COLLABORATION CHALLENGES IN THE GLOBAL AEROSPACE MARKET FOR SMALLER COUNTRIES – AN AUSTRALIAN PERSPECTIVE

W.H. Schofield

Cooperative Research Centre for Advanced Composite Structures
506 Lorimer Street, Fishermans Bend, Victoria, 3207, Australia
b.schofield@crc-acs.com.au

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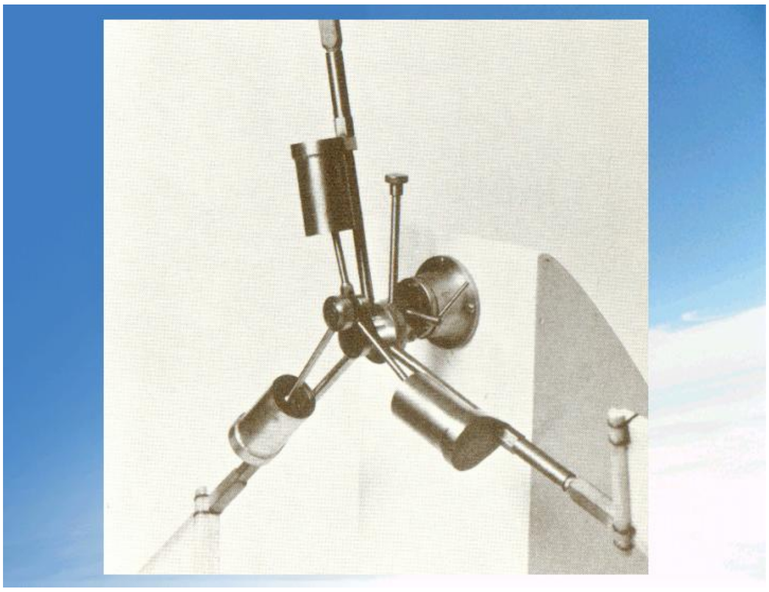
Introduction

According to ICAS, "the knowledge, skills, facilities and finance necessary to progress our profession and associated businesses are no longer found in one place or even close to home". While this is true today for nearly all nations, it has always been true for Australia, and Australia with its vast areas and small distributed population has needed aeronautical services at least as much as any other nation. Australian aeronautical scientists and engineers have from the earliest days responded by inventing and developing niche technologies and using these to gain entry into international programs. There are however caveats to this strategy: the technology must be world class, without which international primes will see Australia as just too far away and therefore too difficult to collaborate with. Another caveat is that Australian owners of world-class niche technology must go out and engage internationally and be willing to openly collaborate in the transfer of their technology and skills. This paper illustrates how Australia has managed international collaboration from the earliest days and how it is now facing up to the challenges of the future.

At the Dawn of Flight

At the dawn of aeronautics – about 1884, Lawrence Hargrave in Sydney started work developing useful theories of aerodynamic lift which he demonstrated with his box kite experiments. In 1894 two of his box kites lifted him high off the ground and he became airborne in a semi-controlled manner.

The magnitude of the lift he generated was of world-wide interest particularly with the Wright Brothers with whom he was collaborating by letter. To achieve flight Hargrave knew he had to develop a light-weight engine to drive a lightweight propeller – this was a considerable challenge in 1890 Australia, which was at that time essentially a remote agricultural country with few facilities for engineering development. Undeterred, Hargrave designed and built no less than 38 engines of many different types.



This is a model of his famous 1889 three-cylinder rotary engine to spin a propeller, which he reported in a paper to the Royal Aeronautical Society. It was, of course, the Wright Brothers with their access to an engine with a good power-to-weight ratio that enabled them to fly in December 1903. Wilbur Wright wrote to Hargrave the month after their flight – it is a rather curious letter – just a quiet, unemotional report to a fellow experimenter, of some progress they had made recently which just happened to include the first powered flights in the world; the letter ends with “when the warm weather returns we shall try to obtain further practice, and make longer flights. I presume that this time of the year is much more favourable for experimenting on your side of the earth than on this and that we may soon hear of your further progress, with kindest regards Wilbur”.

Early Aeronauts

From the start, the geographical size of Australia with its small dispersed population generated an intense interest in aviation. In 1920 the Queensland and Northern Territory Aerial Service, later known by its acronym QANTAS was founded by two former Australian Flying Corps officers, Flight Lieutenants Hudson-Fysh and McGuiness with two war surplus biplanes – their first scheduled flights were to deliver mail between two outback towns Charleville and Cloncurry. QANTAS developed an early reputation for excellent aero engineering which has helped it to survive and be the second oldest airline in the world.

In 1927 an Australian First World War fighter pilot named Charles Kingsford Smith went to the United States to purchase and prepare a Fokker Trimotor aircraft that he named the "Southern Cross". On 31 May 1928, Kingsford-Smith and his crew took off from Oakland, California, arriving in Brisbane via Honolulu and Fiji eight days and 83 flying hours later, having completed the first air crossing of the Pacific. In succeeding months he made the first non-stop flight across the Australian continent and the first flight across the Tasman Sea to New Zealand. In 1929, Kingsford-Smith completed a round-the-world flight. In 1930 at the age of 32, he flew 16,000 kilometers single-handedly and won the England to Australia air race and in 1934, made the first west to east crossing of the Pacific.

Wartime Aircraft Production

In 1938 the Australian Government set up the Aeronautical Research Laboratories (ARL) to support an indigenous aircraft industry. The man they chose to lead the laboratory was an aeronautical engineer who had been barnstorming with Kingsford Smith after the 1919 armistice. His name was Laurie Coombes who came from the British Royal Aircraft Establishment (RAE) and he set up the Australian laboratories as a carbon copy of the RAE. The laboratory exists today, is very well-resourced in aeronautical testing infrastructure and is the origin of many of the aeronautical innovations which I will outline. Access to world class aeronautical infrastructure has been essential to many of Australia's contributions to the aerospace industry.

Australia had in 1936 set-up aircraft manufacturing facilities and – with no history or experience in aircraft production – during the Second World War built no less than 3,500 aircraft of nine different types including

the Australian-designed Boomerang and Wackett Trainer,

the Bristol Beaufort,

and the North American Mustang.

While building aircraft under licence, the Australian companies were often able to significantly improve on the original designs. In 1951 Australia modified the North American F-86 Sabre by replacing the engine with the Rolls-Royce Avon. This involved a complete re-design of the fuselage as the Avon was shorter, wider and lighter than the General Electric J47 engine that it replaced.

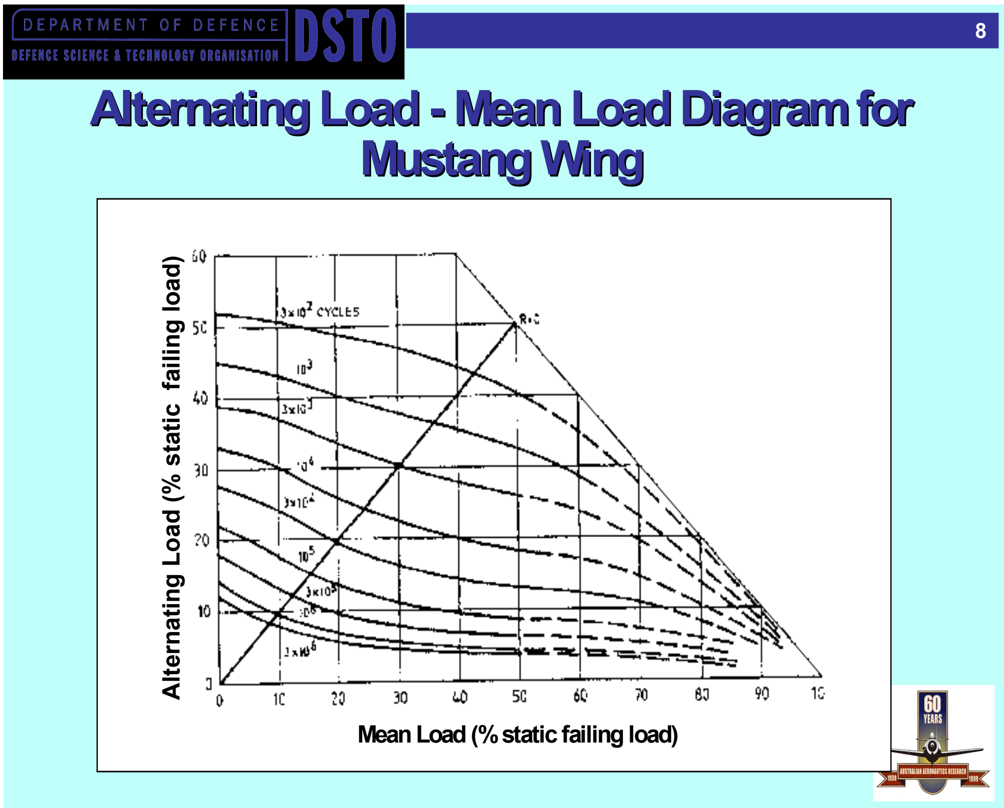
Over 60% of the fuselage had to be redesigned including a 25% increase in the size of the air intake. Other changes included a remodelled cockpit, greater fuel capacity and replacing the Sabre's six machine guns with two 30 mm Aden cannons. All these changes meant considerable collaboration with the Original Equipment Manufacturer (OEM). The greatly remodelled aircraft was designated the CA-27 and was operated by the Australian Air Force and exported to Indonesia and Malaysia.

Aeronautical Research

An important area of Australian research that started during the Second World War was a more scientific approach to aircraft fatigue.

This Stinson aircraft crashed in Australia in 1944 and the Board of Inquiry concluded that the airframe had *'died of old age'*. It was the first case of an in-flight failure of an aircraft structure due to metal fatigue. Today it seems surprising but it appears that the aircraft designers of the day had not taken into account the possibility of fatigue failure due to fluctuating loads. ARL was called in to investigate the crash and afterwards initiated a program on aircraft fatigue that continues today. Two landmark papers from ARL in the 1940s established the basic theory of fatigue and this theory was followed up by a unique program of fatigue testing 222 surplus Mustang wings.

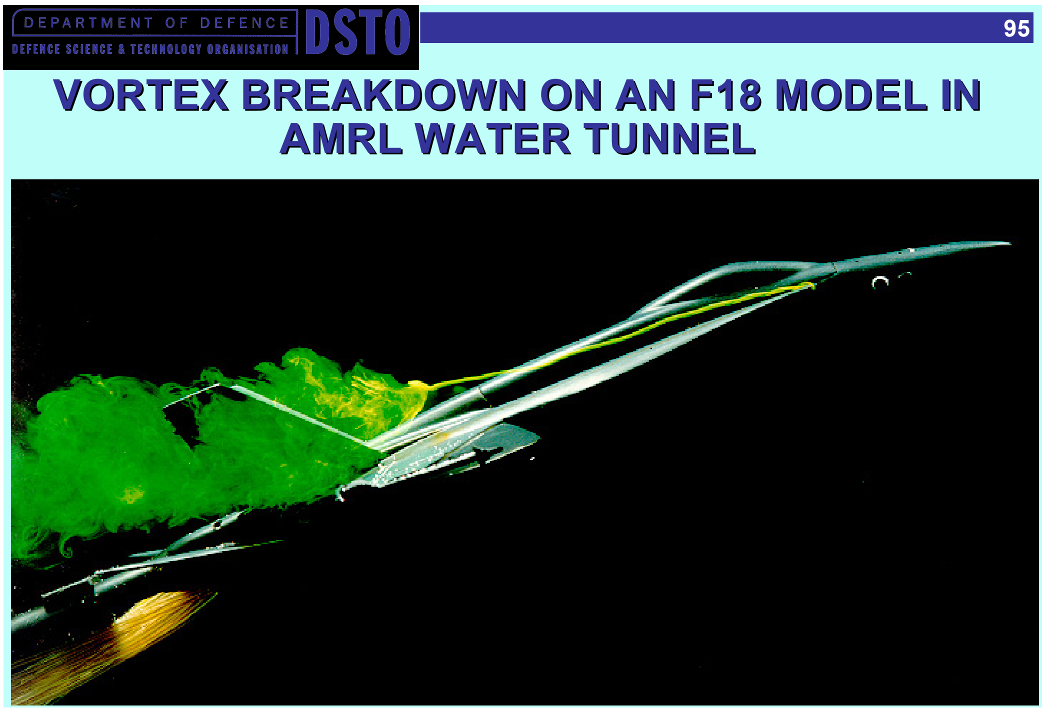
These data from this enormous program of tests led to the determination, for the first and only time, of the statistical distribution of fatigue failures in a single design.



These data are still of interest today, primarily because no one has been able to afford to test over 200 wings of any other aircraft design. This project led Australia into conducting fatigue tests on its military aircraft independent of the manufacturer. The aim of these tests was not the usual one of ensuring the fatigue safety of an aircraft for a given number of flight hours, but instead to scientifically maximize the number of safe flight-hours for the Australian Air Force by using the actual loads profile of Australian operations and continuing the test until major failure. That is, we don't test to a standard or assumed loading profile but start by measuring how the aircraft is being used in Australian service and then fatigue testing the aircraft structure to this Australian specific flight profile and we continue the test until major structural failure occurs. We always try to work in conjunction with the OEM mainly to develop and qualify repairs. When cracking occurs in the test article it is used:

- to develop relevant inspection techniques and intervals for the field
- to determine the rate of crack growth and
- to qualify repair methodology.

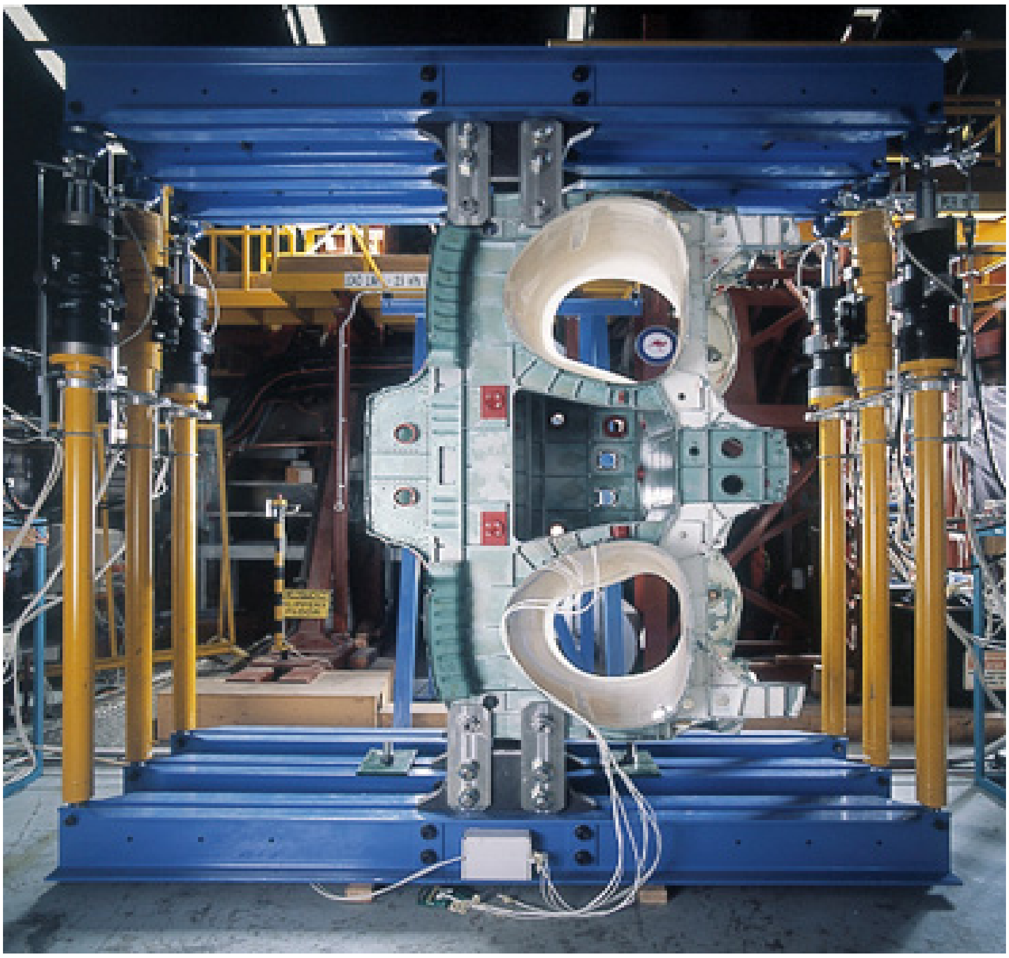
This work became very sophisticated with the fatigue test of Australia's McDonnell Douglas F/A-18A/B Hornets (F18).



This is a picture of the F18 model at high angle of attack in a water tunnel at the Defence Science and Technology Organisation (DSTO) – the successor organisation to ARL. The control and stability of aircraft at high angles of attack are governed by the vortices shown and their breakdown. This picture shows the breakdown of the vortices generated by a leading edge extension to stabilize flow at high angles of attack. When the vortices breakdown in the high adverse pressure gradient over the back of the aircraft, high buffet loads on the empennage are generated. DSTO has measured these dynamic loads at acceleration levels higher than ±500g, which has severe fatigue life implications. Our research showed that the point along the fuselage at which the vortex breaks down is independent of Reynolds Number. The challenge for the Australian based test was to develop a fatigue test rig that could apply high frequency buffet loads and manoeuvre loads at the same time without changing the dynamic response of the aircraft structure. There were test results for manoeuvre loads for the F18 and separate test results for high frequency buffet on the empennage but the response of the structure was highly non-linear and reliable results could only be obtained by applying both loads simultaneously. The next figure shows the very complex loading system developed with the test article being moved into it.

The manoeuvre loads are applied to the empennage by the brown soft rolling air bags in the top left of this picture. These air bags are used to apply the steady loads because they do not change the stiffness of the fatigue article in responding to the buffet loads applied by those large blue electromagnetic shakers.

I believe it is still the most complex fatigue test ever conducted. In 2002 Canada and Australia won the Von Karman award for international collaboration in a project in which this fatigue test was part: Canada's contribution was the fatigue test of the F18 centre fuselage and a F18 wing. The overall aim of the project was to determine the economic life of the F18 mainly by eliminating conservative interpretations of tests by the OEM. The loads were determined accurately from wind tunnel tests and from strain-gauged instrumented aircraft. These first initial tests resulted in DSTO recommending to the Air Force an increase in the structure life of 25%. Later as the aircraft fleets approached their demonstrated fatigue life, the OEM made a number of recommendations to inspect, repair and replace the centre barrels and the Australian Air Force accordingly scheduled 49 of their aircraft to have new centre barrels. DSTO then started a new program to see how much life remained in the 'life expired' centre barrels.



This new program is being conducted in close collaboration with the US Navy and is being closely watched by the other F18 operators - Switzerland, Finland and Canada. Fatigue expired centre barrels from the Australian and US fleets are being fatigue tested to determine if their life could be further extended and to evaluate OEM recommended modifications to the centre barrels and the inspections that go with them. So far the tests have resulted in the Australian Air Force's centre barrel replacement program being terminated at 10 of the planned 49 aircraft. It has also led to a new fatigue life method being investigated – the lead crack concept – which is as it sounds – to securely identify the crack that will determine the fatigue life of the structure. Importantly this second program has improved aircraft availability and has saved the air force an additional $500m. Both programs together have saved approximately $2 billion in current prices which is about 20 to 30 times the cost of the programs. This is a typical result for this type of work; the best payoff was achieved for the PC-9 trainer, approximately 60 to 1.

CASE STUDY: PC-9 FATIGUE TEST

Aircraft interim fatigue life	6,000 hours
Australian target fatigue life	12,000 hours
Increase in fatigue life	100%
Capital cost of PC9 fleet including ancillary costs (in 1996 dollars)	$438 million
Value of additional life arising out of the test (100% of $438 million)	$438 million
Estimated cost of DSTO/RAAF Program	$6.0 million
Estimated cost of RAAF flight program to develop flight load data	$1.1 million
RETURN ON INVESTMENT	**62:1 (or 6,200%)**

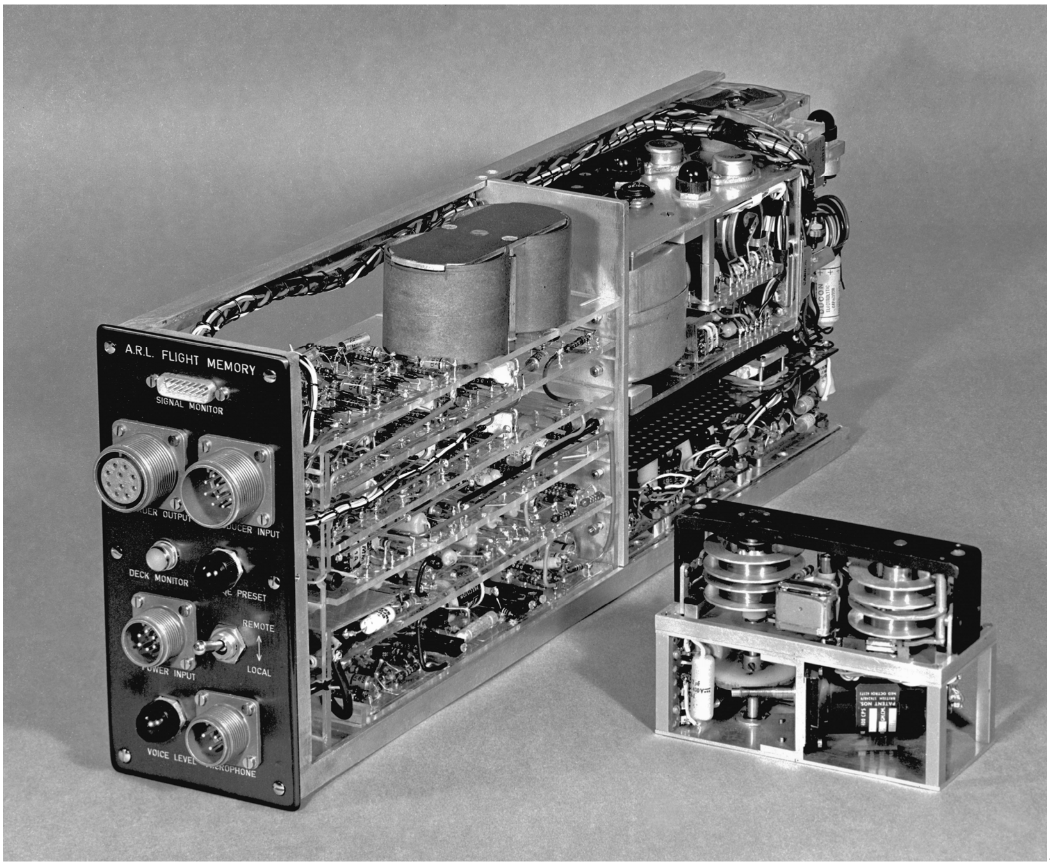
As always wherever possible Australia collaborates with other international authorities and operators. Australia has had collaborative programs in fatigue tests on the Mirage III with Switzerland, F18 Hornet with Canada and the USA, P-3 Orion with Canada and the Netherlands, the PC9 trainer with Switzerland, and on the Hawk with the UK.

Black Box Flight Recorder

The most famous case of aircraft fatigue failures is probably the Comet crashes in the 1950s which led to the invention of the Black Box flight recorder.

In the wake of the Comet crashes in the 1950s, an Australian scientist Dr David Warren saw that the investigation into the causes of these crashes lacked any hard data. He had recently bought one of the first of the wire recorders and saw that a wire recorder in the aircraft could survive an air crash with vital flight data leading up to the crash. He then wrote a seminal technical memorandum in April

1953 describing such a recorder. This early memorandum was quite remarkable in that it described all the essential features of modern flight recorders. Warren then built and tested an early rudimentary recorder shown at the bottom left of this slide. He went on to develop the much more sophisticated recorder shown in the slide.



The work excited little enthusiasm in Australia and was rejected by both Australian civil and military authorities – probably because pilots did not want their cockpit voices recorded, although this was never explicitly stated. It was not until Warren took his recorders to the UK that the work took off, although Australian authorities eventually purchased an inferior system from overseas that proved useless in a subsequent accident in northern Australia. The final development was made in collaboration with UK companies and as we know today, flight recorders are not only fitted to aircraft, but to many forms of land and sea vehicles. However, the fact that an Australian invented the black box flight recorder is little known outside Australia.

Civilian Aircraft Production

From 1970 for 20 years Australia adopted an offsets policy for aircraft purchases – it was probably the only country to have a declared civil offsets policy. No premiums were allowed and Australian companies only were allowed to compete for work. During this time Australia produced components for most western aircraft types:

- Main undercarriage doors
- Rudders
- Elevators
- Ailerons
- Leading edge flaps
- Floor structure
- Engine cowls
- Wing ribs
- Undercarriage fairings
- Passenger doors
- Escape slides

over 7,000 items for:

- Boeing 727/737/747
- AIRBUS A310/320/330/340
- Douglas DC 9/DC10
- Lockheed L1011

With this work, Australia developed an excellent reputation for being on cost and on time with deliveries and this reputation enabled it to continue to win work after the Government terminated the offset policy. Non-offset work has been won on

- Airbus A380
- Boeing 777/737 NG/747-8/787 – and work components for the 787 is current.

An important part of this success was the increasing contribution of local design and technological input.

Australia has designed and built a number of civilian light aircraft including

The Airtourer – an all-metal light low-wing monoplane touring aircraft developed in Australia and subsequently also manufactured in New Zealand. A variant is still being used as the basic trainer for all Australian military pilots.

The Nomad is a twin-engine turboprop, high-winged, "short take-off and landing" (STOL) aircraft. It was designed and built by the Australian Government Aircraft Factories (GAF) at Fishermans Bend, Melbourne. Major users of the design have included the Royal Flying Doctor Service of Australia, the Australian Army and the Australian Customs Service.

Gippsland Aeronautics has designed and is successfully building a small passenger utility aircraft – the GA8 Airvan, and exporting them to eight countries for use in harsh outback environments, such as those encountered in Mozambique, Botswana, Costa Rica, Alaska, Papua-New Guinea and, of course, Australia.

In 1988 Jabiru developed a highly efficient, composite constructed, light aircraft. When the engine they were to use went out of production, the company developed their own lightweight aircraft engines in the 30-120 hp range.

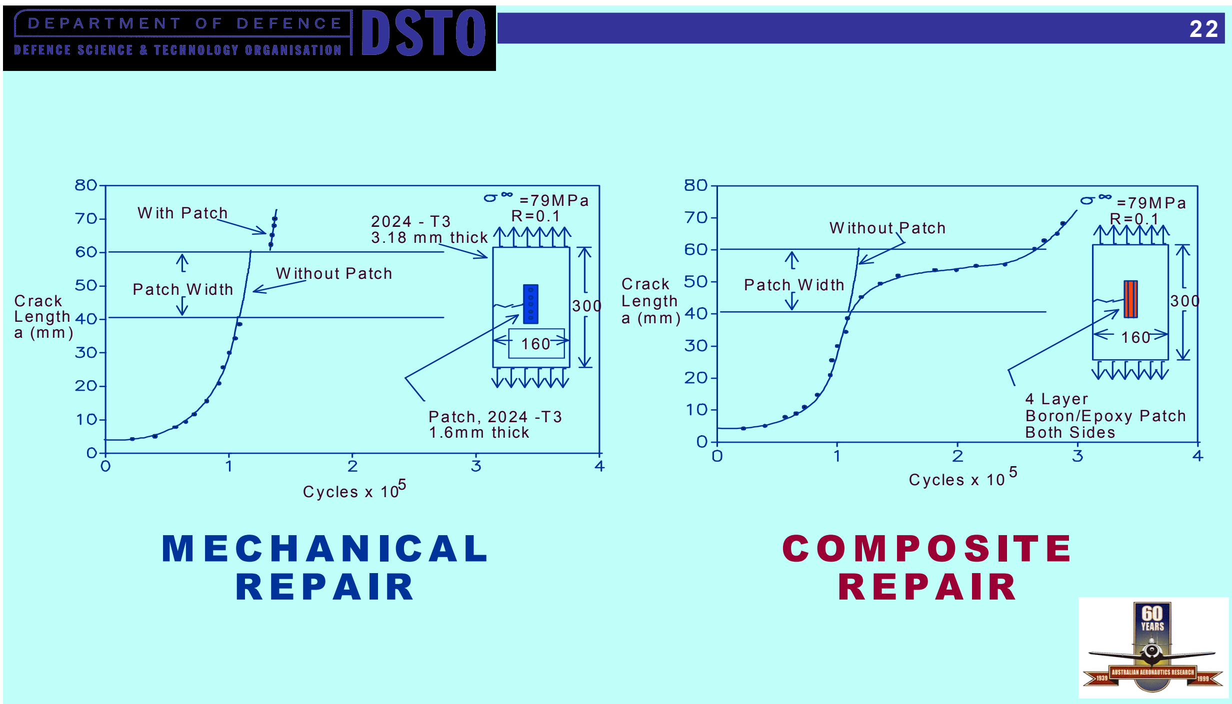
Jabiru aircraft and aircraft kits have been sold to 16 countries and its engines to 31 countries.

New Aircraft Materials

New aircraft materials provide excellent opportunities for a small country to make a contribution. Australia started work on composite materials very early with the development of composite bonded repair technology in the early 1970s. The work arose from the need to develop more effective, cost-efficient repairs for the Australian Defence Force (ADF) aircraft and, secondly, to demonstrate the advantages of high-performance composites to both the ADF and Australian industry – since at the time there was very little activity in this country involving these advanced materials.

Dr Alan Baker pioneered composite bonded repairs in 1972. Composite bonded repair technology is the use of patches made from carbon-fibre/epoxy or boron-fibre/epoxy to reinforce fatigue cracked or corroded metallic aircraft components to prevent further crack growth or to recover strength.

Scientifically designed and applied, composite patches are much better than the traditional mechanical repair made by drilling and riveting a metal doubler over the crack.



This figure shows crack growth rates against fatigue cycles for the two types of repair. The diagram on the left shows that the traditional metal patch slows down the crack growth but when the crack reappears from under the patch its growth rate is just as rapid as before it was patched. In contrast a boron patch, on the right, allows you to track the crack growth under the boron patch – with eddy current probes – and when the crack grows past the patch its growth remains slow. Overall the boron patch is thinner, lighter and gives you three times the life of the conventional repair.

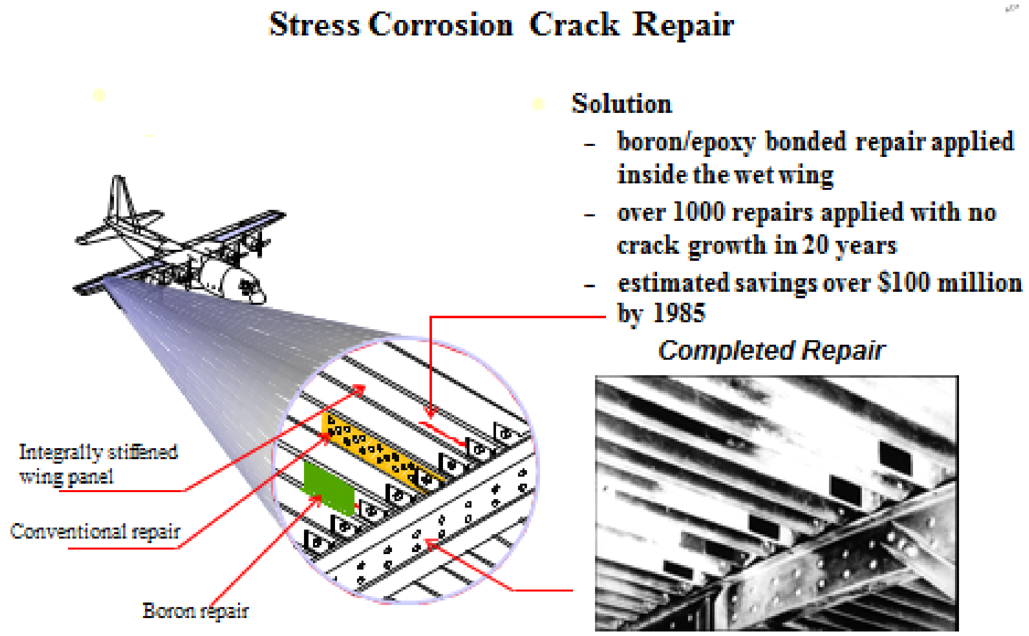
While the process is quite simple in concept the technologies involved are not; they include:

- the development of bonding methodology which when applied *in situ,* provides a strong durable adhesive bond that can survive for many years in the high stress and hostile environments experienced on the surface of an aircraft
- sophisticated analytical and numerical analysis, to design an optimum repair and to predict fatigue performance.

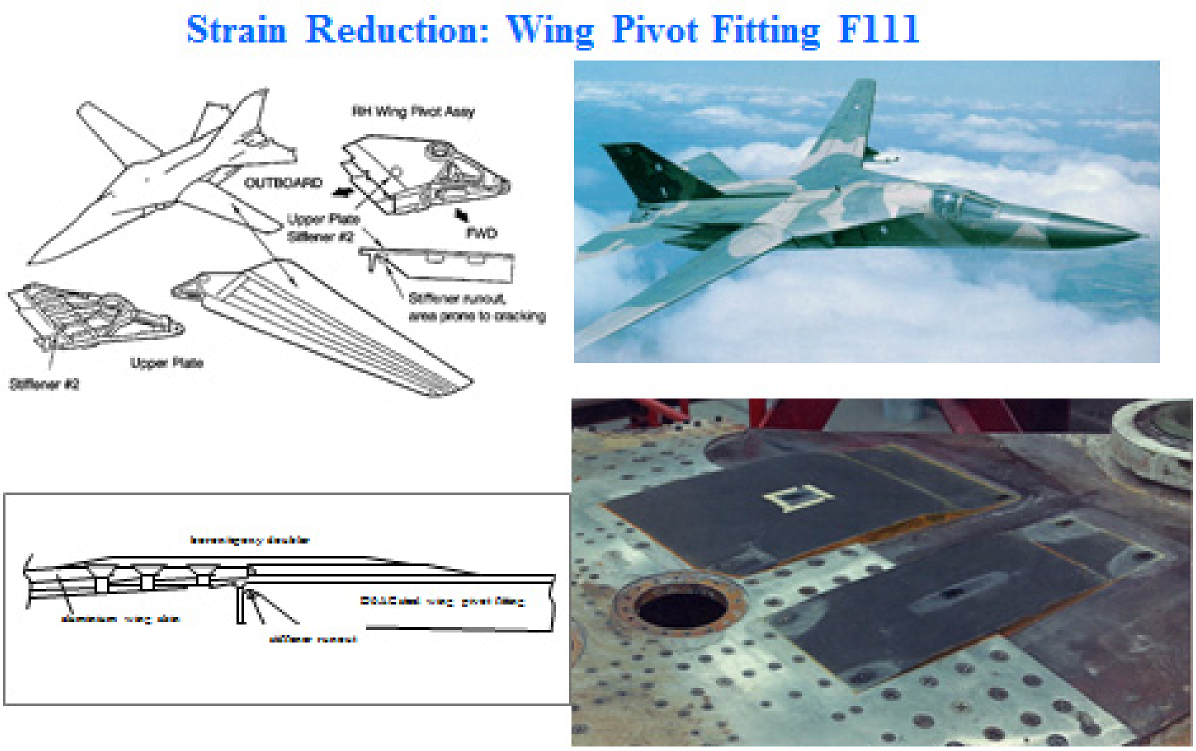
A background in surface physics aids an understanding of the processes involved.

These and many other supporting technologies were pioneered by Baker at DSTO and later in collaboration with the UK, US and Canada. This work culminated in the publication of the standard text "*Advances in Bonded Composite Repair Technology*" with contributions from authors in Australia, UK, USA and Canada. These international collaborative studies attracted many awards in the Technical Cooperation Program (TTCP) and, in 2009, the Royal Aeronautical Society awarded Dr Baker the Gold Award '*for exceptional work leading to substantial advances in aerospace*'.

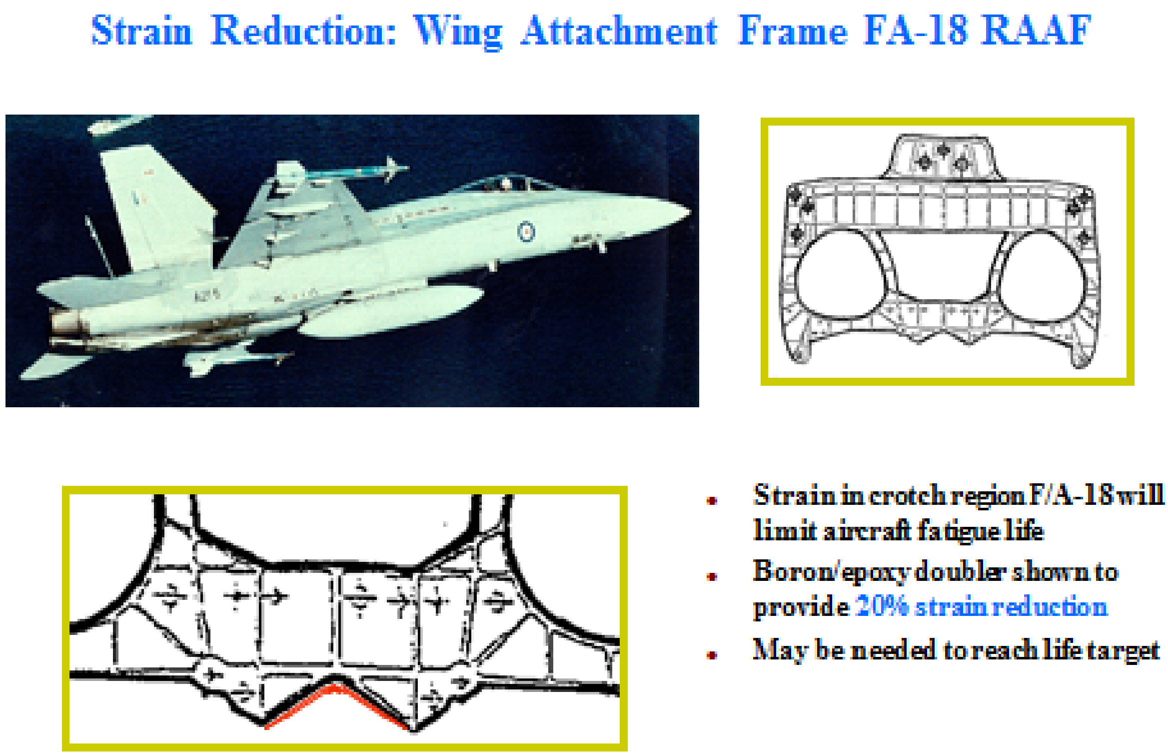
The first application of the technology was in the 1970s when repairs were developed for stress-corrosion cracks in the wings of Australian C130 aircraft.



Applications to many RAAF aircraft have saved the ADF many hundreds of millions of dollars. The technology has been applied to a wide range of aircraft across the world. A major application is to reduce operating stress in major aircraft components such as in the F111 wing pivot fitting,



and in the centre barrel of the Australian F18:



The current limitations in certifying bonded composite repairs (BCRs) for aircraft primary structure stem from the difficulties in inspecting bonded components by conventional non-destructive inspection (NDI). The issue of certification of bonded composite repairs for primary applications is currently being addressed by developing:

- smart-patches, essentially structural-health monitoring (SHM) with optical fibres
- a technique for through-life proof testing

It is hoped that by these approaches, and others not mentioned here, the potential of BCRs can be fully realised.

Following this work, a major collaboration in composite aircraft structures was initiated in Melbourne. In 1990 the Australian Federal Government introduced a program of competitively funding a number of Cooperative Research Centres, which brought together research providers and industrial research users. The participants, both industry and research providers, had to contribute resources into a joint program which was matched with government cash. In the first competitive round in 1991 the Cooperative Research Centre for Aerospace Structures was funded with a major focus on aeronautical application of composites. It has been a great success story of scientific and technical collaboration initially within Australia and now in the international community. The centre later changed its name to the Cooperative Research Centre for Advanced Composite Structures (CRC-ACS) and diversified into Maritime, Automotive, Oil & Gas and other major market sectors. The Centre has, after competition of its initial term, been refunded three times and is now 21 years old with a strong portfolio of clients and collaborators. The last time this august conference was in Australia was 1998, when the Guggenheim Lecture was given by the Dr Gordon Long the then CEO of the Centre; the lecture was entitled “Future Directions in Aeronautical Composites”. Well, several of those directions have been advanced by the Centre in the intervening 14 years.

From the beginning of the Centre, Hawker de Havilland and AeroSpace Technologies Australia, which were later merged to form Boeing Aerostructures Australia, were close partners in developing improved methods of design, manufacture and certification to efficiently increase the composite components in civil aircraft. The culmination of this work was the Australian designed and manufactured wing trailing edge devices of the Boeing 787 Dreamliner. This collaboration secured for Australia an estimated four billion dollar work package, which for a small country like Australia was a big order and it alone more than justified the government investment in the Centre.

The work involved on the Dreamliner gives a view of the range of the Centre’s work:

- Post buckling analysis - stiffened panels and co-cured ailerons
- Design optimisation - conceptual, parametric and cost
- Diaphragm forming - dry preforms and prepregs
- Process simulation - thermal distortion, cure and infusion analysis
- Resin infusion - specific to aerospace

- Bird strike analysis - certification by analysis
- Tool development - to interface with in house tools
- Manufacturing process development - infusion, compaction and microscopy
- Certification Testing

Over the 20 years of its existence, the Centre has worked with many large international aerospace clients including:

- Airbus
- Boeing
- Bombardier
- Cassidian
- EADS
- GKN Aerospace
- US Office of Naval Research

as well as non-aerospace major customers, such as PETRONAS and Vestas.

Australian organisations provide much of the research and development effort, however as the international reputation of the Centre has grown many overseas organisations have been attracted to participating or collaborating with the Centre; of the 28 organisations in the current program the international members are

- EADS, incorporating participation from Airbus, Cassidian and recently Astrium
- Newcastle University, UK
- DLR – German Aerospace Center
- Bishop Aeronautical Engineers, Germany
- University of Bordeaux, France
- Composites Innovation Centre Manitoba, Canada
- University of Auckland, New Zealand
- PETRONAS Research, Malaysia

I have gone into detail here, as it illustrates the thesis of this paper: if a small country with limited resources and well removed from the world centres of Aerospace manufacture can develop a niche world class capability and then actively seek international collaboration, it can very successfully work for decades in the international aerospace industry.

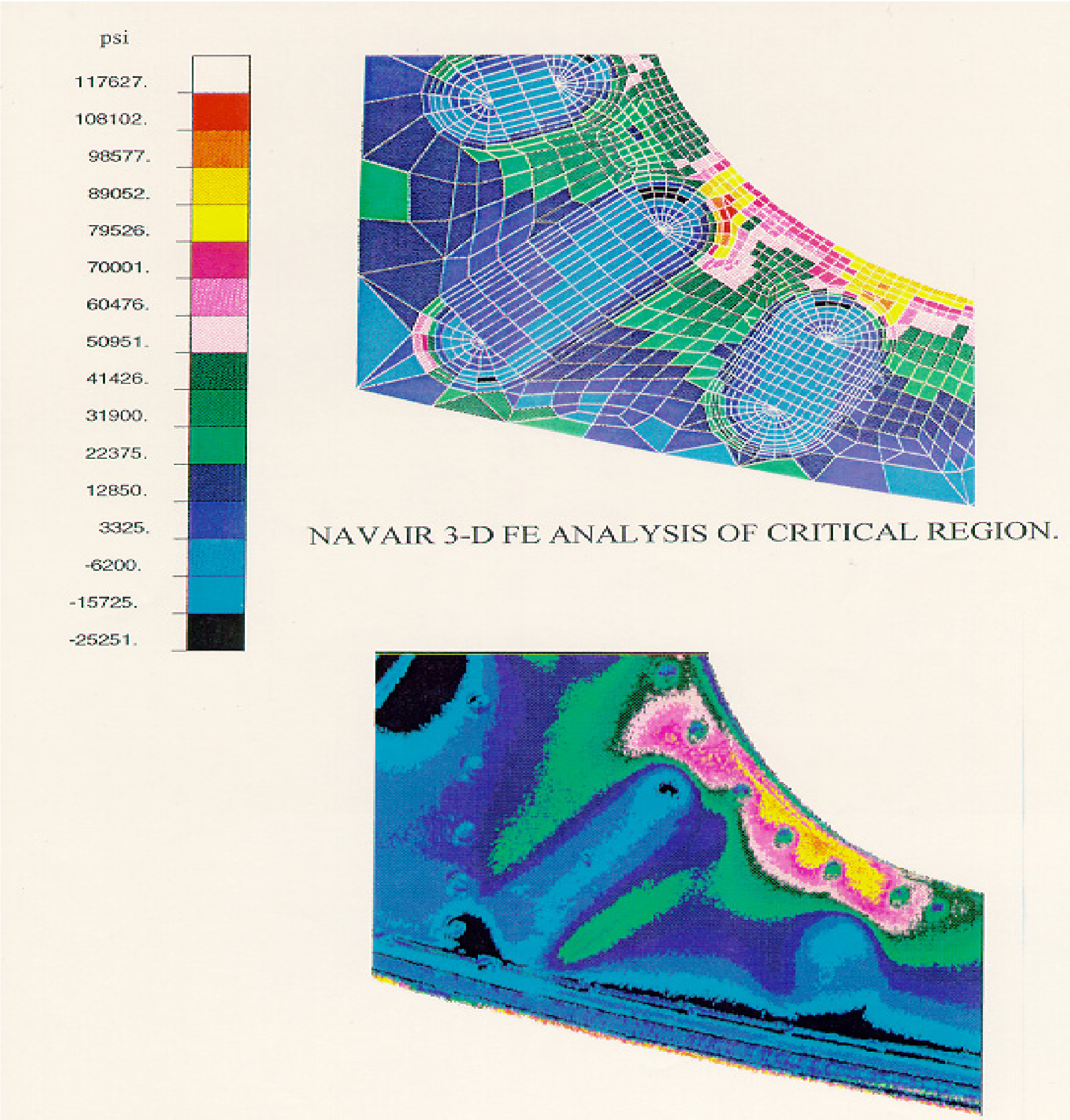
Current aerospace programs in the Centre include:

- Rapid assembly methods for composite aircraft structures
- Systems for aircraft crashworthiness
- Robust Composite repairs
- System development for Structural Health Monitoring
- Composites fire performance.

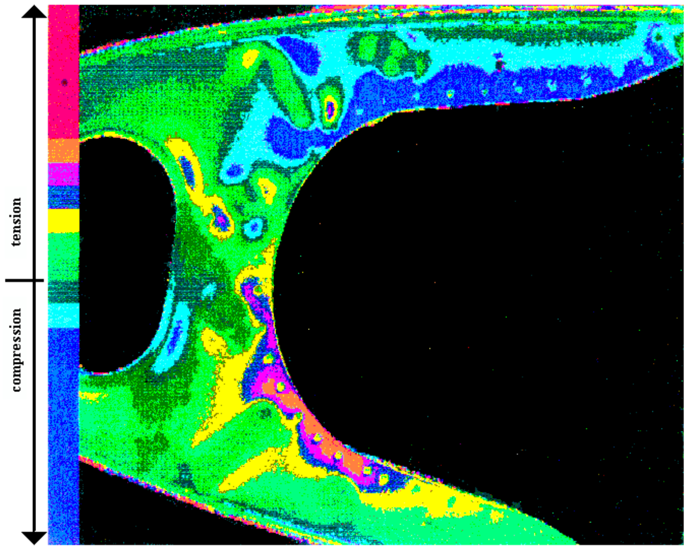
Another international partnership founded over 20 years has been between Boeing and CSIRO. From modest beginnings in 1989 the partnership has grown in extent and fields of co-operation with it now covering; information technologies, aircraft materials, instrumentation and communication technologies. Over the years CSIRO has based onsite representatives at Boeing's offices in the US to assist in the delivery of 35 different contracts. Boeing comes to Australia in its own words 'to source the best technology from the best capabilities in the world'.

Failure Analysis

In the late 1980s, pioneering work was commenced at DSTO Melbourne in the area of Thermographic Stress Analysis. This work impacted many areas including fundamental research which led to a revision of Lord Kelvin's classical theory on thermoelasticity and the development of a new stress imager that resulted in a hundred-fold improvement on the existing technology of the day. The instrument they built was based on a staring infrared (IR) array that could detect temperature differences of a few ten-thousandths of a degree centigrade. This new technology was demonstrated in a highly successful collaborative investigation into the failure of the P-3C Orion wing, which occurred in a crash at Cocos Island in 1991. The collaboration involved DSTO, the United States Navy (USN) and the Lockheed Corporation. The high resolution thermographic stress scans were able to quickly substantiate the 3-D numerical modelling performed by the US Navy, modelling that required very significant computational resources. The comparison of the critical area by the two methods is shown in this figure – the USN 3-D finite element analysis (FEA) is shown at the top with the Australian thermographic scan at the bottom.



The full thermographic scan of the failed wing leading edge is shown in the following figure, where you can see stress concentration effects of the rivets which were not picked up by the 3-D FEA analysis.

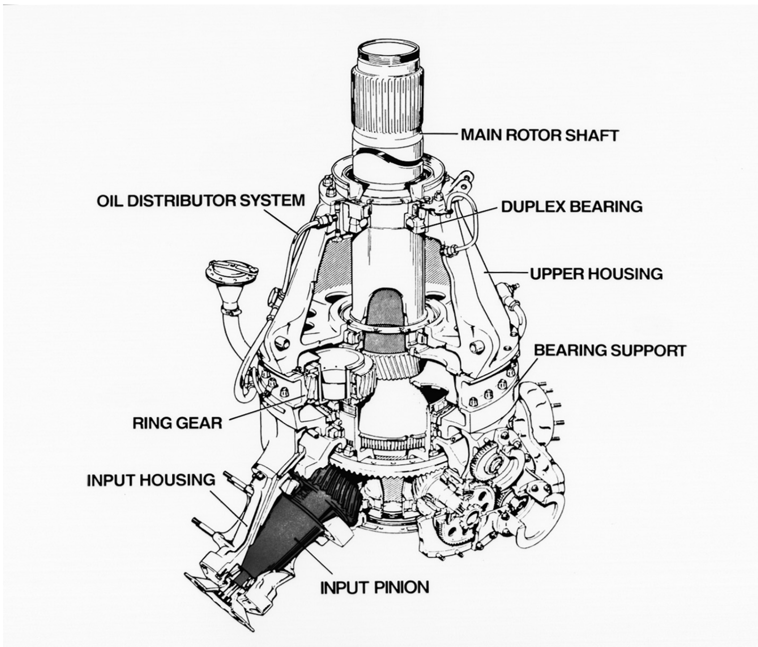


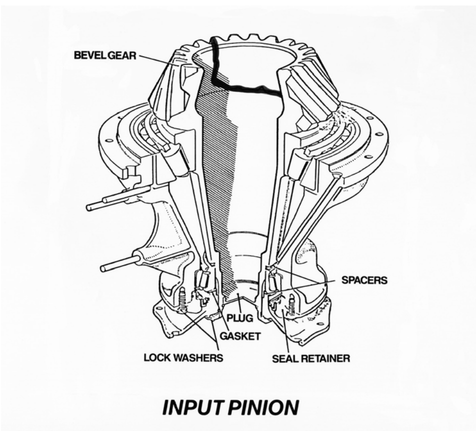
FAST STRESS SCAN OF LEADING EDGE
(NOTE STRESS CONCENTRATION EFFECTS OF STIFFENING DIMPLES).

This collaboration revealed the effects of structural features in this wing that were not hitherto well understood or quantified.

Clever predictive maintenance is an area where a small country can make useful contributions.

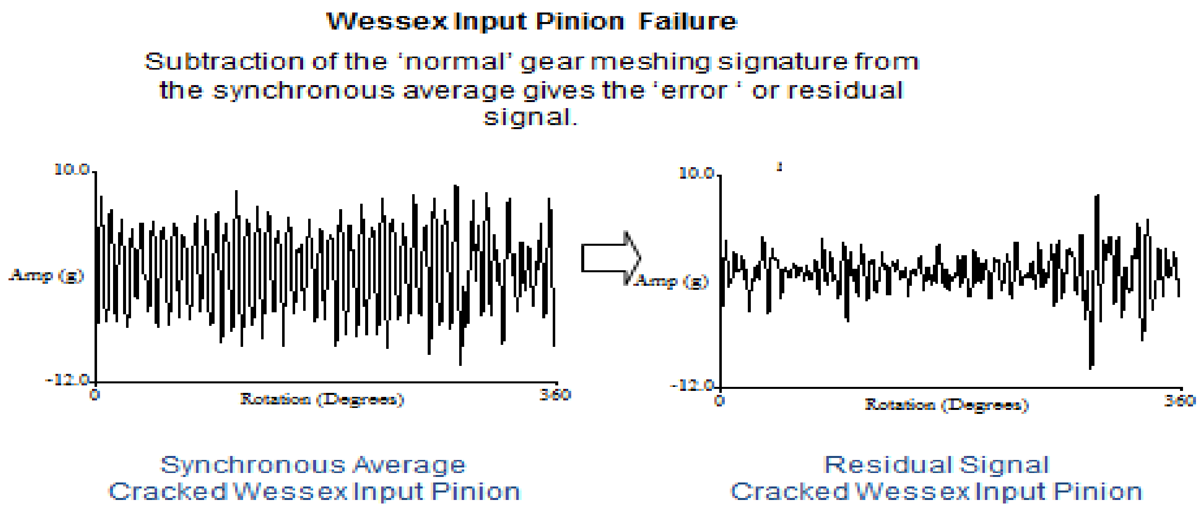
In 1983 an Australian Navy Wessex helicopter crashed into the sea with the loss of two lives. The wreck was recovered and it was determined that the crash was caused by a cracked input pinion in the main rotor gearbox.



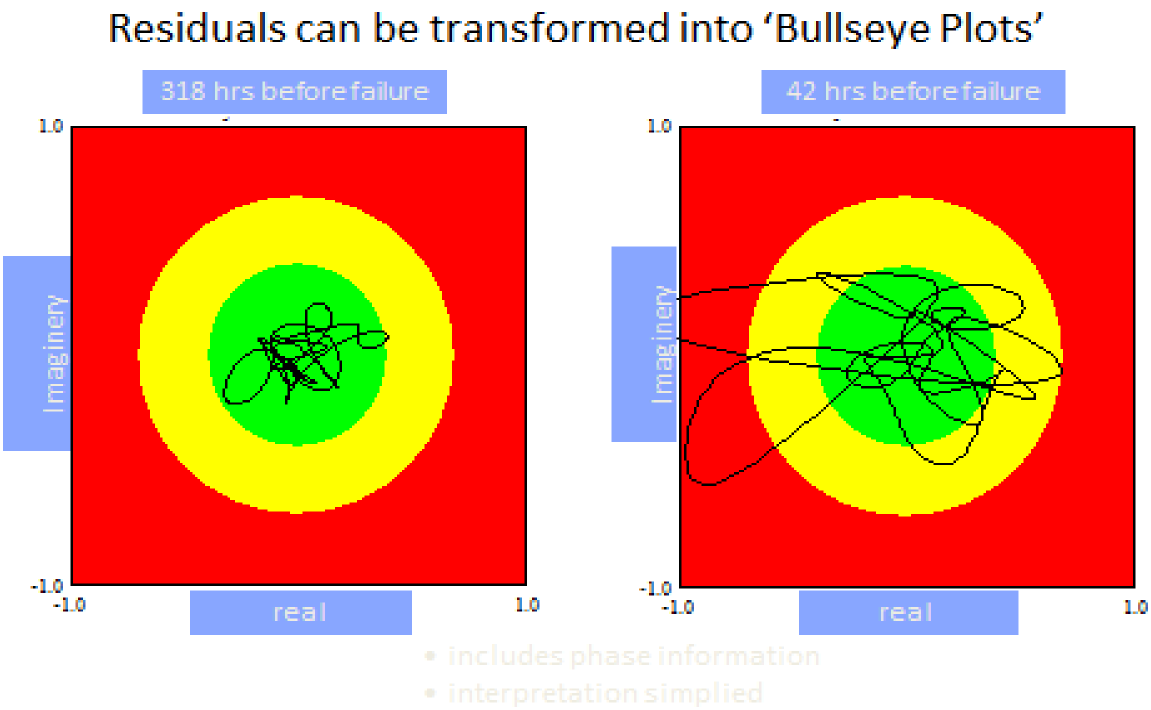


Tape recordings of the vibration of this gearbox had been taken over its service life but the standard analyses of the time had not revealed any problem.

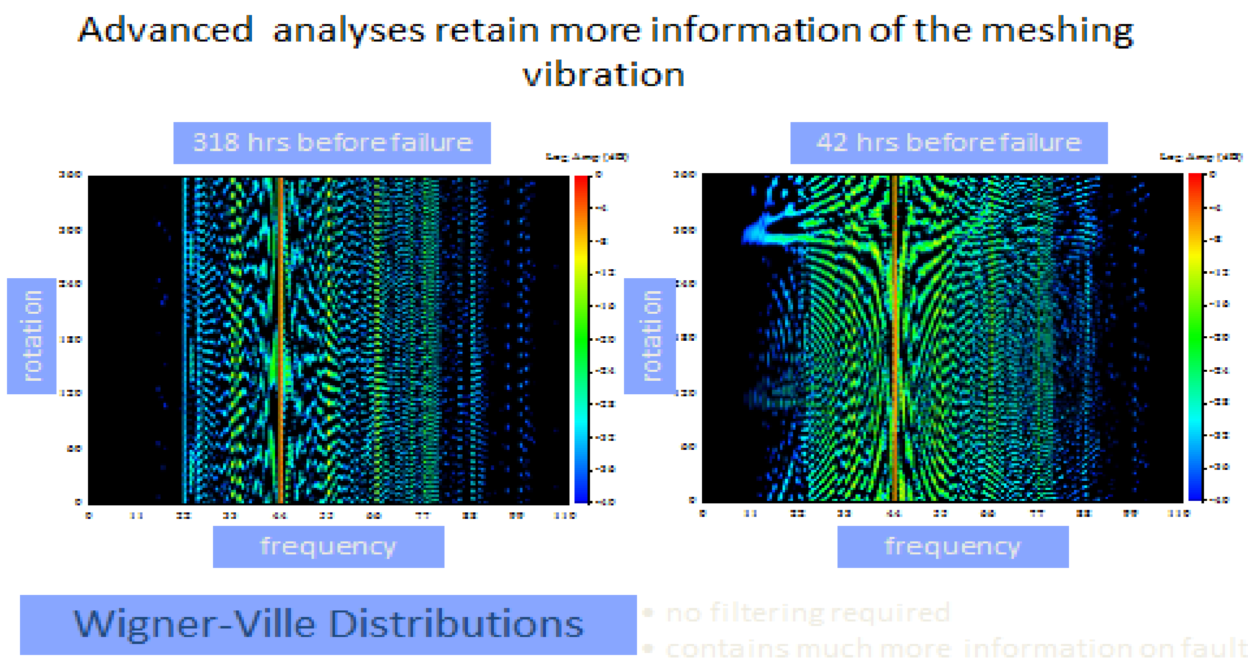
These existing tapes were then reanalysed to see if more advanced methods could have revealed the fault. Firstly they obtained signal averages for the faulty mesh. Today signal averaging is a well known technique but back then it had not been widely used. It consists of averaging the total vibration record over a large number of cycles for a particular shaft in the gearbox. Over a sufficient number of cycles all contributions to the vibration record from other shafts cancel out and we have a clean mesh signature as illustrated in the following.



The signal on the left is the mesh signature of the Wessex Input Pinion obtained after 400 synchronous averages. Now if we subtract from this recorded signal the signature for a perfect set of gear teeth on a perfect set of bearings we are left with the residual error signature – which is shown on the right. To see this more clearly we turn it into a Lissajou figure and put it onto simple bullseye plots shown on the next slide.



These residual error signatures are like fingerprints of the mesh and they grow over time as the gear wears – in this case they are for the cracked Wessex pinion 318 hours before failure, on the left, and 42 flight hours before failure, on the right. Had we had these analysis tools we could have easily detected the fault that claimed two lives 42 hours before the accident. The residuals can also tell you something about the fault. To take a simple case: a chipped tooth will produce an amplitude change whereas a cracked tooth will produce a phase change as well as an amplitude change. This initial work has led to collaboration with Eurocopter and the USN developing ever more sophisticated technology. Derivatives of this Australian work are now applied not only to gearboxes, but also to propellers and turbines. An example of more sophisticated analysis is to employ a Wigner–Ville distribution which retains more information such as energy levels over the period of a mesh.



The technology was tested on the lift fan for the vertical take-off version of the Joint Strike Fighter (JSF) and this may form part of the predictive health monitoring system of the aircraft.

Australia retains its position as a world leader in the field and hosts an important biennial health and usage monitoring conference in Melbourne coinciding with the Australian International Airshow, which is held every two years in Melbourne.

UAVs and Rockets

While designing and building large aircraft in Australia has not been attempted in the last 50 years, designing and building missiles has been a continuing activity. Because Australia has the advantage of large uninhabited spaces, Woomera was chosen in the 1940s for a joint project which involved testing rockets designed in the UK. This in time led to an indigenous capability in rocket science and engineering, which has been employed to design and build a series of UAVs and rocket powered vehicles. Most of these projects involved international collaboration in the later stages of development. In 1948 development commenced on a target drone called Jindivik. It was manufactured by the Government Aircraft Factories and had its first flight in 1952. For the time it had an impressive range and endurance – flying at 490 knots with a ceiling up to 60,000 ft and a range of 670 Nautical miles.

It was in production for 30 years with 550 produced for customers around the world.

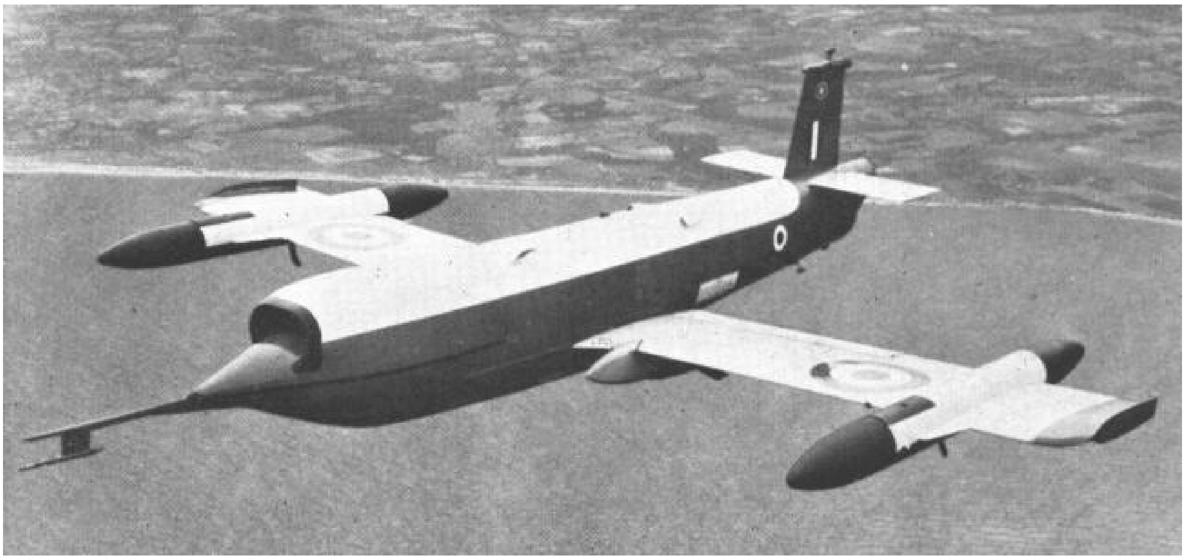


Photo: via Jane's

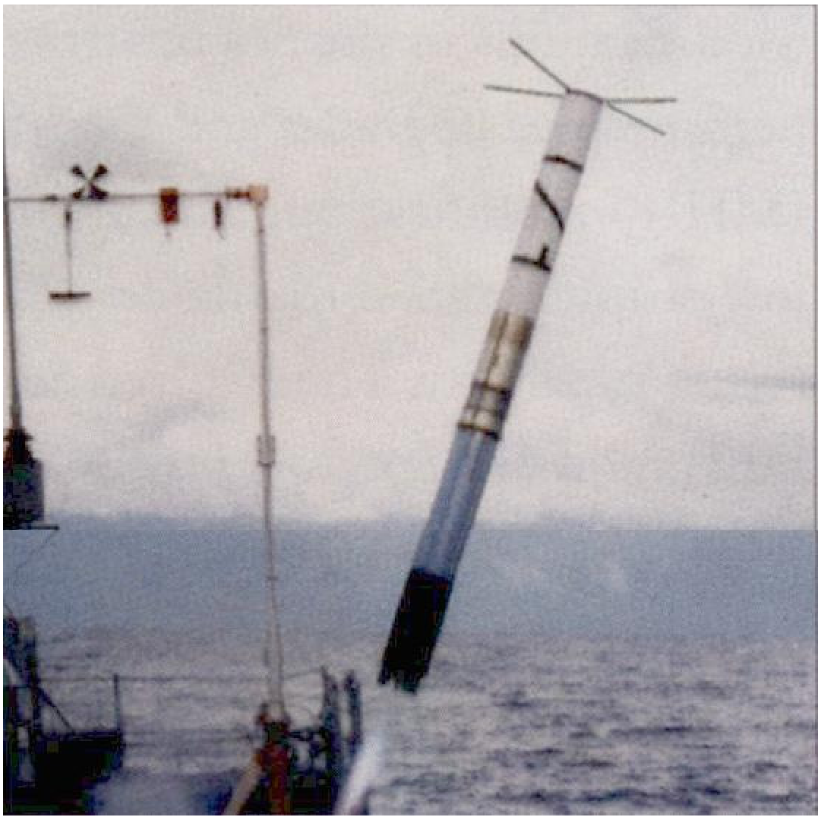
Jindivik Mk.103A (with extended wings)

It was powered by a Bristol Siddeley Viper turbojet, runway-launched and recovered. The drone was radio-controlled either from a ground station or from an accompanying director aircraft. *Jindivik* was used for tests of surface-to-air and air-to-air guided missiles. For this purpose, it could be equipped with:

- transponders for radar-tracking
- radar reflectors
- heat sources for enhanced IR signature

In about 1960, an Australian-designed and built anti-submarine weapon called Ikara was commissioned. Ikara was a ship-launched rocket that carried a homing torpedo to the area of a submarine contact. When the missile arrived at the suspected site of a submarine, it released a torpedo by parachute to hunt the submarine. The initial Australian design was further developed in conjunction with the UK.

Ikara's range was double that of competing systems and had the advantage of an accurate guidance system during flight to ensure optimal torpedo release at the site of the latest submarine contact. Approximately 600 were produced for the Australian, Brazilian and Royal navies from 1960 to 1985 until they were replaced by ship-based helicopter-delivery of torpedos to the submarine contact area. While other missiles and weapons were produced in the years following 1960 the most challenging project was the development in 1979 of the Nulka seduction missile. It grew out of the need for a rapidly deployed counter to sea skimming anti-ship missiles. Australia, with its history of rocketry, developed a rocket capable of stable flight at an altitude of 50 feet. Its attraction over competing seduction systems was its ability for very rapid deployment and its controlled low altitude flight in a wide range of weather conditions. The height and lateral movement control of the rocket are achieved by moving control vanes inserted directly into the jet efflux. The air data system developed for the missile can accurately maintain the height of the rocket in operating conditions from calm to 50 knot winds. Initial work by DSTO was followed by BAE Systems developing a fully-engineered certified system. Nulka became a collaborative project with the US which manufactured the electronic package which seduced the sea skimming missiles away from the ship.



Nulka has been continuously developed and manufactured by BAE Systems since 1988 with over 1,000 rounds sold to the Australian, US and Canadian Navies. BAE Systems is currently a full partner in the development of the Evolved Sea Sparrow Missile. This indigenous capability has resulted in BAE Systems locating its UAV research in Australia.

Hypersonic Research

Australia has a long history of hypersonic research dating back to the early 1960s. The work came to fruition at the University of Queensland where Professor Ray Stalker founded a research school which has been continuously conducting hypersonic research for 40 years. In 2000 the University of Queensland initiated hypersonic testing at the Woomera range in the centre of Australia. This led in 2006 to an eight-year collaborative program called HiFire, which involved DSTO the US Air Force Laboratory, Boeing, BAE Systems and the Universities of Queensland and New South Wales. There will be up to nine flights, some of them using Woomera. Ground based work in Australia and the US with the nine hypersonic flights form an integrated program to improve our capabilities in the areas of:

- hypersonic aerodynamics
- aerothermodynamics
- adaptive flight control systems
- very high temperature materials
- propulsion system design incorporating supersonic combustion, often called Scramjets

As well as scientific background particularly on scramjets, Australia has contributed ground based test and evaluations to develop the vehicle structure, guidance and control systems, materials and flight software.

In parallel with this defence program, a civilian hypersonic program funded by the Australian Space Research Program is being led by the University of Queensland. Its aim is to demonstrate that hypersonic vehicles could provide safe, reliable and economic access to space. The program involves 13 organisations half of them international, so as well as the Australian-based organisations we have:

- DLR – German Aerospace Center
- CIRA –Italy
- JAXA – Japan
- University of Minnesota – USA

Australia attracts this international collaboration because over the last three decades it has become the world leader in the science of hypersonic propulsion which is the main area of technical risk in developing a feasible hypersonic vehicle. The question is can we design a propulsion system which will produce sufficient thrust to overcome the hypersonic drag to produce useful net thrust? The follow-on question is: can we find high temperature material systems that can retain their shape and function with sustained heat loads?

Australia has had a long vibrant association with aeronautics and with ICAS – Laurie Coombes, who came to Australia to set up the Aeronautical Research Laboratories where many of the advances I have talked about today were initiated, is listed as a member of the Honorary Advisory Board in the first ICAS proceedings in Madrid in 1958 and in the second meeting in Zurich in 1960. The proceedings of the fourth meeting in Paris in 1964 list the Australian Division of the Royal Aeronautical Society with L P Coombes as the President.

So Australia throughout its history has been involved internationally in leading edge developments in aerospace, sometimes as a prime but more often as a contributor of world class technology. For all nations aerospace development in the future will be collaborative. This paper has illustrated that no matter how small a country is, it can fully participate in the future of aeronautics if it can generate innovative technology and foster a culture of collaborating internationally.

I would conclude by thanking ICAS for its recognition of Australia's work in aerospace; with this year's ICAS von Kármán award for international collaboration, Australia will have received six ICAS awards for various activities – we must be doing something right.

Acknowledgements

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References

Hudson Shaw, W. and Ruhen, O. (1977), *Lawrence Hargrave: Explorer, Inventor and Aviation Experimenter*, Sydney: Cassell Australia. ISBN 0-7269-3708-8.

Peterson Witham, J., *Black Box: David Warren and the Creation of the Cockpit Voice Recorder*, Lothian Books, 2005.

Wong A.K., Richmond M. and Ryall T.G., *Structural assessment of the Orion P3 wing leading edge by a state-of-the-art thermal imaging system*, Proc. 6th Australian Aeronautical Conference, March 20-23, 1995, pp795-800.

Long, G., *Future Directions in Aeronautical Composites*, ICAS Guggenheim Lecture, Melbourne, Australia, September 1998.