for airline operators*, 2nd edition. Retrieved from http://www.icao.int/safety/fatiguemanagement/Pages/Resources.aspx

ICAO (2016). *Fatigue Management Guide for Air Traffic Service Providers.* Retrieved from http://www.icao.int/safety/fatiguemanagement/Pages/Resources.aspx

Murphy, P. (2002). *Fatigue management during operations: A leader's guide.* Department of Defence (Army), Canberra, Australia. Available on the DASA website.

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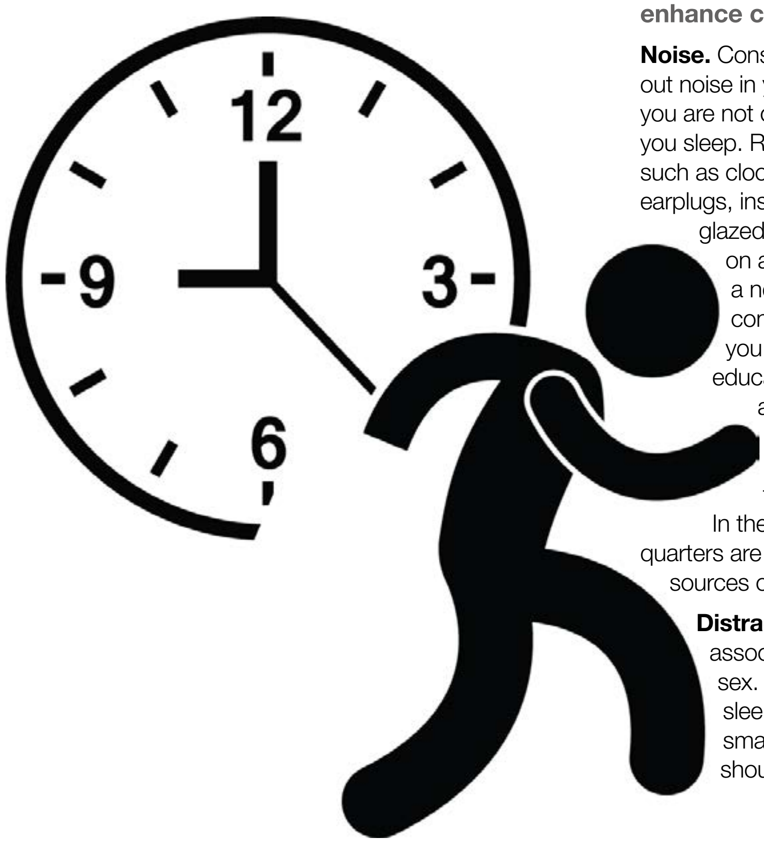
Key points

- Despite decades of denial, fatigue has been implicated in many aviation accidents over the last 30 years.
- Fatigue is a threat to safety because it can impair alertness and performance.
- Many factors contribute to fatigue. It is important for all aviation personnel to monitor and identify the symptoms of fatigue not only in themselves, but in others in their team.
- There are many techniques for preventing the build-up of fatigue, such as good sleep hygiene and a healthy lifestyle.
- There are also techniques for managing fatigue once it has built up; such as napping, task scheduling, strategic use of caffeine, task rotation, social support, and increased cross-checking.
- Organisations also have an important role to play in the prevention and management of fatigue.

Self-care and fatigue

Self-care activities of relevance to fatigue are explored in this chapter. Self-care strategies are often very simple yet highly effective in both the prevention and management of fatigue. The topics examined are:

- sleep hygiene
- sleep difficulties and disorders
- napping
- understanding and managing jet lag
- aspects of nutrition
- hydration
- aspects of caffeine use
- responsible and in formed use of alcohol
- exercise
- informed use of sleep and alertness medications
- social and family life.



Sleep hygiene: setting the scene for sound sleep

An important component of caring for yourself and managing fatigue is to maximise your potential for sleep. Sleep hygiene refers to a collection of behaviours, environmental conditions, and other sleep-related factors that can be adjusted to decrease the time to fall asleep, improve sleep quality, and increase sleep duration. Often, just being reminded of sleep-hygiene factors can promote improved sleep. Strategies such as the timing of exercise, controlling light exposure, and eating sensibly can optimise the chances of attaining good sleep.

There are four broad components of sleep hygiene, irrespective of whether you are at home in your bedroom, staying in a hotel, or on deployment in the field or on a ship.

Control the sleep environment to enhance comfort and avoid disruption

Noise. Consider strategies to prevent or block out noise in your sleep environment. At home, if you are not on call, put phones on silent when you sleep. Remove items from the bedroom, such as clocks, that generate noise. Try soft earplugs, install heavy curtains and/or double-glazed windows in the bedroom. Switch on appropriate background music or a neutral noise (such as a fan or air conditioner) to mask external noises. If you are trying to sleep during the day, educate family, friends, and perhaps even about your shift schedule so they can avoid disturbing you. Teach children to respect your sleep time, or keep them away during daylight sleeping. In the field, try to ensure that sleeping quarters are located away from predictable sources of noise.

Distractions. Your bed should be associated with two things — sleep and sex. If you are having trouble getting to sleep, sources of distraction such as smart phones, TVs and laptops/ipads should be removed from the bedroom.

Avoid potentially upsetting conversations and interactions near bedtime. When not on call, set your mobile to 'do not disturb' mode during sleep periods. Keep a notebook beside your bed to record your thoughts on decisions, ideas or tasks that occur while you are trying to get to sleep. By shelving these concerns until morning you should reduce any worry that you may forget such thoughts during sleep.

Temperature. Sleep onset is generally faster when body temperature is low. Ensuring the bedroom/sleeping quarters are cool for you can be conducive to sleep. What is cool varies between individuals — particularly couples. Extremes of temperature (hot or cold) tend to elicit more frequent awakenings. It is not unreasonable for personnel to be provided with effective and quiet air conditioning in environments that are not conducive to sleep.

Darkness/light exposure. For most people, the darker the sleep environment the better. Thick curtains, eye masks and alarm clocks with a dim setting may assist. Be aware that exposure to sunlight or other bright light sources can reset the body clock. For example, night-shift workers returning home after dawn will have exposure to morning light that can delay their sleep onset (if they were planning to sleep as soon as they arrive home).

Avoid or reduce caffeine, alcohol and nicotine intake

These drugs can interfere with sleep onset and the duration of sleep. They are best avoided if you are suffering from sleep disturbance. In particular, do not ingest caffeine for at least five hours before your intended bedtime.

Foster a routine

Wherever you are, try to establish a regular, relaxing bedtime routine. A behavioural routine before bed can help people to unwind mentally and prepare gradually for sleep. The mental and physical associations of a pre-sleep routine can help to trigger sleep. Such a routine might include a security check, a check of pets and children, shower, oral hygiene, set alarm, diary entry, texts to loved ones, and/or reading. Where possible, make an effort to establish consistency in the time for going to bed. Admittedly, this is not always possible for shift workers on rotating schedules or those on deployment. Nevertheless, make a conscious effort to have one's sleep onset and duration as consistent as possible.

Develop a sleep-friendly lifestyle

Invest in sleep comfort. Consider the time you spend in bed (hopefully about a third of your life) and the importance of sleep. Some people sacrifice bedroom comfort for other spending priorities. Yet a comfortable bed, quality bedding (especially pillows that suit you), noise-reduction furnishings and fixtures, and a quiet airconditioner are among the best quality-of-life returns of any financial investment for the home. Consider what kit might aid your sleeping when deployed.

Exercise. Regular exercise tends to promote and enhance sleep, but there is need to take care with the timing of exercise. Exercise performed within two hours of bedtime may delay the onset of sleep in some people. There is research that suggests exercise done three-to-four hours before bedtime may produce a rebound body cooling effect that is conducive to sleep.

Food and hydration. Avoid large, heavy, and spicy meals and large amounts of fluid within two hours of bedtime. A light snack and a warm milk drink (not coffee) may be helpful to some, especially if it is part of a bedtime routine.

Reduce stress. It is one of life's cruel twists that moderate and high levels of stress tend to interfere with one of the best stress antidotes — sleep. Attempt to actively manage stress in your life. Relaxation techniques like yoga and massage are powerful stress busters and can be helpful in promoting sleep. Common relaxers that can be linked to bedtime at home include listening to gentle music, warm milk drinks, reading or listening to books, reviewing your achievements and positive experiences of the day, a warm shower or bath, massage, and satisfying sex with a regular partner.

Medication. Ensure you understand the side-effects of any sleep medications you take. Many people find that sleeping pills give poor quality sleep and can cause a feeling of grogginess for hours after waking. Recent research has raised serious concerns about the adverse health impacts of some prescription sleep medications.

Health checks. If you are having sleep problems or are in doubt about why you may be experiencing chronic fatigue, then seek professional advice.

Sleep difficulties and disorders

In 2010, an estimated 1.5 million Australians (8.9 per cent of the population) suffered a sleep disorder. With this in mind, it is important to acknowledge that fatigue may be a consequence of an underlying medical condition. Some of the more common sleep disorders are explained below.

Insomnia

Insomnia generally refers to a persistent difficulty in falling asleep or staying asleep. Sometimes insomnia can mean sleep is consistently unrefreshing. Insomnia is the most common type of sleep problem. Indeed, most people experience transient or short-term insomnia several times a year. Such acute episodes of insomnia are considered quite normal. It is thought that about a third of adults experience more debilitating or persistent forms of insomnia at some point in their lives. Insomnia is usually defined as being transient (lasting up to a week), short-term (lasting up to three months), or chronic (more than three months). Not surprisingly, insomnia is more common in shift workers.

There are many contributing factors to insomnia. These include work hours, life stressors, age, and sleep environment. Effective treatments are well established and are often simple. For example, treatment may involve changes to daily schedules, habits, and lifestyle.

The sleep hygiene practices outlined above are useful for people who are experiencing persistent insomnia. In such cases, the following additional methods are often advised:

If you are not asleep within 20 minutes of going to bed, get up and do something constructive (but not too enervating) until you feel tired. When you feel tired, return to bed. Repeat this procedure as many times as it takes until you fall asleep (or you have to get up).

Try not to focus too closely on sleep itself — you cannot force yourself to go to sleep. Instead, try using relaxing, dreamlike imagery to entice sleep.

Sleep apnoea

Sleep apnoea is a breathing-related sleep disorder that interferes with the sleep cycle and reduces the restorative quality of a sleep period. Despite having eight hours in bed, a person with sleep apnoea may be severely sleep deprived. A common result of sleep apnoea is reduced capacity to stay awake during the ensuing wake period. Severe and chronic sleep apnoea is associated with micro-sleeps at work and when driving, even during mid-morning when people are normally most alert.

There are three types of sleep apnoea: central sleep apnoea; obstructive sleep apnoea, and mixed sleep apnoea. During sleep, the brain instructs the muscles of breathing to take a breath. Central sleep apnoea occurs when the brain does not send the signal to the muscles to take a breath, and consequently there is no muscular effort to take a breath. Obstructive sleep apnoea occurs when the brain sends the signal to the muscles and the muscles make an effort to take a breath, but they are unsuccessful because the airway becomes obstructed and prevents an adequate flow of air. This is the most common form of sleep apnoea in Western society. Mixed sleep apnoea, occurs when there is both central sleep apnoea and obstructive sleep apnoea.

Making choking sounds, stopping regular breathing during your sleep, and waking up with a start and gasping for breath are indicators of sleep apnoea. If you have a sleep partner, they are likely to be aware of such symptoms. Sleep apnoea is associated with being overweight.

Sleepwalking

Sleepwalking (somnambulism) is characterised by complex behaviour (not limited to walking) occurring while asleep. These behaviours often occur during the second or third hour of sleep. Sleepwalking activity may include simply sitting up and appearing awake (while actually being asleep) and getting up and walking around. The person is not aware of the activity and normally does not remember it upon waking. Sleepwalking has been known to include other complex activities such as moving furniture, going to the bathroom, dressing and undressing, and even driving motor vehicles.

While moving about, the sleepwalker's eyes are fully or partially open. They avoid obstacles, listen when spoken to, and usually follow simple commands. If a sleepwalker is wakened by a gentle shake, he or she will normally be surprised to find themselves out of bed. An episode of sleepwalking is usually quite brief (lasting seconds or minutes) but can last for 30 minutes or longer. Sleepwalking typically occurs during REM sleep.The causes of sleepwalking are not well understood and limited attention has been given to its treatment in adults. Not surprisingly, people with a history of sleepwalking are excluded from military service on medical grounds (they would be a danger to themselves and others in an operational environment).

Restless legs syndrome (RLS)

This is a disorder that causes a strong urge to move your legs. This urge to move often occurs with strange and unpleasant feelings such as creeping, tingling, or burning. Moving your legs sometimes relieves the urge and the unpleasant feelings.

Periodic limb movements (PLM)

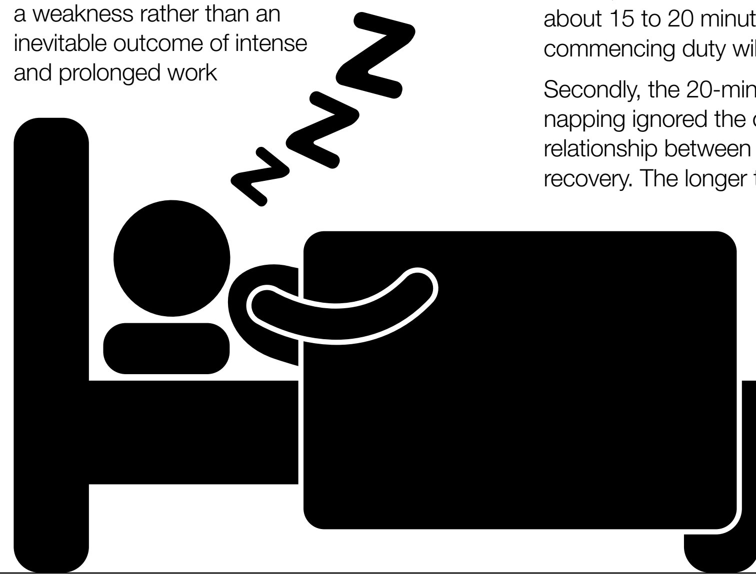
This involves involuntary leg and arm movements while asleep. The movements often disrupt sleep and may cause the person to wake up.

Napping

A nap is defined as any period of sleep less than four hours in duration. When carefully implemented, naps can have a beneficial impact on alertness, performance and mood. Most people satisfy their daily need for sleep in the one continuous period (hopefully for seven to eight hours). If this recommended amount of sleep is not possible in one session, then the use of naps can help to prevent or alleviate the likely symptoms of fatigue.

Barriers to napping

There is often a reluctance to nap at work in Australia when it would be appropriate to do so. This reluctance is likely to stem from cultural aspects of the organisation concerned. For example, admitting being fatigued may be viewed as a weakness rather than an inevitable outcome of intense and prolonged work periods. Or reluctance may simply indicate that napping is not a norm — "the way we do things around here".



Nevertheless, fatigue experts regard napping, when properly scheduled, as perhaps the most effective strategy for maintaining performance during sustained operations. For example, there is evidence that 40-minute naps during long shifts prevent micro-sleeps from occurring during the latter stages of the duty period.

How long should I nap?

Until recently, a prevailing view was that naps should only be of 20 minutes duration. The rationale for this was to avoid sleep inertia — the tendency for people to be drowsy, confused and/or moody upon waking from sleep.

The 20-minute nap rule was premised on the assumption that it takes 20 minutes to reach deep or slow wave sleep and that sleep inertia effects are much more pronounced when one is roused from this stage of sleep. By limiting sleep to 20 minutes, it was thought that this would avoid the onset of deep sleep, and hence prevent the more severe sleep inertia effects.

What this view overlooked; however, was that those who are sleep deprived may reach slow wave sleep more quickly than normal after sleep is initiated, possibly within 10 minutes. In such cases, a 20-minute nap will not avoid sleep inertia.

The 20-minute nap rule has two other shortcomings. Firstly, it has overemphasised the potential impact of sleep inertia. There is marked individual and situational variation in sleep inertia effects, and in most cases, allowing people about 15 to 20 minutes between awakening and commencing duty will dissipate these effects.

Secondly, the 20-minute rule-of-thumb for napping ignored the clear dose-response relationship between sleep and performance recovery. The longer the sleep, the better the benefits. Limiting a nap to 20 minutes in order to avoid the transitory effects of sleep inertia is probably counterproductive. Longer sleep periods will foster significantly improved performance — and for longer periods.

The new rule-of-thumb regarding nap duration is to sleep for as long as operational conditions/ work demands permit. It is important to note that the minimum recommended nap duration is 10 minutes. Naps shorter than 10 minutes do not appear to provide any measurable benefits in terms of recovery or maintenance of performance.

From middle age, night-time sleep tends to get shorter and more fragmented. Napping therefore can be especially appropriate for older workers.

When is the best time to nap?

Naps are most effective when they are taken before the onset of fatigue. Therefore, if possible, naps should be taken before or early in a period of continuous activity or expected sleep loss, rather than when fatigue has become evident. A two-hour preventative or prophylactic nap before a night shift can help many people to maintain adequate performance levels throughout the night.

Recovery naps are those used to counter unacceptable sleepiness on-the-job. Naps used to recover from fatigue need to be longer than preventative naps and, due to higher levels of sleep deprivation, sleep inertia impacts tend to be more severe. Ideally, sleep management should aim to avoid the need for recovery naps.

The timing of naps is important. Avoid scheduling naps that will have you waking during the circadian trough (around 0200 hours until dawn) or the circadian dip (1300 to 1600 hours), as sleep inertia is likely to be most pronounced during these periods. The downside of this advice is that it is more difficult to initiate sleep outside these dips in the circadian cycle.

By way of example, an effective approach for a nightshift worker prior to a first duty might be to nap before work for one to two hours, commencing at about 1500 hours during the circadian dip, and waking after 1600 hours (outside the circadian dip period). Some experts suggest napping until as close as practicable to the start time of a night shift.

If the goal is to maintain performance, naps are usually more effective if taken late afternoon or late evening. To recover performance, daylight morning naps are often of greatest benefit, particularly after a night without sleep.

Naps of at least one hour's duration are needed if the goal is to reduce the occurrence of microsleeps.

To nap or not to nap?

Napping is not an effective strategy for about one in five persons. Some people simply cannot get to sleep within a reasonable time under the conditions typically associated with napping. Furthermore, some people can be inconsistent in their ability to nap, falling asleep easily one day, but failing to nod off the next. As people who suffer from insomnia know all too well, a common paradox of sleep is that the more desperate one is to fall asleep, the less likely it is to occur.

The scheduling of naps should not be used as a means of routinely extending duty periods. However, naps can be useful if the normal work period has to be extended due to operational requirements or unforeseen circumstances. The primary use of napping is to maintain alertness and performance, thereby preserving work safety and security.

Some people dislike napping because of the immediate sleep inertia effects upon waking. Many people rate their mood and their self-perceived fatigue as worse following a nap. For some, sleep inertia can be associated with very unpleasant feelings of nausea. However, the research evidence is quite clear: napping has definite performance benefits that persist for many hours for the majority. Many people are unaware of the performance benefits of napping. Hopefully, with appropriate education, those who are reluctant to nap should be convinced that there are good reasons to do so in particular circumstances.

Making napping effective

The rest environment provided for naps should be as conducive to sleep as possible, preferably air-conditioned, soundproofed, dark and with adequate bedding. A nap in the corner of a busy hangar or operations room is likely to reduce the recuperative value of sleep. Noise and surrounding activity tend to disrupt the brain wave patterns of sleep. The result is disturbed and therefore less restorative sleep.

When planning for scheduled naps in the workplace, factor in an initial period for sleep preparation and sleep onset (getting to sleep) and around 20 minutes for proper wakefulness to be achieved prior to returning to duty. This normally means that a rest period of about one hour is required to enable a 30-minute nap. Of course, with greater experience, some people can become more efficient in their napping.

When the recommended anchor-sleep duration is not possible, or if a work shift has to be significantly extended (beyond 10 hours), the precise scheduling of naps can help to recover and/ or maintain mood, alertness and the mental abilities that are crucial to safe and effective performance in the workplace.

Understanding and managing jet lag

Jet lag is a condition caused when we travel across time zones and our normal circadian rhythms are disrupted. It is experienced in the form of physical and psychological discomfort. Jet lag is more formally known as circadian desynchronosis. The cause of jet lag is the inability of the body of a traveller to instantly adjust their body clock to the time in a different zone. The symptoms of jet lag may include excessive sleepiness, feeling flat or lacking energy, an increase in simple mistakes and forgetfulness, premature awakening or difficulty getting to sleep when desired (insomnia), anxiety, constipation, diarrhoea, confusion, dehydration, headache, irritability, nausea, sweating, and co-ordination problems.

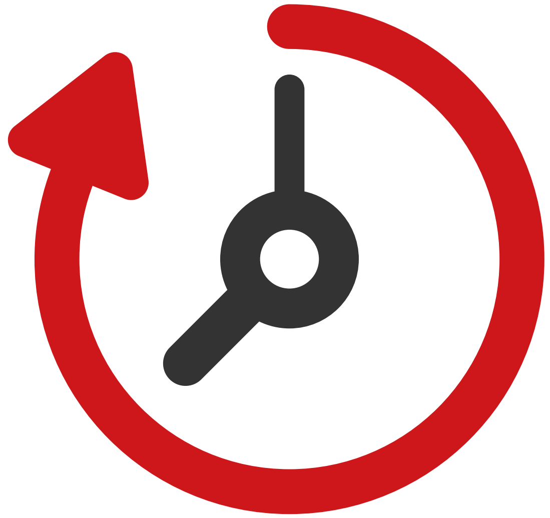
The hypothalamus in our brain is the biological alarm clock that activates various body functions such as hunger, thirst, and sleep. The hypothalamus also regulates body temperature, blood pressure, and the level of hormones and glucose in the bloodstream. It takes time for the hypothalamus to readjust to a new time zone. First, it needs to realise that a change has occurred. The body picks up various clues that the time zone has changed — from differences in eating times, to changes in the environment, such as daylight hours.

The hypothalamus takes time to re-regulate the body's many systems. One rule of thumb is that for each time zone difference (in hours) between the time zone you were accustomed to and the new zone, the body takes about a day to adjust. Therefore, nine time zones equals about nine days until your body is functioning fully in sync with your new surroundings. Most of the symptoms of jet lag; however, subside within three or four days. And, of course, aviation personnel may not stay in the new time zone for that long.

Easing the effects of jet lag

The following tips help to minimise the effects of jet lag.

- **Keep fit.** Regular exercise appears to lessen the severity of jet lag. Conversely, unfit people tend to experience longer periods of jet lag.
- **Change your schedule ahead of travel.** Resetting the body clock is more easily accomplished gradually than all at once.



Depending on the direction you are travelling, and how long you plan to stay at the destination, one option is to start adjusting sleep and eating times before you leave. There is some agreement that shifting your bed and meal times by an hour or two can jumpstart the change in your body clock.

- **Start your travels without a sleep debt.** Ensure you are well rested before your journey begins. Too often we attempt to finish off too many tasks at work or around the house at the last opportunity. Or we sacrifice sleep to finish packing. People who are sleep deprived before travelling are likely to experience greater symptoms of jet lag.
- **Turn your watch, your phone and your mind to destination time as soon as you get on the plane.** Start operating on the destination local time. Eat and sleep accordingly, even if that means skipping meals. If it is 3 am at your final destination, skip the meal on the plane and try to get some sleep.
- **Avoid alcohol.** It is recommended that you do not drink alcoholic beverages the day before, during, or the day after transmeridian flight. Alcohol causes dehydration, can disrupt sleep, and can trigger nausea and general discomfort. If you cannot resist having a drink, certainly do not drink excessive amounts.
- **Avoid caffeine.** Similarly, try not to drink caffeinated drinks before, during, or just after transmeridian flight. Caffeine causes dehydration, can disrupt one's sleep cycle, and tends to amplify any anxieties associated with travel (perhaps you are deploying on operations with all the associated stressors).

- **Stay hydrated.** Drink plenty of water, especially during the flight, to counteract the effects of the dry atmosphere inside the plane. Dehydration and dry air can cause headaches and nasal irritation, which can exacerbate the symptoms associated with jet lag.
- **Exercise and move about on the plane.** Most will have experienced how commercial airlines recommend in-seat exercises and some walking (perhaps every hour or two) during long flights in order to avoid circulatory problems such as deep vein thrombosis.
- **Comfortable clothing.** If you are not on duty, comfortable clothes and shoes aid relaxation during flight.
- **Restful accommodation.** If you are using commercially-available accommodations, research your options with comfort in mind. Do rooms have double glazing, heavy window shades, and air conditioning? Numerous independent hotel rating websites exist that allow you to pick up issues such as noisy rooms, uncomfortable beds, and unserviceable climate control. Upon arrival, check that provisions for noise abatement, environmental control, and light suppression are adequate — and functional. For example, do not accept a room next to the elevator.

- **Enhance your quality of sleep.** A fundamental technique for minimising the effects of jet lag is maximising sleep quality and quantity.
- **Upon arrival, adapt to the local schedule.** If you are to stay in your new location for a week or more, it is generally agreed that the sooner you adapt to the local time zone, the quicker your body will adjust. Therefore, if you arrive at noon local time (but, say, 5 am your time), eat lunch, not breakfast. During the day, expose your body to sunlight (and your eyes — so go without sunglasses for a while) by taking walks or sitting outdoors. The sunlight will cue your hypothalamus to reduce the production of sleep-inducing melatonin during the day, thereby initiating the process of resetting your internal clock.

To sleep or not to sleep?

This section is for Defence personnel travelling on commercial international flights or as passengers on long-haul military flights. Some people believe that they should never sleep on transmeridian flights because it will interfere with adjustment to the destination time zone. However, for Australians going overseas, this approach is simply unreasonable. International travel out of Australia can routinely surpass 24 hours to destination (especially if travelling to Europe). Trying to stay awake for such a period will only exacerbate fatigue and the effects of jet lag upon arrival. Most travellers find it difficult to sleep on aircraft and sleeping at will tends to be more challenging the older one gets. Nevertheless, one approach to easing jet lag is to attempt to link sleep during the flight to normal sleep time at the destination, even if the sleep is only for four or five hours. For example, many flights from Australia reach Heathrow around dawn. Therefore, delaying sleep until the last five or six hours of the flight might help to jumpstart your adaptation to the new time zone.

Nutrition

Managing energy levels with food

Low blood sugar (blood glucose concentration) is a common cause of low energy levels and associated feelings of weariness and sluggishness. However, many people are unaware of the effect of low blood sugar on their alertness or they do not know how to stabilise their blood sugar levels. It is a common belief that snacks loaded with sugar cause a fast rise in blood glucose and can be used as an effective alertness management tool. Research has shown that the presumed relationship between ingested sugar and blood glucose concentration is not reliable. Instead, the glycemic index (GI) has risen to prominence as a means of understanding and stabilising blood sugar levels.

The glycemic index is a ranking of carbohydrates on a scale from 0 to 100 according to the extent to which they raise blood sugar levels after eating. Foods with a high-GI are those which are rapidly digested and absorbed and result in marked fluctuations in blood sugar levels. Low-GI foods, by virtue of their slow digestion and absorption, produce gradual rises in blood sugar and insulin levels, and have proven benefits for health. High-GI foods can be useful as a pick-me-up for non-diabetics. More often than not; however, low-GI foods will be more useful in managing blood sugar levels. Low-GI foods help to maintain a more stable blood sugar level. These foods can be used to raise blood sugar slowly and avoid fast drops in blood sugar (and associated energy levels) that can occur after eating high-GI foods. Low GI foods are ideal as regular snacks across a shift to help avoid substantial changes in energy levels.

There is ample information about GI online. Figure 9–5 is from a brochure available from the Australian GI Foundation, which is associated with the University of Sydney.

Nutrition and sleep

Nutrition is important to our physical and mental health. One element of this relationship between diet and health that is often underappreciated is the impact of nutrition on sleep. Food can influence both the quality and quantity of sleep, and may contribute to sleep disorders. Nutritionists have made the following recommendations with respect to improving the quality of sleep. It is important to note that individuals will differ with respect to the impact of these foods and that the effects may vary over time.

- **Bananas.** Bananas are a good source of potassium and magnesium, which help to relax overstressed muscles. Bananas also contain tryptophan, which converts into serotonin and melatonin when digested, which in turn can help to relax body and mind. Some people report that having a banana and milk smoothie before bed is beneficial for promoting the onset of sleep.
- **Herbal tea.** Herbal teas are increasing in popularity. Their advantage over traditional teas with respect to promoting sleep is that most do not contain caffeine. Many people report that including the preparation and consumption of herbal tea as

Your Low GI Shopping List

To help lower the GI of your diet, we have put together this simple shopping list. *Look for the GI Symbol when shopping – your trusted guide to making healthy, low GI choices.

Breads

- Dense wholegrain breads*
- Grain and seed breads
- Multigrain breads (look for breads where you can see lots of grains)
- White corn tortillas*
- Fruit Loaf such as Raisin bread
- Authentic Sourdough bread

Breakfast Cereals

- Traditional porridge oats
- Bircher Muesli
- Muesli*
- Wholegrain high fibre cereals*

Vegetables

- Sweetcorn
- Carrots
- Peas, frozen or fresh
- Carisma™ Potatoes*
- Broccoli
- Cauliflower
- Capsicum
- Celery
- Tomatoes
- Butternut Pumpkin (lower GI)
- Silverbeet
- Zucchini
- Snowpeas
- Green Beans
- Eggplant
- Squash
- Salad Vegetables
- Leeks &
- Mushrooms – *very low carb or no GI rating*
- Avocadoes

Drinks

- Milo®*
- Sustagen®*
- Fruit Smoothies
- Skim Latte
- Soy Drinks
- Fruit Juice

Snacks

- Grain & Fruit bars
- Nut & Seed bars
- Wholegrain crackers
- Dried fruit and nuts

Legumes

- Split Peas; Green or Red Lentils
- Baked Beans
- Canned & Dried beans – kidney, cannellini, butter, borlotti, chickpeas

Spreads

- Fruit Spreads*
- Nut butters
- Hummus

Main Meal Carbs

- Doongara Low GI White rice*
- Low GI Brown rice*
- Basmati rice (lower GI)
- Pasta, cooked al dente*
- Pearl Couscous*
- Quinoa*
- Pearl Barley
- Fresh Noodles – Hokkein, Udon, Rice
- Soba Noodles
- Buckwheat
- Vermicelli
- Bulgur
- Semolina
- Cracked Wheat

Fruit

- Apples*
- Bananas
- Grapes*
- Strawberries
- Peaches
- Apricots
- Plums
- Canned Fruit in natural juice*
- Pears*
- Kiwi Fruit
- Mango
- Oranges
- Grapefruits
- Berries, fresh or frozen
- Dried fruits such as prunes, raisins, sultanas, apricots

Dairy Foods

- Reduced fat milk
- Reduced fat yoghurt, plain or fruit flavoured
- Reduced fat custard
- Low fat ice-cream*

Figure 9–5. Lower GI food list, from the Australian GI Foundation

part of their bedtime routine helps to promote a readiness for sleep.

- **Almonds.** Almonds also contain magnesium, which helps promote muscle relaxation and sleep. Almonds also provide proteins to help the body maintain a stable blood sugar level while sleeping. There are also almond teas available.
- **Miso soup.** While not to everyone's taste, miso soup is a popular bedtime drink in Japan. Miso is made from soy and contains amino acids, which are thought to boost the production of melatonin — part of the system that regulates the sleep-wake cycle causing drowsiness.
- **Eggs.** Eggs are a good source of protein. Protein is thought to promote the duration of sleep, which will result in feeling more rested upon wakening. Some people find that snacking on a hardboiled egg before bed is beneficial.

Hydration

Your level of hydration affects your alertness. Dehydration saps energy, reduces concentration, and causes fatigue, light-headedness, and headaches. When your body is low on water, it tries to conserve what you have. It does this by reducing your activity and inducing a calm state — that is, sleepiness.

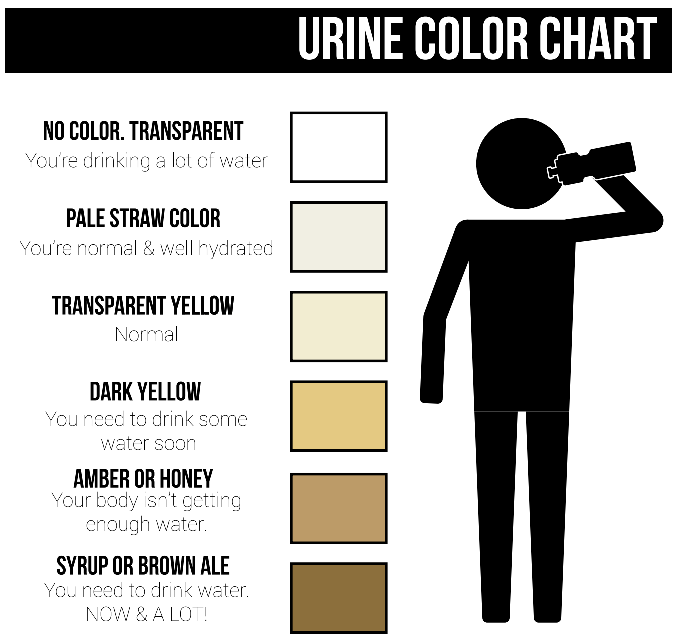


Figure 9–6. The urine colour chart

Most people do not drink enough water to be fully hydrated. In extreme cases, this can result in medical problems, including kidney problems. In most cases; however, the effects of dehydration are short-term and are easily resolved by drinking more fluids, particularly water.

Maintaining hydration

The recommended daily intake of water is two litres or eight glasses — although the science supporting this advice is obscure. One explanation for the two-litre recommendation is that our bodies lose on average 2.5 litres of water a day and in order to maintain a healthy body the fluid needs to be replaced.

Our bodies absorb about 500 ml of liquid from our daily food intake, leaving a requirement for about two litres to be taken as water.

Another approach to maintaining adequate hydration is to drink water regularly so that you are not ever thirsty. For most people this means a glass of water every two hours or so, which happens to equate to about two litres over 16 hours (the normal wake period each day).

A third approach to monitoring hydration is to monitor the frequency, volume, and colour of your urination. Infrequent urination (for example, only once or twice per day) and dark yellow urine indicates inadequate fluid intake. A colour chart is used to determine hydration status (Figure 9–6).

If monitoring your hydration using urine colour, it is important to note the following caveats:

The first urination in the morning is often relatively concentrated. However, the colour of subsequent specimens should be in the range normal range.

Do not judge urine colour within several hours of taking vitamin supplements, as the unabsorbed vitamins can turn urine brighter yellow.

Urine colour underestimates hydration after consumption of diuretic beverages such as alcohol, and in the first few hours of rehydrating after dehydration.

Caffeine

Caffeine occurs naturally in many plants including coffee beans, tea leaves, and cocoa nuts. It is also found in an array of food products and beverages such as chocolate and cola drinks. The amount of caffeine in these substances and products varies tremendously, even within the same item. For example, a standard cup of espresso coffee may have between 180 and 300 mg of caffeine.

The effects of caffeine

If you drink caffeinated beverages, you are probably aware that caffeine can perk you up. If you are low on sleep and need to remain alert, caffeine can assist by blocking adenosine reception in the brain. Adenosine causes blood vessels to dilate and nerve cell activity to slow down, causing drowsiness. Caffeine intake therefore results in increased nerve activity in the brain. The pituitary gland senses this activity and interprets it as an indication of an emergency, thereupon triggering the release of hormones that signal the adrenal glands to produce adrenaline.

Adrenaline is the fight or flight hormone. This explains why, about 30 minutes after drinking coffee, you may notice physical changes such as your hands getting colder (as blood flow to the extremities is reduced), your muscles getting more tense, feeling more animated (or agitated), and your heart beating faster. Other changes that are less obvious to people who have consumed caffeine include dilated pupils, increased blood pressure, slowed blood flow to the stomach, and the release of sugar into the bloodstream by the liver.

All these responses — both obvious and less apparent — are intended to enable the fight or flight response to be optimised. However, if the emergency situation being prepared for is a false alarm (after all, you are just drinking coffee), then you are increasing the stress on the body, and often for no purpose.

It takes caffeine about 20 to 30 minutes to enter your system, and its physiological effects peak after about an hour after the drug reaches the bloodstream. The intake of caffeine can be speeded up with more direct forms of ingestion, such as caffeine-impregnated chewing gum. The noticeable effects of caffeine usually last for four to six hours.

The lasting stimulant effect of caffeine is why most people should avoid having a caffeinated drink too close to sleep time. The half-life of caffeine is about six hours, which means that if you consume 200 mg of caffeine at 1500 hours, by 2100 hours there is still about 100 mg of caffeine in your system. The physiological reason why caffeine reduces your chance of falling asleep is because adenosine reception is important to the onset of sleep (by inducing drowsiness), and to sleep itself, particularly deep sleep. As discussed above, caffeine blocks adenosine reception. Even if you are able to fall asleep with caffeine in your system, your body may miss out on some of the restorative effects of having normal deep sleep.

Caffeine: pros and cons

The advantages of caffeine include:

- nearly everyone has personal experience with using caffeine
- it is not a restricted substance
- it does not appear to interfere with recovery sleep following sleep deprivation
- it has low abuse potential.

There are; however, several disadvantages associated with the use of caffeine. Caffeine is an addictive drug. You may be addicted to caffeine if you feel you cannot function without it and need to consume it every day. Many people deliberately use caffeine as an alertness tool — a mental and physical pick me up. The often-reported instant surge of alertness and energy from the ingestion of caffeine is probably largely placebo (an expectation effect). Any perceived change immediately after ingesting caffeine is likely to be psychological. This is because, as noted above, caffeine actually takes some time (20 to 30 minutes) to enter the bloodstream and even longer (about an hour) after that for its effects to peak. Nevertheless, some people are adamant that they can feel the effects of a coffee instantaneously.

One reason for reports of immediate elevations in mood and energy levels may be related to the social and psychological aspects of preparing a cup of coffee or tea. Making or getting a beverage necessitates a break in work, and movement to the preparation/purchasing area and perhaps another area for ingestion. These activities often will be associated with social interaction. It may be that these coincidental characteristics of making and drinking a beverage are responsible for the reported immediate effects of caffeine ingestion.

The strategic use of caffeine

Most people do not use caffeine effectively as an alertness management tool. They tend to drink coffee and tea when they are not really tired, which means the stimulating effect doesn't have much impact. In addition, regular caffeine consumption leads to increased tolerance, which means that over time we get less effect from the same quantity. When you have a high tolerance to caffeine, drinking one or two cups when you are tired may make little difference to your alertness.

Here are a number of tips on how to use caffeine to its best advantage.

- Avoid drinking caffeinated drinks when you are not tired. The caffeine will have little effect and will contribute to increasing your caffeine tolerance. Your body will get used to having it and, over time, you will need to drink more to get the same effect.
- Avoid drinking caffeinated drinks in the morning. The early part of the day is a time when your body is waking up naturally and you normally will feel more awake as the morning progresses without any need to ingest caffeine. (The fact that many people feel they need to start their day with a coffee in order to wake up properly suggests that they are sleep deprived.)
- Ingesting large amounts of coffee first thing in the morning can exacerbate the effects of the early afternoon circadian dip when most people feel a period of tiredness. This is because of the half-life of caffeine (about six to seven hours). Therefore, drinking a large amount of caffeine at six or seven o'clock in the morning means that the alerting effects will decline from about midday (as you begin to enter the circadian dip).
- Using caffeine to speed up the natural morning waking process may simply increase your tolerance to the drug. One exception may be if you have to get up unusually early in the morning — well before dawn — when the body is still in the circadian trough (the lowest ebb of alertness).
- Avoid caffeinated products for a few hours before bedtime (normally at least two hours, but for some people the optimum abstinence period might be six hours or longer). As previously noted, caffeine acts as a stimulant, and therefore can make falling asleep — and staying asleep — more difficult.

- Be aware that caffeine ingested as a fluid usually takes at least 20 to 30 minutes to enter the system and to take effect; noticeable effects can last four to six hours for most people.
- Be mindful of how much caffeine is in different foods and drinks.
- If you do drink caffeinated drinks, it has been recommended that you increase your water intake to counter caffeine's diuretic effect (that is, an elevated fluid loss due to increased urination). You may have noticed that you need to urinate more frequently when you drink caffeinated drinks.
- Any deliberate use of caffeine as an alertness management tool in the workplace should be properly planned to avoid misuse and/or health risks.
- If caffeine is being relied upon to prevent the decline of alertness in a normal working day, it is likely that there is something wrong with your health or your sleep. Sleep and naps should take priority over pharmacological approaches to alertness management, even if the pharmacological approach is the humble cup of coffee.
- For those who prefer ingesting caffeine in solid form you should note that dark chocolate holds about three times the amount of caffeine as milk chocolate. However, you would have to eat more than 250 grams of dark chocolate to get the equivalent caffeine that is in one large cup of coffee.

Most importantly, be strategic: the less caffeine you drink, the more effective it will be when you need to use it to help you stay awake.

Alcohol

Another important element of self-care is an informed understanding about how alcohol works and how it influences sleep and alertness. Drinking alcohol can lead to increased sleepiness and reduced alertness, even after the alcohol is no longer detectable. This effect is commonly known as a hangover. Intoxication tends to lead to overly optimistic assessments of ability, which in turn, can lead to error and performance failures. We saw earlier that the consumption of alcohol suppresses REM sleep and results in more awakenings during sleep and more frequent shifts in sleep stages, thereby reducing sleep quality and restoration.

The persistent effects of alcohol

An emphasis on blood alcohol level in determining fitness for work has masked a vital issue about alcohol use: its lingering impact on performance, even after BAC has returned to zero. Many people are not aware of the enduring effects that alcohol can have on performance. The persistent effects of alcohol can result in marked impairment of performance for reasons including dehydration, hypoglycaemia, gastrointestinal upset, and disturbances in the vestibular system (the latter of vital importance to piloting an aircraft).

Recent studies have indicated that performance on complex tasks can be measurably impaired for at least eight to 14 hours after last alcohol ingestion. These performance deficits are apparent across a range of psychomotor and mental abilities, and include slowed reaction time, lowered vigilance, difficulties processing radio communications, disruptions to the formation of new memories, and impaired judgement in psycho-motor activities such as determining speed and rate of turn in a vehicle.

Exercise

Exercise can improve sleep

Research has shown that exercise taken between three hours and half an hour prior to bed can increase the amount of deep sleep (important for physical restoration) obtained. Other findings have shown that exercise at night increased the perception the following day of having gained a good night of sleep as well as reducing daytime sleepiness.

Exercise and fatigue

Non-active people who regularly experience fatigue can significantly increase their energy levels while decreasing their reported fatigue by engaging in regular, low intensity exercise. Furthermore, the commonly held belief that an exercise workout will leave already fatigued people even more worn out has been disproved by research. Regular exercise has been shown to increase feelings of energy in most people. This finding suggests that exercise should be a standard fatigue management technique. Exercise certainly has health advantages over some other fatigue management options.

Medication

Medications can affect one's level of fatigue, either by design or as an unintended side-effect. Medication effects vary from person to person, and can vary within the same person depending on time of day, their mood and level of tiredness, and the amount of food in their stomach. Age, gender, and weight/size also influence the overall impact of medications and the rate that they are purged from the body.

For both over the counter prescribed medication check the advice labels and directions for use and confirm your understanding of them with a pharmacist or other relevant health professional.

- If you take prescription medication, and work in safety-sensitive roles, you should:
- ask your doctor about possible interactions with other drugs
- ask your doctor about the drug's effects on performance, such as your ability to drive, fly, and operate machinery and technical equipment
- tell your supervisor what you are taking so they are aware of your situation (depending on the policies and regulations in your workplace).

Sleep aids

The use of sleep aid agents may be considered operationally beneficial when operational requirements disrupt normal sleep-rest cycles. Use of all prescription, non-prescription and complementary medicines must be utilised in accordance with relevant Defence policies.

Social and family life

The challenges — negative spillover

There is a strong relationship between work and social/family life. Shiftwork, in particular, can cause hardships in sustaining family relationships and can lead to detrimental consequences for marriages and children. These outcomes are thought to be the result of negative spillover from work to family.

Spillover refers to the transfer of mood, energy, stress, and skills from one sphere of your life to another. Negative spillover typically refers to work outcomes such as bad moods, fatigue, and stress transferring to life at home and affecting family and friends. Family-to-work spillover can also occur.

Work-related factors that reduce negative spillover include lower work hours, flexible working arrangements (not always an option), supervisory support, job autonomy, and a family-supportive organisational culture. The strongest predictor of negative spillover is number of work hours. Long work shifts are associated with poorer mood and lower energy levels upon return home and are likely to

conflict with traditional family time such as meals and weekends.

Numerous studies have revealed that women working shifts encounter more stress than their male peers because of extra parental and housekeeping responsibilities. However, a recent Australian study suggests that this gender-based trend is changing — Australian men with children are more likely than anyone else — single men and women, and working mothers — to desire more time at home.

Coping with spillover

Fortunately, there are numerous strategies that workers can use to balance work, social, and family time. Perhaps the most common strategies are simply talking about your work schedule(s) with your partner, children, and friends, and actively planning opportunities for shared activities (connecting). Once family and friends understand the need to plan in order to spend time together, it normally becomes routine. The challenge can be when arrangements fall through and one or both sides of the social connection lose patience.

For shift workers, discussion with family, housemates, and close friends about your work schedules also will ensure they are aware of when you are likely to be sleeping. As a result, they can arrange to be out of the house or make sure they do not attempt to contact you when you are sleeping.

Children, in particular, need to understand the need for quiet when you are sleeping. By gaining adequate and undisrupted sleep, you are likely to have more energy for social and family interaction when they occur.

Other strategies for enriching your family and social life will depend on your particular circumstances with respect to shift schedule, family make-up, social networks, available recreational opportunities, and so on. Having strong social connections and maximising the use of social opportunities helps to develop sleep discipline. And good-sleeping habits helps to minimise fatigue. The wellbeing associated with an active social life also helps to buffer the potential for negative spillover from work. The consequent reduction in stress is also important as a means of preventing fatigue.

CHAPTER 10

Leading and working in teams

Overview:

- Groups and teams
- Effective teamwork contributes to safety
- Strategies for fostering teamwork
- Leadership and leadership styles
- Followership
- Strategies for improving leadership and followership

Introduction

Teamwork is one of the six core values of Defence and is fundamental to the co-ordination of a rapid and dynamic workforce able to protect Australia's borders and national interests. Without effective teamwork, Defence could not fulfil its mission. Working in Defence aviation requires individuals to interact with other members of the unit, with personnel outside the unit and with people from different occupational and cultural backgrounds.

Effective team performance requires all members to contribute to the shared knowledge and awareness of the group and to understand when and where they will demonstrate proper leadership or followership. This chapter will discuss the fundamental principles of teamwork, leadership, and followership. It will also discuss strategies for improving teamwork skills and ways of overcoming challenges to teamwork.

AGGREGATE	GROUP	TEAM
• Low interaction • Lack of social structure • Unlikely to meet again in the same combination	• Members interact • Members have an awareness of group identity • Members understand the values, roles, and norms of the group • Members have a common task • Members have established communication patterns • Group has clear goals	• Characterised by effective work procedures and high productivity • Cohesion • Satisfaction among members • Mature role structure

Table 10–1. Characteristics of an aggregate, a group, and a team (Tyson, 1989)

Groups versus teams

The philosopher Aristotle once wrote "the whole is greater than the sum of all parts". The whole refers to a product that can only be achieved by the synergy among the parts when they all come together. In this way something greater is born out of the unity of the separate pieces. Like baking a cake or assembling flat-pack furniture, it is the arrangement and interaction among the parts that creates something entirely new. In the same way, we can achieve much more when working in a team than we can hope to accomplish alone.

Differences between groups and teams

A popular definition of a team is a "distinguishable set of two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have each been assigned specific roles or functions to perform, and who have a limited life-span of membership (Barnes, et al., 2008)".

Note that the term group does not appear in this definition. The differences between groups and teams are important. Throughout a Defence career, there are many occasions that individuals will find themselves working in a group, rather than a team. In fact, personnel will find themselves moving in and out of groups and teams. Some authors use a three-part

"There's no doubt it can be a dangerous sport but the more proficient you become and the better your teamwork is, the less danger is involved.

A good crew learns to react instinctively in pressure situations, avoiding personal injury and damage to the equipment. There's nothing more exhilarating than all working together as a team and catching a big wave and riding it into shore. It's the same in most team environments.

The better the teamwork, the easier you handle critical situations and the more satisfying the experiences are."

ROD MACQUEEN, SURFBOAT CHAMPION AND AUSTRALIA'S WORLD CHAMPION WALLABIES COACH TALKING ABOUT TEAMWORK IN *MACQUEEN AND HITCHCOCK*, 2001, P. 25

distinction: an aggregate (as in an assembly), a group (as in a typical garrison unit), and a team (as in an aircrew or a maintenance team or an air traffic controller shift). Table 10–1 shows the characteristics of each of these units as described by Tyson (1989).

Consistent with Tyson's table of characteristics, Buchholz and Roth (1987) divided the development of a team into three phases. In the first instance, the individuals form a collection or aggregate, lacking social structure and co-ordination. When they begin to develop a common identity, clarify their purpose, and establish norms for working together, the collection becomes a group. Finally, when the members begin to share both the responsibilities and the rewards of the group, and members are committed to the group's purpose, the group becomes a team.

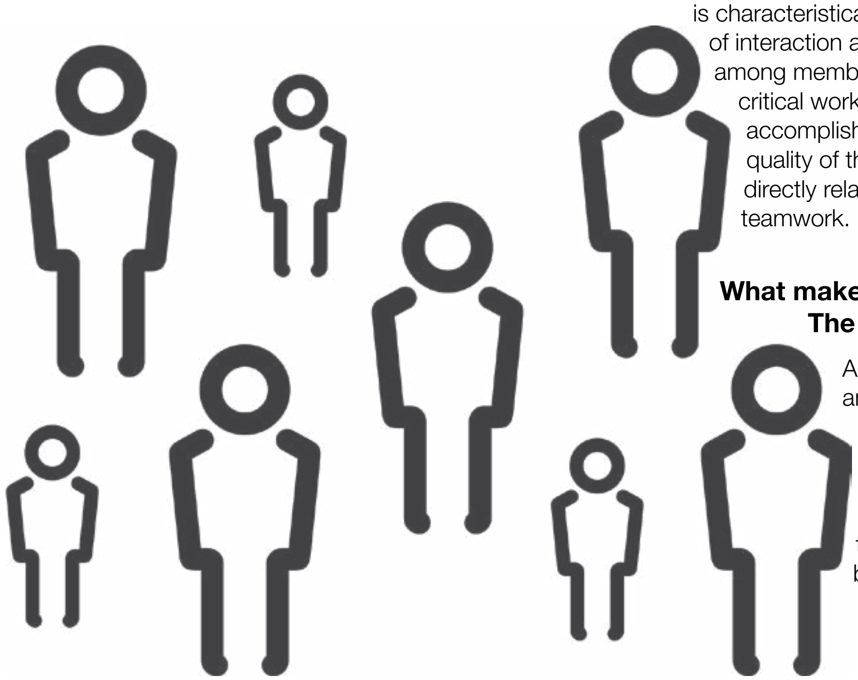
In an organisation like Defence, many groups and teams are already well-established, so new members will face the task of becoming assimilated as quickly and as easily as possible. It is helpful to know whether you are becoming part of a group or a team or perhaps a group that is trying to become a team. That knowledge will shape your expectations.

The role of groups

As Table 10–1 demonstrates, groups can have quite elaborate structures and communication patterns. A group can have its own identity and norms. Fogarty and Shaw (2010) highlighted the influence of group norms on violation behaviour. Within Defence aviation, the Sea King Board of Enquiry referred to a "father-to-son mentality" whereby a tendency for some older members to work outside the rules was encouraging younger members of their teams to do the same [see also the Czar 52 case study later in this chapter]. Data collected via the annual *Snapshot* surveys also show that there is a strong relationship between group compliance and individual compliance. What the group does sets the pattern for what new members will do.

We make these observations to draw attention to the fact that although this chapter is primarily concerned with team performance and team leadership, individual workers are also likely to be members of groups with long-term structures, norms, and values that exert an influence on the performance of members. Some of these groups are large enough to have their own culture, a topic that merits a separate chapter [see Chapter 4].

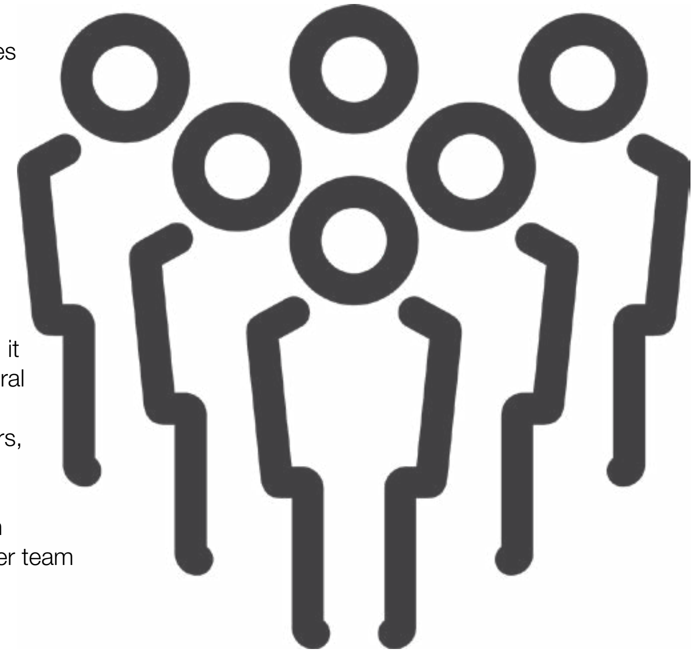
While group influences should not be ignored, they do not have the immediate impact of a team environment where there is characteristically a much higher level of interaction and interdependency among members. Much of the safety-critical work in Defence aviation is accomplished by teams and the quality of the outcomes are often directly related to the quality of the teamwork.



What makes a team effective? The Big Five of teamwork

According to Salas, Sims and Burke (2005), there are five key components of effective teamwork: mutual performance monitoring, adaptability, team orientation, backup behaviour, and leadership.

Mutual performance monitoring



Mutual performance monitoring involves becoming familiar with the roles and duties of other team members. People tend to be unaware of their own work deficiencies, so mutual monitoring can be beneficial in both reducing errors and identifying areas for improvement.

This type of mutual monitoring does not have to be confined to work tasks; it can also include checking on the general wellbeing of other team members. As we have discussed in previous chapters, stress and fatigue are major threats to individual and team performance. Checking on other team members can increase camaraderie and lead to better team performance.

Adaptability

Adaptive teams recognise and respond to unexpected or unplanned changes in their work environment. Adaptability includes an awareness of when situation cues change, identifying whether these changes require revision to the team's plans, and being able to implement a new course of action if required.

Adaptability is also vital when engaging in tasks with unknown parameters or when encountering conditions that are prone to frequent changes. Clearly, there is an element of team situation awareness underpinning adaptability.

It is also important to consider that the person whose task is affected by the cue is not always the person who will be in a position to notice the cue. Take for example the highly dangerous case study 'Crosswinds and crossed wires', which highlights the necessity of communication among team members — in this case ground staff and aircrew — for a team to respond rapidly to unexpected situation cues.

The flight crew of the 727 was relying on the situation awareness and communication efforts of others to correct their own mental models. In the absence of that information, there was no chance of the team adapting to the changed circumstances.

CASE STUDY

Crosswinds and crossed wires

On 24 June, 1996, unexpected severe weather including a tornado, rapidly approached Washington National Airport. Both Shuttle America and the FAA received multiple warnings of the severe weather conditions, but failed to communicate this to the flight crew of a Shuttle Boeing 727 scheduled to fly to LaGuardia Airport, New York. Even while evacuating their control tower, FAA personnel cleared the plane's flight crew for takeoff.

As the plane was taking off, weather conditions reached the runway. Buffeted by violent winds, the left wingtip of the plane made contact with the runway as the plane was gaining lift.

Alarmingly, although officials from Shuttle and the FAA were aware of the wing damage, they failed to communicate this to the flight crew who continued with their flight to New York, fortunately landing safely.

Shared mental models

As a high-risk industry, aviation teams rely on the senses and perceptions of all of its members to create shared situation awareness. Each member contributes to the shared perception of the group, creating a safer environment for everyone. When members of a team do not communicate, information sharing is compromised, which greatly limits the shared mental model of the team — as demonstrated in the following case study.

Low fuel-state case study

On 28 December 1978, during an approach to Portland International Airport (Oregon), a United Airlines DC-8 crashed in a populated area of suburban Portland. The accident resulted in the loss of the lives of eight passengers, the flight engineer and a flight attendant.

The captain had delayed landing the aircraft for about an hour, while the flight crew coped with a landing gear malfunction warning. The investigation determined that the accident probably occurred because the captain failed to monitor the fuel-state of the aircraft properly and didn't respond to advice from crew members about the low fuel. This failure resulted in fuel exhaustion to all four engines.

The captain, and to a lesser extent the crew, had developed a set in which all his attention was concentrated on the possible landing-gear malfunction and directing cabin crew to prepare for an emergency landing. He failed to consider other important factors such as the low fuel-state. Both the first officer and the flight engineer commented on the low fuel but their comments were too half-hearted to make an impact on the captain. Although the captain was in command, he relied on safety critical information from his flight crew. His model was the default shared mental model, lacking fuel-state data, and therefore deficient. Unlike the 'Crosswinds and crossed wires' case study example discussed earlier, this time the failure to adapt had disastrous consequences.

Team orientation

Team orientation refers to the willingness of team members to work together on tasks and to accept input from other team members. Strong team orientation helps to prevent conflict among team members and leads to greater organisational commitment and job satisfaction.

Backup behaviour

Backup behaviour refers to the willingness of team members to provide assistance to other team members. The team acts like a unit; what one part cannot supply, another part will.

Leadership

Salas's fifth and final component of effective teamwork is leadership. This is such an important topic that we will deal with it in more detail later in this chapter. It spans collections of individuals, groups, teams, and Defence itself. Within a team setting, the leadership structure is usually flat with perhaps a head, a deputy head, and section heads. In many cases, there will be just a head that is responsible for making sure the team achieves its objectives. In larger teams, there may also be an unofficial assistant who helps maintain team cohesion (often referred to as the social organiser).

To appreciate the importance of team leadership, we need look no further than the sporting domain where so much credit is given to the captains and coaches of successful sporting teams. Credit from the media and the general public can be misplaced but when a team carries its captain from the field, the gesture is an unmistakeable acknowledgement of the role the leader has played over a long season.

If these are the five key characteristics of successful teams, what steps can we take to improve teamwork? The next section describes some useful strategies.

Strategies for fostering teamwork

Socialise. Social activities help team members form bonds that encourage effective and open communication within a team. The more people interact, the more they become familiar with each other's idiosyncrasies and behaviours. Social activities also help establish a common understanding among team members, reducing the likelihood of any potential misunderstandings within the team. Socialising is about building camaraderie.

Define job roles clearly. Role ambiguity is one of the greatest challenges to teamwork. When team members are unsure who is doing what, it is easy for tasks to be overlooked. Clearly defined roles reduce interpersonal conflict.

Manage stress levels. Stress limits effective communication. If team members are stressed, communication can deteriorate within the team. Chapter 8 outlines some techniques for managing stress.

Learn the roles of your other team members. An important part of effective teamwork is understanding what other team members contribute to the team. This knowledge directly aids mutual performance monitoring, adaptability, team orientation, and backup behaviour.

Communicate effectively. One of the main challenges for teamwork is poor communication. Refer to Chapter 7 for advice on effective communication strategies.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Authority gradient

Defence employs approximately 170,000 individuals across a range of diverse groups, services and professions. The chain of command is the basis of the leadership structure in Defence. The power distance between team members due to rank is referred to as the authority gradient.

A steep authority gradient can occur when a member of the team is of a greater rank and when there is a perception by team members that the higher ranked team member is dominant or overly-controlling in his or her use of authority. Steep authority gradients limit input from team members, reducing the shared mental model of the team. Steep gradients are especially challenging when a person of lower rank is required to take up a leadership position within the team. This situation not only creates tension between the team leader and senior team member but can create confusion for the other team members who may be unsure where direction is coming from. PACE can be a useful tool for resolving steep authority gradient issues.

A shallow authority gradient can occur when there is low power distance between team members or when the team leader encourages an overly democratic approach to team decision-making. If the gradient is too shallow, it can take a long time to make decisions because all members are encouraged to provide input, regardless of knowledge and experience.

Speak Up. One of the challenges in Defence aviation is subordinates not speaking up when they believe their supervisor does not have the necessary information to make a decision or has made a poor decision. Speaking up can be a challenge when there is a perceived high power distance between subordinates and supervisors. Although Australia is generally a low power distance country, the ADF has a higher power distance than most other Australian industries because of the chain of command. Chain of command allows for swift and decisive action in time-sensitive scenarios and aids in the strategic management of a diverse and complex workforce. The downside of chain of command is that it can limit open dialogue among team members and discourage subordinates raising concerns with superiors.

Take, for example, the ill-fated Avianca Fight 52 discussed in Chapter 7. Noting that the entire crew of Flight 52 were Columbian, Salas and Maurino (2010) speculated that a contributing factor to poor flight crew communication was the traditionally high power distance in Columbian culture. The first and second officers on the plane were reluctant to tell the captain what to do. They did not want to appear to be questioning the judgement of the captain and chose not to communicate vital information to the captain.

Personnel in Defence aviation; however, have an obligation to communicate safety and operational concerns, especially during flight. PACE offers a useful tool for subordinates when speaking up in a Defence aviation context.

Leadership

Although there are numerous definitions of the term leadership, it is accepted that it involves a process of social influence whereby a person directs or facilitates members of a group towards a common goal (Bryman, 1986; Northhouse, 2004). As mentioned earlier, leadership is the most important of all the factors that influence teamwork; hence the additional space given to the topic here. There are plenty of instances in the aviation literature of accidents where the captain's leadership was a significant contributing factor. In the DC-8 example cited earlier in this chapter, the crew could have done more to alert the captain to the state of the fuel but there is no doubt that the captain should have been aware of the problem himself, as duly noted in the National Transportation Safety Board (NTSB) report.

Another notable example occurred in Detroit in 1990 when a Boeing 727 collided with a Douglas DC-9 during heavy fog. Eight people died when the wing of the Boeing, under take-off power, sliced through the main fuselage of the DC-9.

The subsequent investigation by the NTSB concluded that the primary cause of the accident was a lack of crew co-ordination that resulted in the DC-9 inadvertently taxiing onto an active runway. However, in commenting on the lack of crew co-ordination involved in this accident, the inquiry specifically observed that during the events immediately preceding the accident, the captain had "... tacitly relinquished his command role of the aircraft" (NTSB, 1991, p.35). Further, it was remarked that the first officer had "... failed to follow repeated instructions from the captain" (NTSB, 1991, p.35). Implicit among these findings was the notion that the captain's lack of appropriate leadership resulted in the breakdown of communication and co-ordination which ultimately lead to the collision.

PACE — A four-step progression to survival

P Probing for a better understanding **A** Alerting captain of the anomalies **C** Challenging suitability of present strategy **E** Emergency warning of critical and immediate dangers

PACE — Probing, Alerting, Challenging, Emergency warning — is a four-step progression going from enquiry to disaster warning. The progression is incremental and operationally relevant. Each step is a building block for the next. Each step serves as a non-threatening signal to the captain that a response to each step is required.

The example below illustrates 'PACE' steps that could and should have been used by the co-pilot of the HS-748 in the Air Illinois, night instrument flight rules (IFR), complete electrical failure accident (NTSB, 1985). The aircraft departed Springfield in night VFR conditions, on an IFR flight plan through a line of predicted thunderstorms. The final destination was Carbondale, the corporate maintenance headquarters. Both generators became inoperative shortly after takeoff, while still in VFR conditions. The captain elected to continue into the frontal system on battery power. The aircraft suffered complete electrical power failure when the battery went dead. All aboard were lost.

Step 1: PROBING statement

"Captain, I need to understand why we are flying like this."

Example for the HS-748 co-pilot: "Captain, I don't understand why we are proceeding into night IFR with a line of heavy rain showers ahead of us. Why don't we maintain VFR (visual flight rules), go back to Springfield and land before the battery goes dead?"

Step 2: ALERTING statement

"Captain, it appears to me that we are on a course of action that is drastically reducing our safety margins and is contrary to both your briefing and to the company's SOPs."

Example for the HS-748 co-pilot: "Captain, if we proceed, from VFR conditions into the line of heavy rain showers, on battery power only, we will crash because we have no way to fly on instruments when our battery goes dead. We should not even be flying day IFR with one generator inoperative, let alone flying night IFR into lightning and heavy rain showers with both generators inoperative."

Step 3: CHALLENGING statement

"Captain, you are placing the passengers and aircraft in irreversible and immediate danger. You must immediately choose a course of action that will reduce our unacceptably high risk levels."

Example for the HS-748 co-pilot: "Captain, you are placing the passengers in a position of a certain crash when the battery goes dead. You must immediately reverse course and get back to night VFR conditions."

Step 4: EMERGENCY warning

"Captain, if you don't immediately increase our safety margins, it is my duty and responsibility to immediately take over control of the aircraft."

Example for the HS-748 co-pilot: "Captain, if you don't immediately reverse course and get back to night VFR conditions, I must take over control of the aircraft. I cannot allow you to subject the passengers to such an unnecessary and high risk of certain death. Under these conditions, it is my duty and responsibility to relieve you of your command."

The 'PACE' steps — Probing, Alerting, Challenging, Emergency warning — require that the captain makes a satisfactory response to the co-pilot at each level of enquiry and intervention. It should be an organisational SOP that if the captain ignores the co-pilot through all four steps of 'PACE', the co-pilot must proceed to assume command and control of the aircraft.

Source: Excerpt from Robert O. Besco's *Releasing the Hook on the Co-pilot's Catch 22.*

> **"When leadership fails and a command climate breaks down, tragic things can happen. This is the story of failed leadership and a command climate which had degenerated into an unhealthy state of apathy and noncompliance — a state which contributed to the tragic crash of a B-52 at Fairchild Air Force Base, on the 24th of June 1994, killing all on board"**

CZAR 52: A PRELUDE TO DISASTER
Source: CTI, n.d

Figure 10–1. Czar 52 shortly before colliding with terrain
Source: Check-six, 2015

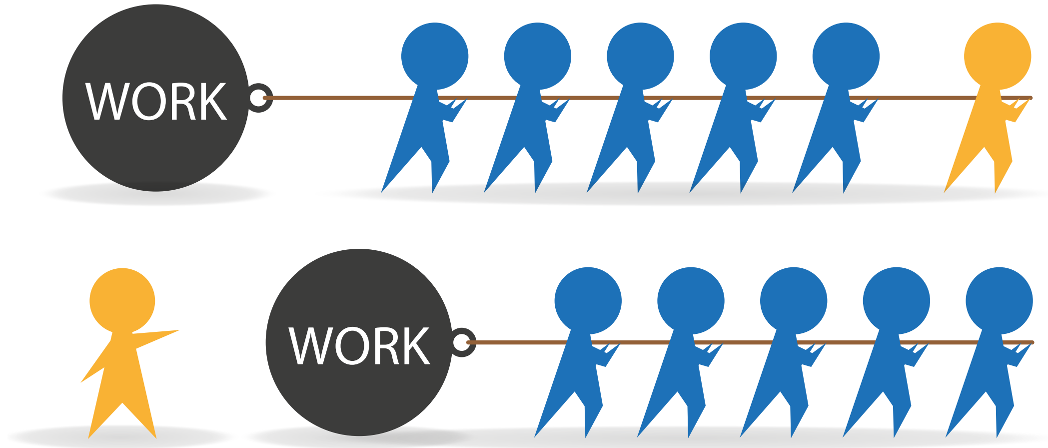
We do not need to look beyond the borders of our own organisation to find instances of poor teamwork due to failures of team leadership. In October 1987, during a two-aircraft route reconnaissance mission in support of an Army exercise, Kiowa A17-19 crashed after a wire strike. The co-pilot died as a result of his injuries. Significant human-factors issues were revealed during the investigation, particularly in the areas of aircrew team management and cockpit authority (DDAAFS, 2014).

These examples all come from aircrew but evidence that leadership is important in other aviation roles is not hard to find. Data from the *Snapshot* surveys consistently indicate that there is a negative relationship between the quality of supervision and errors. Thus, when the quality of supervision is good, there are fewer errors. Furthermore, the relationship is stronger for maintainers than it is for aircrew, suggesting that leadership is even more important in the maintenance environment.

The impact of leadership across different aviation roles is a minor issue. What is clear is that the role of the leader within the aviation industry carries with it a significant level of responsibility. One of the most dramatic examples of ineffective leadership within the aviation environment involves the crash of a Boeing B-52 bomber, Czar 52, in 1994.

The aircraft was piloted by a senior officer who had been authorised to practice a series of manoeuvres in preparation for an airshow. Upon preparing to land at the end of the practice run, the crew was required to execute a go-around because of another aircraft on the runway. At mid-field, Czar 52 began a tight 360-degree left turn around the control tower at only 250 feet altitude above ground level (AGL). Approximately three quarters of the way through the turn, the aircraft banked past 90 degrees, stalled, clipped a power line with the left wing and crashed. There were no survivors.

The subsequent investigation into this accident found significant errors in leadership, disregard for regulations, and breeches of air discipline at multiple levels. Most alarming was the failure of senior officers to act when the pilot had breeched regulations on multiple occasions in the past. His reputation as a skilled pilot appeared to shield him from disciplinary action.



One senior officer remarked that he "is [as] good a B-52 aviator as I have ever seen". However, junior officers were not so enthusiastic, one of them commenting that: "I'm not going to fly with him, I think he's dangerous. He's going to kill someone someday and it's not going to be me." Another junior officer commented that: "There was already some talk of maybe trying some other ridiculous manoeuvres…his lifetime goal was to roll the B-52." (CTI, ND)

The author of the report from which the above material was taken concluded: "These failures included an inability to recognize and correct the actions of a single rogue aviator, which eventually led to an unhealthy command climate and the disintegration of trust between leaders and subordinates."

All the examples described represent cases where leadership was lacking or deficient but they do not tell us anything about how leadership should be exercised. One way of approaching this question is by exploring the notion of leadership styles. There are many taxonomies of leadership style. A common thread in these taxonomies is the degree to which the leader focuses on tasks rather than relationships.

Styles of leadership

One of the most popular taxonomies identifies five leadership styles.

- **Autocratic.** Pure autocratic leadership is where all leader interactions and behaviours are focused on productivity and relationship factors such as social cohesion are effectively ignored.
- **Democratic.** Democratic leadership is characterised by inclusive leader behaviour where followers are given overt responsibility and included in steering tasks such as strategic decision-making. Democratic leadership can be roughly characterised as a balance between task-oriented and relationship-oriented leader behaviour.
- **Laissez-faire.** Laissez-faire leadership is where the leader allows the team members to work autonomously. The leader sets tasks and goals but does not oversee how those tasks are completed or goals are met. A laissez-faire leader will provide resources upon request but otherwise leave employees to self-manage their workload. A laissez-faire style can lead to high job satisfaction but may be harmful when a team requires a high level of co-ordination among its members.
- **Transactional.** Transactional leadership focuses on the provision of rewards and punishment to influence the behaviour of its followership. All work settings are to some degree transactional in that we all work for pay and may experience punishment such as having a bonus or promotion withheld should we under-perform. Transactional leadership focuses on maintaining organisational stability; in contrast to the change-focused approach of transformational leadership.

- **Transformational.** Transformational leaders seek to influence the behaviour of employees not through financial gain but by encouraging employees to absorb the values and goals of the organisation. In this way, employees believe in what the organisation is doing and are motivated because they want the organisation to succeed. When employees care about the success and growth of an organisation, they will go beyond the minimum requirements of their jobs. Transformational leaders emphasise the importance of their followers' roles in the success of the organisation, as well as the importance of what the organisation itself is doing.

Over the years, Defence has moved from an autocratic leadership style to a transformational leadership approach. This movement has been especially evident in the safety area where the majority of personnel now accept the value of working safely.

In 2014, the *Snapshot* Survey asked over 8000 members of the Defence aviation community whether working safely was important to them and whether they worked safely because they were compelled to do so by supervisors and managers. Approximately 75 per cent of the respondents indicated that safety was an important value. Very few respondents indicated that they were working safely simply because of management pressure.

Situational leadership

Although the taxonomy described above provides a useful framework for considering broad types of leadership behaviour, Hersey, Blanchard and Netemeyer (1979) argued there is no best leadership style that can be applied across all situations. Effective leaders need to adjust their styles to suit the capabilities of their subordinates. As the competency level of a team increases, the leadership style will move through four stages: directing, coaching, supporting and delegating.

Stage 1: Directing. During the directing stage, the individual or team lacks knowledge and skill and therefore requires much more guidance. Communication is predominantly one-way with the leader providing clear directions regarding the roles of individual team members and

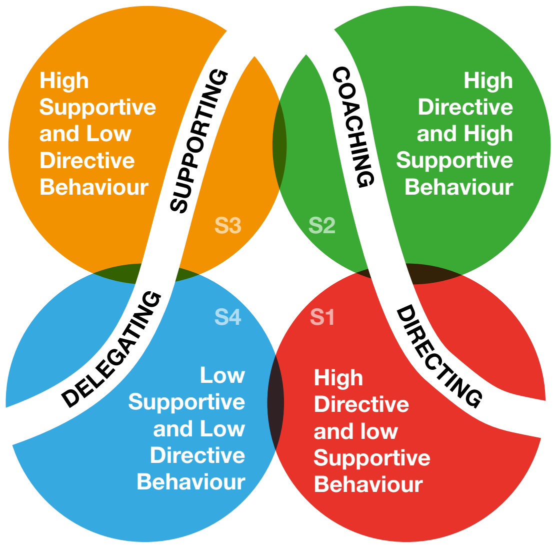


Figure 10–2. A situation-dependent model of leadership styles

specific details on how to perform their given tasks. Defence aviation personnel are likely to experience this style of leadership early in their careers as they are building up their competency in their profession. They may also experience this style of leadership when their role expands and new learning is required.

Stage 2: Coaching. During the coaching stage of Hersey and Blanchard's leadership model, subordinates are now more experienced and communication becomes two-way. The leader is now providing greater social support and considers the development needs of the individual and the team.

Stage 3: Supporting. The competency of the individual or team has improved to the extent that the leader now provides less direction on task execution and focuses more on building team relationships and providing resources. During this stage, employees may have the necessary knowledge and skills but still lack confidence in their abilities.

Stage 4: Delegating. By this stage the leader is confident in the capabilities of the team or individual and provides less oversight on individual tasks. The leader still provides overall guidance and establishes team objectives but focuses on delegating workload to team members and providing feedback on performance.

These various stages and the associated leadership strategies are shown in Figure 10–2.

During an individual's career in Defence aviation, they are likely to experience these different stages with supervisors as you take on new roles and responsibilities and gain expertise. In fact, you will likely shift back to an earlier style each time you take on new roles and responsibilities. In a leadership position, it is important to identify the performance readiness of your team and to adjust the amount of guidance and support accordingly. Leadership styles, while they may be appropriate for given situations, do not guarantee leadership effectiveness. Some useful strategies for achieving effectiveness are outlined in the next section.

Strategies for effective leadership

- **Use of authority and assertiveness.** Create a proper challenge-and-response atmosphere by balancing assertiveness and team-member participation and being prepared to take decisive action if the situation requires it. Leaders must also know when to apply their authority to achieve safe completion of a task.
- **Providing and maintaining standards.** Encourage compliance with standard operating procedures, rules, and regulations. Intervene if necessary. The Czar 52 case study is an excellent example of what can happen if leaders fail to enforce standards.
- **Planning and prioritising.** Apply appropriate methods of planning and prioritising for tasks and delegate roles to achieve best performance. The communication of plans and intentions is important.
- **Managing workload and resources.** Leaders must manage not only their own workload and resources but also those of the team. This strategy may require organising task-sharing to avoid workload peaks and dips. Causes of high workload include unrealistic deadlines and under-resourcing.
- **Consider the developmental needs of your team.** Leaders should move through different stages of situational leadership to accommodate the increased competency of their teams [see Figure 10–2].
- **Avoid role ambiguity.** Ensure all team members understand their roles in task performance and how they personally contribute to the overarching team goals. This understanding is typically achieved through task briefings.
- **Focus on team-member contributions.** Every team member should be aware of the importance of their role in the success and achievements of their team and Defence. Job satisfaction, morale, and performance levels are higher when people feel that they are making useful contributions.
- **Provide feedback.** It is important that leaders provide feedback on task performance, not just when an individual performs poorly but also when they perform well. When criticism is needed, it should be constructive and focus on the task.

Followership

The skills that characterise effective leadership are also applicable, to some extent, to the followers within a group or team. Followership can be defined as the provision of support towards a common goal. It involves not only taking direction from leaders but providing information to team leaders.

A large component of followership is contributing to the shared mental model of the team. It is therefore a supportive role that may become proactive in the interests of safety. The notion of followership has significant implications within the aviation environment, since the hierarchical nature of the aviation industry tends to inhibit, rather than encourage proactive interventions on the part of subordinates.

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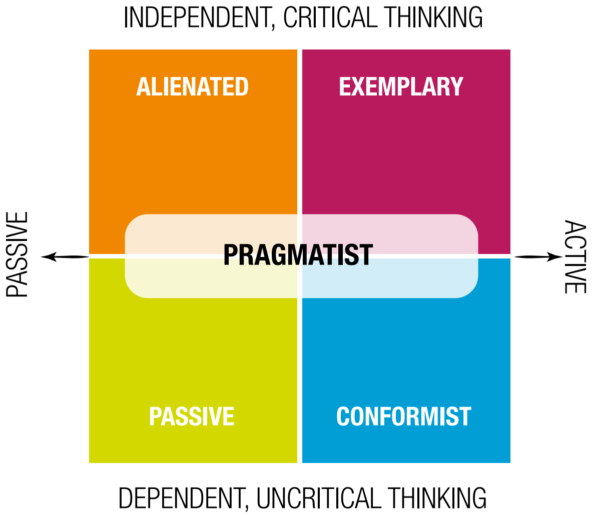

Figure 10–3. Model of followership styles (from Kelly, 1992)

Followership styles

One of the reason's followership has received less attention than leadership is that people assume that everyone knows how to follow. In reality, there are different ways to be a follower, just as there are different ways to be a leader. Kelley (1992) provided a model of followership containing five styles arranged in a grid formation.

The axes of the grid represent the level of independent and critical thought (from dependent, uncritical thinking to independent, critical thinking) and the level of engagement in the team (from passive to active). The model is shown in Figure 10–3.

The interaction of the critical thinking and engagement axes gives rise to the five followership styles.

- **Passive** followers lack self-motivation and require constant encouragement from the leader. They generally lack commitment to the team and organisation. A transactional leadership approach that emphasises performance on a task-by-task basis and does not consider the overall goals of the team or organisation may encourage team members to become passive followers.
- **Conformist** followers are committed to the organisation and the leader but place too much trust in the judgement of the leader.

Conformists are the "yes men" of a team and do not provide information and insight to the leader. This type of team interaction can limit the shared mental model.

- **Alienated** followers can often be exceptional critical thinkers but may seek to undermine the leader and change the direction of the team. Alternatively, alienated followers may represent the mavericks of the organisation who can offer a degree of healthy scepticism without upsetting the stability of the team.
- **Pragmatist** followers take a fence-sitter approach to any decisions or controversy in the team. They are typically the last to respond in a group decision and generally try not to stand out.
- **Exemplary** followers are independent, critical followers who support the goals of the team. They do not follow blindly but try to work with the leader and other team members so that the team has all the information and direction it needs. In Defence aviation, exemplary followers are essential to team performance. A team that has a high proportion of exemplary followers and good leadership is likely to exhibit all five components of effective teamwork.

Strategies for improving followership

- **Self-management** is fundamental to effective followership. Once a person has developed sufficient job proficiency, self-management should reduce the load on the person's supervisor, thus increasing team efficiency.
- **Be courageous.** Anyone that sees or hears of a person or group doing something that compromises safety or Defence values may have an obligation to intervene — and certainly has an obligation to report the incident. Defence aviation promotes the concept of a just culture so taking action should have positive rather than negative consequences for all concerned.
- **Set an example** for other team members. Each member contributes to the attitudes and shared culture of the team. By displaying exemplary followership qualities, an individual encourage others to adopt those qualities.

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Key points

- Teams form an essential part of the Defence aviation workforce. They have characteristics that distinguish them from groups and good teams have characteristics that distinguish them from poor teams.
- While our immediate work teams exert the strongest influence on performance, the influence of wider group structures to which we belong should not be ignored.
- A major influence on team performance is the leader, whose leadership style may vary according to the situation and the maturity of the team.
- Effective leadership is underpinned by effective followership.
- There are strategies for improving teamwork, leadership, and followership.

CHAPTER 11 NTS considerations for aircrew

Overview:

- Military aircrew often work in high-risk, challenging environments
- The consequences of their errors can have immediate and catastrophic effects
- Strategies for managing workload in dynamic environments
- Threat and error management
- Technological advances have changed the way aircrew conduct their tasks
- Advantages and disadvantages of aircraft automation

SECTION 1 Managing mental workload

This section draws on content covered throughout this guidebook to consider the factors that influence the management of mental workload in the cockpit. In particular, how aircrew manage the frequent discrete tasks that interrupt the ongoing prioritised tasks of aviate-navigate-communicate.

The term workload can have a very general meaning. It is often used to describe periods of intense activity. Colleagues say they have a heavy workload, meaning that they have a lot to do, even if they are not actually doing it. However, this chapter, the term workload is used to describe the demands that are placed on the human information-processing system at any given time.

The US Federal Aviation Administration (FAA) demonstrated the importance of mental workload in an emphatic fashion in 1965 when it decreed that minimum flight-crew requirements were to be determined by cockpit workload rather than by the gross weight of the aircraft (Orlady & Orlady, 1999). The revised Federal Aviation Regulations cover workload in Part 25, which specifies airworthiness standards. Appendix D lists seven workload considerations: flight path control, collision avoidance, navigation, communications, operation and monitoring of aircraft engines and systems, flight management system (FMS) operations and monitoring, and command decisions. In a military environment, tasks associated with surveillance, rescue, and combat can be added to the list.

The introduction of this FAA regulation was significant for two reasons: firstly, it highlighted the importance of aircrew workload; secondly, it challenged aviation experts to better understand workload issues and develop methods to support its effective management. These issues will be covered in this section.

The concept of mental workload

Early research into the concept of mental workload was conducted by Charles Spearman, an English engineer and army officer who became interested in psychology. Spearman saw intelligence as a central pool of energy that was required for all cognitive tasks. In addition to the central pool, each task had a unique pool. He likened them to engines, with an engine for each task. Thus, when a calculation needs to be done, the general pool provides the energy for the operation, and the mathematical engine is responsible for the execution of the task. People differ in the amount they have available for general and specific abilities, and tasks differ in the demands the place on both the general and the specific 'engines'.

It is these differences that explain the variation we observe between individuals on cognitive tasks and the fact that we find some cognitive tasks more difficult than others.

Theories of mental workload have advanced considerably since Spearman but the proposition that individuals differ in the mental resources they have available and that tasks differ in their requirements for these mental resources are embedded in modern information-processing models. They form the backbone of our understanding of mental workload in aviation.

The information-processing foundations of mental workload

The information-processing model presented in Chapter 2 contained a sensory store, working memory, long-term memory, a decision and response selection system, a response execution system, and attentional resources.

The model has been replicated in Figure 11–1. To explain the information-processing foundations of mental workload, we need to focus on two components in particular: attentional resources and working memory.

Attentional resources and workload

> **"Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem to be several simultaneously possible trains of thought. Focalisation, concentration of consciousness are of its essence"** (BADDELEY, 1986)

This definition, provided by William James in 1890, captures our experience of attention and its two outstanding characteristics — focalisation and concentration — can be seen in Figure 11–1 where active filtering of information occurs at the beginning of the sequence. Attention, which has sometimes been compared to a spotlight, cannot be everywhere at once and, even if it could, there is insufficient space to hold information coming simultaneously from all the sensory systems. Aircrew will not be able to respond to all the stimuli in their environment, or sensory overload will occur.

You can prove this to yourself anytime by switching your attention between the different sensory systems. Listen to the sounds in the environment. They were there all along but you were not aware of them. Switch your attention to the pressure you feel from sitting, or standing. You are now allowing information from a different sensory system (kinaesthetic) to enter working memory.

If you are fully attending to these inputs, you are probably no longer aware of the auditory stimuli. Switch your attention to the information that is coming through your hands, yet another sensory system (haptic). If you are using controls that require considerable manual dexterity, you will often give priority to sensory information from that channel.

The second key feature of attention is the pool of attentional resources feeding into all other components of the model. The concept of attentional resources is very similar to Spearman's notion of energy (Hunt, 1980). Tasks differ in the amount of attentional resources they require and individuals differ in the amount of resources they have available.

Mental workload is high when individuals find themselves approaching the limits of their attentional resources. We will return to these points after we have discussed working memory, the other component of the information processing model that determines the boundaries of mental workload.

Working memory and workload

The two key features of working memory in relation to mental workload are **time** and **capacity**. Information that needs to be held in working memory must be constantly refreshed or the information will either be lost or subjected to interference from incoming information.

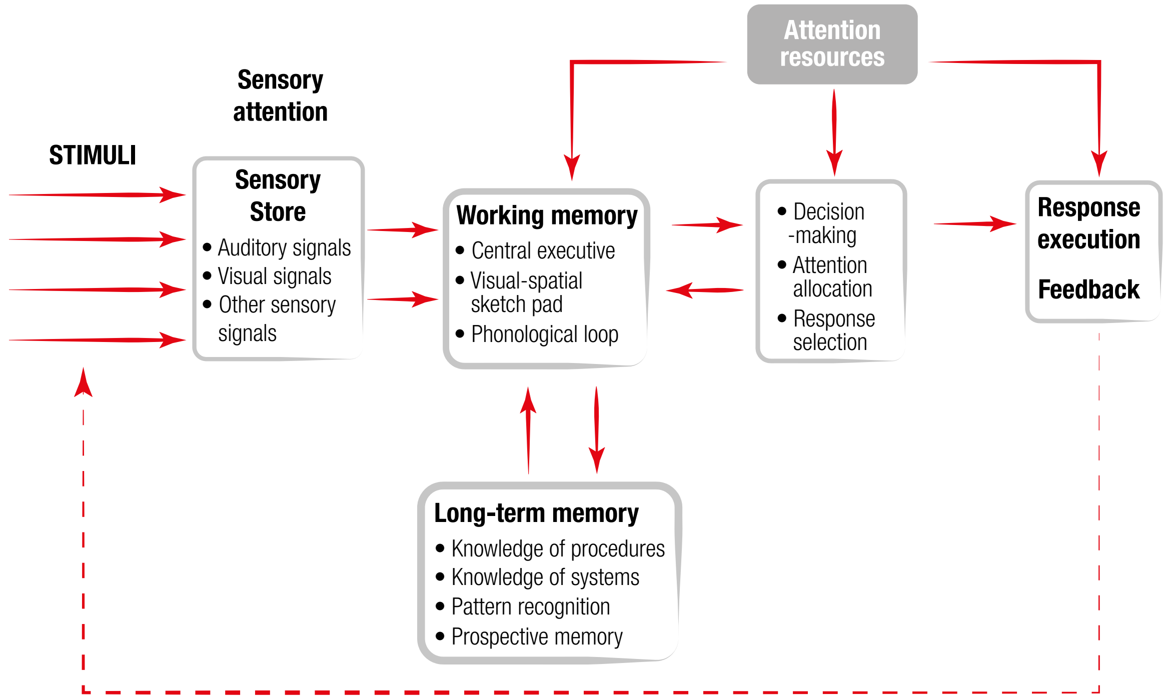


Figure 11–1. A model of information processing

Working memory also has limited capacity. We can repeat a list of about seven letters, digits, or words (Miller, 1956) but when it comes to meaningful items (like instructions) the limit for working memory is about four units (Cowan, 2010). For example, when executing a new procedure that requires more than four steps, errors are likely to occur if the pilot attempts to maintain all of the steps in working memory. Success is much more likely once the steps have been successfully integrated into a small number of chunks (fewer than five), or a single chunk. It is important to understand these information-processing limitations because if the amount of information that a crewmember has to process within a given time exceeds the crew members's capacity, there is a risk that safety will be compromised. The other major consideration in this workload equation is the nature of the tasks themselves.

Task influences on workload

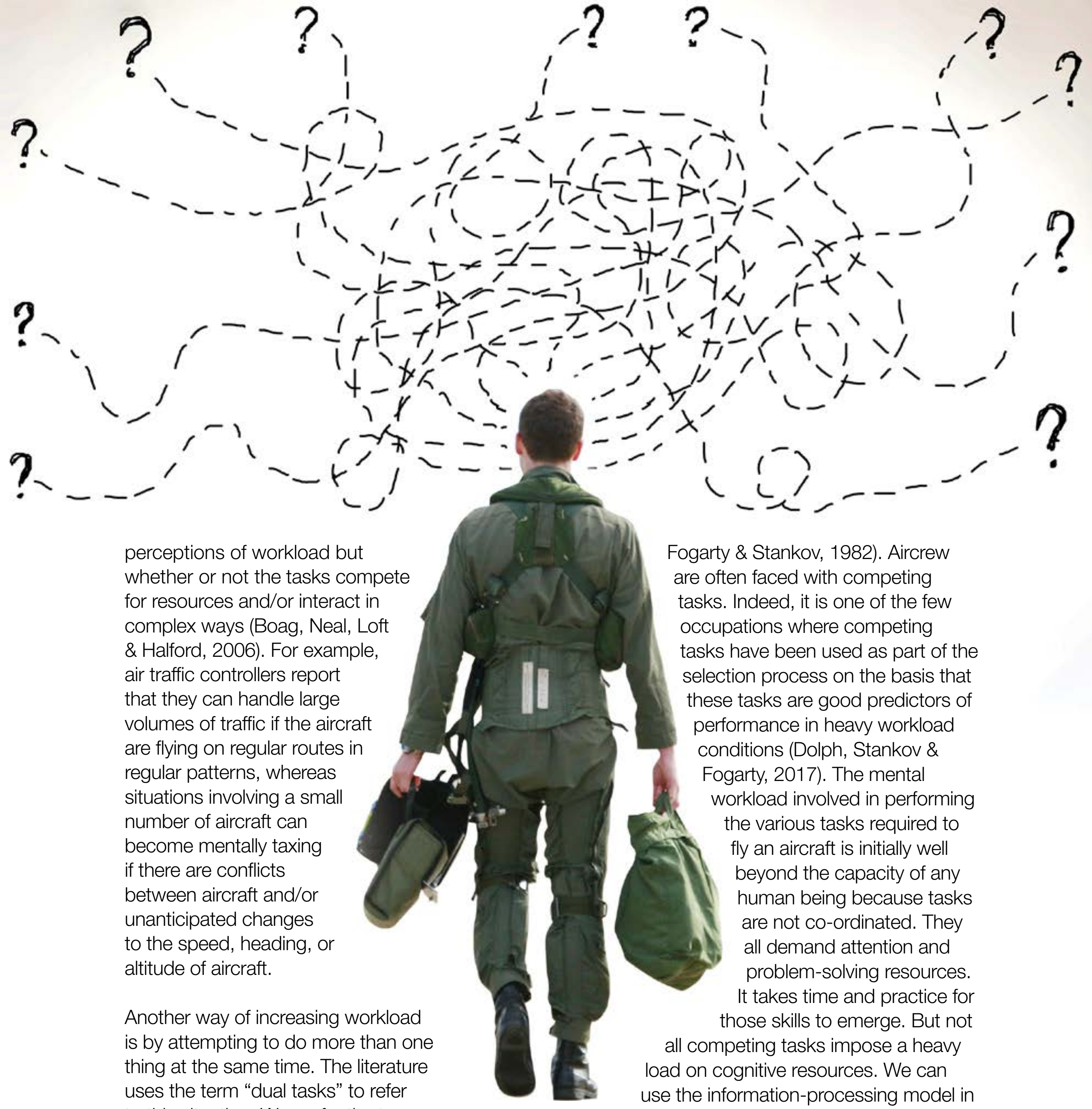
In the past 50 years, a great deal of research has been carried out examining the influence of task difficulty, task complexity, and competition between tasks on mental workload.

Task difficulty and task complexity and workload

A common assumption is that task difficulty and the number of tasks are the major determinants of workload. However, tasks can be difficult without imposing a significant demand on cognitive resources. Reading this text is easy but it would become difficult if the colour of the font was changed to pale yellow or the ambient light was reduced so that the text could hardly be seen.

In a cockpit, this feature of the displays is referred to as conspicuity. Instruments must be easy to read and audio messages easy to hear. If not, the task becomes difficult and may require more attention — and therefore increased workload — without necessarily changing the demands on working memory.

Complexity is a different story altogether. The complexity of a task is determined by the number of related variables that must be processed in parallel in order to complete the task . A consistent finding is that it is not the number of tasks per se that influences



perceptions of workload but whether or not the tasks compete for resources and/or interact in complex ways (Boag, Neal, Loft & Halford, 2006). For example, air traffic controllers report that they can handle large volumes of traffic if the aircraft are flying on regular routes in regular patterns, whereas situations involving a small number of aircraft can become mentally taxing if there are conflicts between aircraft and/or unanticipated changes to the speed, heading, or altitude of aircraft.

Another way of increasing workload is by attempting to do more than one thing at the same time. The literature uses the term "dual tasks" to refer to this situation. We prefer the term "competing tasks" because we are very often doing two or more things at once (dual tasks) without apparent effort and without performance decrements. The term "competing tasks" refers to cases where two or more tasks compete directly for attention or central resources.

Competing tasks and workload

If there is a requirement to process two or more tasks simultaneously, the effect on mental workload can be dramatic (Fogarty, 1987; Fogarty & Stankov, 1982). Aircrew are often faced with competing tasks. Indeed, it is one of the few occupations where competing tasks have been used as part of the selection process on the basis that these tasks are good predictors of performance in heavy workload conditions (Dolph, Stankov & Fogarty, 2017). The mental workload involved in performing the various tasks required to fly an aircraft is initially well beyond the capacity of any human being because tasks are not co-ordinated. They all demand attention and problem-solving resources. It takes time and practice for those skills to emerge. But not all competing tasks impose a heavy load on cognitive resources. We can use the information-processing model in Figure 11–1 to tell us where competition is likely to occur and the type of competition involved.

Competition at the input stage. Tasks are easier to combine when there is no structural interference. Structural interference occurs when tasks rely upon the same input modalities (for example, both tasks rely on auditory input) or output modalities (for example, both tasks require the use of the keyboard). Competition of this kind makes the tasks more difficult but not necessarily more complex. If the competition is at the input stage, the probability of error is increased because information may be missed. If the competition is at the output stage, workload increases because tasks may have to be queued. The converse is also true. Multitasking is easiest when the tasks come through different sensory channels (for example, eyes versus ears) and/or use different output modalities (for example, voice for one task and the keyboard for another). The application of human-factors principles at the job design stage will reduce instances of structural interference.

Partial overlap. Competing tasks are easier to perform when the incoming information is staggered so that attention can be switched between the input channels. Tasks may still compete for working memory space and central processing resources — and workload capacity may still be exceeded — but the competition is lessened at the input stage and that makes a difference to mental workload.

Competition for working-memory storage. When tasks compete for the same working-memory systems, errors will occur as information spills over from these limited capacity short-term storage systems. Workload for the central executive will increase as it tries to resolve the competition for storage. Again, multitasking is easier when the tasks use different working-memory storage systems. For example, an auditory task requiring vocal output combined with a visual one requiring manual output.

Competition for processing resources. If either task is complex, some cognitive effort involving central resources will be required. Combining complex tasks is always going to be difficult. In laboratory situations, when confronted with novel competing tasks of this kind, participants usually ignore one of the tasks rather than risk failing both (Dolph et al., 2017; Fogarty, 1987; Fogarty & Stankov, 1982). However, if the competing tasks have a low complexity rating, the subjective experience of workload may not be high and performance may not suffer.

Concurrent tasks and workload

Concurrent tasks are a form of multitasking where there is no competition at the input or response stage but where you still find yourself doing several things at once. For example, you may start one task and then have to wait for input from elsewhere before it can be completed. In the meantime, you hold the information from that task in working memory while you attend to other tasks, which may also compete for working memory space.

The fact they are concurrent does not mean that such tasks impose a heavy demand on cognitive resources. The mental workload will depend on how many tasks one is performing concurrently, how complex those tasks are, and whether the tasks are likely to interfere with each other.

Concurrent tasks are frequently encountered in daily life. They are the reason you find yourself putting sugar in the tea pot, a case of mixing up the scripts for ongoing tasks!

Concurrent tasks pose a particular challenge for error management among aircrew. Failures of prospective memory [see Figure 11–1] can lead to tasks dropping off the register, similarity of content can lead to interference or confusion between concurrent tasks, and excessive storage or processing requirements will inevitably result in performance decrements. This will be addressed further in managing workload.

Contextual factors and workload

A prominent theme of this guidebook has been the influence of personal and situational factors on performance. Perceptions of workload are influenced by a range of personal and situational factors. Appendix D of Part 25 of the FAA regulations cited earlier lists 10 workload factors that influence aircrew mental workload in a commercial airline environment. The list is not comprehensive and it does not take into consideration the unique demands of military aviation (for example, weapons management) but it represents a generic list of workload factors for aircrew.

- Access and operation of controls.
- Access and conspicuity of instruments/displays.
- Number and complexity of procedures.
- The degree and duration of concentrated mental and physical effort involved in normal operation and in diagnosing and coping with malfunctions and emergencies.
- The extent of required monitoring of the fuel, hydraulic, pressurization, electrical, electronic, de-icing, and other systems while en route.
- Crew member unavailability.
- The degree of automation.
- The communications and navigation workload.
- The possibility of increased workload associated with any emergency.
- Incapacitation of a flight crewmember.

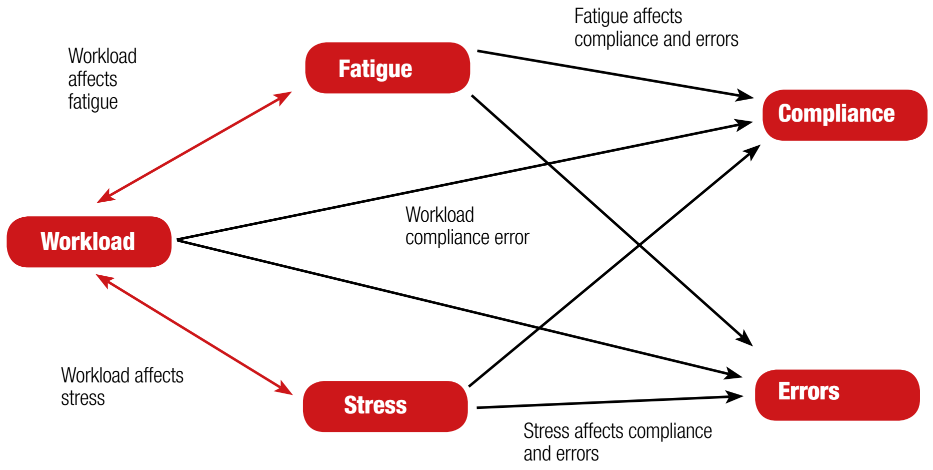


Figure 11–2. The influence of workload on fatigue, stress, compliance, and errors (*Snapshot* 2016)

In addition, the following factors are already discussed in this guidebook.

- Physical and mental state — workload of any type is always more challenging when someone is not at their best.
- Time pressure — there is a direct and inverse relationship between the time allowed to perform tasks and perceptions of workload pressure.
- Environment — sub-optimal conditions (for example, visibility, heat, cold, wind, noise) will increase perceptions of workload.
- Expertise — a high-workload task for a novice may be accomplished with little effort by an experienced and well-trained operator, especially if the task has consistent parameters and is always performed the same way.

Effects of high workload

In addition to understanding the factors that affect workload, it is important to understand the effects of workload on people. Some of the effects of high-workload follow.

Attentional and task focusing. If workload exceeds the capacity of the individual aircrew member, the person may respond by focusing exclusively on one of the tasks (if concurrent or competing) or just part of a complex task. Task shedding is the result. This attentional phenomenon is known as narrowing, coning, or funnelling. Under high-workload conditions, failure and loss of situation awareness is inevitable.

Task reprioritisation. This response usually accompanies task shedding in a competing task or concurrent task situation. The capacity of the individual is being exceeded by the demands of the task so some compensation is necessary. The crew member assigns different priorities to the competing tasks and allocates attention accordingly.

Poor decision-making. We know from the chapter on decision-making that people do not usually examine all the options (the classical model). Rather, they engage in a rapid search of long-term memory to match the current set of circumstances and quickly arrive at what they consider to be a workable solution (naturalistic model). Decision-making itself consumes attentional and processing resources [see Figure 11–1]. Under high-workload conditions, fewer options will be checked and there will be less evaluation of the correctness of the decision.

Disrupted communications. An increased workload tends to shorten communications and reduce the number of exchanges, with a corresponding increase in communication errors. A person absorbed in a difficult or unfamiliar task is less likely to understand what someone is saying.

Increased fatigue, stress, violation, and error. Sustained high workload contributes to fatigue and stress which, in turn, are associated with higher rates of violations and error among aircrew. We see those connections in aviation safety reports. We also see them in statistical modelling work based on data collected in the annual *Snapshot* surveys. Figure 11–2 shows these relationships with the arrows indicating the direction of influence. Note that the arrows connecting workload with stress and fatigue are double-headed, indicating that there is a feedback loop between workload and fatigue and between workload and stress. The higher the workload, the higher the fatigue but high states of fatigue also increase perceptions of workload. Workload and stress have a similar reciprocal relationship.

Threat and error management

Threat and Error Management (TEM) is a framework that recognises error as a normal and expected part of human behaviour. In the course of their duties, individuals and crews will encounter a number of threats (external influences) and/or errors (internal influences) that could lead to an unsafe outcome. Being able to anticipate, recognise and manage threats, errors and unsafe outcomes is a key principle of the TEM framework.

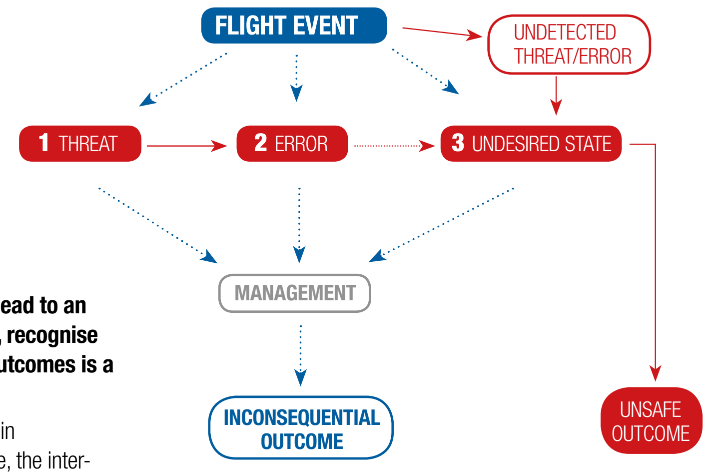


Figure 11–3. Defence aviation TEM model

TEM provides a conceptual model that assists in understanding, from an operational perspective, the inter-relationship between safety and human performance in dynamic operational contexts. The three key components of the TEM framework are illustrated in Figure 11–3:

Threat is defined as an external influence that occurs outside the influence of the crew, but has the potential to negatively impact flight safety. Threats require crew attention and management. Threats may include: adverse weather, traffic, sub-optimal airport conditions, ATC errors, poor external communications and organisational stressors

Error is defined as crew actions or inactions that lead to a deviation from the correct course of action or behaviour for the situation. For the purposes of TEM, violations (that is, intentional deviations) are included in this definition as the detection and correction of these behaviours is managed in the same way.

Undesired state is defined as the position, condition or attitude of an aircraft that clearly reduces safety margins and is the result of ineffective threat or error management. Undesired states may include: deviations in position or speed of the aircraft from what is intended, or incorrect system configurations.

It is important to recognise that an undesired state is not an unsafe outcome; there is still opportunity for the crew to recognise and manage the situation back into a normal state.

A key principle of TEM is that with effective countermeasures, threats, errors and undesired states can be managed into inconsequential outcomes. Some countermeasures include software, such as procedures, training and checklists, or hardware, such as alerting systems and aircraft design. However, it is not enough to rely on the systems that support us. The NTS introduced in this guidebook provide the foundation for employing the following TEM countermeasures:

Planning — it is impossible to predict every threat or error that may occur during the course of a flight, but by effectively planning and preparing for a flight, and briefing anticipated threats and strategies to manage them, crews will be better able to manage the unexpected. This includes understanding potential threats such as fatigue and stress and effectively managing their impact on performance.

Execution — a crew that work well as a team, communicate and make sound decisions will have better situational awareness, and therefore be able to prevent errors, or, detect and effectively manage threats, errors or UAS.

Review — effective threat and error management requires constant vigilance, and that requires crews to constantly review their environment and adapt accordingly. Again, NTS skills such as teamwork, communication, decision-making and situation awareness support effective identification and management of threats and evolving situations.

For individuals and crews, understanding the principles of TEM will assist not only in anticipating, managing and recovering from threats and errors, but it can also be a useful for self-assessment. Using the TEM framework to identify challenges and how they were managed can support individual and crew development. In conjunction with workload management and automation management, TEM supports consistent and effective performance.

Source: CASA Safety Behaviours, *Human Factors Resource Guide for Pilots* (2009)

Threat and error management for workload

So how might aircrew manage "the frequent discrete tasks that interrupt the ongoing prioritised tasks of aviate-navigate-communicate"? We attempt to address this question by reviewing the major causes of workload and identifying methods of managing the associated threats.

Dealing with competing and concurrent tasks is the most likely category to cause workload issues for aircrew. Having to do two or more things at once where the tasks compete for limited resources at either the input, processing, or output stages of task execution is challenging. What are the mechanisms that permit us to perform a number of activities simultaneously? Psychologists have been grappling with this problem since they first started studying the nature of attention. Exactly 100 years ago, McQueen (1917) published a plausible list of strategies:

- attention is switched between the tasks
- one task becomes automatic and does not require attention
- the tasks become fused so that they constitute on complex object
- there is a genuine division of attention between the tasks.

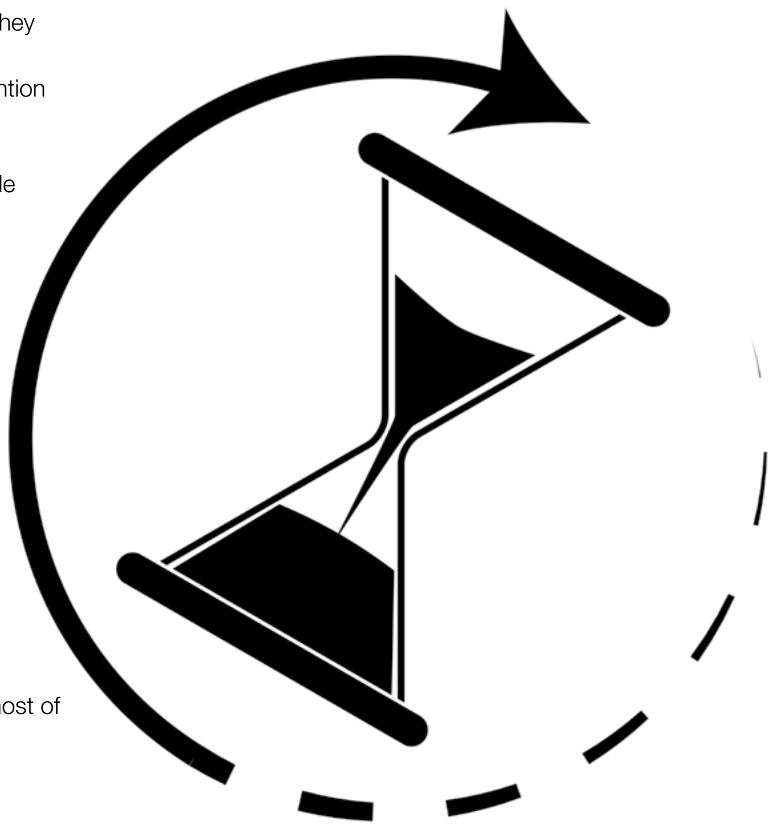
Considering each of these in turn; attention switching is clearly possible when the inputs are staggered, as they are in many concurrent tasks. However, in a work situation it is unlikely that attention switching would be effective for truly simultaneous tasks. Attention switching itself requires effort and will therefore add to the workload.

The option of one task becoming automatic and requiring minimal attention is certainly valid. Although it is a mistake to say that a task requires no attention, there is no doubt that we can do a number of things simultaneously if performance on most of the tasks is highly skilled. Add a complex task to the mixture and the picture changes. The often-quoted example is that of driving a car. Drivers will cease talking or listening to the radio when negotiating difficult stretches of road or difficult traffic conditions. A person may even stop walking if given a difficult computation to perform.

Most competing or concurrent tasks do not give rise to workload issues; it is the element of novelty or inconsistency or complexity of components that creates the mental workload. Training is the answer.

The third option also has considerable merit and is a deliberate strategy for mastering some complex single tasks as well as competing and concurrent tasks. Thus, Boag and colleagues (Boag, et al., 2006) described how the relational complexity of an air traffic control task could be reduced by "chunking" segments so that they formed a co-ordinated whole, rather than a series of discrete parts.

The term "chunking" originated in memory studies where superior performance was observed when long strings of information were broken into smaller chunks. Orators have been using this technique since the time of the Ancient Greeks. They broke their speeches into chunks and visualised the different chunks in different rooms of a house. When they imagined themselves entering a room, they recalled the contents of the chunk associated with that room. Many different physical skills are taught in this fashion.



The last of McQueen's strategies implies that there is a genuine division of attention between the components of a competing task. The empirical evidence for the existence of a genuine divided attention or timesharing factor is weak (Fogarty, 1987). We do not encourage efforts to master such an ability. It would be more profitable to spend time developing skills to the point where tasks become automatic, fused (co-ordinated), or less complex through using chunking to reduce complex sequences to manageable units.

Effective workload-management strategies

In addition to these specific suggestions for reducing workload by improving performance on individual tasks, there are general strategies that can be used to deal with workload issues. Most of the options come down to good supervision, good self-awareness, and effective teamwork [see Chapter 10].

Effective communication. When a particularly distracting problem arises, or the workload becomes unusually heavy in multi-crew environments, one of the crew members should be made responsible for communication while the other remains in control of the mission. Do not interrupt other people to give them information that could wait, if their workload is heavy.

Management of stress. During periods of high workload or high stress, it may be very difficult to ensure critical information is assimilated and acted upon appropriately. It is the responsibility of the crew — collectively and individually — to ensure that critical information is passed, understood, and acted upon in a manner that fits the situation. With co-ordinated activities, workload can be shared or delegated to ensure any one team member is not overloaded.

Effective leadership. Leaders must manage not only their own workload and resources but those of the team. Effective management involves understanding the basic contributors to workload and developing the skills of organising task-sharing to avoid workload peaks and dips. The causes of high workload include unrealistic deadlines and being under-resourced.

Try to plan tasks so that the crew are not left with several things to be done at once. Teamwork among crew members can reduce the likelihood of one crew member being overloaded. In overload situations, always be clear as to who is still in charge of the overall mission.

Maintain situational awareness. Generally, good situational awareness increases safety, reduces workload, enhances performance and improves decision-making.

Ensure effective mission planning. Good mission preparation can reduce your workload.

- Detailed planning minimises the time taken for decision-making during the mission.
- Sufficient briefing prior to the mission will mean that information can be easily absorbed during the mission. For example, knowing the current duty runway and weather conditions before flying will mean you rapidly absorb what the automatic terminal information service (ATIS) is telling you.
- Plan your actions in order to minimise your workload. For example, have the next VHF frequency dialled up ready to select — don't wait until you need it.

Effective threat management. Be mindful that the more complex or challenging, and/or distracting the operating environment becomes, the greater the workload for individual crew members.

Effective workload assignment. Roles and responsibilities should be defined for normal and non-normal situations. Workload assignments should be communicated and acknowledged.

The role of automation

The final option for managing workload moves into the area of technology. Automation serves a number of purposes in aviation including removing the human from dangerous situations, replacing the human for tasks that occur very infrequently and/or are hard to detect, and aiding the human operator [see next section].

The increased use of automation in aviation has been one obvious response to workload problems for aircrew. Automation can help with detection (for example, scanning), decision-making (for example, decision support systems), and control (for example, FMS, autopilots).

There are some dangers associated with using automation. Automation works well if it is seen as an aid rather than as a replacement for the human operator. From a workload point of view, automation should be flexible and adaptive. Flexible in the sense that the crew can choose to use it or not (for example, autopilot). Adaptive in the sense that it is not all-or-none but allows the crew some degree of control.

Summary

Workload is not a simple topic. We need to consider it in the context of the capacity of the human operator, the nature of the tasks being completed, and the technological aids introduced to reduce workload. There is much that can be said about each of these inputs.

The capacities of aircrew members differ because of their training, physiological state, experience, motivation, interest, and expertise. Task demands, on the other hand, vary according to difficulty, complexity, mode of input, mode of response, the nature of competing and concurrent tasks, the priorities attached to those tasks, and the context.

In this section, we have approached all these issues from the point of view of the human information-processing system. It is the key to understanding the experience of workload, how it is assessed, and how it can be managed. Attention and working memory are the central constructs.

When workload is too high (overload), the information-processing system will inevitably fail to detect or respond to important information. When the workload is too low, attentional mechanisms may fail because it takes effort to maintain situation awareness when nothing much is happening. Training, teamwork, and technology are important ways of managing workload. Training because it leads to expertise, teamwork because the group is stronger than the individual, and technology because it is reliable and accurate and under the control of the human operator.

Key points

- Workload varies across individuals according to their expertise and motivation.
- Task complexity is a major determinant of workload. A single task can impose a heavy cognitive load if it is very complex.
- Competing tasks and concurrent tasks pose a special challenge for aircrew until they are well-practised and have become routine.
- Heavy workloads can create feelings of stress and fatigue which can, in the form of a feedback loop, make workloads seem heavier.
- The personal- and work-management techniques discussed throughout this guidebook will help aircrew members to deal with heavy workloads.
- Sound management practices and teamwork will help to avoid workload peaks and troughs.
- Automation can also reduce workload peaks without necessarily leading to the crew member becoming de-skilled in areas covered by automation.

Surprise and startle

Have you ever jumped, or had your entire body physically jerk in response to a loud noise or fright? We refer to this as the startle reflex, and it is an acute (sharp) stress response (that is, the immediate rush of stress hormones, aka the alarm reaction at the beginning of a fight-or-flight response) — in contrast to the slow accumulation of chronic stress. Unlike chronic stress, there is no evidence to suggest that a startle reflex will have any long-lasting cognitive or health effects. However, it can distract aircrew personnel from the task at hand — with fatal consequences.

Compare the following two aviation incidents: Qantas Flight 32 (QF32) and Air France Flight 447 (AF447).

Flying over Indonesia, QF32 experienced an uncontained engine failure due to the breaking of a poorly manufactured sub oil pipe, which subsequently resulted in damage to flight controls, landing gear, fuel system and wing, among other aircraft components.

Despite this severe damage, QF32 managed to successfully make an emergency landing at Singapore's Changi Airport.

Conversely, while flying over the Atlantic Ocean AF447 entered an aerodynamic stall after the aircrew responded poorly to the autopilot disconnecting. The disconnection occurred because of airspeed measurement inconsistencies caused by icing on the aircraft's pitot tubes (pressure measurement instrument). There were no fatalities of QF32, and no survivors of AF447.

Aviator and researcher Dr Wayne Martin offers insight into the role of the startle reflex in the responses of the respective aircrews:

"These pilots would have been confronted with overwhelming external sensory data, all the while under the elevated arousal state brought on by a stressful emergency. Attempts to regain control would perhaps have been swamped by continual incoming external stimuli.

The major difference in these two examples was in their outcome: in the Qantas flight deck the experienced captain immediately pressed the altitude hold button which attenuated a lot of the adverse thrust effects and allowed immediate control of flight path; whereas in the Air France flight deck, the inexperienced first officer, exhibiting strong indications of startle, immediately pulled up, exacerbating the (perfectly survivable) flight-control problem.

The subsequent differences in immediate workload allowed the QF32 crew to make a considered analysis and work through the problem, while the AF447 crew continued to reactively deal with the ambiguous environmental cues in an uncontrolled and unco-ordinated manner."

For pilots, the main effects of the startle reflex are the interruption of the ongoing process (that is, flying the aircraft) and distraction of attention towards the cause of the startle. We have an instinctual response to address the perceived threat, distracting us from other safety-critical tasks.

Further, research suggests that people have a tendency to forget recently learned information when startled, and may therefore run the risk of reverting back to more established learning that may not be the most suitable for the situation, such as mistaking the aircraft for a more familiar previously learnt aircraft.

As the startle response may distract you from tasks at hand and make you forgetful of recently learned information, the best solution for responding to being startled is to rely on simple rule-based response processes. This is why aircrew will experience a great deal of repetition in learning how to respond to safety-critical scenarios in flight training, so that they can respond instinctually and limit the influence of a startle response.

Relying on rules such as the aircraft manual or BOLDFACE may not only limit your chance of error, but may help you regain control as you slide into the appropriate chain of actions. A good place to start is the classic rule of 'aviate, navigate, communicate, administrate'. In severe and heightened cases with fight or flight, this may not be enough.

There are a number of stress-management exercises that may be helpful in reducing the stress of a startle response and help you refocus on the tasks at hand. Breathing exercises can be useful in and outside of the cockpit to reduce the residual stress arousal from a startle.

"Today's aircraft automation controls an airplane more or less as the pilot does. It navigates as the pilot does, or would if pilots could carry out in real time the complex calculations now performed by the computer. It operates the systems as the pilots do, or would do if they do not forget or overlook any of the procedural steps. In the near future, it will communicate with ATC computers, accept and execute ATC clearances, and report its location when not under radar coverage, just as pilots do now. Some have noted that automation usually performs all of these functions correctly, that it does not become tired or distracted or bored or irritable, that it often speaks more clearly and succinctly than pilots do, that its data stream will be easily comprehended by ATC computers in any nation, and that it does all these things without complaints. They have concluded that automation is as capable as the human for these functions, and some air carriers have mandated that it be used whenever possible. Are these 'parts' interchangeable?"

CHARLES E. BILLINGS, *AVIATION AUTOMATION: THE SEARCH FOR A HUMAN-CENTERED APPROACH*, 1996

"I don't want monitors here. I want pilots. . . . Our whole philosophy is that the pilot is in charge of the airplane. We're very anti automation here at this airline."

GREG CRUM, SYSTEM CHIEF PILOT, SOUTHWEST AIRLINES, 1996

It is just over 20 years since the opinions above were offered. Charles Billings seemed to be predicting the replacement of human pilots with automated aircraft. While this has yet to pass, the upsurge of unmanned aerial vehicles/aerial systems is a strong portent that he will eventually be proven prophetic. Interestingly, a recent US Joint Chiefs Chairman, Admiral Michael Mullen, admitted that he believed the Joint Strike Fighter would probably be the last manned fighter/bomber in the US military.

On the other hand, Greg Crum was not an advocate of automation. Yet his very public position against the prevailing shift towards automated aviation systems did not affect his career or his airline. In 2006 he became Vice President, Director of Operations Southwest Airlines, and since 2014, Southwest has carried the most domestic passengers of any U.S. airline. Southwest Airlines almost exclusively uses Boeing 737 aircraft.

Automation is the full or partial replacement of a function previously carried out by a human operator. Another definition of automation is the execution of a task or sub-task, function, or service by a machine agent. Nowadays, automation is pervasive throughout aviation (for instance, flight control, cabin pressurisation, flight systems management including numerous air-traffic control functions, information management and reporting, and baggage handling). The demise — in commercial airliners — of the flight deck positions of radio operator, navigator and most recently, flight engineer has been attributed to the rise of automation.

The terms automation and human-computer interaction are sometimes used interchangeably. However, not all automation involves a computer. And there are several aspects of human-computer interaction on the flight deck that fall outside the domain of automation (such as design interfaces, flight management system functionality, and the relatively slow (evolutionary rather than revolutionary) progress in flight deck computing capability compared to computing power in other industries — and even compared to the modern home.

The current high level of automation on the flight decks of advanced technology aircraft has developed over many generations. As automation levels have increased, many of the monitoring, navigation and communication functions formerly handled by crew are now handled by computerised devices and systems. These devices and systems operate essentially autonomously, requiring limited crew interaction unless an abnormal/emergency situation arises.

Early fly by wire aircraft accidents and incidents

Feb 1990	Air India A320, Bangalore	**Misunderstanding of descent mode**
Jan 1992	Air Inter A320, Strasburg	**Incorrect selection of descent mode**
Sep 1993	Lufthansa A320, Warsaw	**Misunderstanding of G/S mini mode**
Apr 1994	China Airlines A300, Nagoya	**Inappropriate autopilot use**
Nov 1995	American Airlines MD-83, Hartford	**Descent below MDA**
Dec 1995	American Airlines Boeing 757, Cali	**FMS navigation error**

While automation has generally been considered a success story in aviation, there are a number of controversial and unresolved human-factors issues related to the implementation of automation, including design-induced errors, a paradoxical increase in cognitive workload in certain situations, and the potential for an erosion of basic flying skills due to the fundamental shift in the role of the pilot in high technology aircraft (from flyer to systems manager).

In particular, a range of automation-related mishaps in aviation has been recorded [see '*Early fly by wire aircraft accidents and incidents*']. This record suggested that the application of automation technology may have occurred too quickly; without a full understanding of the effects of automation on the operator. According to Billings (1996), these mishaps were associated often with loss of situation or system state awareness due to factors such as complexity, autonomy, and/or inadequate feedback.

Concerns about automation continue to wax and wane. While these concerns have been allayed by the excellent safety records of advanced technology aircraft, some experienced pilots remain wary of automated systems that potentially prevent discretionary control of the aircraft by the pilot in some situations. Quite recent accidents, including Air France AF447 and Qantas QF72 (see 'Surprise and startle' sidebar), have again drawn attention to the potential pitfalls of highly automated flight decks.

Origins of automation

From its inception, aircraft automation was supposed to complement the human. Early aircraft were unstable and difficult to control systems to assist the operator in maintaining control were developed, allowing more cognitive resources of the crew to be spent on navigation, communications, and crew management functions. Automation then began to reduce pilot workload as aircraft capabilities and aviation system complexity increased.

Even in the 1930s, aircraft possessed automation such as rudimentary autopilot. During the 1940s, navigational aids such as the automatic direction finder and instrument landing system were developed. After the Second World War, flight deck automation accelerated and became more sophisticated, but it was not until the 1970s that automation development was fast and furious, underpinned by the advances in computer hardware and processing power. Integrated flight guidance systems appeared and a range of aircraft control systems became automated (for example, spoilers, brakes, throttles). Monitoring, warning, and alerting systems became more complex and led to the demise of the flight engineer as cockpit crew.

Glass-cockpit aircraft became a reality in the 1980s with the introduction of the Boeing 767. Traditional instrumentation was replaced by

CASE STUDY

In-flight upset

Airbus A330-303, VH-QPA, west of Learmonth, 7 October 2008 ATSB Investigation Report AO-2008-070 — Summary

On 7 October 2008, an Airbus A330-303 aircraft, registered VH-QPA and operated as Qantas flight 72, departed Singapore on a scheduled passenger transport service to Perth, Western Australia. While the aircraft was in cruise at 37,000 feet, one of the aircraft's three air data inertial reference units (ADIRUs) started outputting intermittent, incorrect values (spikes) on all flight parameters to other aircraft systems. Two minutes later, in response to spikes in angle of attack (AOA) data, the aircraft's flight control primary computers (FCPCs) commanded the aircraft to pitch down. At least 110 of the 303 passengers and nine of the 12 crew members were injured; 12 of the occupants were seriously injured and another 39 received hospital medical treatment.

Although the FCPC algorithm for processing AOA data was generally very effective, it could not manage a scenario where there were multiple spikes in AOA from one ADIRU that were 1.2 seconds apart. The occurrence was the only known example where this design limitation led to a pitch-down command in over 28 million flight hours on A330/A340 aircraft, and the aircraft manufacturer subsequently redesigned the AOA algorithm to prevent the same type of accident from occurring again.

Each of the intermittent data spikes was probably generated when the LTN-101 ADIRU's central processor unit (CPU) module combined the data value from one parameter with the label for another parameter. The failure mode was probably initiated by a single, rare type of internal or external trigger event combined with a marginal susceptibility to that type of event within a hardware component. There were only three known occasions of the failure mode in over 128 million hours of unit operation. At the aircraft manufacturer's request, the ADIRU manufacturer has modified the LTN-101 ADIRU to improve its ability to detect data transmission failures.

At least 60 of the aircraft's passengers were seated without their seat belts fastened at the time of the first pitch-down. The injury rate and injury severity was substantially greater for those who were not seated or seated without their seat belts fastened.

The investigation identified several lessons or reminders for the manufacturers of complex, safety-critical systems.

Source: ATSB (2008)

computer-generated displays that could be configured by the aircrew to merge specific information from the wealth of information available.

It has not been always a smooth journey for automation in commercial aviation. The introduction of advanced technology aircraft was accompanied by several high profile accidents [see 'Early fly by wire aircraft accidents and incidents'] and a period of cultural change and procedural adjustment for aircrew and other operators within the aviation industry. Procedures have now matured but the initial learning phase has been said to have lasted into the late 1990s.

The push to automate

According to Wiener (1988) the introduction and expansion of flight deck automation has been driven by a range of factors, including:

- opportunities to implement available/developing technologies, including displays
- potential improvements in safety
- reduced costs of flight operations (due to, for example, fewer flight crew reduced maintenance costs associated with wear and tear)
- improvements in situation awareness and information flow
- more precise/efficient flight control and navigation (also enhancing both the economy of operations and safety)
- improved ergonomics and economy of space in the cockpit,
- the special requirements of military missions (particularly the need to reduce cognitive workload)
- reductions in physical and mental workloads for aircrew.

With respect to the last point, it has been argued that automation does not reduce overall workload, it simply changes the nature of work for aircrew on the flight deck.

The advantages of automation in aviation

The opening quote to this section by Charles Billings cleverly contrasts the unreliability, emotionality and interpersonal tensions associated with human operators in aviation with the consistent, rapid, objective and tireless performance of computerised systems. Thankfully, computers are not subject to stress, moodiness, fear, fatigue and personality conflicts.

There is ample evidence that automation has, in general, improved reliability, flight control precision, navigation, and safety within aviation. For instance, the de-crewing of passenger airliners owing to automation and other technology on the flight deck (from four to two flight crew) has not caused safety concerns. Comparative studies of accident and incident rates have shown that, despite increases in air traffic density, current third generation, two-crew commercial jet aircraft have an accident rate 10 times lower than second-generation, three-crew jet airliners, and a rate 15 times lower than first-generation, four-crew commercial jet aircraft (Harris, 2011).

Increased adoption of automation has released many aviation personnel from a range of repetitive and mundane tasks for which humans are poorly suited. Computerised systems have vast information storage capacities (although the ability for human operators to efficiently access this information remains a challenge in some systems).

Integrated automation systems also have helped to extend the technical capabilities of aircraft beyond the constraints of human limitations, for example by enabling automatic landing in instrument meteorological conditions.

It is often decreed that automation reduces workload and frees attentional resources of the human crew. However, as discussed later in this section, this is a controversial claim. Unless automated systems are human-centred and user-friendly (that is, designed with human factors firmly in mind), then it is just as likely for automated systems to increase workload and obscure situation awareness for the operators.

As already mentioned, automation has impacted the role of the human operator, shifting it from flyer or controller to a manager/monitor of systems. Recognition of this change has become one of the modern axioms within the aviation industry.

Levels of automation

There are many degrees — or levels — of automation, varying from full automated control to low-level control. There are many ways to describe these levels. For example, levels of automation can be distinguished by differing levels of consent, autonomy and authority. One taxonomy has stages of automation linked to stages of human information processing. Another approach has been to indicate the degree of task delegation accorded to the machine by the operator (management by delegation, by consent, or by exception).

The British Aerospace Experimental Aircraft Program illustrates one way of describing levels of automation — according to flight deck function.

- **Human functions.** These refer to functions that can only be performed by a human operator without support or augmentation from the aircraft. Such functions might include verbal communication, map reading and visual scanning.
- **Cognitive, supported functions.** These refer to decision-making activities that are aided by information provided by the aircraft. Such functions might include map reading of a moving map display and a take-off configuration go/no-go light).
- **Human, augmented functions.** These are the continuous control operations by human operators that are augmented by aircraft systems. For example, attitude and airspeed control via FBW systems.
- **Human, augmented, automatically-limited functions.** This is where the aircraft is protected by computer monitoring from potential 'out-of-limits' inputs by human operators. For example, a check of waypoint entries and fuel load.
- **Automatic, limited, continuous functions with human override.** More simply, these are automated functions that can be overridden by human control inputs. For example, the autopilot being overridden by continuous throttle and stick inputs.
- **Automatic, limited, discrete functions with human override.** These are automatic functions that can be overridden with discrete human input such as a cancel button.

- **Automatic, autonomous functions.** These are tasks continuously undertaken and monitored independently of the operator. For example, automatic system checks and status monitoring. The operator is only informed in the case of a malfunction or an out-of-limit situation.

Supervisory functions

Given that aircrew are now managers of the flight deck in advanced technology airframes, some theorists have found an examination of supervisory functions when using automated systems more helpful than the concept of levels of automation. For example, Sheridan (1992) proposed the following functions, still relevant today:

- planning
- programming the automation
- monitoring the automation
- diagnosing problems
- intervening if necessary
- learning from experience.

Automation philosophy

The rapid development of automation in aviation was rarely accompanied by well-developed operational doctrine to guide its use. There was some recognition that, in order to manage technological transition effectively, a considered, consistent philosophical foundation was necessary.

Individual airlines, such as Delta, formulated their own 'philosophies of automation' to influence their approach to acquisition, training, and operational procedures. Specific training courses introducing operators to aviation automation were designed and implemented.

The challenge at that time, the early 90s, was transitioning pilots without advanced technology aircraft experience into glass cockpits.

Understandably, many of these pilots had anxieties, misconceptions and biases with respect to the new generation of aircraft.

In terms of the design philosophy underpinning automated aircraft, it is often stated that they are designed to take advantage of the strengths of both machine and human.

- Automation is precise and reliable (but not creative). Its reliability and speed are superior to human capabilities for monitoring systems, making calculations, sustained performance on repetitive and mundane tasks, functioning in accordance with predetermined instructions, and filtering and combining some types of information.
- By contrast, humans are relatively good at intuitive analysis, detecting patterns within changes, flexible responses, creative solutions, and adaptive prioritisation of multiple tasks/objectives.

Charles Billings, the father of human factors in automation, proposed a co-operative philosophy for the implementation of automation on the flight deck as early as 1997. His philosophy was underpinned by the following recommendations:

- the operator must be in command
- to command effectively, the pilot must be involved
- to be involved, the pilot must be informed
- the operator must be able to monitor the automated aircraft systems
- the automated systems must be predictable
- the automated systems must also be able to cross monitor the pilot
- each element of the system must have knowledge of the other's intent.

Human-centred or 'user-friendly' automation

As early as 1979, NASA-Ames began studying the human factors issues surrounding flight deck automation. However this enlightenment did not extend too many of the automation design teams that tended to be technology-driven rather than human-centred in their approach. Human-centred design is characterised by a careful consideration of the capabilities, tendencies, and preferences of the human operator. Too often; however, developments in flight-deck design were driven by how to incorporate available technology rather than the needs of the users — the aircrew.

Human-centred design sits comfortably within the C-SHELL model that is one of the foundation concepts of human factors. For example, to be truly human-centred, a flight deck must have hardware that is designed and implemented with human factors in mind, and proactively supported by documents, checklists, procedures, operational doctrine, and training programs (the software). Issues of interpersonal communication (Liveware to Liveware) should also inform the development of systems and layout.

The existence of a foundation automation philosophy should help to address Culture-related issues of the design and implementation of automation.

It has been said that the goal of human-centred design is to make automation a 'team player' within the aviation system. The focus of design, simply put, should be how do all system components (C-SHELL) best get along together? Fortunately these days, flight deck and aviation system designers and engineers are normally supplemented by human factors specialists who provide a human-centred perspective.

Adaptive automation

Adaptive automation is a more recent approach to addressing problems associated with

CASE STUDY

Data entry error and tailstrike

Boeing 737-838, August 2014

What happened: On 1 August 2014 a Qantas Boeing 737-838 aircraft (operated as QF842) commenced take-off from Sydney Airport. The flight was a scheduled passenger service from Sydney to Darwin. While the aircraft was climbing to cruise level, a cabin crew member reported hearing a 'squeak' during rotation. Suspecting a tailstrike, the flight crew conducted the tailstrike checklist and contacted the operator's maintenance support. With no indication of a tailstrike, they continued to Darwin and landed normally. After landing, the captain noticed some paint was scraped off the protective tailskid. This indicated the aircraft's tail only just contacted the ground during take-off.

What the ATSB found: The ATSB found the tailstrike was the result of two independent and inadvertent data-entry errors in calculating the take-off performance data. As a result, the take-off weight used was 10 tonne lower than the actual weight. This resulted in the take-off speeds and engine thrust setting calculated and used for the take-off being too low. When the aircraft was rotated, it overpitched and contacted the runway. The ATSB also identified the Qantas procedure for conducting a check of the Vref40 speed could be misinterpreted. This negated the effectiveness of that check as a defence for identifying data entry errors.

What's been done as a result: Qantas has advised that, in response to this occurrence, the Central Display Unit pre-flight procedure has been modified. Now, after the take-off data has been compared/verified by both flight crew, they are to check the 'APPROACH REF' page and verify the Vref40 speed. Qantas also advised that the Flight Crew Operating Manual was amended to include a check that the take-off weight in the flight management computer matched that from the final loadsheet. This check was also to ensure the take-off weight from the final loadsheet was not greater than that used for calculating the take-off performance data.

Safety messages: Data-input errors can occur irrespective of pilot experience, operator, aircraft type, location or take-off performance calculation method. Effective management and systems can significantly reduce the risk of errors. Good communication and independent cross-checks between pilots, effective operating procedures, improved aircraft automation systems and software design, and clear and complete flight documentation will all help prevent or uncover data entry errors. The application of correct operating data is a foundational and critical element of flight safety, but errors in the calculation, entry and checking of data are not uncommon. Data input errors remain one of the ATSB's top safety concerns for the travelling public.

Source: Australian Transport Safety Bureau (ATSB, 2015)

operator interactions with automated systems. Broadly, adaptive automation refers to systems in which both the user and the system can initiate changes in the level of automation.

Adaptive automation can change the level or number of systems operating under automatic control on the basis of situational factors (Harris, 2011). For example, a computer may allocate more functions to itself under certain circumstances such as an emergency situation where it detects shortcomings in pilot performance or an unacceptably high pilot workload.

Systems incorporating adaptive automation are increasingly moving beyond models of operator behaviour and workload, to include elements such as flight deck ergonomics, the physiological state of the operator and even group dynamics to aid in task allocation to either the human or machine.

One of the drivers for adaptive automation is the finding that many human operators are beginning to regard adaptive systems as co-workers. Indeed, some operators now expect automated agents to behave like humans. These findings have created new opportunities for designers (and users) transcend traditional ideas of human-computer interaction and system design. With the exception of some military aircraft, at present there is limited implementation of adaptive automation. It is an area attracting more and more applied research.

Enduring problems with automation

While the presumed and claimed benefits of automation are mostly self-evident, the limitations and unintended impacts of automated systems have been slower to emerge or to be formally acknowledged.

As early as the 1980s, there was recognition that the rapid introduction of automation and other computer-based technologies on the flight deck had surpassed the ability of designers and operators to develop a comprehensive strategy for their implementation and use (Ferris, Sarter & Wickens, 2010). Rail, maritime and space transportation domains have experienced similar issues.

Often the issue has been the lack of comprehensive assessments of the potential impacts of automated systems on the performance of human operators. Perhaps the major concerns have proven to be the lacklustre performance of humans in gauging the status of an automated device or system (system awareness) and in monitoring automation systems (most of us are poor at vigilance tasks).

For example, one research study that used a simulated multitask flight deck environment found that an engine-status monitoring task was done twice as well (double the detections) as a manual task compared to when it was under automation control. This effect was evident after only twenty minutes (Parasuraman, Molloy & Singh, 1993).

While some progress has been made in developing an overarching design philosophy for automation in aviation, a number of concerns remain. This section reviews some of the unresolved deficiencies, disadvantages and problems associated with automation devices and automated systems.

Increased workload. Paradoxically, the need to manage automation, particularly data entry tasks, can place additional tasks on the operator that can increase workload. Data entry under time constraints is particularly prone to error and data input errors are one of the ATSB's top safety concerns [see case study 'Data entry error and tailstrike involving Boeing 737-838, Aug 2014']. As automated systems become more complex, this complexity can generate workload in the preparation and execution of system support functions.

Furthering imbalance in the distribution of workload. Automation in most modern aircraft has been called clumsy automation because it has reduced workload where it was already low (that is, in cruise flight) yet increased it, often quite dramatically, where it was already high (approach and departure phases). One approach to addressing this issue has been the development of flight-phase specific displays, where displayed information is automatically selected to provide operators with the most relevant information to support maintenance of situation awareness.

Getting lost in the software. This is a challenge in glass cockpits where there may be fewer displays than the number of active processes are being undertaken and needing to be monitored. It can be difficult to find the right page or dataset efficiently.

Lots of data but no information. This expression has been attributed to the tendency to overload flexible displays with system-related items in an attempt to make automated systems more transparent and easier to monitor. In many cases the resulting clutter leads to confusion, uncertainty or data overload. (To address this issue, some automation is now incorporating decluttering tools in displays.)

Mode errors and confusion. Mode errors occur when an operator thinks a device or system is in a particular mode, and takes what is thought to be appropriate action for that mode; but the device or system is actually in a different mode (mode confusion) — so the action of the operator is actually an error.

Loss of situation awareness. The preceding three issues may explain why automation can reduce operator situation awareness and create significant workload challenges when systems operate unexpectedly. Situation awareness can be adversely affected by poor adherence to automation monitoring and flight discipline, cluttered displays and imprecise SOPs. Loss of situation awareness can be due also to the incorrect perception or comprehension of cockpit information. Perhaps the most problematic situation is when automation malfunctions occur and they are undetected by the human operator or the nature and extent of malfunctions are not evident. There are a number of accident case studies where automation changes, malfunctions or disconnections have not been detected before the situation became unrecoverable.

Cognitive overload (aka information overload). Cognitive or mental overload is an issue examined in several chapters in this guidebook. Clumsy automation (discussed above) is part of this problem. However, cognitive overload can occur at any stage during flight because, similar to getting lost in the software, operators can get lost in the mass of data that is available. At any time it can be difficult to efficiently locate particular pieces of information — or locate them at all. Emergency situations tend to exacerbate this issue and heighten the potential for cognitive overload.

Boredom. High levels of automation can lead to reduced alertness due to inactivity and lack of cognitive stimulation, particularly during the long and highly automated cruise phase of a flight.

Overreliance and over trust. A number of aviation incidents and accidents have been attributed to system designs that lead to overreliance on automation by the operator. Having too much reliance on or trust in automation has generated complacency, loss of skill and reduced situation awareness. There are risks associated with unquestioned or unchallenged acceptance of computer-generated information.

Automation complacency. Complacency is another issue related to overreliance on or over trust in automated systems.

Automation surprise. Automation surprise has been characterised by the following questions: What is it doing? Why did it do that? What will it do next? Will it do that again? Harris (2011) summarised studies on the implementation of flight deck automation which found that even after a year of experience on type, over half of pilots indicated the flight management system occasionally did things that surprised them and 20 per cent of pilots admitted that they did not understand all the modes or features available in their automated systems.

A mode error can be a common cause of automation surprise. Such surprises are more likely to occur when system awareness and situation awareness of the operator are low. Automation surprise also may be an outcome of the human factors quadrella of boredom, overreliance, over trust, and complacency.

However, as the QF72 near Learmonth case study demonstrated, automation surprise may be simply a function of unprecedented actions by an automated system or systems. As the ATSB report noted, the A330/A340 aircraft had accumulated over 28 million flight hours before the QF72 incident without incorrect data from an air data inertial reference unit causing inadvertent elevator commands.

Discontinuity. A close cousin to automation surprise is known as discontinuity. Discontinuity is when there is a sudden and unexpected shift in the pace and/or perceived threat of work. Discontinuity can be induced by the malfunction or unexpected performance of automation.

Air France Flight 447 [see 'Surprise and startle'] provides an example. The operating crew went from a state of high automation and low mental demand into a situation of high mental workload, total loss of automation, the requirement to assume manual control and, presumably, significant stress generated by the emergency situation. The initial occurrence in the active accident sequence is described in the final BEA accident investigation report:

> "At 2 h 10 min 05, the autopilot then the auto-thrust disconnected and the PF said 'I have the controls'. The aeroplane began to roll to the right and the PF made a nose-up and left input. The stall warning triggered briefly twice in a row. The recorded parameters showed a sharp fall from about 275 kt to 60 kt in the speed displayed on the left primary flight display (PFD), then a few moments later in the speed displayed on the integrated standby instrument system (ISIS). The flight control law reconfigured from normal to alternate. The Flight Directors (FD) were not disconnected by the crew, but the crossbars disappeared.
>
> At 2 h 10 min 16, the PNF said 'we've lost the speeds' then 'alternate law protections'. The PF made rapid and high amplitude roll control inputs, more or less from stop to stop. He also made a nose-up input that increased the aeroplane's pitch attitude up to 11° in 10 seconds.
>
> Between 2 h 10 min 18 and 2 h 10 min 25, the PNF read out the ECAM messages in a disorganized manner. He mentioned the loss of autothrust and the reconfiguration to alternate law. The thrust lock function was de-activated. The PNF called out and turned on the wing anti-icing (BEA, 2012, p.22)."

Deskilling. While improvements in the design, training, and operational use of automated systems have contributed to aviation's impressive safety record, these improvements may be contributing to diminished manual skills due to an increased reliance on automation. This represents the Catch 22 of automation.

The AF447 accident appears to demonstrate how aircrew have responded inappropriately to automation failures, perhaps as a result of the erosion of manual skills.

Several recent studies have highlighted the challenges that pilots face in maintaining manual flying proficiency (for example, Casner, Geven, Recker, & Schooler, 2014; Ebbatson, 2009).

The Ebbatson study evaluated the flying skills of a sample of pilots of highly automated aircraft on an unexpected and challenging manual flying task. A significant proportion exhibited poor manual flying performance, judged by a type rating examiner. Performance was significantly influenced by the amount of recent manual handling experience; whereas long-term manual flying experience was not predictive.

Airspeed tracking ability, often cited as a causal factor in manual flying accidents, was significantly degraded in research participants without recent hands on experience. The study therefore supported anecdotal and subjective concerns relating to the loss of manual flying skills in aircrew of advanced technology aircraft.

Pilot authority. In some situations (for example, QF72), pilots may struggle to or be unable to resume complete control of an aircraft under automated control. The re-establishment of pilot authority, instigated by pilot action, must be provided by appropriate tools and/or procedures. Indeed, the International Federation of Air Line Pilots' Associations (IFALPA) has highlighted the potential pitfalls of the highly automated flight deck environment in its publication *Requirements regarding pilot authority and flight control architecture* (2009). IFALPA has advocated a preferred flight deck design requirement as follows:

"The aircraft commander shall be given the authority and capability to select the level of augmentation for the flight control system. Whenever higher levels of augmentation are incorporated in the flight-control structure, the overlaying philosophy and the design shall cater for the possibility that the built in systems cannot detect all possible malfunctions. Therefore the re-establishment of pilot authority, also by pilot action, must be provided by appropriate devices and/or procedures" (IFALPA, 2009, p.2).

> **"We're at a real time of transition here in terms of future aviation. What's going to be manned? What's going to be unmanned? There are those who see [the Joint Strike Fighter] as the last manned fighter/bomber. And I'm one that's inclined to believe it — whether it's right or not."**
>
> ADMIRAL MICHAEL MULLEN, JOINT CHIEFS CHAIRMAN, CONGRESSIONAL TESTIMONY REGARDING THE FUTURE OF MANNED MILITARY AVIATION, 2009

Four generic types of automation problems

Most of the proceeding issues can be distilled into four types of automation problems: use, misuse, disuse and abuse (Parasuaman & Riley, 1997).

- **Automation use problems** refer to the voluntary activation or disengagement of automation by the human operator. Automation is only potentially useful if the human operator chooses to use it. Use of automation is influenced strongly by issues such as trust and perceived reliability.
- **Automation misuse** refers to an overreliance on automation. Overreliance can take the form of using it when it is not appropriate to do so and failing to monitor automated systems properly when they are active. Misuse issues include monitoring complacency, decision vices and skill erosion due to over-reliance.

- **Automation disuse** can occur when the human operator chooses not to use automation, or even to ignore it. Such behaviour is normally associated with trust issues, repeated technical faults (for example, repeated false alarms), or overconfidence in the operator's own skills.
- **Automation abuse** is about the designer rather than the operator. Automation abuse is associated with a technology-driven approach, as contrasted with a human-centred/user-friendly design philosophy. When automation is designed and implemented without due regard for the consequences for human performance, then this can constitute automation abuse. Such approaches tend to result in the role of the operator being a by-product of automation design.

An alternative perspective

Dekker and Woods (2002) challenge those who have suggested that a major problem with automation that it removes the operator from the loop and increases the risk of uncertainty, misunderstanding and consequent error. They also dispute that concepts such as automation complacency and monitoring failures are in any way associated with accidents in advanced technology aircraft.

Dekker and Woods (2002) suggested that in many accidents, the automation was performing as it was supposed to — there was no failure in the system. Rather, aircraft were 'managed' into accidents by pilots who were actively engaged with aircraft systems: for example, searching for information, programming the FMS, planning for the next phase of flight, responding to system demands, and communicating widely and effectively. However, while engaged in these activities, an accident occurred — aircraft were managed into a stall or flown into the ground.

Perhaps the most consistent factor underlying such accidents was a breakdown between the aircrew and the automated flight deck components. The real issue, Dekker and Woods (2002) argued, is the way in which automation is implemented — it can be simplistic and counter-intuitive.

> **"Common issues such as mode-awareness errors have been managed by procedural training; for example, reading the flight mode annunciator aloud, calling mode changes, and fostering awareness of the potential for autopilot mode reversions."**

Dekker (2004) subsequently outlined a number of automation limitations that contribute to such managed accidents, including getting lost in the software, mode errors, not co-ordinating computer entries (a particular challenge when multiple operators are interfacing with the same system), cognitive overload, and not noticing changes. The latter issue is sometimes called 'change blindness'. Change blindness can be the result of poor display design, inappropriate information presentation priorities, or the operator attending to a non-critical display mode.

In all these cases, critical pieces of information are effectively hidden. Adding to this problem is a lack of sufficient display areas in advanced technology flight decks to accommodate all relevant information.

Training for automation

As noted previously, the introduction automation requires tailored training, both technical and non-technical. The aviation industry has responded with practical modifications to training programs and, in some cases, the development of underpinning philosophies of automation. As is often the case, the accident record also has helped to identify training needs [see 'Crash of Asiana Airlines flight 214' at the end of this chapter].

Common issues such as mode-awareness errors have been managed by procedural training; for example, reading the flight mode annunciator aloud, calling mode changes, and fostering awareness of the potential for autopilot mode reversions.

Crew resource management training has usually included modules on managing automation, although such training is often knowledge-based rather than skills-based learning. The change of primary role from flyer to systems manager has been reflected in changes to the traditional captain/co-pilot titles to PF/PNF and subsequently PF/PM.

Given the primacy of the systems manager role on the flight deck, it is worth highlighting that a topical training issue is system-monitoring skills. There is widespread recognition that effective processes to assess monitoring skills, either in basic training or during flight, have yet to be developed. At present, a pilot's monitoring skills are assumed to be adequate if standard currency requirements are met. However, some standards only require that pilots monitor certain items during the take-off and approach phases of flight, such as monitoring engine settings and the status of navigation equipment. Underpinning this issue is the lack of accepted protocols/methods to assess a pilot's ability to monitor the state of the aircraft and its systems, beyond observing call-outs.

Other methods to assess monitoring skills could include measuring a pilots' ability to detect changes to the autopilot settings or deviations from the flight path and to prioritise non-essential tasks during certain phases of flight.

One of the most contentious issues is the belief, recently confirmed by research, that basic manual flying skills have generally eroded across commercial airline pilots due to the directed primacy of and reliance upon of automated flight. The Asiana Flight 214 case study included NTSB recommendations to the airline to "modify your automation policy to provide for more manual flight, both in training and in line operations, to improve pilot proficiency".

There is recent evidence that the effectiveness of pilot training for emergencies and abnormal events is low. Casner, Geven and Williams (2012) found that active 747 pilots dealt impeccably with in-flight emergencies that matched emergencies practiced during training. However, when emergencies were presented in ways that pilots had not yet encountered in training, they frequently struggled or made critical errors. This highlighted the issue that emergency drills in training tend to be predictable exercises in which people know exactly what's coming and when. Predictable training routines take away opportunities to practice recognition skills and creative problem solving [see chapter on decision-making]. The authors of this study concluded that emergencies should not be practised in just one way. Training scenarios should be varied to ensure surprise [see 'Surprise and Startle'].

> **“Automation is neither inherently good nor bad… but it does change the nature of work, and, in doing so, solves some problems while creating others.”**
>
> MARK SCERBO, *THEORETICAL PERSPECTIVES ON ADAPTIVE AUTOMATION*, 1996

Conclusion

Automation is no longer a choice; it is the reality of current technical systems. As with all new technology, care must be taken during the introduction of automation to ensure unforeseen weaknesses in design or implementation do not adversely impact safety. Despite a number of automation-induced accidents and incidents, the safety record of advanced technology aircraft is unparalleled.

However, a number of enduring problems with automated systems are apparent, particularly from a human-factors perspective, and further effort is required to resolve or mitigate them. Perhaps the most topical problem associated with automation is the confirmed degradation of traditional flight manipulation skills due at least in part to overreliance on automation, either by company decree or the personal preference of aircrew.

Many of the other detriments associated with automated systems are related to the operator being ‘out of the loop’. Adaptive automation holds promise of mitigating these particular costs via dynamic, situation-triggered task reallocations between the human and the machine.

A fundamental step preceding the implementation of automated systems is to define and automation philosophy that will help to minimise the many potential, unintended performance consequences of the implementation of automation and computer assistance technology. Because pilots and controllers are now systems monitors/managers, it is essential that the logic and underpinning philosophy of automated systems is clearly understood.

Training for automation should be dynamic, evidence-based and focused on skill-based learning.

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Key points

- Automation is the full or partial replacement of a function previously carried out by a human operator; the execution of a task or sub-task, function, or service by a machine agent.
- Automation is linked with unparalleled safety records in advanced technology aircraft but there are a number of enduring ‘automation problems’, many related to human factors.
- Automation does not reduce overall workload; it changes the nature of work, particularly for aircrew on the flight deck.
- Pilots have predominantly become aircraft managers rather than direct controllers, spending much of their time planning the flight, programming the automation and monitoring its operation rather than actively handling the flying controls.
- Adaptive automation refers to systems in which both the user and the system can initiate changes in the level of automation.
- A clearly articulated automation philosophy should underpin the use of advanced technology.
- The ‘Catch 22’ of automation is that while improvements in the design, training, and operational use of automated systems have contributed to aviation’s impressive safety record, these improvements may be contributing to diminished manual skills due to an increased reliance on automation.

Crash of Asiana Airlines flight 214

Selections from the NTSB Accident Report

Summary of the accident

On 6 July, 2013, a Boeing 777-200ER, operating as Asiana Airlines flight 214, was on approach to runway 28L when it struck a seawall at San Francisco International Airport. Three of the 291 passengers were fatally injured; 40 passengers, 8 of the 12 flight attendants, and 1 of the 4 flight crewmembers received serious injuries. The airplane was destroyed by impact forces and a postcrash fire. Visual meteorological conditions prevailed.

The flight was vectored for a visual approach to runway 28L and intercepted the final approach course about 14 nautical miles (nm) from the threshold at an altitude slightly above the desired 3° glidepath. This set the flight crew up for a straight-in visual approach; however, after the flight crew accepted an air traffic control instruction to maintain 180 knots to 5 nm from the runway, the flight crew mismanaged the airplane's descent, which resulted in the airplane being well above the desired 3° glidepath when it reached the 5 nm point. The flight crew's difficulty in managing the airplane's descent continued as the approach continued.

In an attempt to increase the airplane's descent rate and capture the desired glidepath, the pilot flying (PF) selected an autopilot (A/P) mode (flight level change speed [FLCH SPD]) that instead resulted in the autoflight system initiating a climb because the airplane was below the selected altitude. The PF disconnected the A/P and moved the thrust levers to idle, which caused the autothrottle (A/T) to change to the HOLD mode, a mode in which the A/T does not control airspeed. The PF then pitched the airplane down and increased the descent rate. Neither the PF, the pilot monitoring (PM), nor the observer noted the change in A/T mode to HOLD.

As the airplane reached 500 ft above airport elevation, the point at which Asiana's procedures dictated that the approach must be stabilized, the precision approach path indicator (PAPI) would have shown the flight crew that the airplane was slightly above the desired glidepath. Also, the airspeed, which had been decreasing rapidly, had just reached the proper approach speed of 137 knots. However, the thrust levers were still at idle, and the descent rate was about 1200 ft per minute, well above the descent rate of about 700 fpm needed to maintain the desired glidepath; these were two indications that the approach was not stabilized. Based on these two indications, the flight crew should have determined that the approach was unstabilized and initiated a go-around, but they did not do so.

As the approach continued, it became increasingly unstabilized as the airplane descended below the desired glidepath; the PAPI displayed three and then four red lights, indicating the continuing descent below the glidepath. The decreasing trend in airspeed continued, and about 200 ft, the flight crew became aware of the low airspeed and low path conditions but did not initiate a go-around until the airplane was below 100 ft, at which point the airplane did not have the performance capability to accomplish a go-around. The flight crew's insufficient monitoring of airspeed indications during the approach resulted from expectancy, increased workload, fatigue, and automation reliance.

Select findings

- The flight crew's mismanagement of the airplane's vertical profile during the initial approach led to a period of increased workload that reduced the pilot monitoring's awareness of the pilot flying's actions around the time of the unintended deactivation of automatic airspeed control. Nonstandard communication and co-ordination between the pilot flying and the pilot monitoring when making selections on the mode control panel to control the autopilot flight director system (AFDS) and autothrottle (A/T) likely resulted, at least in part, from role confusion and subsequently degraded their awareness of AFDS and A/T modes.
- Insufficient flight crew monitoring of airspeed indications during the approach likely resulted from expectancy, increased workload, fatigue, and automation reliance.
- The delayed initiation of a go-around by the pilot flying and the pilot monitoring after they became aware of the airplane's low path and airspeed likely resulted from a combination of surprise, nonstandard communication, and role confusion.
- As a result of complexities in the 777 AFCS and inadequacies in related training and documentation, the pilot flying had an inaccurate understanding of how the autopilot flight director system and autothrottle interacted to control airspeed, which led to his inadvertent deactivation of automatic airspeed control.
- If the autothrottle automatic engagement function (wakeup), or a system with similar functionality, had been available during the final approach, it would likely have activated and increased power about 20 seconds before impact, which may have prevented the accident.
- A review of the design of the 777 automatic flight control system, with special attention given to the issues identified in this accident investigation and the issues identified by the FAA and European Aviation Safety Agency during the 787 certification program, could yield insights about how to improve the intuitiveness of the 777 and 787 flight crew interfaces as well as those incorporated into future designs.
- If Asiana Airlines had not allowed an informal practice of keeping the pilot monitoring's (PM) flight director (F/D) on during a visual approach, the PM would likely have switched off both F/Ds, which would have corrected the unintended deactivation of automatic airspeed control.
- By encouraging flight crews to manually fly the airplane before the last 1000 ft of the approach, Asiana Airlines would improve its pilots' abilities to cope with manoeuvring changes commonly experienced at major airports and would allow them to be more proficient in establishing stabilized approaches under demanding conditions; in this accident, the pilot flying may have better used pitch trim, recognized that the airspeed was decaying, and taken the appropriate corrective action.
- A context-dependent low energy alert would help pilots successfully recover from unexpected low-energy situations.

Contributing factors

Contributing to the accident were: (1) the complexities of the autothrottle and autopilot flight director systems that were inadequately described in Boeing's documentation and Asiana's pilot training, which increased the likelihood of mode error; (2) the flight crew's nonstandard communication and co-ordination regarding the use of the autothrottle and autopilot flight director systems…

Recommendations

To the Federal Aviation Administration:

- Require Boeing to develop enhanced 777 training that will improve flight crew understanding of autothrottle modes and automatic activation system logic through improved documentation, and instructor training.
- Require Boeing to revise its 777 Flight Crew Training Manual stall protection demonstration to include an explanation and demonstration of the circumstances in which the autothrottle does not provide low speed protection.
- Convene an expert panel (including members with expertise in human factors, training, and flight operations) to evaluate methods for training flight crews to understand the functionality of automated systems for flightpath management, identify the most effective training methods, and revise training guidance for operators in this area.
- Convene a special certification design review of how the Boeing 777 automatic flight control system controls airspeed and use the results of that evaluation to develop guidance that will help manufacturers improve the intuitiveness of existing and future interfaces between flight crews and autoflight systems.
- Task a panel of human factors, aviation operations, and aircraft design specialists, such as the Avionics Systems Harmonization Working Group, to develop design of context-dependent low energy alerting systems for airplanes engaged in commercial operations and establish requirements for such systems, based on the guidance developed by the panel.

To Asiana Airlines:

- Modify your automation policy to provide for more manual flight, both in training and in line operations, to improve pilot proficiency.

To Boeing:

- Using the guidance developed by the low-energy alerting system panel created in accordance with recommendation [7], develop and evaluate a modification to Boeing wide-body automatic flight control systems to help ensure that the aircraft energy state remains at or above the minimum desired energy condition during any portion of the flight.
- Revise your 777 Flight Crew Operating Manual to include a specific statement that when the autopilot is off and both flight director switches are turned off, the autothrottle mode goes to speed (SPD) mode and maintains the mode control panel-selected speed.

Source: NTSB Accident Report (June 2014). ***Descent below visual glide path and impact with seawall, Asiana Airlines Flight 214, Boeing 777-200ER, HL7742, San Francisco, California, 6 July 2013.***

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CHAPTER 12 NTS considerations for air traffic controllers

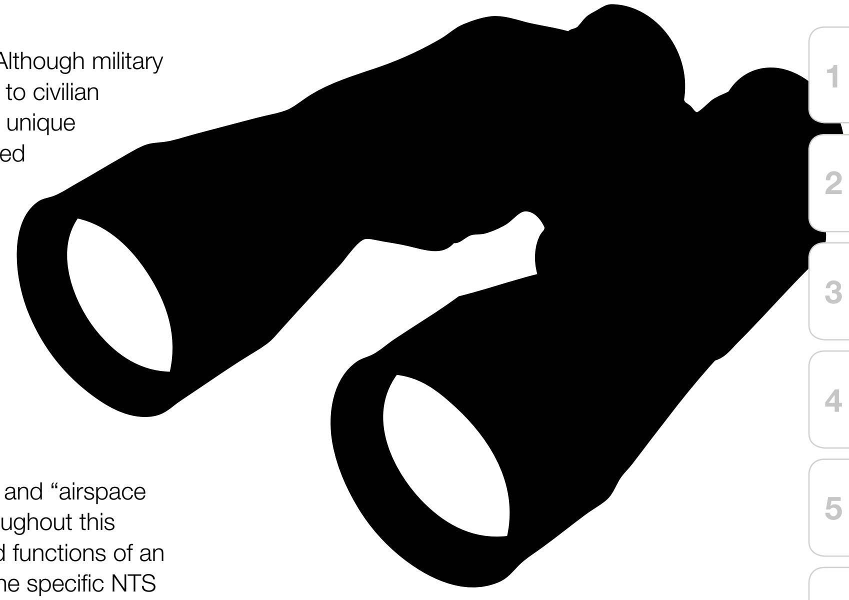
Overview:

- The essential human-performance aspects of controller duties
- Information-processing requirements of the controller role
- Aspects of controller performance most susceptible to error
- Human-factors strategies required to aid delivery of a safe and effective airspace-management capability

Introduction

Rudimentary airspace management procedures were introduced during World War II to deal with night flying and flying operations conducted in conditions of poor visibility. Safety was — and still is — the primary objective of these procedures. Over time, airspace has become more congested and the capabilities of both aircraft and aircraft-management systems has grown exponentially. Consequently, the role of an air traffic controller to manage the airspace and air traffic has become significantly more complex.

The demands on spatial abilities, attentional processes and memory can be considerable, and while technological aids such as radar have reduced the cognitive load, the benefits are often absorbed by increased air-traffic loads. Although military ATCs provide a similar service to civilian ATCs, they are also subject to unique environments, such as deployed operations and mobile operations on board a ship. They often work with highly complex airspace during operations and exercises and with vastly different aircraft types, from fast jets, through to helicopters and unmanned aerial vehicles.



The generic terms "controller" and "airspace management" are utilised throughout this chapter to refer to the role and functions of an ATC. This chapter examines the specific NTS considerations for the controller role, including specific human-performance demands and the consequence of mismatches between demands and performance.

A task analysis of the controller role

Understanding and managing human performance is critical to the safe and effective conduct of the controller role. No matter how advanced the concepts and technology become, human performance remains the key driver of airspace management. Despite the growing use of automation, the controller's work remains very cognitive in nature. A list of controller tasks outlined by Hopkin (1995) is still relevant today:

- The identity of every aircraft must be known, so that none is mistaken for another, and instructions to the pilot of one aircraft are not executed by the pilot of another.
- A controller must know the performance and manoeuvring capabilities of each aircraft type, such as the maximum flight level and rate of climb, and all controller instructions must conform with these capabilities.
- The route, current position, flight level, speed, heading, and the changes of state of aircraft that are turning, climbing, descending, accelerating or decelerating, must all be known.
- There must be a means of communication between the airspace management system and each aircraft, usually including speech between pilots and controllers.
- There must be sufficient evidence about the position of each aircraft in relation to others for the controller to ensure that every aircraft always remains safely separated from all others.
- There must be standardised methods, procedures, instructions and message formats and contents, with rules about when and where airspace-management regulations apply.
- The depiction of the information about each aircraft must allow it to be related to the corresponding information about other aircraft under control at the same time.
- It must be possible to hand over the control responsibility for an aircraft safely from one controller to another, in a way that is unambiguous to both controllers and to the pilot.
- An official record of controller actions and their consequences is essential for each flight, as proof of their occurrence and to facilitate retrospective enquiries about it.

The above task list embraces many of the concepts addressed in previous chapters, including communication, teamwork, situation awareness, and information processing.

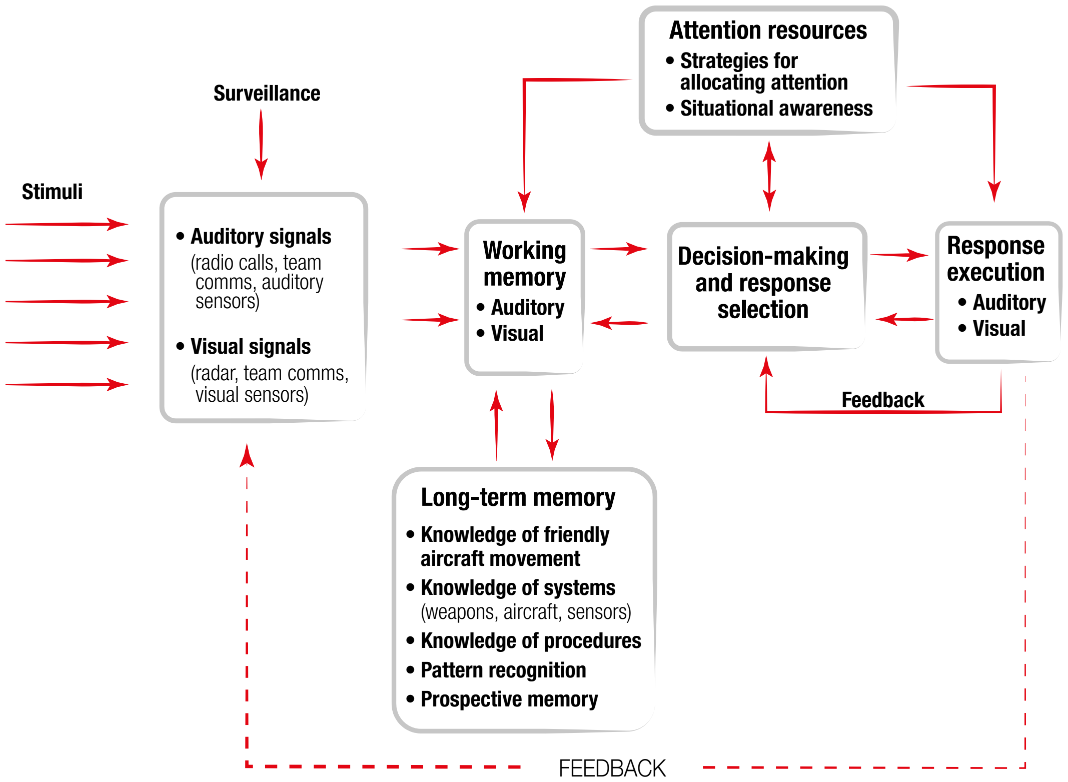


Figure 12–1. Information-processing model for the controller role

Against this general backdrop; however, there are features of the controller role that help to distinguish it from other roles, most notably in terms of its information-processing requirements.

Information-processing requirements of the controller role

Figure 12–1 shows an expanded view of the information-processing model adapted from Wickens and Flach (1988) presented in Chapter 2.

In this model, the external stimuli to which controllers must attend include the weather, radio messages, radar displays, paper printouts, communication from colleagues, and visual sightings of aircraft. These stimuli are mixed in with a host of other sensory stimuli, all competing for attention. Selective attention ensures that the essential information enters working memory before it disappears from the sensory store.

Once the information, whether auditory or visual, is accepted for processing, it is matched against existing knowledge structures and patterns held in long-term memory. A decision is made as to whether there is a ready-made response script or whether a new one has to be generated. A response is then given verbally or via the keyboard (for example, a verbal instruction to a pilot).

During periods of high workload, the middle stages of this information-processing model become crucial. The working-memory system represents the "workbench" at which most of the conscious cognitive activity takes place (Baddeley, 1986).

It is essential that some attention be directed to all ongoing tasks because without continual refreshing, they will drop out of working memory very quickly and situation awareness will be lost. For experienced operators, this is not usually a problem. They have reached the skill-based level of performance [see Chapter 2] where the execution of well-known and routine activities is governed by stored patterns of pre-programmed instructions. For these controllers, responses are automatic, fast, and require little conscious effort. For newer controllers, workload must be managed so that overload does not occur.

Situation awareness [see Chapter 6] is an equally important part of the information-processing model but it is an emergent property of the system rather than a component in its own right. We possess situation awareness when we have detected and attended to the relevant information and understood both its meaning and its implications.

Attention, memory, and decision-making processes are all involved. For example, on the basis of situation awareness, the controller must select an action. A typical action might be a request to alter heading, speed, or altitude. In a familiar situation, this action would be immediately retrieved from long-term memory. In an unfamiliar situation, the controller will use reasoning processes to arrive at a plan and visualise the consequences of the plan in spatial working memory. These planning and decision-making processes also draw heavily on long-term memory (via working memory) where all knowledge is stored.

For a more complete account of the information-processing requirements of the controller role, see Wickens, Mavor, and McGee (1997), *Panel on human factors in air traffic control*.

The information-processing model shown in Figure 12–1 is, of course, essentially the same as the generic one shown in Chapter 2. Controllers have the same cognitive architecture as everyone else. Where they differ is in the relative involvement of particular categories of cognitive tasks and the types of errors to which they are susceptible.

Human error: cognitive vulnerabilities in the controller role

A 2010 Eurocontrol white paper on airspace management identified visual scanning, maintaining attention, situation awareness, and decision-making as key cognitive skills for controllers along with communication, teamwork, and workload management as other key non-technical skills.

Visual scanning

Airspace management is a critical and complex activity, involving scanning and searching for static and dynamic information from a number of sources such as a situation display, flight data display, or directly, as in the case of tower controllers physically sighting aircraft. Vulnerabilities include failure to see an impending conflict, clutter in the visual environment, changing priorities of the elements in the visual environment.

Proper scanning requires the constant sharing of attention with all tasks, thus it is easily degraded by such conditions as distraction, fatigue, boredom, illness, anxiety, or preoccupation.

Many scanning problems can be addressed through automation (for example, conflict alerts) but such tools support rather than replace the requirement for human scanning. Some scanning methods and strategies are known to be particularly effective and can be developed or improved via training.

Maintaining attention

In dynamic environments such as controlling airspace, lapses of attention can have serious consequences. Helping controllers to maintain attention presents design challenges.

Sustaining attention over long periods when there is little traffic is difficult and the controller must ensure that regular scanning is maintained. Distractions, fatigue, health and personal factors can all affect attention

Tips for effective visual scanning

Eliminate bad habits. Learn how to scan properly by knowing where and how to concentrate your search on the areas most critical to you at any given time.

There is no one technique that is best for all. The most important thing is for each individual to develop a scan that is both comfortable and workable.

Do not forget to scan all around to avoid fixation.

and must be managed carefully. When dividing attention (or time-sharing), the controller needs to ensure that tasks do not interfere with each other (for example, simultaneously monitoring traffic and checking a written procedure). Successful application of good design principles can help to ensure that tasks do not interfere with each other (for example, simultaneous visual tasks) and that alerts and alarms are effective and not disruptive.

Keeping the picture (situation awareness and shared understanding)

From the time they take over their position, and throughout their time on duty, controllers manage their situation awareness to build and maintain a mental picture of the current and projected traffic situation and control environment.

As mentioned earlier, this state of awareness is critically dependent on working memory (for example, keeping flight data in memory for a short time), long-term memory (for example, knowing aircraft flight characteristics), and prospective memory (for example, remembering to issue a planned instruction at some point close in the future). Controllers use various resources to support the picture, for instance by 'kicking out' paper flight strips from the column of strips as a reminder.

The predictive component of long-term memory (vital for situation awareness) is heavily dependent on spatial working memory to compute likely trajectories based on current aircraft state, intended plans, and individual aircraft dynamics (Wickens et al., 1997). This predictive component is highly vulnerable to competing demands for attention.

Again, this element of competition is unlikely to cause problems for experienced controllers dealing with routine circumstances in normal workload conditions. Any departure from these conditions; however, increases the likelihood of predictive memory failures.

In addition to maintaining awareness of the unfolding flight plans, the controller needs to establish and maintain shared mental models with each of the pilots, as well as members within the control team and members of external agencies.

Understanding the expectations and plans of each element, whether the pilot of an aircraft or a fellow controller, assists in ensuring that all participants in each of the various scenarios knows exactly what they are required to do. The challenging feature of shared mental models in airspace management is that some parts of the model will not be available to all participants. Thus, pilots do not need to know about all of the traffic around the airport and controllers do not need to know everything that is happening in each of the aircraft.

Additionally, effective communication is essential in order to achieve and maintain a situational awareness that supports all areas of the shared mental model. Assumptions here can be dangerous and intentions need to be clear to all. The controller may need to inform the pilot of the plan early so that the pilot can prepare for what is coming up.

The case study 'Airspace-related event involving Boeing 737, VH-VOM' illustrates the importance of shared understanding between flight crews and controllers (ATSB, 2016).

CASE STUDY Airspace-related event involving Boeing 737, VH-VOM

What happened:

At 1253 Central Standard Time on 27 February 2014, a Boeing Company 737-8FE, registered VH-VOM (VOM), was radar vectored when outside controlled airspace, near Darwin, Northern Territory. Radar vectoring outside controlled airspace was not permitted, and may have brought VOM into conflict with aircraft that were unknown to airspace management.

What the ATSB found:

The ATSB found that weather in the Darwin area resulted in the majority of inbound aircraft diverting around storm cells. These diversions increased workload for the Approach East controller. The increased workload resulted in the controller using non-standard phraseology and not cancelling radar vectors prior to VOM leaving controlled airspace.

Additionally, the flight crew of VOM had not reported 'clear of weather' as expected by the controller. This resulted in a lack of shared understanding between the flight crew and the controller.

What's been done as a result:

Following this occurrence the Department of Defence introduced theoretical and simulator-based training to assist controllers to resolve unusual situations using clear communication and direction. The training reinforces positive and assertive control measures, skills that are especially necessary in high-workload situations.

Safety message:

This occurrence highlights that effective communication is essential for a shared understanding between flight crew and controllers. On this occasion, the use of non-standard phraseology by both parties resulted in different expectations and delay.

Additionally, co-ordination between controllers is an essential component of their duties; however, this is not transmitted via radio. As a result, silence on an airspace-management frequency should not be interpreted by flight crew as an indicator of low workload for the controller.

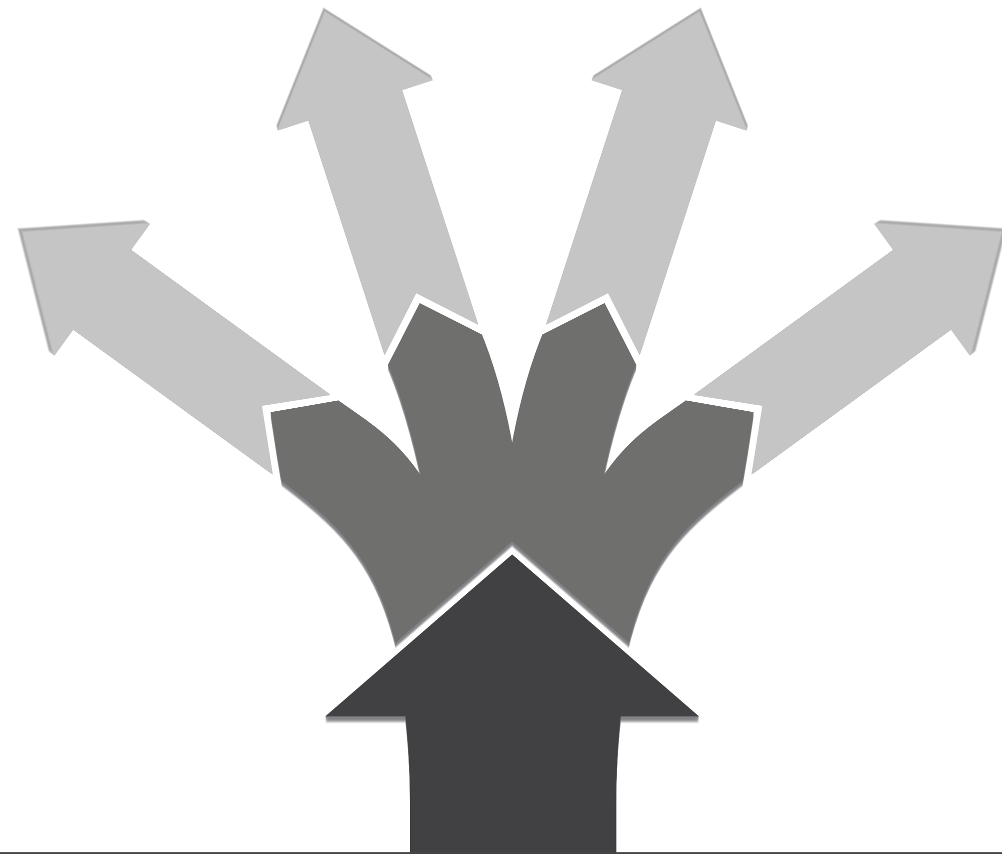
Source: ATSB (2016)

Making decisions

Controllers may make hundreds of decisions during each shift, solving conflicts, managing requests, routing traffic, coordinating traffic, sequencing, take-off and landing instructions, and so forth. It is perhaps a unique professional role in that it makes such frequent demands on safety-related decision-making.

A key determinant of the difficulty of decision-making is the number, type, and complexity of sources of information. While well-designed automation can support decision-making in collecting, analysing and integrating information, the final decision usually rests with the controller.

The principles that were described in the chapter on decision-making apply equally to the controller role. The experienced controller relies upon pattern matching to recognise situations and to select the course of action that has resulted in successful outcomes on previous occasions. When novel elements are present — that is when the scenario involves features that do not correspond with any encountered



CASE STUDY

Determining when to take over positive control rather than rely on pilots 'own navigation' (Eckel, 2013)

What happened:

Most modern airliners have very good weather radar and it is important to strike a balance between allowing the aircraft to use this information and manoeuvre under own navigation and providing positive instruction to the aircraft. Both have pros and cons.

While permitting an aircraft to manoeuvre around weather under own navigation requires fewer transmissions and allows for more instantaneous tracking, it doesn't give the controller any predictability of where the aircraft will fly and how far displaced the aircraft will be. Alternatively, an aircraft being provided with vectors or diversions left/right of track needs new clearances each time they wish to change tracking but is more predictable in flight.

In the above scenario own navigation was a good idea early on but did not provide adequate tracking to enable the aircraft to intercept an instrument approach at a sufficient distance from the airfield. When the 737 captain reported clear of weather, vectors should have been used to enable the aircraft to intercept final.

If the 737 was vectored to establish on final at or outside the IAF they may have lined up with the runway rather than a parallel road 500m north or the airfield. The tower controller's quick reactions averted a dangerous situation that night and the importance of staying vigilant even toward the end of a nightshift was never more apparent.

Being able to quickly make decisions and change instructions are key airspace-management skills but are made harder when working long shifts in the middle of the night. If an aircraft's tracking does not look like it will end in a safe approach, you have a duty of care to do something whether in an approach or a tower control position. In bad weather or in emergency situations this is further underlined. When action is required to avoid a dangerous situation, be assertive.

Source: Eckel, 2013

in formal training or previous experience — the controller will collect additional data and use working memory to generate and test new solutions. The vulnerabilities that apply here include all those that apply to working memory as well as the risk of making false assumptions and the possibility that there may not be additional data.

A not-so-obvious vulnerability emerges when the controller decides that the pilot is in the best position to make decisions about approach and landing. The case study on positive control recounts a situation where a controller decided that the pilots were in a better position to evaluate their options and allowed them to take control of their approach and landing. The controller now believes that this was the less effective option and that he should have taken control and provided vectors for the approach.

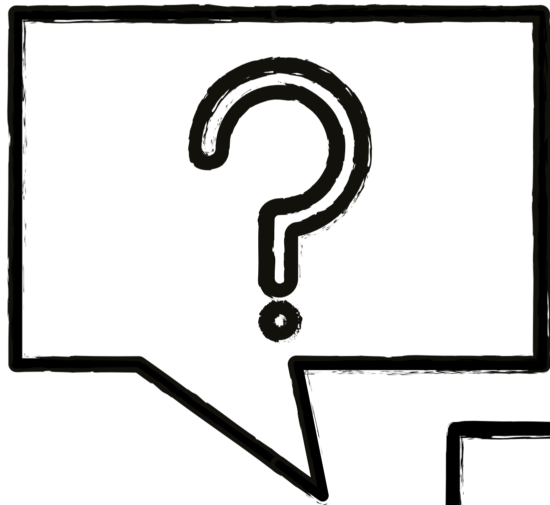
Communicating and working in a team

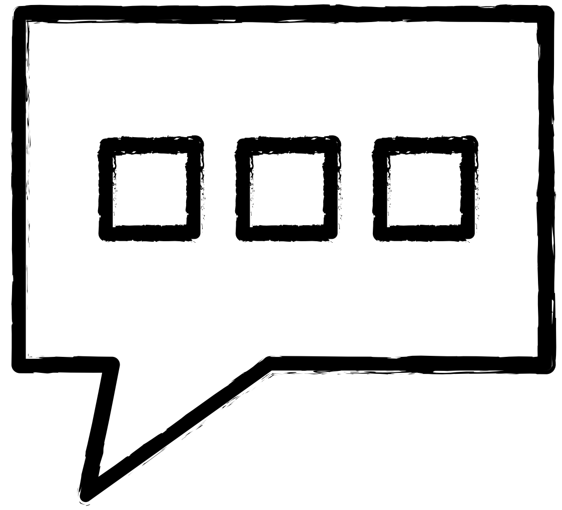
Communication failures are perhaps the biggest single cause of airspace-management incidents (Wickens, et al, 1997). Communications effectiveness depends on a shared mental model between speaker and listener. In a busy control centre, what is most obvious is the speed and frequency of radio-telephone communications. While particular checks have been put in place (such as read-back-hear-back), there is no room for misunderstandings.

A particular vulnerability for controllers is expectation-driven processing: we see or hear what we expect to see or hear. Most of the time, these expectations speed up processing but when the unexpected occurs in conditions of high workload, errors follow. The Garuda Airlines Flight 152 and the Teneriffe 1977 examples described in the chapter on communication illustrate this point very well.

Managing mental workload

The mental workload experienced by a controller will depend on many factors, such as the number of aircraft on frequency, traffic complexity, and fatigue. When workload is too high (overload), the information-processing system will inevitably fail to detect or respond to important information. When the workload is too low, attentional mechanisms may fail because it takes effort to continue visual scanning when nothing much is happening. The question of what is a high workload will vary





according to expertise and the availability of support — including technological aids.

Because it is primarily a reactive role in the sense that the controller is responding to events that were initiated by others, workload is a major vulnerability for this role. Accordingly, controllers must at all times be aware of their mental workload and be willing to speak up and inform the other members of the team when they are approaching their limits.

Privately shedding tasks is obviously not an option. Many of the options come down to good supervision, good self-awareness, and effective teamwork [see Chapter 10]. Signs that a fellow-controller may be nearing his or her limits include leaning close to the radar screen and focusing on certain areas (tunnel vision), fidgeting or otherwise acting nervously, disjointed or confusing transmissions, and being unable to process simple tasks such as recording departure or control instructions.

Managing interference in working memory

Because of its limited capacity, working memory is the component in the information system most taxed by heavy workload. It is also subject to interference. Speaking, for example, can disrupt verbal working memory; scanning can disrupt spatial working memory. A list of letters that sound the same (for example, P, B, C, D, V, E, G, T) is harder to recall than a list of dissimilar-sounding letters (for example, Y, A, D, F, Z, M, U, O).

A list of words that look alike is harder to recall than a list of dissimilar-looking words. These vulnerabilities are very easy to demonstrate. They have been used in short experiments in Psychology 1 classes for decades because they work. The group that is asked to recall similar-sounding letters invariably performs worse.

These aspects of working memory are overcome by design rather than training. The NATO phonetic alphabet (Alpha, Bravo, Charlie, et cetera) is a good example: B, C, and D may be confusable but Bravo, Charlie, and Delta are clearly different and will be both perceived and recalled better than the letters they represent. To quote a passage from the chapter on communication:

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

'SOMETHING I FORGOT TO MENTION...'

In one large UK airspace management centre, a study was carried out by HF specialists into the position handover process, using task analysis, observation, video-recording, incident analysis, procedures review and interviewing techniques. The handover process varied significantly, ranging from detailed briefing by the outgoing controller, to no briefing at all.

In one interview, a controller said that one time, he had just left the ops room and was driving back home, when he suddenly remembered something he'd forgotten to tell the oncoming controller, about an aircraft that was going to be in conflict as soon as it entered the sector. He pulled over and called the oncoming controller with an urgent message: 'Have you seen the Speedbird?' In this case the controller laughed and told him to go home and get some rest; he had already resolved the conflict.

In 1999, an incident pattern was noted in several places in Europe and in the US: incidents were occurring within ten minutes of position handover. In some units, these losses of separation amounted to some 50 per cent of incidents during the position (typically 90 minutes), so clearly something was going wrong. A checklist was developed by/for the controllers to enable them to run through the key items to be discussed (when relevant) for approach and terminal manoeuvring area.

Outcome

A checklist was developed called 'PRAWNS' as this was the anagram of the information required during the handover. The checklist increased briefing time from an average 25 seconds to 41 seconds, but decreased 'settling-in' time markedly, from up to ten minutes to a maximum of 4 minutes. PRAWNS also reduced handover-related features in incidents. In particular, there were:

- fewer information transfer errors
- fewer problems with handover to different watch controllers
- fewer read-back errors
- fewer mentor-trainee problems.

Conclusion

Handover can be a key risk area for human performance. A simple checklist developed with controllers made the safety-critical process of 'getting the picture' both more efficient and more thorough.

P – high/low, minimum priority
R – runways in use
A – airport information
W – weather
N – non-standard priority info
S – flight progress strips

"In order to minimise potential ambiguities and other variances in aviation, there are established rules or protocols regarding which words, phrases or other elements will be used for communicating. For example, the International Civil Aviation Organization (ICAO) phraseology now requires that the word departure is used instead of take-off (except for the single case of the take-off itself) and that terms such as clearances, heading, runway are read-back. This change was introduced to enhance safety following many cases where messages were misinterpreted."

Vulnerabilities of long-term memory

Long-term memory is a vital part of the information-processing system but it is also subject to some unique vulnerabilities. It is the system that holds all our technical and procedural knowledge, all the action scripts, and all the patterns we recognise and use as a basis for decision-making. Because it is unlimited; however, information can easily be lost or prove difficult to retrieve.

If we cannot quickly retrieve information stored in long-term memory, then we lose the advantages that experience confers and we are forced to revert to the knowledge-based or rule-based stage in the novice-to-expert continuum [see Chapter 2].

The solution to retrieval problems is to rely on in-depth processing when first memorising the material and to regularly re-visit the stored knowledge [see Chapter 2].

Knowledge that is stored and never used or refreshed is unlikely to be available when we need it unless it was particularly memorable when we first encountered it.

Briefing

Due to the dynamic and complex nature of the air-traffic environment, formal briefing is not always achievable. Also, due to a number of controller positions rotating at various times, a team brief is not always available. The typical briefing consists of:

- handover of a specific position
- a checklist is used to make the process more efficient, yet ensuring the essential information is covered
- a supervisor delivers a short, informal brief to the team when traffic levels allow
- a supervisor delivers a short, informal brief to each position before taking over control duties
- a self-briefing prior to commencing a handover covering such things as NOTAMS, status of equipment, any exercise-specific documents, changes to procedures, and so forth.

In addition, due to the geographical separation and time pressure, there is a lack of face-to-face briefing with aircrew or external agencies. This lack can at times be alleviated by telephone briefs or debriefs. For example, an aircraft crew wishing to conduct circuits or a display should contact the airspace management unit to discuss the plan, the duration of the activity, and the objectives of the exercise.

This briefing also gives a controller the opportunity to raise any issues or concerns that may affect a specific flight or sortie. The 'Something I forgot to mention' sidebar illustrates the importance of handover briefings in airspace management (Eurocontrol, 2010).

Error management

'Human error' is really just a by-product of normal variability in human performance. This same variability allows humans to keep the air traffic moving, and to recover from near disasters. The same variability allows the system to be flexible and respond to changing conditions. The key lies in ensuring that the system is safe by design and that performance variability is properly handled in both design and management. Errors are the price we pay for having a system that performs extremely well almost all of the time (Eurocontrol, 2010).

It is easy to see how in busy periods for controllers, fatigue and stress could accumulate, leading to errors. The stress management techniques outlined in Chapter 8 can help to reduce errors arising from that source while observance of crew-rest and duty limitations outlined in SafetyMan and following a sensible fatigue-hygiene program [see Chapter 9] will help to maintain satisfactory alertness levels.

The types of errors to which controllers are susceptible can be predicted from the section on vulnerabilities. They fit easily into an error taxonomy based on stages of learning.

- Decision Errors (knowledge-based) occur when operators lack the information needed to make a correct decision. For example, an operator may not realise that a conflict exists

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

or is pending. Reasons for these errors include inexperience, poor scanning, attentional failures, or failures of long-term memory.

- Decision Errors (rule-based) involve selecting an inappropriate rule or action to address a correctly diagnosed situation. The operator in the example cited immediately above may have spotted an impending conflict but advised a solution that did not take into account the characteristics of the aircraft.
- Action Errors (lapses) are due to failures of long-term memory (the prospective memory aspect), such as forgetting to provide an updated flight plan to an aircrew.
- Action Errors (slips) occur at the response stage of the information-processing model and are usually due to attentional failures. Experts are just as susceptible to these types of errors as novices and they are increasingly likely when the operator is stressed, fatigued, or distracted.
- Information Errors occur when the controller performs an action that might be appropriate in one mode without realising that the system is in a different mode, so the same action is no longer appropriate. On 25 January, 2017, a serious mishap was narrowly averted at Australia's Newcastle airport when a passenger jet was given permission to taxi to the runway while a ground worker was still connected by a cable to the A320's nose. The ground worker quickly ran clear of the aircraft and there were no injuries or damage.

The ATSB report did not identify any errors on the part of the controllers who accepted the pilots' request and gave the clearance to begin taxiing but the incident is described here to illustrate mode errors: the clearance instruction was appropriate had the aircraft been in the correct configuration (that is, clear of all obstacles). Mode errors are more often associated with automated systems and are becoming increasingly common.

Automation in the controller environment

This section is adapted from a paper by V. David Hopkin (2010). He provides a fascinating review of the human-factors implications of automation and computer assistance in the domain of airspace management.

It is highly likely that airspace management across the world will experience increasing demands for its services. Current systems have been evolving in order to cope with the anticipated increasing demand. Automated systems and computer assistance are fundamental to this increased capability. There has already been a range of unforeseen impacts due to automation on the flight deck and the same may apply to controllers.

Hopkin defines computer assistance as technical support that permits human intervention or is adaptive in accordance with the needs of individual controllers. In computer assistance, human tasks, roles and functions are central in that they are the hub or focus of activities and are supported by the computer. The human controller retains some means to guide and participate in the processes of computer assistance. Perhaps the defining characteristic of computer assistance is that some human participation is essential; without it a process or function cannot be completed.

In contrast, automation in airspace management generally does not require, and often does not permit, any direct human intervention or participation. The controller generally remains unaware of the actual processes of automation and is usually only aware of its outputs.

According to Hopkin, in airspace management, computer assistance of cognitively complex human functions has always been preferred to their full automation. Practical constraints such as formidable technical difficulties, lack of user acceptance, and issues of legal responsibility have also been at play in preventing full automation within airspace management.

The general expectation is that controller will remain largely computer assisted rather than fully automated with respect to many, perhaps most, of its functions. One exception has been the full automation of the presentation of aircraft within their labels on a radar display — a function that says individual controllers from the task of continuously gathering, storing, transferring, manipulating and presenting data.

Early automation in airspace management was mostly for very simple functions that are routine, continuous or frequently repeated. These automated functions include data gathering and storage, data compilation and correlation, the computation and presentation of summaries of data, the retrieval and updating of data, and data synthesis. An example is the provision of an aircraft's altitude within its label on a radar display. The pace at which automation and computer assistance have been introduced into controlling has been slower than what might be expected. Nevertheless, controllers are increasingly provided with high-quality information from a variety of sources (such as flight plans, navigational data, on-board sensors, prediction aids, weather reports) and means (radar, satellites, data links).

Technological advances

Hopkin discusses a number of technological advances in controlling with human-factors implications. Three of them are described here.

Communications. Spoken messages have been the main means of communication between the controller and aircrew; however there is increasing reliance on data transponded automatically or on request. It is well accepted that voice communication often conveys more than just information, such as the competence, confidence or professionalism of the speaker.

Much can be gleaned from attributes of speech such as accent, pace, pauses, hesitancies, repetitions, acknowledgements, misunderstandings, degree of formality, standardisation, courtesies, choice of vocabulary, message formats and the sequencing of items within a message. More sophisticated communications technology may therefore lack the nuance of spoken exchanges.

Radar. Modern radar displays include labels attached to each aircraft's position showing identity, destination and aspects of current status. Importantly, perhaps in recognition of the challenges of change blindness [see Chapter 6], some radar systems signal significant changes to the controller.

Electronic flight progress strips. These are intended to replace the paper version that has become iconically associated with airspace management. Details of each aircraft for which the controller had responsibility appeared on a paper strip in a holder on a strict board and were amended by hand. On the other hand, electronic strips can be generated and amended automatically but the controller must use input devices to amend them. What has become apparent to experienced controllers is that electronic strips do not capture the full functionality of paper flight strips, which are more complex than they appear.

While most aspects of task performance with paper strips, their manipulation, and the updating are relatively easy to capture electronically, to the controller a strip also serves as a talisman, an emblem, a history, a record and a separate object. Active writing on strips, annotation of them, offsetting them sideways, and initial placement of them in relation to other strips on the board, all help in understanding, memory, and the building of the controller's mental picture of his or her responsible airspace.

In addition, strips collectively denote current activities and future workload. They are observable and accessible to colleagues and supervisors. These aspects have proven more difficult to represent electronically and it remains to be seen whether electronic versions of flight progress strips will ever duplicate the range of cognitive functions and processes of their paper forebears.

Computer assistance with controller procedures

Hopkin discusses the human-factors implications of automation and computer assistance, often in the form of computations, with a range of controller tasks and procedures. His review examines alerting, track deviation,

> **"The introduction of any new form of computer assistance that affects the controller's tasks is likely to change situation awareness and require a synthesis or rematching of the human mental picture ..."**

conflict detection, conflict resolution, approach sequencing, flows and slots, traffic flow management, free flight, legal requirements and consequences for responsibilities. The interested reader is referred to the original source (Hopkin, 2010). The section on conflict resolution is reproduced below.

Conflict resolution. This aid takes conflict detection a stage further. The data used to specify a conflict can be applied to the data on other aircraft traffic to compute and present automatically one or more solutions to the conflict that meet all predefined criteria and rules. If more than one solution is offered to the controller, the order of computer preference usually follows the same rules.

Nominally, the controller can still choose to devise and implement another solution, but controllers are trained and expected to accept the preferred computer solution in normal circumstances.

It can be difficult for the controller who imposes a human solution to ascertain all the factors included in the automated one. However, this becomes necessary either if the automation has taken account of information unknown to the controller or if the controller possesses information that is unavailable to the computer, and invalidates its solution.

One type of conflict detection aid warns the controller of a very imminent conflict and issues a single instruction to resolve it, which the controller is expected to implement at once.

Issues associated with automation

Situation awareness. The potential adverse impact of automation on situation awareness, identified as an issue for flight crew, can also occur with controllers. The introduction of any new form of computer assistance that affects the controller's tasks is likely to change situation awareness and require a synthesis or rematching of the human mental picture (schema) and the machine database.

Support to monitoring tasks. As noted above, one of the first and fully automated functions within airspace management was the identification and tracking of the aircraft on radar displays. This made good human-factors sense, given that we know humans are particularly poor at sustained monitoring tasks.

Predictive support. Some computer-assisted supports, given high-quality data, can make rapid and accurate predictions and plot the consequences of proposed actions — a very useful and efficient tool for controllers.

Impact on workload. Consistent with automation philosophies of airlines and airliner manufacturers, automation and computer assistance within airspace management must not create additional or unnecessary workload, such as replicating spoken messages as data and requiring cumbersome keying procedures for standard tasks.

Cognitive consequences. The potential and actual cognitive consequences of automated systems in airspace management, as discussed above with respect to the introduction of electronic flight progress strips, must be considered — preferably in the design stage.

Accounting for complexity and inconsistency. Air-traffic control procedures, rules and objectives are often more complex than they appear. It is not until attempts to transcribe them into software are made that this complexity becomes evident. The objectives of airspace management are often multiple and rules in certain situations can conflict. This is because airspace management must be safe, orderly, efficient, cost-effective, noise abating, fuel conserving, and responsive to a range of customers.

Reduced observability. An interesting and unplanned consequence of most forms of computer assistance within ATC is that the work of the controller becomes much less observable to others, including co-workers and supervisors. Such loss of observability can make it more difficult for controllers to appreciate the skills of co-workers, acquire new skills through observation, and demonstrate their own competence and accomplishments to others.

Concealment of performance standards. In a similar vein, some forms of computer assistance and automation can compensate for human limitations and lacklustre performance. Strong reliance on automation can mask a controller's actual performance and capability. It is plausible that some controllers who lack basic competencies will not be detected.

Automation-related stress. Automation can generate its own stressors for the human operator. Once again, ATC is no exception to this possibility. Automation-related stress is often related to issues of trust, complexity, uncertainty, and frustration related to a lack of control over automated products and actions.

Team roles. Automation in ATC can change the traditional roles and functions of the team. This is partly due to automation designers not taking into account team functions and not being aware of, or valuing, the benefits and by-products of team interactions such as morale, shared mental models, and mutual trust and respect.

Implications for selection and training. As in all industries, the implementation of automation changes the nature of work for the human operator. This has clear implications for both selection and training. It is possible that some abilities for which controllers have been selected in the past are no longer sufficiently relevant to be retained in selection processes. Similarly the controller's professional knowledge and skills, initially gained through training, should be consistent with the actual work.

Summary

In this chapter, a lot of emphasis has been placed on the cognitive requirements of the controller role. The degree of emphasis is deliberate because it is the information-processing requirements of the controller role that separate it from other aviation roles. It is no accident that Philip Ackerman, a leading researcher in the fields of intelligence and applied cognition, chose to build an airspace management simulator to test his theories about complex skill acquisition (Ackerman, 1992).

His work, which changed the way we think about the abilities required for performing a wide range of jobs, also highlights the cognitive skills we should look for in a controller. These skills embrace all aspects of the information-processing model but particularly those that involve attention, scanning, memory, decision-making, and the property that emerges when all parts of the information processing system are active: situation awareness.

Beside the cognitive skills sits the full range of other non-technical skills that we have covered in earlier chapters. Airspace management takes place in a complex team environment, with rules, concepts and systems constantly evolving. Because it is a rapidly changing and diverse environment, every member of the team needs to have a solid awareness of the human-performance factors and strategies essential to delivering a safe and effective capability.

The fact that so few controller errors occur is due in part to the skills of the individuals and in part to the fact that methods and principles from human factors research are being used to improve human performance and the systems within which controllers operate.

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Key points

- ATC takes place in a complex and dynamic team environment.
- There are unique cognitive challenges which must be understood and managed.
- Key cognitive skills include attention, scanning, memory, decision-making and situation awareness.

CHAPTER 13 NTS considerations for air battle management

Overview:

- Human-performance aspects specific to air battle management (ABM) duties
- Information-processing requirements of the ABM role
- Aspects of ABM performance most susceptible to error
- ABM human-factors strategies required to aid delivery of a safe and effective capability

Introduction

In Chapter 6 on situation awareness, readers learnt that 90 per cent of pilots killed in World War II were likely not aware of their attacker. Statistics such as this cannot be explained simply by human failures; however. Modern technology has taken attackers beyond the reaches of the human sensory system and the sophisticated equipment on board modern aircraft cannot capture the all-round view needed to detect enemies who may be anywhere in three-dimensional space, including on the ground.

During the 1940s, as Commander-in-Chief of the Royal Air Force (RAF) Fighter Command, Air Chief Marshall Sir Hugh Dowding, oversaw the world's first integrated system of air defence designed to defend the United Kingdom from German air assaults during the Battle of Britain. This air defence system became known as the Dowding System and involved information from coastal RADAR stations being processed in a filter room and

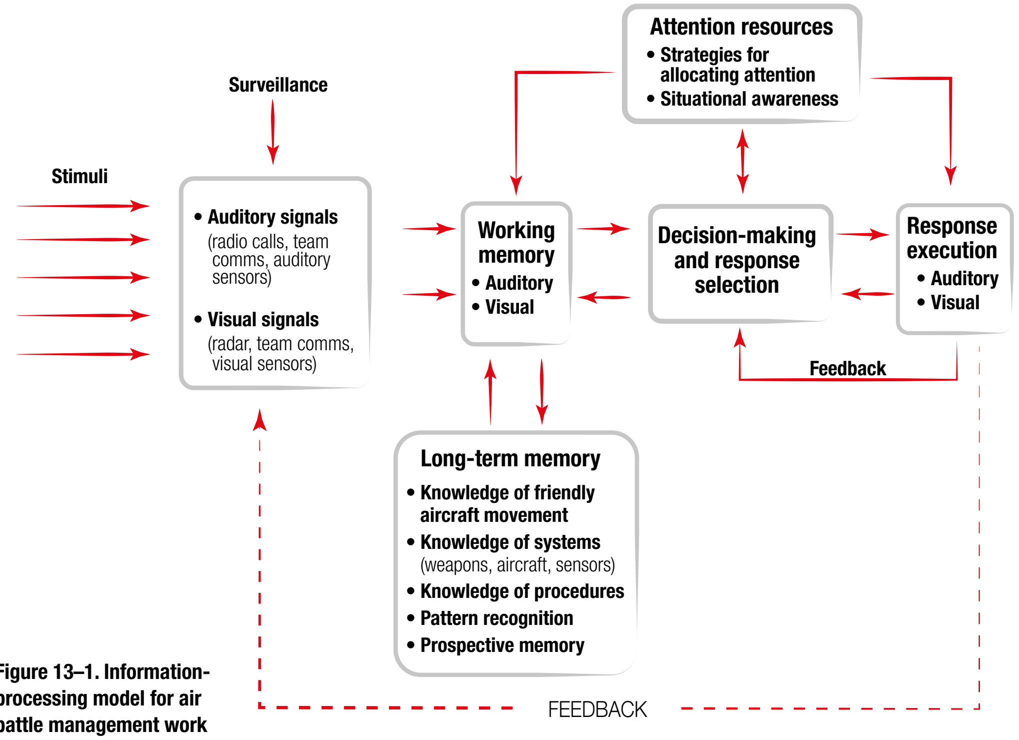


Figure 13–1. Information-processing model for air battle management work

passed on to the operations room at Bentley Priory as well as the operations rooms at four regional group headquarters and their respective sector headquarters. All elements of the Dowding System were served by a complex web of telephone communications operated by the General Post Office. The personnel who operated these assets were known as air battle managers (ABMs). Since these early beginnings, the role of the ABM has been in constant evolution.

The chapter will begin by presenting a summary of the human factors relevant to the ABM role. This material will be followed by a case study that will highlight some key human-factors issues involving pilots and controllers on board a US airborne warning and control system (AWACS).

A cognitive task analysis of the ABM role

The aim of ABM is to manage the air battle at the tactical level in a complex and dynamic environment. ABMs must control air-to-air, air-to-ground and air defence operations, utilising multiple weapons systems. The ABM synchronises and integrates joint and coalition weapons systems (both air and ground assets) to ensure the mission plan is executed, and contingency plans are employed when required. Control of weapons systems requires a detailed knowledge of both friendly and enemy weapons capabilities and tactics. ABMs must understand and integrate friendly data links; ensuring battlespace information is correct and shared appropriately. Finally, the ABM must be able to solve emerging problems in the midst of the confusion created by the loss of friendly resources, enemy force changes, and changes in mission priorities. It is a role that can place a great deal of strain on the emotional and cognitive resources of the operators. Needless to say, understanding and managing human performance is critical to the safe and effective conduct of ABM.

Modelling ABM information-processing requirements

Figure 13–1 shows an expanded view of the information-processing model adapted from Wickens and Flach (1988) that was presented in Chapter 2.

In this model, the external stimuli to which ABMs must attend include the weather, radio messages, radar displays, and communication from colleagues. Selective attention ensures

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

that the essential information enters working memory before it disappears from the sensory store. Once the information, whether auditory or visual, is accepted for processing, it is matched against existing knowledge structures and patterns held in long-term memory. A decision is then made as to what kind of action, if any, is required. A response is then given verbally or via the C2 system (for example, a verbal instruction to a pilot or a colleague).

During periods of high workload, all stages of the information system are very active. Sensory systems are engaged in continuous monitoring to ensure that the data needed for a complete and integrated picture of the operational space are available for development in working memory.

The working memory system, the “workbench” of the brain (Baddeley, 1986), is also busy interrogating long-term memory because that is where we store all job-related knowledge, including knowledge of sensors, aircraft movements, aircraft types, weapon systems, daily plans, and actions that the ABM has yet to execute. A good rule of thumb is to consider long-term memory the repository for any information that is more than 30 seconds old. The result of this surveillance activity is a dynamic picture of the operational space; dynamic because it is constantly being refreshed. Decisions and actions follow. A decision may involve matching the operational picture just formed with the picture expected on the basis of information in long-term memory. An action might involve sharing the operational picture with higher headquarters, colleagues and pilots, or issuing an instruction to a pilot.

Throughout the whole process, it is essential that some attention be directed to all ongoing tasks because without continual refreshing, they will drop out of working memory very quickly and situation awareness will be lost. For experienced operators, this is less of a problem. They have reached the skill-based level of performance [see Chapter 2] where the execution of well-known and routine activities is governed by stored patterns of pre-programmed instructions. For these operators, responses are often automatic, fast, and require little conscious effort. For newer operators, workload must be managed so that overload does not occur.

Situation awareness [see Chapter 6] is an equally important part of the information-processing model but it is an emergent property of the system rather than a component in its own right. We possess situation awareness when we have detected and attended to the relevant information and understood both its meaning and its implications. Attention, memory, and decision-making processes are all involved.

These planning and decision-making processes also draw heavily on long-term memory (via working memory) where all knowledge is stored. For example, an ABM might receive a request from a pilot to confirm the identity of a target that has appeared on the pilot’s radar screen. The ABM might consult long-term memory to see whether a friendly aircraft has been logged in that area or is expected in that area at that time. If the ABM is already tracking the target (likely), the response could be immediate. If not, the answer will await definite identification of the target, possibly with input from the pilot (as happened in the case study reported later in this chapter).

The desired result of these processes is that the ABM is able to provide timely and accurate target identification, threat warning, and (if appropriate) advice regarding rules of engagement. However, in practice things do not always work out as they should and there are some particular areas of vulnerability in the ABM role.

Human error: cognitive vulnerabilities in the ABM role

The information-processing model shown in Figure 13–1 is essentially the same as the generic one shown in Chapter 2. ABMs have the same cognitive architecture as everyone else. Where they differ is in the relative involvement of particular categories of cognitive tasks and the types of errors to which they are susceptible. These tasks include visual scanning, maintaining attention, situation awareness, and decision-making as key cognitive skills for ABMs along with communication, teamwork, and workload management as other key non-technical skills.

Visual scanning

Monitoring traffic is a critical and complex activity, involving scanning and searching for static and dynamic information from a number

of sources such as situation displays, chat systems, and planning documents. Many scanning problems can be addressed through automation (for example, target alerts) but such tools support rather than replace the requirement for human scanning. Some scanning methods and strategies are known to be particularly effective and can be developed or improved via training.

Scanning performance is affected by many internal factors such as expectations — for example, waiting for an order from a higher headquarters such as the Combined Air Operations Centre (CAOC) prior to passing a mission to strike a target — and external factors such as display design. Vulnerabilities include failure to see a target, clutter in the visual environment, and changing priorities of the elements in the visual environment. Proper scanning requires the constant sharing of attention with all tasks, thus it is easily degraded by such conditions as distraction, fatigue, boredom, illness, anxiety, or preoccupation. With a thorough consideration of such human factors in design and training, scanning performance can be optimised.

Maintaining attention

In dynamic environments such as ABM, lapses of attention can have serious consequences. Helping ABMs to maintain attention presents design challenges. Sustaining attention over long periods when there is little activity is difficult and the ABM must ensure that regular scanning is maintained. Distractions, fatigue, health and personal factors can all affect attention and must be managed carefully. When dividing attention (or time-sharing), the controller needs to ensure that tasks do not interfere with each other (for example, simultaneously scanning and checking a

written procedure). Successful application of good design principles can help to ensure that tasks do not interfere with each other (for example, simultaneous visual tasks) and that alerts and alarms are effective and not disruptive.

Keeping the picture (situation awareness and shared understanding)

From the time they take over their position, and throughout their time on duty, ABMs manage their situation awareness to build and maintain a mental picture of the current and projected operational space and control environment. As mentioned earlier, this state of awareness is critically dependent on working memory (for example, keeping an updated tactical picture as it evolves for a short time), long-term memory (for example, knowing the overall mission objectives, including rules of engagement (ROE), intelligence, enemy characteristics), and prospective memory (for example, remembering to issue a rehearsed instruction at some point close in the future).

The predictive component of long-term memory (vital for situation awareness) is heavily dependent on spatial working memory to compute likely trajectories based on current aircraft state, intended plans, and individual aircraft dynamics. This predictive component is highly vulnerable to competing demands for attention. Again, this element of competition is unlikely to cause problems for experienced ABMs dealing with routine circumstances in normal workload conditions. Any departure from these conditions; however, increases the likelihood of predictive memory failures.

In addition to maintaining awareness of the unfolding flight plans, the ABM needs to establish and maintain shared mental models with each of the pilots, as well as members within the control team and members of external agencies. Understanding the expectations and plans of each element, whether the pilot of an aircraft or a fellow ABM, assists in ensuring that all participants in each of the various ongoing scenarios knows exactly what they are required to do. Additionally, effective communication is essential in order to achieve and maintain a situational awareness that supports all areas of the shared mental model. Assumptions here can be dangerous and intentions need to be clear to all.

Shared mental model

The individual ABM must process a number of information sources, often integrating them with information from other types of displays and communications in order to create a mental tactical picture of what is happening. This tactical picture will be the basis for decisions based on the situation, pre-existing plans, known doctrine, and the ROE. In addition, the ABM is required to monitor the progress of the mission to meet the overall aim and, as circumstances change, to support contingent plans that have to be activated.

In an ABM environment, effective situation awareness (SA) involves sharing a tactical picture throughout the team. Traditionally, controllers and control units have been co-located, such as on board an airborne early warning and control (AEW&C) aircraft or at a control and reporting centre (CRC). In modern war fighting; however, it is more likely that these resources will be distributed over several ground-based and airborne locations, thus posing challenges for sharing the tactical picture within the team and with affected external units such as fighters, bombers, tankers, early warning assets, and reconnaissance platforms.

Communicating and working in a team

Effective communication is vital in the ABM environment as the primary role of the ABM is sending and receiving essential time-critical information in the fight. The primary means of communication between controller and pilots is verbal, through the use of radio telephony (RT). Every call an ABM makes on the radio in relation to what a pilot is seeing or doing in the cockpit is critical. Training missions and simulated missions allow the ABM to practice and assess the information that is relayed. As discussed in Chapter 7, the relay of the information is only part of the communication process. As well, the ABM must consider:

- Was the communications channel effective?
- Is the piece of information the priority at that time?
- Does this information increase or decrease the situation awareness of the pilot?
- Was the timeliness of the message optimal; that is, did it increase or decrease the pilot's workload?

Communication effectiveness depends on a shared mental model between speaker and listener. While particular checks have been put in place (such as read-back-hear-back), there is no room for misunderstandings. A particular vulnerability for ABMs is expectation-driven processing: we see or hear what we expect to see or hear. Most of the time, these expectations speed up processing but when the unexpected occurs in conditions of high workload, errors follow. Methods and principles from human-factors research can be applied in the context of design, simulation and operations to assess and improve communication and teamwork.

Making decisions

ABMs may make hundreds of decisions during each duty period; a key determinant of the difficulty of decision-making is the number, type, and complexity of sources of information. Well-designed automation and integration can support decision-making by collecting, analysing and integrating information but the final (action) decision rests with the ABM. Adhering to the ROE for a specific mission and playing a key part in the decision-making process is a very important responsibility for the ABM in the war-fighting environment. The ABM needs to have a thorough understanding of the ROE and 'actions on' before making time-critical decisions during a mission. Any lack of understanding or delay in the actions of ABM can have significant effects on the success or failure of a mission.

Managing mental workload

Workload is a major vulnerability for this role. The mental workload experienced by an ABM will depend on many factors, such as the number of aircraft on frequency, mission complexity, and fatigue. When workload is too high (overload), the information-processing system will inevitably fail to detect or respond to important information. When the workload is too low, attentional mechanisms may fail because it takes effort to continue visual scanning when nothing much is happening. The question of what is a high workload will vary according to expertise and the availability of support — including technological aids.

ABMs must at all times be aware of their mental workload and be willing to speak up and inform the other members of the team when they are approaching their limits. Privately shedding tasks is not an option. Many of the options come down to good supervision, good self-awareness, and effective teamwork [see Chapter 10]. Signs that a colleague may be nearing his or her limits include leaning close to the radar screen and focusing on certain areas (tunnel vision), fidgeting or otherwise acting nervously, disjointed or confusing transmissions, not responding to queries, and being unable to process simple tasks.

Briefing and debriefing

Due to the dynamic and complex nature of the ABM environment, formal briefing is not always achievable. Also, due to a number of ABM positions rotating at various times, a team brief is not always available. The typical briefing consists of:

- handover of a specific position
- a checklist is used to ensure that the essential information is covered
- a supervisor delivers a short, informal brief to the team when activity levels allow
- a supervisor delivers a short, informal brief to each position prior to taking over control duties
- a self-briefing prior to commencing a handover covering such things as NOTAMS, status of equipment, any exercise-specific documents, changes to procedures, and so forth.

Where mission briefs and debriefs are concerned, due to geographical limitations and limited time, there can be a lack of face-to-face briefing with aircrew or external agencies. At times, this problem can be alleviated by telephone or VTC briefs or debriefs. For example, Exercise Pitch Black is a multi-national exercise that has forces spread across the north of Australia. VTC facilities are used for mission planning and briefing to ensure all participants understand the overall plan before going into their individual formation/team briefs. In routine weekly training missions, briefing and debriefing can be quite intensive to ensure that all aspects of the tactical mission are rehearsed, assessed, and debriefed. Lessons learnt are retained for future training missions. All members of the team address both the positive and negative lessons from these debriefings and always seek ways to improve, not only tactically or procedurally but from a human factors perspective.

Automation management

The technologies in support of ABM operations are constantly evolving as the concept of air warfare continuously changes. It is such a dynamic environment that effective automation management is essential towards achieving the aim of the mission. The new technologies aim to support the shared visualisation and understanding of the dynamically shifting environment — both spatial and temporal. Effective communication, teamwork, workload management, leadership, and decision-making are all essential human factors for executing safe and effective automation management.

The ABM crew needs to have a sound knowledge of their primary control system. They also need to have sound knowledge of the capabilities that they are managing within the war-fighting environment. These include, but are not limited to:

- fighter and bomber aircraft systems — radar, electronic warfare (EW), weapons
- other ABM assets — ground and airborne ABM assets
- ISR platforms
- data link
- EW platforms
- other C2 platforms, for example, JSTARS
- air traffic sensors
- threats — for example, jamming and anti-radiation missiles.

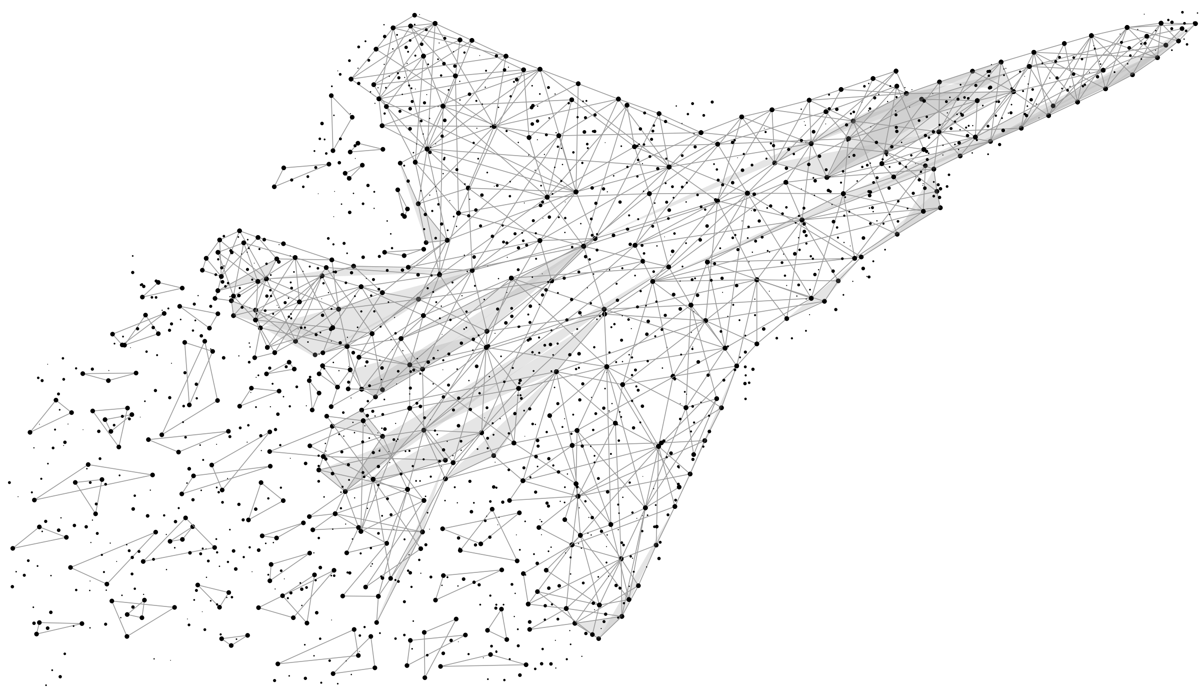
The ergonomics of the ABM system needs to be assessed and planned accurately with all changes in automation. C2 systems have changed a great deal since the earlier years of ABM. With the development of signal processing, alphanumeric displays, high-resolution graphics, and colour-coded displays, the reliance on the human sensors to process raw data has been greatly reduced. The new display capabilities allow much more information to be presented, with a consequent risk of clutter and information overload. Other factors that influence display-related workload include type size, luminance, contrast, colour, and visual coding of alphanumeric symbology.

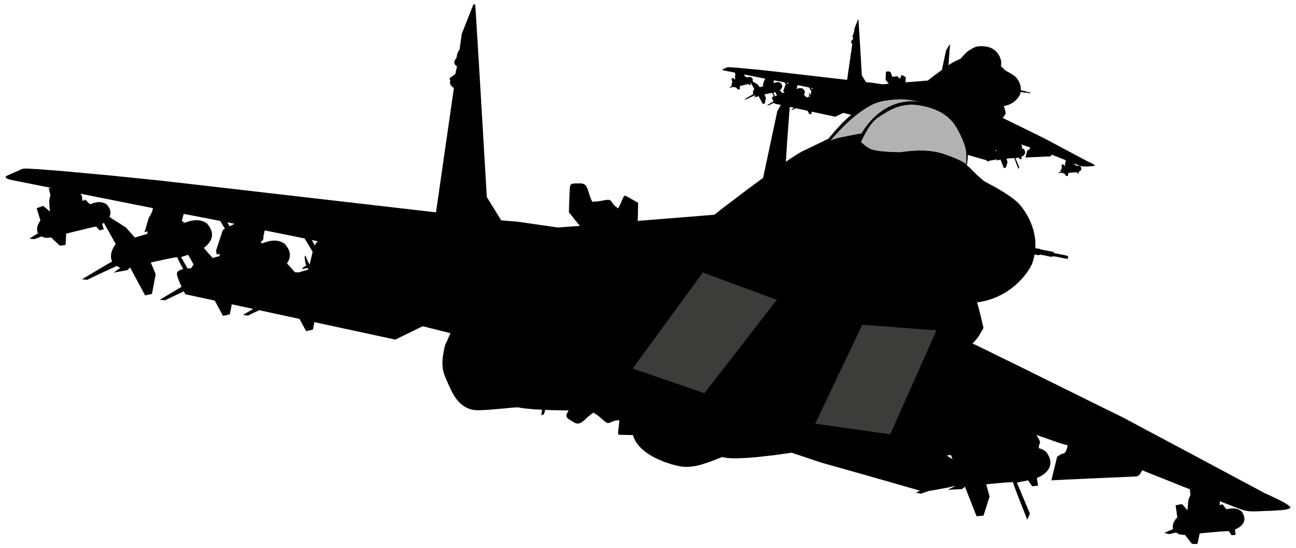
Error management in an ABM environment

It is easy to see how in busy periods for ABMs, fatigue and stress could accumulate, leading to errors. The stress-management techniques outlined in Chapter 8 can help to reduce errors arising from that source while observance of crew-rest and duty limitations outlined in the *Defence Aviation Safety Manual* (DASM) and following a sensible fatigue-hygiene program [see Chapter 9] will help to maintain satisfactory alertness levels.

The types of cognitive errors to which controllers are susceptible can be predicted from the section on vulnerabilities. They fit easily into an error taxonomy based on stages of learning.

- Decision Errors (Knowledge-based) occur when operators lack the information needed to make a correct decision. For example, an operator may not realise that a conflict exists or is pending. Reasons for these errors include inexperience, poor scanning, attentional failures, or failures of long-term memory.
- Decision Errors (Rule-based) involve selecting an inappropriate rule or action to address a correctly diagnosed situation. For example, selecting the wrong ROE option when an enemy target is spotted.
- Action Errors (Lapses) due to failures of long-term memory (the prospective memory aspect), such as forgetting to provide an updated tactical picture to a pilot.
- Action Errors (Slips) occur at the response stage of the information processing model and are usually due to attentional failures.
Experts are just as susceptible to these types of errors as novices and they are increasingly likely when the operator is stressed, fatigued, or distracted.





CASE STUDY

1994 Black Hawk friendly fire tragedy in Iraq

This case study illustrates many of the principles discussed to this point — in this chapter and in earlier sections of the guidebook. While there are a large number of online sources that provide an explanation of this infamous event, this account was given by Levenson, Allen, and Storey at a System Safety Society Conference in 2003. Although the chief concern of this chapter is with the AWACS, to make sense of what happened it is imperative to consider the actions of all participants in the tragedy. The crucial facts are presented first before drawing out further details to illustrate particular human-factors principles.

The essential facts

In 1994, two USAF F-15s patrolling the northern no-fly-zone (NFZ) over Iraq mistakenly shot down two US Army Black Hawk helicopters on a United Nations Mission over the Kurdish region of Iraq. The helicopters were carrying 26 people including 15 U.S. citizens and 11 others (British, French, and Turkish military officers as well as Kurdish citizens). Although there were many contributing factors to this fratricide event, in the context of the current module it is appropriate to note that the two F-15 fighter aircraft were operating under the control of a USAF AWACS.

The weather was clear, all the sophisticated electronic and technical systems appeared to be operational, and the people involved were all highly trained and experienced. Although several controllers were aware of friendly force helicopters active in the F-15's area, none of them advised the F-15 pilots of that fact.

When asked why nothing was said to the pilots, the AWACS mission crew commander explicitly acknowledged that a lack of situation awareness was the contributing factor and went on to state: "What a great call that would have been, you know, if somebody had had the situation awareness, I guess to make that call, but unfortunately they didn't." According to an air combat command official who was familiar with the investigations, over 130 different mistakes were identified as contributing to the accident.

The timeline for the incident

0845: The AWACS took up its position at 32,000 feet on the northern border of Iraq.

0921: The two Black Hawks entered the NFZ. They reported their entry to the AWACS crew, who acknowledged same.

0927: Black Hawks landed in the NFZ to pick up passengers. Their images disappeared from AWACS scopes when they landed.

0935: The two F-15s took off from their base. Their mission was to clear the NFZ of hostile aircraft prior to the entry of coalition forces.

0954: Black Hawks airborne again in NFZ after collecting passengers. They reported their departure, flight route, and destinations to AWACS.

1012: Black Hawks entered mountainous area and disappeared from AWACS radar scopes. AWACS crew thought they had landed again.

1015: Lead F-15 pilot radioed AWACS asking if there was any information for them. The reply was negative.

1022: Lead F-15 pilot reported radar contact with a low-flying, slow-moving aircraft. AWACS responded that there was nothing on their screens in that area. The F-15s queried the radar targets in two available modes (Mode I and Mode IV) with their on-board Identity Friend or Foe (IFF) systems but did not get a definitive response. An additional problem was that the Black Hawks and F-15s were on different radio frequencies and could not speak to each other. Nor could the Black Hawks hear any of the transmissions between the F-15 pilots or between the F-15 pilots and AWACS.

1025: After closing to within 32 km of the targets, the F-15 pilots again queried AWACS, who by this time had radar contact at the reported location and steady IFF returns. AWACS did not inform the F-15 pilots that the targets might be friendly.

1028: The lead F-15 pilot conducted a visual identification (VID) pass and saw what he thought were the silhouettes of two Hinds, a type of Russian helicopter flown by the Iraqis. The F-15 wing pilot also reported seeing two helicopters but did not confirm that he had identified them as Iraqi aircraft. AWACS acknowledged but did not challenge the identification.

1030: The lead F-15 shot down one of the Black Hawks, the wing F-15 shot down the other. There were no survivors.

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Human-factors issues — pilots

- Although the standard procedure was for fighter aircraft to clear the NFZ before any other aircraft entered this space, the Black Hawk pilots had been given permission to fly into the no-fly-zone before it was cleared. However, no one told the F-15 pilots about this exception to the rule. Although the air tasking order (ATO) for the day, which the F-15 pilots should have seen, mentioned that Black Hawk helicopters would be active in the NFZ that day, no times or routes were given. From their actions, one must assume that they were therefore not expecting to find friendly aircraft in the NFZ.

  COMMENT: In human-factors language, there was no shared mental model between the Black Hawk pilots and F-15 pilots. Neither party was aware of the existence of the other within the NFZ. Members of the AWACS crew knew that both types of aircraft were in the NFZ but did not share their mental model.

- When entering the NFZ, the Black Hawk pilots were required to change their Identity Friend or Foe (IFF) code from 42, the code for all friendly fixed-wing aircraft flying in Turkey on that day, to 52, the code to be used by friendly aircraft in the NFZ. They did not do so. They also remained on the enroute radio frequency instead of changing to the frequency to be used in the NFZ.

  COMMENT: These instances of noncompliance (or perhaps memory lapses), when added to the fact that the F-15s were unaware of their presence in the NFZ, meant that some important barriers to error had been side-stepped.

- The Black Hawks could not hear any of the radio transmissions involving the F-15s, nor could the F-15s pick up the IFF signals generated by the Black Hawks.

  COMMENT: These were technical problems. [Not all failures are due to human factors].

- After making a second check of Modes I and IV and again receiving no response, the two F-15 pilots executed a visual identification (VID) pass to confirm that the target was hostile.

  COMMENT: The silhouette of the Black Hawks was not dissimilar to the silhouette of the Iraqi Hind helicopter, especially when the Black Hawk was fitted with additional fuel tanks, as was the case here. The pilots may not have seen Black Hawks in this configuration before. By this stage, the pilots were probably experiencing confirmation bias [see Chapter 5] and were interpreting all ambiguous incoming information as evidence of hostile aircraft.

- The F-15 lead pilot called the AWACS and said they were preparing to engage enemy aircraft, cleared his wingman to shoot, and armed his missiles. He then did one final Mode I check, received a negative response, and pressed the button that released his missile. The wingman fired at the other helicopter and both were destroyed.

  COMMENT: The enquiry noted that there may have been additional pressure on the F-15 pilots in the form of F-16 aircraft that were due to enter the area soon and who might have taken the credit for destroying the targets.

Human-factors issues — AWACS

The AWACS mission crew were responsible for identifying, tracking, and controlling all aircraft enroute to and from the NFZ; for co-ordinating air refuelling; for providing airborne threat warning and control in the NFZ; and for providing surveillance, detection, and identification of all unknown aircraft. The ACE (airspace control element) was responsible for controlling combat operations and for ensuring that the ROE were enforced. The general safety constraint involved in the accident at this level was to prevent misidentification of aircraft by the pilots and any friendly fire that might result (Leveson, Allen & Storey, 2002).

- There were many controllers with confused and overlapping responsibilities for enforcing different aspects of this general constraint. The overlaps and boundary areas in the controlled processes led to serious control coordination problems among those responsible for controlling aircraft in the NFZ. For example, the interaction between the surveillance officer and the senior weapons director regarding tracking the helicopter flight on the radar screen involved several dysfunctional interactions. The surveillance officer put an attention arrow on the senior director's radar scope in an attempt to query him about the lost helicopter symbol that was floating, at one point, unattached to any track. The senior director did not respond to the attention arrow, and it automatically dropped off the screen after 60 seconds. The helicopter symbol (H) dropped off the radar screen when the radar and IFF returns from the Black Hawks faded and did not return until just before the engagement, removing any visual reminder to the AWACS crew that there were Black Hawks inside the NFZ.

  COMMENT: Teamwork and leadership, both core aspects of human factors and non-technical skills, was clearly lacking in the AWACS.

- This was the first shift that this team had ever worked together and, except for the surveillance officer, the first day of their current rotation. Due to last minute orders, the team got only minimal training together, including one simulator session instead of the two full sessions required prior to deploying. In the only session they did have, some of the members of the team were missing and one was later replaced.

  COMMENT: Training was also deficient for such a critical safety role.

- The ACE failed to provide any control commands to the F-15s with respect to following the ROE and firing on the friendly helicopters.

  COMMENT: A communications breakdown because information about the ROE should have been top priority at this point.

- The AWACS crew missed a number of opportunities to let the F-15 pilots know that Black Hawks were in the NFZ. None of the controllers warned the F-15 pilots at any time that there were friendly helicopters in the area. The accident investigation board found that because Army helicopter activities were not normally known at the time of the fighter pilots' daily morning briefings, normal procedures were for the AWACS crews to receive real-time information about their activities from the helicopter crews and to relay that information to the other aircraft in the area. This established procedure obviously was not followed on this occasion.

  COMMENT: The failure of the AWACS enroute controller to warn the F-15 pilots that their targets may have been friendly aircraft indicated a lack of situation awareness. The controller perceived the stimuli on his screen, he may have even understood that they were probably the two Black Hawks (whose images were not always on his screen because of terrain masking/ mountainous terrain), but he certainly did not project the consequences of not sharing this information with the F-15 pilots.

Human-factors issues — command

It is tempting to conclude that although the Black Hawk pilots failed to follow some standard procedures that may have protected them and although the F-15 pilots could have done more to secure a definite identification of the aircraft before firing, the major responsibility for the tragedy rested with the AWACS crew for failing to warn the F-15 pilots that friendly aircraft were known to be in the NFZ. Indeed, it could be argued that this was the position reached by the US Air Force because the only person who had to face court-martial was the AWACS senior director, the person who had the most opportunity to intervene during the build up to the tragedy and the person who openly admitted that there had been a lack of situation awareness.

However, such a conclusion overlooks some of the organisational factors that also contributed to the tragedy.

- Training, which provides the platform for both technical and non-technical skills, is an organisational responsibility. It was deficient in this case. The AWACS crew was mostly new. Experienced controllers were added to the crew to act as advisors but one of them was in the galley at the time of the incident and another was discovered to be taking a nap.
- In addition, the information in the simulator session was not current (for example, the maps were out of date as was the ROE provided) and did not include a listing of Black Hawks as friendly participants.
- The commanders of Operation Provide Comfort (OPC) had failed to integrate helicopters into aircraft operations in the NFZ. Although the fact that Black Hawks were going to enter the NFZ appeared on the daily ATO, no details were available. The two services were functioning as independent units rather than as a team.
- The Black Hawks and F-15s were on different radio frequencies and thus could not speak to each other or hear the transmission between others involved in the incident. The

fact that Army and Air Force technology was incompatible was an outcome of organisational policies.

The United States Secretary of Defence later summarized the errors, omissions, and failures contributing to the accident as:

- the F-15 pilots misidentified the Black Hawks
- the AWACS crew failed to intervene
- helicopters and their operations were not integrated into the Task Force and
- the IFF systems failed (Snook, 2002).

Other ABM vulnerabilities breeched

A total of 130 errors were counted in the investigation. Some that were not listed under the headings of pilot, AWACS, and organisation fall into the vulnerabilities covered earlier in this chapter.

Visual scanning

The signals for the Black Hawks disappeared from the screens when they landed and disappeared again when they entered mountainous terrain. They reappeared briefly immediately before the incident. It should have been possible to project the position of the Black Hawks at any stage because the AWACS crew knew their flight route and destinations. Furthermore, an experienced crew would have known that loss of a signal in mountainous country did not mean the Black Hawks had landed, as assumed by the AWACS crew member responsible for scanning at the time.

Maintaining attention

To assist in the task of tracking (and scanning), helicopter symbols were placed on the screen over the radar signals for the Black Hawks. When the signals disappeared, the surveillance officer put an attention arrow on the senior director's radar scope in an attempt to query him about the lost helicopter symbol that was floating, at one point, unattached to any track. The senior director did not respond to the attention arrow, and it automatically dropped off the screen after 60 seconds.

There were no longer any visual reminders to the AWACS crew that there were Black Hawks inside the NFZ. The failure of the senior director to respond was either a failure of attention (that is, did not notice the query) or a failure of situation awareness (did not project the consequences of not responding).

Keeping the picture

The pilots of the Black Hawks never had the picture. As far as they knew, they were alone. Air battle command was there to help them see what they could not see. The pilots of the F-15s formed the wrong picture. The AWACS crew was missing part of the picture when the Black Hawk signals disappeared and they failed to use information in long-term memory (knowledge of flight paths and destinations) and the resources of visual working memory to fill in the gaps.

Shared mental model — expectation and experience

There was sufficient background information available for all participants in this scenario to have shared a correct mental model, or shared a correct mental model to the point where more caution was exercised.

The Commander of the Combined Task Force thought that appropriate control and coordination was occurring. His mental model was supported by the feedback he received flying as a regular passenger on board the Army helicopter flights where it was his perception that the AWACS crew was monitoring their flight effectively. He was also an active F-16 pilot who attended the F-16 briefings.

At these briefings, he observed that Black Hawk flight schedules were part of the daily ATOs received by the F-16 pilots and assumed that all squadrons were receiving the same information. However, the head of the F-16 squadron with which the Commander flew had gone out of his way to procure the Black Hawk flight information because the F-16s sometimes flew low-level missions where they might encounter the low-flying Army helicopters.

The leader of the F-15 squadron did not take a similar initiative because F-15s never flew similar low-level missions. Clearly, others also were under the impression that the ATOs provided to the F-15 and Black Hawk pilots were consistent, that required information had been distributed to everyone, that official procedures were understood and being followed (Leveson, Allen & Storey, 2002) .

During the course of the unfolding drama, there were many instances where there was no attempt to reach a shared mental model. The wing F-15 pilot did not attempt to reach a shared understanding of the identity of the targets with the lead pilot. The AWACS crew responded passively to communications from the pilots and from each other. A concerted attempt to share the mental model must have revealed the gaps, but that did not happen.

Communicating and working in a team

It would be possible to fill pages describing the communication breakdowns that led to this tragedy. Looking for explanations, the concept of teamwork probably over-rides everything. At an organisational level, helicopter operations were treated as add-ons, rather than as forming a central part of the overall team effort in Operation Provide Comfort (OPC).

The wing F-15 pilot did not challenge his lead's interpretations or hasty decisions. For example, the lead F-15 checked with the wing F-15 after he had conducted his visual identification run by calling "Tally 2 Hinds". AWACS responded "Copy, Hinds". The wing then conducted his own run and reported "Tally 2", which did not address the implied question from his lead: Were the helicopters Hinds? It is interesting to note that the wing F-15 pilot was the one held more culpable by the investigation board because there was no evidence that he firmly believed the targets to belong to the enemy, but attacked them anyway. In the first instance, the lead pilot was not even charged.

Within the AWACS itself, teamwork was obviously lacking among the new, partially-trained crew. The strategy of adding some experienced crew members failed because they were not around when they were needed.

Putting this case study in context

When things go badly wrong, as they did in this instance, the actions of those involved can look very bad indeed, leading one general involved in the investigation to comment during the release of the : "There were a shocking number of instances where people failed to do their job properly" (Wikipedia, N.D.). But the incident must be seen in the context of the overall operation. It occurred after a three-year period during which 27,000 fixed-wing and 1400 helicopter coalition flights took place in the NFZ without interference from Iraqi aircraft or other military units. The case study simply highlights the ever-present need to attend to the non-technical as well as to the technical aspects of safety-critical jobs.

Summary

NTS are an important component of aviation safety in ABM. ABM is a unique environment and one that is very rarely viewed unless you are employed in a war-fighting role. The opening section of this chapter summarises the human-factors issues relating to the ABM role and identifies particular error vulnerabilities associated with the role.

The case study that follows illustrates in a dramatic fashion how easy it is for things to go wrong in an ABM setting. The errors involved pilots, the ABM crew, and the organisation itself. By contrasting what should have happened (first part of chapter) with what did happen in the case study (second part of chapter), we get a clearer view of the strategies the ABM can employ as individuals and as part of a team to ensure delivery of a safe and effective capability.

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Key points

- ABM is a unique environment with particular human-factors vulnerabilities.
- Scanning, attention, shared mental models, automation management and situation awareness are key NTS skills that support the ABM role.

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CHAPTER 14

NTS considerations for Unmanned Aerial Systems (UAS) operations

Overview:

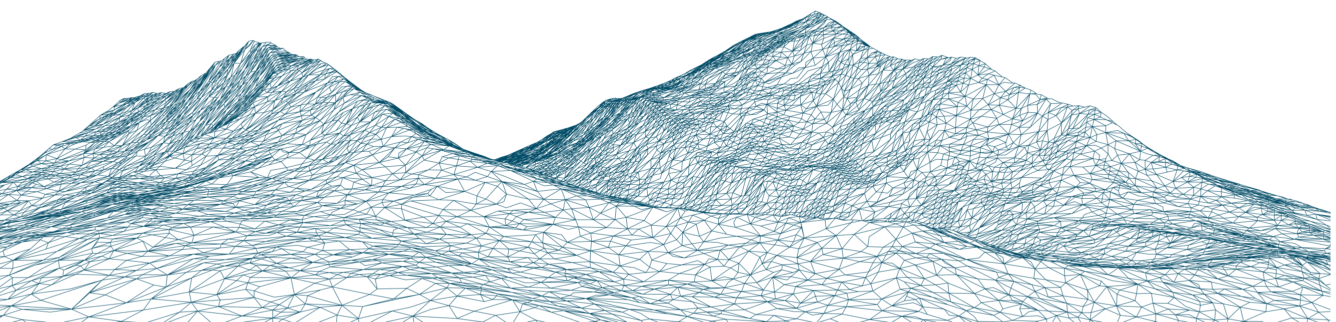
- The different forms unmanned aerial systems (UAS) can take and the associated control systems
- The unique human-factors issues for UAS operations
- Personal, environmental, and operational threats to the safe outcome of UAS missions
- Error-management strategies likely to be effective with UAS operations

Introduction

Unmanned aerial vehicles (UAV) are becoming increasingly complex and are taking on more airborne military tasking than ever before. They provide great flexibility, extended time on task, and reduce the risk of harm to personnel. However, along with these benefits there are also costs. In the United States, 47 military UAVs crashed between 2001 and 2013 in what the military described as Class A accidents, a category involving at least $2 million in damage to the aircraft or other property (Whitlock, 2014).

In Australia, the number of UAS-related civilian safety occurrences reported to the Australian Transport Safety Board (ATSB) increased rapidly during the 2012–2016 period. One half of these occurrences involved near encounters with manned aircraft, almost three-quarters of these occurred between January 2016 and June 2017. The next most common type of occurrence involved collisions with terrain, almost half of which resulted from a loss of control of the UAS (ATSB, 2017).

These statistics, coming as they do in a period when other types of aircraft accidents are becoming much less common, highlight the need to examine technical, regulatory, and human-factors issues surrounding the use of UAS. UAV operators/pilots will encounter many of the same human-factors considerations as manned vehicle operators but there are also some unique challenges. This chapter will discuss the following issues:



- reduced sensory clues, monitoring the command and control (C2) link, time lag between input and response, handling problems, and design problems
- communication and teamwork
- vigilance and workload management
- stressors associated with the UAS role
- error management.

Unique UAS human-factors challenges

Operating a UAV from a distance (teleoperation) introduces a new set of critical variables that must be managed by the operator. Some of these variables are described below.

Reduced sensory clues

As discussed in Chapters 2 and 6 we use environmental cues to make sense of a situation. A common feature of UAS accident investigations is the total surprise expressed by the operators when things suddenly go wrong. UAV operators are remotely located from the vehicle they are controlling, which means that many of the normal cues are not available to help build their situation awareness and to support decision-making.

Operators are not able to hear the aircraft or the sounds around it. If the engine starts missing or cuts out completely, operators may not get the immediate feedback that a pilot would normally receive. They must rely instead upon the electronic systems to warn them of a problem, thus adding to the load carried by the visual system.

The proprioceptors — which provide us with information on body movement including speed, lean, turn, and vibration — are not aligned with what the aircraft is doing, so an operator will not feel an uncommanded turn or even a flip upside down.

Olfactory and tactile cues are also missing. Our sense of smell is typically not highly

> "… thousands of pages of military investigative reports … show a pattern of pilot errors and mechanical failures that have caused drones to crash in the United States again and again — including drones flying in civilian airspace."
>
> (WHITLOCK, 2014)

DEFINITIONS

The terms *remotely piloted aircraft, unmanned aerial systems, unmanned aerial vehicles,* and *drones* are all in common use as descriptors of aerial vehicles that require some degree of remote control. Throughout this chapter, the term *unmanned aerial vehicles* (UAV) will be used to refer to the airborne element of the system and the term *unmanned aircraft system* (UAS) will be used to refer to the entire system, including ground-based components, whether they are manned by a qualified pilot or an operator.

Outside this chapter, it is recognised that in the RAAF the terms *remotely piloted vehicle* (RPV) and *remotely piloted aircraft system* (RPAS) are also used.

Historically within the military the term *drone* was defined as a pilotless, radio-controlled target-towing aircraft. Today *drone* is a popular description used in the media to describe anything that flies without a pilot at the controls of the aircraft, whether continuously controlled by an operator on the ground or capable of flying autonomously.

A *ground control station* (GCS) is the component of the UAS containing the equipment used to control the UAV. A GCS is usually ground-based.

The term *command and control link* (C2) refers to the data link between the UAV and the GCS for the purposes of managing the flight.

Handover is the act of passing operator control from one GCS to another.

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"What if you stepped into your cockpit… and you lost four of your five senses. You only have vision. How can we replace the information?

- you can't hear the engine rpm fluctuating
- you can't feel vibrations, accelerations or motion
- you can't smell the fuel leak
- you can't taste the electrical fire smoke
- and you lose vision in one eye — 30-degree field of view."

(SHIVELY, 2015)

developed but it can tell us whether there is smoke, leaking gas, or excessive friction in our immediate surrounds. Our tactile sense can provide information about heat and vibration. The visual system is under a heavier-than-normal load because the operator is looking through a camera, resulting in monocular vision and a reduced field of view. Monocular vision impedes depth perception.

Without the richness of this sensory information, it is difficult for an operator to maintain awareness of the UAV's state. Even if the information normally provided by our sensory systems is available in electronic form, the lack of immediate sensory cues and the location of the operator remote from the UAV may mean that it takes longer to respond and/or that the severity of the problem is not fully appreciated.

Monitoring the command and control (C2) link

The operator must monitor and manage the C2 link. If the UAV is under direct control, it is essential that the link is maintained at all times. With increasing levels of automation on board the UAV, the importance of the link eases because the UAV can fly unassisted for longer periods. Management and awareness of the link status is particularly critical during control handovers, re-establishing contact when a link has been broken, when operations are being conducted towards the limits of the signal range, and during frequency changes (Shively Hobbs, Lyall & Rorie, 2015).

No C2 link can be guaranteed 100 per cent of the time. Particular care must be taken if a command is likely to produce an unsafe condition if not followed-up with additional commands.

The C2 link is so important that a backup GCS is often established. The location of these backup stations can sometimes create additional problems.

Time lag between input and response

There are various forms of remote control, some involving positioning, others involving continuous control and tracking. UAVs typically involve continuous control and tracking, with the amount of input (continuous versus non-continuous) dependent on the level of automation on board the UAV. A further consideration is that some systems on the UAV may be automated or partially-automated while others are not.

Continuous-control tasks demand short latencies between input and response if high performance standards are to be maintained. Short latencies are dependent on the quality of the data link, the skill level of the operator, and the complexity of the control order. A brief description of the nature of control orders will suffice to show why they are a human-factors consideration.

Control orders involve three levels of complexity, which can be illustrated using examples from everyday life:

- zero order — position control, such as moving a mouse to move a cursor where a change in the position of the mouse results in a change in the position of the cursor
- first order — velocity control, such as depressing the accelerator in a car where a change in pressure results in a new constant speed for the car
- second order — acceleration control, such as a joystick where moving the joystick to a new position causes an accelerating rather than a constant change in the object being controlled.

Zero- and first-order control systems are relatively easy to operate, while second-order systems can be sluggish, unstable, and difficult to handle. Increasing control order causes an increased lag between operator inputs and system responses, even for first-order systems. Turn the wheel of a car and the response is almost immediate. Change the helm of a large ship; however, and it will be some minutes before the ship is on the new course.

Whatever the source of the lag — data link, operator, or control order — systems with longer lags are harder to control because of the cognitive demands required to anticipate where the system will be in the future. Predictor displays help but undershooting and overshooting errors are common, especially among novices.

"I couldn't tell which way it was turning, or if it was straight, if it was upside down, or if it was right side up…. I couldn't grasp what was happening with the aircraft."

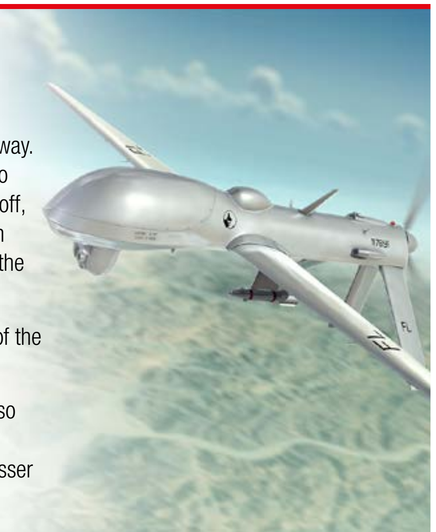
[Predator pilot talking to investigators who were trying to determine how and why the drone was flown upside down before it crashed near Kandahar Air Base on 15 January 2010.] (WHITLOCK, 2014)

In 2010, concerned that a new fleet of Predators might crash into Base housing if they lost their wireless links, the Commanders at Cannon Air Force Base in New Mexico required a backup GCS to be established.

On 28 July, a UAS crew commanded a Predator to taxi towards the runway. As soon as it reached the runway, "the control links sputtered, and video screens in the ground-control station went fuzzy. The Predator zoomed off, even though the pilot had not touched the controls. He pressed a button to slam on the brakes, but the drone did not slow down. It barrelled off the runway and smashed into a fence.." (Whitlock, 2014).

A crew member in the backup GCS had hit a switch and taken control of the Predator without realising the consequence of his actions.

The backup station was programmed to run the throttle at high speed, so the Predator accelerated and crashed. In this instance, the backup RPS took complete control of the UAV but there is always the potential for lesser degrees of interference from other uses of the radio spectrum..



"After departure the unmanned aircraft performed unusually slow rates of turn to the right and tight turns to the left and struggled to track as designated by the operator. Approximately seven minutes into the flight, the outboard section of the right wing separated from the centre wing section. The aircraft immediately entered a rapid clockwise spiral before impacting the ground. The most likely explanation for the crash was that the outboard section of the right wing was incorrectly attached during pre-flight assembly and from launch it flew with difficulty until the wing section eventually separated." (HOBBS, 2010)

Handling problems

Controlling a UAV is a highly skilled task. In addition to the problems caused by lag and limited sensory information, operators must deal with the fact that some inputs are reversed when the UAV is flying towards them. Thus, when the UAV is in sight and is flying away from the operator, a left input will send the UAV left. When the UAV is approaching the operator, the operator must use a right input to send the UAV in that same direction.

Handling problems are not confined to the operators. UAVs have to be maintained. The larger UAVs have dedicated maintenance teams but it is not always clear who should be responsible for the smaller UAVs, some of which are controlled by personal computers. The smaller UAVs are also regularly assembled and disassembled, each operation increasing the chances of an error.

Design problems

There are human-factors principles to guide the design of remote control systems but these principles may not always be followed by the manufacturer. Problems include (Hobbs, 2010):

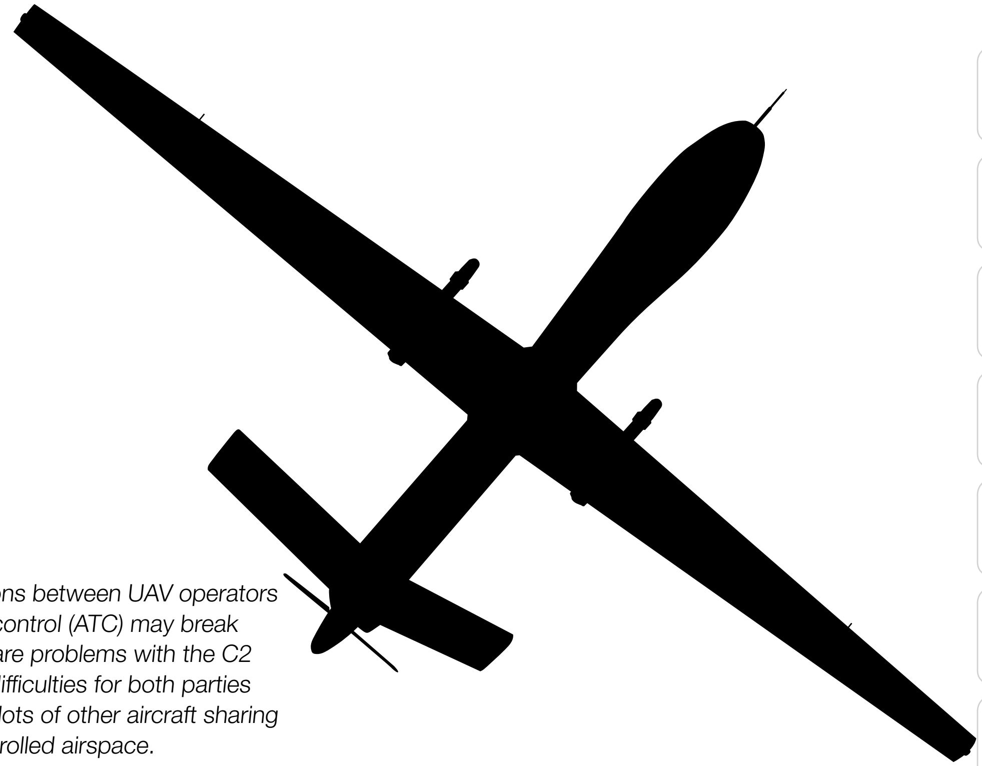
- the use of difficult-to-read colour combinations
- the presentation of large amounts of data in text rather than graphical displays
- the placement of critical controls adjacent to non-critical controls
- non-intuitive automation
- multifunctional controls and displays
- hierarchical menu trees and non-integrated data that overload crew members with raw data and require sustained attention and complex instrument scans

Communication and teamwork challenges

"An irony of 'unmanned' aviation is that even small UAS are typically supported by a team of pilots, sensor operators and support personnel." (Hobbs, 2010)

During ADF UAS operations, it is not unusual to have a team of 12 to 15 personnel supporting the operation. The team will include operators, but also intelligence and analysis personnel who often have limited or no aviation experience. In addition, the team are located in different areas, and may not even have the opportunity to meet in person. Trying to co-ordinate the differing priorities, experience levels and 'languages' can present challenges to the safe and efficient operation of the platform.

Control handovers present a major challenge to communication and teamwork. A handover may occur when an operator takes a break, finishes a shift, or passes control to an operator at a different RPS. "Handovers can be a time of particular risk, associated with system mode errors and co-ordination breakdowns" (Shively, Hobbs, Lyall & Rorie, 2015). The risks are multiplied during this period, especially if the handover involves two stations in different locations or two consoles within the same station.



Communications between UAV operators and air traffic control (ATC) may break down if there are problems with the C2 link, creating difficulties for both parties and also for pilots of other aircraft sharing the same controlled airspace.

Vigilance and workload management

Perhaps more than any other aviation system in military operations, UAV operators are exposed to long periods of low workload, often interrupted by periods of intense activity. Monitoring tasks are not something that humans typically do well.

Sensory-deprivation studies have shown that a person's brain seeks stimulation; they don't like to be inactive, so these long periods of monitoring activity can induce boredom and a lack of engagement.

The problems are magnified if working hours are long and rest periods are short. Fatigue then becomes an issue. For this reason, the crew duty/rest guidelines are consistent with those for pilots.

The periods of high workload can be equally problematic because of the nature of the task. Some of the task features that can create high workload, such as lag and loss of control, have already been discussed. Other features include:

- A lot of task-related information coming through the visual channel, threatening to overload working memory [see Chapter 2].
- Operators often have to work from multiple screens, requiring significant mental integration in working memory to achieve situation awareness.
- A narrow field of view can also restrict situation awareness. UAS operators have reported that they were unaware that their UAS was being targeted by ground fire until fuel was seen to splash on the camera lens (Hobbs, 2010).
- When things go wrong, there may be little time to respond and little cognisance of what went wrong. On 31 August, 2010, in Palmdale California, a $10.3 m reaper crashed on its test flight. About two hours after take-off, the two men in a chase plane saw the Reaper suddenly slow down and go into a spin. It pitched over and corkscrewed into the ground. Investigators concluded that the pilot allowed the UAS to slow down too much and was too narrowly focused to notice that it was about to go into a stall. The pilot testified that that things spiralled out of control so quickly that he did not have time to save the aircraft: "I just couldn't get there in time, not mentally … a few more seconds and it was over." (Whitlock, 2014)

> "A popular saying in the RPAS community is 'This plane was designed by engineers and not pilots!' … one doesn't have to look far to understand that no human-factors engineers were employed during the design phase of development."
>
> (COOKE ET AL., 2017)

Stressors associated with the UAS role

UAS is still an emerging technology and suffers from the same mix of human and technical failures that was evident in the early days of flight. Human-factors considerations are not always paramount and poorly designed interfaces can be a source of stress and higher workload for UAV operators.

The constant flow of new technology, upgrades to existing systems, and the widening range of platforms will be an ongoing source of stress and job dissatisfaction.

Combat stressors can also affect UAS operators, despite the fact they may not be exposed to physical threats themselves. A UAS operator who conducts surveillance before an attack may still feel a strong sense of involvement in the action. A UAS operator who fires a weapon is certainly involved and, unlike fighter pilots and submariners who also fire weapons at a distance, the UAS operator may have been watching the target for some time and will probably have the opportunity to observe the effects of the strike.

Restricted sensory input is a regular feature of the UAS operator's environment and it can become a major stressor when others are dependent on the correct action of the operator, especially in combat situations.

Otherwise, the particular stressors likely to be encountered by a UAV operator depend on the purpose of the mission. Factors such as boredom, additional duties, time pressures, fatigue, and task complexity are encountered in many aviation roles and we have discussed ways of combating such stressors in other chapters.

Error management

The technical skills required to operate a UAV will vary according to the type of UAV and are addressed in formal training programs for pilots, operators, and maintainers. The non-technical skills are the same as those covered in the foundation chapters of this guidebook. They include situation awareness, stress management, fatigue management, workload management, working within your limitations, teamwork, communicating, and making good decisions. Error-management strategies will vary according to the cause of the error but the overall strategy will always be to control the consequences of the errors and to learn from them.

For example, loss of situation awareness is a common complaint in the UAS environment, often caused by a break in the C2 link, which is not the fault of the operator. Failing to take corrective action; however, would be an error. To help regain situation awareness, avoid fixating on one issue and check the whole system for signs of any problems. Do something that will give you time to deal with the problem, like sending the UAV to a higher-altitude if you think the UAV is in danger of hitting the ground [see 'Heron serious incident, Afghanistan 2010']. Improvements in design will also help. For example, lost links may trigger the execution of a pre-programmed procedure, such as a return to the last waypoint at which communication was successful (Hobbs, 2010).

There is no doubt that design improvements will help to reduce errors. For example, mode errors can be reduced by limiting the use of multi-function controls, minimising the number of available modes, and ensuring that the mode status is displayed clearly (Hobbs, 2010). Telecommunications will improve, reducing the threats to C2 links, video technology will improve. However, to some extent these improvements will be offset by the constant push of new technology.

CASE STUDY

Heron serious incident

Afghanistan 2010

The following case study illustrates many of the points made in this chapter.

The A-45 Heron is a medium-altitude long-endurance UAS designed to conduct intelligence, surveillance, reconnaissance and electronic warfare operations. The Heron is a single-engine, pusher-prop, twin-boomed, mid-winged monoplane, normally operated from a GCS by a remote pilot (RP) and payload operator (PO). The workstations consist of commercial computing hardware, bespoke Heron hardware and commercial off-the-shelf infrastructure.

RP are qualified pilots; however, the PO come from a variety of backgrounds and do not all have aviation experience or any cockpit experience. All crews complete ab-initio familiarisation and basic training, and then undergo an operational upgrade program to advance to operational standard. The crew sits side-by-side at their respective stations; however the

Figure 14–1: GCS with pilot box

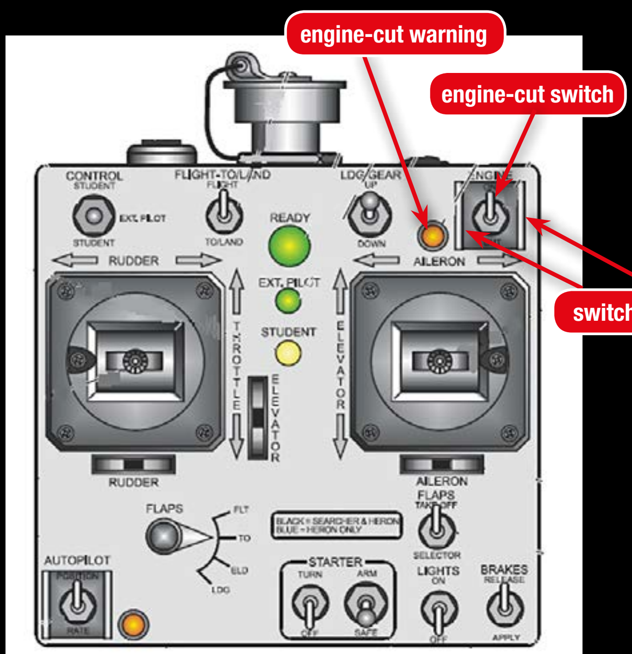


Figure 14–2: Pilot box with engine-cut switch

RP acts as a single pilot for the majority of flying duties with a small amount of cross checking and assistance from the PO.

In June 2010, on completion of operational tasking, the Heron UAV was positioned for a straight-in final with the automated arrival program engaged. Prior to reaching the final approach fix, the automated landing mode was engaged. Immediately, there was an engine-cut warning, and numerous associated alerts and loss of power.

The pilot declared an emergency, and engaged the emergency landing mode. The engine cut occurred at low altitude, and the UAV was not able to make the runway. It impacted the ground and came to rest approximately 1.9 km short of the threshold suffering substantial damage.

Subsequently, the pilot noted the engine-cut switch was in the cut position. There is no reason in normal operations, or the subsequent emergency response, for the switch to be in that position and the pilot did not recall selecting it.

The engine-cut switch is located on the pilot box — a large remote-control box mounted on the console wall to the right of the pilot's head. It is a two-position switch protected by raised metal guards on either side. A warning light illuminates when the switch is in the cut position, but this is obscured from the pilots view by the raised metal guard when in a normal seated position. Immediately to the left of the engine-cut switch is the landing-gear switch. When selecting landing-gear down, and using the thumb and forefinger of the right hand, the engine-cut switch is directly under the knuckles of the right hand. It is possible to inadvertently select cut when selecting landing-gear down.

The investigation determined that it was likely the pilot had done this when preparing for the landing phase.

As a protection measure, the engine cut switch does not activate in some modes of flight, including the arrival mode. It does automatically activate when switching to a mode where it is active, for example the landing mode. While this is an appropriate protection, in this instance, there was a delay between the selection of landing-gear down (and the inadvertent engine cut) and the engine cut activating of three minutes. This in turn made it difficult for the pilot to identify the exact nature of the emergency.

The crew did activate the emergency mode, and carried out all appropriate boldface actions; however, there is no action as part of that to confirm the position of the engine-cut switch. There was no time to conduct the non-boldface or carry out further troubleshooting.

While the investigation concluded that it was likely the pilot had inadvertently selected the engine cut to the cut position when deliberately selecting the landing-gear switch to the down position, it identified a number of human-factors deficiencies in the station and switch design, the training provided by the contractor and the crew procedures.

Key points

- The use of UAVs in military and civil aviation will increase because of advances in automation and teleoperation and the perceived benefits of UAVs.
- To some extent, the technological advances are outstripping the ability to design UAVs according to sound human-factors principles, increasing the chances of errors, incidents, and accidents.
- At this stage of development, many UAS accidents are caused by technical problems, which must be offset by high standards of technical and non-technical training.
- Being aware of human-factors issues in UAV operation and applying human-factors principles in the workplace will help overcome the difficulties associated with the introduction of this still-new technology.

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CHAPTER 15 NTS considerations for engineering and maintenance personnel

Overview:

- Human-factors aspects of maintenance that differentiates it from other work in the aviation field
- Main job demands in Defence aviation maintenance work and the resources available
- How job demands interact with strain and fatigue to influence safety behaviours
- How job resources foster motivation and job satisfaction and help to improve unit performance
- The 12 threats to maintenance performance known as the Dirty Dozen
- How NTS can help to achieve error-avoidance and high performance in maintenance

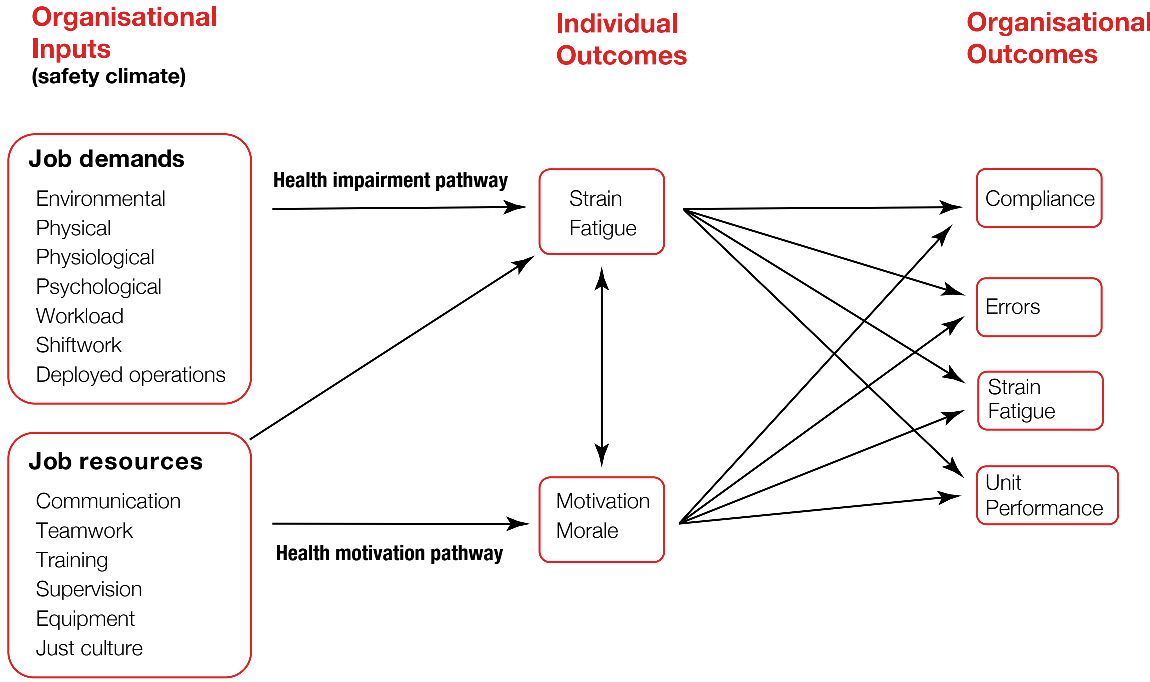


Figure 15–1. The factors that shape maintenance performance

Introduction

Modern aircraft are complex systems. To maintain such systems, the aviation maintainer needs a great deal of technical knowledge and skills. In addition to acquiring mastery of the technical skills, maintainers also need to understand and manage the various non-technical (human-factors) aspects of their work.

This chapter will cover the unique blend of performance-shaping factors that characterise aviation maintenance work by looking at the **demands** of maintenance work, the **resources** maintainers have to deal with these demands, the resulting feelings of **motivation** versus feelings of **strain** and **fatigue**, and the impact of the combination of organisational and individual factors on safety performance. The proposed relationship among these factors — and a guide to the contents of this chapter — is shown in Figure 15–1.

The model shown in Figure 15–1 is based on the Job Demands-Resources model (Bakker & Demerouti, 2007). The model suggests that there are two basic sets of forces acting on the maintainer in a work setting.

The first set is called job demands, and the second set job resources. In essence, job demands put the maintainer under pressure and job resources help them to deal with that pressure.

If high job demands exhaust an individual's mental and physical resources, burnout and lack of commitment may result, leading to violations, errors, reluctance to report errors, and poor performance. This train of events is called the health impairment pathway. If, on the other hand, resources enable the maintainer to cope with demands, positive organisational outcomes such as motivation, engagement, and job satisfaction are likely to follow. This chapter highlights some of the factors that can lead a maintainer down one pathway or the other.

Job demands

Environmental
Physical
Physiological
Psychological
Workload
Shiftwork
Deployed operations

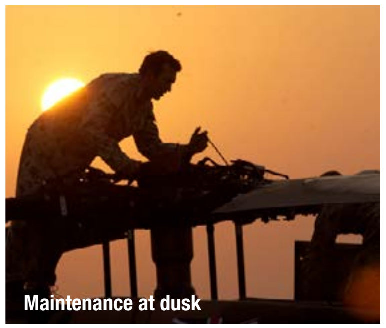


Figure 15–2. Maintenance in different environmental conditions

Job demands for a maintainer

Environmental

A maintainer can expect to work in a range of environments, from line, ship, and field operations (generally outside the hangar), to base maintenance (usually inside a hangar or workshop), in all types of climatic conditions, day and night. Some environmental conditions — especially extreme heat or cold, poor visibility, wind and rain — impose additional demands on maintenance work. If a maintainer is thinking about physical comfort, there are fewer attentional resources to devote to the task.

Physical

Physical demands include working in confined spaces, exposure to fumes, and vibration. Regarding the first of these, confined spaces may reduce effectiveness and increase the risk of error because of reduced dexterity, limited tooling due to space constraints, and limited visibility of components (Figure 15–2). If the space is completely enclosed, some maintainers could begin to feel claustrophobic, with resulting feelings of panic. Working in confined spaces requires dexterity and flexibility as, among other things, tools can be difficult to use (Figure 15–3). To avoid this situation, maintainers faced with this sort of physical demand must be authorised to work in confined spaces.

Sometimes a maintainer has to deal with a combination of environmental and physical factors, such as working in the tropics in a ship-based hangar.

Every effort is made within Defence aviation to protect personnel from chemical hazards but fumes still represent another potential physical challenge for maintainers. Fumes are not always detectable and can affect lungs, eyes, and skin, cause nausea, dizziness, and headaches — with consequent pressure on performance.

A third source of physical demands for maintainers working with larger tools is vibration. Prolonged use of such tools can lead to repetitive strain injury (RSI) or Hand Arm Vibration (HAV). Tasks that require constant use of the same muscle group (for example, winding a crank handle) can lead to the same injury. Any degree of RSI/HAV can affect concentration and impair performance.

"38 to 40 degrees inside the hangar, working in overalls. It was incredibly hot and tiring. Inside the aircraft we were working in a dark cramped space in hot overalls in blazing hot temperatures doing a hard job under time pressure. For the broom closet, we had to use a torch to see. It's a very cramped space. Working in 40-degrees in overalls is not exactly comfortable on a 12-hour shift with broken sleep patterns due to noise on board. It is a challenging work environment."

MAINTENANCE CREW MEMBER DESCRIBING WORKING CONDITIONS ON BOARD HMAS *KANIMBLA* (DEPARTMENT OF DEFENCE, 2007, P.4).

Physiological

Physiological demands — ignoring those due to personal and lifestyle factors — include visual and auditory challenges. The visual challenges include working in poorly-lit areas [see Figure 15–4] and working in conditions where there is so much light that glare becomes a problem. These visual demands pose a particular problem when conducting inspections of aircraft components for signs of fatigue and wear.

Noise from engines and tools is something you expect to experience in a maintenance workshop and can be managed using the recommended communication headsets. However, auditory protection can come at a cost if the maintainer does not make an extra effort to communicate with co-workers and to observe what is happening in the immediate surrounds. Situation awareness can be lost when the brain is missing the 360-degree sensory coverage provided by our auditory system.

Figure 15–3. Working in confined spaces requires dexterity and flexibility as, among other things, tools are difficult to use

Psychological

Psychological stressors include a very broad range of factors such as workload, time pressures, interpersonal conflict, lack of confidence, self-doubt, and anxiety. These stressors are not a problem in themselves; however, if the maintainer is not able to cope with them they can trigger a stress response (also called strain). Psychological stressors are not confined to the workplace. Financial worries, family problems, and a host of other external factors can occupy the maintainer's mind and distract him or her from a task.

A particular psychological stressor for maintainers is the thought that something they may have done (or not done) could be the cause of someone else's injury or death. This thought is not a trivial burden. It is shared by members of other professions — such as police, doctors, and nurses — who deal with it by focusing on professionalism and collegial support. More information on managing stress can be found in Chapter 8.

Figure 15–4. Challenges posed by low illumination

Workload

The effects of high (and low) workload have already been described in Chapter 8. For the maintainer, workload is heavily dependent on the amount of flying being conducted. It tends to be greatest during exercises and deployments. The ratios vary according to the type of aircraft being maintained but it is true for all types that for every hour or flying there are many more hours of maintenance. Workload — usually measured in terms of hours worked per day, week, month, and year — is a major source of strain and fatigue.

The other side of this picture is the amount of time allowed for rest after subtracting hours worked, time allowed for personal care, and commuting. Stipulating maximum duty periods (12 to 14 hours) and minimum rest periods (10 hours) serves as the basis for the management of fatigue-related risk within Defence aviation. Fatigue risk-management processes are used to manage the implementation of necessary risk controls and assign responsibilities for their ongoing monitoring and management. The increased reliance on risk management is designed to achieve benefits in safety as well as, where appropriate, provide greater operational flexibility to commanders.

Shiftwork

Shiftwork is part of the job for many aviation technicians. Late night and early morning work is a problem for most people because it requires overriding our natural body clocks. The result is usually less sleep and greater fatigue. In a 2011 survey of RAAF personnel, 45 per cent of the maintainers and 21.5 per cent of aircrew listed shiftwork as a major cause of fatigue. The difference in percentages reflects the larger proportion of maintainers involved in shiftwork.

Injuries and errors are more common among shiftworkers. In Defence aviation, the risk of maintenance error increases from morning to afternoon to night watch, and as the requirement for successive night watches is sustained (Murphy & Worboys, 2005).

In the wider community, a national survey administered by Safe Work Australia in 2013–14 found that although shiftworkers accounted for only 16 per cent of hours worked, they accounted for 30 per cent of injured workers (Safe Work Australia, 2016).

The ADF has a responsibility to ensure that its shift scheduling practices, workplace conditions, and nature of the work do not generate insupportable levels of fatigue. The individual maintainer, on the other hand, is responsible for good self-care practices that protect the hours available for sleep. More information on fatigue and sleep hygiene is available in Chapter 9.

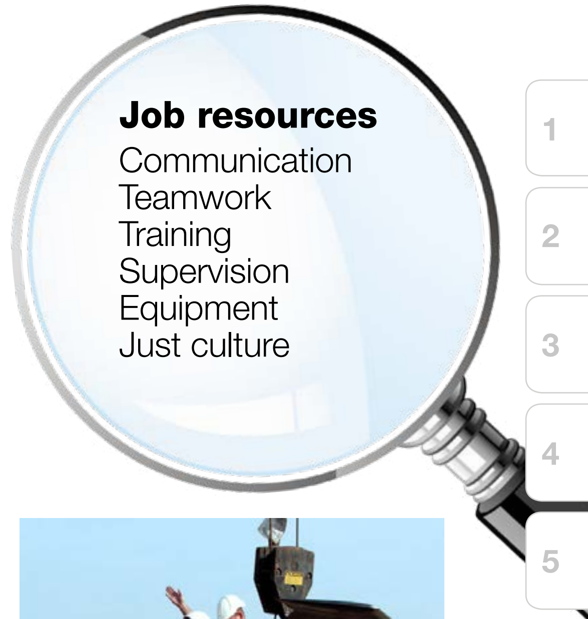
Deployed operations

Deployed operations bring with them a number of unique challenges.

- Safety challenges include the environment (heat, dust, visibility), mental and physical fatigue, and difficulties with logistics and spares support. Components that worked well in Australian conditions might not work so well in the deployed environment.
- Combined and joint operations safety challenges include different equipment and aircraft, different operational standards, different levels of training and experience, and communication difficulties.
- Workload challenges include faster operational tempo, longer shifts, greater administrative load, and an extended logistics support chain. Personnel-management challenges include the relatively low experience levels, supervision and mentoring difficulties, and time away from home and families.

DEFENCE SAFETY MANUAL

Defence has developed work health and safety policies, standards and procedures to reduce risks arising from the work environment and the way activities are performed. *The Defence Safety Manual* (SafetyMan) describes Defence hazard types and required management strategies. For more information see the Defence Work Health and Safety website on the Defence intranet.



Job resources for maintainers

To offset the many demands of maintenance work, there are various resources to draw upon in the work environment.

Communication

The principles and advantages of good communication processes were covered in Chapter 7. In the 2017 *Snapshot* data (N = 12,110), there was a strong positive relationship between communication and job satisfaction, indicating that, despite the demands of maintainer work, personnel felt satisfied with the job if there was a good communication flow:

- across the different sections and workgroups
- between workers and supervisors
- up and down the chain of command
- within their teams.

Teamwork

Chapter 10 emphasised the advantages of good teamwork. Teamwork is essential for good performance in maintenance:

- team members bring different skills to the task (for example, electronic versus mechanical)
- co-operation is needed for some tasks
- work must always be checked by others.

Training

Training is not the answer to every challenge but an expert can generally do a job faster and better than a novice. The expert can do this because he or she has had more training (formal and on-the-job), more experience, and consequently has better technical knowledge of the complex systems being maintained. Defence aviation *Snapshot* data shows that maintainers who feel that their training has prepared them well for their current duties are more likely to feel satisfied with their work, to comply with standards specified in formal instructions, and to make fewer

Figure 15–5. Teamwork in maintenance

errors. The aviation industry knows from bitter experience that training is more likely to achieve these outcomes when it includes non-technical, and technical, skills.

Supervision

Historically, ADF maintenance work has suffered when there has been a shortage of supervisors or when personnel have been promoted too quickly to supervisor level. Supervisors set the standards for the team, they provide (or obtain) knowledge when it is lacking, and they are responsible for ensuring the quality of work completed by the team.

It is an unfortunate fact that too often the term 'supervision' is heard in the context of incident and accident investigations where poor supervision has been a contributing factor. Our annual *Snapshot* surveys reveal that close to 80 per cent of maintainers agree that their supervisors are providing the help and support they need.

Equipment

Maintenance work on complex systems requires the use of correct tools and equipment, which must be readily available. Although we list equipment here as a resource for self-evident reasons, the availability of tools and equipment is not something that a maintainer can always control. The use of correct tools and equipment is a different matter and will be covered in the sections on compliance and the Dirty Dozen.

Just culture

A just and fair culture exists when maintainers can work without fear of negative consequences for themselves when they make errors. It does not; however, absolve individuals and supervisors of their normal responsibilities. Individuals are held accountable for their actions, omissions, or decisions, but the organisation must consider if the actions are commensurate with an individual's experience and training. In the 2017 *Snapshot*, three-quarters of the maintenance workforce felt that:

- the emphasis was on learning from honest mistakes rather than apportioning blame
- they could report safety discrepancies without fear of negative consequences
- when they reported their own errors they would be treated fairly.

Just culture is a resource because it encourages the maintainer to strive for high performance rather than trying to avoid failure. In ADF data, it is positively associated with morale, job satisfaction, and unit performance and negatively associated with psychological distress (strain). More information on culture is in Chapter 4.

Individual outcomes: The health impairment pathway

Individual outcomes are important because it is primarily through them that job demands and job resources influence organisational outcomes. For example, on the health impairment pathway, long work hours can increase fatigue, which then leads to errors; andon the motivation pathway, the availability of resources strengthens motivation and morale, which then affects work performance.

Strain

ADF data tells us that the biggest workplace driver of strain for maintainers is role overload — having too many things to do. This situation can arise during peak periods, especially during exercises and deployments. The Sea King BOI findings, for example, noted that: "Quality of maintenance supervision is being compromised by Aircraft Maintenance Documentation workloads of the Maintenance Manager" (Department of Defence, 2007, p.9). It is often the additional duties that lead to feelings of strain.

Other sources of strain include the remaining factors listed under job demands, plus the usual workplace and garrison hassles that are part of military life (for example, changes to schedule). Job resources reduce the effects of job demands on strain.

Fatigue

Fatigue is driven by all of the demands listed above, but particularly workload and shiftwork, both of which can influence the amount of sleep opportunities available to the maintainer. The effects of fatigue will be discussed in the section on the Dirty Dozen.

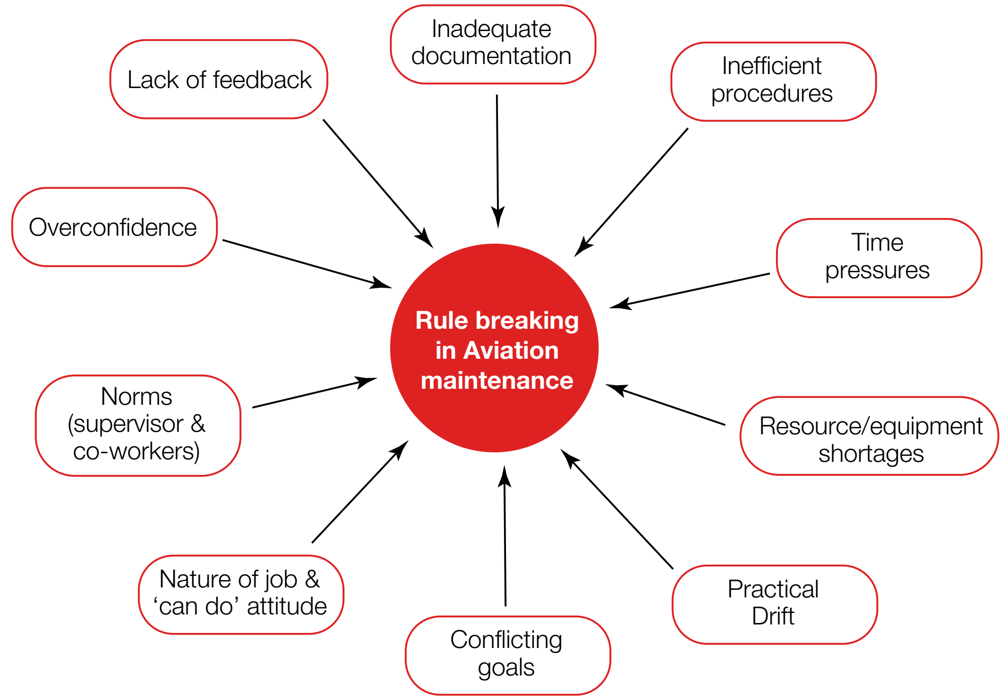
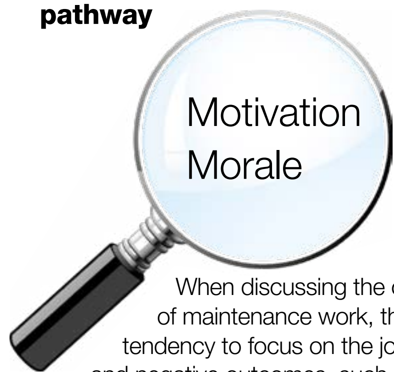


Figure 15–6. The rule-breaking network in aviation maintenance (Fogarty, Murphy, Cooper & McMahon, 2016)

Individual outcomes: The motivation pathway



When discussing the conditions of maintenance work, there is a tendency to focus on the job demands and negative outcomes, such as violations and errors. However, there is merit in looking at the positive side of the equation too. A maintainer workforce that is motivated and has high morale is more likely to comply with procedures, to make fewer errors, to report those errors, and to focus on performance. Resource availability is a major driver of motivation and morale.

Safety behaviours: Compliance

The goal of maintenance is to keep aircraft systems in optimum working order using approved procedures that protect the safety and wellbeing of maintainers and aircrew. Two major threats to this goal are violations and errors.

Compliance, which means following approved procedures at all times, covers all aspects of the work: authorisations, correct tools, correct techniques, correct use of checkpoints, correct logging, and sign-offs. Compliance is extremely important because it improves the chances of error-free performance and safe outcomes.

We know from Defence aviation survey and incident data that maintainers do not always follow rules, despite constant urgings to do so. The diagram in Figure 15–1 suggests that compliance will decrease as demands increase and resources decrease. Defence aviation data support that view. On the basis of Defence aviation safety surveys, we can summarise the causes of rule-breaking behaviour as inadequate documentation, belief that the approved procedure or process is inefficient, time pressure to complete a task, lack of proper equipment, conflicting goals, group norms that favour shortcuts, the nature of the maintenance job, overconfidence, and lack of documentation [see Figure 15–6].

The 10 reasons shown in Figure 15–6 will be covered in in this chapter under Dirty Dozen. For further reading, see Fogarty, Murphy, Cooper, and McMahon (2016).

Safety behaviours: Errors

Chapter 3 covers the basics of error management, so it will suffice here to note the most common types of errors made by maintainers and the top five reasons they give for making these errors.

Here is the ranking of 10 common errors from 1750 Defence aviation maintainers obtained in 2014. The errors are not ranked because the more common procedures offer more opportunities for errors.

1	I have failed to detect a fault when completing a visual inspection
2	I have had difficulty with a task because I misunderstood how a particular aircraft system worked
3	I have resumed at the wrong place when returning to a task after an interruption
4	I have missed out a step(s) in a maintenance task
5	I have lost a component part way through a job
6	I have installed a part the wrong way
7	I have fitted/applied an incorrect component/consumable to the aircraft
8	I have refitted an aircraft panel incorrectly after a task
9	I have forgotten to check that all steps in a procedure were completed
10	I left a tool or some other item in the aircraft/system.

Errors in maintenance

Aircraft maintenance has unique characteristics, which make error management particularly difficult:

- Errors may be buried deep inside aircraft systems. Once maintenance is complete and the aircraft is returned to service, the chances of detecting the error before the next scheduled maintenance may be slight.
- Errors can lie dormant for months, or even years, before causing a problem. A loosely-secured nut may take months to vibrate free, and a fatigue crack caused by improper maintenance may grow slowly over years.

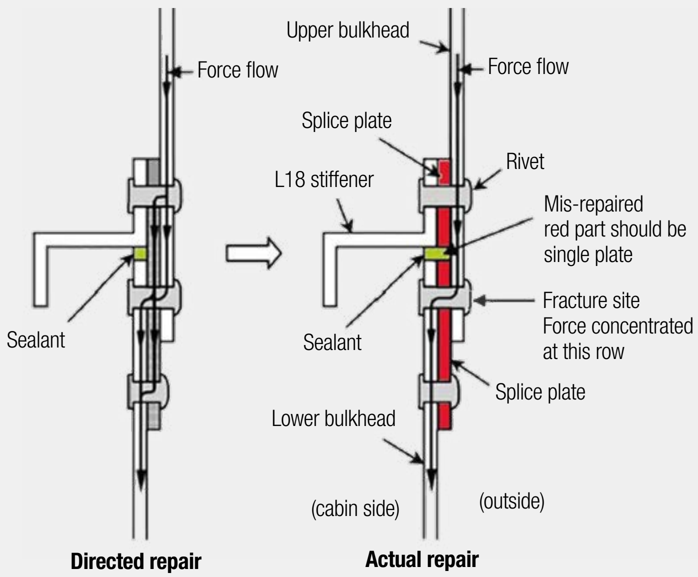


Figure 15–7. Rear pressure bulkhead repair

The world's worst aviation accident involving a single aircraft occurred to a Boeing 747 that had undergone major repairs to its rear pressure bulkhead seven years before the eventual accident. The repair, shown in Figure 15–7, had involved replacing the lower half of the bulkhead, and it should have been spliced to the upper half using a single doubler plate extending under three lines of rivets. For reasons unknown, part of the splice was made using two doubler plates, as shown in the figure above. As a result, the join relied on a single row of rivets. A fatigue facture developed that eventually caused a catastrophic failure of the rear pressure bulkhead. The resulting damage made the aircraft uncontrollable.

Source: CASA *Human Factors Resource Guide for Engineers*

And here are the top five reasons maintainers offer for making errors:

1	too many things to do
2	distractions/interruptions
3	time pressure
4	tiredness
5	stress.

Again, all five of these reasons will be covered in the Dirty Dozen section of this chapter. More information on error, violation and management strategies can be found in Chapter 3.

Safety behaviours: Incident reporting

Errors are accepted as a natural part of maintenance work but every attempt is made to eliminate them as far as possible [see Chapter 3]. One of the strategies involves reporting by maintainers of any errors they make. The underlying assumption is that for every accident, there is a much greater number of incidents, and for every incident, there is a much greater number of errors. If we can gather data on errors, we can learn a lot about accident prevention without having to wait until an accident has occurred.

The measure of success for incident reporting is the proportion of errors self-reported.

Unfortunately, we will never know that number because we will never know how many errors actually occur. We can; however, address the problem of non-reporting by establishing a just culture and finding out what the barriers to reporting are. In the 2015 *Snapshot*, we collected data on the barriers. The most popular reasons are shown below:

1	Reporting safety concerns creates additional workload.
2	The reporting process is too time consuming.
3	The reporting process is more complicated than it needs to be.
4	There is no feedback on what action is taken.
5	Reporting safety concerns interferes with our real work.
6	Mistakes are often held against you.
7	Safety reporting is unlikely to lead to system changes.
8	There is no benefit in reporting a safety occurrence/event that does not result in a negative outcome.
9	There are too many minor safety occurrences/events to report them all
10	People who report safety concerns are viewed as a nuisance.

Reason's study of aviation maintenance engineering

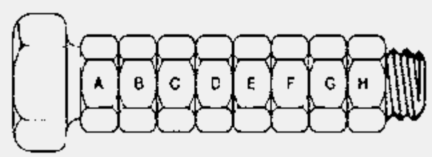


Figure 15–8. Reason's nuts and bolt example

James Reason identified the main causes of maintenance error as being:

- omissions (56 per cent)
- incorrect installation (30 per cent)
- wrong parts (8 per cent)
- other (6 per cent).

It is likely that Reason's findings are representative of the aircraft maintenance industry as a whole. Omissions can occur for a variety of reasons, such as forgetting, deviation from a procedure (accidental or deliberate), or due to distraction. Incorrect installation is unsurprising, as there is usually only one way in which something can be taken apart but many possible ways in which it can be reassembled. Reason illustrates this with a simple example of a bolt and several nuts [see Figure 15–8]. A bolt fitted with eight nuts can only be disassembled one way, but there are more than 40,000 ways in which it can be reassembled incorrectly. Consider how many more error opportunities the average general aviation aircraft presents.

It is encouraging to see that four out of the five most popular reasons concerned time and workload issues (job demands), rather than reluctance to disclose. Just culture was assessed by the item 'Mistakes are held against you'. Its position at number six suggests that Defence aviation still has some way to go before maintainers feel completely comfortable admitting their errors.

Unit performance

When training in human factors became popular back in the 1980s and 1990s, accidents were more frequent than they are now. The picture is much the same in commercial aviation. The year 2010 marked the first year in the history of European aviation that no fatal commercial air transport incidents occurred. The twin strategies of error management and building safety culture have played a big part in aviation's improved safety record. The marked decrease in fatal accidents has given us time to catch our collective breaths and to look at what else we should be doing to improve aviation safety. Non-technical skills training encourages us to consider an approach that looks at high performance as well as avoiding failure. Our goal must be to perform at such a high standard that the chances of failure are minimised. We can do that by avoiding the main error traps — the Dirty Dozen — and by being professional.

The Dirty Dozen

A series of worldwide maintenance-related incidents in the 1980s and 1990s led to the development of the Dirty Dozen — a set of 12 human factors that impair performance in the maintenance environment and have the potential to endanger the lives of fellow workers, passengers, and aircrew. Some of these factors cut right across other topics already covered in this chapter but, with the Dirty Dozen, the focus is on a single aspect of the factor and its negative consequences.

Lack of communication

Communication has already been discussed in this chapter as a job resource. However, there are weak points in the communication chain that can contribute directly to errors and accidents. Shift handovers are a time of particular vulnerability and they are an important part of maintenance. The incoming technician may not be able to see the parts of the job that have been completed because they are now hidden.

It is imperative that the outgoing technician gives a complete and accurate description of work completed, work remaining to be done, and a briefing on any anticipated problems. The absence of either a written or oral handover briefing increases the risk of some operations not being performed or being performed incorrectly.

Complacency (and overconfidence)

As we progress from the novice to expert stage of any established task, the amount of cognitive effort required decreases to the point where performance becomes automatic. Driving a car is a classic example. When we first start learning to drive, the task requires a great deal of concentration and cognitive effort. With practice and instruction, the task becomes so easy that under normal driving conditions we may have to force ourselves to pay attention. Maintenance work is no different. When a task has been performed so many times that a maintainer feels he or she "could do it asleep", overconfidence may lead to complacency, a feeling of self-satisfaction with the work.

Overconfidence and complacency go hand-in-hand and both should be avoided. They can lead to practical drift, which is a gradual but continuous deviation from approved procedures that is so mild that it goes unnoticed until something goes wrong. They can also lead to work not being completed. A repetitive task, especially an inspection task, may not be given enough attention — or even skipped — because the technician has performed the task many times without finding a fault and does not expect to find one now. The key to combating complacency is to devote sufficient attention to even well-learned tasks, to follow procedures, and to expect faults in the materials being inspected.

Managing task handover, pre-task briefings and task changes

Task briefings

Task briefings can help to make sure all members of a team are ready to work together. Pre-task briefings are standard practice for surgeons and pilots, and should be for maintenance personnel as well.

Pre-task briefing

- What's the objective of the task?
- How will it be carried out?
- What equipment will be used?
- Does each person have a clearly assigned role?
- What could go wrong — what are the risks?

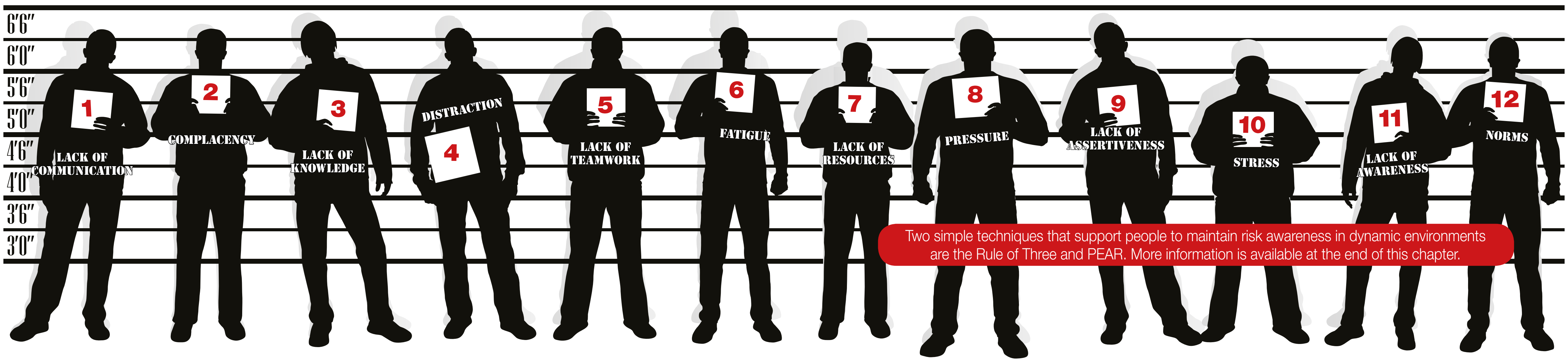
Briefing during the task

- Critique and update existing plans
- Evaluate results of previous decisions
- Inform crew of changes in task

Post-task debrief

- Critique entire task
- Give all crew a chance to comment
- Feedback to crew members
- Identify areas for improvement

Source: CASA *Human Factors Resource Guide for Engineers*



Two simple techniques that support people to maintain risk awareness in dynamic environments are the Rule of Three and PEAR. More information is available at the end of this chapter.

Lack of knowledge

Technical training, both on-the-job and formal, is designed to keep ahead of maintainers' needs and is therefore a resource, but training cannot cover everything. New aircraft types, new procedures, and staff shortages may take workers into areas where they do not feel comfortable.

In the 2017 *Snapshot* survey, 27 per cent of maintainers (N = 2718) indicated that insufficient training negatively impacted the performance of their unit. In the 2016 *Snapshot* survey, 18 per cent of the maintainers (N = 2507) indicated that lack of knowledge sometimes caused them to make errors (the item was not included in the 2017 *Snapshot*). It is almost inevitable that maintainers will find themselves in situations where they lack knowledge, and that should not be a concern. The factor earns its place in the Dirty Dozen because maintainers do not always seek assistance when they lack knowledge. Planning, briefing and tools like the Rule of Three support maintainers in understanding their role and task.

Distraction

Interruptions are a major source of distraction. A colleague asks a question, something happens in the workshop, the supervisor temporarily assigns a worker to another task; these are all external interruptions. Maintainers can be distracted by their own thoughts about non-work issues.

"Sometimes we do not have the right tools for the job as it states in the publication and we can flag these problems and we can notify the people that we do not have the correct tooling, but to order a tool in would take months, and the jobs go on, and then that just becomes part of the workplace culture."

MAINTAINER ON BOARD HMAS *KANIMBLA*
(DEPARTMENT OF DEFENCE, 2007, P. 11)

In *Snapshot* surveys conducted over the past five years, maintainers have consistently ranked distractions among the top three causes of error.

Lack of teamwork

In modern aircraft, it is likely that the expertise to maintain a complex system is distributed among individual maintainers with different levels of experience, training, role specialties, and responsibilities. Aviation maintainers need to function as a team to achieve their goals. Teamwork is covered in detail in Chapter 10. There are few, if any, aspects of teamwork that are unique to the maintenance role.

Fatigue

Fatigue is a major human factor that has contributed to many maintenance errors resulting in accidents. Fatigue is driven by job demands, especially hours worked and hours available for recovery. It is also affected by lifestyle factors, which can reduce the amount of time available for recovery; hence the requirement that personnel should arrive at work in a fit state. Figure 15–9 is based on Folkhard's (2001) work with aviation maintenance engineers. It illustrates how the mean relative risk of making errors at work increases dramatically after eight hours on duty irrespective of the time of day. For example, 10-hour shifts lead to an 11.6 per cent increase in errors compared to eight-hour shifts; while 12-hour shifts have a 27.6 per cent increase in errors.

Although regulations governing hours of service still rely on a model that assumes the length of work time is the factor most relevant to fatigue, this is only one component of the relationship of fatigue to risk. Other factors include the time of day work occurs, the volume and intensity of work, and the amount and quality of sleep obtained. A major influence on amount and quality of sleep is the period allowed for rest between shifts.

Lack of resources

To do their work properly, maintainers need access to the correct parts, tools, and manuals. When they have that access, tools and equipment counts as a resource rather than a job demand, and when that access is partially lacking, it can become a job demand. Problems occur when maintainers start using their own tools and writing out their own versions of procedures.

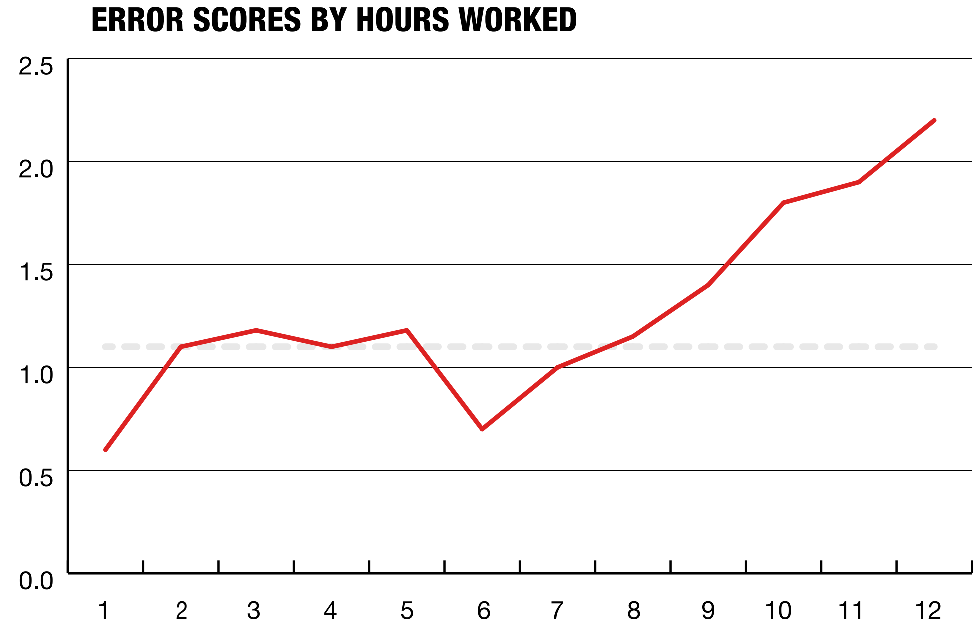


Figure 15–9. Relationship between hours worked and number of errors (Folkhard, 2001)

In the 2017 *Snapshot* survey, 18 per cent of the maintainers indicated that they made errors because they didn't have the right equipment or tools. The consequences of not using the right tools or parts are not always immediately apparent. It can take years for a defective maintenance procedure to have a negative effect on aircraft performance. [See 'Errors in Maintenance']. The Japan Airlines Boeing 747 accident cost 520 lives and was caused by an improvised repair procedure that overcame difficulties maintainers were having fitting a part (FAA, n.d.).

The problem with the practice of using the wrong tools, parts, or equipment is that the "solution" usually appears to work, often for a long time, perhaps for the life of the component or aircraft. It is natural to take corrective action when we see that something is wrong. If we can't see anything wrong, there is nothing in the situation itself that impels us to change our behaviour.

The key to behaviour change is to go beyond our own limited experiences and draw upon the collective experience and wisdom of the industry, which teaches us that the approved parts, tools, equipment and procedures are considered to be the most reliable methods for achieving high-quality maintenance. Japan Airlines Boeing 747 is just one of many documented instances of major accidents that were due to improvised procedures. The ADF has had its own share of problems in this area. The Board of Enquiry (BOI) report on the 2005 Sea King disaster was critical of what appeared to be an accepted practice of using the wrong tools for some tasks.

Pressure

In annual *Snapshot* surveys, time pressure is consistently rated among the top three causes of error by ADF maintainers with over 43 per cent (2015), 36 per cent (2016), and 25 per cent (2017) indicating that they sometimes or often make errors because of time pressure. The pressure is a permanent aspect of the job but it fluctuates depending on how much flying activity is occurring at the time. Pressure is greater immediately before and immediately after exercises, and while on deployment. Maintenance takes time, particularly deeper level maintenance, and pilots require aircraft to be available.

Subsidiary findings of the Inquiry into the 1996 Townsville Army Blackhawk accident indicated that high maintenance workload and pressure to get aircraft onto the flightline led to short cuts; although maintenance problems were not identified as a cause of this crash.

Most high-risk industries experience this sort of pressure and it is often referred to as the clash between production and safety goals. In maintenance, the production goal is to have aircraft online as quickly as possible while the safety goal is to make sure that the maintenance is carried out to the highest possible standard, which may mean keeping the aircraft in the workshop for a longer period.

Attempts to achieve a compromise between these competing goals are usually unsuccessful because they involve some form of violation. Consider a scenario where two aircraft of the same type are in the workshop. One aircraft can be returned to the line reasonably quickly if a component (call it Part A) is replaced but the workshop discovers that there will be a considerable delay obtaining that component.

The other aircraft needs a major overhaul and will be out of action for at least a month but its Part A component is in good order and there is pressure to get the first aircraft back to the line. Satisfying the production goal would involve "cannibalising" the second aircraft so that Part A can be put into the first aircraft. Satisfying the safety goal would mean avoiding the doubling-up of maintenance tasks (hence increased risk) that cannibalising requires.

Some experts in the field now judge the safety status of an organisation by the relative emphasis they place on these two competing goals: safety versus production.

Lack of assertiveness

The pressures discussed in the section immediately above relate to workload and conflicting goals. The other kind of pressure that maintainers are likely to experience is pressure to conform with group norms, to do as others are doing around them, even if that means cutting corners, using incorrect tools, or other forms of violating behaviour. The Sea King BOI drew attention to a common form of this type of pressure when it talked about the influence of older maintainers on younger maintainers. It used the term "father-to-son" mentality to describe the situation whereby the incoming maintainers were encouraged to model the behaviour of the more experienced group members, rather than follow the strict procedural guidelines outlined in the official publications.

Maintainers, whether they are new or experienced, should challenge any practices that do not conform with the written documentation. Assertiveness should come not only from team leaders [see Chapter 10] but also from members.

Stress

Over many years, research with Defence aviation personnel has shown that stress, alongside fatigue, is one of the major causes of errors (Fogarty, 2005). Aside from the issue of making errors, it is difficult to perform well when you are stressed or fatigued. The stressors likely to be encountered in maintenance work can be grouped under three headings: physical, psychological, and physiological. This is discussed in the Job Demands section. More information on stress and stress management can be found in Chapter 8.

Lack of awareness

Situation awareness, which has been covered in Chapter 6, is just as relevant for maintainers as it is for aircrew. Maintainers need to be aware of what is happening around them, they have to understand the implications of what is happening, and they certainly need to be capable of projecting the consequences of current events. The element of projection is arguably the most important of the three for maintainers because everything they do is a preparation for future flights. The strongest motivation for doing one's job well is the thought that someone else's life is totally dependent on the quality of one's work. A lack of any one of these three aspects of awareness is a serious deficiency in a maintainer.

Norms

The term "norms" is a short way of saying "the way things are done around here". They are informal rules, procedures, and attitudes. The source of these norms is likely to include supervisors and co-workers who are closely associated with the individual, especially senior colleagues.

We have already discussed the Sea King BOI's criticism of the father-to-son mentality among some maintenance groups whereby the newer members of the group took their lead from the older members instead of the formal written procedures. Newer members are more likely to do this when there is an element of ambiguity in the situation, a possibility that the unofficial way of doing things might be just as good as the official way, and certainly quicker. As we discussed earlier, it takes a lot of assertiveness for a newcomer to challenge the norms of a group.

Perhaps the biggest single factor in the development of norms is an unconscious, gradual movement away from written procedures over time, a phenomenon called "practical drift" or "drift into failure" (Dekker, 2005). Practical drift is the slow, incremental movement of systems operations towards the edge of the safety envelope. When change occurs incrementally, it rarely attracts attention. If a small step away from written procedure appears to work and to be more efficient, it is not long before that change is considered "normal operations".

This new, unwritten, standard then becomes the stepping-stone for further incremental changes. To an outsider — or a newcomer to the group — looking at the gap between actual and ideal practice, the deviation from approved procedures appears reckless and culpable. To an insider, the gap may have opened so slowly that it was not even noticed.

Supervisors need to demonstrate that they do not tolerate unsafe norms. If supervisors model the unsafe behaviours themselves or "turn a blind eye to them", there is little prospect of changing violation practices in the group.

Professionalism

When discussing unit performance, the point was made that maintenance work is not exclusively about avoiding errors. It is also about achieving high standards of performance.

Fear of failure is certainly a motivator and a very useful one in some situations but it will not carry a person to the top of his or her chosen career. Need for achievement is a stronger motivator for that purpose. The fact is, Defence aviation needs maintainers to have both kinds of motivation. It needs maintainers who never lose their appreciation of the importance of working safely and it needs these same maintainers to be dedicated professionals, always interested in continuous improvement.

PROFESSIONALISM

Professionalism describes the specialist skills, personal feelings and attitude to the work you do. It's what takes you from technically proficient to a high performer, it's your understanding of the wider system, your non-technical skills, and your willingness to put the safety and airworthiness of an aircraft before all else.

Professionals in aviation maintenance are recognised as having three essential characteristics:

- expert knowledge (as distinguished from a practical skill)
- self-control or self-regulation
- a willingness to take responsibility for placing the safety and airworthiness needs of the organisation ahead of individual self-interest.

- **Expert knowledge** comes from experience developed over time, especially when that experience concentrates on particular product types such as specific airframes and components.
- **Self-regulation** is based on beliefs, pride and enthusiasm, with individuals making conscious decisions based on the goals of airworthiness and safety.

Finally, aviation maintenance professionalism comprises those demonstrated practices, education, ethics, and values that sustain the interests of safety above your own self interest.

Developing professionalism

Your professionalism will be influenced by your training, your role models and the organisational culture, but your biggest influence is you.

Professionalism requires a dedication to continuous improvement, and can be practiced and reinforced every day. Some things to consider...

- **Your personal standards.** How you treat yourself, how you treat others, how you behave and how you perform your work. Professionals have attention to detail, adhere to procedure and complete tasks properly.
- **Integrity.** Even if there are resource or time constraints, or others in the organisation are not adhering to procedures, a professional does things correctly. This promotes resistance to at-risk behaviours.
- **Currency.** Defence aviation can be dynamic, professionals keep abreast of changing technologies, tools, maintenance practices and modifications. You can do this by taking extra courses, reading briefing materials, memos and bulletins, and studying maintenance-manual amendments.

Source: CASA *Human Factors Resource Guide for Engineers*

Key points

- Maintenance work has its own blend of demands and resources.
- The balance of these demands and resources takes individuals down either the health impairment or the motivation pathway.
- Strain and fatigue (health impairment) are driven primarily by job demands and contribute directly to safety behaviours such as violations and errors.
- Motivation and job satisfaction, on the other hand, are driven primarily by job resources and help to reduce negative safety behaviours and to improve unit performance.
- While error prevention should remain a major goal in maintenance work, non-technical skills training should also encourage a focus on professionalism and achieving a high performance standard that excludes errors.

Resources

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Maintaining risk awareness

Here are two simple techniques designed to help people maintain risk awareness in dynamic operating environments — RULE OF THREE and PEAR. Used in combination, these techniques enable the identification of emerging risks immediately before and during the execution phase of an activity. They complement deliberate risk-management activities and directly support decisions relating to the adequacy of risk control measures. The use of the RULE OF THREE and PEAR ensures that the management of risk is not confined to the planning phase of a mission or activity. It enhances effective risk management in all activities and at all times.

RULE OF THREE

Do I understand the risks? ...

GREEN — PROCEED: Condition is okay and well within limits or assumptions

AMBER — COMMUNICATE AND CONSIDER, 3 x Ambers = Red = STOP!: While within limits the condition or circumstances is nearing the boundary of being acceptable

RED — STOP!: Condition or circumstance is out of limits or unacceptable

The RULE OF THREE provides a simple way of applying a level of immediate risk management. The basic premise is the traffic-light system. You must always stop if you have a RED, but too many AMBER lights may be just as risky. Occurrences all too often happen because of a combination of relatively minor events and situations.

PEAR directly supports the application of the RULE OF THREE by helping to identify potential concerns, hazards and risks. There are only four words to remember.

P stands for PEOPLE (the humans in the system) and relates to the suitability (physical, cognitive and social) of the selected personnel for a particular task. Suitability not only covers knowledge and skills, but also human-factors considerations such as fatigue, stress and motivations.

E stands for the ENVIRONMENT in which the work is done, not just the physical environment (that is: lighting, temperature, noise levels and time of day) but also the organisation itself (quality of supervision, amount of supervision and pressures to complete task/activity).

A represents the ACTIONS people perform. Actions identify the requirements of the task to help to identify any specific areas that might increase the risk of error, such as ambiguous information, or complex tasks that require specialist knowledge and skills.

R is for the RESOURCES necessary to perform the work. They can be defined as anything that is required to complete the tasks successfully (examples include personnel, procedures, tools, available time and personal protective equipment).

What are your ambers and reds?... *think PEAR*

PEOPLE communication, experience, competency, fatigue, supervision ...

ENVIRONMENT distractions, pressure, location, leadership, hazards ...

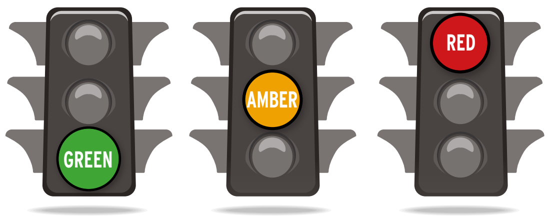
ACTIONS documentation, briefing, application of knowledge, preparation, inspection ...

RESOURCES publications, number of personnel, spares & support equipment, PPE, time ...

Using the RULE OF THREE and PEAR

Effective implementation requires everyone to:

- use PEAR to identify conditions or circumstances that may become a concern to you and others
- speak up if you identify any AMBER or RED conditions or circumstances
- take time to think about the issues and discuss them with your team/supervisor.



AMBER = COMMUNICATE AND CONSIDER

Where the condition or circumstance, while within limits, is nearing the boundary of being acceptable:

- ensure you understand the issues and, if required, seek additional information
- discuss the issue with others in your team, or your immediate supervisor
- consider what can be done to eliminate or minimise an AMBER into a GREEN
- continue if you are satisfied that nothing further can be done but maintain vigilance in this area
- ensure all solutions are appropriate and authorised for use
- add up all the remaining issues classified as AMBER to see if you can proceed with the task/activity
- remember three or more AMBERs equal a RED.

RED = STOP!

Where a condition or circumstance is out of limits or unacceptable:

- Always STOP if you have a RED
- If task/activity is underway, current actions are to be immediately halted and/or the situation stabilised to a safe position in order to evaluate the concern
- Discuss the issue with others in your team, or your immediate supervisor
- Identify what you can and cannot do to eliminate or minimise the concern
- Do not proceed until the RED is eliminated and returns to GREEN (or possibly minimised to AMBER)
- Ensure all solutions are appropriate and authorised for use
- In the event the condition(s) or circumstance(s) cannot be changed, address issue(s) through command chain
- Remember to address any remaining AMBERS.

A RED does not necessarily mean you cannot do the activity — it means stop and reassess the situation and evaluate your options.

ALWAYS APPLY THE PRINCIPLES OF RISK MANAGEMENT

- Apply risk management principles to all AMBER and RED:
  - ✔ try to eliminate all risks
  - ✔ if the risk can't be eliminated, then minimise by applying all reasonable treatments/controls
  - ✔ ensure all treatments/controls are appropriate and authorised for use
  - ✔ ensure all risk-based decisions are made at the appropriate level.

Where and when to apply

Using RULE OF THREE in combination with PEAR allows for a relatively simple methodology for identifying and responding to changes that can occur in the operating environment. The techniques are suitable for incorporation into daily activities, including:

- **Preparation** for a task or activity
- **Brief** of the task or activity to team members
- **Execution** phase of the task or activity
- **Debrief** of the task or activity with team members, supervisor and/or manager.

It is essential that the outcomes of the RULE OF THREE are reviewed following the completion of an activity. Conducting a review is essential to identify what worked, what did not work, and to capture/document any lessons learned. Where this process identifies potential limitations/weaknesses, these are to be fed back into the formal deliberate risk-management process making it more robust for future operations.

What now?

Discuss with your team how you are going to use the RULE OF THREE and PEAR techniques. When working in a team environment, it is important for members to have a clear and common understanding of how the techniques will be used and, in particular, what will constitute an AMBER or RED. Adopt terms like "counting your AMBERS", "managing into the GREEN" or "close to RED".

Knock-it-off & time-out

Integral to the effective use of risk-awareness techniques like RULE OF THREE and PEAR are the concepts of knock-it-off and time-out. These concepts are essential to ensuring everyone has a voice if they see an unsafe situation developing. Verbalising either of these terms sends a message to those involved in a specific action to stop, take a moment to reset and re-evaluate the current situation. Everyone (regardless of rank or position) is empowered to use these terms without any fear of repercussion. When either term is used, all current actions are to be halted immediately, the situation is to be stabilised to a safe position and the concern evaluated.

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PEAR ELEMENTS

DOING	THINKING	INTERACTING
Physical limitations	Knowledge	Team structure
Sensory limitations	Experience	Role definition
Health	Attitude	Leadership
Training	Motivation	Followership
Competent	Confidence	Supervision skills/needs
Authorised	Workload	Interpersonal conflicts
Briefed	Fatigue	Communication
Fatigue	Stress	Mentoring

PHYSICAL	ORGANISATIONAL
Weather	Management style
Location (inside/outside)	Leadership
Facilities/workspace	Staffing levels
Lighting	Size/complexity
Noise	Priorities
Distractions	Pressures
Housekeeping	Morale
Hazards	Norms
Shift (day/night/late)	FEG/wing/unit culture

ACTIONS	
Information requirements	Communication requirements
Preparation	Task management
Briefing/de-briefing	Supervision requirements
Steps/sequence of task	Inspection requirements
Application of knowledge	Documentation requirements
Application of skill	Certification requirements

RESOURCES		
Time	Tech manual	Heating/cooling
Other personnel	Procedures	Facilities
Training	Data	Fixtures
Consumables	Paperwork/signoffs	Signage
Spares	Tools	Quality systems
PPE	Test equipment	GSE
Computers/software	Lighting	Work stands

NOTES

NOTES

CAPABILITY FIRST

DASA

SAFETY ALWAYS