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Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT

Aviation Research and Analysis Report –B20050205

Final

How Old is Too Old? The impact of ageing aircraft on aviation safety

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How Old is Too Old?

The impact of ageing aircraft on aviation safety

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Cover photograph and Page 9: Aloha Airlines flight 243 (AAP Image Library)

Abstract

The purpose of this report was to examine the relationship between ageing aircraft and flight safety, to determine the chronological age of the Australian aircraft fleet, and to review current and future directions for the management of ageing aircraft.

Age can be managed by retiring the aircraft and purchasing a newer aircraft or through adequately maintaining ageing aircraft through additional and specific maintenance. This requires cooperation between regulators, manufactures, maintainers, operators, and owners. Continuing airworthiness programmes and Supplementary Inspection Programmes are methods of ensuring adequate maintenance. Ageing of an aircraft can be a safety issue, but with adequate maintenance, the consequences of ageing can be mitigated. Current and future maintenance programmes will act as a preventative measure to reduce the safety risk associated with ageing aircraft, but only if the operators adhere to the programmes.

In Australia, the average age of fleet of turbofan aircraft is low, and has been is decreasing. Multi-engine turbofan aircraft with a maximum take-off weight between 50,001 and 100,000 kg had the lowest average age in 2005 at just 6 years. This was the only aircraft category whose average age decreased over the period 1995 to 2005. The turbofan aircraft with a maximum take-off weight of more than 100,000 kg had an average age of 11 years in 2005. The high-capacity turbofan aircraft receive extensive continuing airworthiness support from the manufacturers. The low age and extensive continuing airworthiness support provide a double defence to ensure the safety of the Australian multi-engine turbofan aircraft fleet.

The piston engine fixed-wing aircraft fleet, by contrast, had the highest average age at 30 years. These aircraft often do not receive the same level of continuing airworthiness support from the manufacturer as the turbofan aircraft. In Australia, multi-engine piston aircraft are often used in regular public transport and charter operations, and therefore the high average age needs to be considered in relation to their safe operation in passenger services.

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 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 purpose of this report was to investigate the relationship between ageing aircraft and flight safety, as well as to examine current and future methods for ensuring the safety of ageing aircraft. This research examined the literature on aircraft age in relation to safety and reliability, and statistical data on the age of the Australian aircraft fleet.

Ageing processes

There is no single criteria that defines an aircraft as 'old' (Kizer, 1989). The age of an aircraft depends on factors including the chronological age, the number of flight cycles, and the number of flight hours. Determining the age of the aircraft is further complicated by the fact that individual aircraft components age differently depending on these factors.

Some ageing mechanisms such as fatigue occur through repetitive or cyclic loading. While others, such as wear, deterioration, and corrosion occur over time. If not managed, these ageing mechanisms can be a significant safety concern.

Age related accidents and incidents

Around the world, there have been a number of aircraft accidents relating to age. One of the most significant of these accidents was Aloha flight 243. On 28 April 1988, the Boeing 737-200 aircraft sustained an explosive decompression. At the time of the accident, the aircraft had been in service for 19 years and had accumulated a high number of flight cycles[1]. The combination of fatigue and corrosion affected the fuselage skin and led to the failure of the structure.

In addition to the Aloha flight 243 accident, there have been a number of other accidents and incidents related to ageing aircraft. One such age related accident occurred on 12 April 1989, when the rudder of a British Airways Concorde aircraft, registration G-BOAF, fractured and separated in flight. The rudder separation occurred due to ageing of the composite structure. Another accident attributed to ageing was TWA flight 800, on 17 July 1996, where deterioration of the wiring in the wing centre section led to the fuel tank explosion. More recently in 2000 and 2001, Ansett Australia grounded their Boeing 767 aircraft fleet due to structural cracks found in the engine pylons and empennage. These accidents and incidents have highlighted the safety implications resulting from aircraft ageing and have demonstrated the importance of effective continuing airworthiness programmes.

1 A flight cycle is one completed takeoff and landing.

Age of the Australian aircraft fleet

An examination of the Australian aircraft fleet statistics showed that in Australia, aircraft age varies widely between aircraft of different sizes. The average age of medium size multi-engine turbofan aircraft with a maximum take-off weight between 50,000 and 100,000 kg was 6 years in 2005. This was 2 years lower than the average age in 1995. The decrease in average age is possibly a result of the sale overseas and return to financiers of Ansett Australia's aircraft fleet, and the purchase of new aircraft by the other airlines. Ansett's fleet was relatively old and included one of the oldest Boeing 767 fleets in the world.

The average age of Australia's large multi-engine turbofan aircraft (with a maximum take-off weight greater than 100,000 kg) is also low. In 2005, the average age of aircraft in this category was 11 years. In recent years, airlines in Australia that operate high-capacity aircraft have chosen to acquire new aircraft rather than spend the additional money that may be needed to maintain ageing aircraft.

The Australian aircraft fleet of multi-engine turboprop aircraft (with a maximum take-off weight of 27,000 kg or less) had an average age of 18 years in 2005. The small multi-engine turbofan aircraft (with a maximum take-off weight between 5,700 and 50,000 kg) had an average age of 16 years in 2005. While both of these categories of aircraft have relatively low average ages, there was a slight increase in their average ages over the period 1995 to 2005. If the average age continues to increase there may be concern about age-related safety issues.

The aircraft with the highest average age are the single-engine and multi-engine piston fixed-wing aircraft (with a maximum take-off weight of 5,700 or less). Multi-engine fixed-wing aircraft typically used in charter and small low-capacity regular public transport[2] (RPT) had an average age of 31 years in 2005. This was an increase of 10 years from the average age in 1995, indicating that very few new aircraft entered service, and much of the existing fleet remained on the register.

Many regional airlines use multi-engine piston aircraft for low capacity RPT operations, particularly to service remote communities. These airlines often operate with small profit margins that limit their capacity to acquire new or newer aircraft. Operators are therefore left with the option of maintaining their ageing aircraft with only limited continuing airworthiness support from the manufacturer.

The single-engine piston fixed-wing aircraft had an average age of 30 years in 2005. This was an increase in the average age of 7 years over the last decade. These aircraft, typically used in general aviation, might not receive continuing airworthiness support from their manufacturer. In addition, the maintenance requirements are not as stringent for general aviation aircraft compared with regular public transport aircraft.

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2 The ATSB refers to regular public transport operations conducted in aircraft with a maximum capacity of 38 seats or less, or a maximum payload or 4,200 kg or below, as low capacity RPT.

Management of aircraft ageing

Management of aircraft ageing begins in the design phase. An aircraft should be designed taking fatigue and corrosion into consideration. Damage tolerance is a popular method of designing for fatigue. This method assumes that cracks will occur, but can be managed by regularly inspecting the crack prone area. Such inspections ensure that cracks can be identified before they reach a predetermined critical length. Aircraft should also be manufactured using materials that are not prone to corrosion and designed to ensure adequate water drainage.

There are two basic approaches for managing the ageing process. The first method is to replace the aircraft, while the second method is adequate maintenance of the aircraft.

In Australia, high-capacity RPT operators have generally controlled aircraft age by investing in the acquisition of new aircraft to replace their older aircraft. The resultant savings in maintenance costs balance the expense of acquiring new aircraft. While the new aircraft still require maintenance, this is generally less demanding and hence less expensive than maintaining ageing aircraft.

The second method of controlling aircraft ageing, ongoing additional and specific maintenance, is generally most common for general aviation and low-capacity RPT aircraft. These sectors of the aviation industry operate under tight economic constraints with limited capacity to acquire new aircraft, and in any case, the absence of suitable new production aircraft restricts their options for acquiring new aircraft. When maintenance is chosen as the mechanism to control ageing, the programme needs to take into account in-service defects as well as analysis of flight critical components. Manufacturer support is important to ensure the thoroughness of the programme.

Manufacturers of high capacity aircraft have the obligation and resources to provide the continued airworthiness of ageing aircraft. Manufacturers of small aircraft, however, may not have the resources to support their ageing fleet. Some manufacturers of general aviation aircraft have gone against this trend and provided Supplementary Inspection Programmes for ageing aircraft types. Supplementary Inspection Programmes are maintenance schemes that are used after an aircraft reaches a certain number of flight cycles and flight hours. They provide a comprehensive maintenance programme, taking into account in-service information and analysis.

International Directions

Rule-makers in the United States and Europe have been examining the issue of ageing aircraft since the Aloha flight 243 accident. Rules have been adopted and proposed covering the continuing airworthiness of ageing aircraft, the preparation and implementation of damage tolerance based inspection programmes, and the life-limiting of aircraft due to widespread fatigue concerns.

In addition, research programmes such as the National Aging Aircraft Research Program (NAARP) run by the Federal Aviation Administration (FAA) have been working with industry to improve the safety of all categories of ageing aircraft. The National Aging Aircraft Research Program has been expanded to cover not only structural ageing, but also all other safety critical aircraft components.

Conclusions

Australia's high capacity regular public transport aircraft are young, with average ages for the various types below 11 years. However, the single-engine and multi-engine piston fixed-wing aircraft are old and getting older. To ensure the safety of the ageing piston aircraft fleet additional and specific maintenance is required.

Adequate maintenance requires the participation and cooperation of aircraft manufacturers, regulatory authorities, owners, operators, and maintainers. Manufacturers need to ensure continued airworthiness by conducting additional analysis on ageing aircraft and rectifying unexpected problems. Owners, operators, and maintainers need to adequately maintain their aircraft and report defects to the manufacturer and regulatory authorities, who in turn, must ensure that safety-related maintenance information is disseminated quickly among other operators of the type.

Current and future maintenance programmes will act as a preventative measure to reduce the safety risk associated with ageing aircraft. As emphasised by CASA (see Section 8.2), these programmes will only increase safety if operators adhere to them.

ABBREVIATIONS

AAIB	Air Accidents Investigation Branch (United Kingdom)
AUF	Australian Ultralight Federation
CASA	Civil Aviation Safety Authority
CAR	Civil Aviation Regulation
DOTARS	Department of Transport and Regional Services
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration (United States)
FAR	Federal Aviation Regulation (United States)
GA	General aviation
JAA	Joint Aviation Authorities (Europe)
JAR	Joint Aviation Regulation (Europe)
LAME	Licensed aircraft maintenance engineer
MTOW	Maximum take-off weight
NAA	National Airworthiness Authority
NAARP	National Aging Aircraft Research Program
NPA	Notice of proposed amendment
NPRM	Notice of proposed rulemaking
NTSB	National Transportation Safety Board (United States)
RPT	Regular public transport
SID	Supplementary Inspection Document
SIP	Supplementary Inspection Programme
TBO	Time between overhaul
TSB	Transportation Safety Board (Canada)

1 INTRODUCTION

The overall objective of this report was to examine the relationship between ageing aircraft and flight safety. This included an examination of statistical data on the chronological age of the Australian aircraft fleet, and a review of the literature on aircraft age and reliability.

Specifically, the objectives were to:

- examine key safety issues related to aircraft age and those that have been previously identified in accident investigations;
- explore an aircraft's chronological age and relationship to aviation safety;
- identify the factors that contribute to aircraft age and the components that are susceptible to ageing;
- determine the chronological age of the Australian aircraft fleet and how this has changed over time; and
- examine the national and international framework for managing aircraft ageing issues and identify future directions for the management of ageing aircraft.

1.1 Aircraft age

Aircraft age is difficult to define. It is often referred to as simply the chronological age of an aircraft, however, this excludes many important factors. In fact, aircraft age is a combination of the chronological age, the number of flight cycles, and the number of flight hours. Determining an aircraft's age is made even more complex by the fact that individual aircraft components will age at different rates.

Chronological age is particularly relevant for corrosion, as the effects of corrosion increase over time. The effects of wear on components will also increase over time. Flight cycles[3] will cause fatigue in aircraft wings, pressurised sections, and other structural components. The number of flight hours also cause fatigue and so is another important measure of an aircraft's age.

Given the above influences, it is difficult to directly compare aircraft. However, all these factors need consideration when determining if an aircraft is 'old'. Furthermore, other factors can affect the ageing process. These include the maintenance on an aircraft, the type of aircraft operations, and the operational environment. Difficulty arises in quantifying the effective increase in age with additional exposure to these factors. Nevertheless, it is known that these factors will increase the pace and effects of the ageing process (Swift, 1999).

This report predominantly uses chronological age, as there is insufficient data to examine the Australian aircraft fleet in terms of hours flown and flight cycles.

3 Additional pressurisations can result from aircraft climbing to divert to an alternate aerodrome from a missed approach.

1.1.1 Definitions of age

There are a number of terms and expressions used in the literature on ageing aircraft, many of which vary in their meaning and intent. This report refers to a number of age-related terms to examine the ageing issue. These terms are defined below.

Age	Includes three measures; chronological age, number of flight cycles, and number of flight hours.
Chronological age	The length of time since the manufacture of an aircraft or an aircraft component. Chronological age is also referred to as calendar age.
Ageing	Refers to the ageing process and includes two factors: 1) age as defined above (ie chronological age, number of flight cycles, and flight hours); and 2) age-related effects – including fatigue, corrosion, deterioration, and wear.
Ageing process	The process through which an aircraft or component experiences the effects of increasing age.

1.1.2 Design life

Aircraft are typically designed to a specific lifespan, known as the design life of the aircraft. This lifespan allows designers to ensure that throughout the specified life, the aircraft's structure and components operate reliably. Generally, aircraft have a 20-year lifespan with a specified number of flight hours and flight cycles.

Manufacturers test and analyse an aircraft type to ensure that the aircraft can withstand use for the period of the design life. Hence, with regular maintenance, operators can expect reliable service throughout the design life.

Exceeding the design life may be possible in some circumstances, but is likely to increase maintenance costs. In some cases, the cost of maintenance may exceed the replacement cost of the aircraft. As such, it may not be economically viable for an aircraft to continue flying at some point during its life. This has led to the design life being known as the 'economic' design life. Aircraft owners may continue to invest in maintenance rather than outlay the large sums required to acquire new (or newer) aircraft.

Owners or operators need to consider the continuing airworthiness support when deciding to extend the life of their aircraft past the design life. In particular, consideration needs to be given to the availability of maintenance schedules or data on the reliability of an aircraft. For general aviation and low-capacity RPT aircraft, this information is often not available. Cessna is one manufacturer that has developed post-design life maintenance schedules know as Supplementary Inspection Programmes for some of their aircraft types (see Section 7.1.2). In 2005, 26% of the multi-engine piston fixed-wing aircraft with a maximum take-off weight MTOW of 5,700 kg or less was Cessna aircraft.

1.1.3 Economics and aircraft age

Economic factors generally influence an airline's decision to operate their aircraft beyond their economic design life. Aircraft owners and operators generally have been less willing to outlay the large acquisition costs for new aircraft, in comparison to a perceived smaller cost of maintenance (Brannen, 1991). This is particularly true for many small airlines and general aviation operators, who are often unable to afford the high replacement costs. These operators will frequently choose to fly their aircraft past their economic design life.

1.2 Accidents involving ageing aircraft

One of the most significant accidents relating to aircraft ageing is that of Aloha flight 243. The accident involved an explosive decompression in a 19 year old Boeing 737-200 aircraft on 28 April 1988 (described in Section 2.2). According to the United States National Transportation Safety Board (NTSB) accident report, the aircraft had 35,496 airframe flight hours and 89,680 flight cycles, which is an average flight time of 25 minutes. The accident aircraft was considered to be old due to the high number of flight cycles. In addition, the aircraft was operated in a salt water environment (NTSB, 1989).

Although not the first accident where age was an important contributing factor, Aloha flight 243 became a catalyst for a number of significant events, including:

- the industry reviewing all aspects of aircraft life cycles;
- a review of maintenance procedures; and
- the implementation of the Federal Aviation Administration's (FAA) 'National Aging Aircraft Research Program'.

A number of other accidents around the world have highlighted ageing as a safety issue. These include the Concorde G-BOAF accident in 1989, where a section of the rudder fractured due to ageing of the adhesively bonded structure (Hole, 1989); and the accident of TWA flight 800 in 1996, where the fuel tank of the Boeing 747-100 exploded, due to deterioration of wiring inside the wing centre section fuel tank (NTSB, 2000).

In addition, there have been serious incidents due to ageing. One such incident was the structural cracks found in Ansett Australia's Boeing 767 aircraft, engine pylons, and empennage, in 2000 and 2001. The Ansett incident highlighted the need for effective continuing airworthiness programmes (ATSB, 2002).

These accidents and incidents demonstrate the importance of age as a contributing factor in aviation safety. Due to the increasing age of some sections of the Australian aircraft fleet there is a need to investigate this issue more closely.

2 PROCESSES OF AIRCRAFT AGEING

The two key processes that lead to aircraft ageing are fatigue and corrosion. These processes generally affect the aircraft structure, but can also affect wiring, flight controls, powerplants, and other components. Fatigue and corrosion can work independently from one another, or they can interact. The interaction between fatigue and corrosion can increase the rate of ageing to a greater extent than that due to either process alone.

2.1 Fatigue

Fatigue predominately takes place in metal components, but it can also affect non-metallic materials. Fatigue occurs through cyclic loading patterns, where a component is repeatedly loaded. Bending a metal paper clip backwards and forwards is an example of fatigue; the paper clip will not break if only bent once, however, if it is repeatedly loaded, it will eventually break. Fatigue failures will often take place at loads much lower than the materials ultimate strength.

Generally, the initiation point for fatigue will be a microscopic crack that forms at a location of high stress, such as a hole, notch, or material imperfection. The crack will then grow as loads are repeatedly applied. If not detected and treated, the crack will eventually grow to a critical size and failure will occur at loads well below the original strength of the material.

The relationship between repetitive loading and fatigue crack growth, creates a link between fatigue related ageing, the number of flight cycles, and the number of flight hours that an aircraft has accumulated.

Aircraft components that are susceptible to fatigue include most structural components such as the wings, the fuselage, and the engine(s).

2.1.1 Fatigue and aircraft use

Different types of aircraft operations can influence the rate of fatigue, as they subject the aircraft structure to different structural loads. Operations that have the potential to increase fatigue include those likely to involve high-g manoeuvres, such as:

- Aerobatics;
- aerial mustering; and
- aerial agriculture.

These operations produce increased and variable amounts of loading due to the high gust and manoeuvre loads. With this type of loading on the airframe, there will be an increased rate of fatigue.

In addition, for pressurised aircraft, the length of a flight sector influences the fatigue rate. As an aircraft climbs, the aircraft structure will expand due to pressurisation, conversely as an aircraft depressurises during the descent the aircraft structure will contract, thus producing fatigue. Hence, the number of pressurisation cycles is more important than the length of time an aircraft is pressurised.

An aircraft operated on short sectors will be subjected to a greater number of pressurisation cycles compared to another aircraft with the same number of flight hours that is operated on long sectors, thereby increasing the rate of fatigue. Fatigue due to the short sectors was a contributing factor in the Aloha flight 243 accident. The average flight duration of the aircraft involved in the Aloha flight 243 accident was just 25 minutes.

2.1.2 Analysis of fatigue

The effect of fatigue on components can be quantitatively estimated by formal methods of fatigue analysis. Mathematical modelling can predict the rate of crack growth and determine the crack length at which a fracture may occur. This length is known as the critical crack length. This type of fatigue analysis can be used to determine inspection intervals and/or retirement times.

To predict the rate of crack growth and the critical crack length, mathematical models take into account the expected loading on the aircraft over its design life and knowledge of the load paths within the structure.

2.1.3 Designing for fatigue

Fatigue was not considered in the design of early aircraft. Instead, the design criterion was maximum strength. Once fatigue was identified as a failure mechanism it was recognised that it needed to be managed, and that management of fatigue should begin in the design phase.

The increased understanding of fatigue led to the introduction of design techniques such as safe-life, fail-safe, and damage tolerance. By today’s standards, some earlier methods are no longer considered best design practice. However, aircraft designed to those standards still form part of the Australian aircraft fleet. The different design methodologies are discussed below.

Safe-life

Safe-life (also known as safety by retirement) was introduced in the 1940s after fatigue was recognised as a failure mechanism. It specifies a ‘safe’ lifespan within which there is no significant risk of structural failure of a component.

The replacement of components must occur before the component reaches its safe-life to ensure flight safety. Today, the safe-life methodology is only used in a few applications such as the design of some general aviation aircraft, and the design of some structures where the critical crack length is too small to be detected prior to a failure.

Fail-safe

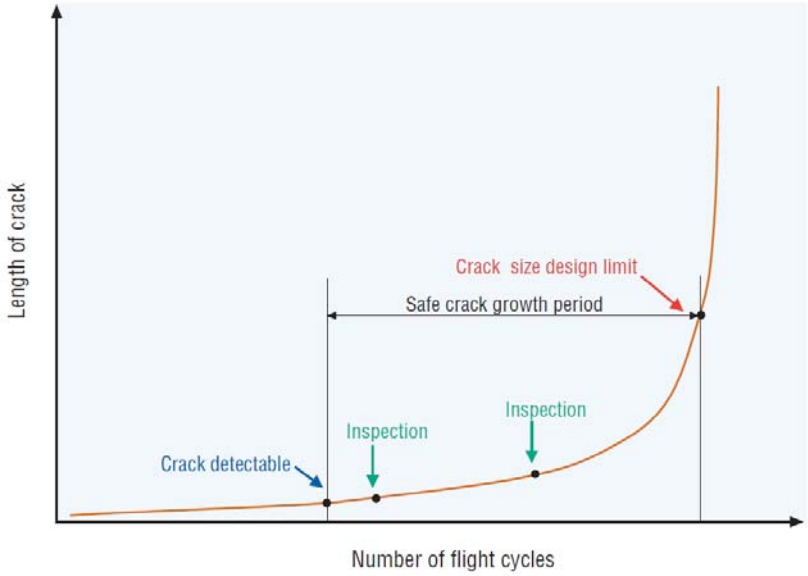
The fail-safe design principle was introduced in the 1950s as an improvement to safe-life. A fail-safe structure should be able to sustain the limit load even when one of the elements has failed (Stinton, 1966). To achieve this requirement, a fail-safe design uses backup structures and secondary load paths. This principle relies on the fact that if the main load path fails, there is a secondary load path to ensure the safety of the aircraft until the failure can be detected.

Damage tolerance

Damage tolerance, or safety by inspection, was developed as a design philosophy in the 1970s as an improvement on the fail-safe principle. The damage tolerance approach is based on the principle that while cracks due to fatigue and corrosion will develop in the aircraft structure, the process can be understood and controlled. A key element is the development of a comprehensive programme of inspections to detect cracks before they can affect flight safety. That is, damage tolerant structures are designed to sustain cracks without catastrophic failure until the damage is detected in scheduled inspections and the damaged part is repaired or replaced (see Figure 1).

In addition, damage tolerance takes into account initial material or manufacturing flaws by assuming an initial crack, which the fail-safe principle does not do.

Figure 1: Theoretical damage tolerance inspection regime to detect cracks before they become critical



A damage tolerant design should allow cracks to be detected before they reach the critical length that will lead to failure. To ensure that this occurs there should be at least two opportunities to detect the crack prior to it reaching its critical length (FAA, 2005b).

The damage tolerance philosophy uses testing and analysis to determine the critical crack length, the residual strength, and the inspection intervals. Tests include flight testing to determine the loads on the structure, and ground testing to determine the fatigue and crack growth characteristics. From the testing and analysis, the critical sites and components susceptible to fatigue can be determined. Fatigue analysis based on flight, ground, and pressurisation loads can then be used to determine crack growth performance and residual strength.

To increase the likelihood of finding a crack prior to a catastrophic structural failure, the structure should be durable. Durability of an aircraft structure comes from having a slow crack growth characteristic and the ability to contain or restrict the progress of damage.

The damage tolerance philosophy is used for transport category aircraft, such as aircraft certified under Federal Aviation Regulation (FAR) part 25. For other categories of aircraft certified under the United States Federal Aviation Regulations, the damage tolerance method may be used but is not mandatory; the safe-life or fail-safe methods may be used instead.

2.2 Corrosion

Corrosion is a time dependent failure mechanism that occurs as a result of chemical or electrochemical degradation of metal. Corrosion generally affects the aircraft structure, however, it can also affect electrical connectors and flight control cables.

Corrosion is more prevalent in marine and coastal environments where there is high humidity and salt water. Salt can increase the rate of the chemical reactions that initiate corrosion. This has significant safety implications for the structures of seaplanes, as they are constantly exposed to salt and humidity.

To prevent or slow down the rate of corrosion, an aircraft's design will incorporate a number of corrosion control methods. These include material selection, material coatings, joint design, and the use of water drainage. Corrosion cannot be eliminated in design, so regular maintenance and inspections are used as additional control measures.

The processes of fatigue and corrosion can interact, leading to an increased likelihood of structural failure. Corrosion can weaken the material and create locations of stress concentration. These locations of high stress are often initiation points for fatigue, and can lead to the failure of the structure earlier than predicted. The failure can also occur in unexpected locations, making detection prior to failure difficult. While corrosion can be a significant safety concern, the combination of fatigue and corrosion is of greater concern to safety than corrosion alone.

Case Study: Corrosion and fatigue – Aloha flight 243, 1988

Aloha Airlines flight 243 is an example of corrosion and fatigue interacting to produce the failure of a structure. The aircraft, a Boeing 737-200, sustained an explosive decompression as it reached cruise altitude (Figure 2). Approximately 5.5 metres of the cabin skin and supporting structure separated from the aircraft, leading to the decompression. Although the aircraft sustained extensive structural damage, it was able to land safely. However, during the decompression one flight attendant was fatally injured when she was swept from the aircraft (NTSB, 1989).

At the time of the accident, the aircraft was 19 years old and had completed 89,680 takeoffs and landings, with an average flight time of 25 minutes (Wanhill, 2002). The aircraft had spent most of its operating life flying between the Hawaiian Islands, exposing it to a highly corrosive environment.

An additional factor was the design of one type of joint (or skin splice) used in the construction of the fuselage. The joint was cold bonded, using an epoxy impregnated scrim cloth, as well as riveted. The cold bonding was designed to transfer the pressure loads evenly across the joint rather than through the rivets.

Figure 2: Aloha Airlines flight 243

Source: AAP Image Library

As the rivets were not designed to be load bearing, knife-edges in the aircraft skin where the skin meet the rivet were deemed acceptable (Wanhill, 2002). However, problems with the cold bonding process meant loads were transferred through the rivets. Hence, the design of the rivets became a problem as knife-edges acted as fatigue crack initiation sites.

The design the Boeing 737-200 aircraft fuselage used the fail-safe design principle that involved the concept of a ‘lead-crack’. In this method, a crack in the fuselage was expected to grow along the skin until it reached a fuselage frame. At the frame, the crack would turn at right angles and a triangular tear would blow out. This was designed to produce only a small hole in the fuselage, which would safely release cabin pressure (Aubury, 1992).

However, at the knife-edges, a number of small fatigue cracks formed in the same longitudinal skin splice and rapidly joined. The small fatigue cracks were too small to be detected by inspection. When the cracks joined, they travelled across multiple frames, meaning that the fail-safe triangular tear and safe blow-out did not occur. This type of failure mechanism, where small cracks form and rapidly join producing failure, is known as multiple site fatigue damage. The Aloha Airlines accident showed that the lead-crack design method is not compatible with multiple site fatigue damage because the cracks joined across multiple frames.

As a result of this dramatic accident, the hazardous combination of fatigue and corrosion was brought to the attention of industry. The safety of ageing aircraft became a priority, with hearings on ageing held in the Aviation Subcommittee of the United States Congress. In addition, the National Aging Aircraft Research Program was formed, to investigate the issue further.

The National Aging Aircraft Research Program has evolved over time and researches many aspects of aircraft ageing, including structural integrity, powerplants, electrical systems, and mechanical systems. The programme investigates the reasons for aircraft ageing and researches methods for mitigating risks to safety. Risk mitigation strategies include the development of new materials, designs, analysis methods, and inspection techniques.

3 COMPONENTS THAT AGE

The various components that make up an aircraft will age differently depending on their materials and usage. Of particular importance are components that are critical to flight safety. Flight critical components can be categorised into three areas:

- structures;
- powerplants; and
- other systems.

3.1 Structures

Aircraft structures include the fuselage, wings, empennage, and flight control surfaces. These components are particularly susceptible to fatigue as they often experience cyclic and dynamic loading. Generally, aircraft structures are constructed of metal so they are also at risk of corrosion.

Although the majority of aircraft structures are metallic, other materials such as carbon fibre composites, wood, or canvas can be used. These materials will not necessarily be subject to the same ageing processes as traditional metallic structures, however, the ageing process will occur in other ways.

3.1.1 Structural reliability

The overall strength of an aircraft structure will depend on the individual strengths of the components that make up the structure. The strength of one component can be different to the strength of another component with the same design and manufactured from the same materials. This difference may result from manufacturing variations or the reduction in the strength of the component because of fatigue or corrosion. Because of these differences, there will always be some variability in the failure times of components of the same design (ATSB, 2005b).

Case study: Environmental degradation – Powered hang glider accident, Whyba Station, Ivanhoe, 1998

The integrity of non-metallic aircraft structures can be affected by ageing. For example, on 24 October 1998, an Airbourne Edge powered hang glider impacted the ground near Ivanhoe in north-western New South Wales, fatally injuring the pilot and passenger. The aircraft experienced severe directional changes and impacted the ground with a steep nose down attitude (AUF, 1998).

The Australian Ultralight Federation (AUF) investigation of the accident found that the aircraft had been stored undercover in a hangar during summer, when severe turbulence meant the aircraft did not fly. However, for the rest of the year, the aircraft was exposed to the elements, as it was rigged and stored outside. Hence, the aircraft had been exposed to ultra violet light for long periods of time.

The sailcloth wing of the Airbourne Edge ultralight was constructed from a nylon-polymer fabric. The upper surface wing skin of the accident aircraft was found to be severely degraded by ultra violet light damage, with approximately 50% of the fibres broken.

The AUF identified the deteriorated sailcloth wing as one of the main contributing factors to the accident. This accident highlights the effect environmental conditions can have on nylon-polymer fabric wing skins.

3.2 Powerplants

Aircraft powerplants are generally overhauled regularly to replace components that are susceptible to ageing. The components in various types of engines will age differently. There are two types of engines discussed in this section; they are piston engines and turbine engines.

3.2.1 Piston engines

Piston engines typically power small aircraft, weighing less than 5,700 kg, and generally have a defined life known as the time between overhaul. At the scheduled overhaul, components that are susceptible to ageing are replaced, including those components that operate under high stresses. Generally, the major dynamic components in piston engines do not experience fatigue and as a result do not have a fatigue life. Rather, the lives of these components are determined through on-condition monitoring.

The number of flight hours and the calendar age of the engine are both important considerations when defining the time between overhaul. The engine(s) in an aircraft that is flown infrequently can deteriorate and the ageing process can occur at a faster pace than for the engine(s) in an aircraft flown on a regular basis (Lycoming, n.d.). With infrequent use, cylinders can rust, abrading the piston rings and resulting in high oil consumption and a loss in power (Landsberg, 2000). In addition, a lack of movement can lead to deterioration in lubrication.

3.2.2 Turbine engines

Unlike piston engines, many components in turbine engines fatigue as a result of the extreme operating environment, including very high temperatures, pressures, and rotational forces. Components in turbine engines can experience temperatures of 1,100^{o}C. Changes in the operating temperature and in the engine speed can induce fatigue in the engine’s components. Hence, turbine engine components have stringent retirement times. There are a number of factors which affect the rate of fatigue and hence the retirement time. These factors include the amount of use, the type of operations flown, and the engine model (Tumer & Bajwa, 1999).

The engine(s) of an aircraft flown on short-haul operations will generally have increased wear and heat damage compared with the engine(s) of an aircraft flown on long-haul flights (Tumer & Bajwa, 1999). The frequent stopping and starting of the engine that occurs in short-haul operations can produce rapid changes in temperature and increased cyclic fatigue. The increased fatigue damage that occurs on short-haul flights leads to the time between overhaul being governed by the number of flight cycles as well as by the number of flight hours.

3.2.3 Ageing of helicopter rotor blades

Helicopter main rotor blades operate under alternating loads, which can induce fatigue cracking. Typically, using normal inspection methods, the critical crack length for a rotor blade can be too small to detect prior to failure. Therefore, a safe-life for the retirement time will generally be given in both flight hours and chronological age.

However, there are uncertainties in predicting main rotor blade operational loads due to factors such as:

- variations in the operating speeds;
- variations in loads at low speed; and
- interactions with the environment.

These factors create uncertainties in predicting load spectrums and fatigue growth, and consequently, the retirement time of the rotor blades need to be calculated to provide a large margin for safety (ATSB, 2005b).

Case study: Helicopter main rotor blade fatigue

On 20 June 2003, a Robinson R22 helicopter, registration VH-OHA, sustained a catastrophic failure of one of the main rotor blades. The two occupants of the helicopter, a flight instructor and student, were fatality injured in the accident. The main rotor blade of the accident aircraft had been in-service for approximately 2,050 hours and for 11 years and 9 months (ATSB, 2005b). The fractured blade is shown in Figure 3.

Figure 3: The fractured main rotor blade of VH-OHA

Source: ATSB (2005)

Prior to the accident (in April 2003) the helicopter had been taken in for maintenance, due to a rapid onset of vibration in the main rotor blade. At this time, the 100 hourly inspection and an engine overhaul were also carried out. The maintenance organisation followed the maintenance instructions but was unable to rectify the vibration problems. The problem was discussed with a number of experienced maintenance engineers, however, the source of the vibrations could not be determined. Eventually, the vibration was reduced to within tolerance levels and the helicopter returned to service. It has since been established that this type of vibration is a warning sign of fatigue in the main rotor blades (ATSB, 2005b).

The ATSB found that the blade failed due to fatigue crack growth at the blade root fitting. There was also an area of adhesive de-bond between the rotor blade skin and the root fitting (ATSB, 2005b).

A similar accident occurred in Israel on 29 February 2004. The main rotor blade of the Robinson R22 helicopter failed at the same location as VH-OHA and showed signs of a similar adhesion disbond and corrosion. Similarly to VH-OHA, the blade of the Israeli accident helicopter failed before reaching its in-service retirement time. The Israeli accident helicopter blade had 1490 hours in-service and was 11.8 years old. At the time of both these accidents, the retirement time for the blade was 2,200 hours in-service or 12 years (ATSB, 2005b). The retirement time of the existing type of main rotor blade has since been reduced and a new blade type has been introduced.

Fatigue, due to the alternating loading on the blades, was a known safety issue in helicopter main rotor blades prior to the accident. There was a retirement time on the Robinson R22 helicopter main rotor blades to ensure, that under normal operations, fatigue cracks would not exceed the critical length. Nevertheless, both these accidents showed that the retirement time did not provide a sufficient factor of safety.

3.3 Systems

Aircraft systems can be defined as the non-structural components (excluding the powerplants). These components include items such as:

- electrical wiring and cables;
- fuel, hydraulic and pneumatic lines;
- electro-mechanical systems; such as pumps, sensors, and actuators; and
- flight instrumentation.

Aircraft systems will generally age with usage and calendar time. This ageing will often occur in the form of wear, deterioration, contamination, and embrittlement. Ageing of flight systems can generate fires and/or failures in flight critical systems.

3.3.1 Wiring

The ageing of aircraft wiring has become a particular area of concern as a result of high profile aircraft accident involving TWA flight 800. And the accident involving Swissair flight 111 off the coast of Nova Scotia, Canada on 2 September 1998, while not age-related, demonstrated the potentially devastating consequences of wire arcing. Accidents such as these have highlighted the potentially catastrophic consequences of ageing aircraft wiring.

The ageing of aircraft wiring often presents as a problem for the insulation rather than to the wiring itself. Insulation deterioration can result in arcing and electrical shorting, which can lead to equipment malfunction, or to smoke or fires. Wiring ages through the combination of a number of factors, including:

- contamination;
- physical abuse;
- environmental factors; and
- changes to the chemical properties of the insulator over time.

Contamination of wiring can be due to small objects, such as metal shavings from structural repairs, which work their way into wire bundles and cut the insulation. Another form of contamination comes from the exposure of wiring to fluids. Some fluids, such as washing solutions and hydraulic fluids, can change the properties of the insulation over time (Brown & Gau, 2001).

Physical abuse can generate breaking of the conductor or insulation. The abuse can occur in many ways, including:

- hanging items from wire bundles;
- handling the wire;
- using the wire bundles as hand or foot holds;
- using a bend radius that is too small; and
- through the dynamic environment where the wire flexes or rubs against other components.

Environmental degradation can affect the ageing of the wire insulator over time through the effects of humidity, temperature, and exposure to the sun. These environmental conditions can lead to embrittlement or degradation of the wire by changing the chemical properties of the insulator.

Changes in the physical and mechanical properties of the conductor and insulator occur from general ageing of the wiring. These changes include embrittlement, and subsequent cracking, of the insulator (Brown & Gau, 2001).

Inspection of wiring is difficult as it may be hidden, or inlayed into inaccessible locations within the aircraft. In addition, inspection techniques are often tedious and difficult. For example, it may be necessary to visually inspect each individual wire using a magnifying glass. The handling of the wires required in the visual inspection process can result in additional damage to the wires. Non-destructive inspection techniques improve the accuracy and reduce the risk of damage in wiring inspections.

Case study: Ageing wiring – TWA flight 800

On 17 July 1996, TWA flight 800 impacted the water in the Atlantic Ocean near New York (Figure 4). All 230 passengers and crew on-board the aircraft were fatally injured. The accident aircraft, a Boeing 747-100, was 25 years old and had accumulated 90,000 flight hours and 18,000 flight cycles.

Figure 4: Reconstruction of TWA flight 800

The NTSB investigation report stated that the accident was probably due to an explosion of the centre wing fuel tank, when the flammable fuel/air mixture in the tank ignited (NTSB, 2000). While the reason for the ignition could not be conclusively determined, the NTSB report stated that it may have been due to a short circuit outside the fuel tank. This short circuit allowed excessive voltage to enter the tank through electrical wiring, which ignited the fuel/air mixture. The report further stated that the condition of the wiring in the aircraft was not atypical for an aircraft of its age (NTSB, 2000).

After the TWA 800 accident, the FAA inspected the fuel tank wiring of a number of different aircraft types. The results of the Boeing 737 aircraft inspections suggested that there was a “near linear relationship between the age of the aircraft in total flight hours and the probability of either having a bare wire or one in which the insulation was chafed half way through the insulation” (Brown & Gau, 2001, p. 10).

3.3.2 Flight instrumentation

Flight instrumentation is another system that will wear over time. Instruments with components that move the most will generally exhibit the greatest wear. For example, gyroscopes are particularly susceptible to wear due to their constant high speed movement (Landsberg, 2000). Importantly, when flight instruments wear, their accuracy can degrade. Modern aircraft typically use glass cockpit displays that do not rely on mechanical gyros and eliminate many of the traditional problems associated with wear. As affordability of these systems improved, they have made their way from flight decks of modern airliners into general aviation aircraft.

3.4 Whole of aircraft reliability

Reliability is defined as the ability of a component to perform its intended function for a specified time (Gunston, 2004). For an aircraft, reliability is the probability that the aircraft as a whole, or a particular system, subsystem, or component will function as intended for the duration of the flight.

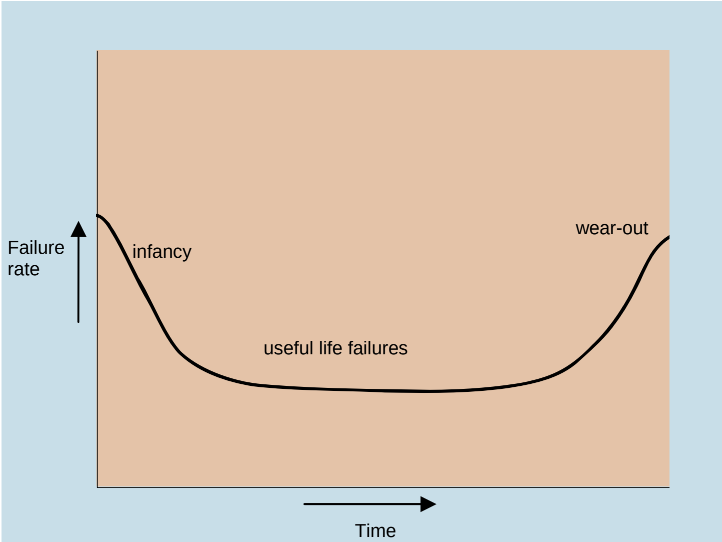
3.4.1 Aircraft life cycle – the bathtub curve

The overall reliability of a system or component through out its life has been described as following a ‘bathtub curve’. The lifecycle in the bathtub curve, shown in Figure 5, involves three phases:

- infancy;
- useful life; and
- wear out.

During infancy, the failure rate decreases over time, as many failures are due to material flaws or problems in manufacture. This phase is less relevant when considering ageing aircraft. In the useful-life phase, failures due to initial flaws gradually decrease while failures due to wear-out gradually increase. Therefore, the average number of failures remains relatively constant throughout the useful-life phase. During the wear-out phase, failures will increase as the product reaches the end of its useful life.

Figure 5: Bathtub curve



The bathtub curve is only a simplified form of reality. For example, the curve does not take into consideration that even while the failure rate is constant, ageing is occurring (Caruso, 2005).

3.4.2 System reliability

For the purposes of determining overall aircraft reliability, it is necessary to break the aircraft down into its systems. The aircraft systems can be further broken down into subsystems and finally components. The various components of an aircraft perform differently as they age. Therefore, the reliability of these different components needs to be considered individually.

The reliability of components can be estimated during the design phase or can be found from in-service failure data. Once the reliability of each individual component is established, it is necessary to determine how the components interact to form the system. This can be a very complex process, requiring knowledge of both the system and the failure rates of the components. As an aircraft ages it passes through its useful life into the wear-out phase. Establishing reliability in this phase is even more complex as components will have non-constant failure rates.

In addition, upgrading and replacement of an aircraft's components occurs continuously as they wear-out. This provides an opportunity for another component to reach the end of its life. In turn, this component will also be replaced or have its life extended. The cyclic process of upgrading and replacing components continues until it becomes uneconomical to further extend the life of the aircraft (Caruso, 2005).

4 THE AGE OF THE AUSTRALIAN PISTON ENGINE FIXED-WING AIRCRAFT FLEET

The following three chapters present data on the calendar age of Australia's aircraft fleet and describe how this has changed over a 10-year period between 1995 and 2005. The fleet is divided into three groups:

- piston engine fixed-wing aircraft;
- turboprop and turbofan fixed-wing aircraft; and
- rotary-wing aircraft.

Within these three groups, the aircraft have been further divided based on the number and type of engines, and by weight category[4]. Weight categories were chosen to be representative of various sizes of aircraft, and were based on the CASA aircraft register weight categories and the ATSB weight categories. This approach enables the establishment of trends across different sectors of the industry.

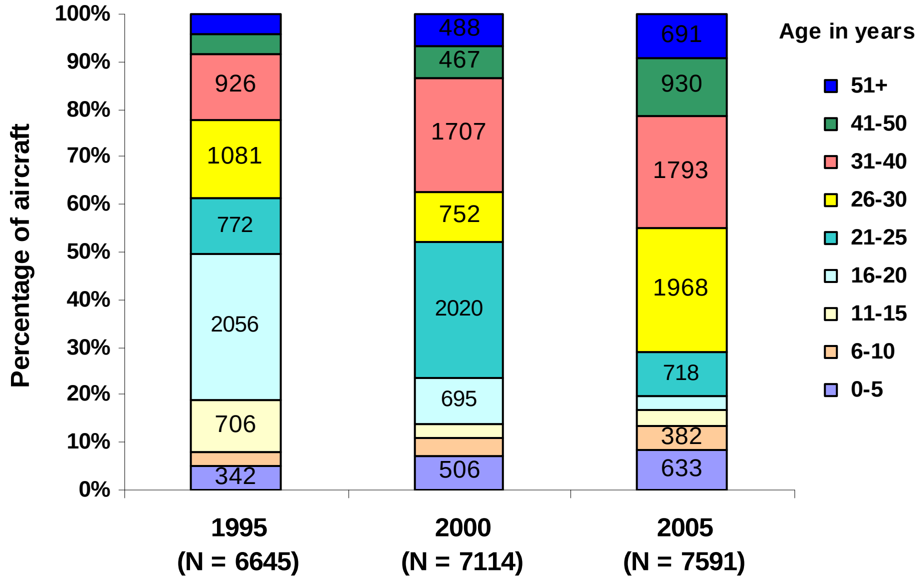
4.1 Single-engine piston fixed-wing aircraft

Aircraft in the single-engine piston fixed-wing aircraft category include most single-engine fixed-wing aircraft, such as those manufactured by Cessna, Raytheon, and New Piper. This aircraft category is the largest of all the aircraft categories with 7,591 aircraft in 2005, accounting for 60% of the all registered aircraft in Australia.

The average age of aircraft in this category increased considerably in calendar years between 1995 and 2005. The average chronological age increased by 7 years from 23 years to 30 years over the 10-year period (see Figure 6). Very few aircraft aged less than 5 years have been registered, and many of the aircraft that entered the register 20 or more years ago remain in service.

4 Some categories, such as single engine turboprop aircraft and piston fixed-wing aircraft with a maximum take-off weight (MTOW) greater than 5,700kg were excluded from the analysis due to the small number of aircraft in these categories on the Australian aircraft register.

Figure 6: Age of single-engine piston fixed-wing aircraft with an MTOW of 5,700 kg or less



Note: 'N' denotes the total number of aircraft in the category for the specified year

The percentage of aircraft aged over 20 years, the typical design life for an aircraft, has increased from 50% to 80% over the 10-year period. The concern is that many aircraft in this category do not receive continuing airworthiness support from the manufacturer. Continuing airworthiness support and adequate maintenance are essential to ensure the flight safety of ageing aircraft (see Section 7).

The percentage of aircraft aged 5 years or less has increased slightly over the period, from 5% in 1995 to 8% in 2005, while the percentage of aircraft aged over 40 years has increased from 8% to 21%.

A subcategory of the aircraft included in the single-engine piston fixed-wing aircraft category are the VH-registered amateur-built single-engine piston fixed-wing aircraft. From 1995 to 2005, there was a 250% increase in the number of aircraft in this subcategory. Amateur-built aircraft are contributing an increasing proportion of the single-engine piston aircraft category, accounting for approximately 10% of registrations by 2005. CASA data on aircraft registrations, grouped according to the year of manufacture, underscores the growing popularity of amateur-built single-engine aircraft. As of 31 December 2005, some 248 amateur-built aircraft manufactured between 2001 and 2004 were registered in Australia. By comparison, only 138 factory-built (or certified) aircraft manufactured during the same period entered the Australian aircraft register.

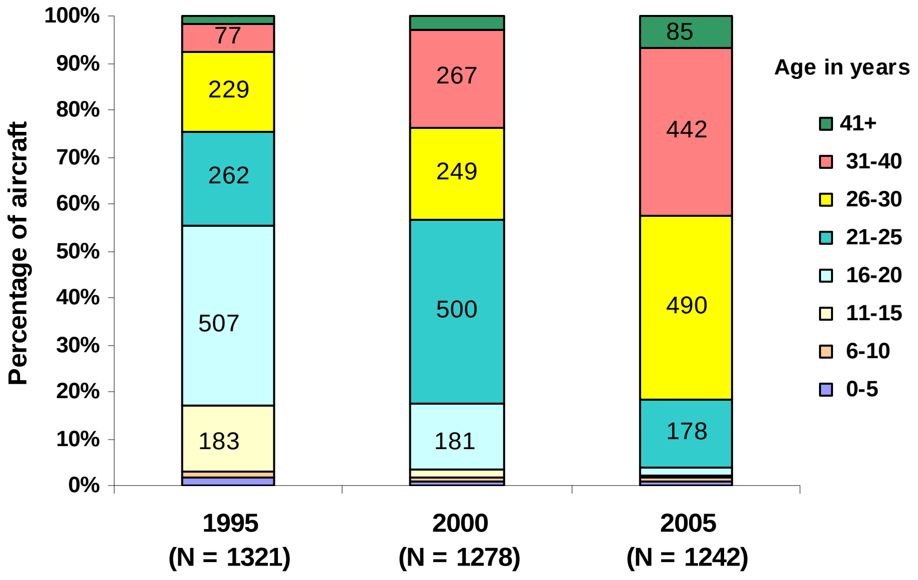
Unlike factory-built aircraft, the average age of amateur-built aircraft is relatively low, reflecting the recent emergence of this type of aircraft as a popular alternative to traditional certified types. The average age of amateur-built aircraft remained at 10 years throughout the period 1995-2005.

4.2 Multi-engine piston aircraft

In Australia, small regional airlines and charter operators typically fly multi-engine piston fixed-wing aircraft. Regional airlines generally operate this type of aircraft on routes that do not have sufficient traffic volumes to support services by larger aircraft. Aircraft such as the Cessna 404, the Piper Navajo, and the Rockwell Aero Commander are typical of the aircraft in this category.

Like the single-engine piston fleet, the average age of multi-engine piston aircraft has steadily increased between 1995 and 2005 (see Figure 7 and Figure 9). In 1995, the average age of multi-engine piston aircraft was 21 years. By 2005, this had increased to 31 years. Very few new aircraft have entered the register, while older aircraft continue to operate.

Figure 7: Multi-engine piston fixed-wing aircraft with a MTOW of 5,700 kg or less



Over the 10-year period, the number of aircraft in excess of 20 years has increased considerably. In 1995, 44% of aircraft were over 20 years, while in 2005 that figure had increased to 97%.

Apart from the general increase in aircraft age over time, one of the reasons for the increasing average age of the fleet is the very small percentage of aircraft aged 5 years or less. From 1995 to 2005, the percentage of aircraft aged 5 years or less remained constant at 1%, as virtually no new aircraft entered service.

The percentage of aircraft over 40 years increased from 2% in 1995 to 7% in 2005, showing that ageing aircraft are not being retired.

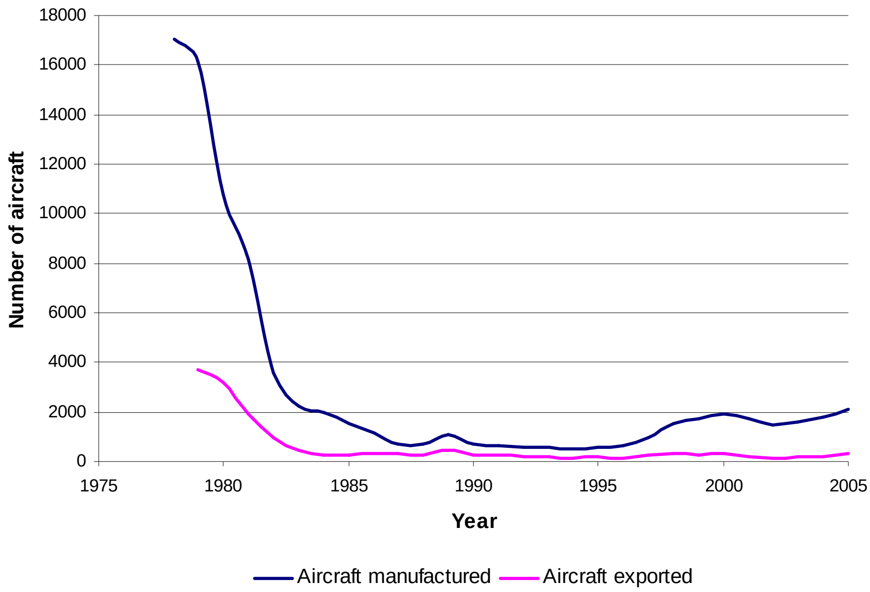
4.3 Summary

Australian aircraft fleet statistics show that the piston engine aircraft used in general aviation and for low-capacity RPT operations are increasing in average age. For single- and multi- engine piston fixed-wing aircraft, over 80% of aircraft are older than 20 years. The increase in average age of the Australian aircraft fleet has partly been made possible by the fact that the life of an aircraft is not determined solely by its economic design life. Rather, an aircraft's life is determined by its operational capability and maintenance costs (Tong, 2001).

Economics plays a large part in the life extension of an aircraft. With the relatively high cost of aircraft replacement, it may be more economical to maintain ageing aircraft rather than to acquire new ones. This has led to many aircraft in Australia's fleet, particularly in general aviation, being flown past their original design life, which is typically 20 years.

The majority of Australian registered general aviation aircraft were produced in the United States. Therefore, manufacturing output in the United States and exchange rate fluctuations directly affected the Australian general aviation industry. From 1982 to 2004 there has been a significant increase in the purchase price for new general aviation aircraft in the United States. In US$2004 a new Cessna 172 cost approximately $100,000 in 1982 and over $150,000 in 2004. The increase in the purchase price of new general aviation aircraft has been attributed to liability issues in the United States. As a consequence of litigation in the 1980s and early 1990s, Cessna ceased production of single engine piston fixed-wing aircraft and the Piper Aircraft Company went into bankruptcy. The United States Congress responded by passing the *General Aviation Revitalization Act* in 1994, which limited liability for general aviation aircraft manufacturers to 18 years. Since then, the production of general aviation aircraft in the United States has started to recover (BTRE, 2005a). The situation is illustrated best is Figure 8, showing the delivery of new aircraft over the thirty years. In 1978, 17,032 piston aircraft were delivered but production levels dropped quickly and have remained low since the early 1980s. By 1994, only 499 piston aircraft were delivered, of which 126 were exported. Since then production has increased, but numbers are still far below the production levels of the late 1970s (GAMA, 2006).

Figure 8: New general aviation fixed-wing aircraft manufactured in the United States



Source: GAMA (2006)

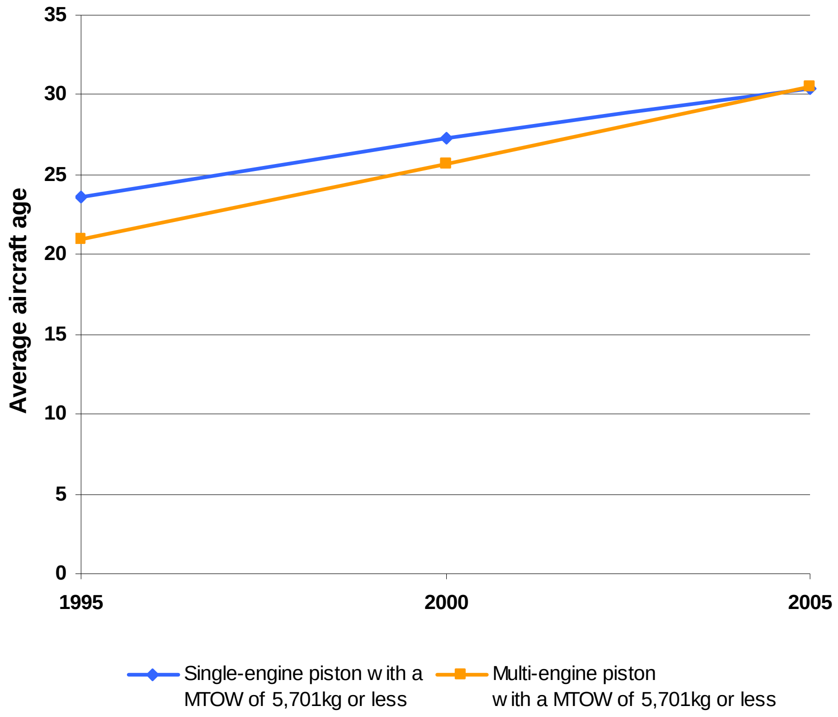
Added to the increase in the price of new general aviation aircraft has been the effect of exchange rate fluctuations since 1983, when the Australian dollar was floated. Exchange rate variations have meant that the cost of a new Cessna 172, in constant 2004 Australian dollars, has increased by approximately 150%, from approximately $140,000 in 1982 to approximately $230,000 in 2004. And exchange rate fluctuation have tended to produce large changes over short periods. For example, in 2001 when the Australian dollar was valued at around US$0.48, a new Cessna 172 would have cost approximately AUD$340,000 (BTRE, 2005a). The increase in price of new general aviation aircraft has decreased the affordability of new aircraft and been a contributing factor to the increase in average age of the general aviation aircraft fleet.

The change in average chronological age for each category of piston fixed-wing aircraft is shown in Figure 9. Piston engine fixed-wing aircraft have the highest average chronological age of all aircraft types and the average age is increasing.

Partly in response to the lack of suitable new replacement aircraft, and partly as a result of economic factors, amateur-built aircraft have become more popular in recent years. However, as these aircraft need to be assembled from a kit (requiring builders to acquire specific skills and invest considerable time), and because they are restricted to personal use, it seems unlikely that amateur-built aircraft will ever match the number of certified piston engine aircraft on the register.

In 2005, the average age of both categories of piston engine fixed-wing aircraft was over 30 years. Of the two piston engine fixed-wing aircraft categories, the multi-engine piston aircraft weighing less than 5,700kg had the highest average age, making it the oldest category of aircraft on the Australian register.

Figure 9: Change in average chronological age of piston fixed-wing aircraft from 1995 to 2005



The average age and the number of aircraft aged over 40 years of both piston single-engine and multi-engine fixed-wing aircraft categories is likely to continue increasing. If the current trends continue, by 2015 the average age of the single-engine fleet will be 37 years and the average age of the multi-engine fleet will be 40 years.

The sectors of the aviation industry that use piston engine fixed-wing aircraft often operate on thin profit margins with limited capacity to purchase aircraft aged 5 years or less. Where old aircraft are replaced, they are often replaced with younger, but not new, aircraft.

For the multi-engine piston aircraft category, over 97% of aircraft are older than the typically 20-year economic design life. Many of these aircraft are used as low-capacity RPT aircraft. As with many single-engine piston aircraft, aircraft in this category might not receive continuing airworthiness support from their manufacturers, so raising concerns about the sustainability of these aircraft as they age.

Australia’s circumstances are not unique. Most single-engine and multi-engine piston aircraft were manufactured in the US, so the challenge of ageing aircraft is faced by many other countries. In the US, for example, the National Transportation Safety Board reported that in 2001 the average age of four seat single-engine aircraft was 32 years (NTSB, 2006b). Multi-engine piston aircraft with between five and seven seats averaged 31 years, and those with eight or more seats were an average of 30 years old.

5 THE AGE OF THE AUSTRALIAN TURBOPROP AND TURBOFAN ENGINE FIXED-WING AIRCRAFT FLEET

Turboprop and turbofan engine fixed-wing aircraft are generally flown by airlines, or used as corporate aircraft. For the purposes of this report multi-engine turbofan aircraft have been broken down into three categories based on MTOW, these include:

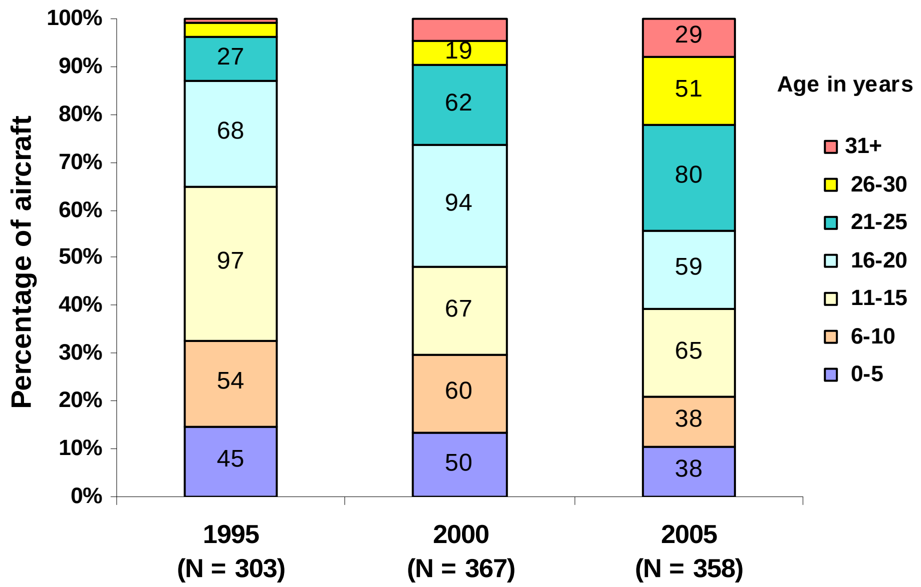
- Small turbofan aircraft with a MTOW between 5,701 kg and 50,000 kg
- Medium turbofan aircraft with a MTOW between 50,001 kg and 100,000 kg; and
- Large turbofan aircraft with a MTOW of greater than 100,000 kg

5.1 Multi-engine turboprop aircraft

Generally, regional airline routes with higher traffic volumes use multi-engine turboprop aircraft. These aircraft include, the Bombardier/de Havilland Dash 8, the Fairchild Metroliner, and the Raytheon/Beechcraft King Air.

As with the Australian piston-engine aircraft fleet, the average calendar age of turboprop-powered aircraft has increased during the period 1995 to 2005, albeit by less than piston engine aircraft (see Figure 10). In 1995, the average age for multi-engine turboprop aircraft was 14 years while in 2005 the average age was 18 years.

Figure 10: Multi-engine turboprop fixed-wing aircraft with a MTOW of 27,000 kg or less



The percentage of aircraft aged over 20 years has increased over the 10-year period. In 1995, 13% of aircraft were over 20 years; increasing to 44% in 2005. The percentage of aircraft aged 5 years or less declined from 15% in 1995 to 11% in 2005.

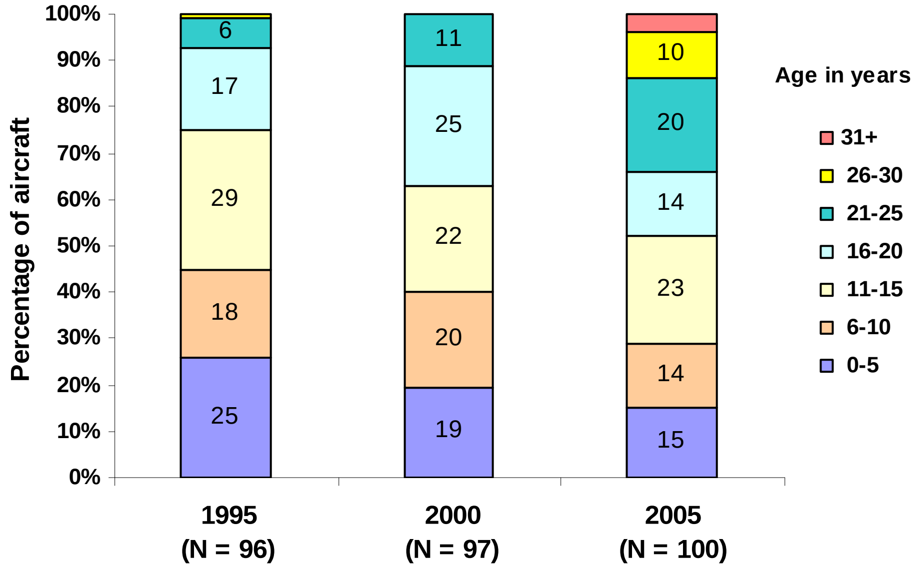
The average age of turboprop-powered aircraft in the Australian aircraft fleet is approximately 10 years less than that of the multi-engine piston engine aircraft. However, the decreasing proportion of aircraft aged 5 years or less entering this category of Australian aircraft fleet will see the average age increase towards 20 years.

5.2 Small multi-engine turbofan aircraft

Turbofan powered aircraft weighing up to 50,000 kg are often used as corporate jets. Aircraft in this category include the Cessna Citation, the Embraer ERJ, the Bombardier/Gates Learjet and Challenger, and Gulfstream series of corporate jets.

The average age of this fleet increased from 11 years in 1995 to 16 years in 2005 (see Figure 11). This increase in average age is similar to that of the other aircraft categories. In particular, it is comparable to the turboprop aircraft category, which contains aircraft of a similar size.

Figure 11: Multi-engine turbofan fixed-wing aircraft with MTOW of 50,000 kg or less



The percentage of aircraft aged over 20 years increased over the reporting period from 7% in 1995 to 34% in 2005. The percentage of aircraft aged 5 years or less decreased from 26% in 1995 to 15% in 2005.

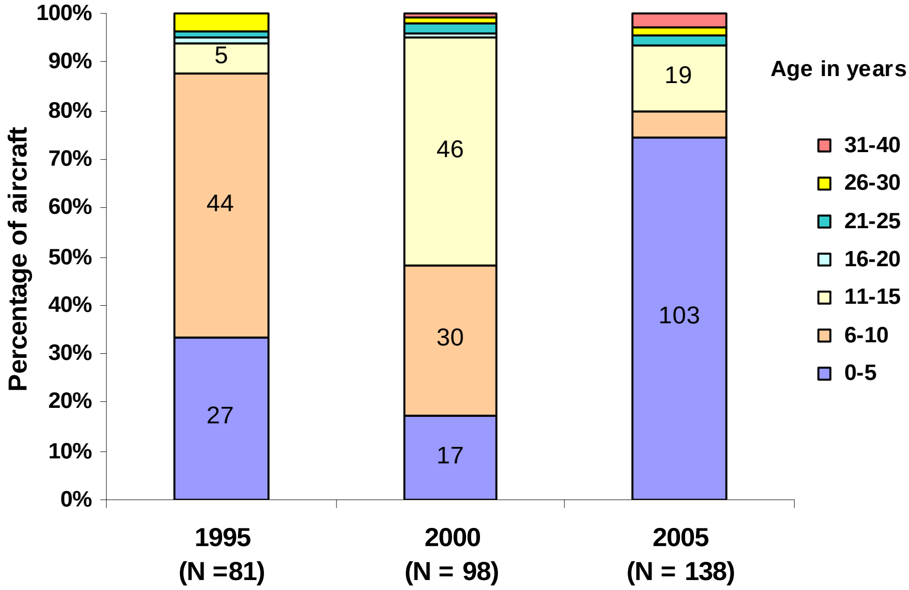
The aircraft in this category have a lower average chronological age, than those in the general aviation and regional airline sectors. However, the trend indicates that the average age is likely to creep up.

5.3 Medium multi-engine turbofan aircraft

Turbofan powered aircraft with a MTOW between 50,001 kg and 100,000 kg include the Boeing 717 and 737 and the Airbus A320. In Australia, these aircraft are used by the major airlines to fly between major centres on domestic routes, and for some international services.

Unlike all other categories, the average age of the medium turbofan fleet has decreased since 1995 (see Figure 12). While the average age of the fleet increased from 8 years to 10 years in between 1995 and 2000, changes in the composition of the Australian domestic market, with new entrants filling the vacuum left by Ansett, saw the average age drop to just 6 years by 2005.

Figure 12: Multi-engine turbofan fixed-wing aircraft with a MTOW between 50,001 kg and 100,000 kg



The percentage of aircraft aged over 20 years has remained relatively constant over the period, at approximately 5%. From 1995 to 2005, the percentage of aircraft aged 5 years or less increased from 36% in 1995 to 74% in 2005, although in 2000 only 17% of aircraft were aged 5 years or less.

The decrease in the average age of aircraft in this category is largely attributable to the acquisition of new Boeing 737 aircraft by both Qantas and Virgin Blue and the acquisition of Airbus A320 aircraft by Jetstar. The collapse of Ansett Australia in 2001 saw the majority of Ansett's aircraft fleet withdrawn from the Australian aircraft register. A number of these aircraft were relatively old. Aircraft in Ansett's fleet were redelivered to their financiers, sold overseas, and sold for parts. [5]

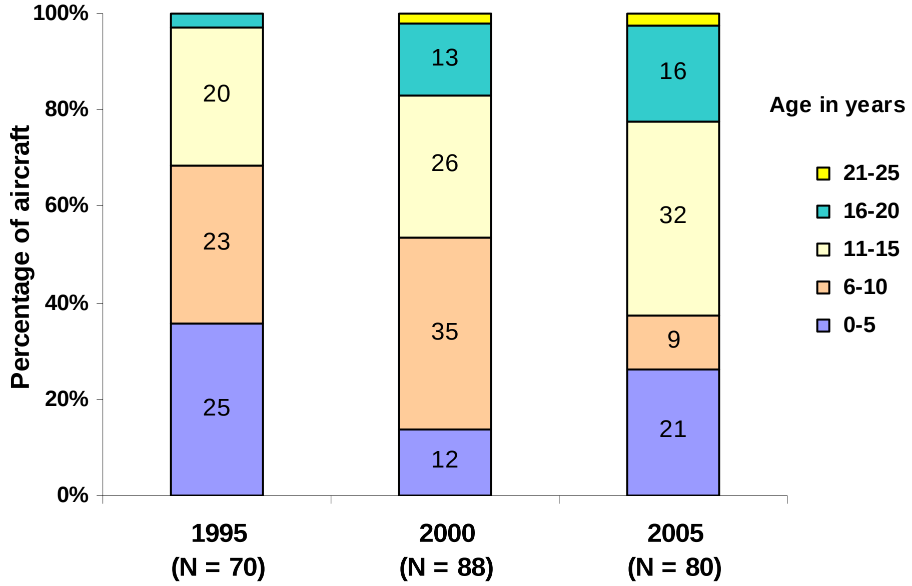
5 The administrators for Ansett Australia website www.ansett.com.au (KordaMentha, n.d.)

5.4 Large multi-engine turbofan aircraft

Multi-engine turbofan aircraft with a MTOW of more than 100,000 kg include aircraft such as the Boeing 767, 747 and the Airbus A330 aircraft. These aircraft are used by airlines to fly the high density domestic routes and on international services.

The average age of aircraft in this category in the Australian aircraft fleet increased from 8 years in 1995 to 11 years in 2005 (see Figure 13). The average age, however, is still well below the 20-year design life usually assigned to aircraft.

Figure 13: Multi-engine turbofan fixed-wing aircraft with a MTOW greater than 100,000 kg



There are very few aircraft aged over 20 years in the large turbofan fixed-wing aircraft category. This ranged from zero in 1995 to 3% in 2005. In 2005, the aircraft aged over 20 years were between 21 and 22 years of age.

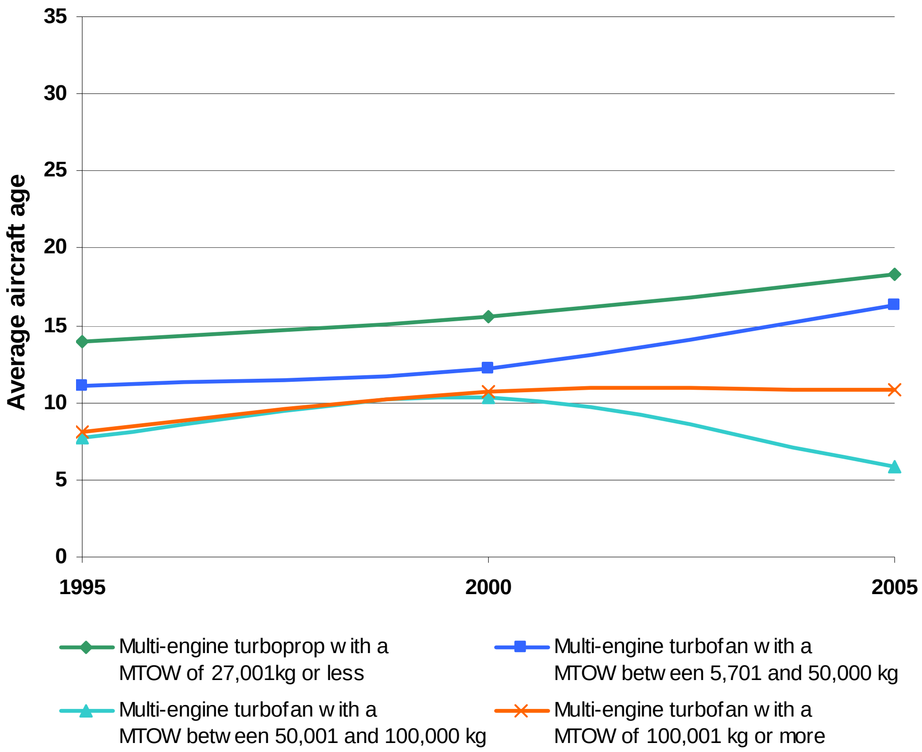
The percentage of aircraft in this category aged 5 years or less fluctuated over the period. The peak occurred in 1995 with 36%, dropping to 14% in 2000 and in 26% in 2005.

There has been an increase in the percentage of aircraft aged 5 years or less in this category in the Australian aircraft fleet between 2000 and 2005. This indicates that some of the aircraft aged over 15 years have been retired and aircraft aged 5 years or less have been introduced into the Australian aircraft fleet. The Boeing 767 aircraft operated by Ansett Australia prior to 2001, have either been sold overseas or returned to their financiers. These Boeing aircraft were among the oldest of this type in the world. Of Ansett's nine Boeing 767-200 aircraft, five were first flown in 1983 and two in 1984 (ATSB, 2002).

5.5 Summary

The change in average chronological age for each category of turboprop and turbofan fixed-wing aircraft is shown in Figure 14. The turboprop and smaller turbofan aircraft (less than 50,000 kg) have lower average ages than piston engine fixed-wing aircraft (30 years), but the average age of the aircraft in these categories is also increasing. Only one category has an average age that is decreasing, namely the medium turbofan engine aircraft category

Figure 14: Change in average chronological age of turboprop and turbofan fixed-wing aircraft from 1995 to 2005



Turboprop Aircraft

Similar to the multi-engine piston aircraft, multi-engine turboprop aircraft are often used on regional RPT routes. However, unlike the piston aircraft categories, the average age of turboprop aircraft was below 20 years and in 2005 was 12 years less than the piston aircraft categories. The average age of the turboprop category was also increasing at a lower rate than that for piston fixed-wing aircraft category.

While the average age of the multi-engine turboprop fixed-wing aircraft was less than that for piston fixed-wing aircraft, the average age of turboprop aircraft in 2005 was approaching 20 years. If this trend continues, in 2015 the average age will be well over the typical design life of 20 years.

Turbofan Aircraft

The average age of turbofan aircraft in the Australian aircraft fleet is considerably less than for piston aircraft and somewhat younger than for turboprop aircraft. The average age of the small turbofan aircraft fleet increased by 5 years over the 10-year period. However, the medium turbofan aircraft have decreased in average age by 2 years over the 10-year period.

The average age of the large turbofan aircraft rose from 8 to 11 years from 1995 to 2005 but then remained constant from 2000 to 2005. Over the next 10-years the average age of the large turbofan aircraft is likely to decrease with the Qantas Airways fleet renewal programme (Qantas Airways, n.d.). Qantas may acquire up to 115 of the new Boeing 787, and anticipates the arrival of its first Airbus A380 in the second half of 2008. The production delays with the A380 mean that initial deliveries will be around 2 years later than planned, making it likely that Qantas may need to retain parts of its current fleet for longer than originally planned.

The average age of the medium turbofan aircraft is likely to remain low due to the planned purchase of new aircraft by Jetstar, Qantas, and Virgin Blue (Qantas Airways, 2005; Virgin Blue, 2005). The average age of this category decreased significantly from 2000 to 2005, due to the fact that Virgin Blue and Qantas both acquired new Boeing 737 aircraft, and Jetstar acquired new Airbus A320 aircraft. The collapse of Ansett Australia resulted in the retirement of the majority of the aircraft from that fleet, many of which were relatively old.

6 THE AGE OF THE AUSTRALIAN ROTARY-WING AIRCRAFT FLEET

In Australia, rotary wing aircraft (referred to in this report as helicopters) perform a number of different roles ranging from flying training and aerial mustering, to heavy lifting and search and rescue operation. For the purposes of this report, helicopters have been divided into three categories based on the number and type of engine(s). These include:

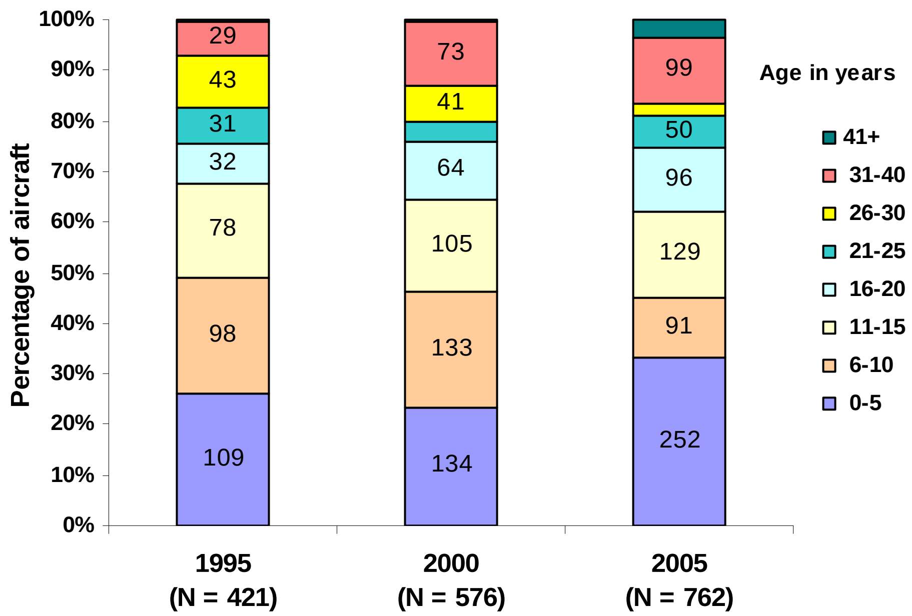
- single-engine piston;
- single-engine turboshaft; and
- multi-engine turboshaft.

6.1 Single-engine piston helicopters

Of the total number of helicopters on the Australian helicopters register, single-engine piston helicopters account for the greatest proportion. The category includes helicopters such as the Robinson R22, the Bell 47, and the Schweizer 300. These helicopters are used in a wide variety of roles ranging from flying training to agriculture, and aerial mustering.

The average age of these helicopters increased slightly over the period from 13 years in 1995 to 16 years in 2005 (see Figure 15). However, it is interesting to note that in the period 1995 to 2005 the fleet size has increased by 181%.

Figure 15: Single-engine piston helicopters with a MTOW of 5,700 kg or less



Over the 10-year period, the percentage of helicopters aged over 20 years increased from 25% in 1995 and 2005 to 30% in 2000.

In 1995, 26% of the fleet was aged 5 years or less compared with 33% in 2005. This increase indicates that as the fleet size increased, the majority of the helicopters that entered the fleet were aged 5 years or less, rather than helicopters aged over 20 years.

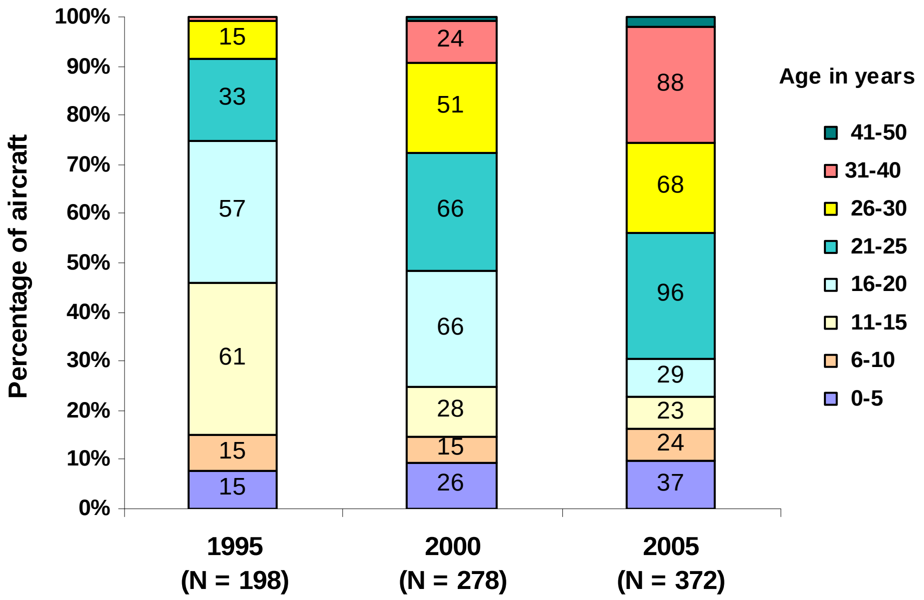
The percentage of helicopters over 40 years increased from 0.2% (one helicopters) in 1995 to 3% (26 helicopters) in 2005.

6.2 Single-engine turboshaft helicopters

This category of helicopters includes helicopters such as the Bell 206 and the Schweizer 330. Helicopters in this category have a variety of uses including aerial work, aerial agriculture, and charter operations.

The average age of single-engine turboshaft helicopters has increased from 16 years to 23 years over the 10-year period. Along with the increase in average age, there has been a substantial increase in the size of the fleet by 190% from 1995 to 2005 (Figure 16).

Figure 16: Single-engine turboshaft helicopters with a MTOW of 5,700 kg or less



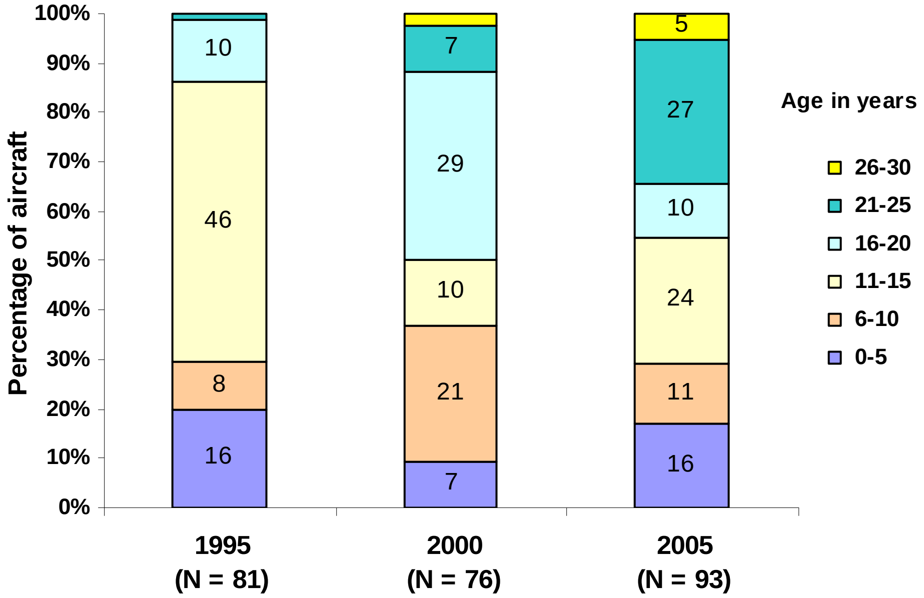
From 1995 to 2005, the percentage of helicopters aged over 20 years increased three-fold from 25% to 76%. The percentage of helicopters aged 5 years or less increased slightly from 8% in 1995 to 10% in 2005. The percentage of helicopters in the fleet aged over 40 years increased from zero in 1995 to 2% in 2005.

Even though the number of helicopters in the fleet increased substantially over the 10-year period, the percentage of helicopters aged 5 years or less increased only slightly. At the same time, the average age of the fleet is increasing. These changes indicate that operators are purchasing second-hand helicopters aged over 20 years rather than helicopters aged less than 5 years.

6.3 Multi-engine turboshaft helicopters

Compared with the other categories of helicopters, there are very few multi-engine turboshaft helicopters, such as the Bell 412, operating in Australia. The average age of helicopters in this category has increased from 12 years in 1995 to 15 years in 2005 (see Figure 17).

Figure 17: Multi-engine turboshaft helicopters with a MTOW of 5,700 kg or less



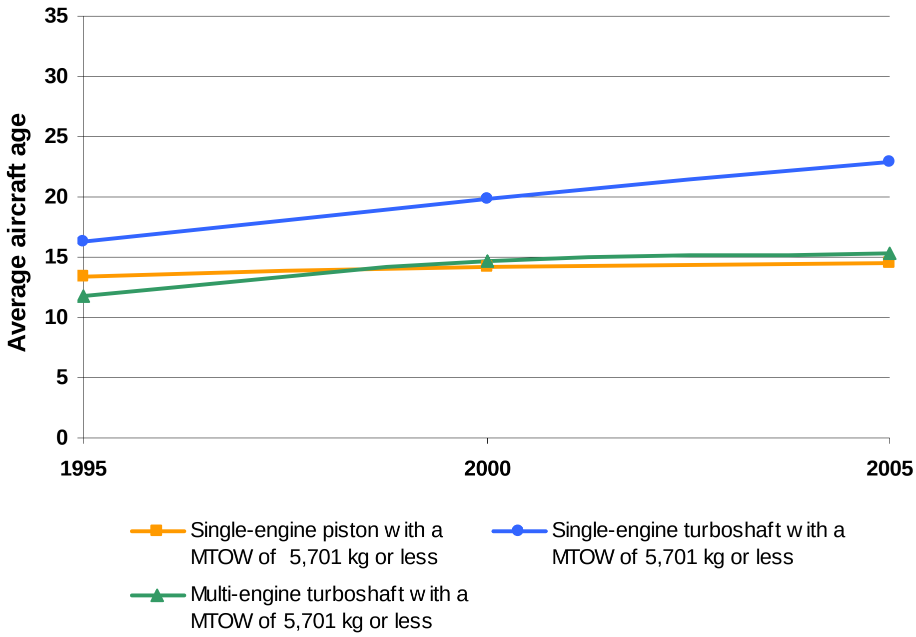
The proportion of helicopters in the fleet aged over 20 years has increased from 1% in 1995 to 34% in 2005. As these helicopters age, the cost and amount of maintenance required to ensure their airworthiness will increase.

Over the period, the percentage of helicopters aged 5 years or less has fluctuated from 20% in 1995, to 9% in 2000, and to 17% in 2005. Even though the percentage of helicopters aged 5 years or less entering the fleet is higher than for piston fixed-wing helicopters, it has not been high enough to reduce the average age of the fleet. This may be partly due to the small increase in the size of the fleet over the 10-year period.

6.4 Summary

The increase in the age of the Australian helicopter fleet between 1995 and 2005 was generally less than the increase in age for the fixed-wing helicopters fleet of comparable size. The average age increased slightly (by 1 year) for single-engine piston helicopters, increased by 4 years for multi-engine turboshaft helicopters, and increased by 7 years for single-engine turboshaft helicopters (see Figure 18).

Figure 18: Change in average chronological age of helicopters from 1995 to 2005



The total size of the helicopter fleet increased by 175% over the 10-year period from 1995 to 2005. During the same period, there was actually a small increase in the average age, as many of the helicopters introduced to the Australian register were second-hand, including some over 20 years old.

In the single-engine turboshaft category, the fleet size increased by 187% (174 helicopters) from 1995 to 2005. However, the data indicate that there were 26 helicopters in 2000, and 37 helicopters in 2005, aged 5 years or less. The remaining 111 helicopters, therefore, have been added to the fleet as older second-hand helicopters.

7 MANAGING AIRCRAFT AGEING

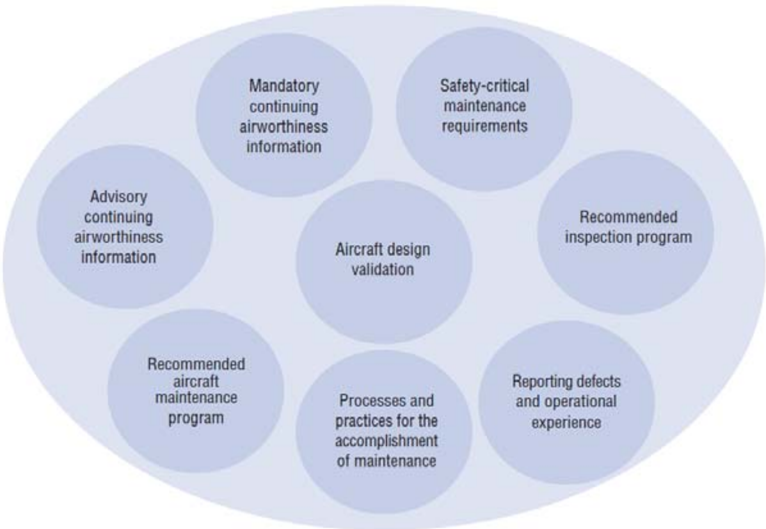
Design standards have improved over time with an increased understanding of fatigue and other failure mechanisms. Therefore, when some ageing aircraft were designed they had to meet a less stringent fatigue design standard than would now be required. In addition, some later aircraft models were designed to these earlier design standards, under a system known as 'grandfathering'[6] (Swift, 2003).

Aircraft that have been designed to less stringent fatigue standards present important safety implications as they age, because fatigue increases with age. As a result, the ageing process needs to be managed throughout an aircraft's life. In-service management includes in-service inspection, continuing airworthiness (see Section 7.1), and maintenance schedules (see Section 7.2).

7.1 Continuing airworthiness

The term continuing airworthiness refers to the tasks required to ensure that an aircraft remains 'fit to fly', throughout its design life, in all the environments and circumstances for which it has been designed and certified. The basic elements of the continuing airworthiness system for an aircraft type are shown in Figure 19.

Figure 19: Basic elements of the continuing airworthiness system



Source: ATSB (2002)

The continuing airworthiness system evolves over the life of an aircraft. The system takes into account the in-service data and defects found by operators. This information is then used to improve the maintenance system, for example by providing fixes for the in-service defects.

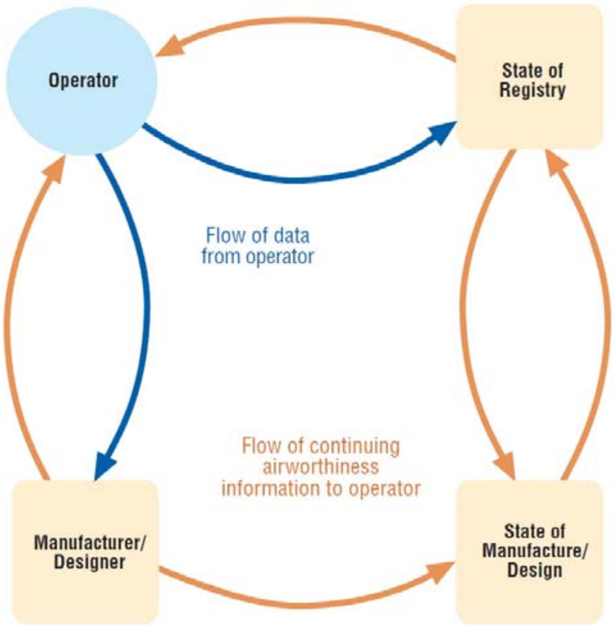
6 Grandfathering refers to the practise by National Airworthiness Authorities (NAA) of allowing new aircraft models to be certified to the same rules as earlier models of the same aircraft type, where there are not substantial changes from those earlier models.

7.1.1 The continuing airworthiness framework

The ICAO international continuing airworthiness system is effectively a system of communication. It is based on ICAO Annex 6, Operation of Aircraft, and ICAO Annex 8, Airworthiness of Aircraft. The system is designed to be used by all of the organisations associated with the design, manufacture, certification, operation, and maintenance of an aircraft. While the system exists for all aircraft types and operations, it is generally used for transport category aircraft. The basic elements of the system are shown in Figure 20.

The system is focused on the operator, who provides in-service operational feedback to the type certificate holder[7]. The type certificate holder finds solutions to any problems and this information is communicated back to the operator (see Figure 20). The blue arrows (➡) show the flow of raw data from the operator to the manufacturer or designer and the state of registry. The yellow arrows (➡) show the flow of continuing airworthiness information from the manufacturer or designer back to the operator.

Figure 20: Information flows associated with continuing airworthiness



Source: ATSB (2002)

Continuing airworthiness information is produced in the form of service bulletins that have varying levels of safety implications and require different actions. Maintenance service bulletins may require inspections, repair, rework, or modifications to the aircraft. The State of Registry is the only agency that can mandate the requirements contained in the continuing airworthiness documentation for aircraft under their jurisdiction. In addition, they are likely to be in the best position to understand their particular operating environment and the issues affecting operators.

7 In this report, the term type certificate holder refers to the designer or manufacturer who holds the type certificate (see the glossary for a definition of type certificate).

Age and continuing airworthiness

The continuing airworthiness system is of particular relevance to ageing aircraft. Operators provide the type certificate holder with in-service information related to fatigue, corrosion, and other ageing issues. The type certificate holder can then determine what repairs, replacements, or modified maintenance schedules, are required to ensure the continued safe operation of the fleet.

The type certificate holder is in the best position to help ensure continuing airworthiness of its ageing aircraft type, since it receives defect reports[8] from all aircraft operators worldwide. From this information, the type certificate holder can develop repairs and modifications to rectify problems that have only begun to show up on a limited number of aircraft.

The type certificate holder has an obligation to provide maintenance support to owners and operators of their aircraft. Manufacturers of high-capacity RPT aircraft meet their responsibilities by providing continuing airworthiness information. However, general aviation and low-capacity RPT aircraft manufacturers may not have the resources or the knowledge to provide on-going maintenance support for their ageing aircraft.

Economics and resources influence type certificate holders when providing support for ageing general aviation and low-capacity RPT aircraft. Some type certificate holders may have taken over the type certificate from the original design company; this means they may not have the records, or specialist staff, to provide ongoing technical support. Original type certificate holders may also face some of these problems.

7.1.2 Supplemental Inspection Programmes

Supplementary Inspection Programmes (SIPs) are used to ensure the continuing airworthiness of ageing aircraft. Maintenance becomes more complex as an aircraft increases in age. Additional maintenance is required in areas where experience has shown fatigue or environmental degradation to be greater than predicted.

This additional maintenance can be incorporated into Supplementary Inspection Programmes. Supplementary Inspection Programmes are additional maintenance schemes that should be used after the aircraft reaches a specified number of flights or hours. Supplementary Inspection Programmes are not just inspections as they include other maintenance tasks and form part of the manufacturer's maintenance manual. The Supplementary Inspection Programme describes where to look for cracks, the equipment that should be used, and the inspection intervals that should be adhered to.

8 Defect reports may not be mandatory for aircraft that do not carry fare-paying passengers.

Supplementary Inspection Programmes are primarily developed by the manufactures of large transport category aircraft. Boeing calls these Airworthiness Limitations Structural Inspections. Transport category aircraft are designed with the knowledge that a Supplementary Inspection Programme may be necessary for their continued airworthiness. However, for old piston and turboprop aircraft this was not the case. Where a Supplementary Inspection Programme is developed later on in life, it is often called Supplementary Inspection Documents (SIDs). Some manufacturers of these small piston and turboprop aircraft have developed Supplementary Inspection Documents. For example, with the support of the FAA through the National Aging Aircraft Research Program Cessna has developed Supplementary Inspection Documents for their 402 aircraft and Fairchild has developed Supplementary Inspection Documents for their SA226/227 Metroliner.

Supplementary Inspection Programmes are effectively mandated by CASA for all aircraft on all maintenance schedules, where a Supplementary Inspection Programme has been developed (CASA, 2006). Specifically, CASA mandates Supplementary Inspection Programmes for aircraft carrying fare-paying passengers when a manufacturer, has developed one (CASA, 2004b).

The implementation of Supplementary Inspection Programmes can be expensive for an operator. The main expenses will generally occur from repairing cracks found in the first run of the inspection programme, rather than from the inspections themselves. Once the aircraft has been inspected and repaired for the first time using Supplementary Inspection Programmes, the cost should decrease as the previously undetected cracks will have been repaired (CASA, 2004b).

Case study: System failure – Ansett Australia

When the system of continuing airworthiness fails, it can have significant consequences. For example in December 2000 and April 2001, Ansett Australia’s fleet of Boeing 767 aircraft were withdrawn from service, due to deficiencies in the continuing airworthiness system.

Ansett was the sixth airline to operate the Boeing 767 and their fleet of Boeing 767 aircraft was among the oldest in the world. Of their nine Boeing 767-200 aircraft, five were first flown in 1983 and two in 1984. These aircraft were used on relatively short domestic sectors, and therefore had accumulated a high number of flight cycles. The Ansett fleet of Boeing 767 aircraft were twice grounded because certain fatigue damage inspections had not been carried out.

In June 1997, Boeing introduced an Airworthiness Limitations Structural Inspection programme for the Boeing 767 aircraft. The programme was part of the damage tolerance requirements and was designed to detect fatigue cracking in susceptible areas that had been identified through tests and in-service experience. There was a requirement to carry out some of the inspections before 25,000 cycles. However, Ansett staff did not originally recognise this requirement and at the time of the Airworthiness Limitations Structural Inspection programmes introduction, some of the Ansett Boeing 767 aircraft had already flown more than 25,000 cycles (ATSB, 2002). In June 2000, further inspections at 25,000 cycles were introduced. These inspections included the Body Station 1809.5 bulkhead (see Figure 21). Ansett initially did not act on these inspections.

Figure 21a: Location of Boeing 767 Body Station 1809.5 bulkhead and wing front spar pitch load fittings

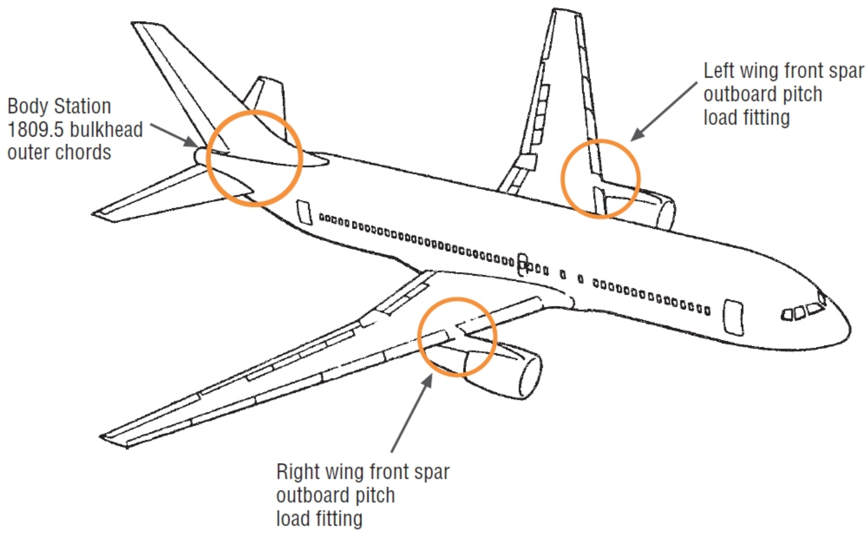
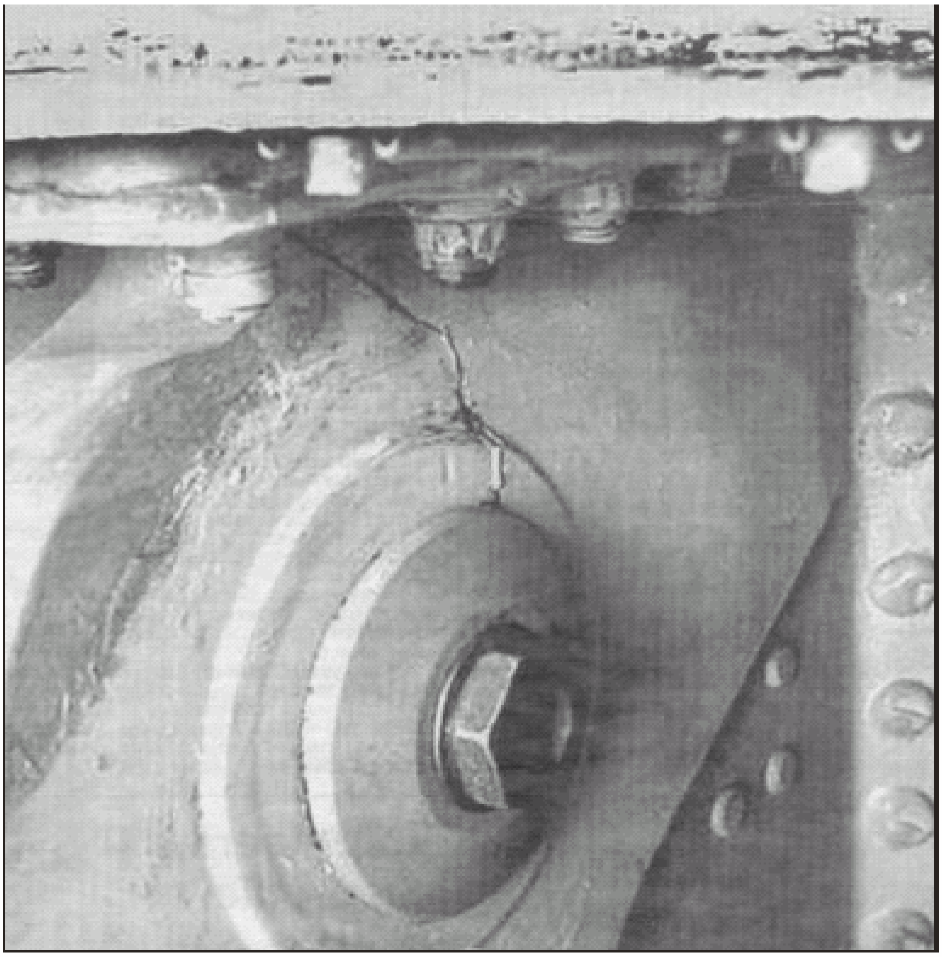


Figure 21b: Cracks found on the front spar outboard pitch load fitting



Source: ATSB (2002)

Ansett management became aware of the oversight in December 2000, when seven aircraft were found to have exceeded the inspection intervals. Ansett withdrew the affected aircraft from service, due to concern about their continuing airworthiness status. Once the required inspections had taken place, the aircraft were reintroduced to service.

Subsequently, in March 2001, Ansett found that they had not implemented a Boeing 767 Alert Service Bulletin issued in March of the previous year. The service bulletin concerned the inspection of the wing front spar outboard pitch load fitting. The inspection was required to be conducted within 180 days from the issuing of the bulletin. As a result the Ansett Boeing 767 aircraft were again grounded.

The ATSB investigation found that there were deficiencies in a number of aspects of the continuing airworthiness system involving Ansett, CASA and the FAA (ATSB, 2002).

The age of the Ansett Boeing 767 fleet and their high number of flight cycles meant that failures in the continuing airworthiness system were of significant concern to flight safety. Inspections on ageing aircraft are more critical because there is an increased probability of finding a crack.

Case study: Rudder failure due to corrosion and debonding

On 12 April 1989, Concorde G-BOAF sustained a rudder separation while travelling from Christchurch, New Zealand to Sydney[9]. At the time of the accident, the aircraft had been in service for 10 years.

The then Australian Civil Aviation Authority (CAA) found that the rudder failed due to delamination of the honeycomb and the skin surface (Hole, 1989). Extensive corrosion on the inner skin surface was also present. According to the British Air Accident Investigation Branch (AAIB), the de-bond had slowly grown to a critical size before rapidly increasing to failure (AAIB, 1993).

The rudder was manufactured with an aluminium alloy skin and aluminium honeycomb inner structure that was bonded together using a phenolic resin. Post manufacture, the rudder assembly had been modified when a trailing edge fairing was riveted to the rudder assembly.

When the rudder was originally constructed, the rivets and fasteners that penetrated through to the honeycomb core were kept to a minimum. This was to prevent moisture breeching the core, leading to corrosion. However, the trailing edge fairing modification relied on a large number of rivet holes (AAIB, 1993).

The CAA investigation found that no sealant paint was present on many of the rivet heads on the undamaged section of the rudder. The unsealed rivet heads may have allowed moister to enter the structure, causing corrosion. The rate of corrosion was increased through a galvanic reaction between the steel in the rivets and the aluminium in the honeycomb and skin.

9 ATSB Occurrence No. 198902719

The CAA investigation found that the de-bond of the skin from the honeycomb core was due to corrosion products wedging between the skin and the adhesive (Hole, 1989).

The Concorde rudder failure is an example of the effects of ageing on an aircraft structure. Over time, corrosion led to the de-bonding and ultimately the failure of the rudder structure. Prior to the G-BOAF accident, the rudder was not considered to be an area susceptible to corrosion and debonding.

As a result of the accident, the British Civil Aviation Authority and the French Direction Générale de l'Aviation Civile issued airworthiness directives, mandating repeated non destructive inspections (NDI) and 'tap' testing to ensure that there was no de-bonding of the rudder structure.

7.2 Scheduled maintenance

Scheduled maintenance is essential to ensure the continuing airworthiness of aircraft. Maintenance includes inspecting the structure for fatigue and corrosion, replacement of life-limited components, and rectifying general wear and tear. Maintenance schedules will vary depending on the CASA requirements for the particular aircraft class.

CASA separates aircraft into two categories, Class A and Class B. A Class A aircraft is an aircraft that has a Certificate of Airworthiness in the transport category and/or is used for regular public transport operations[10]. A Class B aircraft is any aircraft that is not a Class A aircraft[11]. This includes aircraft used for charter operations, aerial work, and private operations.

7.2.1 Maintenance requirements for Class A aircraft

A Class A aircraft is required to have an approved system of maintenance[12]. The approved system must have regard to the manufacturer's maintenance schedule and any inspection programmes and documentation issued by the manufacturer[13].

The process of approval, which is carried out by CASA or an approved industry delegate[14] is to ensure that the schedule is will adequately meet the continuing airworthiness requirements of the aircraft. Generally, an approved maintenance schedule will be a modified version of the manufactures schedule, customised to the owners operations. The approved schedule may also take into account any non-manufacturer supported modifications.

The maintenance required for Class A aircraft is more rigorous in its application and control than the maintenance required for other Australian civil aircraft.

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10 *Civil Aviation Regulation* 1998 2(1), 2(2C), and 206(1)(c)

11 *Civil Aviation Regulation* 1998 2(1)

12 *Civil Aviation Regulation* 1998 39(2)(a)

13 *Civil Aviation Regulation* 1998 42ZY(1)(d)(iii)

14 *Civil Aviation Regulation* 1988 Subregulation 42M

7.2.2 Maintenance requirements for Class B aircraft

Compared to operators of Class A aircraft, operators of Class B aircraft have a greater level of flexibility when deciding on a maintenance schedule for their aircraft. Operators may decide to use an approved maintenance schedule, the manufacturer's maintenance schedule, the CASA maintenance schedule[15], or use a combination of a manufacture's maintenance schedule and the CASA maintenance schedule.

Manufacturer's maintenance schedule

As part of the certification process for a new aircraft type, manufacturers are required to develop a system of maintenance for the aircraft type. Over time, the schedule is updated based on information that the manufacturer receives from operators about in-service defects. The schedule takes into account information received from the worldwide fleet and ensures that issues are addressed across the fleet.

However, when aircraft are modified, the manufacturer's schedule may no longer accurately reflect the required inspection intervals on the aircraft. Structural modifications can change the loading on the structure, which may vary fatigue crack growth. Failures can occur if the schedule is not modified to take into account the changed conditions.

CASA maintenance schedule

The CASA maintenance schedule[16], commonly known as 'Schedule 5', includes two types of inspections; these are a daily inspection, and a periodic inspection.

Schedule 5 is a generic maintenance schedule that does not include aircraft specific maintenance. Hence, if an aircraft has a specific inspection requirement it is not covered. In addition, the schedule does not take into account in-service defect reports. Therefore, aircraft specific problems will not be rectified in this schedule. This is a particular disadvantage for ageing aircraft where it is desirable that known defects are rectified through the manufacture's maintenance schedule or through Supplemental Inspection Programmes.

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15 The CASA maintenance schedule covers any Class B fixed-wing aircraft (*Civil Aviation Regulation* 1988 Subregulation 42B)

16 *Civil Aviation Regulation* 1998 Subregulation 42B and Schedule 5

8 FUTURE MANAGEMENT OF AGEING AIRCRAFT IN AUSTRALIA

Ageing aircraft can be managed in two ways, either through retirement or through comprehensive maintenance programmes that. If maintenance programmes are chosen, these programmes need to be all-inclusive and take into consideration the effects of ageing on the particular aircraft model.

As aircraft age, the time spent on maintenance and the maintenance costs will generally increase. For every 10 years in service, Robinson (2003) suggests that there will be a 15% increase in the time taken to conduct the 100-hourly inspection resulting in an increase in cost. When the cost of maintaining ageing aircraft is considered too high, operators may decide it is more economical to acquire new or newer aircraft.

In addition to the need for more intensive and hence more costly maintenance, operators face the challenge of competing for appropriately qualified maintenance personnel. Licensed Aircraft Maintenance Engineers (LAMEs) are able to certify maintenance for aircraft, and may have either licenses for specific aircraft types (normally for large and complex RPT aircraft), or they may hold a group rating. Those with group ratings service the large fleet of general aviation aircraft. While the number of LAME ratings issued for specific aircraft types has nearly doubled (from 1043 to 2046) over the period 1994 to 2004, the number of LAME ratings issued for ‘group’ aircraft types has remained stagnant with 700 new licenses issued in 1994 and 697 new licences issued in 2004. A more worrying trend is that fewer licences for engine and airframe LAMEs were issued in 2004 compared with 1994. New licences declined by 39.7% for engine LAMEs and 22.2% for airframe LAMEs, and if new licence issues cannot at least keep pace with licence expiries, operators will face the prospect of a shortage of skilled staff in critical areas at the same time that their aircraft require more maintenance (ATSB, 2005a).

8.1 Acquisition of new aircraft

Large Australian RPT operators are avoiding the problems associated with ageing aircraft through the purchase of new aircraft. The Virgin Blue fleet consists of Boeing 737 -700 and -800 aircraft (Virgin Blue, 2005). Qantas has also recently announced the purchase of up to 115 new Boeing 787 aircraft, as part of their fleet renewal programme and have purchased 10 Boeing 737-800 aircraft (Qantas Airways, n.d.). In addition, Jetstar have acquired 23 new Airbus A320-200 aircraft (Jetstar, 2005).

Maintenance is still important for a fleet with an average age less than 10 years. However, the cost of maintenance is likely to be significantly lower than for a fleet with an average age greater than 20 years. This reduced cost is due to the reduced probability of finding corrosion, cracks, and other effects of ageing in new aircraft. Where operators decide to replace their ageing aircraft, but cannot afford to acquire new aircraft they may choose to acquire younger second-hand aircraft.

8.2 Future directions in maintenance programmes

A comprehensive maintenance programme is required when maintenance is chosen as the means of controlling aircraft age. The continued safety of Australia's ageing aircraft depends on communication and cooperation between the aircraft owners and operators, type certificate holders, designers, modifiers and repairers, CASA, the FAA and other regulators (Swift, 2003). The continuing airworthiness system used by RPT aircraft and described in Chapter 7.1 provides a good model for how communication between all parties can be achieved.

There are a number of challenges facing the future maintenance of ageing aircraft in Australia. According to Swift, these challenges include:

- the adequacy of current maintenance schedules to ensure the continuing airworthiness of the aircraft;
- that in the general aviation, and low-capacity RPT sector, it is difficult to encourage manufacturers to support their ageing aircraft;
- that in the general aviation and low-capacity RPT sector, some type certificates have been taken over by other companies; and
- mandating Supplementary Inspection Programmes for aircraft types where Supplementary Inspection Programmes are available may have a detrimental affect on safety.

Changes to type certificate ownership mean the new type certificate holder may not have the design skills or corporate knowledge to develop Supplementary Inspection Programmes.

CASA is concerned that mandating Supplementary Inspection Programmes, where available, may in fact be detrimental to safety rather than a safety enhancement. The reason is that the maintenance costs for aircraft with Supplementary Inspection Programmes are likely to be greater than the maintenance costs for an aircraft without Supplementary Inspection Programmes. As a result, CASA suggests operators may purchase aircraft without Supplementary Inspection Programmes because of the reduced maintenance costs, leading to a reduction in safety (CASA, 2004b).

8.2.1 Supplementary Inspection Programme for the Piper Chieftain

In September 2001, the Aviation Safety Forum[17] wrote to the Minister for Transport and Regional Services recommending that the Government direct CASA and the Department of Transport and Regional Services (DOTARS) to consider developing a Supplementary Inspection Programme for the Piper Chieftain. This programme would be similar to that carried out by Cessna for the Cessna 402, funded through the FAA's National Aging Aircraft Research Program. The Aviation Safety Forum considered that there would be an organisation in Australia with the capacity to develop a SIP for the Piper Chieftain.

17 The Aviation Safety Forum is a consultative body between the aviation industry and CASA, the body advices CASA on strategic issues.

The Aviation Safety Forum chose the Piper Chieftain for this exercise, as it is the most common piston twin-engine fixed-wing aircraft used in regular public transport in Australia. DOTARS and CASA considered the issue and in June 2004, based on CASA's advice, DOTARS advised the Minister that a Supplementary Inspection Programme was not required.

The current requirements include a mandatory spar replacement at 13,000 hours (CASA, 1999). CASA argues that after this, the life of the Piper Chieftain can be extended a further 13,000 hours or approximately 25 years. CASA considered that this would be adequate to ensure the safety of the Piper Chieftain fleet. CASA suggested that although many operators could not afford to buy new aircraft, there are second-hand aircraft in the United States and elsewhere overseas at a reasonable price (B. Byron, personal communication, 7 May, 2004).

8.2.2 Regional and remote airline economics

Australia is the worlds sixth largest country with an area of approximately 7.7 million km^2 (ABS, 2006). Despite the large land mass of Australia, the population is relatively small (approximately 20 million). Furthermore, 84% of the population live in 1% of the land mass, with the majority of the population concentrated along the south east coast. The remaining population is scattered widely across the continent (ABS, 2002).

Due to the large land mass and large distances to travel, air travel is of particular importance in Australia. Regional airlines are significant as they connect remote and regional communities to essential services. Nearly half of Australian non-international scheduled flights are conducted by regional airlines (BTRE, 2005b). However, due to the low traffic volumes, regional routes cannot sustain large aircraft and the airlines often operate with small profit margins (BTRE, 2005b). Regional airlines that are facing cost pressures and financial losses will reduce or discontinue operations on unprofitable routes, which often fly to remote or thinly populated communities (BTRE, 2005b).

Regional airlines have consistently lower load factors, around 15% lower from 1995 to 2005, than those of domestic airlines. Hence, regional carriers have a higher seat per kilometre cost compared to domestic carriers. The regional carriers are also limited by fixed markets with limited opportunities for growth (BTRE, 2005b).

Aircraft used by regional airlines vary from jet aircraft with up to 100 seats, to piston aircraft with nine seats or less. In 2000, 84% of all regional airline passengers were carried on aircraft with between 30 and 100 seats, 13% were carried on aircraft with between 18 and 29 seats, while only 3% were carried on aircraft with less than 18 seats (BTRE, 2005b). In 2004, the percentage of people carried on aircraft of 30 to 100 seats had increased to 87%.

The number of passengers carried on regional airlines increased by 10.8% over the 2003-04 financial year. However, the number of flights decreased, indicating that regional airlines are using larger aircraft, but reducing the frequency of their services. Coinciding with this is a decrease in the number of airports serviced by regional carriers, from 251 airports in 1986-87, to 194 airports in 2000-01, to 156 airports in 2003 (BTRE, 2003). The types of regional airports no longer serviced vary from airports within 200km of an existing service to airports in remote areas.

Over the period 1982 to 2004, there has been a large increase the cost of new aircraft due to liability issues in the United States (BTRE, 2005a). Due to the high cost of new aircraft, it is difficult for low-capacity RPT operators to cover the cost of their acquisition (Swift, 2003). Moreover, the most common piston-engine aircraft used by low capacity RPT and charter operators have been out of production for more than 20 years This results in low-capacity RPT operators extending the life of their current fleet aircraft and acquiring used rather than new aircraft.

8.2.3 CASA's priorities for aviation safety

As a matter of policy, the passenger carrying sectors of the aviation industry are given priority over the commercial non-passenger carrying operations, private flying and sports aviation (CASA, 2004a) [18]. CASA's hierarchy of priorities are listed below.

1. Passenger transport – large aircraft.
2. Passenger transport – small aircraft:
   RPT and charter on small aircraft;
   Humanitarian aerial work (e.g. Royal Flying Doctor Service, Search and Rescue flights).
3. Commercial (i.e. fare paying) recreation (e.g. joy flights).
4. Flying training.
5. Aerial work with participating passengers (e.g. news reporters, geological surveys).
6. Other aerial work:
   Non passenger carrying aerial work (e.g. agriculture, cargo)
   Private transport/personal business.
7. High risk personal recreation/sports aviation.

This hierarchy of priorities applies to the maintenance organisations, aerodromes, and other infrastructure that support each sector of operations. For example, maintenance organisations that service high capacity regular public transport operations have a higher priority than other organisations (CASA, 2004a). In practice, the quantity of resources allocated to various sectors may be modified by a number of factors including; safety functioning, size of operations, availability of resources, and efficiency gains.

8.3 International directions

In the United States and Europe, a number of initiatives in relation to the safety of ageing aircraft have been under consideration over the last 20 years.

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18 Access from CASA website, 8 November 2006.

8.3.1 United States Aging Aircraft Rule

As a result of the 1988 Aloha Airline Accident, the United States Congress passed the *Aging Airplane Safety Act*, in 1991. This Act required the FAA to inspect and review maintenance records of fixed-wing aircraft used in air transportation, to ensure the continuing airworthiness of the aircraft. In addition, the Act required the operators show that the maintenance of the aircraft was adequate to ensure the highest degree of safety (*Aging Airplane Safety Act*, 1991).

The FAA issued a notice of proposed rulemaking titled *Aging Airplane Safety* in April 1999 to address the requirements of the *Aging Airplane Act*. The notice proposed changes to the Federal Aviation Regulations (FARs), which broadly covered all United States registered fixed-wing aircraft operated as regular public transport aircraft. The notice of proposed rulemaking proposed that these aircraft be subject to records reviews and ageing aircraft inspections after the 14th year in service to ensure the adequate and timely maintenance of these aircraft's age sensitive components. The maintenance programmes of the affected aircraft were also to include a damage tolerance based Supplementary Inspection Programme within 4 years of the effective date of the rule (FAA, 1999).

In December 2002, the FAA released the *Aging Airplane Safety* interim final rule. One of the main changes to the proposed rule was that operators of aircraft that initially certified with nine or fewer passenger seats would be allowed to use service history based inspections rather than damage tolerance based inspections (FAA, 2002).

The final rule was issued by the FAA, in February 2005; this rule had a number of changes from the notice of proposed rulemaking and the interim rule. The major changes were that the supplementary inspection requirements were changed to only apply to transport-category, turbine powered, aircraft type certified after 1 January 1958, which had a maximum seating capacity of 30 or more, or a maximum payload of 7,500lbs or more at the time of certification. In addition, the compliance date was extended to 20 December 2010 (FAA, 2005a).

Where maintenance programmes are developed by aircraft manufacturers as a result of this rule, these could be incorporated into the maintenance programmes of applicable Australian aircraft, hence increasing the safety of the Australian aircraft fleet.

8.3.2 FAA notice of proposed rulemaking on widespread fatigue damange in ageing aircraft

On 18 April 2006, the FAA released a notice of proposed rulemaking (NPRM) titled *Aging Aircraft Program: Widespread Fatigue Damage* (FAA, 2006). The proposed rule change is intended to prevent widespread fatigue damage. Through the Federal Aviation Regulations (FARs) type certificate holders are proposed to be required to establish operational limits for transport category aircraft. In addition, it is proposed that the type certificate holders will be required to determine if an aircraft will require maintenance to prevent widespread fatigue damage prior to the aircraft reaching its operational limit. The rule proposes that operators will not be allowed to operate aircraft beyond their operational limits, unless the operator has received an extension and has included the necessary maintenance in its maintenance programme (FAA, 2006). This proposed rule will be applicable to both current and future aircraft.

8.3.3 National Aging Aircraft Research Program

Since 1988, the National Aging Aircraft Research Program has been undertaking research to improve the safety of ageing aircraft. Over this time, some achievements have been:

- the development of non-destructive testing methods for aircraft wiring;
- the development of new more accurate methods of determining aircraft gust and manoeuvre loads;
- the development of a methodology to assess the advancement of widespread fatigue damage and its effect on the residual strength of aircraft structure; and
- to assist in the development of Supplementary Inspection Programmes for two low-capacity regular public transport and charter aircraft; the Cessna 402 aircraft, and the Fairchild Metro SA226/SA227 aircraft.

8.3.4 Management of safety-critical systems

A safety-critical system is one where a failure of the system could adversely affect the safety of the flight. Examples include; the failure of the rudder actuator in USAir flight 427 in 1994, the centre wing fuel tank in TWA flight 800 in 1996, and the rudder system in American Airlines flight 587 in 2001.

In 2006, the NTSB issued a safety report on the treatment of safety-critical systems in transport airplanes (NTSB, 2006d). The safety report focused on the on-going assessment of safety-critical systems throughout the life of the aircraft. The report concluded that at the time there was no process for the reassessment of the underlying assumptions made, for safety-critical systems, during aircraft design against operational experience and new knowledge. The NSTB report recommended that the FAA require a programme for the ongoing monitoring and assessment of safety-critical systems throughout an aircraft’s life (NTSB, 2006d).

Case Study: Grumman G-73T Mallard Seaplane

On 19 December 2005, a Grumman G-73T Turbo Mallard seaplane, N2969, broke up in flight (NTSB, 2006c). The aircraft impacted water near Miami, Florida, after the right wing separated from the aircraft. The two crew and 18 passengers on board were fatally injured. The flight was operating as a scheduled air transport operation.

During the subsequent NTSB investigation, examination of the aircraft structure found fatigue cracking in both wings and corrosion across many areas of the aircraft. There was an indication that the right wing separated near the root, with evidence of fatigue cracking in the lower rear wing spar cap, along the root, and on an internal stringer. Evidence of fatigue cracking was also found on the corresponding area of the intact left wing. Significant corrosion was found in many locations and one of the fatigue cracks on the left wing had started in a corroded area (NTSB, 2006a).

The accident aircraft was manufactured in 1947, the same year the Mallard seaplane was type certified. The aircraft had been modified in 1979, when the passenger seating capacity was increased from 10 to 17 and the original radial piston engines were replaced with turboprop engines. The Grumman G-73T Turbo Mallard seaplane was not subject to the FAA final *Aging Airplane Safety* rule because it was type certified prior to 1 January 1958.

As a result of the Turbo Mallard seaplane accident, on 25 July 2006, the NTSB recommended that the FAA revise the rule to include all fixed-wing aircraft used for regular public transport operations, or fixed-wing aircraft with 30 or more seats used for charter operations. If accepted by the FAA, this change would mean that regular public transport aircraft carrying nine or fewer passengers and those used on scheduled cargo services would be covered by the rule.

The NTSB also noted that the exemptions in the FAA's final-rule were contrary to the instructions in the *Aging Airplane Safety Act (1991)* (NTSB, 2006a).

8.3.5 European Directions

In Europe, the aviation authorities have issued notices of proposed amendments and have initiated rulemaking activity to address ageing aircraft. The European Aviation Safety Agency (EASA) and its predecessor, the Joint Aviation Authorities (JAA), have considered the ageing aircraft issue; this has occurred in part through the European Ageing Aircraft Working Group.

One output of the European Ageing Aircraft Working Group was the JAA Notice of Proposed Amendment (NPA 20-10) titled *Continued Airworthiness of Ageing Aircraft Structure*, which was released on 25 October 2002. The notice of proposed amendment (NPA) discussed:

- supplementary structural inspection programmes;
- service bulletin reviews and mandatory modification programmes;
- corrosion prevention control programmes;
- repair assessment programmes;
- evaluation for widespread fatigue damage;
- Supplementary Type Certificates; and
- the implementation of these programmes.

The notice of proposed amendment was applicable only to large transport category fixed-wing aircraft (JAA, 2003). However, the notice of proposed amendment did not finally result in any changes to the European Joint Aviation Regulations (JARs).

On 25 April 2006, EASA released an updated version of the notice of proposed amendment (NPA No. 05-2006) titled *Ageing Aeroplane Structures*. The updated proposed amendment included the same points as the earlier NPA, as well as a review of ageing aircraft issues and discussion of the options for implementing programmes to fix problems on the current and future aircraft fleet (EASA, 2006).

The updated notice of proposed amendment discussed the future directions for ageing aircraft rulemaking. For large transport category aircraft, the future rulemaking developments include reviewing ageing aircraft issues and looking at options for implementing proposed actions in the current and future aircraft fleet, consideration to which actions should be mandatory and non-mandatory and for which aircraft operations, and develop these options into rules. In addition, EASA plans to develop a regulatory impact assessment for identifying the need for small fixed-wing aircraft, and extend the rules as necessary (EASA, 2006).

The updated notice of proposed amendment (NPA No. 05/2006) is intended to be published as an acceptable means of compliance (AMC 20-20). In addition, EASA has initiated rulemaking activity for 2001-2009 to examine the subject of ageing aircraft and make regulatory proposals.

9 CONCLUSIONS

The picture of ageing aircraft in Australia is a reflection of the two basic approaches to managing the process of ageing: replacement strategies or additional and specific maintenance strategies. On the one hand, Australia's high capacity Regular Passenger Transport fleet is well equipped with modern aircraft. At the other end of the scale, the piston-engine fleet is largely comprised of aircraft that have an average age of 30 years.

9.1 Large turbofan fixed-wing aircraft used for high-capacity regular public transport operations

The high-capacity jet fleet in the 100,001 kg and above MTOW category has been in service for an average of just 11 years. This is slightly higher than was the case in 1995, when these aircraft were an average of 8 years. The mid-size jet aircraft (MTOW between 50,001 and 100,000 kg) are even younger, averaging only 6 years in service, and is made up of more aircraft less than 5 years than was the case a decade ago. The relative youth of this fleet is a consequence of some fundamental changes to the domestic airline market following the collapse of Ansett and the entry of two new airlines; Virgin Blue and Jetstar. In addition, the Qantas group has expanded its domestic fleet with some new aircraft with the purchase of new aircraft, and through the acquisition of Impulse Airlines.

In addition, there are already very well developed procedures in place to ensure the continuing airworthiness of these types of aircraft throughout their service life. Class A aircraft are required to use an approved maintenance schedule meaning that they must take into consideration information provided by the manufacturer including the continuing airworthiness support. Operators of these aircraft provide in-service information back to the manufacturer from which additional maintenance and repairs are developed. As the aircraft age Supplementary Inspection Programmes are introduced to ensure that the structure and components continue to be airworthy. The maintenance systems for large turbofan aircraft provide a high degree of assurance in the continuing airworthiness of an aircraft.

In effect, there is a double defence in place to ensure that the continuing airworthiness of large turbofan aircraft in the Australian aircraft fleet is not compromised by the effects of aircraft ageing. Because the majority of the aircraft in this group are less than 10 years old, problems such as corrosion and structural fatigue are unlikely to manifest themselves in the near future. In addition, if any unforeseen problems do emerge, there are robust procedures in place to identify and remedy them. Therefore, there is every reason to believe that Australia's very good safety record with this section of the aviation industry will not be affected by issues related to ageing aircraft.

9.2 Turboprop fixed-wing aircraft typically used for regular public transport operations

In 2005, turbofan aircraft with a MTOW of 27,000 kg or less had an average age of 18 years. The average age of this section of the fleet rose by 4 years from 1995 to 2005.

In Australia, turboprop aircraft are generally are flown in regular public transport operations on regional routes. They are Class A aircraft and so follow an approved maintenance schedule. The FAA funded the development of a Supplementary Inspection Programme for the Fairchild Metro SA226/SA227 aircraft type.

If the average age of these aircraft continues to rise, the matter of age may become a concern. However, the development of Supplementary Inspection Programmes will help to ensure their continuing airworthiness for passenger operations.

9.3 Multi-engine and single-engine piston fixed-wing aircraft

The multi-engine piston aircraft are old and getting older. In 2005, this section of the Australian aircraft fleet had an average chronological age of 31 years, or about 10 years older than the average age a decade earlier. By 2005, 97% of the aircraft in this category were over 20 years old.

The multi-engine piston fixed-wing aircraft are often used for low-capacity regular public transport operations, particularly by regional airlines. Regional RPT services are typically characterised by the low traffic volumes and small profit margins. Larger turboprop aircraft cannot be operated viably on many of these routes. The cost of investing in new piston-engine aircraft may be prohibitively expensive, so operators are limited to maintaining ageing aircraft or acquiring used aircraft. In any case, the paucity of new piston-engine aircraft suitable for low capacity RPT operators restricts the choices available.

Aircraft used in regular public transport operations have to be maintained to Class A standards. This requires that the aircraft has an approved maintenance schedule, which is required to take into account the manufacturer’s maintenance schedule and any additional information provided subsequently by the manufacturer. However, the current maintenance requirements for charter aircraft are less stringent and operators are allowed to maintain their aircraft using the CASA maintenance schedule. A proposal to develop an Air Transport category, including both RPT and charter operations, would require air charter operators to also comply with Class A standards, possibly resulting in additional costs. While the higher standards might be welcomed by the travelling public, some operators might find their profit margins eroded and their capacity to acquire newer aircraft further reduced.

As aircraft age, the original maintenance schedules alone may not be sufficient to ensure the safety of ageing aircraft. This is problematic for Australia’s multi-engine piston aircraft as they are ageing, possibly without any continuing airworthiness support from the aircraft’s manufacturer. Some aircraft, such as the Cessna 402 have Supplementary Inspection Programmes. Where the manufacturer is either unable or unwilling to develop Supplementary Inspection Programmes the alternative is for a competent engineering organisation to take on this task. CASA would be keen to see industry take on that responsibility for their own interests should ongoing support from the manufacturer be unavailable (Swift, 2003).

Like the multi-engine piston fleet, single-engine piston aircraft are old and getting older. In 2005, the average age of this category was 30 years, an increase of 7 years over the previous decade. Eighty per cent of aircraft in this category were aged over 20 years in 2005.

Single-engine piston aircraft are typically used for training, private or business flying rather than for fare-paying passenger operations, and hence are regulated less stringently than aircraft used in commercial passenger operations. The CASA maintenance schedule requires that inspections be a thorough check to ensure the aircraft will continue to be airworthy until the next periodic inspection. Private operators need to exercise personal responsibility and educate themselves about the issues relating to the maintenance of ageing aircraft. As of March 2006, the United States Aircraft Owners and Pilots Association was in the preliminary stages of developing an online course to introduce pilots to maintenance issues associated with older aircraft (AOPA, 2006). In addition, the FAA, in conjunction with a number of aircraft associations in the United States, has produced a best practise guide to managing ageing in general aviation aircraft (Aging Aircraft Ad Hoc Committee, 2003).

9.4 Rotary-wing aircraft

The helicopter fleet has expanded considerably over the last decade, from 700 helicopters in 1995 to 1227 a decade later, mostly from within the piston and single-engine turboshaft types. Overall, the average age of the helicopter fleet has increased over the last 10 years, but only the single-engine turboshaft fleet has increased beyond 20 years, indicating many turboshaft helicopters have entered service in Australia as older used models.

9.5 Summary

Australia’s circumstances are very similar to those of other countries operating modern airline fleets and have a large and active general aviation sector. The larger turbofan aircraft serving passengers on domestic and international routes are largely new, have well resourced maintenance programmes and the ongoing support of the manufacturers. The piston engine fixed-wing aircraft have been operating for an average of 3 decades. However, chronological age is not the sole determinant of aircraft age and usage rates tend to be much lower for these aircraft, compared with turbofan and turboprop aircraft engaged in commercial air transport operations. Nevertheless, the operators of piston fixed-wing aircraft tended to be much less well resourced, may not have the benefit of long term support from the manufacturer, and may face further challenges should there be a more serious shortage of qualified LAME personnel. Moreover, new aircraft are relatively more expensive now than they were, and production output is only a fraction of its peak in the late 1970s limiting the prospects of acquiring new aircraft.

While ageing aircraft can be a safety issue, with adequate additional and specific maintenance, the impact of ageing can be mitigated. Current and future maintenance programmes will act as a preventative measure to reduce the safety risk associated with ageing aircraft. CASA has stressed that these programmes will only increase safety effectively if operators adhered to them (D. Villiers, personal communication, 22 March, 2006). Managing the consequences of an ageing aircraft population requires cooperative approaches by operators, manufacturers and national regulators to ensure that any defects identified by one operator are notified quickly and efficiently within the industry.

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APPENDIX A: GLOSSARY

Airworthiness Directive

A document that requires mandatory action to address an unsafe condition that exists, or is likely to exists, or could develop, in an aircraft, engine, propeller, or component.

Class A aircraft

Class A aircraft are Australian registered aircraft that are maintained to a specific standard that is required for aircraft certified in the transport category, or that are used in regular public transport operations[19]. The maintenance required for Class A aircraft is more rigorous in its application and control than the maintenance required for other Australian civil aircraft.

Class B aircraft

A Class B aircraft is any aircraft that is not a Class A aircraft[20] this includes aircraft used for charter operations, aerial work, and private operations.

Continuing Airworthiness

The tasks required to ensure that an aircraft remains 'fit to fly', throughout its design life, in all the environments and circumstances for which it has been designed and certified.

Corrosion

Chemical action that leads to the destruction of the surface of a metal.

Cold-bonded

An adhesive composition that requires no applied heat to effect curing and produces a strong bond.

Damage

Change to a structure that occurs during both normal and abnormal operation. Damage that occurs during the normal operation (such as corrosion, fatigue, cracking and wear) may be predicted, and maintenance planning is based on prediction of the rate of damage development during normal operation. Damage during abnormal operation requires special and individual assessment for its management.

Damage tolerant structure

A structure that is able to sustain a given level of fatigue, corrosion, manufacturing defects, or accidental damage, and still withstand design loads without structural failure or excessive structural deformation for a predetermined period that allows for a set number of opportunities to detect the damage.

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19 Civil Aviation Regulations 1988, 2(1), 2(2C), & 206(1c)

20 *Civil Aviation Regulation* 1998 2(1)

Factor of safety

The factor that the limit load is multiplied by to produce load used in design of aircraft or part. It is intended to provide margin of strength against loads greater than limit load, and against uncertainties in materials, construction, load estimation and stress analysis (Gunston, 2004).

Fail-safe structure

A structure designed to retain its required residual strength for a period of unrepaired use after a failure or partial failure of a principal structural element.

Flight cycle

A completed take-off and landing sequence.

Fatigue

Weakening or deterioration of metal or other material through repeated cyclic loading; leading to cracking and ultimately failure.

Fracture

The act of breaking or snapping asunder (*Audels New Mechanical Dictionary for Technical Trades*, 1962).

Fuselage frame

A fuselage frame is transverse element that supports the cross-sectional shape of the fuselage, distributes concentrated loads and act as crack stoppers.

General Aviation

General aviation refers to all non-scheduled civil flying activity other than air transport and sport aviation operations. General aviation operations can be further divided into commercial and non-commercial operations. General aviation commercial operations include charter and aerial work. Aerial work includes, for example, flying training, agriculture operations, surveying, aerial photography, and aerial ambulance operations. Non-commercial refers to private and business operations.

Knife-edge

A sharp edge of a structure; they can be a stress raiser and are often crack initiation points.

Cyclic loads

Repeated application of loads from the operating cycle.

Dynamic loads

A load applied by a dynamic action, as distinct from a static load. Specifically, with respect to aircraft, a load due to acceleration as imposed by manoeuvring, landing gusts, etc.

Gust loads

Increased structural loads due to either a sudden increase in velocity of horizontal wind or a suddenly encountered region of rising or falling air (Gunston, 2004).

Manoeuvre loads

Loads due to any deliberate departure from straight and level flight (Gunston, 2004).

Load path

Sequence of structural elements carrying a load (Gunston, 2004).

Load spectrum

Load spectrum describes the anticipated loads that will be applied to an aircraft during its service life.

Maintenance schedule

Prearranged plan for all maintenance required through life of an item (but subject to revision).

Multiple site fatigue damage (MSD)

Multiple site fatigue damage is where fatigue cracks occur at many locations within the same structural element (Wanhill, 2002). It is a type of Widespread Fatigue Damage (WFD).

Regular Public Transport (RPT)

RPT operations refer to air transport operations used for the commercial purpose of transporting persons generally, or transporting cargo for persons generally. These operations are conducted for hire or reward in accordance with fixed schedules to and from fixed terminals over specific routes with or without intermediate stopping places between terminals.

High-Capacity Regular Public Transport aircraft

A RPT aircraft that is certified as having a maximum seating capacity exceeding 38 seats or a maximum payload exceeding 4,200kg.

Low-Capacity Regular Public Transport aircraft

A RPT aircraft that is certified as having a maximum seating capacity less than or equal to 38 seats or a maximum payload less than or equal to 4,200 kg.

Residual Strength

The maximum load carrying capacity of a damaged structure.

Safe-life structure

A structure designed to withstand a certain number of events (flight cycles, landings, or flight hours) with a low probability that the strength of the structure will degrade below its designed ultimate strength before the end of its approved life.

State of Design

The State (country) having jurisdiction over the Organisation Responsible for the Type Design of an aircraft. (ICAO Annex 13)

State of Manufacture

The State (country) having jurisdiction over the Organisation Responsible for the Final Assembly of an aircraft. (ICAO Annex 13)

State of Registry

The State (country) on whose register an aircraft is entered. (ICAO Annex 13)

State of the Operator

The State (country) in which the operator's principal place of business is located or, if there is no longer such a business, the operator's permanent residence. (ICAO Annex 13)

Supplementary Inspection Document (SID)

A supplementary maintenance schedule intended to be used after the aircraft reaches a specified number of flights or hours. SIDs provide additional maintenance and inspections to ensure the continuing airworthiness of ageing aircraft.

Transport Category

Multi-engine aircraft primarily intended for the regular public transport of passengers or cargo for hire/reward. Transport category generally applies to aircraft with a maximum take-off weight greater than 5,700 kg although aircraft with a maximum take-off weight of less than 5,700 kg may apply to be certified as transport category.

Type Certificate

A type certificate is issued by the civil aviation authority of the State of Design stating the airworthiness standard for the aircraft type, model, aircraft engine or aircraft propeller. Some States use a different term for type certificate, such as type approval certificate, certificate of approval, Fiche de Navigabilité.

Ultimate load

Greatest load than any structural member is required to carry without breaking.

Ultimate Strength

The strength required to bear ultimate loads, or product of greatest load considered possible in service multiplied by the ultimate factor of safety.

VH-registered aircraft

Any aircraft certified by the Civil Aviation Safety Authority to appear on the Australian civil aviation register.

Widespread fatigue damage

Fatigue damage in a structure to the extent that the structure no longer meets its damage tolerance requirements. The presence of cracks of a sufficient size and density in a structure, to the extent that it can no longer maintain its required residual strength.