Managing Ageing Aircraft Parts I/II
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The issue of ageing aircraft is one which often elicits prognoses of gloom and doom, and the recent run of media reports dealing with both commercial aircraft fleets and some of the RAAF's assets are a typical example of how this often misunderstood challenge is perceived. The reality of ageing aircraft is much less exciting than the sensational prophecies of aircraft imminently falling from the skies - managing other than new aircraft is a systematic engineering process which is now very widely practiced. This month's TE will explore some the more important issues in the management of ageing aircraft.

1 Defining an 'Ageing Aircraft'

One of the realities of the world is that any aircraft which rolls off a production line will start ageing once put into service. It will accrue fatigue damage to structural components and load bearing skins, it will experience wearout in a range of moving mechanical and electrical components, it will corrode to varying degrees in various places, and a range of non-metallic materials in the airframe and systems will degrade over time. In this sense every aircraft is an 'ageing aircraft'.

In broad engineering terms, 'ageing aircraft' is a term used to describe aircraft which are exhibiting one or more of the systemic effects of age and use, be it airframe fatigue, corrosion, or component failures through wearout - fatigue engineers tend to be more selective and define 'ageing aircraft' to be aircraft which have exceeded their certified airframe design life. Depending on the design and rate of usage, ageing effects might develop at three, five, ten, fifteen, twenty or even thirty years of age. While airframe flight hours might be used as a metric, the often wide variations in flying loads experienced by particular types can render this metric questionable as an indicator of remaining life - for instance a fighter driven several times a day to its max G rating will accrue fatigue damage much faster than its sibling which is flown at high G much less frequently.

Perhaps the most important point in the 'ageing aircraft' argument is that the useful life of aircraft varies dramatically across types, often across variants in a type, and has strong dependencies on how the aircraft is used and especially, how it is maintained. Those who opt to generalise and draw conclusions about the longevity of one aircraft based upon experience with another aircraft are well and truly missing the point.

This point also underscores another related issue, which is that understanding and managing ageing effects in any aircraft requires a very good depth of engineering insight, experience and type specific knowledge. A well thought out and planned 'ageing aircraft program' for managing a type can literally add decades to its useful life - where large fleets need to be replaced this can save billions or tens of billions to a fleet operator.

Those who might seek simple answers in the 'ageing aircraft' game are going to be disappointed. Much engineering and scientific work must often be done to accurately assess how much life exists in a given type/fleet, and often the results are surprising, be they favourable or unfavourable to life extension.

2 Reliability, Maintainability and the Bathtub Curve

Reliability theory occupies a central role in the management of 'ageing aircraft'. This obscure but vital discipline, which has almost vanished from Australian university engineering syllabi over the last three decades, is concerned with the mathematical prediction of failure rates in equipment, using statistically gathered parameters for individual components. With known failure rate statistics for every component in a design, a reliability engineer can predict with a high level of confidence the Mean Time Between Failure (MTBF) of a design. Indeed, a design can be crafted to meet a specific MTBF.

MTBF is important since it determines how frequently an aircraft has to be repaired, and is thus a measure of its availability for use. A fighter with an MTBF of under 1 hr is likely to be a 'hangar queen', whereas a fighter with an MTBF of many hours will be popular with its operators.

Reliability theorists recognise two basic modes of failure. The first mode is termed 'random failure' and is attributable to hidden manufacturing defects or unanticipated but infrequent causes of component damage. The second mode is termed 'wearout failure' and is attributable to mechanical wear, corrosion, fatigue damage and other cumulative damage effects which cause a component to fail with age.

Both random and wearout failures can vary widely in their statistical behaviour, and are usually characterised by a mean or average failure rate, and some variance or standard deviation in the parameter.

Virtually every design is made up of components, each of which will have component specific mean random failure rates and wearout failure ages. The reliability of the design as a whole will be the result of the aggregate of these failures, and is usually described by 'Lusser's Product Law' (discovered during the prototyping of the A-4/V-2 ballistic missile during WW2). Lusser's Product Law is simple arithmetic - the total reliability of the system is the product of the reliabilities of each and every mission critical component, where reliability is calculated as R = exp (- lamba * time), where lamba is the aforementioned failure rate.

The implications of Lusser are manifold, but engineers dealing with 'ageing aircraft' are most interested in the 'Bathtub Curve', which is a plot of average failure rate for a design over time. Statistically, a high failure rate is seen in the first few weeks or months after the product leaves the factory - this is as a result of defects not found in factory testing, and is termed 'infant mortality'. After the 'infant mortality' phase, products enter what is termed the 'active life' phase during which they exhibit low failure rates, indeed the 'active life' phase is defined as the period during which random failures dominate. Finally, as components begin to wear out (or indeed corrode), the design enters the 'wearout phase' and the failure rate shoots up. Whether we are looking at lightbulbs, bomb nav computer processor boards or wing spars, the Bathtub Curve is a reality which is expensive to ignore.

Aircraft are complicated systems often with tens of thousands or more components, a large proportion of which can be either replaced or repaired. Therefore numerous strategies will exist for managing the maintenance of a fleet, and indeed for dealing with random and wearout failures in components or subsystems.

In the 'ageing aircraft' game the central issue is how to best manage wearout of a specific component or group of components in a design. A well thought out management strategy can see those components which are approaching wearout replaced in blocks, defacto in a fleet block upgrade, thereby removing the problem altogether and maintaining the design in the reliability engineers' 'active life' phase indefinitely.

Whether to retire a design or keep it operating indefinitely is then a function of the cost of block replacement of worn out components, against the utility of the design, and the cost of complete fleet replacement. An airliner which has a residual market value of several million dollars is not a good candidate for a 5 million dollar rewiring effort. Conversely, a specialised airlifter which costs US$ 200M to replace, is apt to be a good candidate for many millions worth of block replacement/repairs if these add a decade or more of life to the fleet.

The key to success in the 'ageing aircraft' game is knowledge and understanding of the idiosyncrasies of the type in question. Poorly planned or non-existent management programs for aircraft crossing the 5-15 years of age point can often see operators trying to maintain a type in the nether regions of the Bathtub Curve - rather than executing a planned block replacement of a worn out component, the operator will end up deluged with seemingly random failures resulting in significant downtime and cost. It is always cheaper to replace a component when an aircraft is down for scheduled depot maintenance, than it is to tow the aircraft off the flightline for an impromptu repair. A robust and bureaucratic system for logging repairs and failures can be an invaluable tool for detecting the onset of wearout in a specific component or subsystem, permitting early corrective action.

Other interesting issues also fall out of block component replacements. If the components being replaced account for instance for 95% of fatigue life issues on that airframe, a block replacement/repair can in effect drive the airframe flight critical component condition back to something very close to a new aircraft. It is no accident that the US Air Force wing rebuilds on the B-52 and KC-135 may see many of these aircraft in operation cca 2040. Both rolled off the production lines in the very early 1960s, making them around 80 years old at retirement.

It is worth underscoring that a good 'ageing aircraft' management plan is not a game for the novice or the engineering illiterate - often very cunning thought and much testing must be performed to devise the best strategy and indeed identify the most likely hot spots in a design, preferably years before these reach wearout.

3 Airframe Fatigue

Airframe fatigue analysis and management is a science in its own right, and happily Australia has world class capabilities in this area at the Melbourne DSTO facility.

Fatigue effects in metals and other materials are an implicit consequence of material physics at a microscopic level. Metals, as the primary structural material in modern aircraft, are of most interest.

A chunk of metal alloy may appear uniform to the naked eye, but under a microscope it will become a grainy mosaic of tightly packed crystals, with interspersed inclusions of various impurities. Typically, each crystal has a uniform crystalline structure and exhibits exceptional mechanical strength - evidenced by the use of 'single crystal' components in modern jet turbines. The crystals are held together by electrical bonds at an atomic level, an effect not unlike a vast number of miniature 'welds'.

If we look at a manufactured metal component closely, we find that the surface may have microscopic scratches and pits - these together with inclusions within the material in the body of the component cause localised stress concentrations when subjected to mechanical loads.

When a metal component is subjected to high levels of mechanical stress, some portion of the microscopic bonds will break, in those areas where the localised stress concentration is highest. If the proportion is very small, or very evenly distributed through the component, the strength of the component will not be impaired. If the damage is concentrated in a particular area, then cracks will develop, and if stress is applied repeatedly, these cracks will grow until eventually the component catastrophically fails.

The distribution of stress in a component does matter. Structural discontinuities such as holes, corners, joints or concave shapes with small radii typically result in higher levels of local stress in the part - this in turn causes the stress around local microscopic imperfections to increase. As a result cracks are typically initiated from inclusions and surface defects in such regions of a component. Where additional surface damage has been caused by maintenance, corrosion pits or fretting (rubbing of metal surfaces in joints), the problem is exacerbated since more opportunities exist for cracks to be initiated. Therefore the fatigue life of a metal component depends not only on its shape and material composition, but also on its microscopic material structure, and surface condition - surface finish indeed matters.

Aircraft are particularly sensitive to fatigue damage since their structural components are nearly always built to be as light as possible and therefore operating at higher stress levels than equivalent non-aviation parts, often leaving little margin for safety in components. Another issue for aircraft is the choice of materials - aluminium alloys still dominate the industry and will for many years to come - aluminium alloy is relatively soft and more prone to fatigue damage than other metals. Where steel is used for high strength in aircraft structures, frequently the alloys in question may be brittle and sensitive to cracking.

Structural components designed for long fatigue lives are such where there are few or indeed no areas in the component where high stresses are concentrated. In practice stress concentrations are an unavoidable evil - the limitations of materials, manufacturing processes, the need for joints with fastener holes and access panels all contribute to stress concentrations in structural components. Such ‘hot spots’ are where cracking will first develop in an aged component, and this is true for any material used. Cracks tend to grow, since the geometry of a crack produces a very high stress concentration at the end of the crack itself. Once a crack grows beyond a particular size, the component will fracture.

An idiosyncratic problem seen with some materials, the 7079 aluminium alloy being an example, is an effect termed ‘stress corrosion’. Stress corrosion is a result of residual stress in a part created as a result of suboptimal manufacturing or assembly processes in stress corrosion sensitive materials, which are then subjected to corrosion attack. In a given environment, which for some such materials can be as benign as demineralised water, such components can develop cracks with age even if the applied mechanical loads are trivial, as not unlike thermally hardened windscreen glass, the component is always under strain.

A well designed structure is ideally one with multiply redundant load bearing paths, which allows the aircraft to straggle home in the event of failure of a key structural component. A key issue for ‘ageing aircraft’ is whether these redundant structural load bearing paths have not suffered cracking damage and are indeed able to support their design loads if another component does indeed fail.

In modern aircraft, fatigue problems arise in three general areas.

1. Internal primary load bearing structural components, such as sections, struts, longerons, spars and supporting frames. Such components are subjected to cyclic stretching, compression and twisting and may develop cracks in stress hot spots. Failure of a primary load bearing component can cause the loss of an aircraft.

2. Load bearing skins, especially lower wing surfaces and fuselage skins in large pressurised aircraft such as transports. Many aircraft use monocoque construction and the skin carries a large proportion of the structural load, failure of a skin can thus be catastrophic.

3. Fastener holes in all categories of component. Fasteners, be they rivets, bolts, screws or

variations on the theme like Taperloks, are widely used to hold parts together. Since mechanical loads are transfered between parts by the fastener and the compressed material surrounding it, the often high local stress concentration leads to fatigue damage around the fastener much earlier than elsewhere in the component, causing localised cracking.

Detection of fatigue damage, usually manifested in cracking, can be performed by various means. Non Destructive Inspection/Testing (NDI/NDT) techniques using ultrasound, electrical eddy currents, optics (light), X-ray scattering or absorption are all widely used, often as part of robotic inspection equipment. These techniques can be further enhanced by the use of computer simulations of stress loads in airframes, since the latter permits prediction of which parts of which components are most likely to develop cracks.

What measures exist for a maintainer if components are found to have fatigue damage?

The first is simply to replace the whole component with a new one. For many components, such as skin panels, this can be done quickly and often very economically. A common practice is to replace the original skin with a replacement made of thicker or tougher material, thus resulting in a more durable replacement part.

Other components might be buried deep inside a structure, and their replacement becomes possibly very expensive, depending on how much of the airframe must be disassembled to replace the part.

There are other techniques which can be used to 'zero time' or life extend components. One technique is the application of boron epoxy composite patches, which transfer part of the stress load otherwise carried by the part. Another is to machine away the cracked material, crack depth and part shape permitting, thus restoring the part to a condition not unlike when new. Fastener holes are frequently reworked by reaming out the hole to get rid of up to several millimetres of fatigue cracked material - an oversized fastener is then employed to replace the original (NB this is also a repair technique widely used for damaged threads). Reworking of fastener holes is a widely used technique and for some components can be performed repeatedly to extend their life more than once - as it is a technique which can often be automated by robot, it is potentially very affordable. The principal issue is long term management since there is a limit to the number of times a hole can be reworked.

Whether any specific design can be 'zero timed' economically depends very much upon the idiosyncrasies of the design. How many components must be replaced or refurbished? How much effort/labour is required in structural rebuilding? How difficult to fabricate are the replacement parts? How difficult is it to determine which parts need to be replaced? There are no trivial all encompassing answers - only a very robust understanding of the aircraft's design and fleet condition allows an accurate assessment of what a 'zero timing' effort will cost. Guesswork could very well see an aircraft replaced at considerable cost, despite it having very significant life extension potential.

A recent development is the use of robotically deployed NDI/NDT tools to manage airframe life by automated inspection. Crack growth is periodically monitored in this fashion during planned servicing, to delay the rework or replacement of cracked parts as late as possible. This policy is based on the idea that cracks of certain lengths can be tolerated in parts, thus deferring the repair cost by hudereds or thousands of flight hours.

In general, determining the fatigue life of any structure is a time consuming and tedious task. The most commonly used technique is to take a representative airframe or parts thereof, instrument it with strain gauges, and cyclically torture it to death until it fails. A detailed post mortem will reveal exactly where and how it failed, and if need be exactly what remedial measures might be taken to extend its life. Statistical spread in component tolerances, assembly tolerances, material behaviour and flight loads has an important consequence - the fatigue life of any given airframe type might have a very large statistical spread. What this means is that some percentage for example might fail at 10,000, some at 15,000, some at 20,000 and so on hours of airframe life. Fatigue engineers account for this by using very large safety factors. A typical safety factor used by the RAAF, and overseas, is that the operational safe fatigue life of a structure is 25% of the fatigue life achieved in a test - or that for an intended operational life of N hours, an example must survive fatigue testing for 4 x N hours, to be considered safe.

Therefore, fatigue life estimates used in practice tend to be very conservative and an airframe may in reality have several times the 'nominal' fatigue life established in testing. Since the fatigue life of any structure depends on the aggregate behaviour of thousands of fasteners and hundreds of components, it is nearly impossible to look at a given airframe and say 'this one will fall to bits at date X'. What fatigue engineers aim to do is establish some bound, in flight hours, up to which there is a negligible chance of a catastrophic failure in primary load bearing structures.

If an airframe is to be flown beyond the safe fatigue life established by fatigue testing, it becomes necessary to perform a 'safety-by-inspection' program - a fatigue engineer will then specify at what intervals which parts need to be inspected for crack growth.

Clearly fatigue life management is a complicated and technically demanding area. The payoff in mastering it properly, for any given airframe, is that often significant economies can be achieved in deferring fleet replacements. For commercial and military operators, having choice in when to replace a fleet buffers against poor availability of replacement aircraft types, but also puts the operator in a stronger commercial negotiating position when dealing with vendors of replacement aircraft.

4 Airframe Corrosion

Corrosion is a sad fact of life with any metal aircraft design. The principal impact of corrosion is that the structural strength of parts is impaired. A corrosion pit can become a stress hot spot and the point at which a crack starts. Corrosion which attacks large areas of a part might change the load bearing structure shape to the point where the part fails.

Most corrosion seen in metal aircraft is galvanic (a.k.a electrolytic) in nature. Galvanic corrosion arises whenever two dissimilar metals are immersed in an electrolyte, usually water which is suitably contaminated (the same basic chemistry as seen in batteries). Importantly, this effect can arise even between microscopic grain boundaries in an alloy component, creating a tiny pit which grows in depth and size over time.

Aircraft are continuously exposed to moisture, be it external exposure in rain and cloud, or water on runways, or internal via condensation of airborne moisture as the aircraft climbs and cools. Maritime aircraft and helicopters must operate with continuous exposure to seawater and salt will get into every imaginable crevice in the airframe. A classical anecdote was the corrosion found in Boeing 707s rebuilt as E-8 JSTARS - many were used as freighters to transport racehorses in their earlier lives, and horse urine provided an aggressive electrolyte. Serious corrosion was found in the lower fuselages as a result.

The best prevention technique is proper surface coating, for aluminium alloys this typically involves anodising the component and then painting it with a tough epoxy or polyurethane based paint. Even so, experience with airliners shows that dust particle impacts, insect impacts and defacto water jet sandblasting by dust grains in water on runways can produce external corrosion problems. Any surface damage to an anodised part creates a tiny surface pit, which might trap moisture and initiate corrosion.

Corrosion can be as serious an airframe life limiter as fatigue, in many instances airframes with much remaining fatigue life die as a result of corrosion damage which is uneconomical to repair. Corrosion is likely to be what eventually kills a large proportion of the USAF KC-135 fleet in time, as structural rebuilds have given the fleet a fatigue life out to 2040. Commercial aircraft rebuilt into tankers are the classical case study.

The economics of corrosion repair can vary widely. Damage to skin panels can often be repaired at modest cost by replacement. More insidious is corrosion resulting from moisture trapped inside structures, hidden from sight. Capilliary action will draw moisture into gaps between parts, where it quietly eats away. The cost of repairs then depends on how much structure needs to be replaced. The USAF E-8 JSTARS rebuilds cost a similar amount to new build 707 airframes.

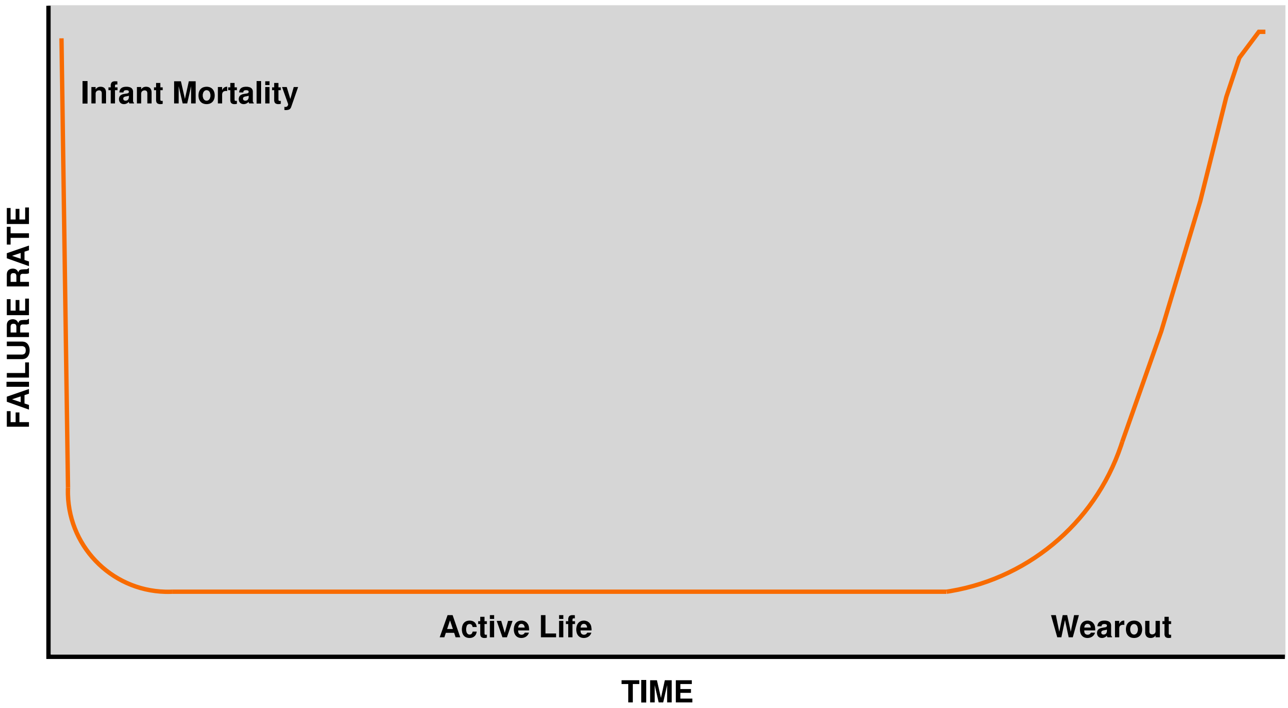

Figure 1: *The 'Bathtub' curve for equipment lifecycles.*

1.Bathtub Curve

2.USAF E-8 JSTARS (not enclosed)

The USAF's fleet of 'new' E-8 JSTARS are rebuilt commercial 707 airframes. Due to often serious corrosion damage in the lower fuselages, the cost of the rebuilds was similar to the cost of newly built 707 airframes. Congressional pressure to 'save money' by closing down the 707 production line and using older airframes did not prove to be the bargain intended in this case.

3.RAAF Boeing KC-707-338C

The RAAF's Boeing 707-338C tankers are a good example of a well aged aircraft, with fatigue damage in the lower wings and centresection, corrosion problems in a number of areas, old wiring and increasingly difficult to support JT3D-3B engines (RAAF).

4.F-111C

The subject of much negative media commentary in recent months, the F-111 is without doubt from a fatigue analysis perspective one of the best understood assets in RAAF service. With a long running structural integrity monitoring program using Cold Proof Load Testing techniques, the F-111's structural integrity is better documented than almost any other type in service.

5.KC-135R

The USAF's KC-135Rs received extensive wing rebuilds, new engines and new avionics. While many have corrosion problems, current USAF planning envisages the type in service well beyond 2030.

6.B-52H

The venerable Buff is currently planned to remain in service until some date close to 2040, making the aircraft 80 years old when retired! The Buff has received wing rebuilds, repeated avionic rebuilds and may yet receive new engines. Given that the cost of a direct replacement, for instance a new build B-2C, runs into hundreds of millions apiece, the economic case for stretching the Buff is hard to dispute. Why is it the cheapest to operate of the USAF's three bombers? In part the maturity of the aircraft's support base permits very precise planning of repairs to age damaged components.

5 Airframe Wiring

Electrical wiring is an ongoing concern in commercial and military aircraft. The problem lies in the degradation with age of organic insulator materials used to clad cable cores. These insulators can be exceptionally thin for aviation cabling, so as to minimise weight and cost. An insulator which has become porous might absorb moisture and fail to properly insulate, an insulator which is embrittled will crack and flake away. With 115 to 240 Volt/400 Hz and 28 VDC electrical distribution in most modern aircraft, insulator failure can lead to short circuits, arcing and fires. If the arcing occurs in a fuel tank, an explosion might result if the right fuel-air mixture is present. A number of recent accidents are attributable to wiring failures, including the tragic Swissair DC-10 fire.

A wide range of insulators have been used for aircraft wiring over the last 40 years, and most have known age related failure modes. Probably the best known is Kapton, which burns well when arcing occurs, but other insulators are also known to degrade with age. Stilan is described as vulnerable to hydraulic and de-icing fluid contamination, XL Tefzel is claimed to crack under vibration loads and burn in arcs, Poly-X is claimed to be vulnerable to solvents and prone to embrittlement, while PVC/NYLON can form a corrosive if exposed to water. Thin wall Teflon is probably the best behaved insulator available, but must be handled carefully due to its cold flow properties. Mixed Teflon - Kapton - Teflon wrapped insulation has been used in some more recent aircraft designs.

While the risk of fires is the principal safety issue driving the public debate on wiring, ageing effects in insulators can impact other cable functions. Radiofrequency coaxial cables used for nav/comm, and EW in military aircraft, are prone to dielectric degradation and moisture ingress with age. This can result in serious signal degradation, impairing the radio frequency performance of systems. An EW system with impaired sensitivity due to cable degradation might be deaf to the SAM shot which kills the aircraft.

The cost of replacing wiring in older aircraft can vary very widely, and can run into many millions for a widebody airliner. As many wiring harnesses are embedded in structural assemblies, their replacement can require significant structural disassembly. Military aircraft usually see large scale wiring replacement during mid life avionic upgrades, and generally are considered less exposed than the large fleets of decades old airliners remaining in use.

6 Systems Components

All components with moving parts, especially fuel and hydraulic pumps, valves, but also rotating electrical machinery and fans, will experience wear, especially in bushes or bearings. This wear can cause the component to sieze, or in rotating machinery, overheat and possibly cause a fire or explosion. Hydraulic and fuel lines often flex with internal pressure transients, resulting in chafing or fatigue damage to the pipe, but frequently also to the supporting structure (these are often termed 'hydraulic hammer' effects). Bleed air pipes, exposed to high temperatures and pressures, can rupture.

Generally, a robust maintenance regime, careful monitoring, and block replacement of such components can be used to very effectively manage ageing. Perhaps the most dramatic example in this category was a KC-135 which exploded in flight due to the seizure of a dry running immersed fuel pump, in an empty vapour filled fuel tank. A block replacement of the pump type across the fleet removed this problem.

In military aircraft, pyrotechnics are subject to ageing. This can manifest itself in either a failure to initiate when fired, or worse, the pyrotechnic becoming sensitive and firing when not commanded.

7 Component Life Cycles and Supply

An issue of key importance in maintaining older aircraft is the availability of replacement components. This is especially true for avionics, but remains an issue for many other parts such as switches, connectors, seals, fittings, fasteners, valves, pumps, generators, motors, servoes, bearings and bushes.

When aircraft are designed such components may be custom built for the design, but frequently also 'industry standard' components or components common to other designs built by that manufacturer will be used. The availability of replacement parts can therefore vary very widely. Engineers recognise the 'life cycle' of a component, which comprises the early production life, full scale production life, residual production life and eventual obsolescence of the component. A fastener design might have a life cycle of decades, whereas a microprocessor might remain in production for less than 18 months, upon which it is obsoleted.

This has important implications for supporting aircraft which as a rule now remain in operation for at least two decades, and sometimes many decades.

Generally, while an aircraft remains in production it is economical to replace parts with originals, but once production ceases the availability of the part will depend on remaining stocks, and frequently non-flyable airframes in storage. The USAF have made extensive use of AMARC to support their B-52 fleet.

A key issue with older aircraft is whether to continue using the original part, either from existing stocks or by contracting an manufacturer to make new examples. Often newer generation technology is more reliable and more durable, and there is a big economic advantage in designing out the original part and replacing it with the equivalent being made for a current production aircraft. Persisting with the use of a failure prone and expensive 1960s, 1970s or 1980s designed component can be the dumbest thing an operator can do. The cost of replacing such a component in the aircraft design can be a small fraction of the long term costs of using the original part.

Computers and semiconductor chips are now a major issue, since their life cycles have dramatically contracted over the last decade. Twenty years ago a transistor or chip might have remained in production for over a decade. Today, a production life of 2 years is considered quite long.

This has spawned a whole cottage industry in Silicon Valley, where a number of smaller semiconductor houses manufacture 'pin-for-pin' replacements of obsoleted Milspec transistors and chips, for which a large base of legacy system users remain.

The modern approach to the computer life cycle problem is twofold. The first is to use industry standard board level interfaces, which permits the replacement of obsoleted processor boards with current production boards, in a defacto continuous block replacement program. The second is to architect the avionic system and software from the outset to permit easy replacement of processor boards. The F-22 pioneered this model, now used in the F-35/JSF and a number of production fighters or retrofits (it is worth noting that the F-22 has gone through several replacement cycles in its computing hardware between prototyping and recently started production, as the politically imposed delays have repeatedly led to the obsolescence of computers chips it used! We can expect a similar pattern with the F-35/JSF.).

8 Ageing Aircraft Support Policies

As is abundantly clear, the 'ageing aircraft issue' is becoming over time the 'fleet support management issue' for most military and commercial operators. Unlike the 1950s and 1960s where dramatic technological growth saw significant pressures to replace commercial and military aircraft as early as possible, the 21st century is an environment where many aircraft might remain viable for decades to come. In the absence of a credible technological peer competitor to the West, military aircraft purchased over the next two decades might remain in service for 40 or 50 years, and over that period they will need to be kept structurally sound and competitive in avionics and weapons.

The central issue in managing any aircraft fleet over a life of several decades is the maintenance policy adopted. A well thought out policy will see ageing effects on all subsystems and structure continuously monitored from the point of service entry, to identify hot spots as early as possible. In general, repairs which are done thoroughly and with a view to longevity tend to be economically better over the long term, than expedient 'quick fix' repairs intended to last the next few years. Replacing a component with a more durable replacement defers the date at which that repair must be repeated again - a part which has been redesigned to eliminate a stress concentration may never need to be touched again - engineer's like to use the term 'fatigue-proofing the component'. The bottom line is that all repairs cost money, and repairing in a manner which defers a future repair on average saves a lot of money over time.

Structures can be particularly sensitive to the quality of repairs or component reworks. The classical problem is where corroded or cracked material is removed to extend the fatigue life of a component. There will be some limit to the number of times metal can be shaved off before a more extensive and expensive rebuild is required. Therefore planning decades ahead and playing conservatively can pay off handsomely in the long run.

The quality of basic maintenance also matters. Flightline and depo servicing which results in stripped fastener heads, improper part tolerancing, inappropriate fastener torqueing, impact damage to parts, damage to anodised surfaces, the use of unsuitable lubricants, paints and sealants, and a plethora of other sloppy maintenance practices can significantly impair the longevity of an aircraft, or significantly drive up the cost of future life extension. This is incidently not only true of aircraft - the spate of railway and other infrastructure accidents throughout the West in recent years is a direct consequence of maintenance policies centred on short term expediency with little thought of the long term results - there is always a high long term price to be paid for 'dumbing down' maintenance to save money in the short term.

The idea of very cheap aircraft maintenance and rapid type replacement cycles is popular in some Canberra circles but there is no credible evidence to support this case in practice. It is nearly always cheaper to keep an existing type in service longer, if it is managed properly and never allowed to enter the back end of the Bathtub Curve.

Viable ageing aircraft programs and smart maintenance require engineering depth in the support organisation, and deskilling a maintenance organisation almost guarantees a longer term breakdown in maintenance policy and quality. Given that most engineers are today paid little more than plumbers (some might argue less than plumbers) the cost differentials between staffing with a good proportion of experienced engineers, against an inadequate proportion, are frequently not dramatic. Brains do matter in this game, and this is a point which has been proven repeatedly over the years - deskilling maintenance organisations can be incredibley expensive in the long run, even if it saves a bit of money in the short term.

An important aspect of repairing the damage done through inept high level maintenance policy decisions is the recovery time. While restaffing with suitably qualified personnel is time consuming in its own right, the time to relearn lost experience and replace lost techniques, tools and procedures can run into years.

Australia has traditionally been a strong player in the smart maintenance game, but the systemic deskilling of many commercial, public sector and ADF maintenance organisations during the 1990s orgy of 'economic (ir-)rationalism' has genuinely damaged the quality of much of the nation's infrastructure support, and some ADF assets have suffered in that process.

What is most tragic about this situation is that it was predictable, and indeed predicted by many in the engineering community a decade ago, but fell on deaf ears as many private and government sector executives sold the 'vast' cost savings to shareholders, public and parliamentarians alike. There are no free lunches in this game, and short term gains inevitably result in long term losses.

9 The ADF and Ageing Aircraft

The ADF operates a mixed fleet of frontline equipment, with design heritages which date back to the 1950s, 1960s, 1970s and 1980s. Many key assets fall into this category. The C-130H and P-3C are both 1950s airframe designs built over a three decade period, the F-111 is a 1960s airframe design, the F/A-18A is a 1970s design with origins in the 1960s, the Boeing 707 is a mid 1950s design as is the Caribou, and the PC-9/A dates back to the 1980s. The recently ordered RAN Seasprites were partly built during the 1960s.

As a result the ADF operates a fleet of ageing aircraft in every sense of the word. What is unfortunate is that a public perception has developed that the age of many of these assets is an inherent cause of high support costs and reason for immediate replacement as soon as possible.

Indeed, some of the media commentary surrounding the F-111 has been nothing but remarkable, and the unwillingness of the DoD/RAAF to seriously challenge it publicly has been no less remarkable. The comments in parliament ridiculing the Seasprite purchase were no less notable - the zero timed and corrosion treated Seasprite airframes may prove to be more durable in the long run than many less robustly built new production helicopters currently in the market. Shiny new products may not be more durable than solid overdesigned 1960s airframes.

The two groundings of the F-111 fleet this year, one due to a test article failure and the other due to a fuel tank explosion, have both focussed media attention on the F-111 and fed a minor orgy of media speculation about the imminent structural collapse of the aircraft.

Contrary to the speculation widely asserted in the media, the RAAF is actually in a very good position with the F-111, arguably in fact better than many other platforms including the F/A-18A.

From a structures perspective, there are several known hot spots in the F-111 which have exhibited cracking in service. While the F-111 wings are largely made of aluminium alloys, the Wing Pivot Fitting (WPF) at the wing root is made of high tensile D6AC steel. The flight critical WPF has a history of developing cracks in the area surrounding the 'mouseholes' for fuel flow, and an internal stiffener runout, and is the subject of a fatigue life rework modification developed by DSTO and currently under test - this rework has the potential to 'fatigue proof' the WPF.

A second flight critical problem area in the wings lies in fatigue cracking around some of the Taperlok fasteners - quality control problems at GD during 1960s manufacture often resulted in misshapen holes, residual material and poor surface finish in the holes, all of which can impair the fatigue life of the hole. A reworking technique which could be used involves reaming out the hole and fitting an oversized Taperlok. This technique is widely used on other aircraft types and often automated by robot to cut costs. Finally the RAAF have a boron patch fix to cover a known stress hot spot in the lower outboard wing.

The good news is that there are around 50 low time F-111D wings, and around 50 late build higher quality F-111F wings in storage at AMARC, which could be retrofitted over the longer term. The RAAF is currently retrofitting F-111F wings to the F-111C and placing the original F-111C/G wings into storage. A wing retrofit requires servicing, optionally deseal/reseal, wiring harness replacement and optionally, retrofit of the FB-111A extended wingtip which is common to the F-111C and G.

While the originally certified safe fatigue life of the unmodified F-111 wing was around 10,000 hours, there are some remaining concerns about the certification fatigue testing for the wings and how it relates to differences in RAAF and USAF operational usage of the aircraft. USAF Tactical Air Command, Strategic Air Command flew frequently different mission profiles to the RAAF, using either ‘short’ or ‘long’ wings with different G-limits and gross weights - USAF SAC FB-111A/F-111G with ‘long’ wings spent much of their lives administratively limited to 3G, yet most often flying SIOP 9 to 12 hour long range nuclear strike profiles, while RAAF and USAF TAC F-111s flew mostly shorter profiles with 6.5 and 7.5 G limits respectively. It is likely that DSTO will remain engaged in wing fatigue life testing for some time yet. It is worth noting that a wing swap on an F-111 takes about three days to perform, if refurbished wings are available in stock - a far cry from time consuming wing replacements in most other types.

The favourite target of F-111 critics is the wing Carry Through Box (CTB), the massive D6AC centresection structure which mounts the F-111 wing pivots. The CTB was the cause of one fatal crash early in the TFX/F-111 program and a number of ground test failures, ultimately traced back to a subcontractor producing substandard CTBs. The safety of the CTB and other D6AC structural components is assured by the use of periodic Cold Proof Load Testing (CPLT), a technique devised in the wake of the TFX program CTB failure. In CPLT, the F-111 is chilled down in a special hangar and subjected to loads using hydraulic rams - crack propagation is then carefully monitored - historically only a small number of F-111s have failed CPLT and broken under the test load.

As the RAAF has invested in a CPLT facility at Amberley, the safety of the CTB and other D6AC components can be assured for as long as the aircraft is operated. Should a CTB problem be discovered, it can be replaced - a 1980s FB-111A rebuild saw exactly this repair performed by GD in Ft Worth, very cost effectively as well, in the days before laser alignment and other modern assembly techniques.

Another known structural hot spot in the F-111 is stress corrosion in a number of the secondary structural components which form the forward fuel tank and bomb bay area structural box. These are not fatigue related but rather a result of the combination of using 7079 alloy and deficient manufacturing and assembly technique. The fuel tank explosion in an F-111C(A) in June must have disappointed F-111 critics - the equivalent of a low calibre AAA hit in the main tank did not cause the aircraft to snap in two as many might have predicted, and the stress corrosion sensitive 7079 parts appear to have held together. Whether the RAAF will need to do anything with the forward fuselage to reach the planned 2015-2020 retirement date depends on the findings of the yet to be completed DSTO Sole Operator Program.

One area which remains under investigation are the aluminium honeycomb panels used to clad much of the fuselage. Moisture ingress can cause corrosion, and the epoxy may degrade with age. DSTO are trialling a technique for replacing these with reverse engineered carbon fibre replacement panels.

Were the RAAF ever interested in stretching the F-111 past 2020, for instance as a result of the JSF proving not to be suitable for the RAAF, then odds are very good that most of the structural work required would be in refurbishing and relifing wings.

In terms of wiring, much of the original cabling in the F-111C and F-111G was replaced during the AUP and AMP block upgrades respectively. Why the fleet was left with very old fuel tank wiring, what appears to be the cause of the near loss of A8-112, despite the widely known experience with arcing in commercial aircraft is a question which many might want to ask.

It is not an overstatement to observe that all three F-111 groundings over the last three years are arguably in the category of predictable problems, and would not have happened had the RAAF been able to establish a genuine 'ageing aircraft program' for the F-111 during the late 1980s or early 1990s. Close observers of the F-111 will recall, that this was the period in which the RAAF was asked to introduce the F-111G without significant funding support, and at very short notice. As things stand, the DSTO SOP was launched fairly late and a full scale 'ageing aircraft program' did not start until Boeing took over depot support last year.

One political observer commented recently to this author that 'the biggest threat the F-111 faces is not as much in genuine engineering problems, but in a DoD upper echelon bureaucracy which might want to dispose of the aircraft as quickly as possible to avoid the embarrassment of past support planning blunders becoming public'!

Meticulous readers of Federal Hansard will note that the former VCDF Gen Mueller testified that DSTO advice was essentially that the F-111's structure could be managed to 2020, and that legacy avionic items in the aircraft would represent a bigger issue in achieving the planned 2020 retirement. Those legacy items are of course the analogue cockpit, radar and portions of the Pave Tack subsystem.

Given that the DoD/RAAF leadership have nailed their flag to the JSF at this time, there is unlikely to be great enthusiasm for F-111 life extension past 2020. However, given the risk factors in the JSF program, it would not be imprudent for the RAAF to protect its position and ensure that the F-111 can be kept longer if needed - a decent batch of non-flying spare F-111F airframes as structural spares would be very cheap strategic insurance, as would be some judiciously chosen upgrades.

The RAAF may be facing a much bigger challenge in the F/A-18A Hornet. While the HUG program will see much of the avionic suite replaced, including wiring, many aircraft in the fleet have accrued significant fatigue damage to the centre fuselage barrel, the primary centresection load bearing structure. Given that RAAF Hornets are flown as air superiority fighters rather than bomb trucks, as used mostly by the USN, on average they accrue much more high G loading than their US operated siblings. Unlike the F-111, with an ample supply of surplus structural components which are relatively cheap to buy, refurbish and indeed quick to retrofit, a fuselage centre barrel replacement or repair in an F/A-18A is major structural rebuild and quite expensive to perform. At this time it is unclear what proportion of the fleet might be in difficulty, as it is also unclear exactly when the JSF might be available in numbers to replace the F/A-18As.

Given that the RAAF does not have a comprehensive F/A-18A engineering support facility of the ilk of the Amberley F-111 WSBU, any ageing aircraft program performed on the F/A-18A will have to be largely performed in the US, and thus incur higher costs as the US industry tends to pay engineers of equal experience much better in comparison with Australian engineers.

The RAAF's Boeing 707-338C tankers are also in some difficulty, as they have significant fatigue damage in the centre sections and corrosion problems in several areas. Much of the wiring is original, and the 1960s JT3D-3B fans are being obsoleted thus presenting supportability problems. How many 707s will remain operational by the time the AIR 5402 tanker replacement is delivered is yet to be determined.

How much life remains in the C-130H and P-3C fleets has yet to be disclosed. New Zealand is reported to have performed a comprehensive structural rebuild on their P-3B fleet, one anecdote claiming the rigging of the refurbished aircraft was so much better the aircraft delivered significantly better take-off performance than the originals.

The trusty Caribou is planned for retirement in 2010, but the odds are that it could last significantly longer with PT6 turboprops and a GA retrofit glass cockpit installed - possibly saving on significant replacement costs, and removing the need for an RAAF Avgas supply chain. Given that a Caribou replacement might demand the rebuilding of numerous runways due to inferior short/soft field performance, the savings could be much larger than many might imagine.

In summary, the age of an aircraft may have little bearing on its feasible service life, if proper strategic planning is put into support and a robust 'ageing aircraft program' is implemented as early as possible in its service life. Quality of maintenance can have a critical impact on the longevity of an airframe, and clever substitution of worn or unsupportable parts can yield very significant long term savings, both in ongoing support costs and deferred replacement costs. How well the ADF grapples with the challenge of ageing aircraft fleets remains to be seen.

Pic.1 Swissair DC-10

The age related breakdown of insulation in wiring bundles has been implicated in numerous airliner fires, frequently resulting in serious loss of life. While Kapton insulation is most frequently identified as the culprit, many other insulators also seriously degrade with age. Replacing the wiring in a large commercial transport can run into millions of dollars per airframe.

Pic.2 TWA 747

While disputes continue over the cause of the fuel tank explosion in the TWA 747, the most likely cause is arcing resulting from insulation breakdown in aged wiring. The recent near loss of F-111C(A) A8-112 near Darwin appears to have been as a result of a similar problem - despite having a large hole blown out of the bottom of the main fuel tank, the F-111 proved to be structurally robust enough to straggle back for an emergency landing. Given that most of the wiring in the F-111 fleet was replaced during the ongoing block upgrades, one might wonder why the aircraft were being flown with a widely known and relatively cheap to fix fuel tank safety hazard in situ.

Pic.3 F-111

The RAAF's F-111 fleet is now in the process of being retrofitted with wings from mothballed USAF F-111Fs. Several years younger by construction and built to a higher quality standard than the F-111C/G wings, the replacement wings will add considerable life to the fleet. With around 50 sets of available wings from mothballed 'hangar queen' F-111Ds, one went into the smelter recently with around 25% of its fatigue life expended, and around 50 sets of remaining F-111F wings available, the RAAF could if need be keep the F-111s supplied with replacement wings for a very very long time, even without the option of relifing wings through modifications and rebuilding (RAAF).

Pic.4 RAAF Caribou

The Caribou is like the F-111 an asset which is prohibitively expensive to properly replace - only the V-22 is a serious equivalent in short/soft field performance. A replacement of the vintage radials with an existing production PT6 turboprop conversion would defer replacement costs, including some possible runway rebuilds, save on recurring operating costs, improve safety, but also remove the need for an RAAF Avgas logistical chain. Therefore the Caribou is an interesting case study in how one might choose to manage a difficult to replace ageing aircraft (RAAF).

Pic.5 F/A-18A Hornet

The RAAF's decision to opt for the underpowered Hornet as a air superiority fighter during the early 1980s may have partly contributed to the aircraft's current fatigue problems - the aircraft may have accrued much more time at high G than many of their US Navy siblings have, the latter flown largely as bomb trucks. It has been widely reported that a large proportion of the Hornet fleet have serious fatigue damage in the centre-section barrel, and may not last until the planned JSF IOC, although the RAAF have yet to publicly disclose the exact condition of the fleet. As the F/A-18A does not have the depth of domestic engineering support the F-111 has, the cost of an overseas managed ageing aircraft program is apt to considerably higher (RAAF).