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Australian Transport Safety Bureau

ATSB SAFETY INFORMATION PAPER

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Final

A Layman's Introduction to Human Factors in Aircraft Accident and Incident Investigation

David Adams

David Adams Consulting

June 2006



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Postal address: PO Box 967, Civic Square ACT 2608
Office location: 15 Mort Street, Canberra City, Australian Capital Territory
Telephone: 1800 621 372; from overseas + 61 2 6274 6590
Accident and serious incident notification: 1800 011 034 (24 hours)
Facsimile: 02 6274 6474; from overseas + 61 2 6274 6474
E-mail: atsbinfo@atsb.gov.au
Internet: www.atsb.gov.au

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A Layman's Introduction to Human Factors in Aircraft Accident and Incident Investigation

Author(s)

Mr David Adams

Organisation that prepared this document

David Adams Consulting,
PO Box 43, Braddon, ACT 2612

Abstract

This information paper seeks to provide people without an in-depth knowledge of the practice of 'Human Factors' a general plain English explanation of what Human Factors is, how it has evolved, and how it is applied to aircraft accident and incident safety investigations. The paper also gives a brief explanation of international agreements and Australian law as they apply to aircraft accident and incident investigations. Human Factors, which includes 'Ergonomics' as it is called in some industries, is the practice of applying scientific knowledge from varied, mostly human science disciplines such as Psychology, Medicine, Anthropometrics and Physiology to designing, building, maintaining and managing systems and products. In general use, the application of human science knowledge to systems and products is to provide the best match between the characteristics of people, with the operation of the systems and products they use. The purpose of applied Human Factors is to build better and safer products and systems. In aircraft accident and incident investigation, the specific purpose of Human Factors is to understand in detail how and why people make errors (including slips and lapses) or commit violations that lead to accidents. In the development of aviation, the scope of Human Factors has evolved from focusing predominantly on the interface between the pilot and the aircraft to the broader application of considering all the human activities of the system that is involved in the placing and supporting the pilot in the operation of the aircraft. This broader focus considers not only the actions of the pilot, but also, the cabin crew, the maintenance crews, air traffic controllers, and the management of the organisation that controls the activities of the aircraft. The Australian Transport Safety Bureau (ATSB) must, with as much certainty as possible, be able to determine not only what happened in any given accidents, but more importantly, why it happened. This information is critical to the ATSB role in making safety recommendations aimed at improving transport safety. The role of the ATSB is clearly defined in the Australian *Transport Safety Investigation Act 2003* (TSI Act) which reflects Australian agreement to the international standards and practices for aircraft accident investigation. Both the TSI Act and international agreements state that the investigation of aircraft accidents by safety agencies such as the ATSB is not an activity for apportioning blame or liability, but rather for the purposes of maintaining or improving safety.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal Bureau within the Australian Government Department of Transport and Regional Services. ATSB investigations are independent of regulatory, operator or other external bodies.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations. Accordingly, the ATSB also conducts investigations and studies of the transport system to identify underlying factors and trends that have the potential to adversely affect safety.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and, where applicable, relevant international agreements. The object of a safety investigation is to determine the circumstances to prevent other similar events. The results of these determinations form the basis for safety action, including recommendations where necessary. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations.

It is not the object of an investigation to determine blame or liability. However, it should be recognised that an investigation report must include factual material of sufficient weight to support the analysis and findings. That material will at times contain information reflecting on the performance of individuals and organisations, and how their actions may have contributed to the outcomes of the matter under investigation. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. While the Bureau issues recommendations to regulatory authorities, industry, or other agencies in order to address safety issues, its preference is for organisations to make safety enhancements during the course of an investigation. The Bureau is pleased to report positive safety action in its final reports rather than make formal recommendations. Recommendations may be issued in conjunction with ATSB reports or independently. A safety issue may lead to a number of similar recommendations, each issued to a different agency.

The ATSB does not have the resources to carry out a full cost-benefit analysis of each safety recommendation. The cost of a recommendation must be balanced against its benefits to safety, and transport safety involves the whole community. Such analysis is a matter for the body to which the recommendation is addressed (for example, the relevant regulatory authority in aviation, marine or rail in consultation with the industry).

EXECUTIVE SUMMARY

The term ‘Human Factors’ refers to the application of scientific knowledge, mostly from the human sciences of psychology, anthropology, physiology and medicine, to the design, construction, operation, management and maintenance of products and systems.

The purpose of the application of this scientific knowledge is to attempt to reduce the likelihood of human error and therefore the likelihood of negative outcomes while operating or using products or systems.

This paper is concerned primarily with the relationship of Human Factors to aircraft accident and incident investigations. The purpose of applying Human Factors knowledge to such investigations is to not only understand what happened in a given accident, but more importantly, why it happened. Without understanding why an accident occurred, safety investigation agencies such as the Australian Transport Safety Bureau (ATSB) are limited in their ability to draw meaningful conclusions and propose effective safety action and recommendations for change.

Most aircraft accidents and incidents are the result of errors (including slips and lapses) made by the people responsible for operating the aviation system. These people could be pilots, air traffic controllers, maintenance staff or executive managers of the various aviation organisations. Some of the errors committed by these people are the result of deliberate violations of rules and procedures. However, even the majority of errors resulting from violations do not come from any intent to harm anyone or commit a crime. Any aircraft crash that is the result of a wilful act intended to cause harm or damage is by definition not an accident and would not fall within the investigative mandate of the ATSB. As has been seen in the US in recent years, and would also be the case here in Australia, aircraft crashes that are the result of wilful violations with the intent of causing harm or damage are investigated by criminal and security investigation authorities.

Some people believe that if a human is given a reasonable task to complete and they are adequately trained, then the individual should be able to repeatedly perform the task without error. However, applied research and accident investigation reports from around the world demonstrate that this view is incorrect. Competent humans conducting even simple tasks continually make errors, but in most cases they recognise the errors they have made and correct them before any consequence of the errors is realised. In a small number of cases they fail to either recognise the errors or fail to correct them before the consequences of the errors are realised.

It is believed by many human science professionals that human error is a normal part of human performance and is related to the very qualities that make us human. That is, our brains allow us to quickly assess large amounts of information and make varying judgements and decisions about that information. However, our ability to vary our judgements and decisions are influenced by many factors and these factors often lead us to make errors.

Since it was known very early on in aviation history that the pilot ‘failed’ significantly more often than the plane did, most aircraft accidents were classified as ‘pilot error’ and often the explanation went little further than that. The use of the term ‘pilot error’ provides a simple, but often misleading explanation of a complex accident sequence.

Sections of the community and some high-risk industries seem to desire a simple explanation for complex events. That is, of what ‘caused’ the event and who is to ‘blame’. Some also tend to see Human Factors as a process of helping individuals avoid their responsibility for accidents.

While the concept of pilot error tends to fit well with the desire to blame someone, it is at odds with international agreements and Australian domestic law.

Australia is a signatory to the international *Convention on International Civil Aviation, 1944* commonly referred to as the Chicago Convention. As a result, the investigation standards and recommended practices outlined in Annex 13 (Aircraft Accident and Incident Investigation) to the Chicago Convention have been incorporated into Australian domestic investigation processes through the Commonwealth *Transport Safety Investigation Act 2003* (TSI Act).

Both Annex 13 and the TSI Act explicitly state that investigations are not for the purpose of apportioning blame or liability. Nothing in either Annex 13 or the TSI Act precludes agencies and organisations which are responsible for apportioning blame or liability, from doing so. However, by international agreement and Australian Law, it is not the role of the ATSB.

Annex 13 recommends that investigation for the purposes of blame or liability should be conducted as separate inquiries (para 5.4.1). The TSI Act states that the object of an investigation under the Act is to ‘improve transport safety’ while cooperating with other investigative bodies (s7).

Safety investigations need to keep focused on why an accident or incident occurred, rather than who is to blame.

With the evolution of human factors, human sciences knowledge is now not only applied against a systems engineering background, but also against a psychosocial and more recently a business management framework. These evolutionary developments break away from the idea that a pilot operates in a vacuum and that accidents are events isolated from the system which nurtured them.

Contemporary human factors application is now as much about understanding how groups of people, be they flight crew, cabin crew, maintenance staff, air traffic controllers or senior management teams operate, and why they make decisions and behave in particular ways, as it is about individuals. It is also now about viewing accidents as part of the overall complex system which supported all the aspects of the operation. As such, it is about understanding how organisations manage risk and balance their safety obligations with their business imperatives.

The ATSB conducts investigations and undertakes specific safety research and education programs. The practices of the ATSB with respect to these activities and the application of Human Factors is in alignment with Australia’s international obligations and domestic law. Its activities are also in line with international best practice.

Human factors incorporate a broad and complex body of applied scientific knowledge aimed at more clearly understanding why errors occur. In this way, the application of human factors knowledge is no different to the application of any other body of scientific knowledge.

ABBREVIATIONS

ATSB	Australian Transport Safety Bureau
CRM	Crew resource management
ICAO	International Civil Aviation Organization
NASA	United States National Aeronautics and Space Administration
TSI Act	<i>Transport Safety Investigation Act (2003)</i>

1 INTRODUCTION

1.1 Background to this paper

The term, Human Factors, is a relatively new term that is not well understood by some sectors of the community.

Apart from a lack of knowledge about the subject, the misunderstanding seems to be partly due to the fact that some people seem to believe that investigations into accidents explicitly for the purposes of improving transport safety should be concerned with identifying and punishing the people guilty of causing those accidents.

Given this view, and the fact that in many cases Human Factors investigations tend to confirm that people who have accidents are victims of their own human frailties, some members of the community seem to believe modern Human Factors investigations simply help guilty parties avoid taking responsibility for their actions.

These notions are completely at odds with the purpose of a safety investigation which, first and foremost, must be concerned with understanding why an accident occurred and, on that basis, making effective recommendations to prevent recurrence and improve transport safety for both the Australian and international travelling public.

In an effort to increase the level of general understanding within the community, the Executive Director of the ATSB commissioned this layman's information report.

1.2 Objective of this paper

Human Factors is a large and complex subject and a full or detailed coverage of the topic is beyond the scope of this paper. The objective of this paper is to give a layman's general explanation of the history, development and application of Human Factors, particularly as it relates to safety investigations of aircraft accidents and incidents.

The ATSB would welcome constructive suggestions for improvement of this paper for a future edition. Any suggestions should be mindful of the introductory focus of the paper. The ATSB runs a five-day course on introductory human factors which includes much more depth and employs a number of specialist human factors investigators. Any suggestions should be sent by email to alan.stray@atsb.gov.au by 31 August 2006.

ORIGIN AND MEANING OF THE TERM HUMAN FACTORS

Human Factors is a body of knowledge that has evolved rather than been discovered or invented. It is therefore impossible to determine when Human Factors was first practiced. It could be argued that within the limitations of their knowledge and technology, ancient civilisations probably applied Human Factors knowledge to their endeavours as far back as 5000 BC or even earlier. However, what can be determined with a much greater degree of accuracy is how and when the English language term Human Factors first appeared and what in contemporary times it means.

The term Human Factors has its origins in aviation, and while the term was used informally in literature in British Royal Air Force accident investigation reports in the 1940s, (ATSB Human Factors training material) it was not until 1957 that it was first formally used to describe the modern practice (Edwards, 1988).

The term was used to refer to the application of scientific knowledge, concepts, models, and theories derived mainly from human science disciplines such as psychology, physiology, medicine, anthropometrics and others. The knowledge was applied to improving the efficiency of operation and the reduction of human error leading to aircraft accidents.

Almost from the birth of powered heavier-than-air flight, it was recognised, as indeed it is to this day, that most aircraft accidents and incidents result not from some problem associated with the aircraft (such as a mechanical malfunction), but rather from the actions and decisions of the people associated with the operation of the aircraft. Most aircraft occurrence investigation agencies around the world estimate that between 70 per cent and 90 per cent of all aircraft accidents and incidents are the result of the actions and decisions of people involved in aircraft maintenance and operation. Not surprisingly, ATSB estimates reflect this international trend.

While aviation specialists were developing all facets of aviation operations, it was recognised by the engineers who designed and built the aircraft that they, at least initially, did not have a good understanding of the characteristics and limitations of the people who were responsible for operating them.

Between the beginning of the First World War, and the end of the Second World War, an emphasis was placed on designing more user-friendly aircraft.

In the late 1940's in the United Kingdom, an interdisciplinary group of scientists who had been engaged upon a variety of 'Human Problems' associated with the war effort decided to form a society concerned with the human aspects of the working environment. Thus in 1950, the Ergonomics Research Society (now the Ergonomics Society) was born. The word ergonomics was coined by Professor K.F.H. Murrell, derived from the Greek meaning, 'the science of work'. In the United States, analogous developments took place leading, in 1957, to the formation of the Human Factors Society (Edwards, 1988, p4-5).

Edwards goes on to state that 'For the present purposes...the terms ergonomics and Human Factors may be regarded as synonymous (1988, p5)

Interestingly, the Human Factors Society changed its name to the Human Factors and Ergonomics Society (HFES) in 1992.

Edwards defined Human Factors (ergonomics) in the following words:

Human factors (or ergonomics) may be defined as the technology concerned to optimize the relationship between people and their activities by the systematic application of the human sciences, integrated within a framework of system engineering (1988, p 9).

While views do vary, the term Human Factors has become the generally accepted term within the aviation community, and many consider ergonomics to be a narrower field of study associated with equipment design and construction to better interact with the abilities and limitations of the operators, to be a subset of the broader discipline of Human Factors.

Christensen, Topmiller and Gill, define Human Factors as follows:

Human factors is an eclectic field encompassing disciplines such as psychology, engineering, ergonomics, anthropometry and psychophysiology. Specifically, human factors is that branch of science and technology that includes what is known and theorised about human behavioural, cognitive, and biological characteristics that can be validly applied to specification, design, evaluation, operation, maintenance of products, jobs tasks, and systems to enhance safe, effective, and satisfying use by individuals, groups and organisations. (1988, p7-8)

Essentially, the objective of Human Factors is to optimise the relationship between the human operator, technology and the environment.

A simple search of the Internet seeking a definition of Human Factors reveals many similar yet slightly different definitions of Human Factors.

However, they all tend to have two things in common:

1. Human Factors involve the application of facts, theories and concepts from many recognised disciplines, mostly involving the human sciences.
2. The aim is to interface the best characteristics of people with the best characteristics of systems (equipment, training, procedures, management etc) design and construction, maintenance, management and operation, with a view to eliminating or at least reducing errors in operation (whether or not it be the operation of an aircraft, a train, a mobile phone, a ship, a nuclear power plant, or a nuclear submarine, or an assembly line).

None of the existing recognised disciplines can of themselves account for the full range of existing knowledge about how and why humans function the way we do. As a result, the process of trying to consider human performance as a subject in its own right has necessitated a new term – within aviation, the term generally used, is Human Factors.

3.1 From the dawn of flight to World War 1

The practice of applied Human Factors was clearly being practiced in aviation some 50 years before it was given a title. However, like aviation, some of the varied disciplines that make up the contemporary practice of Human Factors were themselves new and undeveloped. The discipline of psychology in its contemporary form started to develop around the end of the 1800s and so in many ways was just as new and undeveloped as aviation itself.

While aviation had been born of civilian initiatives, it was not until the beginning of World War 1 (WW1) that aircraft started to be seen as a product with a real role to play rather than just as a novelty item. Military requirements rapidly developed the role of aircraft as a military vehicle. In the early days of WW1 aircraft were used as battle field observation platforms, but quickly became weapons of war when they were used to drop bombs and shoot down enemy aircraft.

During the First World War, the British Royal Flying Corps recorded that, of every 100 aviators killed while flying, two met their death at the hands of the enemy, eight died because of mechanical or structural failures of their aircraft, and 90 perished as a result of what the Flying Corps described as their own individual deficiencies (U.S Army Technical Manual, 1941).

Military commanders quickly became interested in trying to reduce the number of aircraft and aircrew that they were losing as a result of their pilots 'individual deficiencies'. It could be claimed that these realisations gave birth to the practice of Human Factors in accident investigation.

While it was recognised very early in the development of aviation that not all humans were as capable as each other when it came to successfully and repeatedly flying an aircraft, the level of knowledge about the characteristics and limitations of human performance was not well developed.

Bond et al state:

Some men are bright, some dull: some tall, some are short. People will vary on almost any conceivable dimension (1989, ch 3, p7-8)).

As a result of this type of intuitive observation of the variability between humans and therefore human performance, an emphasis was put on devising ways of selecting people with the correct skills and attitudes to fly aircraft. Based on many different criteria, these selection processes are now a more important and scientific process than ever. However, it was also recognised that even having selected the candidates with what was felt to be the necessary qualities they still make errors which lead to accidents and incidents. Many of those occurrences were attributed to a lack of training and so pilot training became a focus of limiting human performance variability, particularly as the aircraft became bigger, faster and more complicated.

During the same period, engineers were constantly refining the design and construction of their aircraft so that the pilots and the aircraft were more compatible with each others performance limitations.

While Human Factors continued to develop in the areas of ergonomics, pilot selection and training, it became clearer that human error and accidents in aviation were related to such processes as pilot judgement, cognition and sensory perception. While these processes all have a physiological base, they are all psychological processes. As such, Human Factors started to draw heavily on what is now commonly called 'aviation psychology'.

3.2 Post World War 1 to the beginning of World War 2

After World War 1, the construction and operation of aircraft again became a major civilian interest. While ex-military pilots and aircraft were used for civilian entertainment in the form of air races and Barn Storming stunts, the early twenties also saw the introduction of the first civilian airlines and air mail services. Our own QANTAS Airlines, arguably one of the oldest if not the oldest airline continuing to operate anywhere in the world was established on 16 November 1920.

In the 1920s and 30s, aircraft developed from predominantly low powered Bi-planes made often of nothing more than wood, canvas and wire, and that could only be flown safely in good visual conditions, to high powered monoplanes made of steel and aluminium that allowed a pilot to fly the aircraft by instruments where no external visual cues were available.

During this period, Human Factors or ergonomics continued to develop, although as yet not formally given a separate title. An interesting example of this development can be found in the development of the 'Link Trainer'. Pilots could now fly aircraft by instruments with out the need for external visual reference. However, the process of training them to do so was a dangerous activity. To reduce this danger, and to help operators to select pilots that were better suited to instrument flying, an American, Edwin Albert Link, built the Link Trainer which today is generally recognised as the forerunner to model flight simulators which are used in training by most if not all airlines and military aviation groups throughout the world.

The Link Trainer was a wooden, cockpit like, contraption in which a pilot would sit closed off from any external visual reference by a wooden canopy. The interior of the trainer contained the instruments necessary for non visual flight and aircraft controls for flying an aircraft. These instruments and controls were connected to an external instructor's console and a number of air operated bellows taken from organs. As the pilot responded to the readings on the flight instruments and moved the controls, the air bellows moved the aircraft in response. This allowed instructors to assess an individual's natural skill in flying an aircraft or allow the individual to be taught to fly an aircraft using only instruments without the cost or risk of actually flying a plane.

The Link trainer was first patented in 1929 and when first offered for sale to the United States Army Air Corps was refused. Interestingly, in 1932 Link Aviation of Binghamton, New York sold 100 of the trainers for amusement as a kind of 1930s arcade game. Ironically, one of the first military organisations to take the trainer seriously was the Japanese Navy which purchased Link Trainers in 1935. However, by the beginning of WW2, 35 countries were using the Link Trainer for selection and instrument training.

3.3 World War 2 to circa 1970s

With the advent of the Second World War, and armed with the knowledge of aircraft losses during the First World War, and recognising that during the 1920s and 30s aircraft and aircraft operations had changed significantly, both the British and the Americans started to invest heavily in applying Human Factors knowledge to aviation operations. These efforts now not only drew on practitioners such as pilots and engineers, but also increasingly on academic specialist from Universities.

The scope of Human Factors expanded rapidly, applying knowledge and techniques to better pilot selection in the form of better and more stringent medical and psychological standards. New psychometric measures were developed and devices such as flight simulators were developed and used. Research was undertaken into spatial disorientation, fatigue and pilot information processing abilities etc. However, these developments continued to focus on individual pilots. These developments while providing a wealth of new information tended to reinforce the concept of individual 'Pilot Error' as being the only real explanation for all accidents that did not involve a mechanical failure of the aircraft.

At the end of WW2, academic research into Human Factors continued in a civilian context and expanded into many Universities throughout the world. One of the first Universities to open a school specifically aimed at aviation and specialising in Human Factors was the University of Illinois which in 1946 established the University of Illinois, Institute of Aviation. Also in 1946 the UK opened the Cranfield College of Aeronautics; however, it did not receive university status until 1969. The list of universities now involved in aviation and Human Factors in general is now seemingly endless.

In the mid 1970s, the focus of Human Factors in research, investigation and line operations started to expand to consider broader human factor issues.

Examples of the broadening focus of Human Factors can be seen in the aftermath of a number of aircraft accidents in the early 1970s. On 29 December 1972, the entire flight crew of a United States Eastern Airlines Lockheed L-1011 TriStar became so ingrossed in trying to diagnose the reason for a landing gear warning light that none of them heard a warning tone that indicated the aircraft was descending below its safe altitude. The aircraft hit the ground and killed 99 of the 176 people on board.

The US National Transportation Safety Board (NTSB) investigation report stated that the probable cause of the accident was, 'The failure of the crew to monitor the flight instruments during the final four minutes of flight....' (NTSB report AAR-73-14). While this statement of probable cause is factually correct, it provides little explanation of why and how to prevent it again.

How could a highly trained and experienced crew unknowingly fly a fully-functioning aircraft into the ground without realising what was occurring? Of course the simple answer (which is included in the NTSB report) is that the crew were distracted by the landing gear warning light. However, this explanation simply raises other questions. Why were all three crew members distracted? And, what measures could be implemented to prevent future crews from becoming distracted?

The accident involving the TriStar and other similar accidents at that time, initially led to research (Ruffell-Smith, 1979; Foushee, 1984) and then to the development of a training program initially called 'Cockpit Resource Management' or CRM (Helmreich, 1987).

The initial research looked at how aircraft captains allocate tasks between crew members and how crew members responded to each other. This research showed that there were many errors that occurred because of poor crew coordination. The origin of these issues could involve personality, cultural biases, communications skills and many other factors that influence the way groups of people interact with each other and how they go about managing and solving problems. If you consider the TriStar accident referred to above, the captain certainly had sufficient human resources to ensure the landing-light problem was investigated, while at the same time the aircraft was flown safely to its destination. However, the tasks were not clearly allocated or communicated to the crew and as a result, everyone was trying to solve the problem of the warning light while no one was actually flying the aircraft.

The development of CRM training initially focussed on the flight crew, but it was soon realised that while communications and good resource management was critical to the cockpit, the problems between the flight crew and the other members of the crew could be just as critical. A large modern passenger aircraft can have upward of 20 flight attendants all who have critical roles to play in the operation of an aircraft, and all of whom may hold potentially critical information about the state of the aircraft. As a result Cockpit Resource Management evolved into 'Crew Resource Management'.

CRM as developed by Professor Robert Helmreich, at the University of Texas, is now practiced by most airlines. It is also now applied broadly from flight and cabin crew to maintenance staff and air traffic controllers, in fact any group of people who may be directly involved in the operational safety of the aircraft.

3.4 Development from 1970s to today

CRM is now considered to be in its 'Fifth Generation' of development and has led to a number of spin off practices. One of the main current focuses within contemporary CRM is 'threat and error management' where both operating crews and management are trained to analyse errors in great detail to not only identify errors after they have been made, but also to recognise threats that can lead to errors before the error occurs. This process not only allows individuals to learn but also allows the organisation to learn and help put in place affective mitigation strategies to identified threats.

With the expanded focus of Human Factors now considering not only the actions of individuals, but also groups of individuals, be they operators or managers of operators, a new concept and term started to develop. Investigation authorities started to use the term 'systemic investigations'. This term simply referred to an investigation with a broader focus. Such investigations look at the entire system that support the operation of the aircraft that may have been involved in an accident or incident, not just at those things or people who were proximal to the accident or incident.

This evolutionary change has led to yet another term. The term is 'organisational accidents'. One of the most notable proponents of this concept is Professor James Reason of Manchester University.

A full explanation of this topic can be found in Professor Reason's book 'Managing the Risks of Organisational Accidents (1997)'.

In his book, Professor Reason states:

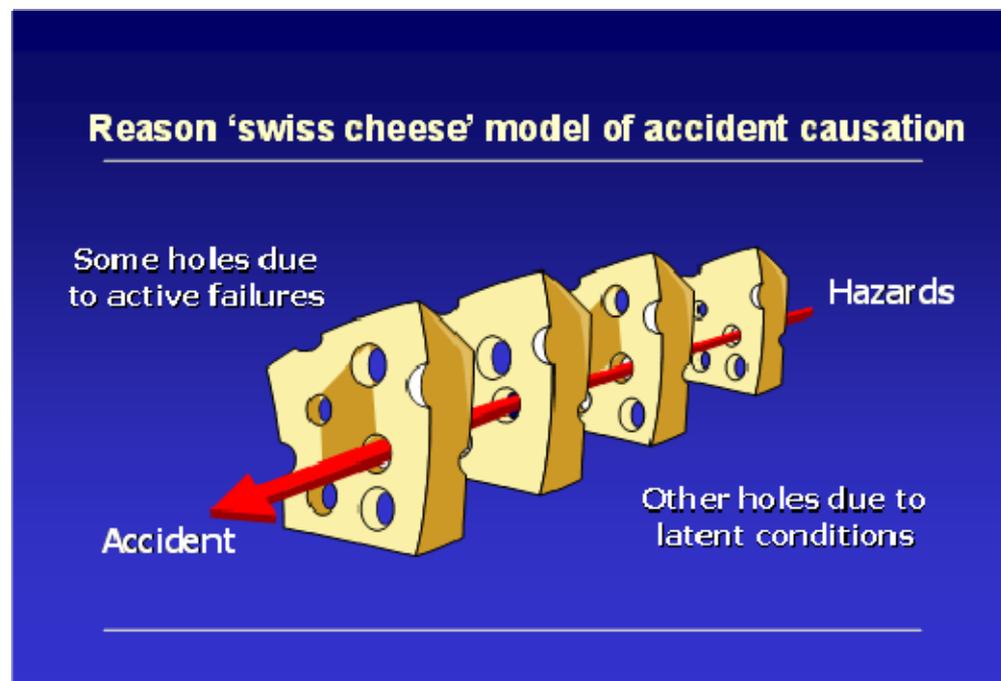
There are two kinds of accidents: those that happen to individuals and those that happen to organisations. Individual accidents are by far the larger in number, but they are not the main concern of this book. Our focus will be upon 'organisational accidents'. These are the comparatively rare, but often catastrophic, events that occur within complex modern technologies such as nuclear power plants, commercial aviation, the petrochemical industry, chemical process plants, marine and rail transport, banks and stadiums.

Organisational accidents have multiple causes involving many people operating at different levels of their respective companies.

Whereas the nature (though not necessarily the frequency) of individual accidents has remained relatively unchanged over the years, organisational accidents are a product of recent times or, more specifically, a product of technological innovations which have radically altered the relationship between systems and their human elements. (1997, p1)

James Reason has developed a model for people to understand how organisational accidents occur. The model is commonly called the Reason model but is also sometimes called the 'Swiss Cheese' model.

Figure 1: Reason 'swiss cheese' model



While figure 1 gives a general graphic explanation of the model, a full explanation of the Reason Model is beyond the scope of this paper. However, the fundamental tenet of the model is that organisational factors, such as senior management decisions, can combine with local workplace factors such as poorly trained staff, and unsafe acts, such as maintenance staff applying the incorrect torque to a bolt. The combination of these factors can then penetrate the organisations defences and potentially result in a catastrophic event.

From this concept, contemporary investigations look not just at the actions of the individual operators sitting at the controls, but also at the broader actions of the organisation that supports those individuals to do their job in a professional and safe manner. What defences does an organisation have? Are the organisations aware of the risks they face? How do organisations manage their risks? Does an organisation have goals that conflict with their safety management activities? These are just some of the issues that contemporary investigations now ask.

An example of an organisational accident is the loss of the US National Aeronautics and Space Administration (NASA) space shuttle, Challenger, on 28 January 1986. In this accident, a rubber O-ring in one of the shuttles solid rocket boosters failed just after lift-off, allowing flames to breach the main fuel tank causing the shuttle to explode.

The manufacturers of the solid rocket boosters had warned NASA management that if the air temperature at launch was below a specific level, the O- rings in the boosters could fail. The air temperature on the day of the accident was significantly below the level specified by the manufacturer. Both the manufacturer and NASA's own engineers warned the head of mission control not to go ahead with the launch.

It was viewed by management that it was important to NASA's future that they demonstrate the commercial success of the Space Shuttle Program. In turn, NASA senior management pressured the manufacturer of the rocket boosters to agree to the launch. While NASA and the manufacturers engineers were still advising against it, the manufacturer finally agreed to sign off on the launch 72 seconds after lift off an O-ring failed and the shuttle exploded, killing all on board This accident was not a result of the actions of the individuals at the controls of the shuttle, but by the senior decision-makers of NASA, and the inability of the organisation to balance its safety obligations with its operational environment.

In the subsequent 'Report of the Presidential Commission on the Space Shuttle Challenger Accident' (1986) it is stated:

'The Commission concluded that there was a serious flaw in the decision making process leading up to the launch of flight 51-L. A well structured and managed system emphasising safety would have flagged the rising doubts about the solid rocket booster joint seal.'

Human Factors started with the development of aviation and was initially concerned only with the design of equipment and the training of pilots. It now deals with a much broader range of human science issues and has expanded its focus from individuals to entire organisations and systems. It is concerned with every level and every function within organisations that create the environment in which individuals design, construct, maintain and operate complex systems.

3.5 The nature of human error

Human Factors is the practice of applying scientific knowledge with the intention of reducing human error. However, understanding human error is a huge, complex and incomplete subject. For a more complete understanding of contemporary human error theory and practice, it is recommended that people interested in this subject start by reading Professor James Reason's book 'Human Error' (1990). However, the scientific literature dealing with this subject is voluminous.

Humans make errors for a large number of reasons. They make errors because they have not been adequately trained to perform tasks, or because they do not have the basic ability to perform the task even if they were trained. They commit errors because the task is beyond normal human abilities. They commit errors because they misinterpret information important to the performance of the task. They commit errors because some event occurring during the performance of the task changes the nature of the task in a way that they have never encountered. They also commit errors because of influences such as stress, distraction, fatigue, illness, visual illusions, spatial disorientation, old age, immaturity, cultural beliefs and the list goes on and on.

If you endeavour to systematically analyse human error the issues become even more complicated. Did the error occur because the operator did something they shouldn't have done? Did they not do something they should have done? Was the error in operation not related to the operator, but rather the people who designed the system the operator was using? Was the error unintentional or misguidedly deliberate? Did the error related to senior management decisions that may have inadvertently led the controlling organisation to pursue goals that conflicted with safety goals?

In aircraft accidents, many, and many combinations of the error considerations raised in the previous paragraphs can be identified.

While these considerations are important to on going research into systematically understanding human error enough to be able to predict it and therefore perhaps prevent or reduce it, they are critical to accident investigators charged with the task of providing timely explanations of what happened, why it happened and how it might be prevented from happening again.

Contemporary Human Factors research has attempted to understand human error by analysing human error within various models. That is, human errors are classified in particular ways and divided into components that are given specific titles. None of the models provide a complete answer, but each provides important mechanisms by which human error can be scientifically studied. Reason 1990 and 1997 provides a good technical explanation of the characteristics and application of some of these models. One of the important goals of studying human error is the attempt to derive estimates of error probability.

One example of this type of assessment is research undertaken by Kirwin (1994). By using both research and expert assessment within the Nuclear Power industry, Kirwin produced numerical error probability rates for a number of generic tasks. Some of these estimates are presented below:

1.	General rate for errors involving very high stress levels	0.3
2.	Complicated non-routine tasks, with stress	0.3
3.	Non-routine operation with other duties at the same time	0.1
11.	Errors in simple routine operations	0.001
12.	Selection of wrong switch (dissimilar in shape)	0.001

While the absolute values presented by Kirwin may be questioned, the process allows organisations to build a hierarchy of error types and rates. This information in turn allows organisations to understand where in their operations they are most at risk. From a safety investigation point of view, this type of analysis provides direction about what are the most important issues that need to be understood and how actions aimed at mitigating the effects of human error can be designed into processes such as better personnel selection and training, better procedures design, better work environment design.

HUMAN FACTORS IN ACCIDENT AND INCIDENT INVESTIGATION

The immediate operational focus of Human Factors during the First and Second World Wars shaped the evolution of Human Factors, particularly the application of Human Factors in accident investigation, for the next 30 to 50 or so years.

As seen in the quotation from the British Royal Flying Corps previously referred to in this paper, losses during the First World War, appeared to be related to only two issues, 'aircraft failures' and 'pilot failures'. Since the vast majority of the failures were attributable to pilots, the predominant focus of Human Factors in aviation investigations was on the failures of the pilots, in particular, individual pilots; those unfortunate enough to have been involved in an accident or serious incident.

The focus of Human Factors on the pilot, led to the use of the term 'Pilot Error' which, from a cultural perspective, carries a link to our society's apparent desire to find someone to blame. While pilots do clearly make errors, they are not the only people within the operation of a complex air transport system that make errors that lead to accidents. The notion of blame correspondingly leads society in general to the notion of punishment.

While it could be argued that the entire aviation community was slow to recognise that the strict focus on the performance of the pilot was causing operators and investigators to ignore or not see the significance of factors other than pilot error, it should also be recognised that aviation was the first transport mode to break this mind set.

Most aircraft operators and accident investigators were pilots or engineers who did not have the background training or knowledge (or the knowledge simply didn't exist at that time) to probe deeply enough into the exact nature or reasons for 'individual human deficiencies'. As a result, investigation into human performance and aircraft accidents in particular, tended to give reasonably good explanations of what happened in a given accident but provided much less explanation of why it happened. As a result, the general explanation for most aircraft accidents was 'pilot error' and the more detailed explanation often went little further than statements such as, 'the pilot failed to maintain his assigned altitude'. Up until the early 1980s, the Australian accident and incident investigation agencies, and indeed many if not most, other international accident investigation agencies, produced reports and entered information into databases that used this same language. It seemed that the pilot somehow operated in a vacuum and that no other persons or circumstances involved in the complex process of getting an aircraft from one point to another ever had anything to do with the sequences of events that lead to the accident. However, the Australian safety investigation agency (the former Bureau of Air Safety Investigation and since 1999 the ATSB) is seen internationally as one of the leaders in developing investigation processes that look past the simple concept of pilot error.

A good example of this changing international reality can be seen in the accident involving Airbus A300, American Airlines flight 587 in New York City on 12 November 2001 (NTSB report AAR-04/04). In this accident, the tail fin of the aircraft broke off the aircraft just after takeoff from New York. The aircraft subsequently crashed killing all 260 people on board and 5 people on the ground.

During the investigation, which is still hotly contested, it was found that, in response to air turbulence created by another aircraft, the First Officer of Flight 587 used the aircraft rudder pedals to try to stabilise his aircraft. The First Officer moved the rudder from one extreme position to the other (an action called rudder reversal) five times in a row. This action caused the tail fin to simply snap off.

Initially, suspicion fell on the manufacturer and the design and/or construction of the tail fin. How could the tail fin of a modern and relatively new jet airliner simply snap off? The investigation found that the First Officer's rudder input exceeded the load limitations of the tail fin. Was this just another pilot error accident? It seemed impossible to many in the airline industry that simply reversing the rudder in a modern jet aircraft could result in the tail fin snapping off and so the finger was pointed back at the aircraft manufacturer. But the aircraft manufacturer responded by pointing out that the rudder load limitations for that aircraft model were publicly documented and pointed the finger at American Airlines training which taught flight crew to use the rudder when trying to correct the aircraft flight path in situations such as that experienced by Flight 587.

The airline responded to the aircraft manufacturer's statements by stating that they had never been told by the manufacturer that repeated rudder reversals had a cumulative load effect that could lead to an overload situation. It was then revealed that this critical piece of information was applicable to almost all large aircraft regardless of who manufactured them. This realisation implicated everyone, the manufacturers, the aircraft certification and regulatory agencies, and the airlines that operated the aircraft and trained the pilots. Both Airbus and Boeing have since put out clear warnings that repeated and excessive rudder reversals can result in forces that may exceed the design limits of the tail fin.

Did the First Officer commit an error? Indeed he did, but it appears he was not aware that he was committing an error because he had been trained to use the rudder to correct the aircraft's flight path and he had not been made fully aware of the effects of rapid rudder reversal.

Had the investigation into this accident simply concluded that the probable cause of the accident was 'as a result of loads beyond ultimate design that were created by the first officer's unnecessary and excessive rudder pedal inputs', the true extent of the problem may not have been realised and the measures needed to prevent it from occurring again may not have been put in place.

The main problem with taking the approach of explaining most accidents in terms of just pilot error, and concentrating on what they failed to do as opposed to why they failed to do it, provides very little scope for identifying all of the factors that contribute to an accident, and in isolation, often leads to incomplete and therefore incorrect findings. If an investigation produces incomplete or incorrect findings then it is almost certain to produce incorrect or incomplete solutions, if any, to a particular problem.

However, the expanding focus of Human Factors did not come without its own share of problems, particularly for investigators.

Depending on the accident, there are many things related to human performance that can be proven as fact, cockpit voice recorders, air traffic control tapes, flight data recorders, procedure manuals, records of management decisions can all provide data that directly show what certain individuals did or didn't do, and on what basis they may or may not have made a particular decision. However, without the availability of such direct evidence, the pursuit of various Human Factors issues becomes more subjective (than most other applied analysis) and more dependent on finding evidence that supports the probability of an event rather than a proven cause and effect relationship between a decision or action and an outcome. Human Factors conclusions can not be allowed to be formed just on the basis of possibility. Human Factors issues like other considerations must either be proven or at the very least based on evidence that supports a reasonable probability that certain events are related to specific causes.

A simple example of this type of dilemma is pilot fatigue. How can you prove that a dead pilot made a particular decision or control input because of fatigue? The short answer is; you can't. Yet fatigue is commonly identified as a factor in many types of accident, particularly road accidents. Just proving that the pilot or driver was fatigued is some times near impossible, so to then make the next leap and conclude that a particular action was a result of fatigue is even more difficult.

To deal with the problems of some Human Factors evidence the ATSB has developed a number of investigation analysis tools that guide investigators toward the accumulation of evidence that hopefully allows them to reach conclusions based on probability rather than direct proof. Most other investigation agencies use the same types of tools. One of the tools used by the ATSB is called the 'Existence/Influence test'. In this test, and continuing to use fatigue as an example, investigators are required to show as much evidence as they can find that a pilot was fatigued, then show as much evidence as they can that the pilots actions were a result of or influenced by fatigue. To use an extreme example, if you were able to find evidence that a particular pilot had not had any sleep in the 48 hours immediately prior to an accident, and had made commented about feeling extremely tired, then you can draw a reasonable conclusion that the pilot was 'probably fatigued'. If you were also able to then find evidence that in the last 12 hours of operation the number of errors the pilot made had significantly increased and that the final accident sequence occurred because of an error made by the pilot, then you can also draw a reasonable conclusion that his action were 'probably influenced' by fatigue. Of course in less extreme examples, the probability of the relationship becomes less convincing.

When not being able to conclusively prove the existence of a particular factor or its influence, the alternatives are to pursue issues based on the reasonable probability of their existence, or simply ignore the issues. However if you are conducting a safety investigation aimed at trying to understand why an accident occurred and make recommendations that may prevent the same type of accident from occurring again, you can't afford to ignore such issues.

The types of issues outlined in the previous paragraph, although for slightly different reasons, are also encountered in conducting organisational investigations. Delving deeply into an entire organisation's operations and what they see as their defences is often open to a large degree of interpretation. However, conducting systemic investigations into how organisational issues that seem distant from a particular catastrophic event can bring about significantly more valuable safety lessons than just concentrating on the action of one or two individuals.

5

INTERNATIONAL STANDARDS FOR ACCIDENT AND INCIDENT INVESTIGATION

The first attempts to coordinate international aircraft operations were undertaken in London in 1910, but failed. After the First World War, international coordination of aircraft operations was successful in 1919 when the Paris Convention was signed. With the advancements in aviation during the Second World War, it was recognised that a new agreement on international aircraft operations was needed, and on 7 December 1944 the Convention on International Civil Aviation (the Chicago Convention) was signed. In April 1947, the International Civil Aviation Organization (ICAO) was created as an extension of the United Nations (Bartsch, 2004).

Australia is one of the original signatories to the Chicago Convention, which, to this day, still provides authority for the international standards and recommended practices for all aspects of aviation.

Australia has a full-time presence at the ICAO headquarters in Montreal, Canada and has 'part 1' status on the Council of ICAO. The Council of ICAO is the governing body of ICAO and having part 1 status identifies Australia as one of the 10 nations of the world classified as being of chief importance to international aviation.

Australia ratified the Chicago Convention under Australian law through the Air Navigation Act (1920). The Air Navigation Act 1920 had been enacted in response to the international standards contained in the superseded Paris Convention of 1919.

One of the Annexes to the Chicago Convention is Annex 13 – Aircraft Accident and Incident Investigation, and was first agreed on 11 April 1951. It was ratified under the Australian Air Navigation Act (1920) at Part 2, Section 3A (1) of that Act. Annex 13 documents all of the international standards and recommended practices that apply to the investigation of accidents and incident. Annex 13 initially applied to only those large aircraft engaged in international air navigation. In simple terms, these agreed standards and practices initially applied to large foreign aircraft in Australian sovereign territory, and to Australian aircraft in other ICAO states' sovereign territory. It did not apply to large or small aircraft that were involved only in domestic travel.

Between April 1951 and July 2001, Annex 13 has been reviewed and amended to apply to all aircraft accidents and incidents over a specific weight and gives specific rights to not only the country of aircraft registration, but also to the countries where the aircraft was designed and manufactured. However, while its applicability has changed, most of the basic tenets of the Annex have not.

Paragraph 3.1 of Annex 13, 'Objective of the Investigation' states:

The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It is not the purpose of this activity to apportion blame or liability.

At paragraph 5.4.1 of Annex 13, the recommended practice states:

Any judicial or administrative proceedings to apportion blame or liability should be separate from any investigation conducted under the provisions of this Annex.

The two quotes from Annex 13 to the Chicago Convention make two things very clear.

1. Aircraft accident and incident investigation under ICAO standards and recommended practices is about preventing future accidents, and
2. Nothing in the ICAO agreements prevents a state from conducting proceedings to apportion blame or liability as a separate exercise to a safety investigation.

ICAO also strongly supports the practice of Human Factors and produce a large amount of Human Factors guidance material, including guidance material for safety investigations.

THE TRANSPORT SAFETY INVESTIGATION ACT 2003

Annex 13 to the Chicago Convention initially applied only to aircraft involved in international air navigation. However, all signatories to the Chicago Convention were faced with the question of what standards and practices should they apply to domestic aircraft accident and incident investigation. Most countries, including Australia, elected to simply mirror the requirements of Annex 13 in the legislation that applied to domestic operations.

The development of the legal requirements for the investigation of Australian domestic accidents and incidents took place in the 1960s and in the subsequent decades, was amended in line with the amendments to Annex 13. Initially, these requirements were given effect within the Air Navigation Act (1920). However, when in 1999, the then Bureau of Air Safety Investigation became a multi modal safety body known as the ATSB, the legislation was reviewed. On 1 July 2003 the *Transport Safety Investigation Act 2003* (TSI Act) and associated regulations came into effect. The Act and regulations included a continued authority for the investigation of aviation and marine accidents and incidents, and new powers to investigate interstate rail accidents and incidents.

Section 7 of the TSI Act, 'Object of this Act', states:

The main object of this Act is to improve transport safety by providing for:

- (a) the reporting of transport safety matters; and
- (b) independent investigations into transport accidents and other incidents that might affect transport safety; and
- (c) the making of safety action statements and safety recommendations that draw on the results of those investigations; and
- (d) publication of the results of those investigations in the interests of transport safety.

Another object of this Act is that, during the investigation of a transport safety matter under this Act, there be co-operation between the Executive Director (of the ATSB) and any other Commonwealth agency or person having powers under another law of the Commonwealth to also investigate the matter.

The following are not objectives of this Act:

- (a) apportioning blame for transport accidents or incidents;
- (b) providing the means to determine the liability of any person in respect of a transport accident or incident;
- (c) assisting in court proceedings between parties (except as expressly provided by this Act);
- (d) allowing any adverse inference to be drawn from the fact that a person is subject to an investigation under this Act.

Section 27 of the TSI Act , ‘Reports not Admissible as Evidence’, reinforces these intentions by stating;

- (1) A report under section 25 is not admissible in evidence in any civil or criminal proceedings.
- (2) Subsection (1) does not apply to a Coronial inquiry.
- (3) A draft report under section 26 is not admissible in evidence in any civil or criminal proceeding.

These sections of the TSI Act reflect the international agreements contained in Annex 13 to the Chicago Convention and expand the concepts to cover all transport accident and incident investigations under the Act. That is, under Australian law, investigations carried out by the ATSB under the TSI Act, are for the purposes of maintaining and improving transport safety and not for apportioning blame or liability.

Apart from international standards and domestic law, and the need to stay focused on why an accident occurred, rather than who to blame, there are two other very practical reasons why safety investigations are non-punitive.

Firstly, the investigation of aircraft accidents is a process where often, much of the evidence that is needed to determine why it occurred has been destroyed. Secondly, because of the complexity of the systems and events involved, it is most often necessary to seek the full cooperation of involved parties and other experts to enable a comprehensive understanding of the circumstances of the occurrence. This could include such parties as those that were responsible for the design, construction, maintenance and operation of the aircraft. If the nature of a safety investigation was more like that conducted by a criminal or civil court which primarily seeks to apportion blame or assign liability, such cooperation is less likely to be forthcoming. Indeed, such parties may find themselves as ‘defendants’ in the investigation if such a model was used. The result would be that vital safety information that may help to prevent similar accidents could be denied to the safety investigation and an opportunity to improve safety for the benefit of the travelling public, lost.

Secondly, the nature of what is acceptable evidence within a judicial investigation which seeks to apportion blame or assign liability, and what is acceptable evidence within a safety investigation, is very different. Because of the nature of major accidents and the process of trying to establish why the accident occurred, most safety investigations involve varying degrees of circumstantial evidence based on probability rather than proven fact. Also the evidence of an inquiry-type investigation does not collect evidence in the way evidence for a criminal or civil proceeding is collected.

This is particularly true of many Human Factors issues. Such evidence is not generally acceptable in judicial investigations, or to the same degree. If safety investigations were forced to follow strict rules of evidence to determine its findings, such a requirement could severely limit the investigative agency in terms of the findings it could confidently make, and mitigating safety action it could recommend.

Even when a major accident is put into the hands of the judiciary it is investigated under the rules of a Coronial or Royal Commission of Inquiry. A Judicial Inquiry does not follow the same rules of evidence as does a criminal or civil court proceeding. In fact, an inquiry is able to consider and make findings based on exactly the same type of evidence as a safety investigation authority. And, if grounds for punitive or liability proceedings are apparent, an investigation to determine blame or liability must be carried out separately to that inquiry using stricter rules of evidence.

Human Factors in aircraft accident and incident investigation is concerned with the application of knowledge about how people function. The goal of the application is to understand why people and organisations involved in the design, manufacture, maintenance and management of aircraft operations make errors that lead to, or have the potential to lead to aircraft accidents.

The goal of understanding why people and organisations involved in aviation make errors is to produce safety reports and recommendations for change that will reduce the likelihood of aircraft accidents.

Human Factors has evolved from an initial focus on the engineering interface between a machine and its operator to a broader focus of looking at the interface between all facets of a system and their interface with all the people operating the system.

Human Factors are a critical part of the safety investigation process and are at the heart of most aircraft accidents.

The Australian Transport Safety Bureau is responsible for conducting all safety investigations into aircraft accidents and incidents within Australia.

International agreement and practice, and Australian domestic law specify that safety investigations are not for the purposes of allocating blame or liability.

The Australian Transport Safety Bureau's conduct of safety investigations is in complete accordance Australia's international agreements and Australian law, and international best practice.

The Australian Transport Safety Bureau functions in a similar way to a Coronial or Royal Commission of Inquiry in that none of these three types inquiry follow the rules of evidence that are used in a criminal or civil proceeding.

Nothing in international agreement or Australian law prevents other Australian agencies or organisations from conducting investigations into aircraft accidents that are for purposes other than improving aviation safety. However, this is not the role of the ATSB.

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