Australian Government

Department of Defence

Innovators & Aviators

Stories of
Defence Science supporting ***RAAF***
across ***100 years***

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Department of Defence.
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Foreword

Chief Defence Scientist

The evolution of the Royal Australian Air Force (RAAF) from a small fleet of plywood and canvas bi-planes in 1921 to one of the most capable air forces in the world today demonstrates what can be achieved by being bold, embracing innovation and pushing boundaries.

That drive to innovate, to do things better, faster, smarter is in the RAAF DNA, and explains, I think, the long and enduring relationship that we Defence scientists have enjoyed with our winged colleagues throughout their history.

Just as the RAAF has evolved, Defence science too has transformed in that time. In 1921, it was still very much an emerging field. Early Defence scientists were primarily chemists advising on the handling and storage of munitions. While this was important scientific support for the RAAF, it was the establishment of a dedicated aeronautical research facility at Fishermans Bend in Victoria in 1939, followed by a guided weapons research facility in South Australia that truly forged the bond between Defence scientists and our RAAF counterparts that endures to this day.

It's hard to think of an aspect of the RAAF that Defence scientists have not touched in some way. Airframes and engines; weapons and stores; signature management, information systems, electronic warfare; even the complex psychological and physiological factors that contribute to the performance of RAAF personnel – all these areas have benefited from the expert research and analysis of Defence scientists and engineers. The purpose of this research remains the same today as it was in 1921: to enhance RAAF capability and maximise the performance, survivability, availability and safety of RAAF aircraft and crew.

This book celebrates the long and enduring partnership between the RAAF and the Defence Science and Technology Group. It captures the science, the scientists and the stories that form our shared history.

The next century of air force operations promises to be as exciting as the past one, as the RAAF transforms to a fifth generation fighting force and beyond. And there will undoubtedly be unforeseen challenges that continue to require the unique and specialised skillsets and S&T solutions that DSTG will lead in order to deliver future capability.

I congratulate the RAAF on their centenary and I look forward to continuing to work with them to push the boundaries of innovation and technology and redefine what is possible.

Tanya Monro

Professor Tanya Monro

Chief Defence Scientist

Foreword

Chief of Aerospace Division

It gives me great pleasure to write a short foreword to this book, which provides a demonstration of the close working relationship between the Defence Science and Technology Group, in all its iterations, and the RAAF for 100 years.

The effectiveness and impact of the joint work undertaken by both organisations has not been fully chronicled and this is the first attempt to capture some of the creative and inventive sparks that have solved the various science and technological challenges confronting the RAAF and Defence more broadly.

It is a snapshot of some of the top achievements, including the challenges and the risks as well as the opportunities.

By closely working together, from RAAF's modest beginnings in 1921 – breakthrough science from DSTG has assisted the RAAF to achieve world-leading capability, in electronic warfare, command and control, and systems integration.

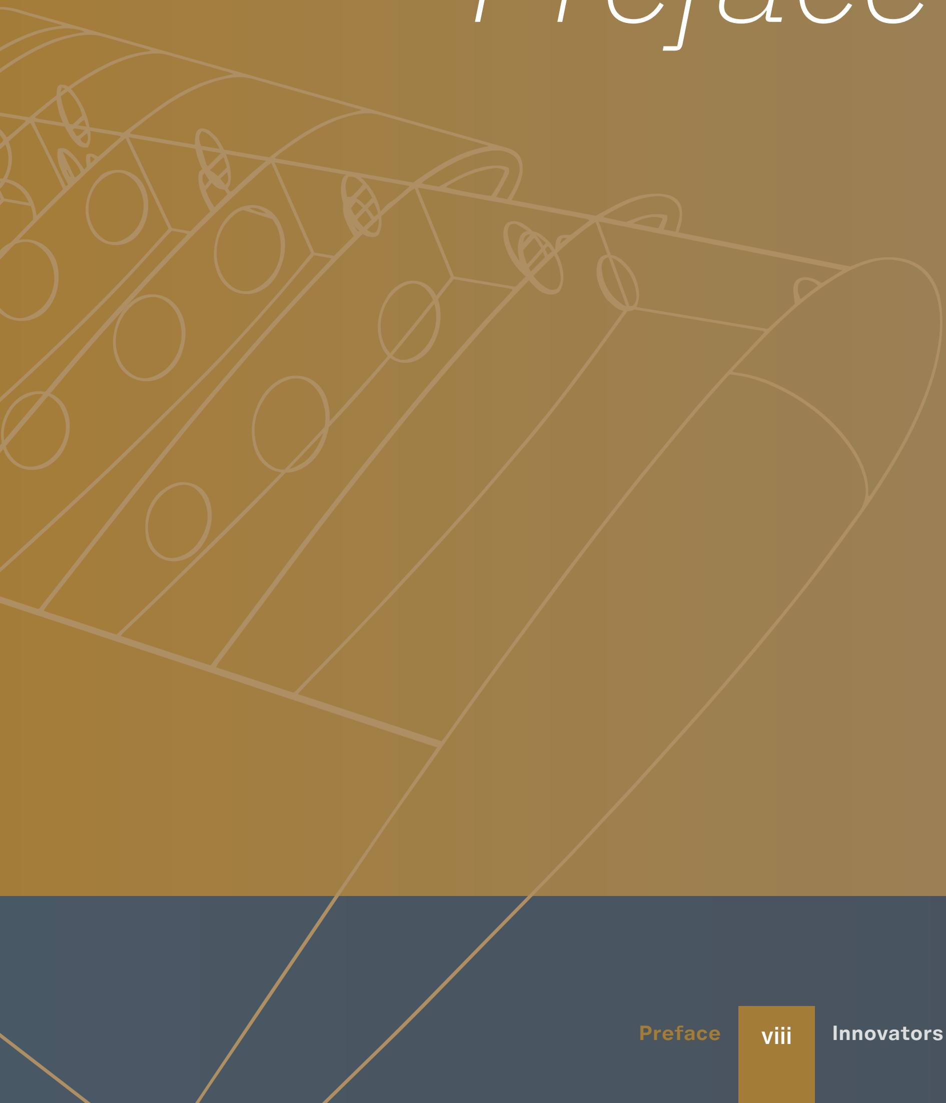
Through our joint efforts the RAAF has pioneered world-leading aircraft, such as Loyal Wingman, the Joint Strike Fighter and now space initiatives.

As we honour the significant achievements of the RAAF's airmen and women over the past century, this book is an opportunity to reflect upon our enduring partnership that has helped evolve the RAAF into the world-leading air force it is today – and for the next 100 years.

I know you will find this book inspirational and enjoyable reading.

Dr Katerina Agostino
Chief of Aerospace Division

Preface



Dear Air Marshall Hupfeld,

Congratulations from the Defence Science and Technology Group (DSTG) on the centenary of the Royal Australian Air Force (RAAF). This magnificent milestone has inspired us to create a book that celebrates not just the science and technology achievements that have benefitted the RAAF, but also the support that RAAF has provided DSTG across the decades. In this book, we have endeavoured to showcase a variety of examples that demonstrate the application of DSTG's niche, and often sovereign, capabilities that have contributed to the RAAF developing as one of the safest, capable, economically efficient and informed air forces in the world.

Although Defence science in Australia has been recorded as having commenced in 1907, the serious beginnings of Defence aeronautical sciences dates back to 1939 with the establishment of the CSIR Division of Aeronautics at Fishermans Bend, Victoria. Together with the Long Range Weapons Establishment in South Australia, these would form the core of what is today's DSTG. Since those early years, DSTG's remit has expanded to support all three services and other national agencies, but we are proud to say we have had an enduring relationship with the RAAF for 82 of its 100 years. It has been an exemplar of achieving more, together.

The main title of this book '*Innovators and Aviators*' is a nod to both DSTG and the RAAF. Innovators being an inherent part of DSTG's *raison d'etre* and the RAAF's journey on its transformation into a fifth generation air force; and Aviators, acknowledging not just the people who operate the aircraft, but all those in a blue uniform who sustain them on operations or behind the scenes, during times of conflict and in peace. In writing this book, the authors thank and acknowledge all the DSTG staff past and present who have pioneered the innovations, investigations and integrations, and just as importantly, for recording their work. Without these, this task would not have been possible. And then there are the other contributors, those who have been willing to share their personal recollections and imagery not readily available elsewhere; these have been equally as valuable.

The following pages provide but a mere snapshot of the work that DSTG (and former namesakes) have done to support just a handful of RAAF aircraft and systems. The book was structured in this way – as opposed to highlighting various technical streams – because, irrespective of strategy, capability, executing a mission or scientific achievement, there is one common denominator – the aircraft (and systems), the tools of the RAAF's trade. This was to appeal to a readership who are captivated by aircraft and their capabilities; to shine a light on the science and technology that has supported various fleets, and to acknowledge the support the RAAF have provided in making aircraft and aircrew accessible to advance this research.

A brief introduction about the early days of DSTG precedes five chapters that were selected to cover the breadth of roles the RAAF conduct with their aircraft and land-based systems. These chapters are: *Uncrewed Aerial Systems* (Radioplane, Jindivik, Global Hawk, Heron, Autonomous Teaming System and Triton), *Surveillance & Control* (E-7A Wedgetail and Jindalee over-the-horizon radar), *C-130 Hercules* (still in service after 63 years), *Fighter/Attack Aircraft* (F-111, Classic Hornet and JSF), and *Maritime Patrol & Response* (P-3 Orion and P-8 Poseidon).

We hope you enjoy this book as a precursor to a richer and larger volume that will celebrate more aircraft, support systems, capabilities and stories from both RAAF and DSTG perspectives that have contributed to our shared history and successes, and augurs well for the next century of partnering.


AIR FORCE

Introduction

This book aims to briefly illustrate to our colleagues and friends in the Royal Australian Air Force (RAAF) and beyond the enduring commitment by the people of Defence Science and Technology Group (DTSG) to defending Australia and securing peace in the air domain using the most advanced science and applications of it. The highest priority for the people of DSTG has always been and will remain finding new ways to help those conducting operations to fulfil their mission and return safely.

DSTG wishes to celebrate our shared history with the RAAF as they mark their 100th birthday. This book is not a comprehensive and detailed historical record, but rather provides a snapshot of some of the research and engineering with the most impact on the RAAF during the past century. Naturally, only unclassified, publically available material can be presented, so there are some amazing research stories not included. Lastly, despite several written histories of the organisations that now make up DSTG, the organisation has not been focussed on capturing and curating its work, so much of that history and many photographs have been lost.

A brief description of the changes to the organisation is given in this introduction, while the remainder of the book tells the stories of several RAAF capabilities from the most important science and technology contributions by DSTG across our shared history.

Where does DSTG come from?

Defence Science and Technology Group was originally formed at a similar time to the Australian Flying Corps (AFC) and the RAAF, since its origins includes the Munitions Supply Laboratory (MSL), an organisation that had its beginnings in 1907 when Cecil Napier Hake was appointed the first Chemical Adviser to the Department of Defence. While the science and engineering involved in producing cordite and guns, or better military grade steels and fuels might not have been aimed at supporting the AFC or RAAF, they nonetheless benefitted greatly when it came time to build, arm and fuel Australian aircraft. Despite all the changes of organisational name in the 114 years to 2021, the application of specialist knowledge to solve the most difficult problems has not changed. The name changes have resulted from sequential amalgamations to now form the Defence Science and Technology Group (DSTG) of 2021.

Air domain science and technology in support of the ADF effectively commenced in 1939 with the establishment of the Division of Aeronautics of the Council for Scientific and Industrial Research (CSIR). This civilian organisation was deliberately and directly focused on research and engineering to support the nascent Australian aircraft industry, which by then was working entirely to support the RAAF in the Second World War. The laboratory was located adjacent to the two government aircraft factories and the associated aerodrome at Fishermans Bend in Victoria, with the first buildings finished in war time haste by April 1940. Aeronautics research was transferred from the statutory authority CSIR to the Department of Supply in 1949, with the clear intention of changing the research program to directly support Defence. At that point the name was changed to Aeronautical Research Laboratories (ARL), a name that lasted 40 years.

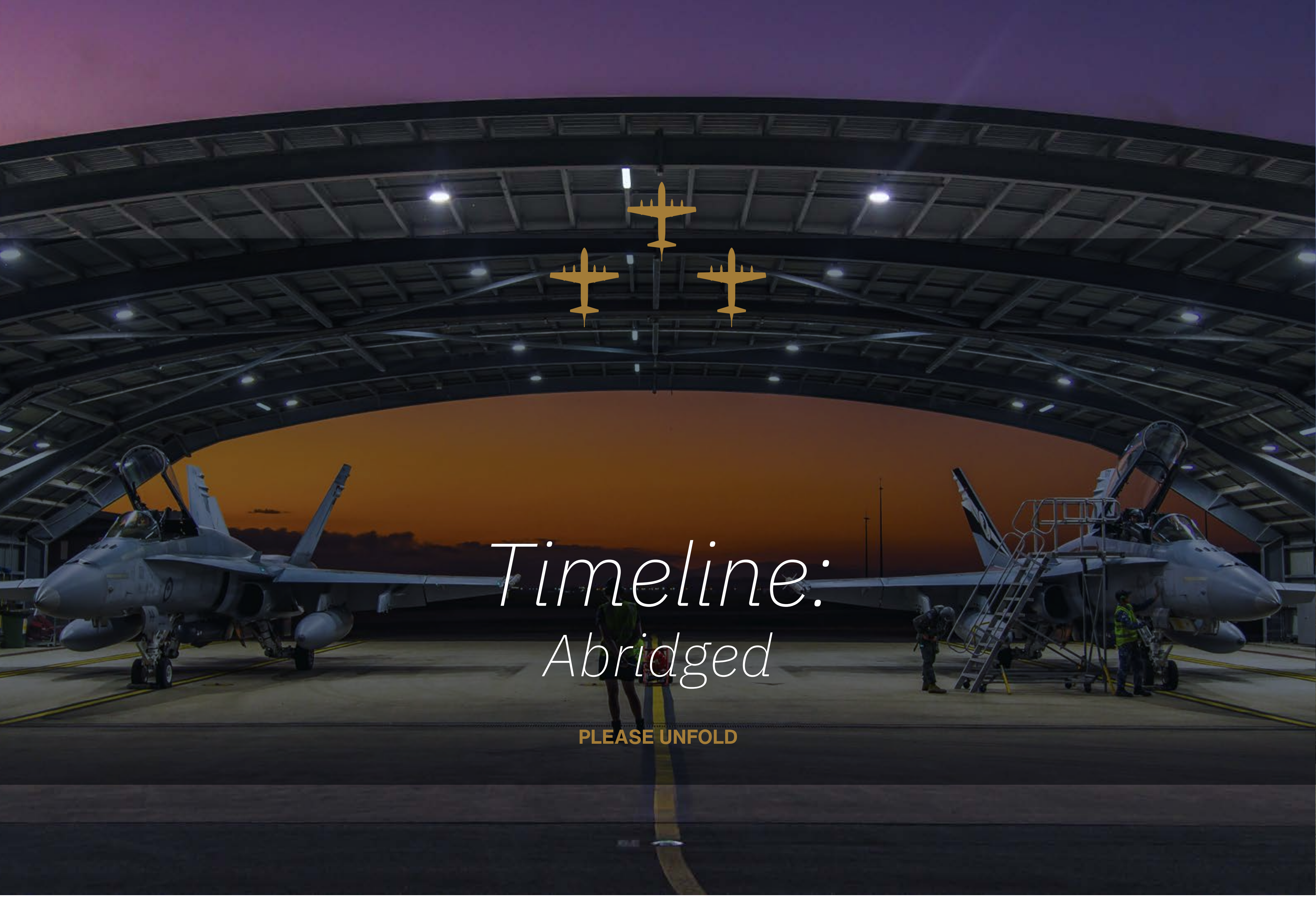
Fishermans Bend Aerodrome 10 March 1949. Showing ARL nearest with three sawtooth roofs behind the Administration/office building. Commonwealth Aircraft Corporation (CAC) is on the other side of the runway along the river and Government Aircraft Factory (GAF) beyond that towards the entry of the Yarra River into Port Phillip Bay.

Australian Defence Scientific Service badge.

Another major strand of defence aeronautical research was established at Salisbury in South Australia as a result of the 1946 UK-Australia Project Agreement on long-range weapons, otherwise known as rockets or missiles. Australia was initially to provide only the vast testing range in central Australia and instrumented facilities to test UK developed weapons, but the tyranny of distance from Europe meant that an increasing amount of the science and engineering was necessary from local organisations, which multiplied considerably. Without tracing the complete lineage, the major organisations located at Salisbury and using the Woomera Test Range were called Weapons Research Establishment (WRE), Weapons Systems Research Laboratory (WSRL) and Electronics Research Laboratory (ERL). Although retaining their laboratory names, they came under the umbrella Australian Defence Scientific Service (ADSS).

As a result of a review of Defence by then Secretary Arthur Tange, in 1974 ADSS at Salisbury was merged with MSL and ARL in Melbourne to form the Defence Science and Technology Organisation (DSTO) as the science and technology arm of Defence. In that merger MSL was changed to Materials Research Laboratory (MRL) with a focus on both Royal Australian Navy and Australian Army research, but ARL retained its name except for becoming a singular laboratory. All three organisations retained their separate identities, with minimal collaboration between the sites. That lasted until in 1994 when MRL and ARL were merged to form Aeronautical and Maritime Research Laboratories (AMRL), which then changed to Platforms Sciences Laboratory (PSL) in a DSTO restructure in 2002. The DSTO finally changed its name in 2015, and today it stands as DSTG.

Looking south across the Long Range Weapons Research Establishment (LRWE) site at Salisbury in the early 1950s before RAAF Base Edinburgh was constructed on the adjacent site in 1953. The site clearly shows its wartime heritage as the Salisbury Munitions Factory. The name of the location changed to Edinburgh in 1997.



Timeline:

Abridged

PLEASE UNFOLD

1940s

1939-40

Aeronautical and Engine Research Test Laboratory established at Fishermans Bend as part of the CSIR Division of Aeronautics.

1947

Arthur Wills of the CSIR division of Aeronautics initiates a research program to develop a database on aircraft fatigue.

1947

First trials at Woomera: parachute testing by Royal Aircraft Establishment.

1948

Design and development of a sub-sonic uncrewed jet-propelled target plane prototype begins following a series of meetings held in London between representatives of the British and Australian governments. Two versions designed and built by the Government Aircraft Factories and later the Aeronautical Research Laboratories: a crewed version 'Pika' (two only built) and an uncrewed version 'Jindivik'.

1950s

1950–1962

Alf Payne and W.W. Johnston, Aeronautical Research Laboratory, Fishermans Bend (ARL), lead a pioneering research program into the fatigue behaviour of aircraft structures. Extending over a period of 12 years, 222 Mustang aircraft wings are tested. **The research is the most extensive series of fatigue tests of a full-scale structure ever undertaken and the results are subsequently used as an authoritative reference by the aeronautical industry.**

1952

The first successful Jindivik test undertaken on 28 August 1952 from Evetts Field near Woomera, SA.

1953

Dr David Warren, ARL invents the first black box flight recorder. Dr Warren and his team — Kenneth Fraser, Lane Sear and Dr Walter Boswell — spend the next several years developing the technology.

1954–1975

The first firing trial using the Jindivik Mk1 as a target undertaken (1 October 1954) at Range E, Woomera, SA. Jindivik continues in service at Woomera until 27 June 1975.

1959

Fish-eye lens camera designed and developed by Weapons Research Establishment for Jindivik trials.

1960s

1967

Design work on Australia's first satellite, WRESAT, begins — a joint venture between Weapons Research Establishment, Salisbury, and Physics Department, University of Adelaide. US Department of Defense, NASA and Ministry of Technology, UK, provide assistance. WRESAT launched at Woomera, SA, 29 November.

1968

Scientific advice on F-111 to the RAAF commences at Fishermans Bend. Over the years, this has included structural integrity testing, bonded repair research, durability and damage tolerance analysis. The aircraft was retired in 2010.

1970s

1970

Jindalee high frequency over-the-horizon radar (OTHR) becomes a core DSTO research project developed to provide surveillance across Australia's northern sea and air approaches.

1972

Dr Alan Baker and his team at ARL begin pioneering research and development into use of composite bonded repair technology to prolong the airframe life of several RAAF fleets, with the Hercules C-130E becoming the first significant adopter. **DSTO becomes world leader in the technology.**

1977

RAAF places request with Defence Research Centre, Salisbury, to investigate glide bomb technology — leads to General Test Vehicle (GTV) program, later known as 'Kerkanya'.

1979

DSTO scientist John Curtin conducts a study exposing limitations in the Orion Electronic Support Measures (ESM) system. Goes on to play a major role in the development and redesign of a new ESM system, the ALR-2001, with AWA Defence Industries (now part of British Aerospace Australia) that has significantly enhanced the Orion's maritime surveillance capability.

1980s

Early 1980s

Research begins at ARL into helicopter gearbox failures.

1983

Australian patent granted for the Pilot's Force Measurement Glove invented by DSTO's Dr Garth Morgan, William Menadue and Robert Clarke at the request of RAAF's Aircraft Research and Development Unit (8 June). **A world first for Australian engineers and an invention that revolutionised in-flight testing procedures.**

1988

RAAF takes decision that a full-scale structural test on the empennage of the F/A-18 Hornet is required in order to establish its economic safe life.

1989

Project AuSAR (Australian Synthetic Aperture Radar) begins — in an advanced state of design by 1992.

c. 1989

Pilot's Force Measurement Glove Technology transferred to Normalair-Garrett Australia to undertake development and manufacture. Company markets the glove as the 'Control Stick Force Measurement Glove'.

1990s

c. 1992

DSTO and AWA Defence Industries develop to concept demonstrator stage the ALR-2002 Radar Warning Receiver — first such complex receiver to be designed and built in Australia to meet the RAAF's operational requirement for a replacement radar warning receiver for the F-111 aircraft. Developed over a period of 15 months.

1993

An AMRL vibration investigation identifies input bearing failures in the F/A-18 airframe mounted accessory drive (AMAD) gearbox as the primary cause of two in-flight fires and associated maintenance actions are recommended.

1993

DSTO commissions the Air Operations Simulation Centre at Fishermans Bend to become Defence's first aerospace human-in-the-loop simulation research facility.

1995

Helitech Industries Pty Ltd, in collaboration with DSTO, develops a composite bonded repair for the United States Air Force C-141 Starlifter heavy transport aircraft.

1995

Full-scale testing of major components of F/A-18 Hornet commences at Fishermans Bend under the International Follow-On Structural Test Project, a joint venture between Canada and Australia. On completion, 23,000 hours of test 'flying' had been carried out in a specially designed rig that duplicated the stresses and loads that an F/A-18 Hornet would experience in real flight.

1999

High Altitude Endurance Unmanned Aerial Vehicle (HAE UAV) Project Arrangement (PA) signed. Negotiated under the auspices of the Deutch-Ayers Memorandum of Understanding, the PA authorised the joint development and testing of the Global Hawk HAE UAV system which included the implementation of new sensor and system capabilities for maritime surveillance and improved mission flexibility based on DSTO research and advice.

2000s

2000

The P-3 Service Life Assessment Program, a major international collaborative effort involving DSTO, commences at Fishermans Bend. The program involves full-scale fatigue tests and associated analysis on the complete P-3 Orion Aircraft. The data provided will enable the RAAF to safely manage the structural integrity of the fleet until the planned withdrawal date.

c. 2000

DSTO designs and builds a military imaging laser radar, known as LADAR, as a concept demonstrator for battlefield surveillance — emerges from the highly successful LADS (Laser Airborne Depth Sounder) technology.

2001

Global Hawk makes international aviation history by successfully completing the first non-stop flight across the Pacific Ocean by an autonomous aircraft. Flies from Edwards Airforce Base, California, and arrives at RAAF Edinburgh, SA, on 23 April. Remains in Australia for six weeks where its system is integrated with a DSTO-developed ground station to allow Australian operators to control aspects of the Global Hawk sensor operations and to analyse the imagery data collected by its sensors while flying around Australia.

2003

Collaborative research on spin testing to evaluate the lifespan of parts – involving Australia, the United States, Canada, and South Africa – informs the management of T-56 engines and significantly enhances the availability of the RAAF C-130H.

2004

Collaboration between Australia, the United States, Canada, and the Netherlands on the P-3C Service Life Assessment Program informs RAAF service life substantiation and life extension options.

2004

DSTO and BAE systems, manufacturer of the RAAF's Hawk Mk127 Lead-in Fighter, enter a commercial business agreement to conduct comprehensive fatigue testing on the aircraft. This full-scale fatigue test was conducted at DSTO's H.A. Wills Structures and Materials Test Centre at Fishermans Bend. Cycling began in 2006 and ended in 2020 after five lifetimes of loading (representing 50,000 flight hours) had been applied.

2005

DSTO delivers the Air Defence Ground Environment simulator (ADGESim) for training RAAF Air Battle Managers at RAAF East Sale and RAAF Williamtown.

2005

The first simulated training missions involving RAAF F/A-18 operators and US Air Force F-16 operators are conducted via distributed simulation network between DSTO and the US Air Force Research Labs during Exercise Pacific Link.

2006

Australian ASRAAM (Advanced Short Range Air-to-Air Missile) software support Capability (AASSC) established by DSTO in Edinburgh.

2006

DSTO and US Air Force sign a $70m agreement to advance research in hypersonic flight. The HIFIRE project, an eight-year program, is one of the largest collaborative ventures between DSTO and US. University of Queensland and University of New South Wales at the Australian Defence Force Academy are also involved.

2007

First demonstration of a prototype autonomous, self-powered structural health monitor for composite bonded patches removed from a RAAF F/A-18 Hornet after 12 months of successful flight testing.

2008

DSTO's full-scale fatigue testing of ex-service F/A-18 Hornet centre barrels extends service life to the aircraft and saves Defence around $400m in replacement costs.

2008

A series of tests involving the Joint Direct Attack Munition – Extended Range (JDAM-ER) are completed at Woomera. The JDAM-ER wing kit was developed by Boeing's Hawker de Havilland subsidiary based on DSTO's original 'Kerkanya' technology.

2008

DSTO hosts the first Black Skies synthetic training research exercise, providing virtual preparation for RAAF operators prior to Exercise Pitch Black.

2009

First successful launch under the HIFIRE (Hypersonic International Flight Research Experimentation) program takes place at the Woomera test range.

2009

The DSTO-RAAF Australian Airborne Countermeasures Team (AACT) are awarded Chief of Air Force Gold Commendations for their work improving the AAR-60 airborne platform countermeasure system.

2009

Research by DSTO's Michael Royce and Merrilyn Fiebig along with RAAF 92 Wing and Surveillance Response Group (SRG) informs upgrades of the electro-optical imaging system onboard the RAAF AP3-C, leading to vastly increased capability for the fleet.

2010s

2010

DSTO developed software vastly improves the dynamic balancing of propellers for the RAAF C-130J-30 aircraft. This saves the RAAF millions of dollars in maintenance hours and fuel and frees up personnel and aircraft for other tasks.

2010

DSTO hosts the first Australian node in the international distributed mission training Exercise Coalition Virtual Flag, delivering coalition training through distributed simulation for RAAF F/A-18 aircrew.

2012

The International Council of the Aeronautical Sciences awards DSTO, US Air Force Research Laboratory, Boeing Research and Technology, and the University of Queensland the von Karman award for international cooperation in aeronautics for the HIFIRE program.

2012

E-7A Wedgetail Air Battle Management teams prepare for Pitch Black for the first time via distributed simulation using DSTO's Wedgetail Integrated Research Environment (WIRE) system during Exercise Black Skies.

2014

The Minister for Defence commissions DSTO's "Iron Bird" F-35 Electromagnetic Environment Effects (E3) facility, designed to study the impact of radio frequency emissions on the aircraft's electronic systems.

2015

DSTO analysis and treatment of fatigue cracking in F/A-18A/B centreline pylons leads to the rapid return to service of the pylons in support of operations in the Middle East.

2015

RAAF Training Aircraft Systems Program Office (TASPO) accepts the DSTO-developed Filter Screening Tool (FST) into service for routine assessment of Pilatus PC-9/A training aircraft engine lubrication filters.

2016

The Air Warfare Centre Distributed Training Centre (DTC) is established at RAAF Williamtown as a joint venture between RAAF and DSTO to transition DSTO developments in distributed mission training into service.

2016

The DSTO-developed Wedgetail Integrated Research Environment (WIRE) is transitioned via Boeing into the Virtual Wedgetail distributed mission training system for RAAF 42WG.

2017

DSTO's Marcus McDonald is awarded the Medal for Exceptional Public Service, recognising his outstanding contribution to the F-35 program whilst on secondment to the F-35 Joint Program Office (JPO) in the US. This is the highest award of the US Office of the Secretary of Defense to a non-US civilian officer.

2017

DSTO licenses 1 MILLIKELVIN Pty Ltd to commercialise DSTO's MiTE (Microbolometer Thermoelastic Evaluation) stress imaging technology.

2018

DSTG's Paul Marsden receives the US Secretary of Defense Medal for Exceptional Public Service for his contribution as Prognostics and Health Management Requirements/Verification, Test, and Evaluation Lead within the F-35 Lightning II JPO from 2015 to 2018.

2019

The commercialised version of DSTG's MiTE technology for measuring stress on aircraft structures is officially released to the market.

2019

DSTG, RAAF, the UK's Defence Science and Technology Laboratory (Dstl) and BAE Systems achieve the first flight of a persistent high-altitude solar-electric aircraft at the Woomera test range.

2020s

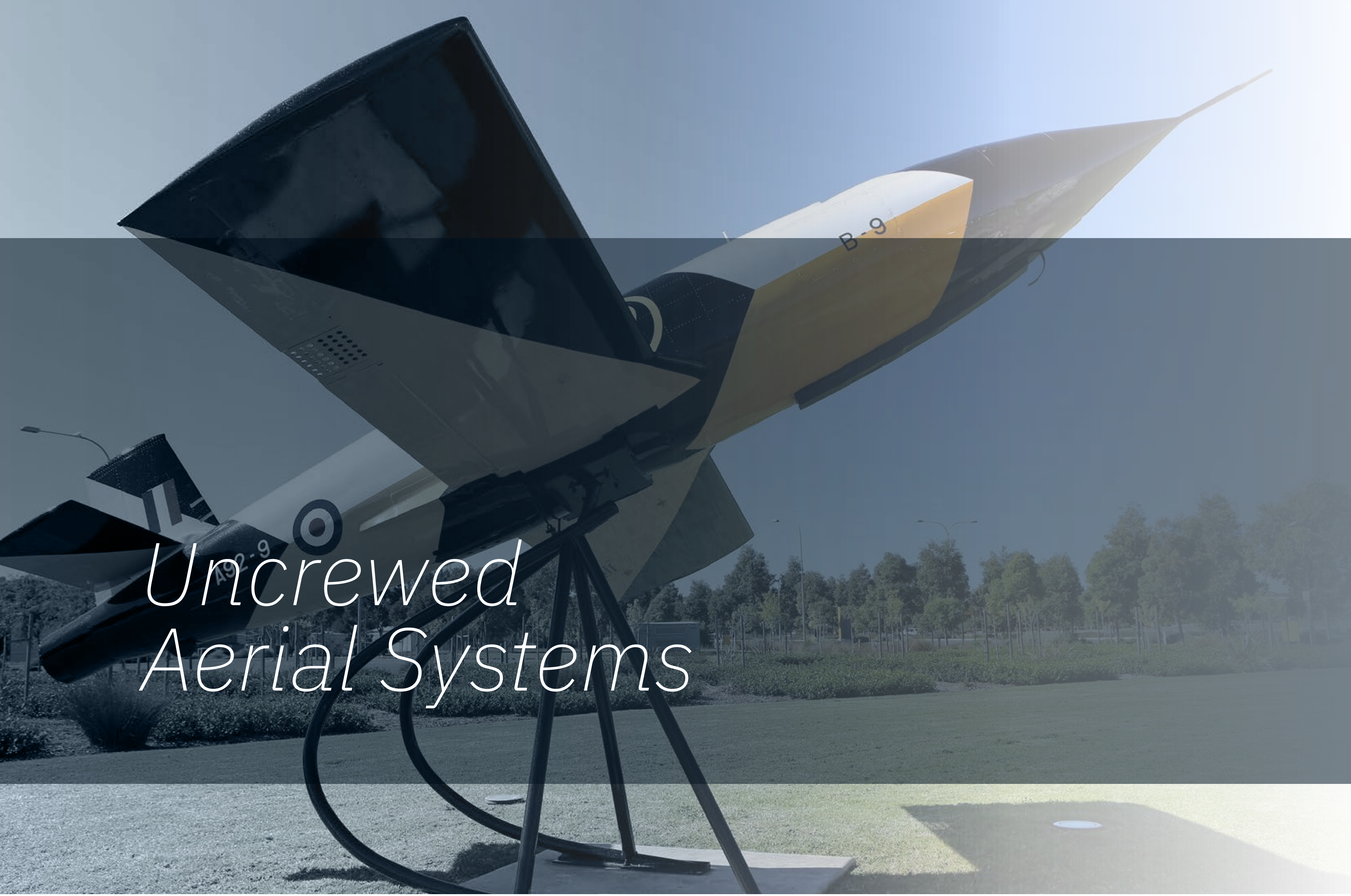
2021

DSTG successfully demonstrates particle image velocimetry (PIV) in the Transonic Wind Tunnel at Fishermans Bend, enhancing Australia's ability to ensure the safe carriage and release of stores by fighter aircraft.

2021

DSTG and industry partner Australian Munitions establish the first local capability to produce the BLU-117 munition for the RAAF F-35A.

Uncrewed Aerial Systems



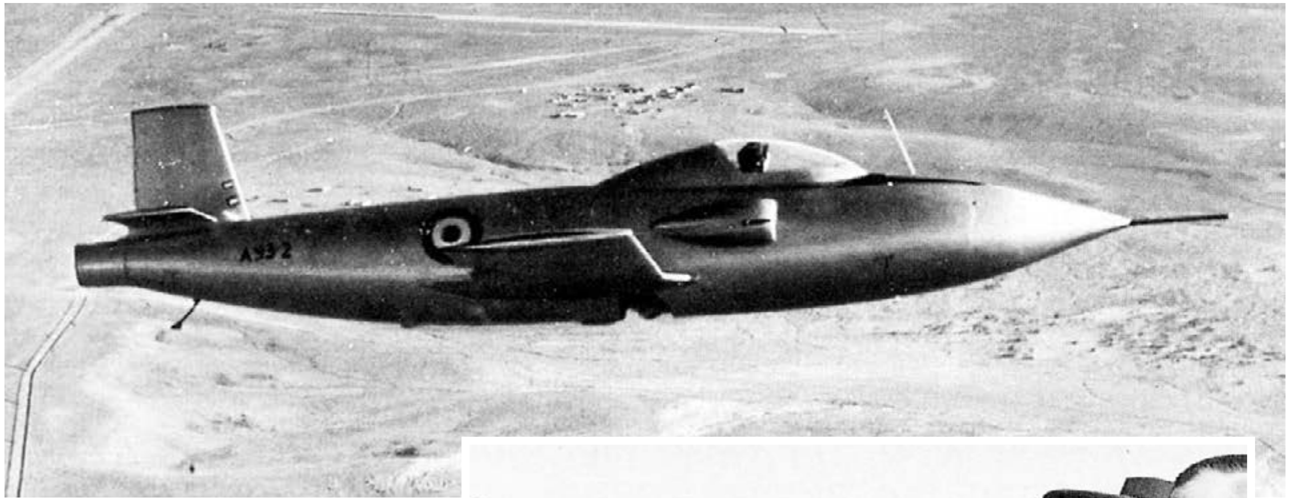
The earliest recorded experiments with remotely controlled aircraft by defence scientific and technical researchers in Australia was a short flight in 1947 of an aerial target drone built by the US company Radioplane. Members from CSIR Division of Aeronautics (which later became part of DSTG), RAAF's Aircraft Research and Development Unit (ARDU) and MSL travelled to Sydney in a RAAF Dakota to meet with members from Sydney University and CSIR Department of Radiophysics Laboratory.

Unnamed Wing Commander with the radio control unit for the OQ-21 aerial target drone, whilst another RAAF officer looks on, 1947.

Jindivik

At the same time that defence researchers experimented with remotely piloted vehicles, the Australia-Anglo Joint Project for the testing of guided missiles would also lead to the development of the pilotless, jet-powered Jindivik aerial target drone. Named after the Aboriginal term for 'hunted one', the Jindivik was created from a British specification, which was then designed and built by the Government Aircraft Factories (GAF) at Fishermans Bend. Over 500 would be produced between 1951 and 1986, in several variants. Interestingly, as the aircraft had no undercarriage, it was launched from a trolley and used a retractable skid for landing. A crew of five people[1] at ground level were responsible for flying the aircraft.

Two types of aircraft were designed initially: a piloted version called Pika and the uncrewed radio controlled Jindivik. The Pika has the honour of being the first and only designed, built and flown piloted jet aircraft in Australia. But only two Pikas were built, as their purpose was to prove the basic Jindivik design and its electronic guidance and control systems. The first successful flight of the Pika occurred on 31 October 1950, followed by the Jindivik on 28 August 1952, both at Woomera, South Australia. And the first trial of using a Jindivik Mk1 as a target took place on 1 October 1954. Subsequent Mk2, Mk3A and Mk3B Jindiviks were designed and developed, and continued in service at Woomera until 1975. Whilst the initial users were the RAAF and WRE operating out of Woomera (Evetts Field), subsequent overseas customers were the Swedish (1957), UK (1960) and US (1962) defence forces. The UK also ordered another small batch of Jindiviks in the 1990s. In 1967, the RAN also became a customer, operating the type from the Jervis Bay Missile Range.

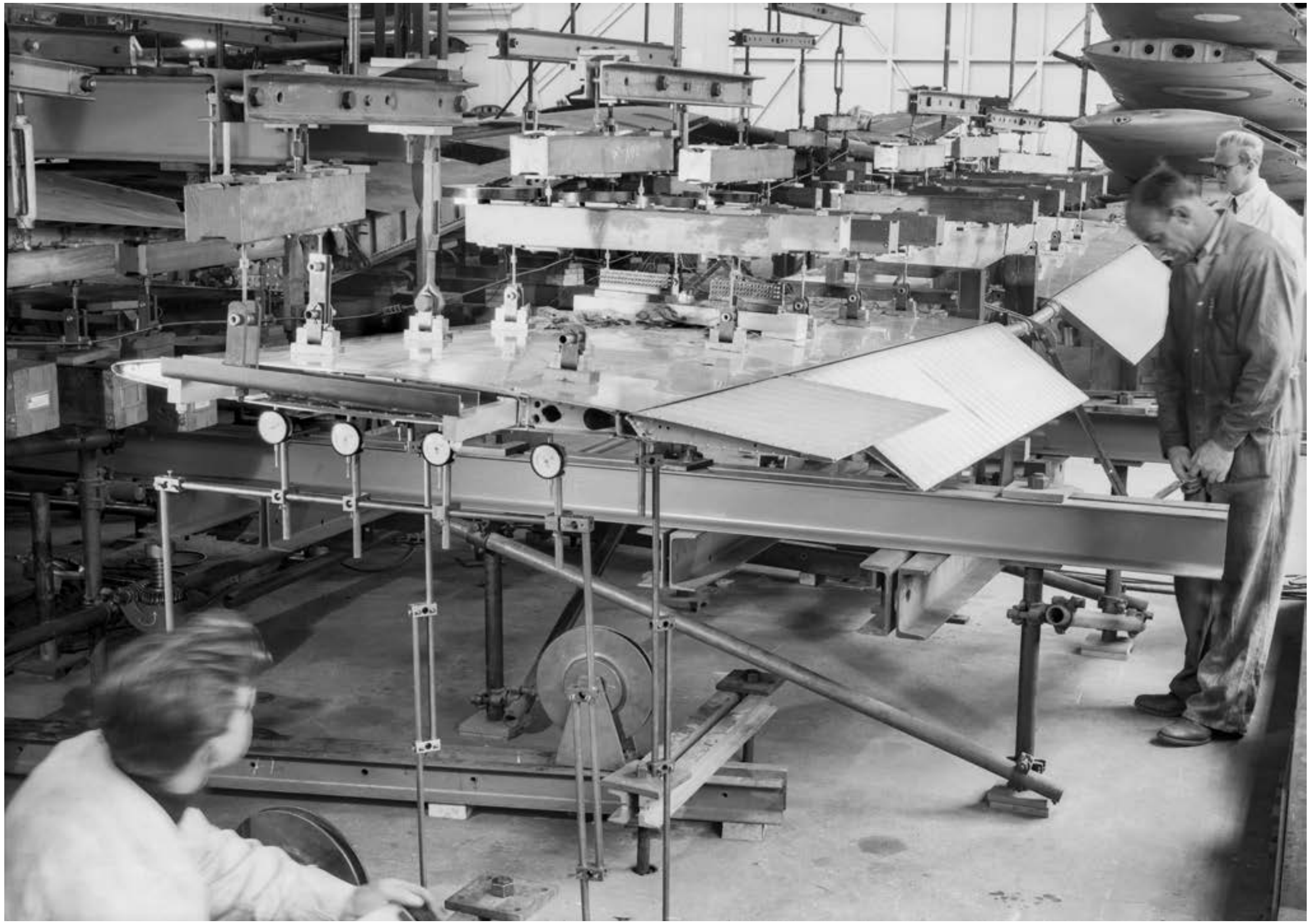


Pika A93-2 in flight over Woomera.

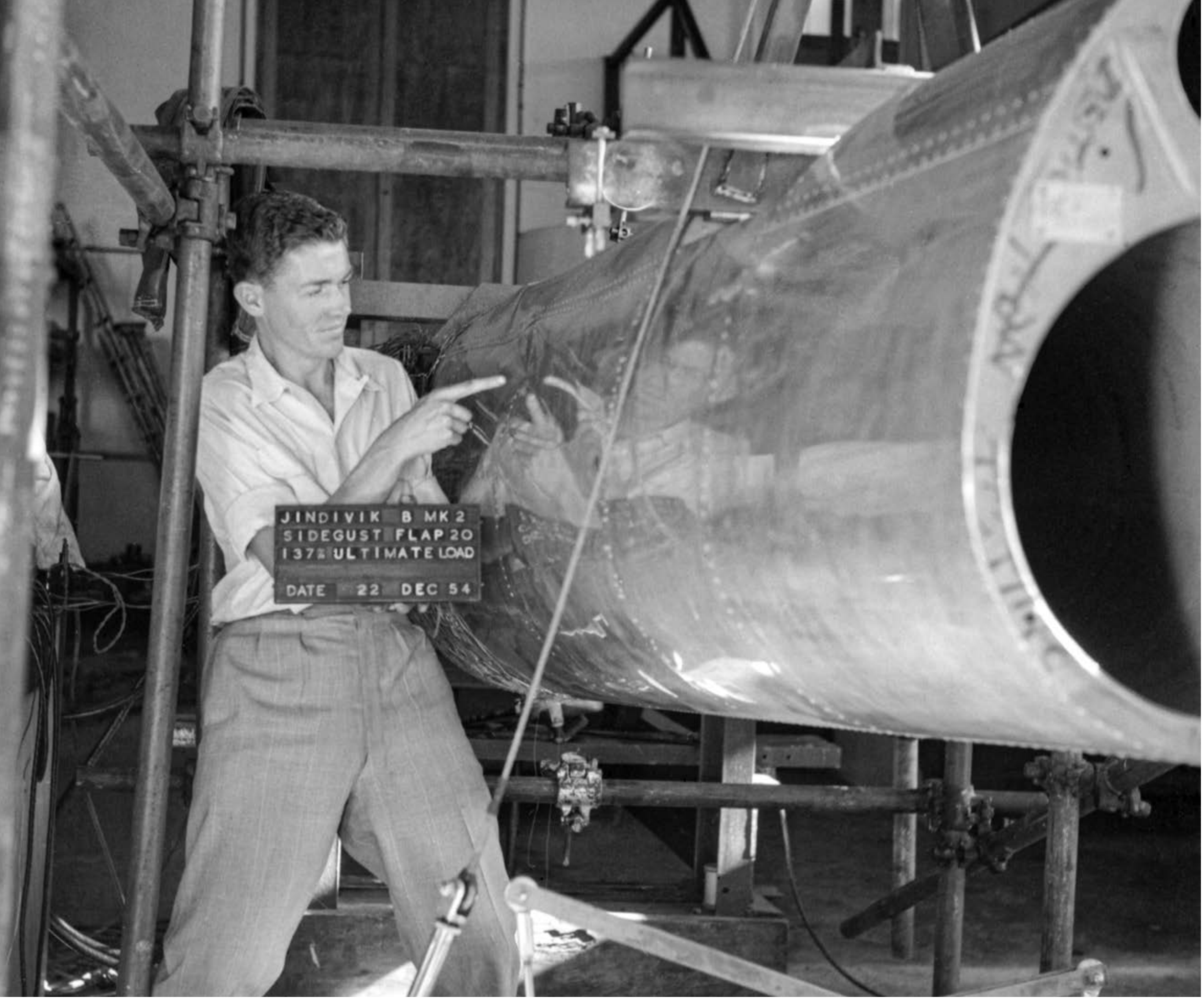
Prime Minister Bob Menzies presses the ‘take off’ button for a Jindivik demonstration flight in May 1953.

1 A skipper and navigator (positioned at the Flight Control Centre), a batsman (positioned at the end of the runway) and a pilot (positioned side on to the runway at the required touch down point). A second navigator was stationed at an instrumentation location.

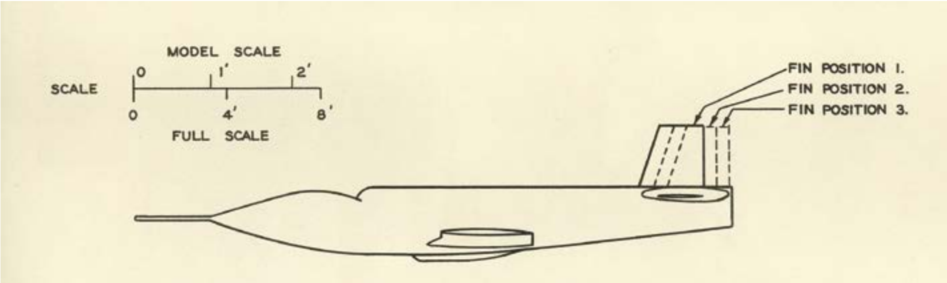
The ARL's pioneering expertise in flight performance, flutter and vibration analysis and structural testing was heavily relied upon for the development of the new aircraft type, and extensive wind tunnel testing was also conducted on scale models of different marks and configurations. Meanwhile, the Royal Aircraft Establishment (RAE) in the UK and the Australian Long Range Weapons Establishment/Weapons Research Establishment (LRWE/WRE) played crucial roles in developing the control equipment and instrumentation, and in project planning, although this latter role was assumed by the RAAF, and then later still by civilian contractors. Not all Jindiviks suffered the fate of a missile strike; some crashed due to other causes and staff from both ARL and WRE would collaborate for these crash investigations. In addition to helping with the development of the Jindivik, defence researchers based at WRE were also responsible for operating their own fleet of Jindiviks, when they took over control of target operations from the RAAF Air Trials Unit in 1967.



Static strength testing of a Jindivik wing at ARL, Fishermans Bend, October 1953. Note the stack of Mustang wings in the top right of the image.

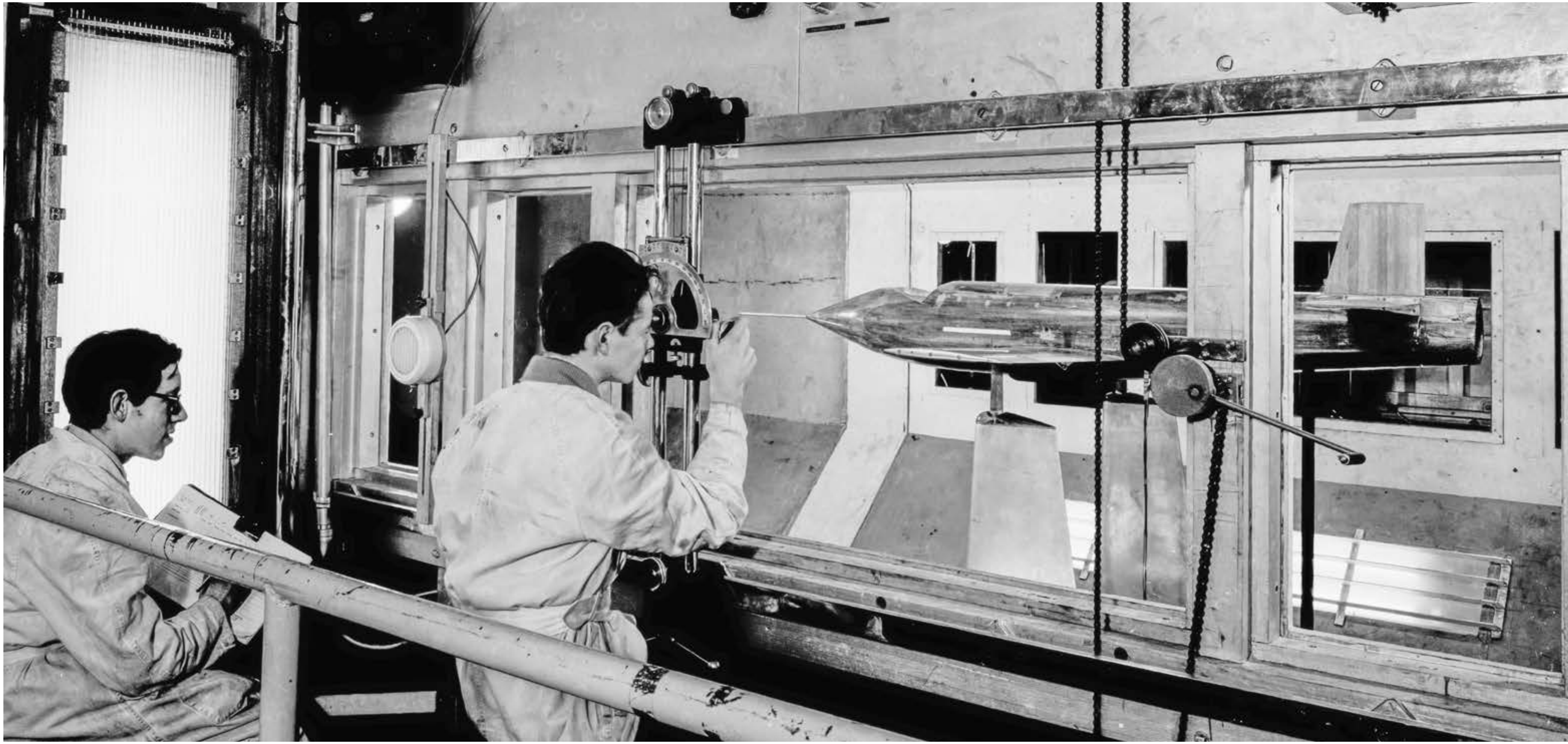


The ARL staff member shown here points to the collapsed section of a rear fuselage test article, which failed during a static strength test after being subjected to a side gust case with 20° flaps at 137% ultimate load, December 1954.



Side projection of 2/7th scale model of Jindivik Mk 2 with three different vertical tail configurations.

View of model in the 9' x 7' low speed wind tunnel showing 'taileron' and fairing, with fin in 'position 1', whilst staff members record data through the viewing window.



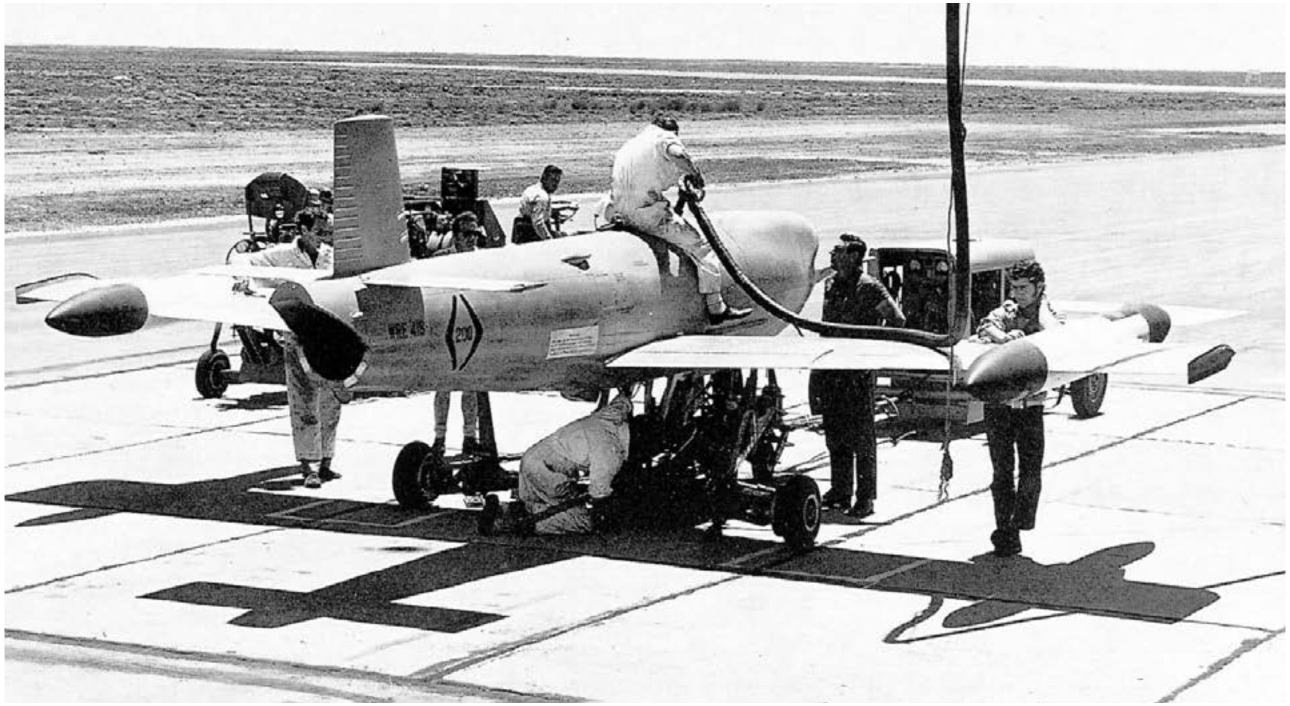
2/7th scale Jindivik wind tunnel model with Mk 3 pods and wing tip extensions undergoes testing in the 9’ x 7’ low speed wind tunnel, 1957.

ARL undertook performance evaluations of the Mk 2 Jindivik, A92-60 on behalf of the RAAF, with a particular focus on the NACA submerged-type engine air intake. Woomera, circa 1958.

A quarter scale Jindivik model with Mk 7 wingtip fuel pods being prepared for testing in the low speed wind tunnel at Fishermans Bend, 1965.

Jindivik Mk 3B WRE-602 undergoing ground vibration testing at Fishermans Bend, around 1970. Measurements of low frequency wing bending and torsion modes were made as the basis for the mathematical model of the aircraft's aeroelastic characteristics when fitted with Mk 7/8 wingtip pods. The inset (top left) shows the vibration module set up on the wingtip pods.

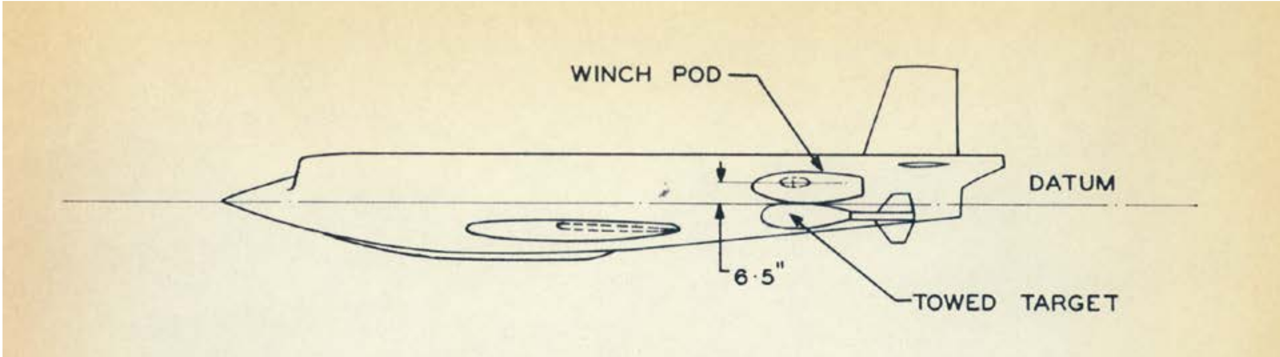
With each new production mark of the Jindivik came improved functionality and reliability. Remarkably, in the later years, one plane (WRE-418) was able to survive an incredible 285 flights over 10 years before being shot down by a Rapier missile in 1974. According to the commanding officer of the trials unit, COL Mike Goodeve-Ballard, feelings ran high when his Rapier proved too good for this battered Jindivik, and he was not quickly forgiven by the target service people who had patched it up and put it back in the air so often. One factor in this excellent performance was the intrinsic durability and resilience of the design. Planes limped home with almost unbelievable amounts of damage after missile strikes.



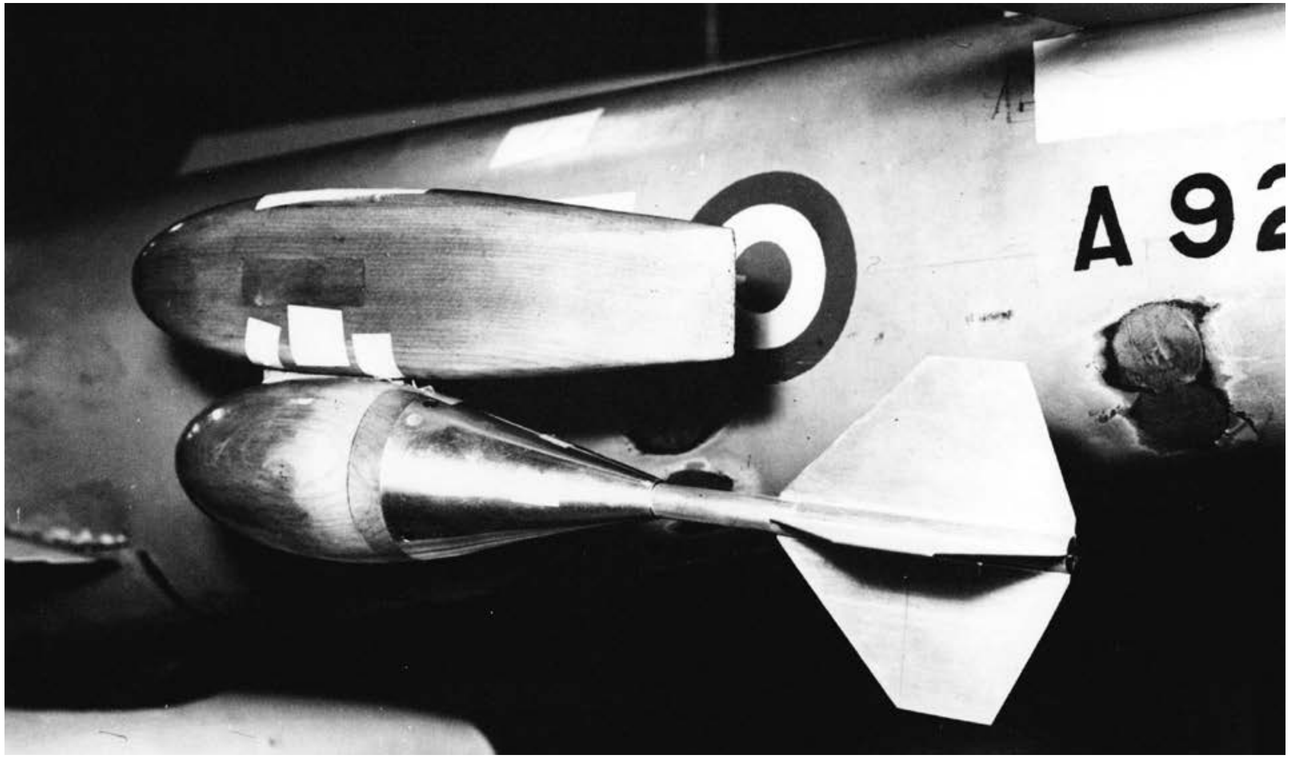
WRE-418, a survivor of 285 flights, being serviced by a Short Bros and Harland crew at Evetts Field. Note the outboard wing extensions on the wingtip pods (more easily discernible by the aircraft's shadow) which were used for high altitude flights. Incredibly, a RAN operated Jindivik at Jervis Bay was noted as eclipsing this record with 324 flights.

Aside from being the primary target itself, one of the developments for the Jindivik was its ability to carry and deploy smaller towed targets on a wire cable that was reeled out. These were developed as it became apparent that shooting Jindiviks out of the sky was an expensive business. Therefore, to economise on Jindiviks, much effort went into designing suitable decoys that could be towed below the plane to provide a cheap and disposable target which the missile could actually strike. These concepts were also tested and evaluated in ARL's wind tunnels. WRE developed an effective system called Tonic[2] in which two torpedo like objects were stored under the wings close to the fuselage, from where they could be streamed out and winched in as required. To augment its signature to the missile, each Tonic could carry a radar transponder or reflector for radar-homing missiles or six flares to provide a lure for infra-red homing missiles. If two Tonics were deployed simultaneously it presented the missile with an interesting discrimination problem.

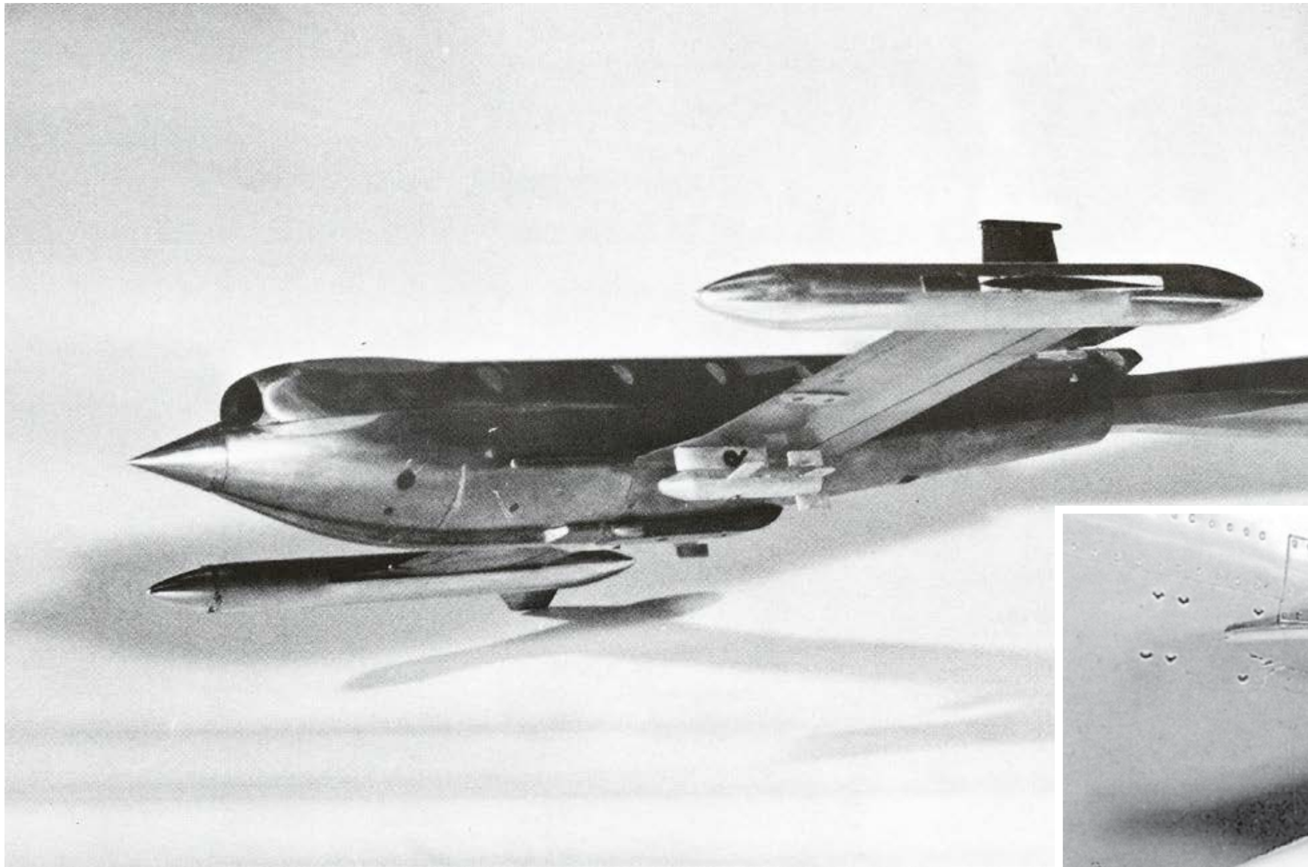
2 Tonic, the name of the towed target deployed from Jindivik, was chosen based on the assumption that ***Jin***divik and ***Tonic*** would 'go well together'.



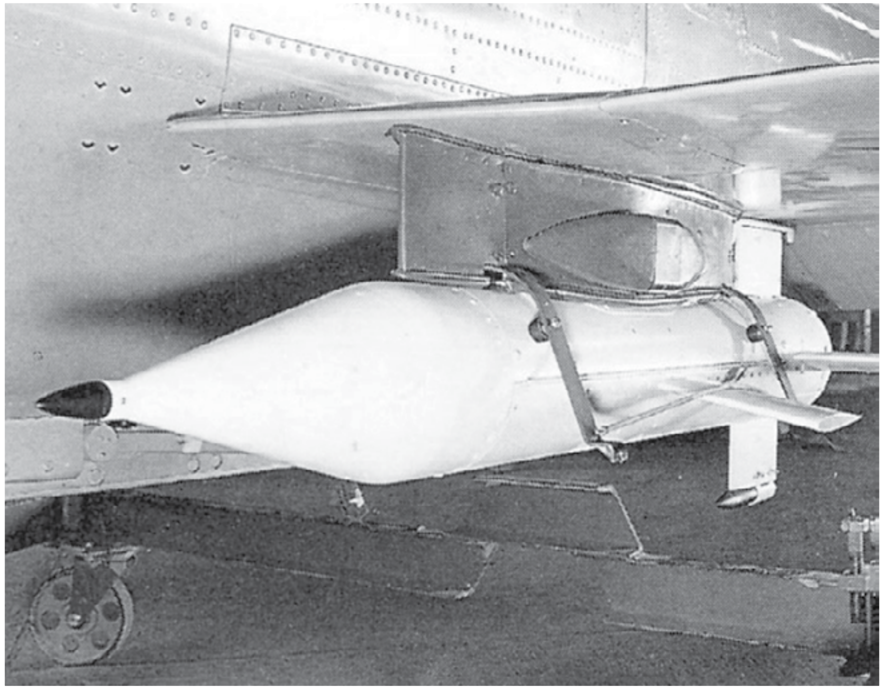
Side projection of 2/7th scale model of Jindivik showing winch pod and an early towed target called 'Ginger' which was mounted on the port side of rear fuselage.



View of model in the 9' x 7' low speed wind tunnel, 1963.

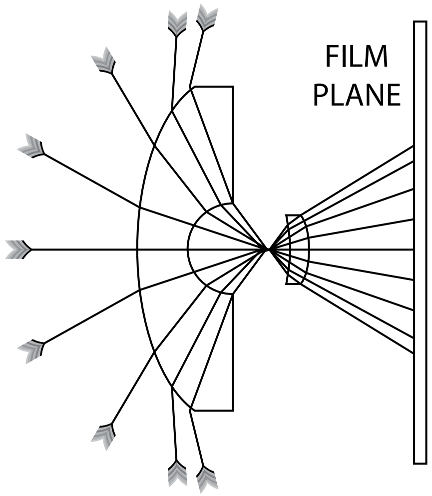


1/20th scale Jindivik model with underwing 'Tonic' towed targets for use in the transonic wind tunnel, 1976.

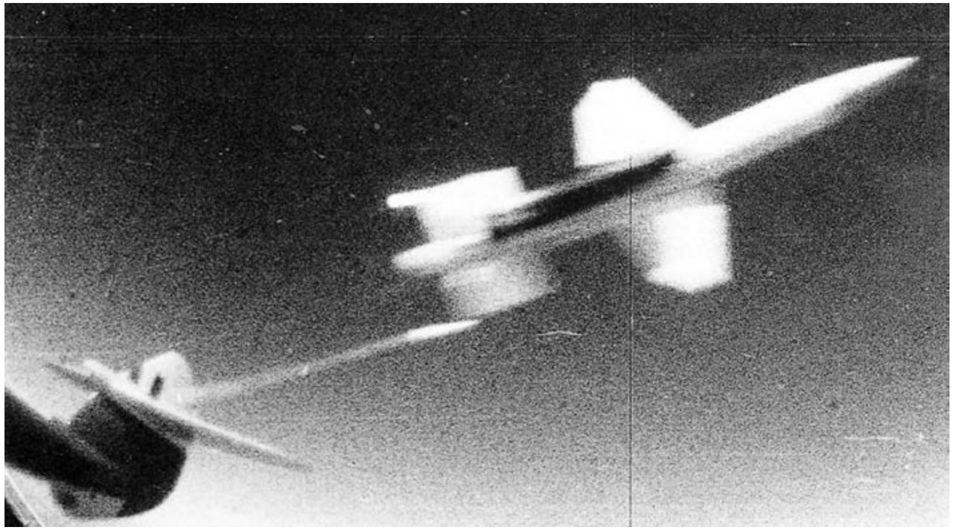


'Tonic' towed target decoy mounted under a Jindivik wing.

Other pioneering work was associated with the Jindivik development. The aircraft carried the Weapons Research Establishment Target Recorder (WRETAR) cameras with fish-eye lenses to gather information about missile behaviour. WRETAR was one of a series of cameras designed and made at this time by engineers at WRE for use in the target trials. This made it possible to use two cameras in each wing pod where previously a RAE-designed four camera system was used in order to provide complete spherical coverage of the sky. The WRETAR's fish-eye lens was relatively cheap to produce, which was an important point as each Jindivik was not expected to last more than five sorties. Its special value was that equal radial angles in space in front of the lens gave equal radial distances (measured out from the centre) on the flat film. This naturally distorted the image, especially at the edges, but it was ideal for measuring angles, which was the whole purpose of the lens.



Graphic illustrating the 186-degree field of view of the WRE ultra-wide-angle lens.



Although not mounted on a Jindivik, this frame from a WRETAR camera on a Meteor target aircraft captures the moment of interception by a Red Duster anti-aircraft missile during an acceptance trial in 1958. This encounter was close enough to damage the Meteor target.


U.S. AIR FORCE
SOUTHERN CROSS II
882005

Global Hawk demonstration 2001

On 23 April 2001, a United States Air Force (USAF) Global Hawk touched down at RAAF Edinburgh, SA, after a non-stop flight of over 23 hours across the pacific from the US. This was the first time any Uncrewed Aerial System (UAS) had crossed the Pacific Ocean and the aircraft was christened 'Southern Cross II'.

The Global Hawk visited Australia for a DSTO demonstration trial of the vehicle and its intelligence, surveillance and reconnaissance (ISR) sensors, communications and analysis systems. This trial would provide DSTO with the necessary data to advise the RAAF and the Australian Government on acquiring and using these systems for the maritime surveillance role. Over six weeks the aircraft flew 11 surveillance missions out of RAAF Edinburgh over the coast of Australia, ranging from a large section of northern Western Australia to the Torres Strait and much of the eastern seaboard.

An important part of the trial was evaluation of DSTO's modifications to the Global Hawk sensor systems. The Australian deployment of the Global Hawk was the culmination of two years' collaboration between the United States and Australia that included software modifications to the radar and electro-optical and infrared sensors, system control with a focus on support to maritime surveillance. Radar scientists from DSTO also added new modes for broad-area maritime surveillance and single-pass target classification over ocean and coastal areas.

The USAF Global Hawk UAV which flew for over 23 hours across the pacific from the US to Australia.

A Ku band satellite communications dish was installed at RAAF Edinburgh for in-flight adjustments to the carefully prepared Global Hawk flight plans as well as to receive radar and camera data from thousands of kilometres away.

Heron detachment to Operation Slipper

Between 2010 and 2017, the RAAF 5FLT operated five leased Heron Remotely Piloted Aerial Systems in an ISR and communications role. For the first five years the Heron was operated from Kandahar airbase in Afghanistan as an urgent response to protect Australian troops engaged in Operation Slipper from improvised explosive devices (IEDs) and ambushes. As part of that urgent operational response, a DSTO physicist (Merrilyn Fiebig), who was in Afghanistan on the way to Tarin Kowt to assist the Australian Army with their Scan Eagle UAV video systems, was quickly diverted to assist RAAF 5FLT at Kandahar airbase. Merrilyn was able to identify and resolve the technical difficulties preventing dissemination and full use of the live motion video to ground forces and headquarters and was credited with helping 5FLT meet their operational target date.

In 2009 Merrilyn Fiebig (far right) of DSTO advises the Commander of the Heron Detachment at Kandahar air base, WGCDR Jason Gamlin and SQNLDR John Porter (left to right) on the modifications to video transmission and processing systems aboard one of five leased Heron UAS.

Maritime UAS: MQ-4C Triton

Following the success of the Global Hawk UAV maritime patrol trials mentioned earlier, RAAF began a new project to explore the possibility of acquiring a fleet of similar aircraft to complement the Poseidon P-8A fleet. In 2006, Defence entered an agreement with United States Navy (USN) to develop an operational capability for broad area maritime surveillance. As part of this arrangement, nine DSTO staff and several RAAF members travelled to the USA in 2007 to join the USN team evaluating the competing industry proposals. The DSTO and RAAF participants also assessed the proposals against the RAAF's requirements and advised the Australian project office on the strengths and weaknesses of the option eventually selected – the Northrop Grumman Triton. Two DSTO members and one RAAF member remained embedded as cooperative program personnel within the USN Triton program office.

After a pause, the project proceeded in 2013, to develop a proposal for the Australian Government's approval of a Triton fleet acquisition for the RAAF. A large team of DSTO specialists set about further exploring the technical risks associated with Triton development and the many aspects of operating this unique platform in the Australian environment, ranging from anti-collision sensors required to facilitate airspace access to the effects of lightning strikes and hangar air conditioning.

Other novel considerations included the sensor system challenges of conducting maritime surveillance from higher altitudes, and the satellite communications requirements to support effective remote surveillance. The Australian Government's approval of the first Triton purchase was achieved in 2018 and DSTG has continued to work on reducing the technical risks to the project, and refining the concepts for how RAAF will use this unprecedented capability. DSTG members embedded with USN continue to contribute to the cooperative Australian/US development of the Triton capability, and the roadmap for its future improvement.

USAF RQ-4B Global Hawk Block 30 flies into Avalon Airshow 2015.

A mock-up of the MQ-4C Triton was exhibited in Blamey Square Russell Offices in 2014 by Northrop Grumman in advance of the Defence and Government decisions to acquire six Tritons under AIR 7000 Phase 1B.

Triton in service will represent a substantial increase in ADF capability for ISR across a large fraction of the world's surface, encompassing much of the Indo-Pacific region. As mentioned previously, DSTO contributed new radar modes to the Global Hawk maritime surveillance demonstration in 2001 and collaboration on sensor development has developed since then.

From 2016 Boeing Australia and the RAAF have been developing the Loyal Wingman, and in February 2021 the first flight took place at Woomera, South Australia.

Boeing Airpower Teaming System

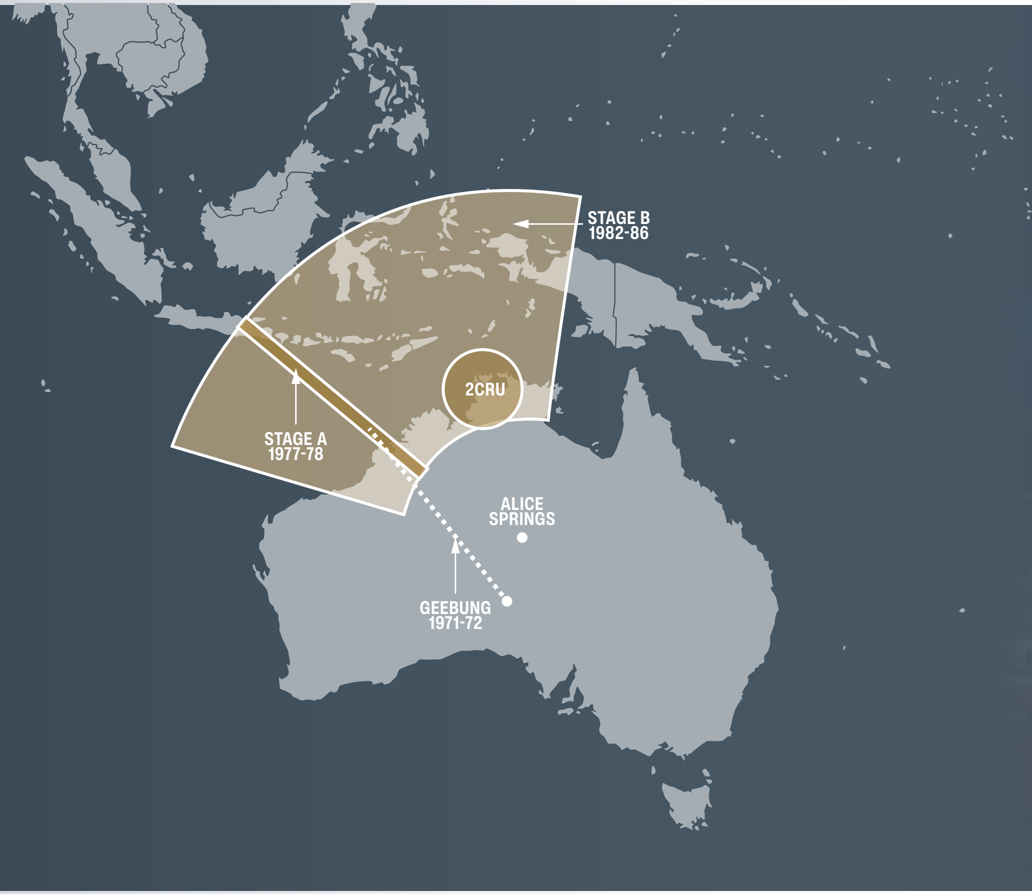
The Boeing Airpower Teaming System (ATS) refers to a single, or group of, semi-autonomous UAS serving other crewed aircraft, such as fighters or AEW&C, as a 'loyal wingman'. The ATS vehicle itself is a conventional take-off and landing, transonic, single-engine aircraft. Under Project DEF6014, Boeing Defence Australia, Australian industry partners and the Commonwealth of Australia worked together to design, manufacture and test the Boeing ATS. DSTG contributed a range of specialist high-technology advice and testing to assist with the development of the Boeing ATS. The project was co-funded by Defence and Boeing Defence Australia.

Low Speed Wind Tunnel (LSWT) model of the Boeing ATS in the tunnel at DSTG Fishermans Bend in 2017

For the RAAF, the ATS program represented a pathfinder for the integration of autonomous and artificial intelligence systems into the air force in order to create a human-machine team. In the development of the vehicle, aerodynamic data from testing in both the low-speed and transonic wind tunnels at DSTG Fishermans Bend assisted in the design for stability and tuning the control system. Natural frequency and damping data for the airframe was provided from ground vibration testing performed by DSTG to ensure flight testing for envelope expansion could be conducted with confidence. An investigation of nose wheel shimmy using DSTG mechanical testing machines resulted in a slight redesign to ensure take-offs and landings were uneventful. Assistance was also provided with mission planning software for the autopilot. DSTG also played a key role in the characterisation and selection of the vehicle's airframe coatings. DSTG continues to contribute to this significant Defence program.

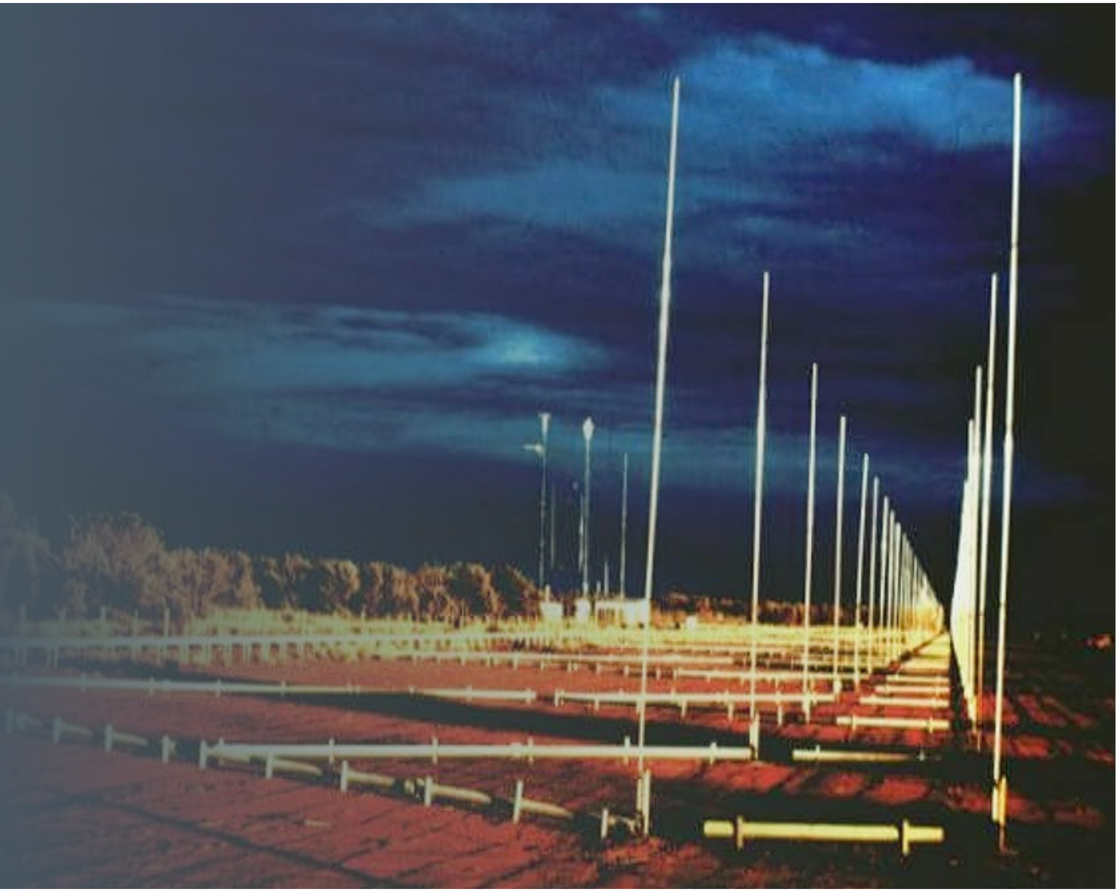
Scale model of the Boeing ATS located in the transonic wind tunnel at DSTG Fishermans Bend in 2017.

Surveillance & Control



Location of facilities involved in Australia's OTHR capability.

The Jindalee Operational Radar Network (JORN) and the Wedgetail E-7A Airborne Early Warning and Control (AEW&C) represent effective modern surveillance and control capabilities that are the result of decades of dedicated pursuit of ambitious scientific and technical goals. As we marked 100 years of the RAAF both capabilities were fully operational and at the centre of three Defence and RAAF strategies: information warfare dominance, network centric warfare and airpower, and delivering joint effects into the battlespace. This chapter covers highpoints of the DSTG involvement in delivering these capabilities to support the RAAF, starting with JORN.

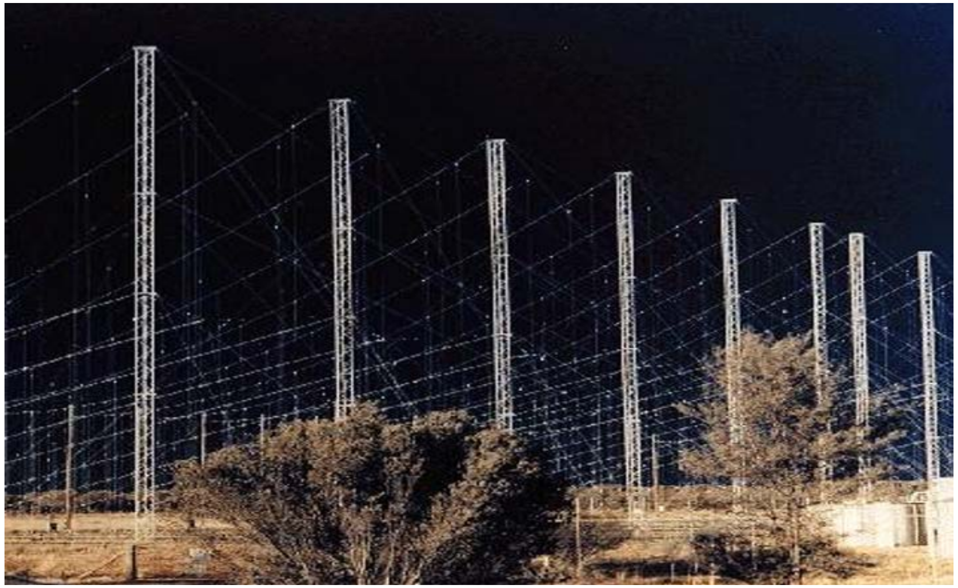


Jindalee Stage A receiver array near Alice Springs produced several narrow beams centred on the A76 international air route.

Project Jindalee to JORN

The past 70 years has seen over-the-horizon radar (OTHR) technology develop from an initial concept to a potent operational capability. Experiments were conducted initially in 1952, then from 1957 WRE used the techniques to track rockets launched from Woomera as part of the Anglo-Australian Joint Project. The first prototype system was successfully trialled during Project Geebung in 1971 and 1972 and WRE became part of the DSTO in 1974.

Project Jindalee was approved as two stages by Defence in 1974. Stage A trialled an emitter and receiver array for a narrow sector, while Stage B covered a wide sector and became the initial operational facility in 1982. The remote transmitter site, located 100 km north-east of Alice Springs, was operated by a single WRE technician who lived on site. The receiver site was operated by four WRE staff who lived in Alice Springs. Although not part of the original plan, an initial ship detection trial in December 1977 demonstrated that it was possible to detect ships off the north-west coast.



Jindalee Stage B transmit array that was still in operation in 2021.

The Stage A program was a great success. A small Australian team with a small budget had managed to build, deploy and operate a significant OTHR capability and demonstrate that the ionosphere over north-west Australia was suitable for supporting OTHR as a real-time surveillance capability.

The Stage B radar was a substantially more ambitious system that demonstrated operational capabilities including automatic tracking while scanning over at least a 60° sector. The radar was designed and built entirely within WRE, but operation and maintenance was contracted to Amalgamated Wireless Australasia.

Development commenced in February 1979 and by April 1982 a 'minimum system' configuration was deployed, a non-scanning radar with basic processing and display. Enhancements followed in rapid order with selectable surveillance regions, ship detection, helicopter classification, dual frequency capability, an automated tracking system and automated radar management system introduced over the next two years.

From 1984 to 1986, seven Joint Service Evaluation Trials were conducted to evaluate the radar's detection and tracking performance. RAAF technicians operated the radar for the first time and various RAAF and RAN platforms were used as targets. Significant enhancements to radar and frequency management system functionality continued to be made during this period.

The Jindalee Stage B receive array is 2.8 km long with 924 fan antennas and a copper mesh ground screen to enhance performance at low elevation angles.

Following these technical successes, the 1987 Defence White Paper committed to building JORN, including two new radar installations, at Longreach (Queensland) and Laverton (Western Australia), and a control centre, transferring operation of the radars from DSTO to Defence units.

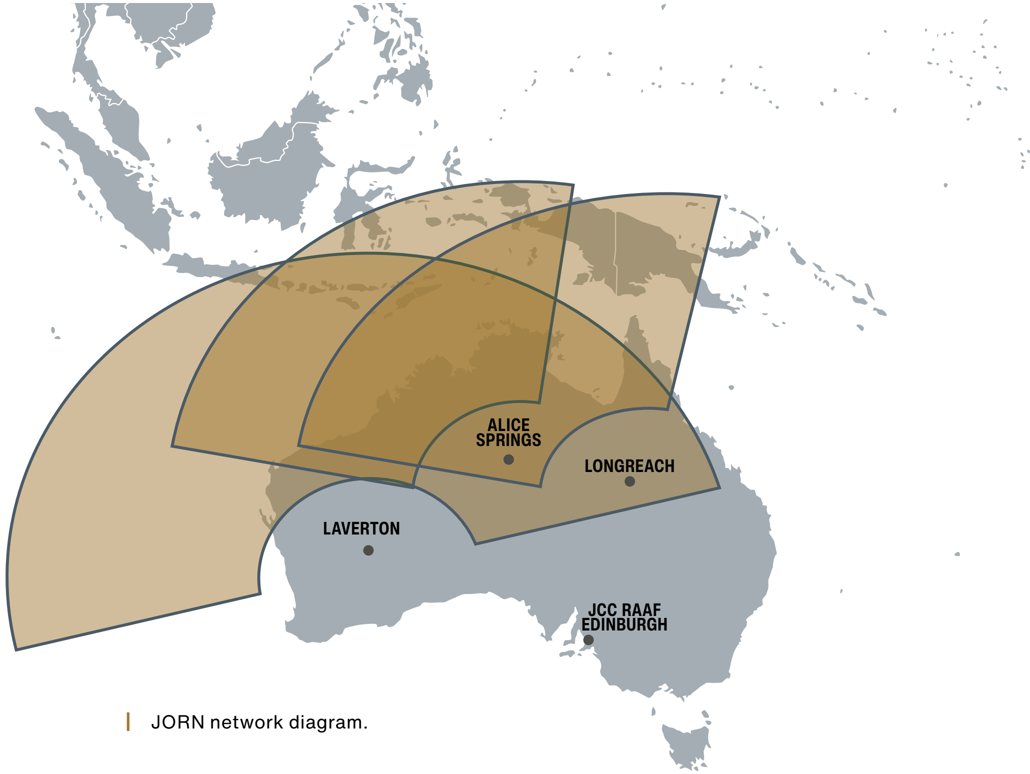
On 1 January 1993 the early JORN was transferred to the RAAF with the establishment of No 1 Radar Surveillance Unit (1RSU). The capability of the radar was further enhanced through a series of DSTO-developed software and hardware upgrades.

(Above) RAN and RAAF personnel in the JORN operations room in the early 1990s.

(Left) F/A-18 Hornets flew a low pass over the receive array en-route from Williamtown to Darwin for a radar evaluation trial.

The Laverton transmit site used two orthogonal transmit antennas with a single set of transmitters that could be rapidly switched from one array to the other, while the Longreach radar used a single set of antennas.

Laverton transmit array from the air.



JORN network diagram.

The JORN comprised two radar sites near Longreach and Laverton operated remotely at RAAF Edinburgh, South Australia, while the Alice Springs site in the Northern Territory remained mainly for research and development.

The Laverton transmit site used two orthogonal transmit antennas with a single set of transmitters that could be rapidly switched from one array to the other, while the Longreach radar used a single set of antennas.

The receive array uses fat monopoles to improve performance across the high frequency band and to reduce the effect of wind induced motion on the received signals.

The Laverton orthogonal receive arrays.

RAAF Edinburgh JORN operations room.

CPL Andrew Gleave in the JCC control room at RAAF Edinburgh in 2020.

Under the current upgrade project, DSTG remains intimately involved in cutting-edge research and transitioning innovations into a highly cost effective surveillance and control capability, well ahead of the rest of the world in OTHR.

An experimental array installed at the Laverton site.

Strong partnerships continue with the RAAF, the industry team of BAE Systems and Lockheed Martin Australia, and the US Department of Defense on advancing the OTHR capability for surveillance and control.

The presentation of the 2010 Minister's Achievement Award to Dr Gordon Frazer (second from right) was attended by (left to right) US Ambassador Jeffrey Bleich, Secretary of Defence Ian Watt, and Minister for Defence Personnel, Materiel & Science Greg Combet and CDF AM Angus Houston (far right).

The DSTO Jindalee team was awarded the CSIRO Medal for Scientific achievement in 1989. Since the awards began in 1988, three DSTG staff have received the Minister's Achievement Award for Outstanding Scientific Contribution to Defence for their work on the Jindalee project, or later the JORN: Dr Fred Earl 1989, Dr Stuart Anderson 1992 and Dr Gordon Frazer 2009.

Wedgetail – the world's premier airborne early warning & control capability

By 2021 the Wedgetail E-7A had become the world's leading airborne early warning and control (AEW&C) capability and a centre piece of the ADF network centric warfare strategy. Developed almost solely based on Australian requirements with a strong and knowledgeable customer voice from the RAAF, CASG and DSTG, the E-7A was subsequently acquired by Turkey, South Korea and the UK, with the US making initial moves in 2021 to acquire Wedgetail to replace their venerable E-3 Sentry.

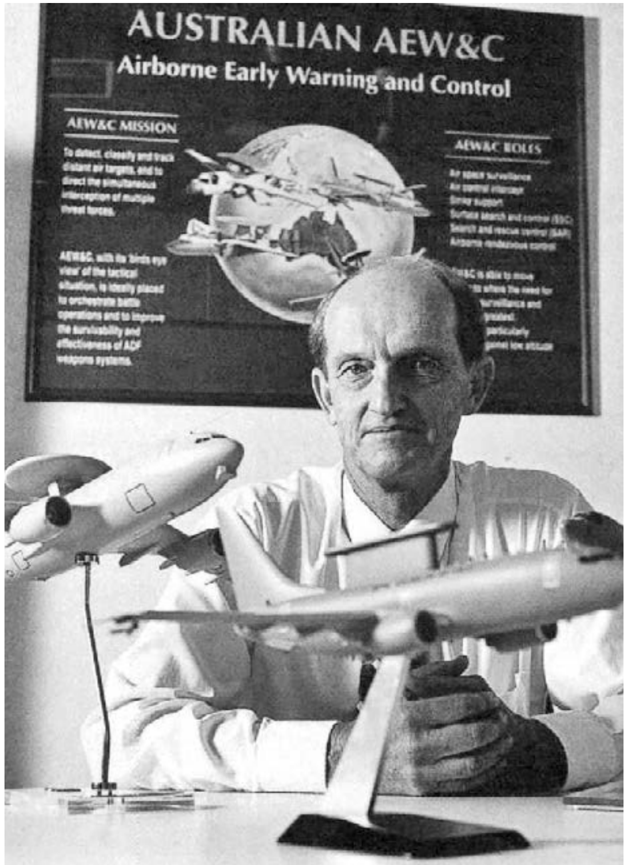
Realisation of the Wedgetail capability relied heavily on the impact of DSTG science and engineering and the close relationships DSTG built up with the RAAF, CASG, Boeing Defense,

RAAF E-7A Wedgetail from 2SQN taking off from Eielson AFB during Red Flag Alaska 21-3.

Northrop Grumman, BAE Systems, and many other partners over many years. The primary purpose of this new capability was to augment the JORN in improving surveillance to the north of Australia, but network centric warfare in any theatre was increasingly important.

Wedgetail proved itself in the Middle East Area of Operations since deployment in 2014 as part of OP OKRA. In May 2015 the Wedgetail capability was declared fully operational, marking a major milestone in the development process. In April 2016, the sole E-7A deployed to the Middle East theatre achieved a 100% mission success rate, flying 36 sorties of 12 to 17 hours duration in command of all coalition aircraft over the battlefield as became routine.

A RAAF E-7A Wedgetail from 2SQN approaches to land in front of a flight of F-35As during Exercise Red Flag Alaska 2021-3 held at Eielson AFB from 12 to 27 Aug 2021. The exercise saw the Wedgetail participate with RAAF F-35A Lightning and F/A-18G Growler aircraft.



Dr Alan Duus was the AEW&C project officer in DSTO for most of the 1990s.

Operations analysis

The work that led to the development of the Wedgetail began in 1994, when Defence requested DSTO to evaluate possible solutions to address a gap in Defence's surveillance capability. DSTO experts were involved across the areas of operational analysis, weapons, aircraft performance, radar, communications, self-protection and human factors. After conducting extensive operations analysis across multiple scenarios, DSTO's recommendation was that AEW&C was the most effective means to address the surveillance capability gap.

Following the recommendations, DSTO undertook further operations analysis in the form of simulations with more detailed scenarios, and in-depth studies of the available technology to define the capabilities the acquisition aspired to attain. This information guided a Request for Proposal that was issued to Defence suppliers in 1996.

The Defence Materiel Organisation (DMO), DSTO and RAAF jointly evaluated supplier responses, with Boeing, Lockheed-Martin and Raytheon E-Systems awarded Initial Design Activity contracts in 1998.

To assess the Initial Design Activity submissions, DSTG again used operations analysis simulations in which the three AEW&C options were tested against enemy fighters and future threats. The simulation outcomes were made available to the Defence Committees as a video of radar tracks, showing that the poorer performing AEW&Cs were neutralised due to their inability to detect attackers at sufficient range or to apply measures to defeat attacks. This demonstration technique, newly developed by DSTG, dramatically illustrated which was the optimal option – the proposal by Boeing.

Declared as the preferred option in 1999, the Boeing AEW&C solution consisted of a 737-700NG aircraft fitted with a multi-role electronically scanned array (MESA) radar and 10 operator consoles. This option was chosen to ensure Australia would get a capability custom-made for its needs and the most advanced radar technology.

The development phase

DSTG support for the project now focused on further clarifying and detailing Defence needs, considering the impacts of Boeing design decisions and performing research on crewing, tactics and procedures that would inform the development process early on and the test and evaluation (T&E) phases to follow.

A key part of this support was provided by DSTO staff embedded in the Resident Project Team located in the United States. DSTG staff worked alongside their DMO and RAAF colleagues and contributed significant expertise in the areas of radar, multi-sensor integration, mission systems integration, communications, human factors and tactical data links. From January 2000 to December 2012, a total of 21 DSTO staff, up to 6 at a time, worked in Seattle (with Boeing Defence) and Baltimore (Northrop Grumman Electronic Systems Division).

Inevitably with a high-tech project like Wedgetail – a capability new to Australia and a first-of-type worldwide – some risks materialised that led to delivery delays and cost overruns. By 2005, Wedgetail had entered the T&E stage, but the first two AEW&Cs were not accepted into RAAF service in Australia until May 2010 due to various performance deficiencies.

DSTO proposed a number of achievable solutions, often delivering very cost-effective outcomes. DSTO's technical support, moreover, vitally assisted Project Wedgetail's managers by providing them with a means to gauge whether technical and performance requirements were being met. The Resident Project Team advisors, by applying project management skills, were also instrumental in negotiating some responsibility demarcation impasses that arose between contractors.

The areas in which DSTO provided the most significant technical support to the RAAF included:

Radar

The primary sensor of an E-7A is the Northrop Grumman L-band MESA radar above the rear fuselage, including the 'Top Hat' array. The MESA radar provides air-to-air coverage, air-to-surface coverage, integrated Identification Friend or Foe (IFF), special track beams and focused sector operation. Wedgetail was the first application of this type of radar system.

The initial under-performance of Wedgetail's MESA radar during development was a major concern. A collaborative study between DSTO, MIT Lincoln Laboratories, and Northrop Grumman found that radar deficiencies could be remediated, and a large number of remediation options were developed. This highly successful study resulted in significant capability enhancements.

Mission computing

In 1996 DSTO established a Mission Systems Research Centre at Edinburgh, South Australia, to study aircraft mission systems and research ways of achieving desired mission performance. Using hardware and software from Boeing and operational software loads when they became available, the Wedgetail representation in this facility was called the AEW&C Mission Systems Testbed (MST). The MST was credited with major advances in improving system performance, troubleshooting problems, reducing costs and training operators and scientists alike. From about 2011 the MST changed name to the Wedgetail Integration Research Environment (WIRE), continuing with the same research role.

Based in the AEW&C MST at DSTO Edinburgh, 'Net Warrior' experiments in network centric warfare were used to explore new way for disparate systems to better share information.

Networks & datalinks

With Wedgetail required to source information from and supply it to many types of assets in the ADF as well as those of coalition partners, an ability to interoperate with many different systems was essential to deliver joint effects. Wedgetail's capabilities for tactical information exchange through data links were found to be deficient, and DSTO advice on implementing data links to particular standards was critical for resolving these issues.

Supported by the AEW&C System Program Office and Boeing, from early 2006 several divisions of DSTO with separate 'battlelabs' producing simulation models of various aspects of weapon systems began a series of collaborative experimentation exercises called Net Warrior, run across the internal DSTO network. Through Net Warrior, technological and systems issues that were multidisciplinary in nature were investigated, such as platform connectivity, mission system integration, multi sensor integration, weapon system integration and human system integration. The AEW&C MST was one of the essential nodes of this network.

Tactics development & training systems

From July 2002, DSTG undertook a series of human-in-the-loop experiments, called Exercise Armchair Warrior. Aircrew (pilots and Air Warfare Officers) from RAAF's 2SQN were stationed at representative consoles in a laboratory and completed virtual missions to develop and test tactics and procedures. The AEW&C MST at DSTO Edinburgh was initially the key node in these linked experiments, but in 2004 the Armchair Warrior 4 exercise was conducted at the 2SQN headquarters at RAAF Williamtown. This exercise used deployed computing resources and the Wedgetail Capability Modelling Environment developed under contract to the AEW&C Systems Program Office by KESEM International in partnership with DSTO.

In conjunction with the 2005 Avalon Airshow, CAF AM Angus Houston hosted the chiefs of 16 air forces to witness 2SQN operators and DSTO analysts engaged in Exercise Armchair Warrior at DSTO Fishermans Bend.

RAAF and DSTO participants prepare to participate in Armchair Warrior 4 during 2004 at 2SQN HQ RAAF Williamtown.

Distributed Training Centre leads the way

The Distributed Training Centre (DTC), inextricably linked with delivery of Wedgetail operational capability, represents a major contribution by DSTG in terms of the impact on improving RAAF capability. Originally known as the Joint Air Warfare Battle Laboratory (JAWBL), the DTC is having pervasive, synergistic effects across ADF air warfare capabilities. By enabling a wide variety of combat elements to take part in shared mission rehearsals using the full suite of advanced tactics and techniques, this capability represents a significant step towards the vision of 'Red Flag every Friday'.

Since 2016 the DTC at RAAF Williamtown has been used to train and prepare crews for participation in major exercises such as Exercise Pitch Black (Ex PB) using distributed simulation. Distributed simulation means all players take part in the same mission and scenario, regardless of the physical location of their simulator.

The foundations for the establishment of the DTC were laid during the Black Skies series of research exercises, conducted by DSTG every 2 years from 2008. Exercise Black Skies (EBS) saw both ground-based (Air Defence Ground Environment) and airborne (Wedgetail) Air Battle Managers (ABMs) and F/A-18 pilots visit DSTG Fishermans Bend to participate in linked simulations a few days or weeks before they participated in Ex PB. Comparisons of the performance during the live exercises of those who had participated in EBS against those that did not, demonstrated clear and repeatable benefits of the prior synthetic training experience.

EBS 2012 was the first time the Air Defence Ground Environment and the Wedgetail Integrated Research Environment (WIRE) were linked in a virtual exercise with operators in the loop, further enhancing the networking and training realism. This system was later transitioned to become the Virtual Wedgetail simulator at RAAF Williamtown.

EBS 2016 marked the initial operational demonstration exercise for the JAWBL. In 2017, the facility was renamed the DTC and it achieved full operational capacity by hosting Exercise Diamond Thunder for the inaugural Air Warfare Instructor Course (AWIC).

Lessons learnt from those and other linked simulation activities enabled DSTG and the RAAF to join Exercise Coalition Virtual Flag (Ex CVF) from 2012 using DSTG simulation facilities. This is now a regular occurrence in the DTC, with RAAF pilots and ABMs flying missions replicating Ex Red Flag, linked with simulators from the US, UK and Canada on a regular basis.

Future upgrades

DSTG continues to support the evolution of the Wedgetail capability with ongoing research that will lead to improvements in current system performance and the establishment of proof-of-concepts for future implementations. The AEW&C capability was always recognised as requiring continual upgrade on a wide range of refresh cycle times to meet evolving threats and use new technologies. Many scientific and technical driven activities have increased in scale and frequency and are planned to continue for the foreseeable future as a partnership between DSTG, RAAF, CASG and industry partners.

Ground, ship and air combat controllers prepare to participate in Exercise Black Skies 2016 at the Joint Air Warfare Battle Lab, RAAF Williamtown. The facility and the exercise were designed and monitored by DSTG, then built and supported by a range of contractor staff.

A RAAF Air battle manager from 2SQN participates in Exercise Coalition Virtual Flag 22-1 at the Distributed Training Centre RAAF WIlliamtown in November 2021.

C-130 Hercules

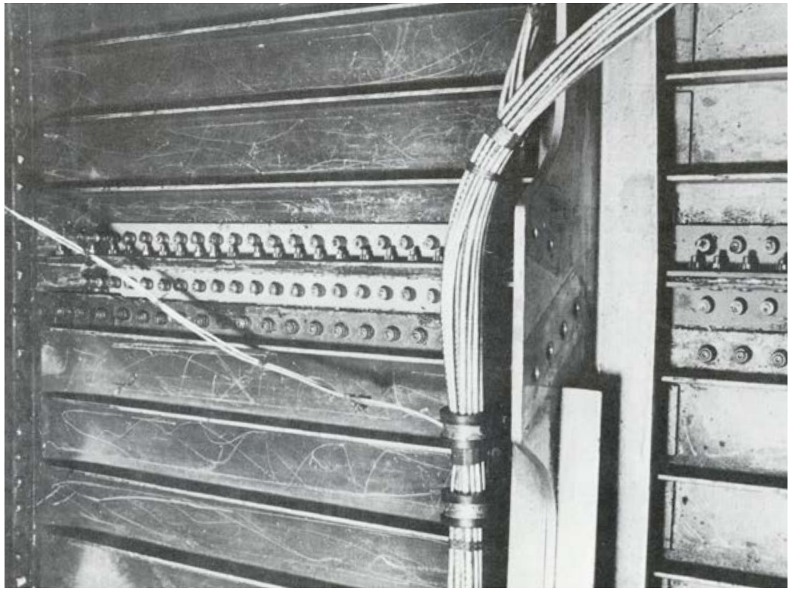
With almost 70 air forces around the world operating the C-130 Hercules, the RAAF has the distinction of being the first air force to adopt the aircraft outside of the US. Furthermore, the Hercules is RAAF's longest serving aircraft type, being flown for over 63 years and 850,000 flying hours.

The RAAF have operated four types of Hercules; the C-130A (1958–1978), C-130E (1966–2000), C-130H (1978–2012) and C-130J-30 (1999–present). The iconic Lockheed design has certainly been enduring, with the same basic form of the aircraft remaining unchanged over the decades. DSTG has consistently provided valuable support to the RAAF fleet of Hercules, addressing a variety of issues and challenges that have allowed the Hercules to continue their important work around the world, as safely and economically as possible. In this section, we cover a few examples of the support provided.

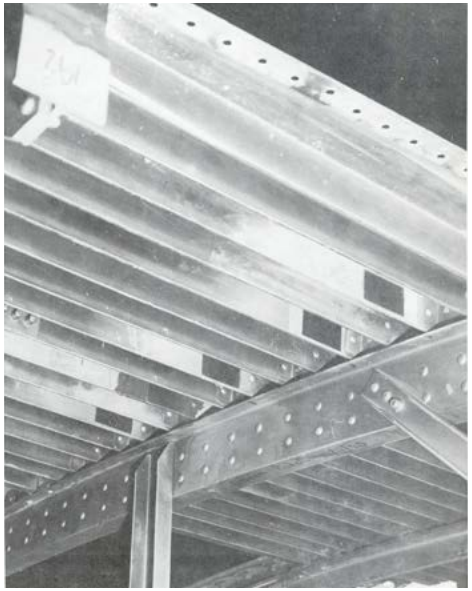
RAAF air movement personnel load a watercraft onto C-130J-30 A97-448 at RAAF Base Amberley in February 2022, as part of Operation Tonga Assist, in response to the devastating volcanic eruption that occurred in the island nation in January 2022.

Crack patching technology for C-130E wings

In the early 1970s, ARL began exploring the use of advanced composites in future RAAF aircraft. To provide confidence in these new aerospace materials, the researchers considered it important to find applications that could be of immediate benefit to RAAF. So when Alan Baker joined ARL in 1972 to lead the composites program, he suggested that creating adhesively bonded composite patches to repair metallic airframe components suffering cracking due to fatigue or stress-corrosion a good demonstration of the technology. This application, called 'crack patching' technology, was subsequently used extensively to repair the C-130E, and other RAAF aircraft including the F-111, Mirage and Macchi.



View looking up at underside of C-130E wing plank showing the standard riveted repair scheme to address stress-corrosion cracking.



View of the boron/epoxy patches bonded over the cracks.

The decision to repair the C-130E using crack patching resulted from discussions with engineering staff at Headquarters Support Command and 2AD at RAAF Base Richmond. They were interested in finding a low risk solution to address stress-corrosion cracking in the C-130E wings, a widespread problem for these aircraft. ARL staff suggested an adhesively bonded repair scheme. The RAAF agreed to trial the technology, which was a significant factor in the adoption and widespread use of the technology across not only their own aircraft, but some USAF aircraft as well.

The stress-corrosion cracking RAAF observed were in the C-130E wing's internal stiffener features, a result of the combined effect of environmental sensitivity and residual stress from rivets used to attach the stiffeners to the wing's internal structure. The original repair method was to rivet metal brackets to the stiffeners, a very time-consuming process that essentially repeated the original problem of cracking by introducing additional rivets – and stress points – that led to more cracking. Some believe that these repairs might have contributed to wing fatigue failures in some early USAF Hercules.

By contrast, the crack patching procedure proposed by ARL was to adhesively bond thin boron/epoxy patches over the cracked regions, which would not produce additional cracking, and seal the sensitive area from the environment. These repairs – over 1000 of them – were applied by RAAF technicians and could be completed in one standard work day, compared with six days for the standard riveted procedure. Headquarters Support Command were responsible for the approval of these repairs in the mid-1970s.

Because of the effectiveness of bonded repairs, the RAAF was the only air force able to operate C-130E aircraft throughout its service life without having to replace the outer wing structure. An Inspector General Program evaluation conducted in 1989 estimated that this repair saved the ADF approximately AUD $10 million, approximately $200 million in today's figures. A few years later in 1994, GPCAPT Noel Schmidt, then Director Technical Airworthiness, recalled presenting at a conference on the repair program.

> *'I recall including the statement that the RAAF C-13OE fleet were the only C-130Es in the world still flying at the time with their original outer wings, while other operators had undertaken wing replacements. This was based on solid evidence from both USAF and Lockheed at the time, hence this statement was not made lightly!'*

GPCAPT Schmidt recalled that this statement attracted some audible gasps and exclamations from the audience which included some senior Defence officials and emphasised the value of the locally developed repairs.

ACM Sir Angus Houston (Retd) also noted,

> *'As OC 86 Wing, I deeply appreciated DST's support in a number of areas. What stands out, however, is the boron-epoxy technology which was applied to C-130E wings to prevent stress-corrosion cracking. This enabled the aircraft life to be extended into the late 1990s.'*

Following the success of crack patching on the C-130E, improved capabilities were developed in all aspects of crack patching technology, including measures to ensure durable adhesive repairs in severe aircraft environments (so much so that the USAF referred to the process as the 'Australian Surface Treatment'), as well as in analytical and finite element design and testing procedures.

C-130J-30 Wing fatigue test program

In 2003, the RAAF and the UK Royal Air Force embarked on a long term collaboration to test the life span (also known as its structural life of type, or SLOT) of the C-130J-30 wings. Understanding the SLOT helps the operator proactively manage the assets as safely and economically as possible throughout their intended service life. This wingtip-to-wingtip structural test program, called the C-130J-30 Hercules Wing Fatigue Test Program, used servo-hydraulic actuators to apply simulated wing loads to a test article in order to assess the structural integrity of the wings under the RAAF's unique operating conditions. This program was managed by Marshall Aerospace and Defence Group (MADG) in Cambridge (UK), supported by embedded RAAF officers from the Directorate General Technical Airworthiness (DGTA) as well as defence scientists from DSTO.

After seven years of applying test loads, on 25 November 2015 the program was successfully concluded, demonstrating structural durability and residual strength over two nominal lifetimes

The C-130J-30 test article wing was a production wing sourced from Lockheed Martin Aero. Shown in the test rig at Marshall Aerospace, a total of 40 servo-hydraulic actuators applied the loads (24 on the wing, 3 per engine and 4 on the fuselage side walls) whilst an airbag was used under the centre wing carry through structure. This durability and damage tolerance test was completed according the requirements of the US military specification JSSG-2006.

of test loading (equivalent to 62,500 flying hours). At the completion of this testing, a period of severe constant amplitude loading was applied to the test article to accelerate the growth of fatigue damage and identify life limiting structure, thus extracting as much useful information from the test as possible. This was successfully achieved a short time later, when multi-site damage in critical structural elements grew to a point that resulted in catastrophic structural failure of the port side wing.

Despite the substantial costs involved in this testing, the return on investment was significant, with a wealth of high quality data developed to inform ongoing structural sustainment and airworthiness of the RAAF fleet in addition to eliminating the requirement for costly centre wing replacements in RAAF service.

Whilst a truly collaborative international program with support from multiple organisations and staff, the program owes a particular debt to those RAAF and DSTG staff who were co-located at MADG over the course of the program. Across the thirteen years (with actual test cycling commencing in 2009), six RAAF engineering officers[1] and seven DSTG scientists[2] were sequentially embedded as pairs within the Royal Air Force Project Office and MADG respectively, with the primary aim of representing Australia in this complex and expensive structural substantiation program. This long-term co-location of RAAF and DSTG staff forged greater levels of innovation, trust, respect and friendship, between the two unique Defence groups, which played out across a backdrop of timeless, cobbled Cambridge University streets and picture postcard vistas of the River Cam.

1 SQNLDR’s Paul Connor, Darren Hahn, Greg Lamb, David Child, Matthew Grinham and Aaron Jozelich.

2 Daniel Franke, Kate Niessen, Robert Ogden, David Hartley, Kai Maxfield, Doug Williams and Ian Poulter.

DSTG’s support to the T56 engine

The RAAF’s C-130E and C-130H were powered by the T56 turboprop engine, which is also used on the P-3 Orion. Production of these engines began in the 1950s and quickly dominated the market, and although most civilian airlines began retiring the engine in the early 1970s, the T56 remains in service in thousands of military aircraft and a few remaining small civil operators. Over 18,000 were produced, and 200 million flying hours accumulated, making it a significantly large fleet in its time. The original manufacturer Allison was bought by Rolls-Royce in 1995 and became known as Rolls-Royce Corporation – US (RRC-US). In 2020 the T56 (with the A-427A engine version) continued to be in production for the USN E-2D Hawkeye.

DSTG’s support to the RAAF on the T56 engine is illustrated by two significant examples, both of which resulted in advice that dramatically changed the RAAF’s response to those engine issues.

Investigation of turbine blade failures on the C-130E T56 engine

Turbine blades operate at the highest temperatures and rotational speeds seen in a gas-turbine engine. These conditions cause materials to undergo phase changes in crystalline structure, producing fatigue cracking, oxidation and creep – a type of metal deformation that occurs usually at elevated temperatures but below the yield strength of a metal. Reliability of these components is crucial to returning safely after each flight. Besides the turbine blades there were several other components in this large turboprop engine requiring intensive airworthiness management to reduce risks to crews, missions and the sustainability of the fleet.

A new turbine blade from a late model T56 engine before undergoing test and inspection by DSTO.

During 1998–1999 there was a significant increase in the number of first stage high pressure turbine blade fatigue failures in the T56 engine used on RAAF C-130E aircraft. Thirteen such failures occurred and always resulted in loss of the turbine, with profound implications to the airworthiness of the aircraft. The failure mechanism initially proposed by RRC-US was that blade airfoils were uncurling as a consequence of metallic creep. The uncurling was claimed to result in a decrease in the blade resonant frequency, making it coincident with an engine vibration order, thus making the blades susceptible to fatigue failure. As a consequence, the initial recommendation was an extensive, and hence expensive, frequency screening program for the blades.

However, DSTO investigated the failures and determined that untwist of the blades actually led to an increase in the blade resonant frequency, moving it away from the engine vibration order. Furthermore, after extensive investigation DSTO identified that an increased turbine inlet temperature had resulted in extension of the blade, resulting in the turbine blade tip rubbing and leading to subsequent fatigue failure. DSTO's proposed failure mechanism was subsequently accepted by RRC-US, who advised T56 operators to reduce the allowable turbine inlet temperature, which stopped the failures from occurring. This solution helped the RAAF avoid the substantial cost of frequency screening all blades in the Hercules and Orion fleets.

T56 International collaborative program: component Spin Rig testing

Just prior to 2001, RRC-US re-analysed some of the original material data and associated material testing of the T56, which resulted in RRC-US dramatically reducing the life spans, or fixed lives, of many safety-critical rotating components within the engine. These reduced lives meant all engine operators around the world needed to replace the engine components quicker than they and the manufacturers expected, creating supply issues, and forcing aircraft operators to ground many aircraft when their engines reached the new lower life limits.

To avoid a lack of serviceable engines, DSTO together with other operators of the T56, including the USN, USAF, Canadian Forces and the National Research Council, CSIR of South Africa, and with RRC-US, began a test program to revalidate new (and hopefully longer) lives for the affected components. Each country performed testing of two or three components, with a couple being done by two countries to enable cross checking to occur.

In 2001 DSTO began testing T56 turbine spacers and disks in a specially designed Spin Rig at Fishermans Bend. Originally developed for the F-111 Sole Operator Program, the Spin Rig is a solid steel cylinder able to spin a production turbine disk and blades at extremely high speeds and temperatures, similar to the conditions in the

The DSTO Spin Rig in 2003 surrounded by members from the international partnership including the RAAF, USN, Canadian Forces, South African Air Force and DSTO. The group was formed to investigate and extend the fatigue life of the T56 engine, particularly its turbine blades, turbine disks and the spacers between disks. DSTO and RAAF personnel include (in alphabetical order) Ross Antoniou, Andrew Brandham, Andrew Cruickshank, Sam Fisher, Jian Hou, Joanna Kappas, Ben Parmington, Paul Parolo, Frank Skidmore, Sonya Slater, Gordon Stocks, Wenyi Wang, Brian Wicks and Wyman Zhuang.

hot-section of a jet turbine engine. This testing was able to verify the safe lives of the disks and spacers and RRC-US accepted these results – the first time they had used the results of spin testing to determine the fatigue life of these particular engine components. These predictions allowed the engines and the fleets to be confidently returned to service without expensive and intrusive upgrades or significant additional inspection maintenance burdens.

C-130J-30 In-flight propeller balancing

The introduction of the C-130J-30 to Australia in 1999 heralded a major change in the avionic capability of the Lockheed Martin Hercules series. Immediately apparent was the 'glass' cockpit, and 2-crew operation. However, underlying these changes was a completely new software system, integrated with the airframe and engines. The engines were also a totally new power plant, the RRC-US AE 2100D3. Along with the new engines was an advanced engine monitoring capability that allowed engine data to be downloaded after each flight to a ground maintenance system. It was this feature that DSTO began investigating in 2002.

Initially the attention of DSTO propulsion staff was focussed on the overall engine monitoring capability. However, it soon became evident that the parameters required for in-flight propeller balancing were also potentially available: vibration and phase data from the integrated sensors. Dynamic propeller balancing is carried out to correct for unwanted vibrations during flight, which can be caused by the slightest imbalances brought about by an engine change or reinstallation, or repair works. The existing procedure to balance propellers was to operate the engines on the ground (ground runs), with wires and equipment temporarily installed. This procedure required at least a full day of ground runs and numerous engine starts. If the engine monitoring data could be used instead to replace this procedure, it could be a significant saving in reduced engine run time, maintenance hours, and negligible data collection set up procedures.

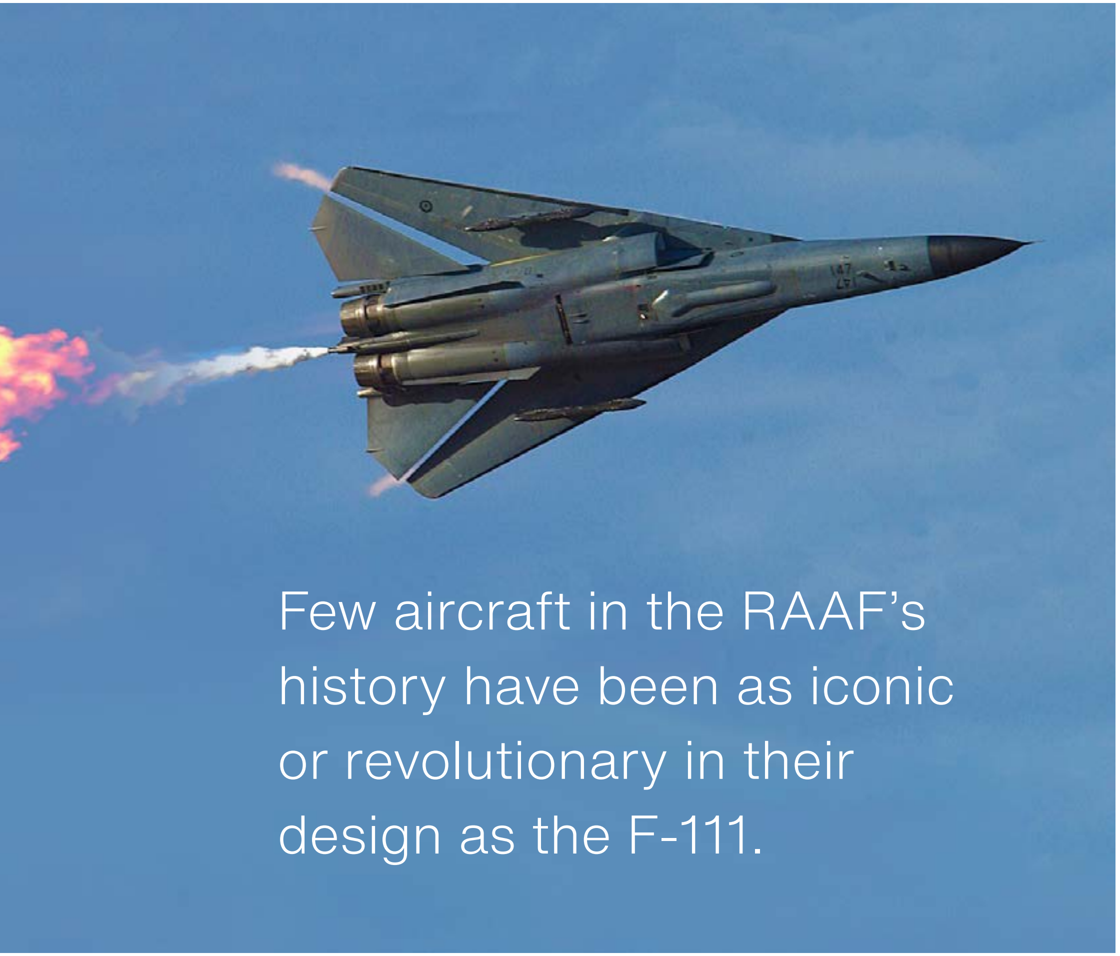
To test the suitability of using the onboard monitoring system for propeller balancing, DSTO carried out several ground runs to look more closely at engine vibration data under controlled conditions, with the support of Air Lift Systems Program Office (ALSPO) and 37SQN. The results of these tests showed that the previously unused sensor data could be used to develop a balance solution. Brian Rebecchi, who was head of the powertrain diagnostics group, acknowledged the support from SQNLDR Vince Chong and SQNLDR Herman Wong from 37SQN was pivotal in getting this project off the ground.

> *'Without their enduring support ... this would never have made it'.*

With the support of the newly formed C-130 Joint Users Group in 2003, DSTO moved forward with this alternative procedure, gaining support from Lockheed Martin Aero for an initial flight trial to be carried out by RAAF (ALSPO), as well as a USN test pilot assigned to Australia to participate. The trial confirmed the success of the procedure, and the RAAF began developing a certified system to be shared with other C-130J-30 users around the world. Further development of the procedure has now been undertaken by Lockheed Martin Aero, and incorporated into their ground maintenance system.

DSTO members Paul Marsden (left), Brian Rebbechi (third from right), and Ken Vaughan (far right) with members of the flight test crew in front of a C-130J-30.

Fighter & Attack Aircraft



> Few aircraft in the RAAF's history have been as iconic or revolutionary in their design as the F-111.

F-111C A8-147 demonstrating the famous 'dump and burn' display.

F-111

Designed in the early 1960s, and affectionately known as the 'pig' in Australia, the F-111 aircraft was manufactured by General Dynamics (GD)[1] throughout the mid to late 1960s and into the early 1970s. The aircraft featured variable sweep pivoting wings, could operate at low level, day or night, in all weather conditions, carrying a large payload over a long range, and was capable of speeds up to Mach 2.5. Some 562 aircraft were produced, covering several different models and two main variants (featuring short and long wings). Australia was the only country other than the USA to operate the F-111, and when the USAF retired their last aircraft in 1998, this left the RAAF as the sole operator. DSTO played a major role in supporting many aspects of the aircraft for over 40 years.

1 Later renamed Lockheed Martin.

DSTO & F-111 structures

On 27 August 1968, a week before the RAAF F-111 acceptance ceremony, a premature failure of the ultra high strength steel wing carry through structure occurred on GD's F-111 full-scale fatigue test article. Delivery plans were put 'on hold' shortly thereafter and all aircraft (RAAF and USAF) were grounded. The RAAF, along with DSTO, were invited by the US to participate in the failure investigation. Back at DSTO Fishermans Bend, an F-111 Scientific Advisory Panel was formed, and for the next three years they advised the RAAF, the Department of Air and Department of Defence on an almost weekly basis on issues with the aircraft.

Then, on 22 December 1969, an F-111A crashed when its port wing separated from the aircraft during a routine training flight. This prompted the delivery of the RAAF F-111s to be suspended indefinitely with the aircraft going into long term storage. The failure came from a pre-existing manufacturing flaw in the wing pivot fitting, the inner part of the wing structure. It became apparent that the existence of small production flaws, the inadequate inspection procedures

RAAF F-111Cs in long term storage at Fort Worth between 1968-1972.

of the time, and the material characteristics of the high strength steel were very real concerns that needed to be addressed urgently. This incident became the motivation for adopting fracture mechanics principles for the first time in managing the structural integrity of an aircraft.

Finally, after the Australian aircraft had undergone extensive structural improvements, passed the necessary inspections and cold proof load testing (CPLT)[2], the first 6 (of 24) aircraft[3] arrived at Amberley on 1 June 1973, over 4 and a half years after the official handover ceremony.

F-111 CPLT – wings shown subjected to 7.33 g force up-loading whilst at a temperature of –40°.

Arrival ceremony for first F-111C aircraft at RAAF Base Amberley, 1973.

2 This novel test was devised to assure structural integrity of locations in the high strength steel that had undetectable critical crack sizes or were inaccessible to inspection via more conventional means. In this test, the entire aircraft was cooled to –40° C in a purpose-built environmental chamber, where the low temperature further reduced the fracture toughness of the steel and hence the critical crack size. Proof loads corresponding to +7.33 g and –2.4 g were then applied with the wings swept at 56° (later CPLTs introduced a second load application at 26° with the negative component increasing to –3.0 g). A successful test (i.e. no failure) confirmed the absence of any flaws above the small critical crack size, and cleared the structure for a further period of safe operations. The CPLT was applied every 2,000 flying hours.

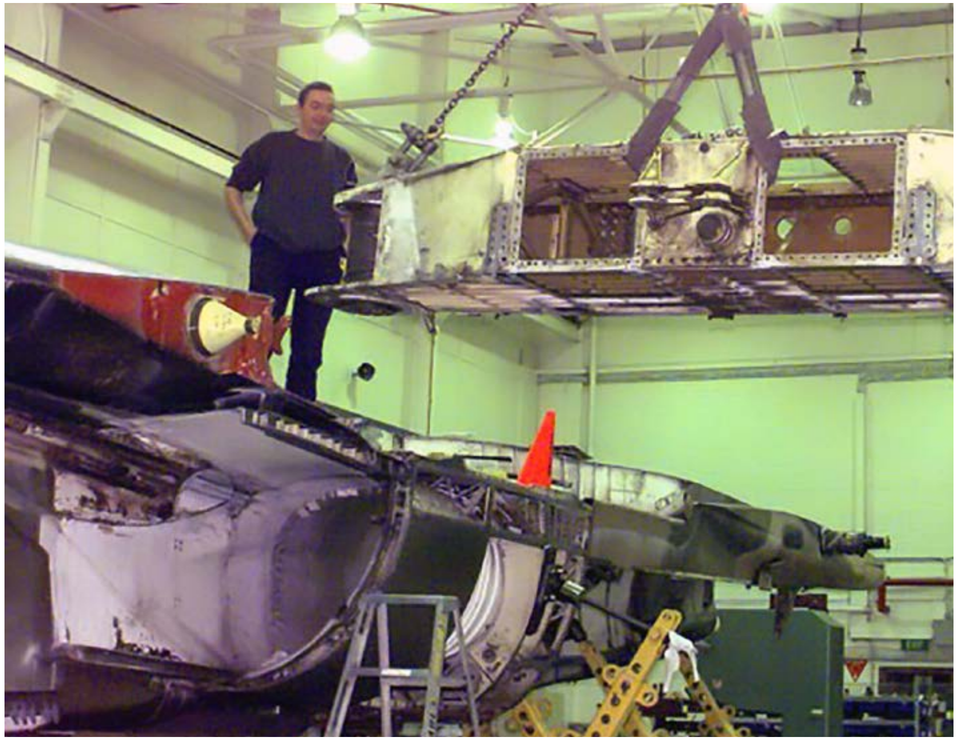
3 The total number introduced into service was 43; this included 4 F-111A (attrition aircraft) and 15 F-111G (only 8 in flying condition; remainder for spares). F-111D and F-111F wing sets were later introduced into the fleet.

The Sole Operator Program

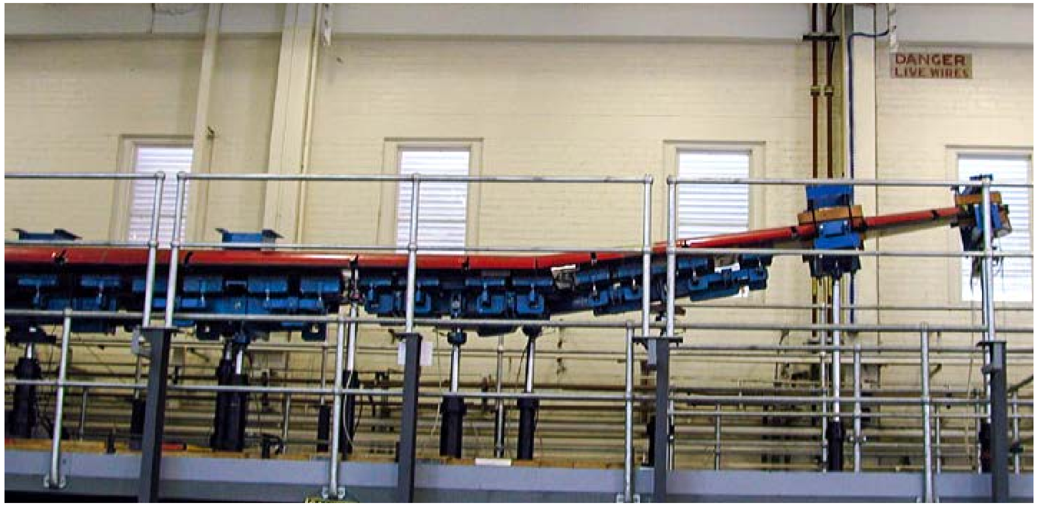
The 1996 USAF decision to retire their F-111 fleet prompted the establishment of the RAAF F-111 Sole Operator Program (SOP). This tripartite program between the RAAF, DSTO and Australian industry through AeroStructures[4] ran from 1997 to 2008, and was responsible for the development and maintenance of an in-country capability needed for the continuing safe operation of the RAAF fleet when support from the US was rapidly diminishing. To facilitate the development of the sovereign capabilities, a technology and information transfer process was instigated whereby DSTO and AeroStructures staff were attached to Lockheed Martin between 1998 and 2000. Other significant structural aspects of the SOP were the fatigue test and teardown of a retired F-111C wing, teardown of an USAF airframe (representative of RAAF), and development of analytical tools and techniques for structural assessments. Without taking this proactive course of action, Australia's ability to continue as the world's only operator of this complex aircraft safely and economically through to 2010 would have been severely challenged.

4 Now QinetiQ

The fuselage teardown article (USAF aircraft 67-106, a veteran of the Vietnam War) en route to Fishermans Bend in 1999.

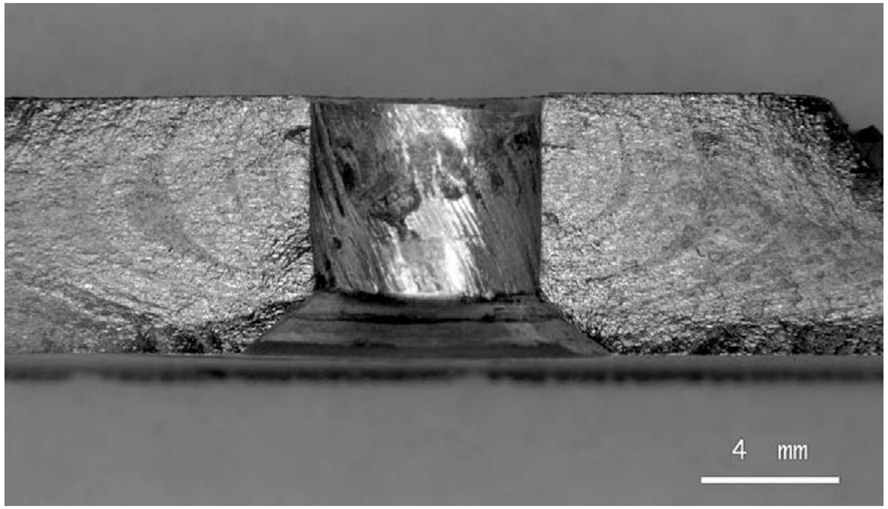


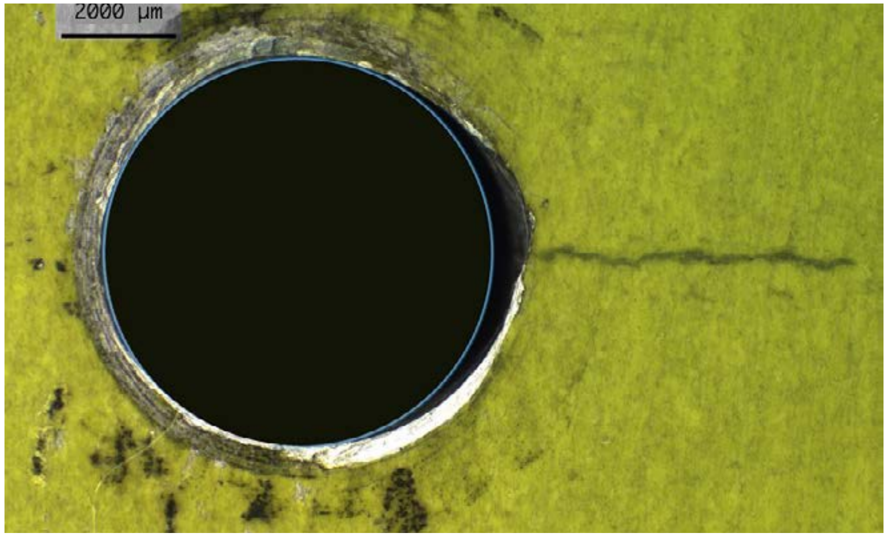
Removal of the wing carry through structure. The teardown concluded that this aircraft was representative of a 30+ year old aircraft in the RAAF fleet, and that it was in relatively good condition considering its age.



(Left) The upwards slanting portion of the outer wing indicates the failure location of the Wing Damage Enhancement Test article at Fishermans Bend, which had been removed from aircraft A8-145.

(Below) Fatigue crack markings on the fracture surface of the hole which caused the failure, and (bottom) an example of one of many other poor build quality holes that were found elsewhere in the wing during the teardown.





Wing damage enhancement test

The main objective of the Wing Damage Enhancement Test was to enhance existing damage in an ex-fleet F-111C wing by applying further representative service loads to it in a test rig. This was done to identify potential structural hotspots before they appeared in the fleet. Testing of a retired RAAF wing commenced in March 2000 and ceased in February 2002 after an unexpected catastrophic failure.

The failure originated from a poorly finished fastener hole, at a location not subject to inspection. The failure investigation revealed the cracking had initiated in service well before testing began. What was more worrying was that other poor quality holes in the wing were also identified. The teardown of the wing highlighted the very real probability that similar quality issues might exist elsewhere within the fleet, creating literally hundreds of candidate sites for fatigue crack initiation.

Following this failure, the Wing Recovery Program was established, which put in place an interim safe life span limit for the wings while investigations continued. However, some wings had already exceeded the imposed limit, resulting in some aircraft being grounded. Outcomes from the Wing Recovery Program had a major impact on the fleet, which including replacing RAAF wings with retired USAF F-111D and F-111F wings[5], the introduction of an automated non-destructive inspection capability[6] and the requirement for additional fatigue testing, known as the F-Wing Economic Life Determination (F-WELD) test. This test's outcomes contributed to the development of a revised certification basis and structural management plan for the ongoing management of the ex-USAF wings for RAAF long wing operations.

The F-WELD test article under high positive g loading at Fishermans Bend. This wing had been removed from USAF aircraft 72-1449 which took part in the Operation El Dorado Canyon air strikes against Libya in 1986.

The SAIC automated non-destructive inspection system was used extensively throughout the F-WELD test and then implemented for fleet inspections at RAAF Base Amberley.

5 Based on their supposed better build quality and generally lower accumulated airframe hours. These wings were also the short version. The RAAF converted them to the long configuration with the addition of wing tip extensions.

6 DSTO staff carried out the formal assessment and procedural development of the Science Applications International Corporation (SAIC) Ultraspec-MP system.

F/A-18A/B Classic Hornet

There is hardly a key aspect of the F/A-18A/B 'Classic' Hornet, and the role of its operators and maintainers, that DSTG has not contributed to; from the initial selection of the aircraft, through to establishing RAAF specific airframe life limits, the various phases of the Project AIR 5376 Hornet Upgrade Program for weapons, systems and structural enhancements, and supporting active deployments.

RAAF Classic Hornet A21-48 shows off its lines, 2010.

DSTG's involvement with the Classic Hornet has also yielded huge financial return on investment when it comes to scientific and technical support for Defence programs. When Defence commissioned its First Principles Review in 2014, DSTO was asked to articulate its 'value proposition'. DSTO commissioned an independent review of the economic value of the scientific and technical program between 2003 and 2015; and of the ten case studies that were selected[7], three involved the Classic Hornet. The aircraft's centre barrel testing, Advanced Short Range Air-to-Air Missile (ASRAAM) integration and Joint Direct Attack Munition – Extended Range (JDAM-ER) development projects each had an 'assessed tangible benefit' of $443 million, $110 million and $853 million respectively.

7 Two other case studies involved other RAAF aircraft, specifically the P-3 Orion service life extension program and E-7A Wedgetail radar. JORN was also selected, and these are all mentioned elsewhere in this book.

Chief Defence Scientist, Professor Fink (right) discussing technical aspects of the Classic Hornet with Lane Costle from Northrop Corporation (who would later retire as Vice President of Northrop Grumman) during a factory visit in 1984. (Professor Fink was also accompanied by RAAF GPCAPT Greg Searle on that visit).

New Tactical Fighter

Even before the selection of the Classic Hornet in October 1981 as the New Tactical Fighter to replace the Mirage fleet, DSTO experts were involved with evaluating the contenders vying for the role as the RAAF's next jet fighter. From 1979-1981, several DSTO experts accompanied RAAF engineering officers on visits to the US to assess the relative merits of the McDonnell Aircraft Corporation's F-18 (as it was known then) and General Dynamics' F-16.

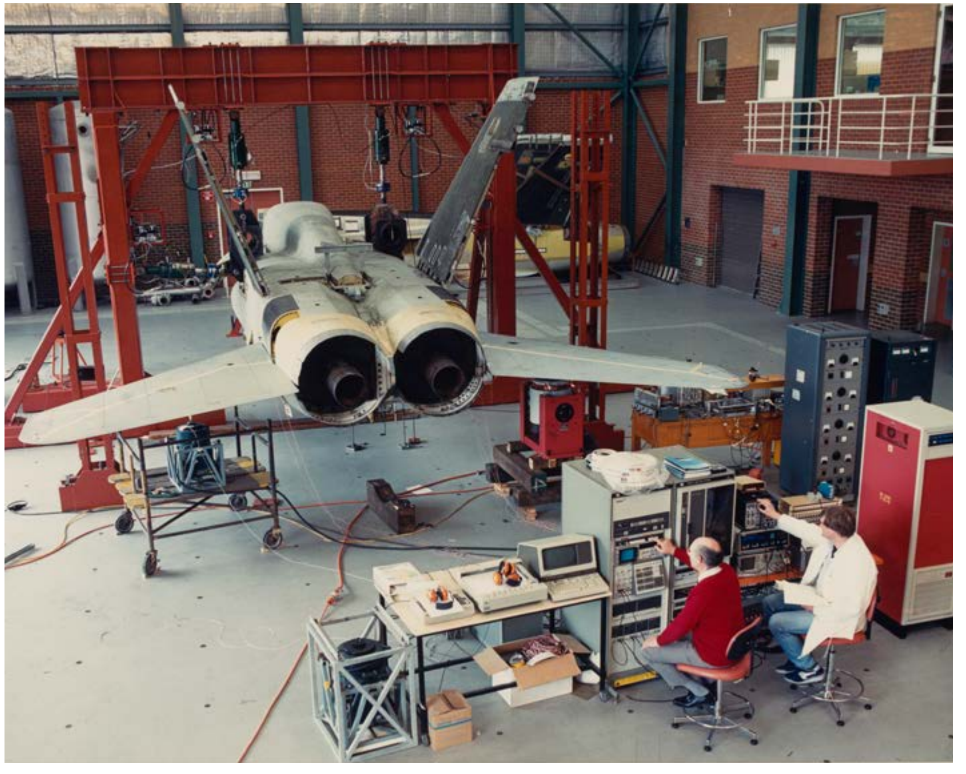
Establishing & extending structural life limits

In 1984, Australia and Canada began formulating a plan to conduct further structural testing for their respective fleets given the similarities in operational usage; airframe configuration; airframe management philosophies; and the requirement to certify the airframe life span to the conditions that the aircraft would be used. This led to the creation of the joint project called the International Follow-On Structural Test Project (IFOSTP) that primarily involved three full-scale fatigue tests.

Australia would test the rear fuselage and empennage, whilst Canada tested the forward and centre fuselage and wing. These tests were supported by flight trials programs and test loads development programs involving wind tunnel testing and computational fluid dynamics modelling.

The Hornet design featured an inner wing leading edge extension (LEX) that generates fuselage and inner wing lift which allowed the aircraft to fly high angle of attack (AOA) manoeuvres, and the outwardly canted twin vertical tails exploited the high energy vortices generated by each LEX to provide directional stability at these conditions. The downside was that at AOA greater than 10 degrees, the vortices broke down and buffeted the structure downstream, exciting resonant frequencies in the tail surfaces resulting in high localised accelerations (up to 500 g) and stress levels in key structural components. The biggest technical challenge for the structural test was therefore how to represent the buffet loading in a realistic way, concurrently with the high mean inertial loads experienced during these high AOA

Dennis Carnell (left) and Alberto Gonzalez (right) at the controls of the low speed wind tunnel at Fishermans Bend, with the 1/9th scale Classic Hornet model undergoing aerodynamic measurement testing, circa 1990.

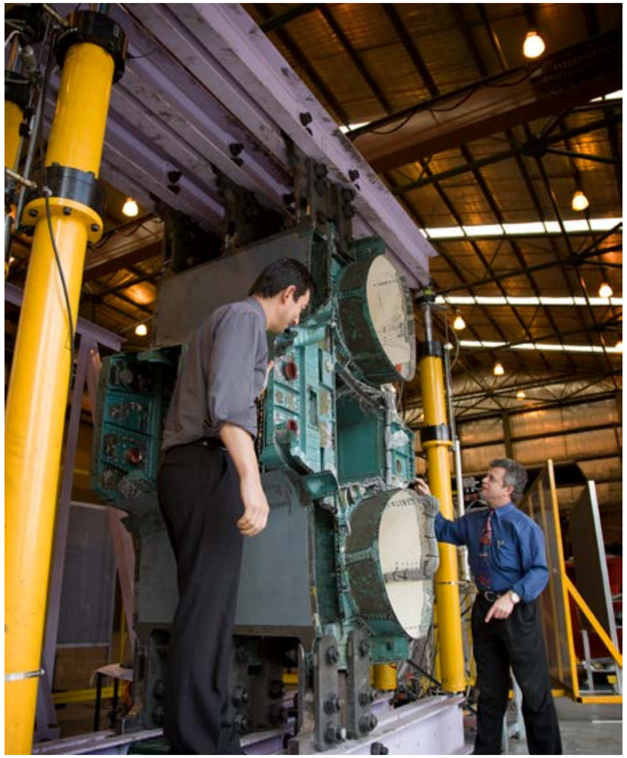


Vibration testing of the tail surfaces was conducted on a ‘commissioning’ article (called ST01) prior to the completion of the test rig construction and commencement of loading on the aft fuselage and empennage full-scale test article (called FT46) at DSTO Fishermans Bend.

manoeuvres. The system that DSTO engineers devised to apply both types of loading simultaneously was to use specially designed, opposing pairs of ‘rolling sleeve’ airbags on either side of each tail surface for the manoeuvre loads, whilst using powerful electromagnetic shakers to apply the dynamic buffet loads, literally ‘flying’ the test article through these high AOA regimes in real time. This world-leading full-scale test program still stands as some of the most advanced ever undertaken, with the results underpinning the structural integrity management of the RAAF fleet.

Looking at the back end of the FT46 test article in the completed IFOSTP rig at DSTO Fishermans Bend. The test article was slid into position via the rail system along the floor.

The success of IFOSTP received international recognition when in 2002 its partners were awarded the prestigious von Karman award for International Cooperation in Aeronautics. Coupled with other programs at DSTO such as 'FINAL' and 'HOWSAT', DSTO played a major role in the RAAF Classic Hornets reaching their planned withdrawal date with minimal operational disruption and paving the way for the introduction of the F-35 into service.



(Above) The HOWSAT test program at Fishermans Bend was successfully used to develop a through-life management strategy for the outer wing in RAAF service after interpretation of previous full-scale fatigue tests conducted overseas had proven futile.

(Left) Geoff Swanton (left) and Lorrie Molent (right) inspect the 'FINAL CB9' test article at DSTO Fishermans Bend in 2008 that was retired from A21-107. Results from these tests were used by the RAAF to re-evaluate the requirement to replace the centre barrel structures on up to 49 of the fleet; ultimately only 10 were replaced resulting in approximately $400 million saved and minimising the impact on aircraft availability.

APG-73 Radar & the ECM Testbed

In early 1997, DSTO was engaged by the RAAF to evaluate the APG-73 radar as part of the Project AIR 5376 Hornet Upgrade Program. The APG-73 was one of the candidates to replace the APG-65 and the RAAF wanted to know how capable it was against electronic countermeasures (ECM).

Fortuitously, DSTO was about to take delivery of a state-of-the-art digital radio frequency memory (DRFM) jamming system, known as the ECM Testbed, designed and developed in-house and in collaboration with Defence Research and Development Canada (DRDC). The problem was that the ECM Testbed was already 18 months late in delivery, was unproven, and DSTO had no capability to use it in flight tests, and the RAAF needed the testing to be completed by November 1997. A small DSTO core team was assembled, ably supported by RAAF's ARDU.

The Pel-Air Learjet VH-SLJ was modified to carry the ECM testbed for flight testing with an F/A-18A at RAAF Edinburgh.

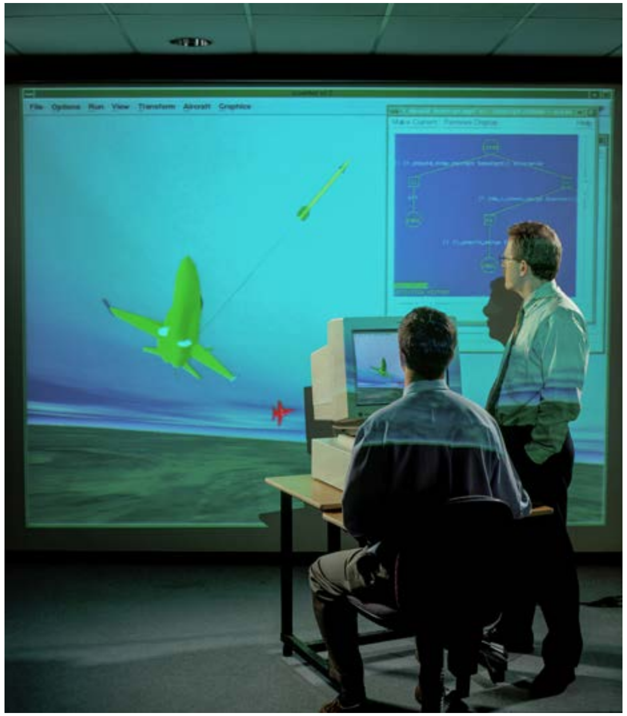
The ECM Testbed was delivered in late February, and once acceptance testing and training was completed it was shipped to the APG-65 test facility in Sydney where the team developed and tested some preliminary ECM techniques and learnt how to use the equipment. The testbed was then immediately packed up again and shipped to the US Navy APG-73 test facility at the Naval Air Weapons Station in China Lake, where the team developed and tested ECM techniques in preparation for flight trials.

The flight testing program was very successful and led to a co-development program between the USN and DSTO that saw DSTO engineers working in the US developing and testing radar software to improve the performance of the APG-73 radar against ECM. The testbed has become the backbone of DSTG's research and development of advanced ECM techniques and has been used continuously for 25 years, including on a number of FCI courses.

JSF to F-35A

DSTG support for the F-35 represents the culmination of many research activities dating back decades. In 1996 the New Air Combat Capability (NACC) Project commenced to replace the F/A-18 Classic Hornet and the F-111.

Three F-35A Lightning II aircraft flying over the Pacific Ocean during a training exercise.



Combat effectiveness researchers David McIlroy and Michael Howlett evaluate the outputs of computer modelling engagements at DSTO in the early 1990s.

RAAF SQNLDR Russell Mills discusses F-35 tactics development with DSTO scientist Simon Goss in a simulation using intelligent agents at Fishermans Bend, in March 2003.

Operations analysis

Initially this work involved operational analysis and air combat effectiveness modelling to evaluate a wide range of possible replacements. At that stage in the US the competition to replace several front-line combat aircraft was known as the Joint Advanced Strike Technology project, which commenced in 1993 and later became the Joint Strike Fighter (JSF) Program Office (JPO).

This operational analysis relied on computer models and wargaming. From the mid-1990s DSTO began using intelligent agents to represent pilots on both sides of 'red vs blue' engagements in constructive simulations, a world-leading development. The combat models relied on detailed performance models for aerodynamics, weapons, mission systems and command and control systems.

As part of the JSF program, the RAAF and DSTO participated in a series of evaluation periods in the Lockheed Martin Partner Manned Tactical Simulator, called Exercise Agile Endeavour. During these evaluation periods selected pilots represented their nation's interests to help define requirements for the design as well as evaluate the aircraft being developed for the

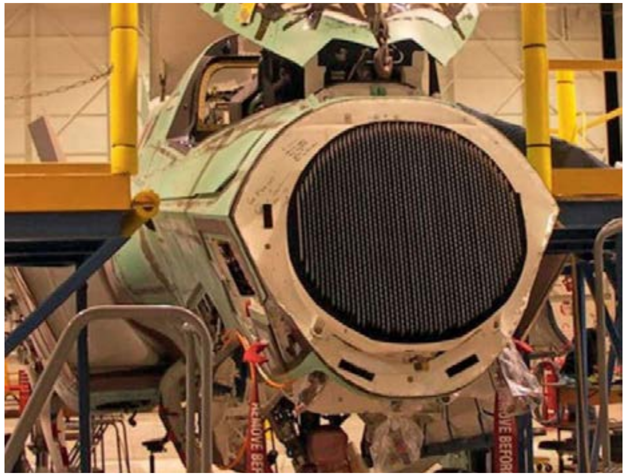
Australian and Canadian air force pilots and defence scientists pose in front of AA-1, the first production F-35 at Lockheed Martin Facility in Fort Worth, Texas. They were attending EX AGILE ENDEAVOUR 2006 at the nearby simulator facility). DSTO analysts in this photo include Michael Turner (2nd left), Bruce Fairlie (3rd left) and Dale Quinn (on stair).

program. RAAF F/A-18 pilots were able to fly simulated missions using Australian scenarios designed and evaluated by DSTO operations analysts.

DSTO operations analysts, supported by researchers across DSTO, continued to support the New Air Combat Capability until the aircraft transitioned into service in 2020, and continues to support the in-service operation and technology upgrade program of the F-35.

Mission systems

Mission systems and stealth technologies represent a more significant component of the capability of an F-35 compared to previous fighters. DSTG was well placed with decades of prior research and development of sensors and countermeasures across the electromagnetic spectrum from radio links, microwave radars to optical wavelengths, complemented by significant advances in data fusion and presentation techniques. This helped to ensure RAAF combat pilots gain and retain the most situational awareness while denying that to adversaries.



The APG-81 AESA radar represents the primary long-range sensor system on the F-35 and at the time represented a significant advancement on any other combat aircraft radar, including that on the earlier USAF F-22.

The joint Australian and US FLOTE team at Eglin Air Force Base. Sabreliner (left) and CATBird 737 modified with a nose section and radar of an F-35, a representative cockpit and several other EW systems (right).

Radar countermeasures

When invited by the F-35 JPO to try to jam the AN/APG-81 radar, DST) jumped at the opportunity. A small team of electronic warfare (EW), radar and data fusion experts was assembled, kicking off a 10 year collaboration between DSTG and the JPO that culminated in the trial series, named Loan Of Test Equipment (LOTE) and Follow-on LOTE (FLOTE).

In November 2008, DSTO conducted the first LOTE trial in the USA with the JPO, Northrop Grumman Electronic Systems (NGES) and Lockheed Martin Corporation (LM). The DSTO team brought their digital radio frequency memory experimental jammer, called the ECM Testbed to the NGES Baltimore radar laboratory, the first non-US team to do so. After a few days of testing, it was clear the ECM Testbed was giving the radar a good work out. LOTE resulted in improvements to the operational radar software as well as providing DSTO, DMO and the RAAF with an improved understanding of the performance and capability of the radar.

Following the success of the LOTE trial, a follow-on trial was proposed to measure the impact of electronic attack on the F-35 platform, by investigating the impact of jamming at the mission system level during a flight test. The FLOTE trial was conducted at Eglin Air Force

Base, Florida, in March 2014 and involved the use of the ECM Testbed fitted into a commercial Sabreliner jet in flight trials with the LM F-35 Cooperative Avionics Testbed (CATBird). The CATBird was a unique test platform designed for the F-35 consisting of a Boeing 737 aircraft with an F-35 cockpit, wings and sensors including an APG-81 radar installed at the front of the aircraft and a bank of analyst workstations in the main cabin.

FLOTE provided the JPO with an independent assessment of the performance of the F-35 mission system against advanced electronic attack; LM with a wealth of test data on the performance of their system against a plethora of advanced electronic attack techniques; and DSTO with insight into the functionality and performance of the F-35 mission system.

The DSTO FLOTE Team in front of the Sabreliner. Rick Langdon (top centre); Matthew Dragovic (top right); Kruger White, David Palumbo, Scott Capon, Peter Juett, Neal Cotgrove, Michael Bell (bottom left to right).

Exercise Rogue Ambush 21-1 at RAAF Darwin was the graduation exercise for the first class of pilots to convert to the F-35 with 2OCU in Australia, June 2021. A graduation candidate is wearing the Gen III HMD and an enhanced combat survival vest.

Human factors & the Generation III HMD

By developing new experimental techniques DSTG human factors scientists worked with the helmet provider BAE Systems and the JPO from 2012 to evaluate acceptable limits for the requirements on latency and jitter and contribute to the Generation III helmet design.

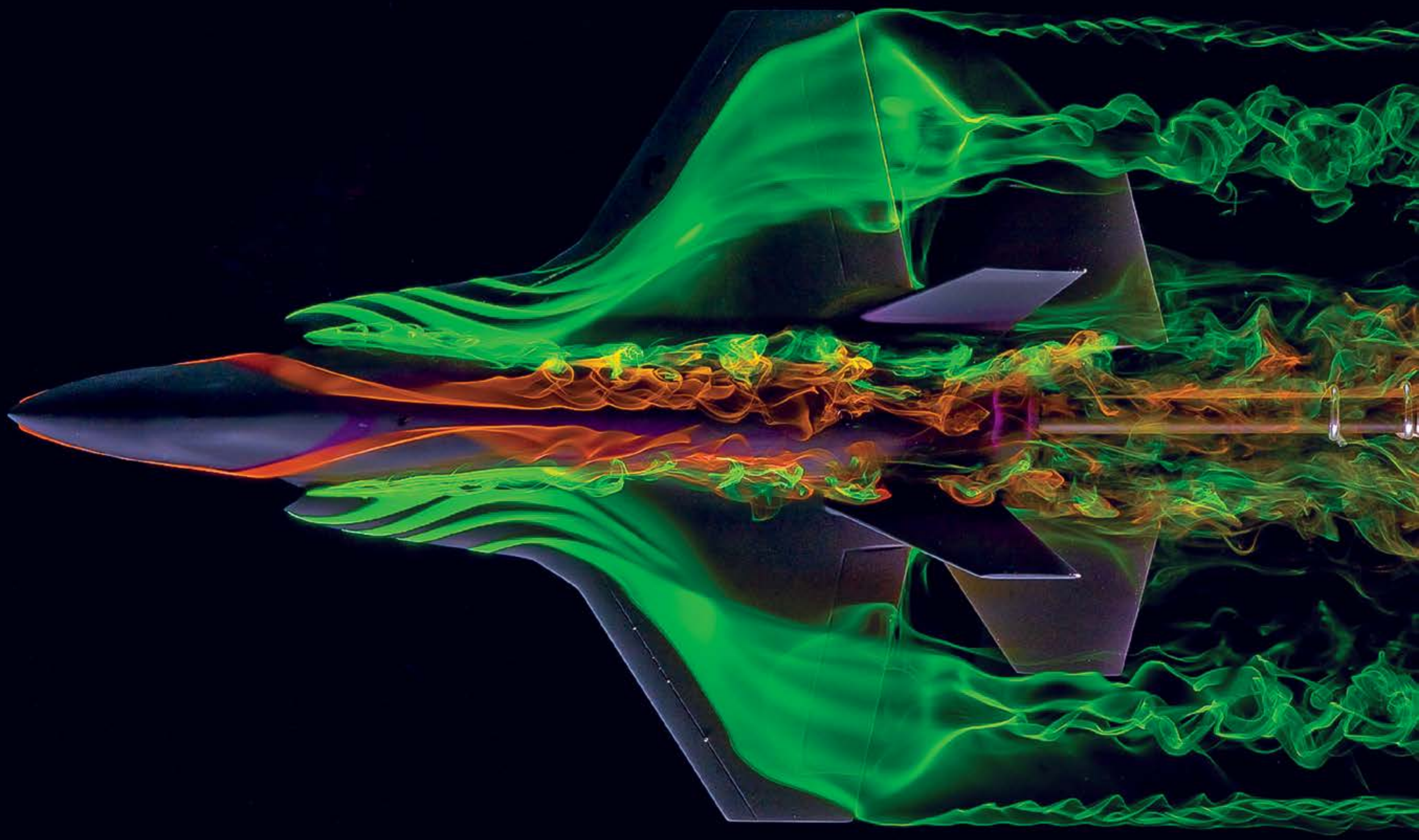
The first RAAF pilot to qualify on the F-35, SQNLDR Andrew Jackson after his final conversion course flight in the type at Eglin AFB, Florida in 2015, wearing the Generation II Helmet Mounted Display (HMD) that is a critical part of the F-35 weapon system. Distinctly different from legacy fighters, the F-35 has no head up display, but relies entirely on the HMD and a single large format touch screen forming the upper part of the instrument panel.

Aerodynamics still the basis of combat performance

The steel Low Speed Wind Tunnel F-35A model took many hundreds of hours to design and construct with intricate embedded instrumentation. The model was instrumented with many fine pressure tapping ports in a grid across one of the thin vertical tails to study airframe buffet that may reduce fatigue lives.

The Transonic Wind Tunnel at DSTG Fishermans Bend was used to explore the behavior of stores during carriage and just after release. Testing of the GBU-61 in 2021 was performed under the Aircraft Stores Compatibility (ASC) Project Arrangement (PA) between Defence and the JPO, the AWC and US Air Force Seek Eagle Office (AFSEO). The Australian testing shouldered a significant burden to assist all JSF partners nations, through the JPO, in expanding the variety of weapons cleared for safe carriage and release from the F-35. Other weapons cleared or scheduled for clearance under the ASC PA included the JDAM-ER and JASSM, two of the most important long-range strike weapons for external carriage on the F-35.

From 2008 DSTO was testing with a 1/10th scale model of the F-35 in the Low Speed Wind Tunnel at Fishermans Bend in Melbourne and Stephen Lam was one of the senior engineers with decades of experience in wind-tunnel modelling.



A visualisation of the sources of airframe buffet can be seen in this beautiful image of an F-35 scale model in the DSTG water tunnel with fluorescent dyes injected from key points within the model.

A model of a GBU-61 2000lb Joint Direct Attack Munition (JDAM) positioned below a partial F-35 model in the DSTG Transonic Wind Tunnel at Fishermans Bend in 2021.

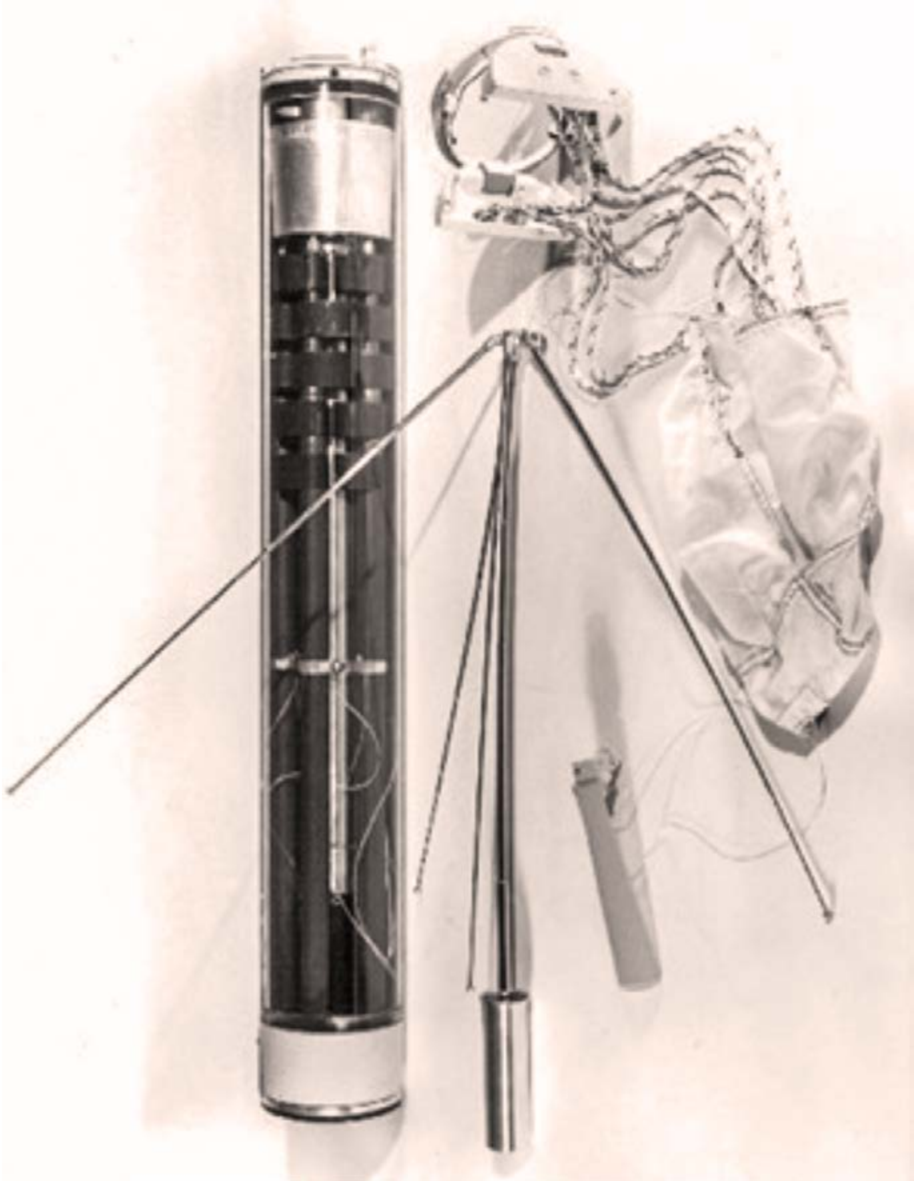
NACC project postings

From 2002 the NACC project established three types of positions that were almost continuously filled in 3 year terms by senior DSTO scientists and engineers until 2021. Director, Deputy Director and analyst positions were established in the NACC project office to manage the large range of science and technology projects supporting the project. F-35 S&T advisor positions for Mission Systems and Air Vehicles were established in Washington, DC, to advise the project on developments affecting technical risks and support Australian industry technological efforts to buy their way on to the fast paced JSF development program. Two Collaborative Program Personnel positions were established with the JPO in the fields of Prognostics and Health Management and Airframe Structural Integrity. Prognostics and Health Management is a fault diagnosis and prediction sub-system of the F-35 crucial for achieving aircraft availability and affordability targets. The Airframe Structural Integrity positions were first filled from 2012 until after the major certification fatigue tests concluded in 2018.

Maritime Patrol & Response

A formation of the last three generations of maritime surveillance and response aircraft on the arrival of the first RAAF P-8A at RAAF Edinburgh in 2016: P2V Neptune, AP-3C Orion and P-8A Poseidon.

DSTG has a long history in providing maritime surveillance support to the RAAF. In 1952, the ERL was asked by the RAAF to improve the maritime navigation system for the Lockheed P2V Neptune. ERL researchers designed and demonstrated in flight an alternative long-range maritime navigation system that used Doppler signals from forward and sideways facing antenna to continuously measure speed and drift over water, allowing a more precise determination of position over long periods and in all weathers. Going further, the ERL researchers demonstrated their side-looking linear array was superior in detecting submarines at longer ranges than the standard AN/APS-20 radar system on the aircraft, resulting in upgrades to the surveillance capability.



Barra prototype, circa 1978.

The Barra sonobuoy development

First used effectively in World War II by the USN, the P2V Neptune, P-3 Orion and now the P-8A Poseidon in RAAF service have continued dropping progressively more advanced sonobuoys to detect ever quieter submarines. From 1981 until retirement from the anti-submarine warfare (ASW) role in 2018, RAAF Orions used the 'Barra' sonobuoy, which was developed in Australia with substantial research and development input from DSTO. By the time the Barra entered service with the RAF (Nimrod) and RAAF (Orion) it was described as a world leading innovation.

The Barra innovation story started in 1964 when W.A.S. Butement (Chief Superintendent Australian Defence Scientific Service) proposed a cruciform hydrophone array using new piezo ceramic transducers for an upgraded directional sonobuoy design. With RAN and RAAF support, WRE and a team of industry partners conducted feasibility studies, operational use studies, initial and then development trials. Production of thousands of the expendable Barra commenced in 1980 with Amalgamated Wireless Australasia and finished in 2006.

DSTO researched ways to improve the Barra, such as reducing the cost and complexity by using a very large scale integration chip from 1989. Operations analysis continued to improve tactics and techniques by using bi-static and then multi-static passive and active arrays to detect quieter submarines. However, after the Orion's withdrawal from service, P-8 Poseidons and MH-60R Sea Hawks are currently only certified to use US manufactured sonobuoys, so the Barra innovation story appears to have ended after over three decades of operational success.

Advanced electronic support measures

In 1979, Defence scientist and electronic warfare expert, John Curtin, exposed limitations in the Orion's original electronic support measures (ESM) system. ESM systems are used to passively detect, locate and classify radio frequency threats. After defining the Australian operational requirements for a replacement ESM system, he went on to contribute to the design, development and installation of a new system – the AN/ALR-2001. The system was produced and fitted to RAAF Orions from 1990 by Amalgamated Wireless Australasia Defence Industries, who became part of BAE Systems Australia from 1996.

Regarded as one of the world's most advanced ESM systems at the time, the ALR-2001 significantly enhanced the Orion's maritime surveillance capability, and Curtin received the Minister's Award for Achievement in Defence Science in 1996. The RAAF Wedgetail also has an upgraded version of the ALR-2001 by BAE Systems Australia, but the P-8A has a different system from Northrop Grumman.

Orion Avionics Concept Laboratory

In 1984 an Orion was badly damaged by a fire originating in the crew oxygen system while the aircraft was undergoing maintenance at RAAF Edinburgh. In 1989 the scrapped fuselage was delivered to the adjacent DSTO Salisbury site to become the Orion Avionics Concept Laboratory (ORACL), providing beneficial science and technology support to the RAAF Orion fleet and many others.

The ORACL at DTSO Salisbury.

Internal view of the ORACL in 1992 with modern operator consoles simulating a P-3.

In 1991 the ORACL was a state-of-the-art research facility with Sun workstations running X Windows, track balls and keypads, and some of the first touch screen controllers representing future consoles for maritime patrol operators. Shown are DSTO engineers Peter Temple (nearer) and Mark Davies.

With systems and architectures relatively easily reconfigured or upgraded, the ORACL facility was essential to prepare DSTO and the RAAF for the rapidly increasing reliance of modern aircraft on their mission systems sensors, computing systems, data links and especially the software. The facility allowed DSTO to provide reliable advice on improving systems integration issues, sensor data fusion, human machine interfaces and tactical procedures. The benefits flowed through, not just to further upgrades of P-3C to AP-3C, but to mission systems for Classic Hornet, Wedgetail, F-35 and other software intensive weapon systems, including ground defence systems.

Extending the service life of the Orion

From 1999 to 2006, DSTO worked with RAAF and DMO engineers on the international P-3 Service Life Assessment Program (P-3 SLAP). This program involved assessing in great detail the airframe condition of the RAAF fleet and full-scale fatigue testing of a P-3C Orion across a number of countries. It led to a significant life extension for the aircraft under the Service Life Extension Program (P-3 SLEP) from 2006 to 2012, saving approximately $100 million over the remaining life of the P-3 fleet.

The Australian contribution to the SLAP/SLEP was full-scale fatigue testing of a P-3 empennage obtained from the USN, after it resided for some years in the Arizona desert at the Boneyard. The test ran from 2001 to 2003 and was completed on schedule and budget, delivering all the required information to assure the structural fatigue life of the fleet beyond the planned withdrawal.

P-3C empennage test set up.

Electro-optical & infrared upgrades

In 2006 when the RAAF proposed an evolutionary upgrade to the next level of analogue electro-optical and infrared sensors of the Orion fleet, DSTO scientists were able to demonstrate the advantages of going digital. In Project AIR 5276 CAP 1, the camera and end-to-end system were upgraded to provide the best electro-optical and infrared capability on any Orion fleet. The new Star SAFIRE HD camera and the data processing and sharing system provided standards-compliant live motion video to special forces on the ground and to headquarters, as well as high-quality metadata to operators in the Orion to improve sensor employment.

DSTO Physicist Merrilyn Fiebig and FLTLT Glenn Murray with the Star SAFIRE HD EO/IR turret installed on a RAAF AP-3C.

Senior ADF officers singled this out as a **'life saving capability'** during operations over land in the Middle East Area of Operations.

P-8A Poseidon – Potent force

The Poseidon will increasingly be a potent force on future battlefields aided by DSTG's science and technology. DSTG has assessed the technical risks for many of the sub-systems of the Poseidon and made critical improvements in several, as well as the concept of operations, tactics and training systems. Blessed with the long range and payload of a modern civilian turbofan airliner, adding long-range sensors and advanced weapons, the Poseidon provides the RAAF with a potent surveillance and strike capability.

The graceful, slender wing of the P-8A in flight over St. Vincent Gulf.

DSTO AIR 7000 Project S&T Advisor and OA lead Martin Cross briefs a 92WG crew before they engage in a simulated wargame using the SHORE at DSTO Fishermans Bend.

Operations analysis

As RAAF began to consider options to replace the Orion fleet, DSTO was providing operational analysis to identify suitable replacements. DSTO assisted Defence with submissions to periodic Force Structure Reviews and White Papers using the combat analysis tools and skills built up over decades, and internationally benchmarked and validated against expert inputs by ADF operators during exercises, wargames and simulations.

When Project AIR 7000 commenced in 2005, a Technical Risk Assessment was already being prepared regarding several options, with the USN/Boeing proposal for the P-8 Poseidon ultimately accepted. The opportunity to use the USN plan to produce 117 aircraft for their own fleet and continually upgrade the mission systems throughout the life of the fleet was a positive factor.

From 2007 DSTO operations analysts embarked on an ambitious plan to build a capability now known as the Synthetic Human-in-the-Loop Operations Research Environment (SHORE) to emulate both the hardware and software of the Poseidon. The SHORE also relied on detailed performance models for the aircraft and many of the mission systems, such as radar, acoustics, and electronic support measures and counter measures, which drove scientific and engineering evaluation of current and future systems, better informing the RAAF on the capability to be acquired.

The advantage of this system was the flexibility to change either hardware or software representations without the time required to test and certify on airworthy aircraft. The facility was used to research the operational effectiveness of future capability options using 92WG operators 'flying' representative missions and campaigns. DSTO analysts designed and ran the SHORE, using simulated missions to conduct experiments, then analysed and reported the results. This work helped push Australian requirements into the development and upgrade plans, and clarified the role of the P-8A in the Australian context.

In 2012, a Force Composition Study examined the required size and mix of the combined Poseidon and the Triton MQ-4C fleets for maximum cost-effectiveness in their planned roles. The long endurance and huge search volume of the Triton were contrasted against the operational flexibility and weapons release authority of the P-8A, among other trade-offs.

11SQN operators on board a RAAF P-8A Poseidon during the training drop of a UNIPAC II SAR kit over St. Vincent Gulf in 2019.

Acoustics & anti-submarine warfare

Airborne ASW has evolved to mainly focus on acoustic detection using sonobuoys dropped into the sea, and radar to detect parts of submarines above the waves. In the late 1990s DSTO was expanding the science and practice of ASW by conducting world leading research to add an active pinging sonobuoy within a field of passive receivers listening for reflections. The multi-static active coherent (MAC) capability was added to the Australian Barra sonobuoy by developing and demonstrating the RASSPUTIN active sonobuoy with industry under a Capability Technology Demonstrator (CTD) project. While the multi-static processing capability was added to the sonar processor aboard the AP-3C, the MAC capability was not used on the AP-3C due to other operational priorities for RAAF at the time.

The RAAF is a partner in the P-8A spiral development program and from 2020 that includes the use of a USN developed MAC suite of active and passive sonobuoys. DSTG ASW scientists have developed a strong and trusted relationship with both PMA-290, the USN project office responsible for acquisition and sustainment of the P-8A, and PMA-264 Air Acoustic ASW project office with responsibility for developing USN airborne ASW sensors and processing. DSTG and the RAAF have

On the arrival of the first RAAF P-8A in Australia in November 2016, 92WG held a hangar party attended by DSTG acoustics and radar scientists, (left to right): Sergey Simakov, Fiona Fletcher, Lesley Kelly and Brett Haywood.

joined with the USN to form the Joint Acoustic Technical Working Group (JATWG) that meets regularly to exchange technical information and plan collaborative research. The JATWG collaboration was successful in being awarded a Coalition Warfare Project which will commence US financial year 2023 and involves a joint data gathering exercise and development of enhanced processing techniques to improve the robustness of MAC in challenging cluttered environments.

In a wider collaboration with The Technical Cooperation Program (TTCP) countries on advancing multi-static operational capability, DSTG has engaged in acoustic ASW research programs to improve crucial system metrics and mission planning capabilities. With deep expertise in these fields, DSTG developed software tools and supported 92WG to develop an analysis capability for MAC engagements, to fully understand MAC performance and has supported 92WG use of Australian-specific environmental data and predictions in the MAC mission planning tool to optimise MAC fields for use in Australian operational areas.

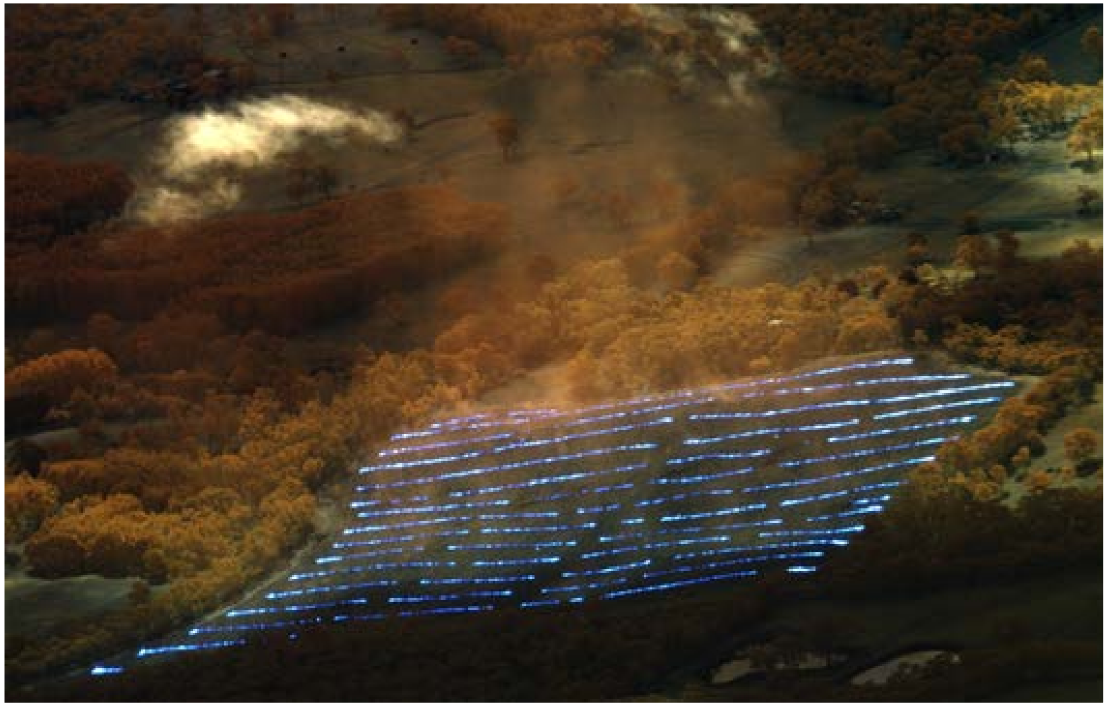
Hyperspectral sensor trials under the Coalition Warfighting Program

The current MX-20HD camera and laser turret on the Poseidon and Triton collects high spatial resolution broadband colour and mid-wave infrared (MWIR) motion imagery. Trials of hyperspectral imaging (HSI) cameras sought to evaluate new cameras operating in different wavelengths to identify the best upgrade paths for the electro-optic systems on board both USN and RAAF aircraft. HSI is collected as a 3D data structure across the visible and all 3 IR bands from short wave infrared (SWIR – reflected from the sun) to long wave infrared (LWIR – emitted by objects) bands, with the added dimension being frequency. In 2019 DSTG integrated two hyperspectral systems onto the Defence Experimental Airborne Platform (DEAP), a Beechcraft 1900C aircraft testbed configured with sensors under the fuselage. As part of a jointly funded Coalition Warfighting Program trial, the USN brought its developmental SWIR turreted sensor to Australia and DSTG used its LWIR sensor, as well as the existing MX-20.

DSTG scientists calibrating hyperspectral sensors mounted under the DEAP Beechcraft 1900C at RAAF Edinburgh for a comparative trial in 2019 with a RAAF P-8A Poseidon. (Left to right): Dr Tim Bubner (DSTG Hyperspectral Lead), Steve Lang (DEAP Lead pilot), Merrilyn Fiebig (Project Lead) and Gavin Fowler (LWIR Sensor Technical Lead). In the right photo Gavin is cooling the LWIR sensors with Helium before take-off.

In addition, the RAAF participated with a 92WG P-8A using its MX-20HD camera system for a direct comparison with the new technology on the DEAP. Unplanned, the DEAP and Poseidon found a fire burn-off activity to collaboratively image as a useful addition to the co-collected dataset and demonstrated the agility of the coordination between the DEAP and the Poseidon.

The project was highly successful in demonstrating long-range visualisation through haze and smoke, improved anomaly detection useful in maritime SAR and better false alarm suppression in littoral or reef environments. This work provides a foundation to shape and influence the AIR 7000/PMA-290 program for future upgrades and acquisition decisions.



Smoke obscures the visible image (left) but the HSI shows the flames of a planned burn-off through the smoke (below).

PMA-290 embedded personnel

RAAF and DSTO specialists were embedded from mid-2011 in PMA-290, the program office in charge of P-8 System Development and Demonstration (SDD) program at Naval Air Station Pax River, Maryland. As Cooperative Program Personnel, both RAAF and DSTO embedded staff were working for PMA-290 to manage the acquisition, development, support and delivery of the Maritime Patrol and Reconnaissance Aircraft. Up to four DSTO staff were embedded at any one time from 2011, and in 2022 the program was ongoing with two positions. Depending on their skill sets, the posted personnel played lead roles in the fields of interoperability, networking, mission systems and software, or crew environments and training.

All of these positions had a role in defining requirements for the next upgrade cycle (Increment 3), planned to be introduced to P-8A fleets worldwide from 2030 and the RAAF P-8A fleet under AIR 7000 Phase 2C. Embedded RAAF officers and DSTG staff also played a leading role in negotiating USN and RAAF requirements through the Naval Aviation Requirements Group (NARG) within the Office of Chief of Naval Operations, effectively charting the future development pathway for the P-8A. Subsequently, DSTG developed a new capability gap analysis and management system that included multiple simulations and wargames with USN P-8A operators at their base, NAS Jacksonville in Florida. Using advanced expert elicitation techniques they were able to collect and distil evidence based rationales for Increment 3 capabilities.

USN P-8A flight test aircraft T-5 on the flight line at NAS Patuxent River in 2013, with DSTO embedded staff (left to right): Emilio Matricciani, Norman Lante, Michael Mathers and Bradley Wolfgang.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Summary

The RAAF is one of the most technologically advanced and professionally competent air forces in the world, not just for its size, but in absolute terms. This is a testament to the people of the RAAF over the last century and the culture of excellence they have built up. An integral part of that culture is the passionate support provided by the people of the science and technology arm of Defence, known as Defence Science and Technology Group.

Although the forerunners of today's DSTG were created before World War I, direct organisational support to the RAAF was born in the looming shadow of World War II. Created as an aid to industrial scale aircraft production, the wind tunnels, engine test houses and structural testing machines of the CSIR Division of Aeronautics at Fishermans Bend were vital to the war effort and the growth in Australian air power that followed. Through the development of the science and engineering practice of aircraft fatigue life estimation and extension, the RAAF was able to retain dominant capabilities like the Orion, Hercules, Classic Hornet and the F-111 (the latter for over a decade as the world's sole operator) in higher states of readiness for longer periods. There are other themes that endure, for example, aerodynamics and airframe structural response are as much issues today as they were 60 years ago. A case in point is the Jindivik and Loyal Wingman; two ground breaking sovereign UAS designs that have undergone testing in DSTG's wind tunnels and been subjected to ground vibration testing and analysis.

DSTG's ability to inject value to other phases of fleet size lifecycles cannot be understated; this extends to employing operational analysis and technical risk assessments to inform the acquisition process, supporting operations, reducing maintenance burdens and developing capability upgrades and enhancements. And now, as the RAAF completes the leap forward to stealthy, highly networked, next generation air combat with the F-35, DSTG has been integral to that journey. Two great examples presented were DSTG's contributions to the F-35 Generation III helmet display solutions, and the assistance in establishing the Distributed Training Centre at RAAF Williamtown, where networked team performance can be practiced to the highest levels.

Another predecessor to DSTG, the Long Range Weapons Establishment, may have commenced in Salisbury to support British rocket testing and development in the desert at Woomera, before it too provided direct support to the RAAF. With the highly advanced JORN, the RAAF leads the world in using OTHR technology for sophisticated surveillance and control. Between JORN and the Wedgetail AEW&C fleet – developed to Australian requirements with some key Australian developed technologies or advice – the RAAF now possesses two of the world's leading capabilities for this mission. When the relatively new Poseidon and the soon to arrive Triton enter into service, that list of world leading surveillance and control capabilities supported through partnership with DSTG grows to four.

Those developments were not by accident, but through careful study of the future operational needs and their overlap with future technologies, as well as persistent research and development of those technologies to achieve new missions and capabilities. Now, as mission systems performance and network resilience become the dominant means to surviving and winning in all domains, DSTG is already well positioned to lead Defence in the evolving fight.

There are many personal stories where individuals have made a difference plus further examples of innovation and more depth that has not been included here. These will be captured in a fuller, follow on book that will attempt to capture and curate more of this rich history.

The folk of DSTG and its predecessor organisations have been proud to work with our uniformed colleagues to enhance capability, provide immediate support to operations, assist in defining requirements for acquisition, develop unique and world leading ideas and advance them through to real-life operational systems, provide new ways to assess the viable life of air systems, improve air safety, save money (worth billions over the decades) and ultimately save lives. This collaborative environment has also extended to partnerships with allied nations and manufacturers; many successes have involved embedded DSTG staff in overseas project offices or working together on mutually beneficial testing and technology programs at home and abroad.

This partnership between DSTG and RAAF has forged deep relationships between generations of 'innovators' and 'aviators', developed and based on mutual respect and trust, with one aim in mind, the shared goal of protecting Australia and its national interests. This is a summary of the first one hundred years and we eagerly move onto the challenges of the next one hundred years in partnership between our Australian innovators and aviators.

As the Royal Australian Air Force (RAAF) celebrates its 100th birthday, we look back at the lasting partnership between the RAAF and the Defence Science and Technology Group (DSTG). From our decades of collaboration, we share stories and images of our innovation and excellence, from helping to develop uncrewed jets, to advanced electronic warfare. These stories demonstrate the significant impact, achievements, and tireless dedication of countless individuals and teams to protecting Australia and its national interests.