NULKA A Compelling Story

Ingenuity : Partnership : Perseverance

Australian Government

Department of Defence

NULKA

A Compelling Story

INGENUITY : PARTNERSHIP : PERSEVERANCE

David Gambling, Mal Crozier and Don Northam

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FOREWORD

Science and technology have many roles in supporting defence capability but none is more important than researching novel ideas and initiating projects that meet critical national security requirements. The Nulka active missile decoy program is a project that typifies this role.

Nulka did not have an easy birth. From the initial concept developed by Australia's Defence Science and Technology Organisation in the early 1970s, Nulka faced many hurdles — technical, managerial and political — before it became the state-of-the-art ship protection system that we see deployed on more than 150 Australian, United States and Canadian warships today.

In 1986 Australia and the United States signed an agreement to undertake full-scale collaborative development of the Nulka concept. Later BAE Systems (then AWA Defence Industries) was contracted for the engineering development of the Nulka system and rocket vehicle, with the United States companies Lockheed Martin Sippican Inc and ADI-Thales engaged to develop the electronic payload and rocket motor respectively. In 1996 Australia and the United States commenced joint production of the Nulka decoys for their respective navies. The early involvement of industry, coupled with the partnership between Australia and the United States, were the crucial ingredients for this successful project to finally lead to full production of Nulka by 1999.

In 2007 Nulka reached a landmark, providing protection for 100 ships — 83 in the United States Navy, 14 in the Royal Australian Navy and three in the Canadian Navy. It is scheduled to be installed in over 160 ships.

Nulka has been Australia's largest regular defence export for many years and in 2010, the delivery of the 1000th Nulka round was celebrated. The total investment in Nulka by the three navies to date is around $1 billion.

The evolution of Nulka into a successful defence capability is a credit to the skills, dedication and energy of the large numbers of scientists and engineers in Defence and industry both in Australia and the United States.

One cannot underestimate the contributions made by the Defence Science and Technology Organisation, the Defence Materiel Organisation, the United States Naval Research Laboratory including the Naval Weapon Centres at Dahlgren and Crane, BAE Systems, Lockheed Martin Sippican Inc, Aerojet and Thales (then ADI) along with many smaller but important organisations.

The Nulka story is an exemplary record of how science and engineering, industry and Defence, the United States and Australia, can all come together to create a piece of history.

Many of the players involved in the original development of Nulka have moved on or retired. Nonetheless they deserve to be congratulated for their unique innovation that protects the lives of our sailors at sea. Importantly, their story needs to be told to inspire our new generation of professionals.

We thank the authors for bringing that story to life and commend this book to you.

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PREFACE

The story of Nulka is, in many ways, several inter-woven stories. It is first and foremost the story of a superb, sustained feat of engineering to introduce into service an electronic decoy system capable of defeating advanced anti-ship missiles.

Nulka was never a large project by military standards, but was highly complex, and involved the development and proving of several fundamentally new technologies in order to meet requirements for decoying.

There was, for example, the development of the thrust vectored rocket, ‘Hoveroc’, which solved the problem of how to develop a small carrier vehicle which could fly relatively slowly while supporting a sizeable payload mass. Also, there was an amazing advance in payload antenna design that greatly simplified the mechanics of decoying, and thereby increased the system’s operational effectiveness.

These, and a host of other technological achievements, were made possible by the fertile, collaborative environment that existed in the Defence Science and Technology Organisation and defence industry in those times. Scientists and engineers were able and willing to work across organisational lines to solve the many multi-disciplinary problems that always exist in complex system developments.

The Nulka Decoy Project originated in Australia in the early 1970s, but it needs to be acknowledged that its inception followed closely the earlier pioneering work on off-board decoys carried out by the United States Naval Research Laboratory (NRL) during the 1960s and early 1970s. For example, scientists and engineers in NRL’s Tactical Electronic Warfare Division had undertaken numerous studies on the use of off-board decoys for warship protection, had investigated a wide range of decoy concepts, and had fostered exploratory development of high performance, low cost electronic components and devices which could sustain the accelerations inherent in rapid response decoy launches. In addition, the United States Navy had generously provided to Australia, through staff exchanges and international agreements, highly useful background knowledge and information on its off-board decoy programs as well as information on anti-ship missiles and the threat they posed to navies. Knowledge of the state of development of decoy electronics technologies was particularly important to the Australian endeavour. Without this, it is unlikely that the Australian project could have proceeded during those early years.

Noteworthy also have been the sustained and highly competent efforts by Australian and United States industry, which for more than two decades carried out the lion's share of the engineering development and manufacturing tasks of the Nulka program. This is an impressive achievement, given that Nulka was the first joint program of its kind. In the process, industry's belief in and commitment to Nulka on a great many occasions were instrumental to the project's continuation.

Tribute is also due to the Australian Navy's electronic warfare community which strongly supported Nulka throughout its development, as well as staff of the numerous project offices that were formed in DSTO and the Australian Department of Defence to coordinate and manage the Nulka program, firstly as an Australian development, then collaboratively with the United States Navy. Finally, there needs to be acknowledgement of the pivotal contributions of the joint Australia-United States Program Offices to Nulka's full scale development and production, that were critical to the project's success.

Throughout its history, Nulka engaged many people, from within research and development communities, naval and other defence organisations, and industry. The story of Nulka is therefore one of people and their contributions. Because of the project's timescale — that extended over decades — they can be seen as a passing parade of players who came into the project, often to make an important, if not vital contribution, and then move on. As well, there has been a core of personnel that stayed with and supported the project for long periods, committed to seeing it through. As this history reveals, the inspiration, ingenuity and persistence of participants in all phases of Nulka have been the ingredients of its success.

Nulka is also a story of persuasion, or more accurately, attempted persuasion. For the decoy to be affordable, it was clear from the outset that Australian scientists would have to find a collaborative partner to reduce development and unit costs. Throughout the 1970s and much of the 1980s, almost all NATO countries, the United States in particular, failed to appreciate the need to counter advanced western sea skimmers such as Exocet. Despite Australia's best efforts, this attitude remained until the dramatic sinking of HMS *Sheffield* during the Falklands war. Consequently, Australia laboured alone in the early years of the project.

Australian decision-makers were not readily persuaded, either. First of all, indigenous development of military systems, especially in an area such as electronic counter measures, was generally opposed. Further, there existed within the policy communities in the Australian Navy and DSTO, a preference for 'hard kill' solutions using offensive weapons, and legendary opposition to the use of 'soft kill' systems for ship defence, where non-offensive devices were used. Such opposition was not confined to Australia.

A major effort was needed to show that the traditional 'hard kill' idea of meeting fire-power with fire-power could not work in the new environment. Designers of sea skimmers had realised that the situation was asymmetric, that is, they could attack in a region of the operational envelope where the 'hard kill' defences could not engage them effectively.

We in the electronic warfare community made some headway in convincing Australian decision-makers that the low altitude vulnerability problem was real, to a degree at least sufficient to maintain the program. However, it was not until HMS *Sheffield* and the USS *Stark* were hit by Exocet missiles under conditions where 'hard kill' systems ought to have managed easily, that wider recognition of the problem began to occur.

I worked both sides of this issue during my career in maritime strike as well as ship defence. I have observed that the adversary in the ascendant at any time tends to change cyclically. There have been impressive improvements in ship defence capabilities in recent times, but it is important to remember that attackers are equally able to exploit technology advances. In this sense the Nulka story is but one excerpt from the never-ending story of the contest between strike and counter-strike systems.

To some, the Nulka/Winnin record may appear to conflict with this last statement. After all, the program now spans four decades, well over a thousand decoy systems have been delivered, around 150 ships have been fitted for Nulka operations and there is yet no end in sight. The concept has stood the test of time. The explanation is that, in any era, electronic decoys can be configured to provide a generic counter measure to radar guided missiles. The parameters for Nulka/Winnin were set originally to defeat the known missile threats that appeared during the time of its development. However, the situation is not static. New radar techniques may be incorporated into anti-ship missiles which could reduce the decoy's effectiveness. To counter this, upgrades to the decoy electronics would be required, but this is feasible. The point is that the entire system would not have to be replaced. This 'grandfather's axe' approach for Nulka should endure for as long as radar remains the all-weather sensor of choice for anti-ship missile designers.

Scot Allison
Former Director
Electronics Research Laboratory, DSTO

ACKNOWLEDGEMENTS

In October 2010, close to 40 years after Nulka was barely an idea, Australia celebrated the production of the 1000th round of this innovative active missile decoy. This milestone signified the remarkable success of a joint program by Australia and the United States, the first in the electronic warfare domain. By 2013 Nulka had been fitted to more than 150 surface warships of Australia, the United States and Canada. The history of this successful international project, particularly the significant technical breakthroughs, the unique paths taken in technology, politics, and engineering, and the sheer determination by a number of committed individuals, demanded to be told.

In telling the story, we have deviated from chronological order sometimes to highlight interesting technical or political issues. Readers unfamiliar with the development project should note that the early development of the decoy technology was carried out under Project Winnin, which comprised an Advanced Feasibility Study phase, ending with the flight demonstration of the first rocket-propelled vehicle called 'Hoveroc' and a Concept Development phase. In 1986 Australia and the United States formed a joint project, Nulka, which also became the name of the decoy.

This story belongs to the several hundred people who dedicated major parts of their careers to the Nulka project. We thank all those people who agreed to be interviewed, searched their memories, diaries and bookshelves, and to those who provided documents or photographs. We estimate there were more than 100 people in Australia and overseas who made contributions to this book. We quickly found that the process of using individual recollections needed to be iterative as memories were stimulated by an emerging storyline. We have also been astonished to find how fallible the memory is and certainly had to resort to rationalising most accounts by independent research.

It should be noted that there are many aspects which are classified by the authorities and cannot be included. So, the details of some innovations and personal contributions are necessarily missing. Furthermore, in the process of keeping the book to an appropriate length for the general reader, we have omitted many areas of detail that reveal the determination and efforts of many individual contributors to make Nulka a success. We sincerely apologise to them and hope they understand.

Most importantly, we would like to thank those from both Australia and the United States who made valuable contributions, opinions and advice on events and content. Many spent inordinate amounts of time reflecting on specific issues to ensure the story is as accurate an account as could be of events that are now up to 42 years old.

It became clear to us as we spoke to people, that the project's long duration and its diversity of subject matter meant that few if any of the hundreds of participants were ever aware of the whole story. It is now time to tell that story, and we hope you enjoy the telling.

Readers should note that a version of the history written by Mal Crozier entitled 'The Nulka Story – the Rocket that Thought it was a Ship' includes greater detail on the efforts by many on the technical challenges.

David Gambling, Mal Crozier and Don Northam

CHAPTER 1

The emerging threat to ships and initial analysis

In an era when ship defence programs focused primarily on early Soviet missile threats, the respective defence science laboratories in the United States and Australia realised the importance of emerging threats and established research and development programs on critical counter measures technologies.

Russia's successes in designing guided missiles for land, air and sea applications posed a formidable challenge during the Cold War in the 1960s, and its armoury of radar-guided anti-ship missiles was comprehensive. This armoury included the Styx sea-launched missiles and the Kelt air-launched missiles, which were designed to attack naval carrier groups, flotillas and other surface units. The potential threat of these weapons forced many navies, particularly those of the West, to provide defences against them. The prime ship defences of the time were gunfire and missiles: these were known as the 'hard kill' options.

However, Russian tacticians sought to counter 'hard kill' defences through coordinated attacks with salvos of missiles which could saturate and overcome ship defence systems. New types of on-board jammers were introduced to confuse or deceive the radar seekers of attacking missiles, but, in turn, the missile designers responded with a smarter, more diverse family of seeker heads.[1] So a specific jamming technique had to be found for each threat missile, making it operationally more difficult to use these 'soft kill' techniques. Chaff was introduced as the first of the off-board decoy techniques. Chaff is reflective aluminium coated fibreglass thread that is dispersed to form a radar reflective cloud in the air away from a ship. It is deployed from the ship by a rocket-propelled canister. The position of the cloud is greatly affected by winds and the ship's course, but its cheapness made it attractive to most navies, including that of Australia.

By the early 1970s, the United States had a huge national commitment, and supported a major industry devoted to 'hard kill' weapons and to 'soft kill' options, including chaff and on-board jammer systems, that could contain the Soviet missile threat. There developed the familiar play and counter-play in which the designers of offensive and defensive systems engaged.

The sinking of the Israeli naval vessel *Eilat* by an Egyptian Styx anti-ship missile in the aftermath of the Six-Day War of June 1967 suddenly focused world attention on the vulnerability of expensive naval ships to anti-ship missiles. It also highlighted the growing proliferation of these weapons throughout the world by means of international arms deals. The United States Navy felt particularly vulnerable as it executed missions in the waters around Vietnam, during the Vietnam War from 1965–1972. This concern was reinforced during the Indo-Pakistan War of 1971, when naval vessels were again lost because of missile attacks. The Israelis demonstrated two years later during the Yom Kippur War with Egypt and Syria they had learnt the lesson by successfully countering waves of attacks of Styx missiles by deploying enormous amounts of chaff. The advent of anti-ship missiles caused much consternation among navies everywhere and highlighted a desperate need to strengthen and diversify their ship defences.

The Arab-Israeli *Eilat* incident triggered several developments in ship self-defence, particularly in the United States Navy. It also triggered major developments of offensive weapons around the world, which were to have a profound impact on the effectiveness of these self-defence measures.

A feasibility study by General Dynamics in Pomona, California, into means of protection for ships against missile attack led to demonstration tests at White Sands, New Mexico, of a rapid-firing gun system in 1970. The centrepiece of this system was a radar developed by General Dynamics which tracked shells as well as the target. This system became known as the Phalanx close-in weapon system. Introducing the system to the United States Navy fleet began in 1980. Six tonnes of equipment were required to produce a 'wall of shells' to destroy a missile less than six seconds before it hit the ship.

Phalanx was deployed successfully, but there remained strong support in the United States Navy for a lightweight, quick reaction, lethal, close-in anti-missile, missile system to augment the longer range Sea Sparrow missile. The Rolling Airframe Missile (RAM) program began full scale development following an agreement with the West German Navy in June 1979. Sea trials were first conducted in December 1986. However, RAM was not extensively deployed in the United States Navy until the late 1990s.

The research and development community in the United States at that time had forecast the development of even smarter missiles which would be capable of discriminating against on-board jammers, and scientists were already working on several rudimentary off-board decoy concepts. Most significantly, scientists at NRL were pioneering the development of off-board decoy technologies, including low cost, high power travelling wave tubes, as they considered the lack of this technology to be a major impediment to the development of off-board decoys.[2]

The United States Navy, however, was unable to identify such an advanced threat to their ships and remained unreceptive. The situation in the United Kingdom was similar.

The approach of the Royal Australian Navy (RAN) to ship self-defence was based on an assumption that future adversaries would be equipped with Soviet-designed missiles. It also assumed that weapons would play the major defensive role, complemented by chaff, even though RAN ships were fitted only with guns at the time. Overlaid on this approach was a defence-wide policy position that believed that electronic warfare counter measures were expensive, technologically complex, and could readily become obsolete. Consequently, there was little interest in the electronic warfare business other than buying ready-made weapons off-shore.

If ever there was a fresh, top-down approach to the design of a missile, it was Exocet.

Evolution of anti-ship capable missiles and electronic warfare requirements in the 1960s and 1970s

Meanwhile, clever French missile designers had started serious work on a new generation missile with advanced features. This was to have a major impact on the vulnerability of surface vessels. The missile was named Exocet. The French company Nord — later Aerospatiale — had started defining an offensive missile in 1965 but the French and Greek navies initiated the development only 10 months after the *Eilat* incident of mid 1967. The Exocet underwent operational evaluation testing in the 18 months to June 1974. This missile became widely known through media reports of the devastation it wrought on more than 135 tankers and cargo ships during the Iraq-Iran Gulf War of 1981–1985. The stretch of water near the Kharg Island oil terminal became nicknamed ‘Exocet Alley’.

The development of Exocet represented a fresh, top-down approach to the design of a missile, and its French designers are to be admired for their innovation. Their solution for exploiting the weaknesses in existing ship defences was a masterstroke. The poor coverage of surveillance radars close to the sea surface led the French to design Exocet to fly just above the sea surface and underneath a ship’s radar envelope, leaving only seconds for the ship to react. Exocet was a formidable weapon because of its monopulse[3] radar seeker and smart electronics that enabled it to discriminate against chaff and on-board counter measures, and its ability to be employed in saturation attacks timed for simultaneous impact.

Still, considerable time passed before the sea-skimmer, exemplified by Exocet, was considered as a new, generic class of threat to navies. Defence experts continued to assume that existing ship defences were sufficient.

1-1 : The Exocet anti-ship missile was a formidable new generation weapon.

Reports in the early 1970s that the French Government was willing to consider sales of Exocet to countries in South-East Asia — Australia's area of special interest — caused Scot Allison, an Australian electronic warfare specialist within the then Weapons Research Establishment (WRE), Salisbury, South Australia, to take special notice. Allison was a mathematician who had joined WRE during the early 1960s, and had worked on several United Kingdom guided weapon programs as well as in electronic warfare. He was aware, therefore, of the potential of sea-skimmers such as Exocet, and challenges to be faced in defeating them.

Allison concluded very early that most warships would be much more vulnerable to Exocet-type missiles than to Russian missiles, because several options were already available for defeating the Soviet variants, but virtually none for sea-skimmers. And it appeared that Exocet was going to be available to Australia's neighbouring countries.

The United States Navy, with its massive investment in missile, gun, and on-board electronic warfare systems, aimed at countering the Soviet threat, was unlikely to divert attention to address counter measures to 'friendlies' in the early 1970s. In fact, United States policy reflected that of many NATO countries, which was not to develop counter measures specifically against the weapons of friendly countries. This position of the United States, echoed by the United Kingdom, remained throughout the 1970s.

The development of the French Exocet was not the only offensive missile to be developed because of the sinking of the *Eilat* in 1967. The United States Navy adapted the requirements and preliminary designs for a new missile proposed by McDonnell Douglas to be launched from P3 Orion aircraft to attack Russian submarines. Development of the missile, now known as Harpoon, commenced in 1971 and entered service in United States Navy surface ships in 1977. The capabilities of this weapon exceeded those of Exocet and production and sales of it were twice those for Exocet. It did not figure highly in early studies but later became another strong influence on the need for self protection measures.

Engagement modelling efforts at the United States Naval Research Laboratory

Detailed engagement modelling suitable for the evaluation of counter measures techniques commenced in NRL in the early 1970s. There were some efforts in engagement modelling under the Effectiveness of Naval Electronic Warfare Systems (ENEWS) program but this was primarily aimed at addressing force level issues. Detailed descriptions of weapons seekers and their reaction to counter measures were not included in these models.

Limitations in intelligence meant there was no facility to deal with uncertainties in threat radar configurations. By 1970, the Advanced Techniques Branch at NRL under Russel Brandenburg was charged with responsibility for developing models and simulations for evaluating counter measures techniques against the full range of Soviet anti-ship missiles. This work was in its earliest stage when Scot Allison joined NRL in 1970. Tim Consroe and Laird Moffett later developed a detailed simulation of the Soviet Styx missile in an extensive counter measures environment. This work, led by Joe Lawrence in the Advanced Techniques Branch, then headed by Jerry Friedman, was later extended after Allison's departure to cover a wider spectrum of threats and counter measures.

Although the work began from a relatively low base, the environment in the Advanced Techniques Branch was ideal for engagement analysis and modelling. This was because:

- There was a well documented data base on the SSN2, and partial, but still good, data bases on many other Soviet threats and Soviet tactics;

- There were tests and trials programs using air-borne threat simulators, which provided experimental data against which to compare model predictions. The SSN2 simulator experiments were led by Norm Lesko and Dave Woodson, and while they did not believe in modelling and simulation, they were valuable sources of information;

- There was an extremely useful data base on ship radar cross-sections, giving variations with respect to aspect and polarisation, without which the modelling could not have proceeded;

- There were experimental (hardware) programs on chaff and on-board/off-board repeater techniques, led variously by John Montgomery and Rich Thorn, which provided more experimental data on counter measures performance.

NRL's Advanced Techniques Branch was unique in a global sense in providing such a high level of support to engagement modelling for electronic warfare purposes. There was, of course, considerable scepticism within Advanced Techniques Branch and the Tactical Electronic Warfare Division at NRL, more generally, about the value of computer modelling to predict electronic warfare performance. Some believed there was a necessary choice between either hardware development and testing, or computer-based development, and opted for the former.

1-2 : Studies by DSTO's Scot Allison concluded that an active off-board decoy was the most effective means to counter the new generation of missiles. He fought for the acceptance of this new decoy system in all forums, from the laboratory to the most senior echelons in the Australian and the United States navies.

Ship modelling in Australia

Australia's capabilities in ship defence modelling in the late 1960s were virtually non existent. This concerned Scot Allison's supervisor, Alex Biggs. Recognising that Allison had developed some advanced techniques in the modelling of ground-to-air missiles such as the United Kingdom Bloodhound, Biggs believed an exchange with the renowned United States NRL might provide an opportunity for valuable intellectual exchange. The aim was to develop computer-based design techniques that would allow exploration of new counter measures concepts without having to resort to protracted and expensive at-sea experimentation, which had been the standard approach used by NRL's Tactical Electronic Warfare Division during the 1960s. This indeed proved to be the case and Scot Allison became immersed in the analysis of counter measures to existing and emerging Soviet anti-ship missiles following his secondment to NRL.

This attachment, and others that followed, had a major impact on the success of the Nulka program, and highlighted the importance of The United States Navy/Australian Personnel Exchange Program.

On his return to Australia from NRL in 1972, Allison was determined to introduce to the RAN his ideas on countering emerging naval missile technologies, but he soon discovered there were few sympathisers in the Department of Defence, and he quickly became aware of barriers to the development of electronic warfare in Australia.

1-3 : Commander Keith Callins was the first RAN Director of Electronic Warfare, Navy, and sponsored Allison's original work. He was a vigorous protagonist of electronic warfare within the Australian Navy.

Callins and Allison considered using the Kibbitz rotary wing vehicle from Dornier Aeronautical as a platform for electronic warfare and surveillance research. However, this vehicle was tethered to a ship, so was never a candidate as an active decoy.

Still, Allison found an important sympathiser in the first Director Electronic Warfare, Navy (DEW-N), Commander Keith Callins, who was deeply committed to electronic warfare and had founded the first Navy Tactical Electronic Warfare School at HMAS *Watson* in 1963. Callins had developed a clear understanding of the research being undertaken in the international community during his posting as Australian Naval Representative United Kingdom in 1970–1973, and later sponsored Australia's participation in The Technical Cooperation Program (TTCP)[4] and America, Britain, Canada and Australia (ABCA) forums.[5] This latter forum became an important source of information exchange for Australia and was enthusiastically supported by Callin's successor, Commander Robin Herron.

Keith Callins sponsored a research program defining the need to protect ships against generic missile threats on the premise that Australia might eventually stimulate interest on the topic in the United States.

Allison's early paper on integrated ship defence, developed in 1973, addressed electronic warfare effectiveness against the sea-skimming class of missile as part of an integrated combat system incorporating radars, weapons, and electronic warfare. He had obtained, fortuitously, through Keith Callins, some very useful but incomplete information on these types of missile, and was able to develop a detailed simulation of the system, including a 'pulse-by-pulse' simulation of its radar seeker based on his earlier Bloodhound work. John Gardner, a research scientist who had also worked in the United Kingdom-Australia Joint Project, joined Scot Allison and modelled the guidance and control, aerodynamics, and propulsion systems based on information and pictures published in open literature concerning Exocet's flight performance. He also modelled the height control system and acceleration measurements thought to have been necessary for the missile to skim close to the sea surface. Helen Johnson also supported this work through documentation of the model.

Scot Allison's analysis of sea-skimming principles showed that a missile using a radio altimeter alone for height control would have a high probability of hitting the sea. He showed that an inertial based sensor with integrating accelerometers was required in addition to a radio altimeter to fly a fixed height trajectory over the ocean swell. This inertial navigation system would have to be of a reasonably high quality, with a position accuracy of one nautical mile per hour, and would be very expensive, at approximately A$200 000, and very bulky. Allison wondered why the French would go to this level of cost to fly so low. He became convinced that it was because everyone suspected that approaching under radar coverage would be an advantage, and that this hoped-for advantage must have been tested and validated by the French who must have known how vulnerable warships would be.

There were other reasons for having an inertial navigation system, but not one of this high grade and consequent high cost.

Scot Allison noted:

In one fell swoop, the introduction of this second generation of anti-ship missile massively reduced the effectiveness of defensive missile systems, nullified close-in gun weapon systems (through the anti-ship missile's ability to manoeuvre) and defeated on-board electronic counter measures and chaff. That is, it created a gaping hole in ship defences even if detected early, but the situation was likely to be worse because its sea-skimming capabilities made late detection the norm — as was revealed subsequently in real life experiences in Falklands and Persian Gulf operations. To overcome these defensive deficiencies, one would have had to do the impossible and (variously) raise ship radars many metres up their masts or acquire gun systems that had guided rather than ballistic projectiles (still under development in 2005). Alternatively the passive homing Rolling Airframe Missile (RAM) would have to be made capable of dealing with multiple threats — not a simple task, and not possible in those times. Yet, at the time, the potential threat of the sea-skimmer was very much under-estimated by navies, especially by the weapons communities. For example, the new Phalanx Close-In-Weapons System (CIWS), with its ability to throw up 'a wall of shells', was reckoned as the way to solve the problem, but the reality was that the wall would have been erected in the wrong place.

It was clear that a small missile approaching very close to the sea surface would not be detected until it was relatively close to its target, and therefore the number of defensive missile salvos that could be directed against it would be reduced. In other words, it would take fewer sea-skimmers to kill a target using this tactic, and this would more than offset the additional unit cost incurred by fitting the expensive inertial navigation system. Furthermore, this grade of inertial system enabled improvements to be made in the quality of targeting at launch, and, if needed, the programming of trajectories for sea-skimmer salvos to impact simultaneously and thereby overcome active defences. It was also true that those active defences would be less effective because the attack was flying very low, which meant the defending missile was likely to detonate incorrectly as the fuse was confused by the sea surface.

Allison's modelling showed that an active off-board decoy with a specific set of design parameters was a much more effective solution, particularly when used in conjunction with existing defence systems. A layered approach to ship self-defence was needed and the off-board decoy would provide another very effective layer to attacks detected in the middle distances from the ship.

The active off-board decoy he had in mind comprised an electronic payload and a carrier vehicle to behave with ship-like characteristics. The payload would confuse the missile — or missiles — electronically and cause them to miss the ship. The physics of the decoying action against anti-ship missiles were well understood at this time and had been successfully demonstrated in the field by both the British and United States navies in the 1960s.

However, Allison and Gardner also found that decoy characteristics would need to vary depending on the type of attacking missile. There was no 'one size fits all' set of characteristics that could be employed universally. There were two particular criteria to be met in the case of sea-skimmers, which had not applied previously in relation to existing Soviet or United States designed anti-ship missiles. One criterion directly affected the payload and made the design of a payload antenna system particularly difficult in a small space. The other criterion put special demands on the motion of the carrier vehicle, which ruled out many vehicle options. Australia's solutions to these key issues were both innovative and unique.

A key technology would also be required to make the payload viable. This was low cost, high power with a wide bandwidth. Very few countries, with the exception of the United States, had a significant capability in that technology. As well, the decoy had to be physically realisable within limited space and weight constraints.

The requirements for the carrier vehicle were becoming apparent, but as yet there were no obvious solutions.

The importance of international cooperation programs

The service-based ABCA-4 and research-based TTCP forums to facilitate cooperation between the governments of the United States, United Kingdom, Canada, Australia and New Zealand played an important role from the earliest stages of the Nulka technology development. ABCA-4 had a significant degree of control over the TTCP Subgroup Q program, thereby ensuring a strong customer focus. At the time, Subgroup Q was unique in TTCP for having this internationally directed customer focus that proved highly successful because the research was directed towards high priority navy operational requirements.

Allison realised the importance of suitable travelling wave tubes to the success of the off-board decoy concept and the lack of such a capability in Australia, and quickly identified the need to forge a close relationship with the United States. This posed a stumbling block for two reasons: firstly, travelling wave tube technology was deemed by the United States as 'critical defence technology', with information subject to very stringent release criteria; secondly, Scot Allison believed he would have to convince policy advisors in the United States Navy, who did not perceive western-type missiles to be a threat, that inertial navigation systems were likely to be introduced into future variants of Soviet missiles. So he needed to address United States operational requirements as well as those applicable to Australia.

Despite Allison's success within the TTCP community, official resistance continued in the naval and defence funding establishments in both the USA and Australia.

Allison's decision to submit his work to TTCP proved to be pivotal for Nulka. He believed that convincing the United States — and Australian — authorities could be achieved only through a bottom-up 'education' process, where results of his work could be scrutinised by world experts in the field. The relevant multi-nation TTCP forum on naval electronic warfare, Technical Panel QTP-7, offered an opportunity for that body to take ownership of his idea.

Technical Panel QTP-7 backed Scot Allison's work, and with support from Ted Hayman, the Australian National Leader of TTCP Subgroup Q, and Commander Keith Callins, the Subgroup created a new Technical Panel (QTP-11) towards the end of 1974 to consider the issue. Allison took on the task of proving the operational need.

Results of the decoy study were not appreciated and accepted by QTP-11 until 1976–1977; then the parent body, TTCP Subgroup Q, accepted the Panel's recommendation for future off-board decoy based counter measures. This acceptance laid the groundwork for off-board counter measures development programs in each participating nation, and particularly and, ultimately, the development of Nulka.

Still, official resistance continued in the naval and defence funding establishments in both the United States and Australia despite Allison's success within the TTCP community.

Allison thought he might be 'losing the war', because there remained continuing official disinterest in counter measures to sea-skimmers in both the United States and United Kingdom. This left Australia in the position of being the only nation within the western alliance doing anything substantial in systems development, except for low cost studies entirely funded by the defence research laboratories in this field. However, this work proved useful in the 1980s, because the sinking of HMS *Sheffield* and later, the damaging of USS *Stark*, both by Exocet missiles, caused navies everywhere to realise the inadequacy of their former defensive strategies for protection of ships from missile attack.

Australia became recognised as the leader in the field because of the pioneering work initiated by Scot Allison. The United Kingdom and the United States began to appreciate the deficiency in the defence capability against the new generation missile threats. But still the Australian decision-makers did not exactly rush to address this deficiency.

CHAPTER 2

Early technology efforts in the United States and Australia, 1975-1981

Recognising the need to put more in-depth efforts on counter measures to the emerging anti-ship missile threat, the government research laboratories at the NRL and DSTO stepped up their respective programs on systems simulation and critical hardware developments. In Australia, this work culminated in successful flight demonstrations of the hovering rocket, 'Hoveroc', which opened the doors to further development and collaboration with the United States.

Collaboration became a prime objective for the nascent program.

Two Australian defence researchers, Scot Allison and Bill Dickson, met in early 1975 to determine means to overcome resistance within the Department of Defence to electronic warfare technique developments in Australia. Dickson had recently returned from an attachment to Rear Admiral Julian Lake's staff at the Airborne Countermeasures Branch of the NRL in 1974, where he worked on the joint service testing of the United States Navy and Air Force airborne counter measures. Dickson led the test team that also worked with the Applied Physics Laboratory of the Johns Hopkins University. This work provided him with access to privileged information, an understanding of counter measures hardware issues, and, most importantly, gained Lyn Cosby's respect for Dickson's abilities, which was to have a later impact on Nulka. Moreover, Dickson had learned that the United States had recently made a breakthrough on lower cost, high power, travelling wave tubes, which was the critical off-board decoy technology.

Collaboration thus became a prime objective for the nascent program. As do all good engineers and scientists, Scot Allison and Bill Dickson dreamed of building a demonstrator decoy, with the intention of encouraging collaboration with the United States. More importantly though, the pair agreed that Dickson would concentrate on implementation of the hardware solution of the decoy concept, while Allison continued to address operational issues and define operational requirements for both the Australian and United States navies. Allison was required to lobby and persuade key Defence people, and to promote and establish the concept within the international community. The decision to articulate the need for this new concept, as well as addressing the solution to the need, became a defining moment for the future program.

Allison convinced his managers to fund studies to define more clearly the technical requirements of his proposal for an off-board decoy to counter sea-skimmers. Bill Dickson very rapidly assumed the role of Technical Feasibility Leader, developing a 'straw man' set of requirements for the decoy vehicle, payload and system. He also began to promote awareness of the venture within DSTO and to explore the availability of critical payload components and devices from international companies.

Thus began the process of putting flesh on the bones of the idea. The decoy project had begun to gather momentum.

2-1 : The late Commander James Armstrong as Deputy Director Electronic Warfare, Navy was influential in defining the Naval Staff Target for an active decoy capability. Seen here with his wife Anne, he was widely known for his expertise in electronic warfare.

Bill Dickson went on to define the initial version of all system requirements, including the flight parameters, wind effects, and — later — launcher issues, location on a ship, and matters related to integration with a ship's combat system. Space and weight for the launcher and stowage containers on a ship were critical factors in having a system accepted, so they had to be minimised. There were the more familiar criteria including required payload power, bandwidth, sensitivity and minimum decoy lifetime, which would be needed to protect different classes of ship. The key performance requirements for the carrier vehicle demanded that it should not require data transmissions once deployed, that it accept a programmable trajectory prior to launch, and that its speed should not be greater than that of a ship while flying very low above the sea. However, the most important features were that it should be very quick to deploy and be deployable safely in all weather conditions. Clearly, it was also important that the decoy be produced at a reasonable price because it must compete initially with inexpensive chaff cartridges.

This early definition of the system requirements was the focus of attention for those seeking a solution to the problem of a suitable vehicle to carry the payload and became the starting point for the more detailed studies during the Advanced Feasibility Study phase of the initial Project Winnin that was approved in March 1979.

At this time there already existed a sizeable body of decoy theory developed by the electronic warfare community which was supported by modelling and field tests. The modelling predicted that the off-board active decoy would be effective against Exocet and many other anti-ship missiles within the assumptions made. The major uncertainties concerning decoy effectiveness occurred because of limited knowledge of threat characteristics and the environment, particularly at low altitudes over the sea. The uncertainty was heightened by lack of intelligence concerning the never-ending interplay between counter measure designers and missile designers, because it was never known who was in the ascendancy.

Initial theoretical system studies by Allison, showing successful seduction of modern anti-ship missiles by an active expendable decoy, represented the ship target by a radiating point source of fluctuating amplitude. Vic Sobolewski, a research scientist in DSTO's Electronic Warfare Studies Group, investigated anti-ship missile seduction in a more realistic operational and physical environment by developing more realistic computer models of the decoying process. Sobolewski supported Scot Allison's earlier conceptual studies in 1978–1979, by introducing simple multipath reflections off the sea surface, prominent for the low angle of attack geometries faced by sea-skimmers, into his free-space, statistical, point-target models of the ship radar reflections — radar cross section.[6] This 'multipath' caused the radar cross section to fluctuate.

The most important improvement was to devise a model showing how a real ship appeared to the radar seeker in the sea-skimming missile. Sobolewski's investigations in 1980–1981 showed that a real ship appeared as multiple reflectors distributed over the length and height of a ship, which, together with multipath, caused the radar cross section to fluctuate, and the aim point to shift, or 'glint'. There was little ship radar cross section data available at this time and Sobolewski had to be satisfied initially with a median value based on broad brush figures discussed within the TTCP community. He later used a three dimensional envelope based on scaled measurements of ship models from British colleagues. This was included with the decoy attitude, motion and related parameters, including proximity of the sea surface, to derive more realistic radar signals received by the missile seeker. Around 1983, second order effects on the decoy — including decoy sea surface reflections and decoy-ship reflections — were also examined. These models later had to be compared with measurements taken from ships. Optimum decoy trajectories were produced with Bob Davies' support, combined with Allison's and Gardner's sea-skimmer model.

2-2 : DSTO's Vic Sobolewski developed realistic simulations of the radar frequency characteristics of ships and the effects of the sea. His work had a major impact on payload systems studies.

The earlier models developed by Allison and Gardner were sufficient for determining key decoy parameters such as power level, antenna characteristics, and payload sensitivity and delay. Sobolewski's work allowed a more detailed examination of decoy behaviour in the close-in environment surrounding the defending ship. It was here that failure to identify and attend to details could lead to reduced performance.

Additional resources were needed by June 1981 to address the ever-growing tactics and decoy systems issues. Consequently, an expanded team led by Gino Beltrame, that included Ron Evans and Cos Melino, adopted a three degree-of-freedom model of the vehicle developed by Mather Mason from the Aeronautical Research Laboratory (ARL) in Melbourne. Beltrame and his team used this and Sobolewski's radar cross section/multipath models to form a decoy effectiveness model. This model used updated aerodynamics from the Government Aircraft Factories vehicle team in Melbourne in order to obtain realistic tilt angles for the decoy vehicle in flight. A representation of the payload characteristics including antenna beamwidth and pointing angle was also included.

Gino Beltrame used the one-on-one model to study decoy deployment tactics and produced contours of missile effectiveness versus ship aspect and the range of speed and track angle values that would be suitable for the vehicle. He also investigated payload power requirements as well as the effect of changing antenna beamwidth and pointing angle.

Bob Dyne of Central Studies Establishment, quite separately prepared a report to inform the Canberra Central Office on issues relating to decoy effectiveness, including the impact of attack from any direction. During this time, Vic Sobolewski and Bill Dickson reduced the complexity of dealing with many threats by dividing them into three categories. This enabled them to define the key decoy positioning requirements for each scenario. These simplified positioning scenarios were of great assistance in the early work at the Government Aircraft Factories to define the flight control system.

The Aeronautical Research Laboratory's involvement in vehicle modelling grew during this time, and Rodney Brown set out to generate a far more detailed, but portable, model of the decoy by adapting an existing model of Ikara, the Australian ship-launched rocket that deployed a torpedo. This would later be used for research activities at the Aeronautical Research Laboratory. Mather Mason's model was used to study the effects of wind and other environmental factors on the position of the decoy and showed that decoy requirements would be determined by a single scenario. It came as no surprise that this scenario was based on the sea-skimmer case. The launch phase positioning for the decoy was crucial to success against this threat.

Evolution of decoy electronics technologies including broadband travelling wave tubes in the United States

There was a tendency by United States Navy planners to focus only on short term, identifiable threats, but NRL's Tactical Electronic Warfare Division took the view that the Navy could be confronted by technological surprise at any time, and that new counter measures would be required to deal with any new situation. This led to several programs that examined advanced concepts for counter measures, as well as development of new electronics technologies to support implementation of these concepts. One key focus was on off-board decoys and their associated electronic components. Such decoys were generic in nature and, when deployed correctly, were effective against a wide range of radar seekers.

The significance of these pioneering efforts was that, for the first time, people were able to understand what aspects of decoy counter measures could be handled by existing technology, and those requiring additional research and development. Suitable vehicles for decoy carriage, and affordable wide band, high power micro-wave devices, were identified as major problem areas needing to be addressed.

The thrust of United States research in off-board decoys had two elements: firstly to employ off-board decoys as alternative targets and so divert attack from actual ships ('dilution decoys'), and secondly in the seduction role of diverting the missile away from the ship after the missile seeker has locked on to the ship.

Exploratory decoy research at NRL during the late 1960s and 1970s was led primarily by Lyn Cosby, Superintendent, Tactical Electronic Warfare Division. A key focus was the development of wide band travelling wave tubes as affordable power sources for electronic decoys. Historically, travelling wave tubes were expensive and used almost exclusively for platform based electronic counter measures. The aim was to trade some travelling wave tubes performance parameters, such as tube life time, in exchange for lowering their cost by notionally at least an order of magnitude. This approach stimulated considerable interest from United States industry and helped to make the concept of using travelling wave tubes in off-board applications a practical proposition.

Attention through these years turned to the use of travelling wave tubes in expendable applications. This led to experimental developments in high power, wide band travelling wave tubes that could be packaged in a small vehicle and meet the associated requirements for warm-up time, ruggedness and storage life.

A key requirement was that the decoy needed no on-board ship maintenance and long storage life. This became known as the 'wooden round' concept. Associated with this was the non-negotiable requirement to use fixed, non-trainable launchers because of the penalties of top-deck weight and cost.

NRL's efforts changed the perception of off-board decoys from that of a futuristic possibility to something that could be developed in the near term.

In the late 1970s the United States Navy's Reconnaissance, Electronic Warfare, Special Operations, Navy Office released Requests For Proposals for an active electronic decoy and an active electronic buoy, both to be launched from the MK 137 Super Rapid Bloom Off-Board Chaff launcher. The active electronic decoy was designed as an airborne seduction decoy, while the active electronic buoy was to be deployed in the water from the ship to create a significant separation distance. It was then to function as a distraction decoy with a radio command link to the ship. The active electronic decoy work was awarded to Raytheon and Sanders Associates — now BAE Systems — with NRL also being funded to develop a version: the Active Electronic Buoy development was awarded to Dalmo Victor.

Wes Libby and Dave Donovan were on the winning Raytheon team. Both of them joined Lockheed Martin Sippican, a private defense electronics contractor located in Marion, Massachusetts, in the 1980s, to initiate that company's industry research and development efforts aimed at capturing the Ship Launched Electronic Decoy work, which was to evolve into the development of the Nulka payload. Raytheon and Sanders both delivered decoy designs that met the prime requirements for performance with an ability to transmit and receive signals simultaneously. However, NRL was unable to

2-3 : Bill Dickson had an in-depth awareness of electronic warfare and galvanised resources to find solutions to requirements for a decoy. His energy, enthusiasm and persuasive abilities provided impetus to the project from the beginning, and for many years afterwards.

meet this requirement and delivered a prototype with a switch to implement this function. The United States Navy did not proceed with the anticipated development program due to uncertainty regarding a viable flight vehicle that remained unresolved until the Australian government offered the Winnin flight vehicle to the United States in the mid 1980s. A prototype active electronic buoy was completed, but the engineering development did not start until the early 1980s, and did not proceed to production.

NRL's efforts changed the perception of off-board decoys from that of a futuristic possibility to something that could be developed in the near term, should advances in threat missile systems occur. This view was increasingly endorsed by the United States Naval Electronics Systems Command (NAVELEX), in part because of its understanding of the manner in which naval warfare had changed because of events in the 1970s Yom Kippur War. In particular, Rear Admiral Julian Lake, then head of NAVELEX, emphasised the need to apply lessons learned from this war to future United States Navy operations.

Certainly, both Scot Allison and Bill Dickson appreciated the work done by NRL during their attachments to that organisation. Both had backgrounds in guided weapons systems and knew that many existing electronic warfare techniques were reaching their practical limits. They formed the firm belief that new solutions such as active off-board decoys were required. The United States Navy's position on dealing with immediate Soviet threats limited initiatives in operational off-board decoy developments, but the scene was set for others who found themselves confronted with more sophisticated and capable threats of western origin to exploit off-board decoy concepts and technologies pioneered by NRL.

Development of 'hovering rockets' in Australia and related technologies: early concept studies

Early Australian systems studies led to a refinement of the top level decoy parameters, and gave impetus to Dickson's energetic efforts in exploring the vehicle concepts, and engaging experts across and beyond DSTO. The interesting but difficult job was to find a suitable carrier vehicle, and options included balloons, parachutes, rockets, gliders, towed autogyros, fixed wing aircraft, rotary wing aircraft and boats. Most options were quickly eliminated, but the use of helicopters looked promising.

Australia strongly encouraged Don Northam, on exchange from NRL in 1975, to work at the Australian defence laboratories on a modelling and simulation study into the viability of the helicopter option for use as the decoy vehicle. Australians working on the decoy project believed that this might also facilitate potential future collaboration with the United States. Don's studies were critical. He showed that the helicopter must have full twisting/flapping blades, and that the power system would need to spin up the blades very quickly if it was to perform into the wind, as well as sustain rotation throughout flight. The initial concept was to have the helicopter deployed upwards using a separate launching rocket and then have the rotor spun up using some means of providing thrust through jets at the tips of the rotor blades. This problem of finding a suitable method for sustaining the vehicle definitely needed propulsion expertise.

2-4 : Don Northam was on exchange from NRL when he first made a contribution to Winnin. Twenty years later he returned to NRL and, among other tasks, led the development of a United States Navy captive carry unit and various bench trials and led the captive carry of the payload in various at-sea trials of the Nulka payload.

The need for access to a wide range of skills and disciplines was presented to senior management of DSTO in late 1976. Cyril Cook, then Director of Weapons Research and Development Wing, called for a panel of experts to address the search for a suitable carrier vehicle. The first meeting in February 1977 was chaired by Phil Pearson, from the Aerodynamics Division, and members included Dr John Baxter, Bob Irvine and Bill Jolley from Propulsion Division, Mary Evans from Aerodynamics Division with Bill Dickson and Don Northam from the Electronic Warfare Division. John Baxter was the Senior Principal Research Scientist in charge of propulsion engineering and a noted entrepreneur; Bill Jolley was a relatively new scientist working for Bill Bradfield, but was an experienced scientist with expertise in both liquid and solid propellants.

The propulsion group first considered propelling the rotor using a solid fuel gas generator at the rotor tip. Bill Bradfield then suggested it might be possible to pump hypergolic propellants to the nozzles in the rotor tips where they would ignite spontaneously, though this could prove very tricky with rotating rotors. Bill Jolley wrote ‘We also talked about using a liquid fuel — Iso Propyl Nitrate, IPN — fed up through the rotor hardware. But we quickly quashed those ideas as unworkable and dangerous’. However, records show a helicopter with the IPN stored in the rotor stabilising weights was studied further during the program from 1983. There remained questions about whether the rotor blades should be fixed or contra rotating and how to deploy the blades from a packaged position. The difficulties in powering the rotor blunted the enthusiasm for helicopter use, so the search for new ideas continued.

Don Northam's investigation of the helicopter option prevented the Department wasting considerable resources.

Don Northam's study was not encouraging, but it saved Australia the potential waste of significant resources in proceeding with a costly experimental program. In addition to this, Don's work progressively exposed the complexities associated with deploying and controlling a rotary wing vehicle in the low altitude maritime environment, and identified the stringent requirements for any power plant that would sustain the vehicle for the duration of the decoying operation. The effect was to narrow the range of viable vehicle propulsion options and, in the process, to eliminate the most obvious, attractive but impractical of these. In this way Don contributed to the establishment of a climate of seeking 'outside the box' solutions that spawned the multi-disciplinary approach which led to the proposal for a thrust vectored hovering rocket.

Bill Jolley recalled initial meetings of the expert panel:

At about the third meeting I suggested the possibility of using a rocket vehicle standing on end because, at least in principle, I knew that it was technically possible; after all, they had landed on the moon that way a few years before. I hadn't worked out any details of the implementation, but felt convinced that it was feasible. The details would need to be developed by people with expertise in those areas. John Baxter was not overly enthusiastic about the idea, although he must have had second thoughts and later consulted with Bill Bradfield. Bill did some quick calculations and informed John that in principle a rocket could provide the power requirement to enable a vehicle to hover for the duration then being talked about.

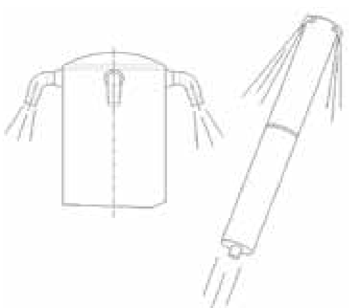
Bill Jolley's idea started a stream of new vehicle concepts based on the idea of it being held aloft by the thrust of a rocket motor. Consideration was given to liquid propellant rockets, but the weight and major safety issues with fuel fires made it most unattractive.

Thoughts that 'it would be nice to do with a solid propellant rocket' emerged, but initially were considered unrealistic because of lack of thrust magnitude and vector control technology, particularly for a rocket where the weight would diminish dramatically as its propellant burned. Nevertheless, despite these difficulties, the idea of using a solid propellant rocket gained support and became the basis for all future considerations of a rocket solution.

Two proposals suggested the payload be supported by a rocket motor mounted on top of the vehicle. The thrust to support the payload required that the motor gases be redirected downwards. The first of these ideas had three 'gooseneck' shaped long nozzles emanating from the outer top edge of the motor and curved around to direct the efflux downwards.

As for the helicopter, the vehicle was to be projected skywards using a separate rocket motor and then the thrust from the 'gooseneck' nozzles would keep the vehicle aloft for the required time. One difficulty was that such vehicles naturally oscillated.

2-5 : DSTO's Bill Jolley proposed that a vertical rocket, after the style seen landing a man on the moon, might be a concept to pursue. The term 'Hoveroc' was born.



2-6 : Sketch of the 'Gooseneck' Vehicle. An early idea was the inverted rocket using nozzles at the top. The payload hung below the rocket motor, after being ejected skywards using a separate motor.

2-7 : Sketch of the 'Directly Supported Rocket' vehicle. One of several ideas preceding the 'Hovering Rocket' was a large conventional rocket motor with multiple nozzles. The thrust was to be varied in the secondary nozzles.

The alternative to the gooseneck nozzles was to use a device which used the 'Coanda' principle to change the direction of gas flow by having it attached to a convex surface. The team understood that 'Coanda-effect nozzles' were used on a Russian sustainer rocket motor designated the RPG-6, but none knew whether it would work for a 180 degree change in direction

Certainly, ideas for supporting a payload using rocket motors appeared more promising than the helicopter, but the vehicles could not be very accurately positioned in space. Additionally, there was a belief that payload performance would be affected by ionised gases thought to be in the motor efflux.

Neither the 'Coanda' nor 'Gooseneck' ideas lasted very long, but Bill Jolley and Bill Bradfield coined the name 'Hovroc' for the concept. This was soon changed to 'Hoveroc', short for 'hovering rocket' and the nickname stuck.

2-8 : John Baxter, from Propulsion Division, played an important entrepreneurial role in bringing together Alan Smith's flight vehicle and dynamics experience with Arnold Deans' rocket motor and thrust vectoring experience. The 'Hoveroc' evolved.

In subsequent years, both the Chief Defence Scientist (Dr John Farrands) and the head of Force Development and Analysis (George Cawsey) expressed the opinion that the hovering rocket vehicle could not be made to work.

Dr John Baxter, like Bill Dickson, was active in persuading other experts to assist. Alan Smith, the chief designer on the Turana target drone development at the Government Aircraft Factories at Fishermans Bend, Victoria, had air vehicle systems experience from the earlier Malkara wire guided anti-tank missile, Ikara and Jindivik target drone development projects. So it was logical to invite Alan Smith to join the group. Similarly, Arnold Deans from Propulsion Division, who had extensive rocket motor experience on the Malkara and Ikara projects and had designed the booster motor for the Turana drone, was asked to join the quest. Much dialogue between Bill Dickson, John Baxter, Alan Smith and Arnold Deans followed.

A top-mounted rocket motor with nozzles at the top was desirable from a stability point of view, but Alan Smith pointed out that, with active control, a rocket with the nozzle at the bottom could be made 'stable', much like balancing a broomstick on a finger. Smith also believed that the rocket supported vehicle would meet its requirements only if both the vehicle attitude and height were actively controlled. Hitherto, the hope had been to adjust the thrust required by positioning a device prior to flight, and the inclusion of gyroscopes for the attitude control had been opposed because they were known to be expensive.

However, with a few calculations, Smith convinced Bill Dickson that it was not possible to meet the accuracy requirements without active control of height. This was a bold assertion because there was no known precedent for controlling the orientation as well as height for this inherently unstable vehicle. Smith was then able to explain that this vehicle could be moved at a certain speed and direction by tilting over. This proposed vehicle, with the rocket efflux at the bottom, now had an omni-directional manoeuvring capability that appeared to suit the requirements for an active decoy.

Several proposals were advanced for adjusting the rocket motor's thrust during the course of these discussions in April 1977. One of these was referred to as the 'directly supported rocket'. It proposed a solid propellant motor with multiple nozzles with the magnitude of thrust being varied by graphite valves housed inside the motor chamber. The valves were intended to affect the gas available to the nozzles. The attitude control was to be by means of pieces of metal being dabbed into the motor gas efflux. Records show that the vehicle length and diameter would be quite large for a very modest payload mass, albeit for a flight time that was nearly twice what

2-9 : GAF's Alan Smith (left) developed the basic idea of the 'Hovering Rocket' in conjunction with Arnold Deans (right) and provided the flight control experience to conclude this concept was achievable and the superior solution. The photograph was taken at the 'FSED Tenth Anniversary' in January 1998.

was later agreed upon.[7] Recollections are that there were no known precedents for the method of using a graphite slider valve inside the motor chamber. An alternative to the graphite valves involved using pintle nozzles as a secondary nozzle. These valves were known to exist and in their simplest form would turn the nozzle on or off. One of these was constructed in later years and shown to work. There were other proposals to vary the throat area of the main nozzle, but details of how this was to be achieved remain unknown, and perhaps were not known at the time.

However, Alan Smith and Arnold Deans considered precedents from previous projects. They believed that the piece of metal — referred to as a normal tab — that was used on Ikara and Turana to control attitude might be able to control height as well. The experience with a single axis of motor thrust vectoring indicated that those systems generated some thrust spoilage needed for height control, as well as torques needed for attitude control, which suggested that the idea of multiple tabs was worth analysing in more detail for this hovering rocket.

Initial estimates showed that the level of thrust spoiling from three tabs might be sufficient, but four tabs would be better.[8] However, it was essential that the motor thrust be made to reduce to match accurately the weight as the motor burnt, thus requiring a tapered motor charge. A viable concept for the carrier vehicle was born, and the 'Hoveroc' concept as we know it had begun to emerge.

Alan Smith presented the results of his deliberations to a gathering at Propulsion Division in May 1977.[9] For the first time, he defined the relation between motor mass, non-propulsive mass — which included everything other than the propulsion unit — and the flight time for the required tapered motor charge. This showed that a hovering rocket concept was feasible for flight times up to approximately half those initially believed to be required. Thrust vectoring requirements were achievable, but it was agreed that measurements be made on the thrust spoilage for multiple tabs as soon as possible. A full development study and preferably building of a prototype vehicle to demonstrate the technology were strong recommendations. Acceptance of this report provided the foundation for development of the vehicle now referred to as 'Hoveroc'.

Jim Crompton, Superintendent Systems Analysis Division, gave great support to these embryonic ideas and allocated his maximum delegation of A$30 000 for a more in-depth analysis. He also sought approval to put the investigation on the Systems Analysis Division's program of work. Arnold Deans pursued the spoilage of thrust using tabs. Lloyd Odgers, head of Rocket Motor Engineering group, and Bill Jolley at the Propulsion Division, studied the design of a tapered motor charge and worked with Alan Smith and Mal Crozier at the Government Aircraft Factories to consider the vehicle issues. Clearly, there was already a considerable range and depth of skills and disciplines available within Australia.

There remained many challenges. The thrust vectoring system of the rocket would be required to perform for a much longer time than anything used in Australia previously. It was known that the tab used on the Rodinga boost motor for the Turana drone eroded and wore away as the motor burnt. This tab was simply a piece of special metal inserted into the motor efflux to cause a change in direction and magnitude of the motor thrust. Arnold Deans proposed that a ramp tab, sloped to the efflux flow, would be necessary for this new long-burning application, though Alan Smith initially opposed the ramp tab idea because it was unclear how it would achieve the spoilage of the normal tab system. The behaviour of supersonic flow of hot gases was the speciality of very few people. Still, Deans completed the testing of a single sloped ramp tab over the next few months and all were delighted that the tests confirmed the expectation that the erosion would be less, and the spoilage performance was similar to the 'Rodinga' tab. The first test at least showed promise.

While Arnold completed these tests, Alan Smith pondered the advantages of the 'vertical rocket concept' over other contenders, particularly the helicopter. He concluded that this vehicle would be superior in clearing the ship in adverse weather conditions and that the vehicle should not be a fixed wing aircraft or one with a high aerodynamic lift-to-mass ratio. A low aerodynamic signature was necessary to ensure that adverse wind fields around a ship in storm conditions did not cause large, unsafe variations in the vehicle's planned trajectory.

DSTO funding allowed Mal Crozier at the Government Aircraft Factories to work with Alan Smith on developing the hovering rocket concept. Crozier's task was to develop a simulation model of the vehicle dynamics and motion, including a preliminary flight control system. The computer model included aerodynamics based on those for cylinders and bodies of revolution at high angles of attack. A rudimentary flight controller was developed to stabilise the tilt and direction. The three tab thrust vectoring system was included along with the shaped thrust profile. The ability of the vehicle to manoeuvre at launch could now be assessed.

The December 1977 report showed that the vehicle system proposal was eminently feasible. Mal Crozier's involvement in the total vehicle simulations, including design of the autopilot, was to place him in a pivotal role in the development of the first 'Hoveroc', and then the Nulka vehicle, which continued for more than three decades.

The 'Hoveroc vehicle' concept as the payload carrier became the favoured solution, but it was not adopted as the only solution immediately. Several years of studies and a flight test were necessary before there was confidence in the feasibility of the rudimentary aspects of such a vehicle. Even assuming it worked, the major issue remained its weight and size and whether it was compatible with the existing chaff launcher. It was apparent that there were advantages for the payload designers in a vehicle which did not have wings or rotor blades, but compromises on flight time to reduce the size were going to be difficult to accept and sell to the electronic warfare community. Later studies showed that the flight time could be halved, but weight and size continued to be a challenge. The helicopter proposal remained as an option and was proposed for further studies in later programs. Several variants of payloads also remained to be examined. Clearly, studies of many issues associated with this concept were required.

Seeking approval for a demonstrator project in Australia

The potential of the hovering rocket concept led the Australian defence laboratories to seek more substantial funding from the Department of Defence in order to demonstrate the technology with a flight test. The proposal did not include development of a counter measures payload for the vehicle but it included studies to investigate payload technologies and to study system issues.

The timing of the submission was not propitious. The Department of Defence was then undergoing huge change, including the creation of a centralised committee structure to approve expenditure. The approval process included an analysis of force level capabilities undertaken by the Force Development and Analysis Division (FDA), and created fierce competition for project funds across the Department. The defence laboratories had also recently transferred from the former Department of Supply, which was renowned for large development projects with large budgets, and their standing with the Department of Defence was not high. Lower-scale research-related projects required approval of a central defence authority, known as the Defence Science and Technology Committee, over which the Force Development and Analysis Division had a major influence.

> *Funding for an EW project was strongly opposed by the Navy weapons community, as this was seen as a competitor for the tightly controlled and diminishing defence budget.*

Moreover, the defence budget was shrinking and the national welfare budget was expanding. The Australian public was not particularly interested in defence, and hostility to Australia's participation in the Vietnam War had continued to fester in some sectors of the population. Furthermore, the strategic advice for the ensuing decade suggested there was no major military threat to Australia.

In this environment, the Navy weapons community strongly opposed the request for funding for an electronic warfare project because they believed this competed for the tightly controlled and diminishing defence budget.

The proposal, under the project name of Winnin, initially received little support from the department. But, after persistent negotiation by senior defence laboratory staff, the Defence Science and Technology Committee finally agreed to consider it on the proviso that a study be carried out addressing FDA's concerns about the relative contributions to ship defence of missile, gun and electronic warfare systems. Scot Allison was charged with the study, which was to consider attack scenarios, guns, missile defence systems and electronic warfare options. The study was also to look into the operational need for ship defence, considering Australian, United States and United Kingdom needs.

Fortunately, Allison had already done much of the work in the early 1970s, and he completed the task in about three months. For the scenarios specified, Allison was able to show that the 'hard kill' defences of destroyers and frigates would be vulnerable to saturation attacks by anti-ship missiles, especially low altitude attacks by sea-skimmers. He also showed that fitting the proposed decoy system would restore defensive capability of ships to an acceptable level. Central to this approach would be the adoption of a concept of integrated ship defence, using both 'hard kill' and 'soft kill' to best advantage.

Allison had presented the findings of his study on an integrated weapons and decoy defence system to the Defence Steering Group by December 1978. The study showed the benefits of an off-board active decoy integrated with 'hard kill' systems to overcome surprise and saturation attacks by sea-skimming missiles.

One clear and important situation that favoured the decoy approach was when multiple missiles approached the target ship within a short space of time. The guns and the rapid-firing, close-in weapons system, Phalanx, was unable to deal with this situation, though the decoy system could. Important also was the fact that Exocet was the first sea-skimmer likely to be used by the navies of South-East Asia, thereby making Australia particularly vulnerable. On this occasion, Allison and Dickson put the proposal before the key desk officers of the committee to address each of their concerns, while DSTO's Roger Creaser targeted the 'non-believers' in FDA. Finally, in March 1979, Chief Defence Scientist, Tom Fink, obtained unanimous Defence Science and Technology Committee endorsement, which paved the way for the 'Hoveroc' flight demonstration in May 1981 under the Winnin Advanced Feasibility Study (AFS).

Winnin Advanced Feasibility Study

The primary aim of the Winnin Advanced Feasibility Study was to build a vehicle and acquire a film record of flight that showed the concept of a hovering rocket to be feasible. In addition, there was a range of study tasks related to the operational system.

There would also be a vehicle and launcher study to define the broad weight and size trade-offs for a vehicle. The length and diameter trade-offs were of particular interest because of the need to fit the vehicle conveniently into the small diameter (130 mm) tube of the launcher used for chaff decoys by many navies. This launcher is referred to as the Super Rapid Bloom Off-Board Chaff Mark 137 launcher. The Propulsion Division was to examine motor charge options and the most appropriate propellant chemistry.

The likely cost of the decoy was a focus of attention and was overtly a driver in design proposals throughout the Winnin program. All involved knew that a customer would first consider the price of a chaff round, then the worth of the extra performance of this active decoy. No customer would give first consideration to the high price of 'hard kill' weapons. The price of a decoy had to be tens of thousands of dollars rather than hundreds of thousands because chaff was so inexpensive. That Bill Dickson, a research scientist, examined the cost of payloads showed how serious he and others in the project considered low cost to be a driver for an acceptable decoy solution.

Dickson provided an estimate of the likely number of decoy sales and completed a rudimentary estimate that a decoy could cost no more than US$20 000. In 1979, however, it was impossible to find information on key elements of the payload. Moreover, the United States — potentially the largest customer — had no stated requirement for a decoy, so this actual figure was somewhat academic. By 1982, the estimated overall cost per round had increased to US$30 000, arbitrarily split equally between the payload and vehicle. This target persisted for 20 years, in the face of huge effects due to inflation and reductions in forecast production rates.

As activities, enthusiasm and tempo increased, Bill Dickson, at a relatively junior level, was in a situation where he was responsible for a fairly high level of commitment from another division which was also funding the Government Aircraft Factories' efforts with propulsion research money. Dickson came under considerable pressure during this period and maintained his enthusiasm and drive in extremely difficult circumstances. Lloyd Odgers had no doubt that the propulsion commitment would have collapsed had Dickson faltered, and the ability to continue would have been overtaken by other events. Winnin would not have been completed — nor Nulka developed.

Rocket motor propellant studies

The search for the appropriate propellant for the production decoy vehicle began at DSTO's Propulsion Division in 1979. The studies were called PAVO, after a group of stars, prompted by Bill Bradfield's expertise in astronomy. Bradfield, Bob Irvine, Peter Winch and Bill Jolley were involved in the motor design studies, along with Juan Hooper, Brian Hamshere and Neil Ayres on the propellants.

There were two options for the charge. One was based on a cast composite propellant and the other on a cast double base propellant. Lloyd Odgers preferred the latter for two reasons: firstly, Propulsion Division and the RAN had extensive experience with this type in Ikara for both the RAN and Royal Navy; secondly, technology existed to make the propellant burning-rate almost independent of temperature. But Juan Hooper, an expert in the more recently developed cast composite propellant, favoured its improved physical and mechanical properties and its lower vulnerability to bullet and fragment damage. The latter propellant had desirable safety properties in fires and similar wartime environments, and for that reason was the preferred choice of the United States Navy in new missile weapon applications.

Both propellant options were pursued in the early phases of the studies. Juan Hooper and Brian Hamshere carried out research and development on the cast composite propellant option while Neil Ayres addressed the cast double base propellant.

The design of a minimum weight motor required the thrust to decrease as the motor burned, though the thrust was always required to exceed that weight by a known amount. The accuracy to which this could be achieved was crucial. Many PAVO motor firings were undertaken in such a manner as to quickly refine estimates of thrust as a function of temperature and manufacturing variations.

The charge for the PAVO studies was of a cylindrical design and inhibited on the outside with a uniform thickness of ablative-resistant material to ensure cigarette-like burning characteristics, and prevent cone burning around the edges which would lead to increased thrust. However, the most important part of the study was to establish which propellant technology to use. The propellant was required to have a much lower burn rate than any ever used before. It was also important to have a burn rate with low sensitivity

2-10 : DSTO's Juan Hooper developed the first platonised cast composite propellant. He made continuing contributions to the development of the motor.

2-11 : Bob Scott was Project Manager for the 'Hoveroc' vehicle development at the Government Aircraft Factories. He continued as a project manager from 1979 to 1991 as the program evolved to Full Scale Engineering Development.

to temperature. The weight of the motor and the thrust spoilage requirements would be minimised by having a low sensitivity to temperature. The alternative was to maintain a constant temperature in the launcher, which was an issue that remained the subject of much debate over ensuing years. The interesting thing about this motor was that the thrust and hence the pressure varied, but a constant burn rate was required. A recipe was needed to produce a plateau in the burn rate — no burn rate variation with pressure, a platonised propellant — as the pressure varied.

Only the rocket motor based on a cast composite propellant charge performed to specification in full scale rocket motor firings after two years of intense experimental work. Juan Hooper and Brian Hamshere had achieved what no others had done. They had developed a cast composite propellant with a plateau in the burn rate characteristics, low burn rate sensitivity to temperature, and at the required low burning rate range.

The cast composite propellant charge was selected for further development of the operational system. This was a good result, and meant the desirable performance characteristics of the cast double base propellant were now available in the new highly desirable and safer propellant being mandated in the United States. This was to facilitate the passage of the Nulka system through the necessary safety approvals. Later, in 1993, Brian Hamshere and Juan Hooper had their patent accepted for the copper chelate ballistic modifier which was the key to their success.

David Kilpin, Peter Hilton and Jack Braun addressed inhibitor technologies. A new vertically oriented motor firing rig was necessary because this represented the normal flight attitude. This was especially important in assessing how much the inhibitor actually added to thrust and/or contributed to the mass of combustion products through the mechanisms of ablation or burning. The flatness of the burning face, referred to as cone burning, was important because the net thrust over weight, as a function of time, was required to be constant.

So, after a long period of experimentation, a material was found with the right balance of properties to serve as a layer of insulation between the inhibitor and the outer case of the rocket motor. Peter Winch and Bob Irvine completed the search for a suitable material and undertook theoretical studies on cone burning. Bill Jolley had derived the detailed relationships between thrust profile, mass and the motor dimensions for any given propellant characteristics. These were important to the vehicle configuration studies being undertaken at the Government Aircraft Factories.

The early idea was that the motor was not required to have a long life because it was to be part of a high use, throwaway item. However, that idea changed and the charges were stored for long periods at elevated temperatures to predict the length of time the chemical agents would remain stable. None then appreciated that there was no need for speedy results of these tests because 14 years were to pass before the start of serious production for operational service.

2-12 : Lloyd Odgers of Propulsion Division, DSTO, was the 'Hoveroc' Program Manager. He managed the development of the propulsion unit and worked with the Government Aircraft Factories on the flight vehicle development.

'Hoveroc' experimental vehicle development

Lloyd Odgers, head of the Propulsion Engineering Group in Propulsion Division, was the obvious choice to be Program Manager for the 'Hoveroc' experimental test vehicle development work. He was experienced in rocket motor engineering and projects after working on all the major Australian motor developments for Malkara, Ikara and Turana. Odgers was the ideal choice to harness the variety of skills in Propulsion Division, as well as to liaise with the Government Aircraft Factories, the Explosives Factory, Maribyrnong, and the Ordnance Factory, Maribyrnong. Mike Jakab assisted Odgers as deputy project manager, project engineer and trials coordinator, and Arnold Deans became a critical member of the team.

2-13 : Mike Jakab assisted Lloyd Odgers as deputy project manager and led the preparations for the 'Hoveroc' trials. He continued as Project Manager of Propulsion Division activities into the Concept Development phase.

Bob Scott became the project manager at the design department at the Government Aircraft Factories and led the team of about nine people. He was known to many through his involvement on Ikara and as a project manager and designer for the majority of the Turana drone program.

The program for the experimental test vehicle was to demonstrate that a cylindrical vehicle, standing vertically and supported by a rocket motor, could be made to fly and move correctly at low height. The use of a modified sustainer motor — called Murawa from the Ikara weapon — allowed designers to use other existing major components which otherwise would be too heavy. It was serendipitous that this motor could be readily adapted to be the basis of this key experiment.

2-14 : The shortening of the Murawa sustainer motor is clear from the weld to the motor case. The use of this motor allowed the use of many existing components for the flight control system.

The weight of the vehicle and hence the motor length was determined by the initial thrust of that existing motor. But, as the motor burned the weight reduced. So the motor charge was tapered in a lathe as well as being shortened considerably, then reinserted into a shortened and rewelded motor case. Bill Jolley spent much of 1978 deriving equations and completing the definition of the overall geometry of the motor charge required for this vehicle.[10] The initial thrust was boosted for a short time by propellant material applied to the initial burning surface. This gave sufficient thrust impulse at ignition to enable a zero length launcher to be used. During the trials this was simply a stand on which the vehicle rested with clamps used to prevent the vehicle from falling over prior to launch. The clamps were removed at an appropriate time in the test. Fine wires strung across the face of the motor nozzle provided the signal to the autopilot that the vehicle was about to move.

The flight control system for this vehicle was relatively simple compared to the later Nulka flight controller. Pitch, roll and yaw angles were controlled as well as height. The controller was essentially linear and did not attempt to make use of the highly non-linear region of the thrust control unit being developed by Arnold Deans. This non-linearity became evident only at a late stage in the testing of the thrust control unit. However, one thing that appeared different about this vehicle was the high rate at which the mass changed — as a percentage of the total — compared to other vehicles. The effect of a mass rate change altered the normally used equations of motion, but this was not considered to be important. The control and stability analyses used computer tools developed for the Turana autopilot design to generate the small perturbation derivatives and transfer function required by the designer of the control laws. Frequency response methods were used to design the control laws that were then verified on the computer model of the flight vehicle. The flight controller for the vehicle did not use a digital computer but rather operational computing amplifiers, similar to an analogue computer.

2-15 : The completed flight control system showing electronics and top cover to the vehicle.

The effects of noise in the control system were of constant concern to Mal Crozier. The attitude stability was achieved using electronic differentiation rather than the more expensive option of providing rate gyroscopes. This was a technique used in Ikara and Turana. However, in the 'Hoveroc' it was known there would be vortex shedding off the cylindrical body at frequencies and magnitudes that were difficult to predict. The ability to filter these effects was limited by the analogue electronics. So there were trade-offs between stability and noise, which would be resolved only at the system's first free flight.

The system used an Ikara displacement gyroscope for pitch and roll angles, and a rate gyroscope for azimuth from the Turana drone. A pressure sensor mounted in the body measured atmospheric pressure, to derive height. The speed range was limited so that the effects of pressure distribution around the cylinder would not cause large height errors. The power amplifiers used to drive the four electric servo-mechanisms to operate the thrust control unit were from the Ikara production line. A telesender used on Turana was included, and a new technology lead acid gel battery used on motorbikes provided electrical power. The electronics to provide the flight and stability control demands from the sensor data were designed and manufactured specifically for this project. The tilt demands were hard-wired into this electronics but could be pre-selected at launch through an infrared communications link to the electronics unit, similar to a television remote control.

The aerodynamics used for the stability and control analysis was based on extensive consideration of the literature. No wind tunnel testing occurred. The maximum speed range was limited by the necessity to avoid the expected transition as the air flow around the cylinder changed from laminar to turbulent flow. This reduced speed range was significant, because it meant flight testing could be undertaken in a more limited space which meant it was less expensive and easier to obtain reasonable film coverage. It also meant the Proof Range at Port Wakefield in South Australia could be used as a test area rather than the expensive Woomera range. Furthermore, the two existing high towers at Port Wakefield appeared appropriate for a tethering system for the vehicle tests.

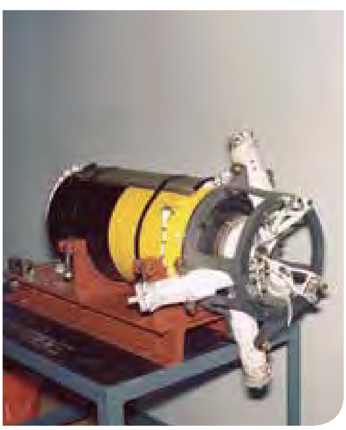
The computation tools for predicting tilt angles and thrust control requirements were developed by the Government Aircraft Factories team. The mass of all components of the vehicle was strictly controlled and budgeted accurately to ensure correct height control. The Government Aircraft Factories' hybrid computer was used in conjunction with the flight control system hardware to ensure integrity of the design and delivered hardware. The real-time modelling highlighted the importance of setting the positions of the

2-16 : Arnold Deans fathered the development of the Winnin thrust vectoring system.

limits of travel for the tabs with respect to the efflux. If the tabs were required to be out for climbing then they were not effective for pitch and roll control and the vehicle tended to tumble. These computer tools were used to define the requirements for the development of the thrust control system by Arnold Deans. The models of the thrust vector system and the motor thrust profiles were progressively improved after lengthy discussions with Propulsion Division.

Thrust vectoring system

The Propulsion Division/Government Aircraft Factories team had considerable experience with the performance of a single blade inserted — normal to flow — in a rocket motor efflux. However, this new application required three or four blades inserted to control at least three axes of motion. Both the lateral forces and axial forces were now important, not only the lateral forces as in previous work with the Ikara and Turana single tab systems. Four tabs for control of the decoy's tilt in pitch and roll angles would provide a simple control solution because the tabs would be aligned with the pitch and roll axes. However, a three tabs configuration was preferable over four tabs in the crowded and harsh environment of the motor nozzle, but was a more complicated control issue because two of the three were not aligned with the pitch and roll axes, leading to a coupling effect between the two. Furthermore, the requirement was to get large force changes in the efflux axial direction. The requirement for the system to operate for 50 to 100 times longer than the well-proven Ikara thrust vectoring control system was of major concern.



2-17 : The three tab system with the two vanes used for controlling the orientation of the 'Hoveroc' experimental test vehicle.

Arnold Deans proposed that the inserted tabs be inclined to the axial flow stream to prolong the life of the blades as well as give flexibility in achieving axial (spoilage) and normal forces (vectoring). None had previous experience using multiple inclined tabs.

The 'Hoveroc' design ultimately employed three ramped spoiler tabs symmetrically placed around the circumference of the nozzle for pitch, roll and thrust control. The design of this tab system was complicated by the interacting supersonic shock waves from the tabs. Each of the ramped spoiler tabs was controlled by a separate electric actuator. Also, a pair of vane tabs was inserted in the motor efflux for spin control. These were angled to the efflux to generate a torque around the longitudinal axis of the motor. The vane tabs, situated to minimise cross-coupling effects on the spoiler tabs, were controlled by a simple ring structure driven by a single electrical actuator, which enabled only one tab in at a time. This thrust vectoring system with the flight control methodology was patented in November 1980 in the names of Alan Smith, Arnold Deans and Mal Crozier.[11]

Arnold Deans became heavily involved in test programs to characterise the forces produced when multiple tabs were inserted in the rocket efflux because there was no theory or previous experience available to predict tab performance.

2-18 : Mal Crozier's early modelling of the hovering rocket was ideal experience for his role as designer for the experimental test vehicle and his later leadership in the development of the decoy's flight control system through to the present day.

Testing the thrust vectoring system

Arnold Deans designed a two-axis test rig for measuring the lateral and axial forces produced by the tabs and vanes. Two motor firings in this rig were necessary to characterise the thrust vectoring system. The immense number of combinations of tab positions led Jim Mapletoft to introduce the new microprocessors into the rocket motor testing and development process. The actuators were driven in step combinations so that lateral and spin forces of various combinations of vane and spoiler tabs could be accurately measured as they were inserted in the exhaust flow. This was all undertaken in a rig that vibrated continuously and required considerable automatic filtering to allow automatic data analysis. Arnold Deans was able to detect changes in axial thrust of 0.1 per cent. This was all new at the time and made necessary by the complexity and magnitude of the project. The test rigs were complex and required meticulous care in calibration and set up to obtain good results. Bob Irvine, supported by Peter Winch, became responsible for designing another test firing rig to measure accurately the net thrust minus the weight, by holding the motor in the vertical position.

2-19 : The thrust control system and the modified Murawa rocket motor under test.

Two exploratory firings each of 10 seconds duration were carried out on a test motor fitted with a single ramp tab. The aim was to investigate the effects of geometry, to observe the gas flow pattern when the tabs were inserted over a range of angles, and to seek assurance that the method of fastening the ramp tab and its insulator was satisfactory. One of the tests compared the ramp tab with the previously used tab that was normal to the motor efflux. These were followed by two firings to examine the vane configuration for generating a torque around the vehicle longitudinal axis known as spin. These tests provided the basis for the three tab system for the flight test vehicle.[12]

2-20 : The integrity of the flight control unit being examined by testing to ensure that it functioned while being subjected to severe vibration levels at the GAF Environmental Testing Laboratory.

Arnold Deans tested the prototype thrust control system in four tests using the two axis test rig during 1979, followed by another four tests during 1980 leading to the vehicle tests in the gimballed rig. An additional three firings were conducted after these vehicle tests leading to the free flight testing in 1981. These tests established the performance of the three tab system working in conjunction with the vanes for spin control.[13]

Arnold developed an empirical model for the complex interactions found to occur between individual tabs. Des Kay later developed a computer model of the three tab vectoring system based on the physics and supersonic aerodynamics of the tabs which was essentially the same as that later used for the Nulka system. This was a fine tribute to the experience, diligence and skill of Arnold Deans and his protogé, Des Kay.

Tilt control testing in gimbals

While Arnold and his people built and tested motor and thrust vectoring control hardware, the small team at the Government Aircraft Factories built electronics, and assembled and tested the flight control unit. George Cureton was the draftsman who defined the vehicle layout, and Bill Bloom coordinated the electronics from Ian Oxworth and assembly by Zanek Uttendorfsky with assistance from Graham Boothroyd. Chris Zombolis provided the telemetry expertise.[14] Laurie Harris provided his expertise on gyroscopes and pressure sensors as well as servo-motors. Wayne Sykes was the modeller and used the computer model to perform all the final functional testing.

2-21 : The 'Hoveroc' test vehicle being tested while being allowed to rotate in a set of gimbals. The tests of the Winnin thrust vectoring system were successfully completed in October 1980.

Mike Jakab at Propulsion Division organised the design and manufacture of the new, shaped, motor charge and assembled it in the shortened motor body. Motor bodies had to be proof-tested and several motors were fired, and the firing interrupted, to examine the motor integrity and the degree of coning in the propellant burning surface. Jim Mapletoft and Don Prettejohn were essential to these activities. Kevin Rolph completed the assembly of the motor ignition system and the firing circuits, and took care of safety issues.

The first three vehicles were tested in a gimbal rig designed by George Cureton at the GP1 site at DSTO in October 1980. All flight functions were tested, except the height control. The rig allowed

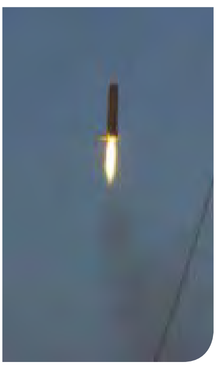
2-22 : The 'Hoveroc' gimbal test teams of October 1980. From left to right; back row: Mike Jakab (PD), Arthur Seager (DNOI), Ken Naismith (DSTO), Wally Lebedew (PD), Arnold Deans (PD) Graham Boothroyd (GAF), Bob Scott (GAF), Unidentified. Front row: DNOI officer, Alwyn Wilson, (PD), Barry Thompson (GAF), Wayne Sykes (GAF), Chris Zombolis (GAF), Pat Miles (PD), Ian Oxworth (GAF), Jim Mapletoft (PD), Lloyd Odgers (PD), Zanek Uttendorfsky (GAF), Mal Crozier (GAF), David Fraser (PD) and Don Prettejohn (PD).

angular motion in three axes and permitted external disturbing torques to be applied. All three tests were highly successful and showed excellent correlation with computer model predictions. However, there was much concern after the first test because the motor internal pressure, on telemetry, was irregular and noisy for 50 per cent of the duration. This suggested the potential for an explosive motor failure, though was found to be due to the resonating vibrations of the gimbal rig itself. Dave Symmons of the Government Aircraft Factories had measured and characterised the vibration modes of the rig, but a change had been made to it when setting to work at DSTO. The rig as originally built did not fit the mounting fixtures at the test site and a new cantilevered foot was welded to it to correct the situation.

Flight tests at Port Wakefield, South Australia

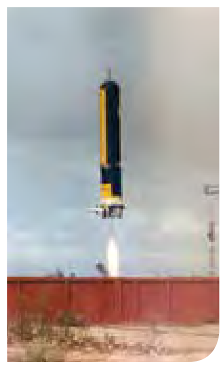
The tethered flight test of the 'Hoveroc' occurred at Port Wakefield on 26 April 1981, as planned. The first third of the test was visibly controlled flight, albeit with two instances of surviving the end of tether disturbance. Afterwards, the motion became chaotic. The tethering system required a person to take up the slack in the line manually to prevent it becoming tangled with the motor, while allowing movement of the vehicle. Graham Boothroyd suffered hand

2-23 : The 'Hoveroc' tethered test used two large towers at Port Wakefield Proof Range, South Australia.



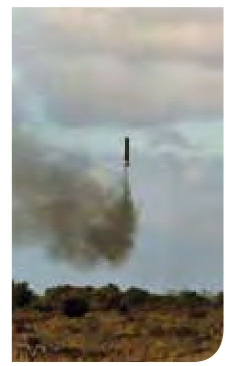
2-24 : The principle of hovering flight was first demonstrated by tethering the vehicle in a successful demonstration on 26 April 1981.

2-25 : Two successful flight tests were conducted in May 1981 at Port Wakefield, South Australia. This photograph is a close up soon after launch.



2-26 : The launching of the 'Hoveroc' test vehicle on 2 May 1981.

2-27 : The 'Hoveroc' test vehicle shown at a lower altitude immediately prior to burnout and landing in a bed of seaweed.



2-28 : The second free flight test was conducted on 7 May 1981. This photograph clearly shows translating movement across the coastal landscape.

burns during the process because no one had been able to devise an affordable automatic system for doing this satisfactorily. Mal Crozier and Arnold Deans were completely satisfied that the system was successfully controlling in all aspects after a few hours of analysis of the telemetry record. Essentially, the result was as expected from the modelling. However, many days were required to convince everyone that the time for a free flight test had arrived. Lloyd Odgers and Bob Scott presented the case to Ted Hayman who had long discussions with colleagues in Canberra.

The first free flight took place on 2 May 1981. It was a complete success with the vehicle gently descending to the ground, as planned. Poor weather delayed the second free flight test until 7 May 1981. This was more ambitious and included an in-flight manoeuvre, but the vehicle gently descended into the three metre deep seaweed bed bordering the beach.

Lloyd Odgers was keenly aware of the significance of the flight tests and observed:

I was located some 20 metres from the launcher and 10 metres above it, in a lightly-protected observation tower, accompanied by an Army officer. His role was to provide surveillance for personnel safety — that task kept him busy! As the countdown proceeded, I had time to reflect on my stake in all this. I had, from the very start, a conviction that a credible demonstration on film would be critical to the project progressing to something real. As the early studies proceeded I had also developed a deepening conviction of Australia's need for what we now know as Nulka. I was convinced that the substantial intellectual and material capital that was Australia's guided-weapon capability at the time was an asset to be exploited and enhanced in the interest of our national defence preparedness. Success in this 'Hoveroc' project appeared essential if our R & D and industry skills were to survive. There seemed to be a lot hanging on this trial.

2-29 : The 'Hoveroc' flight test team posed after a completely successful series at Port Wakefield, South Australia. Team members are from left to right; back row: Bob Weldon (PD), Unidentified, Mike Jakab (PD), Lloyd Odgers (PD), Peter Winch (PD), Kevin Rolph (PD), Wayne Sykes (GAF), Charles Penny (PD), Jim Mapletoft (PD). Middle row: Ken Naismith (camera) (DSTO), Graham Boothroyd (GAF), Bob Scott (seated) (GAF), Ian Oxworth (GAF), DNOI officer. Front row: George Cureton, Major Warren Feakes (CO PEE), Don Prettejohn (PD), Mal Crozier (GAF), Zanek Uttendorfsky (GAF), Arnold Deans (PD), Photographer, Wally Lebedew (PD).

2-30 : Jim Crompton, as Director of the Weapons Systems Research Laboratory, was a long standing supporter of the Winnin program. In 1984, he accepted the South Australian Division of the Institute of Engineers Australia award for Engineering Excellence, on behalf of the 'Hoveroc' teams of Propulsion Division and Government Aircraft Factories.

Six successful flights from six trials for the hovering rocket development was an outstanding result. It was a career highlight for most of those involved in the rocket's development. A small team of approximately 20 people successfully achieved something significant which was new and novel and within time and budget. In part, it was because sensible program objectives were set and remained unchanged. Also, the smallness of the group meant communication was excellent and focused. It was also important to have enthusiastic, competent people in the team. There is no doubt that the project's success was also due to the expertise of Lloyd Odgers and Bob Scott. Odgers was an excellent program manager and rocket motor systems engineer, as well as an accomplished diplomat. Scott was a clear thinking 'can do' person and the pair made a great management team. Mike Jakab, Odgers' lieutenant, ensured the program ran to schedule and budget. Apart from his engineering duties, he prepared detailed statements of work and schedules to keep everyone focused. Bob Scott did the same at the Government Aircraft Factories.

Defining the spin torque required for the vehicle was particularly complex and difficult for Arnold Dean's vane system to deliver. The vehicles flown were capable of only half the original 'guesstimate' of what might be needed. Ultimately, both flight tests used up to 95 per cent of available torque, though only in the latter few seconds of flight. The problem of defining the spin torque requirement continued to be a major issue through later years.

The final event for most of those involved in the story of the 'Hoveroc' vehicle occurred in March 1984. At a ceremony in Adelaide, John Bannon, then South Australian Premier, presented the South Australian Division of the Institute of Engineers Australia Award for Engineering Excellence to Jim Crompton, representing the Propulsion Division and the Government Aircraft Factories teams. The citation read: 'For excellence in engineering, in particular for achievement of a superior level of stability to a rocket powered hovering vehicle'.

'Hoveroc' and Winnin had first come to the attention of the media and *Defence News* in May 1982, following the Falklands War. The award, coming two years after the Falklands War, renewed Australian media interest in the Winnin program.[15] Many and varied articles on the scope of defence research and development in Australia appeared in 1984, including references to attempts to find a collaborating partner for development of an off-board decoy.

Antenna research in Australia

The highest risk element of the payload concept for the decoy was the antenna design, apart from the travelling wave tube design, to which Australia was unable to contribute. There was a need for a radical, high performance antenna design that would produce a payload capable of meeting the concept of operations for the decoy system. Many regarded the antenna requirements as impossible to meet, but neither Allison nor Dickson was among them. Fortuitously, the Electronic Warfare Division had a talented microwave engineer named Ken Harvey, who had acquired a reputation in Australia and the United Kingdom for achieving the seemingly impossible with microwaves.

2-31 : DSTO's Ken Harvey made key breakthroughs in the design of suitable antenna and played a major role in developing a payload.

Ken Harvey began his work on the payload in early 1978, supported by his technician Ross Campbell. Harvey had received advice from Bill Dickson on the broad requirements for the payload, but there were few explicit and defined requirements, so the emphasis was on defining what was possible. However, it was not until 1980 that Bill Dickson, Vic Sobolewski, Ken Harvey, Gino Beltrame and Ron Evans began concerted analysis work on the payload.

The inability to be explicit about payload requirements flowed from uncertainty concerning potential collaborative work. Australian scientists needed information about potential partners' classes of ship requiring protection, as well as their range of threats. Such information was expected to influence the effective decoy radiated power and would most likely affect the choice of antenna parameters, such as beamwidth and bandwidth. The inherent angular stability of the decoy's flight control system would also be a factor.

Ken Harvey sought to maximise antenna patterns, keeping in mind the payload performance issue. He started designing and building antennas that were omnidirectional in azimuth, but soon found it was impossible to achieve the power requirements. Still, Harvey kept returning to the desirability of omnidirectional antennas. Using a steerable antenna was quickly discarded because of the limited space and cable entry issues. So the system had to be based on limited beamwidth antennas. This had a major effect on the vehicle design as it required a more powerful spin control system. However, it set the 'Hoveroc' vehicle solution apart and ahead of the alternative helicopter solution. It was now mandatory to direct the antenna by rotating the vehicle independently of the track. Fortunately, the 'Hoveroc' could be rotated much faster than the helicopter.

Ken Harvey made a breakthrough in antenna design.

By 1981, there was a clearer picture of what system components would be possible, and this continued to evolve over the ensuing five years. Ken Harvey had been able to produce an antenna design, which had excellent pattern characteristics over a wide band of frequencies. A major challenge in the antenna design tests was in finding suitable facilities and locations to make measurements of low-level signals that were present in antenna experiments. Reflections from buildings and the ground were also a major problem, but ultimately solved by building a wooden structure with the antennas pointing upwards.

Harvey's antenna design represented a breakthrough, especially for the antenna type necessary to mount into the cylinder of the vehicle while allowing cables to pass by. Harvey's design was patented and received accolades from the electronic warfare community. He had used a software model conceived 10 years earlier to define curved sides in the antenna to produce good results. Ross Campbell built and tested the antenna to confirm the calculations. Much later, Harvey used a modern computer-aided three dimensional antenna design tool and found this modelling of the old design exactly matched the tested results, which gave him increased confidence in the new tools. This innovative solution proved a suitable payload was feasible and gave impetus to the decoy project at a time when world experts believed it could not be done.

At the end of the Advanced Feasibility phase in August 1981, Harvey was able to report that he had a breakthrough on antenna designs required for a payload. In addition, he was able to report on test results of a range of surface wave absorbers to improve payload performance if required. A viable payload was still not possible, even on paper. However, Ken Harvey persevered.

CHAPTER 3

Overcoming obstacles, 1981–1984

The Winnin Advanced Feasibility Study faced continued opposition and obstacles. This was not unusual for complex multi-disciplined development projects. Some of the experiences are recounted in this chapter to show the extent of the problems and the determination of the 'believers'.

All of the exploratory work in Australia under the Winnin Advanced Feasibility Study was achieved through internal funding by the government laboratories, backed by strong support from the Director Electronic Warfare, Navy, without which the project would not have proceeded.

The seeding of United States Navy interest, June 1981

There was renewed interest in Australia in finding a collaborative partner following the successful trials of 'Hoveroc'. Australia could not afford the development costs to produce the decoy and needed a partner to boost production numbers and thereby reduce unit costs. Also, it was vital that the partner was able to facilitate access to the high power, low cost travelling wave tube technology.

Scot Allison recognised the need to have much more than simply a concept of an active decoy to have any chance of securing a partner. A potential partner would need to see tests and demonstrations of key, high risk aspects of the system. The Australian team found solutions to several special requirements that related to the new generation threats that had not been fully addressed by the United States Navy over the period. This certainly influenced the eventual collaboration outcome. The Naval Research Laboratory and several supporting companies developed decoy payloads over several years, but most effort was based on requirements related to the older Russian threat. Allison contended that 'had we not succeeded in having both vehicle and payload designs of comparable maturity before proceeding to advanced development, then I doubt we would have signed up with anyone.'

Scot Allison was well aware of the status of off-board electronic warfare decoy and payload technologies in many countries. He believed that the United States Navy provided the best chance for a collaborative customer. The United Kingdom apparently came to the same conclusion and hoped to collaborate with the United States on its decoy concept named Siren. Consequently, the United Kingdom was never a serious prospective collaborator with Australia, and was, in fact, more a potential competitor. The situation was apparent to anyone within the ABCA community where there was a common belief that no single NATO country had a navy that could justify being a major collaborative customer. The French were hardly likely to support the development of a counter measure to their successful export, Exocet.

Fortunately for the success of the project, DSTO's Henry d'Assumpcao, then Superintendent of Electronic Warfare Division, had formed a close and lasting relationship with Martin Kamhi, the civilian head of the United States Navy electronic warfare programs, in the late 1970s. Kamhi was to have a major influence on United States attitudes and consequently on his country's acceptance of the joint project concept. Similarly, d'Assumpcao had championed the decoy project at the highest levels within Australia, and the environment began to change.

Henry d'Assumpcao sent Allison to the United States with film of 'Hoveroc' in flight to inform the Reconnaissance and Electronic Warfare System Office Navy (REWSON) office of the outcome of the 'Hoveroc' trials, in an endeavour to persuade the United States to collaborate with Australia in a joint venture. The decision to approach REWSON, rather than the NRL, marked a major change in strategy. At this stage the proposal was for collaborative exploratory development, but the way was being cleared to proceed to collaboration in engineering development should the outcome of the first phase prove fruitful.

Martin Kamhi exclaimed 'That's it!' and Australia's vehicle concept was instantly recognised.

Allison met United States personnel at the United States Navy's REWSON office in June 1981. Those present were the head of Naval Electronics Command, as well as Martin Kamhi, John Montgomery, then head of Offboard Countermeasures Branch in NRL's Tactical Electronic Warfare Division; the head of the Vehicle Research Section under Montgomery, Frank Klemm; and a great many others. The briefing room was packed.

Though unsure of what reception he might receive, Scot Allison found the audience most attentive. There was near total silence during the screening of the film of the successful Winnin trials until near the conclusion when Kamhi exclaimed, 'That's it!' In an instant, it became apparent that Australian credibility had grown enormously in Kamhi's estimation, a view that spread rapidly through the assembled gathering. Allison had demonstrated that Australia was able to make a significant contribution to any collaborative endeavour. In return Australia might now expect that necessary information on the critical travelling wave tube technology would be forthcoming.

But a number of obstacles were soon raised during discussion of the way ahead.

Scot Allison recalled:

Martin wanted the work to proceed under the defence exchange forum, ABCA-4, but Henry declined because of royalty issues, and insisted it be carried out under the Clifford-Fairhall Agreement.[16] *The REWSON people were not aware of this agreement, and therefore were not enthusiastic. I recall visiting Martin and his deputy Jim Sullivan several times during 1982–1983 to push progress towards an agreement, but, while they were positive towards collaboration, they were clearly dragging their heels on Clifford-Fairhall; perhaps hoping we would relent and go under ABCA-4. We were at this stage faced with the full inertia of the United States Navy's Research, Development, Test and Evaluation (RDT&E) funding and regulatory system.*

3-1 : Henry d' Assumpcao, Superintendent of Electronic Warfare Division, DSTO, and later Director of Electronics Research Laboratory, overcame a number of major obstacles in the project over several years. Through his personal friendship with Martin Kamhi, the civilian Head of the United States Navy electronic warfare programs, d' Assumpcao assisted with Australia's early negotiations on the project.

The seeds for collaboration were sown, but there were early signs that they might never germinate. However, collaboration in development of the Active Expendable Decoy was later discussed in the ABCA-4 forum held at HMAS *Watson* in Sydney in October 1981. All nations present endorsed the desirability of off-board systems for countering anti-ship missiles, but both the United Kingdom and Canadian representatives stated that they did not have the resources to contribute to development in the short term.

However, the United States Navy leader Martin Kamhi was keen to discuss an agreement to exchange information with Bill Dickson and DEW-N Commander Ian Pfennigwerth. Dickson worked all that night to prepare an agreement for signature the next day. This was a non-binding accord and included the sharing of technical information on the decoy and the development of common operational concepts and specifications for an operational system.

This agreement prepared the way for future collaborative information exchange, and Australia was able to tailor its research program to emerging United States Navy requirements, though many years elapsed before there was a binding agreement for engineering development.

Planning in Australia for development and pre-production

Before the Advanced Feasibility Study phase was complete, and even before the 'Hoveroc' flight tests, Ted Hayman at Electronics Research Laboratory had made a submission to the Defence Science and Technology Committee meeting in March 1981 for a 12-month 'Project Definition Study'. This work, to continue under the Winnin program, proposed issuing the Naval Staff Target for the Royal Australian Navy system, studies to clarify vehicle and launcher design options, and additional consideration of the payload, which included the services of a company to build hardware. By June 1981, the proposal had become a 21-month program ending June 1983 and included demonstration tests for a payload. The plans now included the phases to follow the project definition.

3-2 : HMS *Sheffield* ablaze after being hit by an Exocet missile on 4 May 1982. © Crown Copyright: IWM

They were referred to as 'Technology Demonstrations', 'Engineering Development' and 'Pre-Production', each of two years' duration to end in December 1988. The technology demonstration was to include flying five decoys, preparing a full development cost plan through to acquisition, and negotiation of future sales of the system. This phase, calculated to end in June 1985, would demonstrate how an active decoy could 'seduce' a missile from a ship. The Defence Science and Technology Committee considered the proposal in November 1981.

Ted Hayman had already begun to plan the program beyond the feasibility program in 1981, but there was no official extension to the Winnin program until 1983.

The influence of the sinking of HMS *Sheffield* in the Falkland Islands

Developments during the Falklands War in 1982 served to enhance the Australians' cause. In May 1982, Captain James Salt, skipper of HMS *Sheffield*, peered intently at the surveillance radar screen as his ship was in a high state of alert because it was known Argentinean Super Etendard aircraft were in the air with Exocet missiles. Suddenly, without warning, a small blip appeared at close range, and almost simultaneously the watch on deck reported a visual contact. Four seconds later an Exocet slammed into the side of the ship and penetrated the hull. The explosive charge failed to detonate, but the burning rocket motor ignited the *Sheffield's* aluminium alloy hull. The fire put *Sheffield* out of action and she was damaged beyond repair. She sank under tow soon after. The Frigate HMS *Antelope* was severely damaged by another Exocet, 19 days later. HMS *Glamorgan* was damaged by a shore launched Exocet, and the container ship *Atlantic Conveyor* was hit by an air-launched Exocet intended for one of the United Kingdom aircraft carriers, HMS *Hermes* or *Invincible*. Almost overnight, United States and United Kingdom perceptions changed concerning the threat to surface ships and the need for adequate counter measures. This was reinforced later in May 1987 by damage to the USS *Stark* by the same class of missile. As with *Sheffield*, the first detection of the incoming Exocet was reported to be 'visual'. For the first time, a western-made missile had threatened United States assets, and its effectiveness was proven beyond doubt.

It is perhaps ironic that both the United States and United Kingdom vessels were never engaged by Soviet missiles despite their preparations for this eventuality. The only occasions on which they were attacked and hit by anti-ship missiles were those involving Exocet, which was never formally rated as a threat. In both instances involving the *Sheffield* and *Stark*, the visual sighting of the incoming missile was at short range, and coincident with the radar — which demonstrated the capability of the missile to penetrate undetected below radar defences.

Almost overnight, perceptions about the threat and the need for adequate counter measures in the US and the UK changed.

While events were unfolding in the Falkland Islands, Commander Ian Pfennigwerth, DEW-N, Murray Evans and Scot Allison were meeting those in the United States Navy who might influence the shape of the decoy program to be put to the defence committees. Importantly, Rear Admiral S J Hostettler showed interest in a program that aimed to have an active decoy into naval service in the United States Navy by 1988.

Continued planning in Australia

Ted Hayman of the Electronics Research Laboratory chaired a meeting at the Aeronautical Research Laboratory on 15 June 1982 to initiate work for the first development cost plan for this decoy program. It was predicated on collaboration with the United States Navy and Hostettler's timescale. A month later working parties from Electronics Research Laboratory, the Weapons Systems Research Laboratory, the Aeronautical Research Laboratory, the Government Aircraft Factories, and the Ordnance Factory and the Explosives Factory, both at Maribyrnong, had defined the program. Records show the estimated cost to be A$59 million: the same figure that AWA signed up to six years later, in quite different circumstances.

The journey through the Defence Committees in Australia 1982–1985

Funding for the stages from Full Scale Engineering Development to acquisition required approval in Australia by the high level Force Structure Committee. Approval for most proposals meant the projects went into Year Two or later of the Five Year Defence Plan. Consequently, there was a service requirement that in theory resulted from a gap in the operational capability. Having the project as part of Year One of the Five Year Defence Plan became a major hurdle.

There was fierce competition for a share of the Defence budget and the DSTO laboratories were inexperienced with the committee process.

The Force Structure Committee, like the Defence Science and Technology Committee, was serviced by Force Development and Analysis Division, making it probably the most powerful division in Defence. When preparing Force Structure Committee agenda papers, Force Development and Analysis staff scrutinised and quantified as many aspects as possible of each and every proposal. This was to ensure that major capital equipment acquisitions were aligned to strategic guidance and priorities. Close attention was also applied to cost and it was customary to include options in an agenda paper so that comparative judgments could be reached on which acquisition option was most cost-effective. The result was fierce competition for a share of the Defence budget and tensions arose between the services and Force Development and Analysis Division and sometimes between the different services. The Force Structure Committee, as a result, became an extremely powerful committee. DSTO, particularly the laboratories, had little first-hand experience of this way of conducting business.

The Defence Force Development Committee was the other major review committee of great importance. This committee was chaired by the Secretary of Defence but included many members who were common to the Force Structure Committee. All proposals for the yearly defence budget were reviewed and controlled by this committee.

The committee process had become quite adversarial as the Winnin project went forward and that it successfully passed through the process can be attributed to the efforts and endurance of those individuals involved.

The program inspired by United States Navy Rear Admiral Hostettler and all others proposed were modified significantly by deliberations of the Defence Force Development Committee. On 8 September 1982, this committee considered a proposal that Australia embark on a concept development – Condev – program as the next stage in the Australia decoy development and production initiative. The issue of possible later collaboration was kept open. The Defence Force Development Committee was adamant that cost-sharing opportunities be explored with potential partners before committing to a program. The Chief Defence Scientist was directed to dispatch a negotiating team to the United States and Italy for discussions on a Winnin collaborative arrangement. The visit occurred the following month.

At this time Winnin negotiations were somewhat complicated by a re-organisation in the Defence Department which saw the government factories and defence research laboratories placed in the Department of Defence Support which had a focus on fostering Australian industry and capitalising on Australian research and development capacity. DSTO was encouraged to look for a partner beyond the United States in such countries as Italy and the United Kingdom which had research programs and industry capabilities in travelling wave tubes and related payload technology.

The negotiating team, led by Bill Howard, Superintendent Major Projects DSTO, reported to the Defence Force Development Committee on 25 November 1982 and concluded that prospects for collaborative development were high but not likely in the near-term. The selection of an acceptable decoy system by any country could not be based on a concept and ideas alone. Collaboration would only occur if there was a concept development program to match the exploratory payload development work already underway in countries such as the United States and Italy.

The Defence Force Development Committee endorsed the need for a development program and by January 1983 DSTO had put forward a task plan for a six month interim program of work to justify the allocated budget of A$1.9 million to be spent across the Electronics Research Laboratory, Weapons Systems Research Laboratory, Aeronautical Research Laboratory, and the Government Aircraft Factories, with nominal amounts for the Ordnance Factory and Explosives Factory at Maribyrnong. This was a small start but represented a significant escalation in scale over the Advanced Feasibility Study.

However, support for Winnin in many sectors of the Department of Defence was weak, including the Royal Australian Navy: new helicopters for the Army and destroyers for the Navy were considered much more important. Fortunately for the project, there was a small cadre of believers including the Director Electronic Warfare-Navy and Rear Admiral Ian Knox, Chief Naval Operations and Plans, who believed that the Australian Navy was a small ship navy and could not afford to lose a single ship. Within this environment, Roger Creaser, a recent recruit in the Force Development and Analysis Division, was tasked in mid 1982 with preparing a paper to show how Winnin fitted into Defence's strategic priorities. Roger Creaser worked with Scot Allison and Bill Dickson to strengthen the technical case for the Winnin solution and they defined the list of key decoy parameters which later proved invaluable in addressing committee questions.

A new Winnin Project Office

Roy Kane joined the Winnin project in 1983, after Jim Crompton invited him to become the full-time Winnin Project Manager after Ted Hayman sought to pursue other activities. Kane managed the project office located in Adelaide, while Project Director Murray Evans focused on the numerous vehicle problems facing the program at that critical time. Roy Kane was to inject a systems engineering discipline into the management of the project.

Peter MacDowell and Ray Girdham supported Kane in the new project office. By 1985 the team had expanded to include Brian Edwards, as the technical leader, Lieutenant Commander David Farley, technical officers Bill Goodes and Malcolm Frost, followed by John Kean. Both Brian Edwards and John Kean were recruited from industry – Thorn EMI and Fairey Aviation respectively – which, in the event, was appropriate, because the project was to depend on industry. Roy Kane became the Project Director in August 1985.

Kane adopted practices from the United States Navy Program Managers' Guide to benefit not only the Concept Development phase of Winnin, but also the joint project negotiations in later years. That Guide was subsequently used to advantage in other projects.

Roger Creaser recalled, 'Just before Christmas 1982, Force Structure Committee Chairman, Deputy Secretary B Alan Wrigley, a non-supporter, told me that it was no use supporting Winnin if the Navy did not want it, and he was aware that they had refused to take a clear position on Winnin.'[17] Wrigley decided that the RAN should write a position paper on Winnin over the Christmas-New Year break and deliver it to him when he returned after the Australia Day holiday weekend. He believed that the Navy could not manage this and,

3-3 : Roger Creaser prepared many papers required by the Defence committees and influenced many senior people on those committees to secure approvals for an indigenous development program known as Winnin Concept Development.

without a position paper, Winnin could legitimately be taken off the Force Structure Committee agenda for 1983. Roger Creaser obliged by working over Christmas and delivered the paper for the Navy.

Wrigley quite astutely continued to request the Navy to show its hand over Winnin before he would consider even allowing the project to progress to the Force Structure Committee. The meeting was held in March 1983 and Rear Admiral Knox opened by making a strong case for Winnin to become part of the force structure. Under the Alan Wrigley approach to the Force Structure Committee, the battle had actually been won before the meeting, but nevertheless, the strong formal support from Navy was both necessary and symbolic. The Force Structure Committee process also served to raise the profile of Winnin considerably.

The Force Structure Committee endorsed the requirement for an active off-board decoy in March 1983, but not the means to fund development of such a system. The Navy allocated funding in year four of the Five Year Development Plan for the acquisition of the decoy, but funding to allow it to proceed to the point of being available for acquisition was required immediately since the funding for the Winnin Concept Development allocated by the Defence Force Development Committee was nearly exhausted: future funding by the committee was essential for the project's future.

Meanwhile, management teams at all establishments provided material to develop the three year phased program to be known as Condev.[18] Phases one and two were defined and costed by May. The total cost of the program was estimated to be A$19 million. Phase two, with an expected start date in June 1984 had begun by including a flight trial with at least one trial carrying a prototype payload in order to be in a strong position for negotiating a collaborative engineering development. However, this was not going to be achievable and the program length was reduced by three months. The aim was to be 'in a position to build a decoy for flight trials'. In the event, there was no prospect for collaboration. Phase two became a 15-month program to close off the work with meaningful documentation of achievements for future possibilities. The program of work was presented in two phases, because this was judged to be more palatable to the committees and allowed the option of curtailing the project should the risks or costs become too high. It also meant the committee could hedge its bets by providing a partial approval to the first phase only.

The Defence Force Development Committee meeting of December 1983 was not without some drama, though Creaser was confident of success after having canvassed sufficient votes. Secretary of Defence, Bill Pritchard, was not well disposed towards Winnin, or in the opinion of many, any indigenous developed technology. But he relented when he could see that the members of the committee supported Winnin becoming a major project. In the space of one year Creaser had worked relentlessly and engineered the passage of the Winnin program through the three crucial defence committees.

This first phase funding, albeit barely covering another 12 months, signalled an official start for many, though momentum had been building from the beginning of 1983. However, this interim approval required more work by Roger Creaser before a final approval for a significant program was confirmed.

Roger Creaser wrote:

In 1984, I began work on a new DFDC agenda paper to secure the remainder of the program. There was intense competition for funds in the defence budget and opposition to Winnin developed as it was realised Defence was embarking on a program where the funding demands would be major and ongoing.

The Defence Force Development Committee meeting was held in July 1984 and the agenda paper addressed various options for funding beyond this first phase, together with an extensive assessment of technical risk, using invaluable contributions from Murray Evans of the Aeronautical Research Laboratory. Additionally, Roger Creaser had proposed that the Defence Force Development Committee endorse defined outcomes for the program agreed by Aeronautical Research Laboratory and Electronics Research Laboratory as well as the funds. Previous experience had shown that agreement on outcomes for the program would facilitate the seeking of extra funds in the event that these outcomes were not completely achieved, as was often the case. This meeting was very prolonged, unlike the previous committee gathering, and in fact lost its way. With time running out, the committee endorsed the funding only.

The Defence Force Development Committee became anxious about implications of its endorsement of the program because it was contingent on collaboration with the United States at a time when there were separate developments there. Fortunately, the situation in the United States Navy improved dramatically by October 1984. A new management team in the United States Navy changed relations between the nations. Within weeks Captain Beale and Commander Sam Anderson visited Australia to learn about Winnin as a candidate for the United States Navy Ship Launched Electronic Decoy program. Three major visits took place between the United States Navy and the Winnin team between October 1984 and the following February 1985.

The next progress report to the Defence Force Development Committee went before the momentous meeting of April 1985. The discussion paper was prepared around the topic of options for funding the engineering development. Much had happened in the United States Navy by April. The meeting made key decisions on cost sharing and changes to management in the expectation that collaboration with the United States Navy would occur.

An interim research exchange agreement

While departmental approval was being sought for Winnin in Australia, a bi-lateral agreement was signed by Howitt and Parsons with the United States Navy on 22 May 1984, which paved the way for the ultimate agreement to proceed with development. This agreement was in accordance with the Clifford-Fairhall Agreement and concerned the difficult issues of the roles of the participants, protection of intellectual property and production guarantees. These latter two issues were of particular concern to the government factories and caused considerable dialogue between the government departments on this aspect of the draft agreement.

Continued efforts to find a partner

The outstanding success of the 'Hoveroc' trials at Port Wakefield, and Ken Harvey's success with aspects of the payload, gave the Australian decoy design a clear superiority over options being pursued overseas. These advances could not be duplicated cheaply or quickly. Because of this lead, Australia was well-placed for negotiating collaboration under an arrangement where Australia would develop the vehicle, and the partner would develop the payload, probably to the Australian design.

DSTO efforts on collaboration were almost exclusively directed towards the United States Navy as the preferred partner, customer, and developer, though Department of Defence Support efforts were to pursue other options, particularly concerning the 'partner developer'. DSTO found there were useful discussions over the following years, but they failed to bear fruit. Not until 1985 were there any serious signs that the United States Navy would entertain collaboration.

Further negotiations with the United States Navy

There were many Australian missions to the United States during the period 1982–1986 with the aim of securing the United States as a partner. The sinking of HMS *Sheffield* in May 1982 graphically demonstrated the potency of Exocet and the thinking within the United States Navy slowly moved away from a single, long-standing focus on Soviet threats.

Eventually, the United States laboratories became seriously interested in the Winnin concept, after gaining information through the ABCA-4 agreement on information exchange.

The United States Navy became increasingly confident about the vehicle concept, but believed it was premature to enter a joint program. There were major differences of opinion on several aspects of the required payload characteristics. There were no substantive discussions on specifications, advanced development programs and timings until 1984.

It was clear that a Memorandum of Understanding would require the signature of the United States Secretary of Defense and this was expected to take a considerable time to achieve. Originally estimated to take 18 months, securing the final signature was to take 46 months. Martin Kamhi proposed the need to establish affordability and military worth of the system, before considering the production guarantees.

By late 1982, neither the United States Navy nor the Royal Australian Navy had an official written requirement for an active decoy. The number of rounds per ship was agreed upon — four times the current number — based on a number of threats per attack scenario, which proved much higher than considered likely in later periods.

Teams from Australia visited the United States and other countries on many occasions from 1982 to 1986 in search of a collaborating partner for developing the ship self-defence system.

Changing strategic circumstances

Several events occurred in the 1980s to herald a change in the strategic policies of the United States, United Kingdom and Australia. The first was the sinking of HMS *Sheffield* in 1982. While having no immediate impact on the acquisition programs of the respective countries, it created an awareness of the shortcomings of the 'hard kill' defences and spawned a renewed interest in off-board decoys as part of a ship integrated defence system.

The Royal Australian Navy's proposal for an aircraft carrier to succeed HMAS *Melbourne* foundered, as did its hopes for a major blue-water role. At the same time, there was a growing appreciation of the importance of operations in the archipelagic littorals of South East Asia that might well present threats of Western as well as Soviet origin. Later United States experiences in the Persian Gulf in 1987 highlighted the growing impact of this brown-water environment and threats close to shore for destroyer and frigate sized ships.

The Winnin concept was to fit well with the new strategic policies of Australia and its major allies.

Back in the United States and opposition

Concerted studies on the Winnin Condev program began in 1983, but it was not until June 1984 that a mission returned to the United States. Winnin had gained support in Australia and it was time to talk with the Americans again.

Captain Alan Brecht (DEW-N) led this visit, accompanied by Murray Evans, Ralph Crook (AEL-launcher and handling issues), Bill Dickson (EWD-payload issues), Bob Scott (Winnin Project Manager) and Jim Daly from the Department of Defence Support. The team was able to report on Winnin development progress over the previous 18 months. A prime item development specification was given to the United States Navy for consideration and cost estimates for the decoy were discussed.

Mike Ripley Lottee, an experienced manager on the United States team, participated enthusiastically over the following 18 months. He recommended that the program be run from DSTO with a support contractor. Lottee was from the Naval Weapons Center at China Lake where government personnel, assisted by a contractor, had

3-4 : From left to right: Murray Evans (ARL), Captain Alan Brecht (DEW-N RAN), Bill Dickson (EWD DSTO) and Bob Scott (GAF) visiting the United States Navy in May–June 1984. Ralph Crook, from Advanced Engineering Laboratory took the photograph. Ralph presented work done on developing launcher concepts. The launcher concept influenced technical work during concept development.

undertaken the engineering of many missile systems. This was to be the reverse of the model adopted in Australia. Bob Scott recalled that at China Lake the team learned that development programs in the United States were invariably funded on a cost-plus basis to the Critical Design Review phase. Only after the design was approved would a contractor move to a fixed price contract. Nulka was later to be fixed price.

The important news from this visit was that the United States Navy agreed to proceed with development of a decoy system. The United States decision-makers had made a Milestone I decision in September 1983 to evaluate all contenders for an active expendable decoy program. A formal operational requirement document was finalised. The next milestone was to be a Sponsors Program Review in June 1985, at which time a decision would be made about the preferred solution, with engineering development to follow. This review fitted nicely with the Defence Force Development Committee review of May 1985 concerning Winnin's future. But now it was evident that NRL was proposing to meet the operational requirement with a folding wing vehicle to carry a payload deployed from one of four fixed launchers. NRL was undertaking laboratory work on a payload and benefiting from the travelling wave tube developments by Varian on the Active Expendable Buoy program.

The United States Navy revealed that the cost estimates for the Active Expendable Buoy payload were approximately twice the anticipated US$21 000.

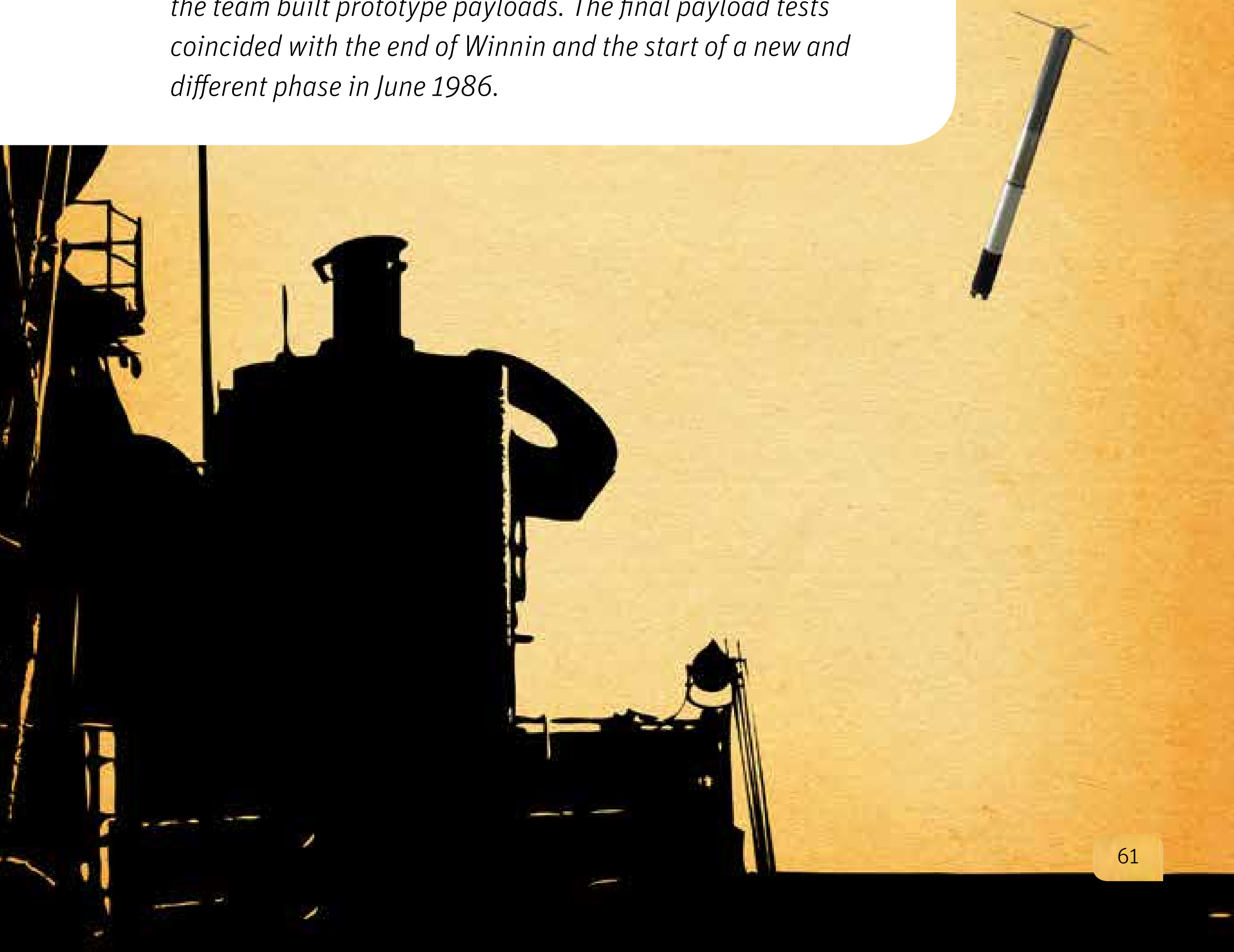
Martin Kamahi had talked about May 1985 as a sensible date for beginning collaboration discussions, but it was clear from this visit that the possibility of collaboration was far from certain. The Active Expendable Buoy program was underway and there were competing proposals from Australia's potential collaborating partner. Roger Lough later advised that collaboration on Winnin had almost disappeared from the table following a United States mission to Australia in March 1984. Several United States participants appeared opposed to development undertaken outside the United States.

Captain Bob Wickland, equivalent to the RAN DEW-N, advised that Winnin would be considered with the Active Expendable Buoy program, the NRL vehicle solution, and any others. However, matters were to change within two months, immediately prior to a planned United States Navy visit to Australia in October 1984. Captain Beale replaced Captain Wickland as program director and Commander Sam Anderson became the new program manager for the Ship Launched Electronic Decoy program. Anderson was to be a driving force in achieving an outcome for Australia.

CHAPTER 4

The Winnin Concept Development phase, 1983–1986

Progress on the unique rocket motor and thrust control system by the motor consortium probably exceeded progress in all other areas. Sufficient work was completed on concepts for the launcher and vehicle configuration to complement the search for a development partner. An innovative solution was devised for the measurement of height and airspeed and, after many ideas, a viable solution to controlling spin of the vehicle was developed. The decoy payload concepts were developed and the team built prototype payloads. The final payload tests coincided with the end of Winnin and the start of a new and different phase in June 1986.



Condev saw a number of specialised teams formed in DSTO and industry to focus on specific vehicle issues driven by operational requirements.

The successful demonstration of the 'Hoveroc' vehicle in May 1981 set a new pace for the project. The immediate need was for a work program to define the real operational system based on the carrier vehicle concept demonstrated at the 'Hoveroc' flight tests. The flight vehicle for the operational system would be entirely new and quite different. The 'Hoveroc' had been designed and built in only 20 months, starting in March 1979, with the limited objective of demonstrating the principle of flight control. While funding approval was being sought for the Concept Development phase, initiatives had to be taken to retain key personnel and engage new players. Continued efforts were also made to attract the United States as a partner. Condev did not commence officially until endorsement of the operational requirement by the Force Structure Committee in March 1983. Limited work was carried out using existing funds, and further funding was approved by the Defence Force Development Committee in December 1983 and later in June 1984.

The requirements of all parts of an operational system had to be defined and solutions found to meet the operational and technical requirements. The technical scope of the related studies included all aspects of the flight vehicle, its launcher and firing system, the payload and ship integration issues. This required building prototypes of the high risk parts with tests to demonstrate the feasibility of the solution. Even the building and testing of flight vehicles were considered to prepare for Full Scale Engineering Development.

4-1 : Murray Evans, Superintendent Systems Division at the Aeronautical Research Laboratory, became the Winnin Project Director and played a leading role in having the Winnin vehicle adopted as the United States Navy's Ship Launched Electronic Decoy. He made personal contributions to a solution to the air speed and height sensor problem, starting in late 1981, and to decoy spin control.

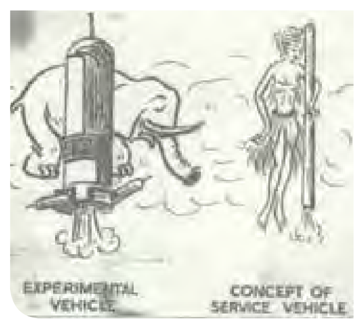
AFS Project Manager, Lloyd Odgers, recognised that all the technologies of Winnin were akin to those of a guided missile and he believed it was imperative for the project to have access to guided weapons technology support within DSTO. In late 1981, he arranged with Ralph Cartwright, Acting Director of the Aeronautical Research Laboratory in Melbourne, to meet with Murray Evans, Chief of the Systems Division. Evans and his division became involved in the Winnin program and he later became Project Director of Winnin Condev. Evans was highly respected for his systems understanding of controlled air vehicles, through his leadership of the Ikara anti-submarine weapon system development, and his important role on the earlier Malkara anti-tank weapon program for the United Kingdom Ministry of Defence. On these programs Evans had led and coordinated large teams of people with a diverse range of skills across several organisations. He was to provide strong leadership to this project through his ability to understand key technical issues, and through his ability to articulate the Australian position during many discussions with the United States Navy.

Murray Evans was to spend most of 1982 exploring concepts for decoy issues such as the measurement of height and the chaff launcher compatibility, in between visits to the United States.

Developing the vehicle concept

Following the europhia of the 'Hoveroc' flight trials, the team at the Government Aircraft Factories dispersed, leaving only a couple of members to think about the vehicle, its control system, and the launchers for the operational system. Bob Scott participated with the DSTO laboratories in putting together cost estimates and a program of work for submissions to Canberra. But even the few who had the expertise to define the future vehicle had higher priority work when funding for Winnin was uncertain in 1982. However, the Government Aircraft Factories generated several study reports during 1982 using funding remaining from the feasibility studies and internal support.

Staff at the Aeronautical Research Laboratory had begun preparing computer models of the 'hovering rocket' for the Electronic Warfare Division studies in the latter part of the Advanced Feasibility Study in early 1981. Consequently, Keith Cameron, Rodney Brown and Dr Mather Mason, from Ron Whitten's System Operations Group, were familiar with the vehicle concepts when Murray Evans became involved in late 1981 as head of Systems Division. Mather Mason later became involved in preparing systems specifications and in spin control unit studies. Rod Brown continued to generate a simulation model of the decoy as well as devote a large amount of time on wind tunnel testing. They were later joined by Dr Chris Guy as the new Operations Group leader. Guy's area of interest was in flight control and sensors. Others joined as Condev developed, including Fen Gerrand, Reg Arkell, Brian Catchpole, Art Keeler and Tommy Atkins; the latter three worked on the Air Data Unit development. Other important contributions came from Neill Pollock on aerodynamics and Bill Rice on spin control. Mark Halpern and, later, Michael Turner contributed on the vehicle modelling. Key staff from the wind tunnel section included Neill Matheson, Kevin O'Dwyer and Ian Amott.



4-2 : The 'Hoveroc' concept demonstrator vehicle contrasted with the required Winnin operational vehicle as seen by a cartoonist in 1983.

The team under Murray Evans at the Aeronautical Research Laboratory became the Research and Development Authority while the team at the Government Aircraft Factories under Bob Scott was the Design Authority for the upper body, which included the vehicle — less propulsion — and the Coordinating Design Authority for the round, and aspects directly affecting the round. The other major group was a consortium of rocket motor people under Geoff Heath of the Explosives Factory, Maribyrnong. Although the groups were being formed during 1982, the roles and organisational relationships were not confirmed or effective until the official start of the Condev program in March 1983. The first of 25 regular technical coordination meetings for the program occurred in August 1983 and continued to the final two-day review meeting on 15–16 June 1986.

The mass of the payload was the key unknown. Size and weight modelling proceeded to establish the diameter of the vehicle which in turn determined the design of the launcher.

During the build-up to Condev in 1982, the Government Aircraft Factories team grew from Bob Scott, Mal Crozier, Wayne Sykes (modelling and control) and Laurie Harris (sensors) to include Ian Griffiths (control systems), Paul Maliphant (aerodynamics), George Cureton (design draftsman) and Peter King (mechanical engineering). Then Dave Taunton, Dino Appla and Winston Furlong joined the control and modelling group, working with aerodynamics engineers Brad Yelland, Lachlan Thompson and Rob Fraser.

Paul McGlynn joined the spin control unit and John Wilson, assisted by Alan Sherwood (stress analysis), assumed all mechanical engineering duties. Electronics and instrumentation personnel were John White, Dave Prowse, Ian Oxworth, Eddy Heim, Roy Willmott and Brian O'Callagan. Rob Winton assisted Bob Scott on cost and scheduling and Paul Maliphant became the coordinating vehicle design engineer, dealing with such matters as mass budgets, vehicle assembly and interfaces to all sub-assemblies, including the payload, motor and Air Data Unit.

Decoy size

The mass and length of a decoy in its canister greatly affected the launcher design and the logistics and acceptability of handling the decoy around the ship. It was clear to all that if the decoy could be made small enough and 130 mm in diameter, it could fit in the standard Mark 137 chaff launcher, which would suit most navies around the world including those of Australia and the United States. Decoy size predictions were the first system issue to be addressed for the operational decoy, starting in March 1981 and continuing into the Full Scale Engineering Development phase.

The mass of the 'Hoveroc' vehicle was defined by the thrust available in the existing Murawa rocket motor. However, to build a new vehicle to a minimum weight and size required a highly iterative process of refining all non-propulsive components, then iterating the thrust and mass of the rocket motor. This required a large computer program developed by the Government Aircraft Factories for estimating the vehicle mass, length and diameter. The relations between motor mass and the thrust the motor delivered were prepared by the Propulsion Division.

All groups responsible for components of the decoy repeatedly supplied estimates against target masses and sizes generated from the program. The mass of the payload was the key unknown. Size and weight modelling proceeded to establish the diameter of the vehicle, which in turn determined the launcher. An important example of its use was to show that the older motor propellant technology produced a lighter and shorter decoy than the newer preferred cast composite propellant. The model was also used to produce the required thrust profile for the prototype rocket motor development.

It soon became obvious that the operational vehicle could not sensibly be 130 mm in diameter. The 150 mm diameter model produced a much more practical dimension for the vehicle. This was very disappointing, but George Cureton and Peter King developed several schematics to show how a larger diameter vehicle could be accommodated in the standard off-board chaff decoy, Mark 137 launcher. Motor temperature sensitivity and thrust tolerances were known and made it possible to compute the reduction in length to be gained by maintaining the rocket motor at a fixed temperature when in its launcher. This work on launcher arrangements accelerated in the months prior to the fact-finding mission to the United States in May 1982. The team went to the United States Navy armed with shorter fatter decoys, and proposals for modifications to the chaff launcher including those with the facility to condition the decoy thermally.

Launchers

An important aspect of visits to the United States Navy in May 1982 and October 1982 was to gauge the reaction to the preferred 150 mm vehicle diameter, as well as the notion of providing heating for the rocket motor while stored in the launcher. This thermal conditioning eliminated a large thrust variation and reduced the vehicle length, making it more acceptable to reducing the diameter to the 130 mm. The effect on length was greatest for the preferred new motor propellant. There was a negative reaction to the idea of thermal conditioning, which was understandable from those who were familiar only with the chaff decoys. Studies proceeded for several years, but thermal conditioning remained unacceptable to ship operators.

The initial work on launchers and schemes for adapting the chaff launchers, with or without thermal conditioning, was undertaken at the Government Aircraft Factories in conjunction with the vehicle mass and size modelling. Later in September 1983, this work went to the Advanced Engineering Laboratory at DSTO. It was clear at this stage the vehicle was going to be 150 mm in diameter, and a transportable box containing 10 decoys in their launch tubes was presented to the United States Navy in June 1984. This was the preferred Royal Australian Navy solution, but that of the United States Navy involved fixing a box to the plinth of the chaff launcher. The Advanced Engineering Laboratory also presented the results of its tests of manhandling the decoys from a storage locker to the launch box under rough sea conditions. The need was assessed to be an astonishingly large number of decoys to be carried — four times those actually used — which necessitated the extra storage locker. By 1985, the preferred launcher was a flat cabinet fixed to the ship, housing four decoys — ‘the flat pack design’. This concept went forward into the engineering development.

The Winnin rocket motor

The Condev phase for the rocket motor mainly concerned developing the manufacturing techniques to be used in the operational decoy vehicle. This aim was achieved more successfully than all other aspects of the Winnin program, thanks to efforts of the Propulsion Division and the Explosives and Ordnance Factories at Maribyrnong. These three establishments had a long tradition of working together and were referred to as the propulsion consortium. They had learned from previous development projects that the chief factor concerning a rocket motor was having proven processes for manufacture. A variation or void in fixing the inhibitor material around the propellant could, in extreme cases, cause a motor to explode. A rocket motor nozzle had to be insulated from other materials but had also to remain accurately located as the materials expanded. Solving these issues required the right choice of design, material preparation, assembly and test.

Geoff Heath from the Explosives Factory, Maribyrnong, was seconded to Adelaide to be project coordinator for all Winnin work at DSTO and the two factories. Chris Holland managed the development of manufacturing processes at the Explosives Factory while Ian Marshall, head of the cast composite charge section, and Neill Farrar (Rocket Motor Engineering) were key players in the production aspects. Juan Hooper and his team at the Propulsion Division brought their newly developed 'cast composite' propellant technology along with the older cast double base technology.

David Berrill from the Ordnance Factory, Maribyrnong, joined Arnold Deans and Des Kay in Adelaide to participate in the development of the thrust control unit, and Zoltan Janka at the Ordnance Factory led the engineering effort for the development of the rocket motor case and the thrust control unit hardware. No work had been previously undertaken on the case design. However, the Ordnance Factory brought newly developed experience with light weight cases for the booster motor on the Harpoon missile.

Special maraging steel was required for the lightweight motor and this required high tolerance forming techniques.

The motor design was based on a thrust and burn time requirement derived from the early 1983 estimates of total vehicle weight. The payload mass was the least understood element affecting the required thrust, but nothing was known accurately. It was clear that a major iteration on the design would be necessary if this motor was ever to be used in a flight test vehicle carrying a payload.

There evolved a design for casting the propellant into a taper beaker of inhibitor, along with a method for supporting the resulting charge in the motor case. The innovation for the motor case design was to flow form the tube using a special maraging steel, characterised by its light weight and high strength, rather than machine forging.

Experience using a flow forming machine was delayed by 18 months when the million dollar machine arrived at Ordnance Factory, Maribyrnong, extensively damaged, and had to be returned to Germany for repairs.

The complete light weight rocket motor came together for the first time in a firing in May 1985. Over the following 12 months the Explosives Factory, Maribyrnong, built 113 motor charges and others were manufactured at the pilot plant at DSTO for development tests. Thirty-six rocket motors had been fired at the Explosives Factory's test site at Ravenhall, Victoria, when the Condev phase formally ended. Plans for flying 24 advance development models were overtaken by successful efforts to secure the United States Navy as a partner in a collaborative development.

However, one of the biggest issues for the motor team was the emerging need to meet the insensitive munitions requirements for rocket motors. The preferred ‘cast composite’ propellant did not help reduce the mass, but was the only means of meeting these new requirements. John Cawley and Louise Barrington took the lead on the insensitive munitions program and organised the first fuel fire test for the cast double base motor in November 1982 at Port Wakefield, and followed this with comprehensive tests of the cast composite motor in February 1986.

Winnin thrust vectoring system

Arnold Deans turned his attention to the requirements of the Winnin Thrust Control Unit following the ‘Hoveroc’ success. This unit needed to develop twice the performance in half the space of its predecessor. Arnold’s new assistant Des Kay began working on a computer model based on the physics of the supersonic flow over the tabs of the Thrust Control Unit. This was an essential tool for scaling down the size of the unit while increasing its output performance. It also became an essential tool for the flight control specialists at the Government Aircraft Factories, because tests of single and multiple tabs showed major changes in characteristics as the tabs were inserted further than ever before. Testing to January 1984 confirmed the shape and size of the tabs, but also included tabs that swivelled to produce a spin torque. Testing of this variant ceased as the aerodynamic solution to this problem of controlling the azimuth angle of the decoy was developed in Melbourne during 1984.

All early tests were aimed at assessing thrust vectoring performance where light weight was not necessary. However, it became clear that the durability of fixing a molybdenum tab on aluminium, with or without insulation, was unsatisfactory. This led David Berrill to initiate a new approach. The first step was to use an all-molybdenum arm to guarantee it would survive, and then use high speed colour photography to study how the temperatures varied over the tab arm, and where the deflected efflux travelled. Armed with this knowledge, Berrill could make judgements on the form and size of the steel part of the arm and define deflector plates. The idea of using insulation was discarded in favour of adopting molybdenum rivets.

Preparation for tests of rocket motors did not happen quickly and there was always the potential for many things to go wrong. Building the multi-component test rig for measuring forces and moments in three axes was a major design exercise and needed reworking. However, some performance data for a representative tab arm was measured in the first test attached to the Winnin light weight rocket motor in the reworked multi-component test rig in October 1985. Not until April 1987 was the definitive performance of the tab assembly established in a comprehensive series of tests that made Des Kay confident with the computer model of performance.

Tests of four prototype thrust control units followed in November of that year. Laurie Harris at the Government Aircraft Factories provided the servo-motor systems to actuate the tabs for these risk reducing tests. This was the first time a system that looked like a flight standard Thrust Control Unit had been demonstrated to survive the harsh environment. David Berrill and those at the Ordnance Factory, Maribyrnong, could afford to relax a little. Two months later the joint program development contract began.

A height and airspeed sensor

A handful of engineers at the Government Aircraft Factories had continued working on the project following completion of the 'Hoveroc' flight trials, and they began identifying the more serious technical issues that needed to be addressed for the operational vehicle. Vehicle mass and size had been discussed, but determining the cost in relation to performance of the flight control system was now considered a crucial task. The speed of flight would need to be much higher than for 'Hoveroc' and that meant the simple height measurement technique to be used would need to account for the effects of air flowing around the cylindrical body.

It was clear that the use of a speed sensor and control loop would facilitate use of a less accurate and therefore cheaper gyroscope in the vehicle's stabilisation system. An airspeed sensor would be less expensive and lighter than accelerometer-based sensors. Simple as the sensing of vehicle airspeed and direction might appear, the classical anemometer propeller and vane system was considered unsuitable because it was fragile and had to be located at the vehicle's top end. The pitot-static sensor for airspeed and height used on aircraft was unusable because it did not measure direction of the airstream and would also be directly affected by the omnidirectional

The ADU became a 'technology weapon' in the subsequent efforts to secure a collaborative partner.

airflow around the cylinder. The unique nature of this flying cylinder meant that a new concept was needed to sense air velocity – speed and direction – and vehicle height.

Murray Evans at the Aeronautical Research Laboratory started taking an interest in this problem soon after he had been approached in late 1981 to take a leading role in the yet to be defined concept development program. Group sessions led to the idea for what was to be known as the Air Data Unit. The proposal for and subsequent development of the Air Data Unit was based on the idea of creating airflow in and out of a number of radial tubes from the outside cylindrical surface to a central space. The pressure in this space would be used for height measurement, but each tube had a fluid diode, facilitating flow in but resisting flow out. The pressure in the central space was pumped up by the array of fluid diodes in such a way as to eliminate the effects of the circumferential pressures. The diodes were such as to give a measure of ambient static pressure that indicated barometric height. A fluidic vortex diode was designed for the Air Data Unit and a complete assembly was tested in the Aeronautical Research Laboratory wind tunnel in June 1982, even before the official Concept Development phase had begun. The test results confirmed the principle was sound. The next step was to measure the air velocity in each of the tubes before it entered the fluidic diode using ultrasonic devices similar to Doppler-based speed radar. Software was then needed to choose the three tubes with the highest speed and deduce the airspeed and direction.

This was a very innovative concept for the sensing of height, airspeed and its direction in the particular circumstances of a cylinder moving slowly through the atmosphere. It was also advantageous in that it needed to be located somewhere equidistant from the ends of the cylinder. The device became a 'technology weapon' in subsequent efforts to secure a collaborative partner but retain the vehicle development task for Australia. As well as being guarded about disclosing the working of the sensor, the Aeronautical Research Laboratory prepared patents in 1985 for the height sensing and speed sensing ideas to protect the intellectual property. By this stage the design had advanced and many tests of it had been completed.

However, during the period from 1987 to the Nulka engineering development stage it became apparent that manufacturing the ultrasonic components was difficult and corrections for errors in the sensors became complex. Fortunately, some work had been done on an alternative method and the Air Data Unit was subsequently abandoned for the Pressure Air Data Assembly based on measuring the pressure distribution around the cylinder directly.

ARL fortuitously discovered the spin-controlling effect of a paddle, like a moveable rudder.

Spin control concepts

The decoy had to control its spin in order to be effective, and the simplest control loop considered to maintain spin control turned out to be the most vexatious. Defining the amount and the method of providing a controlling torque about the spin axis was a problem from the first day of the 'Hoveroc' program. The vanes in the motor efflux used on the Advanced Feasibility Study 'Hoveroc' vehicle were required to be smaller and less likely to produce the increased torque needed to provide spin control for the new vehicle. Every measurement and estimation tended to increase the projected maximum torque required. The major issue was due to asymmetry in the vehicle body, which was difficult to estimate: equally difficult was quantification of the effect of asymmetry on the vehicle.

The Propulsion Division at DSTO Salisbury, examined various vanes, tabs and nozzle schemes in the rocket motor, but the Aeronautical Research Laboratory fortuitously discovered the spin-controlling effect of a paddle, like a moveable rudder. The Government Aircraft Factories evolved this concept from a fan-based system. The drawback to this flexible solution to spin control was the potential to affect the payload detrimentally. Vanes and paddles were tested in August 1984 and cleared the way for the choice of the vane system. Both the Aeronautical Research Laboratory and the Government Aircraft Factories worked enthusiastically to resolve this vexatious issue in time to be able to present it as part of the case for the United States selecting the Australian vehicle as its active expendable decoy in 1985. The solution was developed further during 1987 so that a prototype spin control unit became a crucial part of the first deliverable to the United States Navy in October 1987.

4-3 : Spin Control Unit and electronics.

Vehicle flight control and modelling

The control systems engineers at the Government Aircraft Factories began examining issues that needed to be addressed to control the motion of the operational decoy. They needed to understand the vehicle requirements for successful decoying resulting from the work at Electronic Warfare Division at DSTO as well as the limitations of the thrust vectoring system being devised by the propulsion consortium. They had already identified the need for a special height and speed sensor, but also recognised that the dynamics of the vehicle, its sensors, and the thrust and spin control units were non-linear. The characteristics of the thrust control unit in particular were non-linear due to interactions between the shock waves created by the three separate control tabs. The flight controller — or autopilot — would therefore need to be a digital microprocessor. There was no way analogue electronics could execute the complex angle transformations and non-linear control algorithms needed for this unusual vehicle which had to be capable of motion in any direction while separately directing an antenna to any other defined direction.

Cost versus performance was a major driver in the choice of sensors for the control system.

The lead control engineers at the Government Aircraft Factories had experience on at least one autopilot design project for aircraft, but all of these were analogue. Consequently, they set out to extend their knowledge and computer tools to deal with the control and stability aspects of sample data control systems. Others developed their skills in using the early microprocessors that became available during the early 1980s.

Cost in relation to performance became a major driver in the choice of sensors for the control system. The most critical sensor choice was to find a suitably small, but practical and affordable device, for measuring the three angles of orientation needed for controlling the decoy cylinder in flight. Existing rate gyroscopes tended to be smaller but less accurate than displacement gyroscopes. However, there were many new-technology rate gyroscopes being developed by companies around the world during the 1980s that promised amazing performance at greatly reduced prices. Several of these rate gyroscopes were evaluated and found wanting. In order to evaluate their own ideas for an inexpensive performing system for stabilising the decoy, both the Aeronautical Research Laboratory and the Government Aircraft Factories designed and built several experimental rate and displacement gyroscopes during 1983–1984, but the capability to manufacture gyroscopes in Australia had declined dramatically since the early 1970s. Only expensive rate gyroscopes were available in 1986.

Dr Frank Klemm from NRL had supplied data sheets on a small displacement gyroscope as early as 1982 during the first visit to the United States, but it took five years for three samples to arrive in Australia: these were units being developed for a new missile program for the United States Army. The transfer was ultimately instigated by Commander Sam Anderson, the new Ship Launched Electronic Decoy Project Manager in the United States Navy. One of two gyroscopes being developed for this missile program was tailored for use on the decoy by the United States vendor during the first six months of the later Nulka Full Scale Engineering Development project and was adopted. The remarkably small size and excellent performance was made possible by the ingenious rotor spin up and caging system. The unit was surprisingly affordable at US$500 per unit because of a program where they would be produced by the thousands.

The Australian tradition of using simulation models for developing defence related products continued into the development of the decoy under Winnin and then under the Nulka project. The Aeronautical Research Laboratory maintained an all digital computer model and the Government Aircraft Factories based all flight vehicle work on real-time hybrid — digital and analogue — computer models which could be used to include the real autopilot and sensor hardware.

These models were continually revised as wind tunnel data on vehicle aerodynamics became available, or as literature reviews defined typical ship motion values and environmental conditions. At any one time they represented the latest that was known about factors that affected the flight of the vehicle.

Reports on the aerodynamics of air ships and cables sufficed for the ‘Hoveroc’ vehicle, but the design requirements for the operational vehicle warranted detailed aerodynamic data. The vehicle aerodynamics were measured in two series of tests each at two wind tunnels between 1984 and 1986. The tunnel at the Aeronautical Research Laboratory produced very low turbulence in its airstream, while that at Monash University produced a high turbulence stream: both were used. The major debate among the vehicle designers at both the Aeronautical Research Laboratory and the Government Aircraft Factories concerned the degree of air turbulence in the atmosphere and the degree of surface roughness to apply to the vehicle. The aerodynamics of the cylinder affected almost everything to do with its performance, and its surface texture was expected to have an impact on the speed at which the flow changed from laminar to turbulent, causing a dramatic change in the magnitude of the drag and the forces trying to tip the cylinder. The manoeuvrability of the vehicle was an issue along with flight control and the amount of thrust vectoring required. Even aspects of the payload were determined by the aerodynamics. The surface texture and turbulence issues were later resolved during engineering development, when flight tests confirmed the validity of the decision to have a smooth surface treatment.

The vehicle position and height predictions of the vehicle simulations were important to Electronic Warfare Division as they began to understand the decoy positioning requirements for the system to be effective. The standard Super Rapid Bloom Off-Board Chaff launcher angles were not optimum, so studies were required to define the required range of angles. Similarly, the angular motion of the ship and height requirements led to the definition of the speed at which the vehicle was ejected from the launcher. The requirements for positioning became more difficult and the range of conditions widened so, by the end of Condev, it was necessary that the launcher provide the means to eject the vehicle at different speeds. This was a major additional complication to the launcher concept which later caused much discussion and extra work.

Close of Condev for the flight vehicle

During the 18 months to June 1986, all participants in the Condev program prepared sub-assembly specifications that included the functional requirements and performance parameters. These specifications represented the outcome of much computer modelling, engineering assessment and, in some cases, prototype testing of what was needed and what was achievable. Detailed vehicle and sub-assembly drawings existed for building the Advanced Development Model vehicles, and there were separate layouts for the Engineering Development Model (EDM) which included a payload. These were prepared for flight trials as planned in the definition of the Condev program which included the definition and initial implementation of a means to initiate the launch of a decoy for trials.

Planning for decoy-vehicle flight trials had also begun as the United States Navy interest increased during 1985. A discussion paper on the flight trials prepared by the Government Aircraft Factories in April 1985 marked the beginning of Condev flight trials at Woomera and at sea. The DSTO Trials planning group and Navy D TRIALS representatives visited Woomera and identified the work required to prepare the range for the tests. Many planning issues had been identified but not resolved when Condev was terminated in September 1986.

The benefits of the preparation of specifications, weight budgets and interface definitions became apparent in the latter months of 1985 and afterwards. Much information was exchanged with the United States Navy following the exploratory visit by Peter Hider and Roy Kane in September 1985. Agreement was reached on many specifics, such as the use of the split transformer for motor ignition, changing the vehicle diameter, doubling payload power, the wooden round concept — which required no on-ship testing as opposed to on-ship self test — and putting the antenna outside the payload assembly. Australia was able to respond quickly and there was a determination to maximise working level communications in preparation for a future program start. This all provided a positive background to negotiations occurring in high places.

Approval for the Condev program prevented expenditure on trials hardware and even made it difficult to acquire items for test and evaluation. The Condev phase was characterised by more paper studies than many in the business of development had previously experienced.

A synopsis of the Condev flight vehicle work

In June 1986, the Condev program took on different administrative and engineering elements, with many of the vehicle requirements having to be changed. The Nulka joint program, which started 18 months later, built on several concepts and technologies derived from the Condev program, but the two most advanced items had to be extensively re-engineered. Still, the tools and expertise to do this efficiently were already in place. The least obvious outcome was that the program emphatically closed off many blind alleys which otherwise might have consumed resources and time during the joint program. During the 18 months following Condev there were to be more studies, referred to as ‘risk reduction studies’, to eliminate other options before the engineering development began.

The degree of progress made on the rocket motor during Condev exceeded that of all other areas, but a great deal of work was still required on the Thrust Control Unit. Even the motor had to be changed significantly to accommodate the need for a heavier electronic payload and a longer flight time. The estimates for the payload had increased during Condev, but they remained as uncertain as they were in the beginning. The prototype payload flown by Electronic Warfare Division provided only a little improvement on the confidence level for the estimates affecting the vehicle design. A central issue during engineering development was for all assemblies to meet the weight budget.

The Spin Control Unit proved to be the most complete of all the major sub-assemblies. There was a consensus that the launcher concept was satisfactory, but this was to take some unexpected turns during engineering development. The mortar launch concept was understood, but the computer model needed actual tests to give certainty to the outputs.

The Air Data Unit remained under development and solutions were still being developed to reduce errors. A new concept for this critical sensor was proposed and developed during the Full Scale Engineering Development phase. Computer models existed for potential flight control implementations, and digital flight control electronics existed but their use was aimed at the interim Advanced Development Model vehicle. The digital electronics world was moving so quickly that this material was obsolete before the Full Scale Engineering Development phase started.

The cost of a decoy

Bill Dickson's early cost estimate of US$20 000 for the cost of a decoy was academic, but it emphasised the need for 'economy' which was to be reinforced by every contact with the United States Navy over the period from 1982. The issue certainly affected the technical trade-offs attempted during the Condev phase.

The decoy cost was driven politically by the price of a chaff round. Time would show that this US$30K cost figure and the baseline number of decoys to be built each year, 1500, were both out by an order of magnitude, but each in the wrong way.

The unit cost of a decoy had been an important, perennial issue for the United States Navy. Unlike their missile counterparts, electronic warfare decoys were considered 'expendable'. The selection of an acceptable goal for unit cost for an active decoy was therefore an exercise in pragmatism. Given that estimates of suitable travelling wave tubes in quantity production cost around US$10 000, it was unrealistic to expect payloads to cost less than US$20 000. With about US$10 000 added for the vehicle, the baseline cost was about US$30 000. There were many discussions concerning the credibility of this figure, but anything much higher would likely have seen the project falter in 1982. At that time, it was argued that electronic warfare defence of a ship would require considerably fewer active decoys than chaff rounds, and so a higher unit price for decoys could be tolerated, but this argument could not be carried too far.

Still, one advantage of having a stringent price target early in the program meant that low unit cost was expected to be a major driver of future decoy development.

From as early as any in the project can remember, the target price for the decoy had been set at US$30 000 in 1982 prices. Dr Martin Kamhi had argued that any active decoy would have to be less than US$30 000 during the Australian visit to the United States Navy in May 1982. Production was envisaged as high as 1500 units per year for five years. The principal component in the payload was believed to limit the production rate and represented 25 to 30 per cent of this target cost. By comparison, it was said that a chaff round was US$1000 in quantities of 2000 and the new Sea Gnat round was US$5000. Two years later United States Rear Admiral David Altwegg conceded that a decoy was unlikely to cost less than US$42 000 and would be a non-starter at US$60 000 per decoy. This was based on estimates for an active payload for the Active Expendable Buoy program starting in the United States.

Barry Watson, the AWA Aerosystems program manager in 1992, observed:

This infamously low US$30 000 round price created an unrealistic expectation for the round pricing, which we had to defend at every design review. The project offices gradually came to accept that the decoy was virtually equivalent to a missile and a new pigeonhole had to be created for the active decoy class. It wasn't chaff and it wasn't a missile.

Time would show that this US$30 000 cost figure underestimated the eventual cost by about 10 times and the baseline number of 1500 decoys to be built each year exceeded the approved number by more than 10 times, allowing no scope for potential cost reductions.

Electronic warfare systems studies

Active decoys were neither simple munitions like chaff, nor were they missiles, although the decoy vehicle aspects were more akin to missile technology. Therefore, more in-depth system studies were required in the Winnin Condev phase and beyond on how the active decoy should be used and deployed to counter incoming missiles successfully. There were numerous operational issues to be addressed. The physical size and shape of the ship had an effect,

4-4 : Gino Beltrame acquired a detailed knowledge of the engagement dynamics by his modelling studies and then played a key systems role in later tests which ultimately included those conducted during the joint program. He was of immense assistance to the British Aerospace team during the mid 1990s and received a citation from Rear Admiral Paige of the United States Navy Theater Air Defence Branch for his contributions to the joint program.

4-5 : Cos Melino had a long association with the computer modelling of the decoy effectiveness. This included models used for tests off Newcastle in 1985. Significantly, his models were the basis for the development of a Ship Air Defence Model (SADM) by British Aerospace in 1998.

and even the ship course and speed might affect the result. Gino Beltrame and Ron Evans continued to develop and refine their high level missile engagement models that were used to address these questions. The vehicle not only had to be able to carry the payload, but also manoeuvre and control it as required to achieve its task. Key parameters affecting the operational performance of the payload included height, tilt, speed, time of flight and flight profiles.

With an in-depth understanding of decoy deployment gained through his modelling, Gino Beltrame's role became pivotal in the project. His work was later to lead to the development of high level specifications for decoy operation and for the system's fire control rules. He became responsible for evaluation of Nulka operational trials, provided important inputs to the vehicle and systems prime item development specifications drafted prior to the Joint Project Agreement with the United States, and the finalised specifications for the following engineering development. The work of Beltrame and his small team was outstanding and their results were frequently used in the high level negotiations with the United States. Beltrame was the DSTO Research and Development Authority during the Full Scale Engineering Development phase of Nulka.

Vic Sobolewski modelled the effects of scattering from the sea surface and its effects on the optimum height of the decoy. After being promoted to Communications Division in 1983, Sobolewski returned in 1985 to the Electronic Warfare Systems Group under John Curtin. This group was involved in trials, payload studies and hardware development. Sobolewski continued with his analysis of operational performance of the decoy with realistic targets and environments. His detailed analysis of the physical environment was world-leading and underpinned the payload development.

Cos Melino joined the project in 1983 and developed a detailed system model of the threat missile, ship and the decoy, which incorporated previous models developed by John Gardner (missile), Scot Allison (seeker), Vic Sobolewski (radar reflections and multipath), Mather Mason (decoy vehicle) and Gino Beltrame and Ron Evans (payload). This large detailed system model incorporated a considerable amount of the corporate knowledge about the decoy system to that time, and it was intended to be used to predict the likely outcomes of trials and tests using specific threats. Later versions of this model used radar cross-section measurements of RAN FFG7 frigates made by Cheng Anderson.

The detailed system model was also used to calibrate the simpler models created that would compute much faster. These simpler models were generally produced by Evans and were used for trade-off studies and development of fire control rules for decoy deployment. As well as undertaking modelling studies related to decoy performance, Cos Melino produced a model to support the payload development tests that culminated in a ship-trial at Jervis Bay in 1986. Melino produced a digital simulation of the Cyrano monopulse radar from a RAAF Mirage aircraft used to represent the missile threat. He incorporated this into the system model, then used the model to plan and predict the outcome of the Winnin 'decoy system concept tests' held off Newcastle in August 1985. His task also included analysing these test results and validating the simulation model.

Much later, in 1994, Gino Beltrame, Cos Melino and, later, Miro Dubovinsky developed the tables of deployment tactics for the decoy vehicle for the RAN FFG7 and FFH frigates during the Active Missile Decoy phase. These tables are known as the Nulka Decoy Algorithm tables and became a feature of the AWA-developed decoy deployment algorithms. The work involved development and running of the detailed signal level model and the simpler, but much faster, system model to generate the effectiveness data used to produce the Nulka Decoy Algorithm tables. Both Melino and Beltrame were involved in analysing payload aspects of the first Nulka decoy tests from a ship at Jervis Bay in 1992.

Developing a payload

As Scot Allison settled into his new position as Superintendent Electronic Warfare Division in early 1982, he saw that plans for a concept development program were based almost totally on the carrier vehicle. At this time it was assumed that Australia would move into the engineering development of the decoy vehicle and seek to acquire an overseas partner to develop the payload for the vehicle to carry. However, by the time a partner had been secured the vehicle development would be significantly ahead of that of the payload. Allison became concerned that the project's aim, namely to develop a decoy system that would meet the RAN's needs, was shifting in response to pressure to exploit the 'Hoveroc' vehicle technology before it was duplicated by others. The vehicle concept had been demonstrated in principle in flight trials, but the payload remained a concept on paper. And there would be potential

Scot Allison wrote:

If we didn't have payload experience we would have had to wait a couple of years while our partner got up to speed in overcoming what were clearly formidable payload problems, so the project would be a long time in delivering. One could even imagine that a new generation of sea-skimmers would be near to entering service. It made sense for us to make as much progress as possible and transfer that experience to a collaborating partner. We wanted our partner to be in a position to hit the ground running.

Alternatively, there was the danger that the partner would be reluctant to go the hard yards, and select instead a conventional payload design in order to save time, with the result that the decoy would meet only half, and hence not the RAN's, requirement. I feared this was a situation that might have been accepted by our decision-makers, because, though it sounds bizarre, in those days many thought it was only necessary to meet the detailed requirement for the decoy positioning, and that any payload with the requisite power would suffice. In fact, it needed to be sheeted home that meeting the associated payload requirements was equally important and crucial. The sea-skimmer scenario created some difficult design problems for the payload.

collaborative partners who would need to be convinced their payload concept was compatible with 'Hoveroc' before they would commit to the Australian carrier vehicle technology. Scot Allison concluded that it was imperative that Australia demonstrate its payload concepts as well as the vehicle concepts.

Approval was gained for a program to demonstrate that an operational payload was feasible, despite considerable resistance from within DSTO itself. It then became necessary to change the structure of the development team within the Electronic Warfare Division to focus on bringing the payload design to a level of maturity comparable with that of the vehicle, prior to commencement of collaboration. John Curtin became head of Electronic Warfare Techniques Group with the goal of developing a fully engineered payload and testing it in sea trials under a helicopter.

The payload development task was well financed by the Australian Project Office, and the team grew to 30 people. It included John Curtin (task manager), Bill Dickson (requirements), Ken Harvey (system design), and Vic Sobolewski (systems studies and external radar propagation). Other members were: Nick Lioutas (assisting Ken Harvey), Dennis Miller (electronic systems developer), Richard

Lindop (electronic systems design), Ian Coat, Brian Ayton, Bill Adderley, Ross Campbell, Alan Peake (electronics technician and software developer), Ian Gregory (trials organiser and logistics), Peter Dadswell, and Ian Bleeby, on attachment from the United Kingdom. John Bell did a fine job in negotiating with the Royal Australian Navy regarding coordination of the trials and preparation of the detailed trials instructions. Lieutenant Commander Andrew Robb from the Navy contributed to the running of the trials. Air Force assets were organised by Lieutenant Commander Casey Dykstra at D TRIALS group.

Demonstration of the payload technology was essential to prove to the potential partner that the total decoy concept was feasible.

John Curtin, Vic Sobolewski and Ken Harvey developed the design parameters for the demonstration payload during this time, based on knowledge of the characteristics of the test ship and the radar to be used as a threat as well as the key parameters of a sea-skimmer threat. Bill Dickson was sent to NRL on several occasions between 1983 and 1986 to negotiate with NRL on a joint payload specification. The combination of requirements combined with the antenna characteristics provided a viable implementation for this prototype payload. This effort proved the performance and integrity of a payload concept in the low altitude maritime environment. This, together with the 'Hoveroc' vehicle demonstrations, gave a high level of confidence in the viability of the decoy overall. That was Scot Allison's vision.

4-6 : John Curtin, as head of Electronic Warfare Techniques group, led a large team to develop and test the Australian payload. He played a pivotal role in its design and testing and later (1987) participated in reviews to choose the payload contractor in the United States.

John Curtin and his team applied themselves to the engineering development of the payload to be used in full scale trials, and began planning a comprehensive series of trials to gather data prior to these full scale tests. This spawned the concept of the Captive Carry Unit for the payload. Not all trials required the use of a travelling wave tube-type payload and, to keep the payload work on schedule, the initial data gathering trials were carried out using tuneable magnetron transmitters that were both helicopter and ship-deck mounted.

The vehicle size, shape, and tilt angles influenced the choice of antenna apertures in azimuth and elevation, as well as determining the payload performance environment. The format and packaging of the payload was also constrained by vehicle requirements. The vehicle designers, on the other hand, laid out Flight Control Unit components so that an antenna could be placed near the bottom of the unit to maximise the distance between antennas.

Richard Lindop and Peter Dadswell undertook valuable work on novel radar frequency designs for the payload, and proposed an original waveguide structure for a low loss transmission line. The transmission line, built into a groove cut as a helix in the thick wall of the payload cylinder, saved weight and space. The design and method of fabrication were patented in 1987. Dadswell's waveguide components were shipped to NRL for use in one of its prototype payloads. A Ken Harvey antenna was also supplied for engineers at NRL to assess. These exchanges of components and associated engineering data were in return for the provision of payloads being developed at NRL. Cooperation with the United States Navy was accelerating towards a decoy development program to start in the next year. There were, however, some differences between the NRL and Electronic Warfare Division approaches but these were ultimately resolved during the early part of 1986. The Australian waveguide was inherently cheaper, but was overtaken by developments and not used in the decoy system. Ken Harvey's antenna work showed a viable payload was technically feasible and was crucial for establishing collaboration with the United States and the successful development of Nulka.

A suitable travelling wave tube amplifier was essential for DSTO's demonstration payload. DSTO had bought a Varian amplifier but this was packaged for laboratory use rather than airborne tests.

Bill Dickson recalled:

NRL had available two developmental travelling wave tube amplifiers having the required power output, radar frequency broadband coverage, and packaging suited to an experimental payload, so we could see that if NRL and DSTO collaborated under the ABCA-4 agreement then we could get a good payload feasibility demonstration.

The packaging of the NRL travelling wave tube and its associated electronics posed a challenge for their integration in the limited space of the cylindrical payload structure. Other challenges included the need for a rapid warm-up of the travelling wave tube and the cost of the electrical power supplies. The thermal batteries readily available did not have sufficient power, so Bill Dickson looked at procuring others from overseas. Dickson was to learn that United States companies seemed to have a different philosophy regarding low cost. In their minds 'low cost' seemed to mean what the customer could afford.

A Captive Carry Unit for the payload tests

The design and building of a Winnin payload proceeded in parallel with the data gathering tests, using the magnetron, or simplified payload. As this payload began to take shape, there was a need to consider how to hold and direct it in a manner similar to it being in an operational decoy. A helicopter-mounted unit referred to as the Captive Carry Unit was needed to enable the payload to rotate and tilt independently and be clear of the helicopter to prevent ring-around problems. This presented both concept and design challenges solved during a group 'brainstorming session' that gave rise to the concept ultimately implemented.

Many people were involved in the design and development of the magnetron and travelling wave tube type payloads, the Captive Carry Unit and other trials equipment. Richard Lindop undertook much of the design while Peter Dadswell and Dennis Miller took responsibility for its manufacture. The engineered payloads and the Captive Carry Unit, in particular, were developed using the electronic and mechanical design and fabrication capabilities of the Advanced Engineering Laboratory. The power supplies for the tuneable magnetron transmitters were developed and built by local industry.

The Captive Carry Unit was a major development, and Steve Penniment and his team at Advanced Engineering Laboratory did an outstanding job to design, fabricate and test the system. Penniment's assistant was Ron Conyers and, at one stage, there were three drawing offices involved in preparing printed circuit boards. The Captive Carry Unit used a large, heavy top section containing the power supply batteries, electronics and control system. The payload was suspended below this unit and its pointing angle was controlled by a servo-motor. Direction control was achieved by using a large trailing vane attached to the top unit to hold it steady while the servo-motor rotated the payload assembly. The designers were proud of the manner in which they controlled the tilt angle of the payload: they used a commercial window winder mechanism with a Volkswagen steering damper strut to dampen the motion.

4-7 : The captive carry unit in flight.

4-8 : The team guiding the captive carry unit into first docking rig.

4-9 : The captive carry unit under helicopter and improved docking rig.

A close-up view of the captive carry unit (left picture). Team members guiding the captive carry unit into the first unsatisfactory docking rig (centre photograph). The new docking rig (right photograph) was much more satisfactory. The captive carry unit is seen here under the Navy Sea King helicopter at Point Perpendicular, Jervis Bay, NSW.

Data gathering tests

4-10 : The Mirage sweeps low over Stockton Beach near Williamtown, New South Wales, simulating a missile during the early tests to confirm decoying action.

The DSTO payload design was achieved through a comprehensive series of modelling and data gathering tests. The need for data gathering expanded as the models were required to reproduce realistic effects of significance. Vic Sobolewski modelled the radar reflections from the ship and electromagnetic aspects of the environment and looked for data to validate his models. He and Ken Harvey organised many tests on the antenna field using the payload on the wooden tower and strategically placed corner reflectors on the ground. A large wooden structure was fabricated to make measurements outdoors in order to avoid the radar reflections encountered when testing indoors. The majority of tests required development of special instrumentation capable of measuring very-low-power signals with a large dynamic range.

The aim of another series of tests in August 1984 was to measure the impact of the spin control vanes on antenna performance. The assumption, until 1984, was that the spin control would use the rocket motor. Ken Harvey, understandably, was annoyed by these intrusions into 'his' antenna space after all his efforts to successfully meet all the required payload parameters. The effect on the payload was measurable, but fortunately not significant enough to rule out using the vanes to solve the vexatious problem of controlling vehicle spin.

4-11 : Some of the Electronic Warfare Division team. From left to right: John Bell, Norman Jeffries, Mike Bell, Nick Lioutas, Gino Beltrame, Peter Bensted, Brian Ayton and Cos Melino.

Major trials were held at Stockton Beach, south of Williamtown, in 1985 to see if the means of detecting and recognising an approaching missile could differentiate between missiles homing on one ship or another accompanying it. Three corner reflectors were fixed on the beach, and a purpose-built radar receiving and detection system was located nearby. A Mirage with its Cyrano radar acted as the missile. Gino Beltrame, the trial planner and officer in scientific charge, requested the pilot to fly as low as possible in order to observe any multi-path effects while the radar receiver recorded the Cyrano radar signal.

4-12 : John Bell (foreground), Warrant Officer Cauley (on left), Corporal Marks, AC Brennon and Richard Lindop discuss the telemetry and camera pod designed to fit underneath the Mirage aircraft for payload testing.

Demonstrating decoying action

Another series of tests, designed to prove the decoy system concept, was carried out about 60 miles out to sea, off Newcastle, in August 1985. These tests were important to many people who were not privy to the body of knowledge within the electronic warfare community. The tests involved HMAS *Canberra*, a Sea King helicopter carrying a rudimentary, simplified, magnetron-based payload to simulate the decoy, and a Mirage aircraft with an instrumented Cyrano radar simulating the threat missile. Another magnetron incorporating a small delay was installed on the ship. This ship magnetron was tracked by a second range gate, which Richard Lindop cleverly conceived, to enable the radar to track both the helicopter and ship as they separated in the trial. A telemetry pod was developed for the Mirage to relay a real-time display of the location of the tracking gate in relation to the ship. This showed that a conceptual decoy successfully seduced the Cyrano radar away from the ship.

4-13 : Testing of the multi-path characteristics over the sea on the 'King Fish West' oil rig in Bass Strait in December 1987.

Richard Lindop, Dennis Miller and Ken Harvey spent a fortnight on a different type of vessel in December 1987. They boarded the 'King Fish West' oil rig in Bass Strait, to measure radar multi-path characteristics in accordance with a plan by Vic Sobolewski to validate his computer model. Miller remembered how it was initially daunting working at great heights above the sea, but they quickly adapted to this rather foreign environment.

Winnin payload testing

The Winnin payload emerged from the workshops and testing during 1985. The tower testing had shown the payload had achieved a high standard of antenna performance. The team under Ken Harvey's direction had shown a considerable amount of ingenuity and perseverance to achieve a satisfactory payload design. Harvey's expertise on all things to do with microwave antennas had been an important contribution. The significance of his achievement was later acknowledged by several experts in the United States, including Jim Sullivan, the technical advisor to the United States Space and Naval Warfare Systems Command Project Office and NRL technicians, who said that Harvey's work had achieved the 'impossible'. This was an important contribution to the efforts to collaborate with the United States Navy.

One of the first payloads was used for decoying trials at Port Wakefield. A motor launch was sent from Port Adelaide into Gulf St Vincent with a large corner reflector to represent the ship under attack. The modified Cyrano radar from a now-obsolete Mirage fighter was stationed at Port Wakefield and a real payload was carried in the Captive Carry Unit under a helicopter to simulate the decoying action. Decoying action was successfully demonstrated a couple of times, but on the third occasion the Captive Carry Unit separated from the helicopter winch and fell into a ploughed paddock and was severely damaged. The cause of the accident was traced to the use of an unwired shackle to connect the unit to the helicopter winch.

Steve Penniment, Dennis Miller and the team were horrified but undeterred by this major setback and, with renewed vigour, worked solidly for three months to rebuild the unit. One consolation was that the travelling wave tube in the payload remained operational after the impact with the ground — giving some indication of its durability.

Payload tests at Point Perpendicular

Full scale tests of the payload were held off Point Perpendicular, Jervis Bay, in July and August 1986. The DSTO team had already proved the payload in previous tests, so the Point Perpendicular trial was mainly to demonstrate the Australian system to the United States Navy team. This was officially a joint Australian/United States trial from a number of perspectives. Most importantly, United States representatives were able to ascertain the conduct and efficacy of the trial, and gain a first-hand perspective of the significance of the conclusions. Also, the loan of the NRL developmental travelling wave tube amplifiers was pivotal to the trials. Frank Klemm, Chris Wallace and another engineer from NRL participated in these tests.

The threat was stationary for this trial. It was represented by a simulator set up on the cliff-top, while the position of the ship and the helicopter, carrying the payload, were measured using the precision-radar tracking system at the Jervis Bay range. John Curtin, the OISC, planned the trials. Curtin recalled how difficult it was to organise so many participants, activities and equipment at the remote rugged location, more than a thousand kilometres from Salisbury. Even a diesel generator had to be supplied because the lighthouse power supply could not sustain the load.

4-14 : An aerial view of trials equipment placed near the lighthouse at the spectacular Point Perpendicular at Jervis Bay, New South Wales.

John Curtin wrote:

The fact that we accomplished most if not all of what we set out to achieve, without any major or even minor foul-ups, is a tribute to the 20–30 people who participated and to around double that number who contributed to its preparation. There was some frustration over the poor reliability of the travelling wave tubes and we were fortunate that the NRL participants had supplied a couple of their developmental payloads. The tubes had similar parameters and were definitely more robust.

Development of a working electronic payload and demonstrations of its effectiveness showed that the concept was valid and functioned as expected with real naval ships in the appropriate environment.

4-15 : Telemetry and simulator antennas received data from the payload and Captive Carry Unit and a simulator represented the missile.

The earlier 1985 testing at Newcastle, in particular, was timely because it occurred just as the United States established the Ship Launched Electronic Decoy Project Office and was seriously considering collaboration with Australia. The most important aspect of this achievement was that it reduced the risk of failing to produce an operational payload. This was important to any program manager prior to embarking on the expenditure of huge amounts of money for a major development.

The experience gained from the payload development gave Australia even more credibility, and demonstrated that it was able to make valuable contributions to the drafting of a sound and realistic payload specification for any future program. Australia's proposal to double the power required of the electronic payload was a direct outcome of this prototype testing.

The successful experiments off Jervis Bay in August 1986 concluded payload developments during the Winnin Condev program, and the following month marked the official end of Condev. However, the joint gathering of United States and Australian teams at Jervis Bay coincided with a gathering of important United States and Australian politicians across the Pacific. Both gatherings followed several years of Australia searching for a collaborative partner.

4-16 : The 1986 Point Perpendicular Trials Team group photograph. From left to right: John Robinson (NRL), Roger Morgan, Lieutenant Peter Arnold (RAN), Bill Dickson, Ian Coat, Tony Perry, Dennis Miller, Ian Gregory, Bill Adderley, Alan Peake, Ross Campbell, Chris Wallace (NRL), Frank Klemm (NRL), Richard Lindop, John Curtin, Ken Harvey, Vic Sobolewski.

Payload efforts in the United States

During this time and in parallel with the DSTO and NRL efforts, Lockheed Martin Sippican in the United States independently made a strategic business decision to fund an internal research and development effort to develop a decoy payload to position itself to win the Active Electronic Decoy Request For Proposals which was planned for some time in the future.

To this end, Lockheed Martin Sippican hired Wes Libby and Dave Donovan as consultants, based on their experience at Raytheon, Dave Stone because of his travelling wave tube experience at Varian, and it assigned Mark Small, a resident electrical engineer, along with another manufacturing engineer to the team. Bernie Mitchell joined the Lockheed Martin Sippican development team as program manager in February 1986 followed a few months later by Donna Edwards in the role of manufacturing engineer.

The internal research and development team developed a payload design concept during the period from 1984–1986, and concluded by delivering a prototype payload to NRL in mid 1986 for testing in the state-of-the-art anechoic chamber.

Lockheed Martin Sippican focused on developing wideband, quick reaction, travelling wave tube technology, and developing an antenna

The successful payload tests at Point Perpendicular gave confidence to the US that the technology was feasible.

and packaging design that met a stringent design requirement. The company worked closely with Varian Associates and Teledyne, both of which were located in the Bay Area, south of San Francisco.

The design approach quickly settled on the Varian technology as it was a mature version of a tube used on the ALQ 135 system and, with some design tweaking, met the transmitter requirement far better than the model proposed by Teledyne. Varian was selected by Lockheed Martin Sippican as the tube supplier and maintained its position ever since.

The chamber testing at NRL in 1986 was highly successful, with the payload testing the limits of its anechoic chamber. The measured data from that testing was then used in the Lockheed Martin Sippican proposal to provide the technical discriminators.

CHAPTER 5

Achieving collaboration, 1984–1986

Intense negotiations from 1984 to the first quarter of 1986 paved the way for a meeting in July in Hawaii where final agreement was reached on a joint development project. The Memorandum of Agreement was signed by Australia's Minister for Defence and the United States Secretary of the Navy on 10 August 1986.

5-1 : Captain Alan Brecht, as Director Electronic Warfare, Navy (DEW-N), played an important role in discussions leading to collaboration with the United States Navy. Ten years later he played a key role in negotiating the new Memorandum of Understanding with the United States Navy on production.

5-2 : Commander Sam Anderson, United States Navy, was a driving force in the selection of the Australian decoy system for the United States Navy Ship Launched Electronic Decoy program. His 'can do' attitude was highly regarded by all those Australians who worked with him during his tour of duty to June 1986.

Following his appointment as Program Manager for the Ship Launched Electronic Decoy program, Commander Sam Anderson wasted no time in visiting Australia, and arrived in the first weeks of October 1984. He was accompanied by Mike Ripley Lottee and Lou Ireland, and was later joined by Frank Klemm. This was a fact-finding mission to view the Australian Winnin program at first hand in order to present results to a United States Navy panel review in early November. The objective of the November review was to reduce the program options for the Ship Launched Electronic Decoy project ahead of the final decision to be made for the vehicle technology in May 1985. Feedback on the Australian Winnin program from the October visit was positive, and Australia's project executive lost no time in travelling to the United States in early November, with an official request to brief a panel of three admirals in the Pentagon.

The Australian delegation of Captain Alan Brecht, Murray Evans, Scot Allison and Bob Scott travelled to the United States in November 1984 to provide the information required and discuss items to be included in a Winnin brief to the forthcoming Admirals Panel Review comprising Admirals Fleming, Schick and Nyquist, scheduled four weeks later. The Winnin program was to be considered in that review as one option along with others from NRL – the folding wing aeroplane –and the Naval Surface Warfare Center at White Oak. Captain Beale and Commander Anderson clearly wanted to ensure Winnin was presented positively, and judged in accordance with the same conditions as the others. Even so, the Australians were at a disadvantage because of legal issues associated with Winnin's offshore origins. The Australians were reminded again that the NATO Sea Gnat production annex to the Memorandum of Understanding had taken three years to consummate, and if Winnin was to be a joint program there was a need for a Memorandum of Understanding to start from May 1985, only six months in the future. The message was not to pursue the guarantees on production. It was unlikely this date would be achieved, so the Defence Force Development Committee meeting in Australia to review Condev had to consider proceeding to phase three based on a letter of intent from the United States.

The strength of United States interest was evident when it was announced in early February 1985 that a large team of United States Navy personnel, representing every conceivable aspect of the future program, was to arrive in four weeks for detailed discussions. Prior to their arrival, the assumption in Australia was that a joint program was to be proposed and that schedule and cost issues were to be discussed. However, the United States representatives proposed a joint program on condition that the Australia contributed at least US$10 million for the first year and was a major contributor for succeeding years.[19] Australia's contribution had to exceed 30 per cent of the United States Navy estimate of US$80 million for the total project cost. In these preliminary discussions, the message from the United States Navy was that Australia was considered a risky partner unless it made a significant real cash contribution. Again, the Australians were warned that Martin Kamhi might still not approve a joint program if production guarantees were sought. The inference was that the United States would prefer to proceed independently.

The US initially saw Australia as a potentially risky partner if it did not put up substantial funding and continued to press for production.

Further negotiations, 1985–1986

The mid 1980s was characterised by detailed negotiations between the United States and Australia in an attempt to reach consensus on technical requirements and funding prior to a formal agreement being signed by the parties.

A decision in Australia by the Defence Force Development Committee on 30 May 1985 to approve between A$6 million and A$10 million for a collaborative program paved the way for the Australians to approach the United States. A new project team, under Program Manager Peter Hider, was appointed to manage the transition of the Winnin program from research to production. The team, comprising people from the Royal Australian Navy, DSTO and the Office of Defence Production, was also to negotiate the collaborative agreement with the United States.

5-3 : Roy Kane was the senior defence science representative on the team that negotiated the agreements with the United States Navy to develop the Winnin concept collaboratively. This role developed from his time as a program manager and later as the Project Director for the Winnin Concept Development program.

Peter Hider, Roy Kane, and others travelled to the United States in September 1985 to promote the collaborative development of the Ship Launched Electronic Decoy program, to exchange information, and to gain an understanding of the principles of any agreement. Despite the positive attitude of the participants, Peter Hider was unable to obtain an assurance from the United States on a role for Australian industry in production through 'dual sourcing' of the production between one Australian contractor and one United States contractor. The best he could achieve was an agreement to have further discussions on the matter.

Considerable progress was achieved on the technical aspects, however. There would be a common work breakdown with country unique items identified. The United States Navy agreed to review the

Operational Requirements Document and the Test and Evaluation Master Plan prepared by Australia.

Both countries intended to use the FFG-7 frigate as the trials ship — RAN nominated HMAS *Darwin* — and the United States Navy was happy to adopt the Australian stand-alone launcher for the development program. Even a larger vehicle diameter, which impacted on the launcher, was to be revisited. The payload contractors for the United States Navy Active Electronic Buoy program — Teledyne and Varian — were concerned about achieving the required levels of antenna performance and Australia agreed that NRL could test Ken Harvey's antennas. Australia was able to allay fears about key technical issues by reporting on the successful payload tests at Stockton Beach and off Newcastle. Roy Kane relayed to the United States the Electronic Warfare Division recommendation to double the payload power, and the notion of two grades of payload was discussed. The United States Navy had amended its ideas for a 'wooden round' concept and called for the round to be tested at the depot level. Kane also reported that the Winnin flight vehicle had flight capabilities that could broaden its performance to be effective against various types of threat trackers.

The United States Navy team returned to Australia in November 1985, by which time the Australians had gained an understanding of the project costs: they learned that Commander Anderson had secured US$43 million in principle and was looking for US$23 million from Australia. This was far above the A$10 million maximum set by the Defence Force Development Committee. The United States Navy estimated that vehicle costs represented half of the total, with the payload and all else comprising the other half.

Help from politicians

The Hawke Labor government that came to power in 1983 was quick to affirm its commitment to the ANZUS Treaty, mainly to allay fears in the United States generated by the earlier Whitlam Labor government (1972–1975). In June 1985, seven months after Kim Beazley became Minister for Defence, local media broke the news that Australia was assisting the United States in monitoring tests of the MX missile that formed part of President Reagan's Strategic Defence Initiative, popularly known as 'Star Wars'. Reagan had personally and vigorously pressed Bob Hawke to be associated with the initiative and Hawke had just as vigorously refused. The United

States relieved the political pressure for the Hawke government by finding an alternative airfield for the support aircraft to use in the missile tests. However, it was obvious that this failure to fulfil the promise first made by the Fraser Coalition government on the MX tests was embarrassing for the government and particularly Kim Beazley, the defence minister. Beazley believed that Australia's defence security depended on robust relations with the United States, but believed it must be a two-way relationship. At the time Australia was the second largest purchaser of United States arms after Saudi Arabia and was in the process of acquiring six new FFG frigates and a large number of F/A-18 Hornet aircraft from the United States and the bill for these aircraft was increasing: that was also going to be embarrassing for Beazley.

5-4: Then Minister for Defence, Kim Beazley played a pivotal role when he convinced the United States Secretary of Defense, Caspar Weinberger, to partner Australia on the development of the active off-board decoy.
Image courtesy of www.dfat.gov.au

The tension with the United States was relieved by a serendipitous meeting between Kim Beazley and United States Secretary of Defense Caspar Weinberger.

Beazley recalled the event that ultimately led to an agreement between the two countries:

I had papers on the Winnin project with me when I met Cap Weinberger by accident, prior to joint defence meetings. Winnin was not on the agenda. I had the papers because the Department had concluded that the American interest in the Australian decoy was waning and it appeared as if the Winnin project would have to be terminated.

The discussion at this unplanned meeting began with Beazley's concern that Australia was buying huge amounts of defence materiel from the United States while the latter bought nothing from Australia.

Beazley continued:

Weinberger's response to me was along the lines of 'I am sick of you always complaining about this. You say you want us to buy but you never present me with practical proposals'. The light bulb went on and I reached back into my briefcase for the Winnin papers and replied 'what about this?' We then had a brief discussion about the project and Weinberger instructed his officials to ensure the success of the project — no matter what!

5-5 : Dr Roger Lough initially researched aspects of the rocket motor for Winnin during the Concept Development phase from 1983, but later played a facilitating role as the Australian Counsellor Defence Science in Washington in the two years leading to the signing of the Memorandum of Agreement with the United States Navy.

The serendipitous intervention by important political figures certainly accelerated the search for a collaborating partner and made the Australian financial contribution more acceptable to the United States Navy.

The Australia-United States agreement

The efforts of the Hider group, the senior DSTO team, and Sam Anderson's Ship Launched Electronic Decoy office bore fruit during the second quarter of 1986. There were many issues to be resolved during the months of negotiations. Each was recorded in what was to be a 70-page agreement. The work packages for the program were grouped into three categories namely, United States Navy unique, Australian unique, and shared. The country unique packages were to be wholly funded within the respective country and the cost of the shared work was to be allocated in a defined ratio. The agreed cost model showed the total program cost to be A$110 million of which A$87 million was defined as shared work. The development of the decoy including the payload and other sub-systems formed the whole of the shared package.

The Hider and Anderson parties met in Hawaii in July 1986 for what was to become the final meeting. After some difficult negotiations, the parties agreed that the United States would bear 78 per cent of the costs, leaving Australia with 22 per cent of the costs.

Roy Kane recalled:

In negotiating, we relied heavily on the United States concept of 'Dual Sourcing' for critical items. They always had two contractors to supply critical items (e.g. Harpoon). They typically bought 70 per cent from the lower bidder and gave the remainder to the other. In this way both contractors were kept up to speed. Our proposal was that for Nulka, an Australian contractor should be the other half of the dual source.

The agreement was unique. Never before had the United States been party to a major development of a military munition or electronic warfare system with an overseas country.

The compromise that sealed the deal was that each party would have equal rights and ownership of all intellectual property from the shared work under the Full Scale Engineering Development phase, and that they would consult prior to production. Regardless of whether production was joint or unilateral, there was an agreement that competent sources from both countries would be afforded the right to compete. Both countries recognised in writing that it would most likely be in their best interests to use the development contractors for the initial production. This was a sensible outcome, because the reality was that the company that undertook the low rate initial production run always had the schedule advantage when it came to the later production. Only after the second or third production runs would the dual-sourcing game begin. Sales to third parties were not excluded, but required both countries to agree. A new Memorandum of Agreement to cover production was prepared much later in 1994.

The terms of the Memorandum of Agreement were finalised by the Hider and Anderson teams in Hawaii, and signed later by Australia's Minister for Defence and the United States Secretary of the Navy on 10 August 1986. The following day, Minister Kim Beazley and the United States Secretary of Defense, Caspar Weinberger, announced the agreement at the inaugural Australian-United States Ministerial meeting in San Francisco.[20]

The joint program was to cost about A$130 million. The budgets were based on a collaborative program cost of A$110.7 million with an outlay from Australia valued at A$36.6 million, and work to be done in Australia valued at A$72.2 million.

It was a neat result financially. The unique United States costs and 78 per cent of the shared costs totalled the US$50 million that had been approved earlier for the United States Navy Ship Launched Electronic Decoy program. The Australian contribution was the modest A$17.6 million in DSTO charges and administration, and A$19 million in budget charges by contractors, which together happened to represent the estimated vehicle development costs.

The press releases announcing the historic Memorandum of Agreement referred to the new program as 'Nulka'.[21] Bill Goodes of the Salisbury project office had proposed the name 'Nulka' which, as speed was the essence for both the decoy and the project, appeared quite appropriate. One of the Aboriginal languages defines 'Nulka' to mean 'Be Quick'. This continued the tradition of using Aboriginal words for Australian indigenous projects.

Launching the decoy.

CHAPTER 6

Full scale engineering development, 1988–1993

The beginning of the long awaited development of an active expendable decoy system began in 1988 with new requirements, new management and organisational structures, and new people. The challenge of developing the real thing was to demand the maximum in technical and management skills from many people and organisations in particularly turbulent times. The primary focus now was the engineering and testing of the system. The Nulka decoy flight tests occurred 10 years after the successful 'Hoveroc' flights, but this time it represented an operational system, not a concept. An amazing amount of work, innovation and dedication resulted in impressive results in the all-important operational evaluation tests and set the scene for eventual introduction of the decoy into the Australian and United States navies.

The Memorandum of Agreement signed on 11 August 1986 for the joint development of Nulka defined the government-to-government project management structure. Both governments were to have a program manager at Navy Captain level with a team to manage joint and country-unique tasks.[22] The Australian Project Office was established in Canberra under the Assistant Chief Materiel Navy, Rear Admiral West. The United States Navy position also carried the role of Joint Program Manager with the Australian counterpart as the deputy. These teams were to be monitored by a Joint Steering Group of more senior personnel from each country, and all were required to meet quarterly. The United States Navy Program Office provided the link into other United States organisations such as the Weapons System Explosives Safety Review Board, Operational Test and Evaluation Force, the Navy laboratories and the fleet agencies, while the Australian Project Office provided links to DSTO, the Australian Ordnance Council and selected other RAN departments.

A high level operational specification for the system was jointly established, and the navies agreed to make full use of United States military standards for management and system equipment. This was the traditional approach, although at the time the United States Defense Department was moving away from many of the standards in an attempt to reduce the cost of military hardware. This became a major challenge for the Australian project team, as it imposed on them an array of new processes and procedures, with reviews and acceptance criteria, covering every aspect of the product life-cycle, and it had significant impact on the Full Scale Engineering Development phase. The program was limited to the development to operational evaluation testing, and excluded production issues. However, both governments had equal ownership of all the intellectual property delivered under the agreed joint tasks.

From day one, the office activities were directed towards defining the scope of work and terms of the contract to go to the industry contractors by means of a request for tender. There were specifications to be written for all systems, and the United States Project Office was required to perform liaison and reporting duties under the terms of the Memorandum of Agreement. From September 1986 to February 1987 the Australian project team at Salisbury, South Australia, devoted its entire efforts to producing a series of requirement specifications for Nulka which met the United States applicable defence requirements. Roger Lough, on attachment in

Washington, was able to assist by assuring that United States Navy standards and documentation requirements were passed to the Australian Project Office. The United States was responsible for the payload while the fire control sub-systems were specific to each country.

6-1 : Jim Smith (right) started in the Australian Nulka Project Office (AUSPO) as the Systems Engineering Manager then became the Project Director from May 1988 to November 1989. He is seen here with Brian Edwards (left) and the Senior Systems Engineer from the United States Nulka Project Office, Nick Rauseo.

The first Joint Program Office meetings occurred in Washington in November 1986 and both teams were able to report good progress on preparation of management plans and master test plans for the new program. Captain Graeme McNally's counterpart in the United States Navy was Captain Mulford and the day-to-day project manager was Carl Espeland, who had worked with the previous United States incumbent, Commander Sam Anderson. The systems for managing finances and the complex arrangements for money transfers and currency exchange rates between governments were established, implementing many of the Memorandum of Agreement requirements. The important issues were to achieve progress in putting the contracts in place, both in Australia and the United States. However, the Australian Project Office also arranged to progress interim technical studies with the DSTO and the government factories through the Office of Defence Production's Nulka Engineering Manager, Alan Smith, in Melbourne. This program was referred to as the Advanced Development Model risk reduction program devised to design and build a prototype flight vehicle using the technologies studied during the Winnin program. Progress on this lagged, because the schedule of activities overlapped plans for the full scale engineering development phase.

6-2 : Members of the United States Navy and Australian project offices met at Northbourne House, Canberra, in April 1987, for the first of many joint project meetings.

Left to right; back row: Lieutenant Commander Ian Donald (RAN Liaison), John Phillips (AUSPO Finance Manager), Gary Smith (USPO), Nick Rauseo (USPO), John Kean (DSTO AUSPO), Don Jenson (NSWC Crane), Chris Edwards (AUSPO), LCDR Sid Lemon (ILS Manager AUSPO), Paul Escallier (USPO), Lieutenant Commander Phil Rogers (RAN, AUSPO). Front row: Tania Iffland (AUSPO), Commander Mike Mathis (USN), Captain Mike Mulford (USN), Captain Graeme McNally (RAN), Deborah Curtis (DSTO AUSPO); Lieutenant Commander David Farley (RAN, DSTO AUSPO); Bill Goodes (DSTO AUSPO).

A risk reduction program for advanced development models

Graeme McNally, Australia's Project Director, saw the need for a risk reduction program for the Australian technology solutions for the vehicle — with its associated risks — before he could transfer them to the future contractor. The rocket motor development by the Propulsion Division and factories consortium was evident and appeared under control, but other parts of the vehicle had only been assessed on paper.

McNally's original proposal to build and fly a prototype vehicle within a highly optimistic timeframe of 18 months was not pursued, but he agreed to an Alan Smith proposal to define a set of analysis, study and development tasks that were within the available budget and schedule. Alan Smith managed this risk reduction program across the Government Aircraft Factories, the Ordnance Factory, Maribyrnong, the Explosives Factory, Maribyrnong, and the Aeronautical Research Laboratory during 1986 and 1987. Bob Scott subsequently assumed control and completed the program on schedule. The program included the first major series of tests with Nulka-like rocket motors and the thrust control unit. Computer estimates of the decoy velocity exiting a canister were finally validated by tests using short burn motors. Work continued on the Air Data Unit at the Aeronautical Research Laboratory that included tests with it fitted in a simulated decoy in the wind tunnel. AeroSpace Technologies of Australia (ASTA), formerly the Government Aircraft Factories, contracted Plessey to begin planning the means of building the Air Data Unit in a production environment. The pressure fields for winds over a ship were established in the wind tunnel at Technisearch, at the Royal Melbourne Institute of Technology.

A study comparing performance of the three options for flight control to define the way ahead for the flight control system was completed along with a separate and final study report[23] to find an alternative to the Air Data Unit in the event that the tunnel tests showed no improvement over the earlier tests during Condev. Many alternatives were considered, but the recommendation was to proceed with a new sensor, based on directly measuring the pressure distribution around the cylinder using pressure sensors, then computing height and speed from the physics of the distribution. A 'golden test decoy', to be used for testing the performance of the payload interfaces to the vehicle, was delivered to the United States Navy for use by the payload contractor, and drawings were supplied defining the interface requirements for the payload.

During this period, those at Electronic Warfare Division who had been working on the Australian payload and decoy system studies prepared reports recording their achievements and attempted to document the reasons for many of the decoy system requirements, which were then written into new specifications. Similar reports by Gino Beltrame and others provided valuable assistance to the Nulka Program Offices and contractors over forthcoming years.

Re-organisation of defence industries in Australia

The year 1986 ushered in a revolutionary change to defence industries in Australia, commencing with the preparation of a White Paper, 'Review of Defence Capabilities' by Paul Dibb.

The review recommended the rationalisation and privatisation of government-owned munitions and explosives industries, under a new privately-owned consortium, later known as Australian Defence Industries (ADI). This included closure of the Ordnance Factory, Maribyrnong, in 1992 and the Explosives Factory, also at Maribyrnong. Selected aspects of their capabilities had been shifted to modernised factories at Mulwala in 1988. Plant and equipment applicable to the design and development of the Nulka motor were transferred to a small new building on the DSTO site at Salisbury which was referred to as Propulsion Development Facility. Even the DSTO expertise and facilities concerning rocket motors were to be dispersed.

The Government Aircraft Factories were rationalised, downsized, privatised then sold. Staff had believed that the factories were to be closed completely, until the trade unions, of which there were 23 on the site, persuaded the Labor government, through the Australian Council of Trades Unions, to rationalise the factories and proceed to privatise it. The Government Aircraft Factories were privatised and renamed AeroSpace Technologies of Australia (ASTA) in 1987, but continued to be downsized to a niche 'composite materials manufacturing plant' later acquired by the Boeing Aircraft Company, when it employed about a tenth of the numbers of the 1980s.

FSED commenced amidst a major re-organisation of defence industries in Australia.

Similar changes occurred in the private defence factories. AWA Ltd acquired Thorn EMI and Fairey Australasia in 1987 to form AWA Defence Industries (AWADI). Then, in 1989, all AWA defence interests were transferred to AWADI, which was then sold to British Aerospace Australia (BAE Systems) in 1996. Facilities and people were reduced.

Awarding the Australian Full Scale Engineering Development (FSED) phase contract

Amid this major rationalisation of the Australian government factories, the Request for Tender for the prime contractor role for Nulka was issued to two Australian companies, AWA Ltd and Computer Sciences Australia (CSA), on the basis that they were 100 per cent Australian-owned companies. This was an important consideration, given the sensitive nature of the development and security classification attached to almost all elements of the project.

After a gruelling period of negotiations and six proposals by AWA, the prime contract for Nulka was awarded to AWA on 16 January 1988, which included teaming with ASTA on the decoy flight control unit and the Ordnance and Explosive Factories at Maribyrnong for the propulsion unit. AWA Aerospace Division became responsible for the launching sub-system and the manual fire control system. The Aeronautical Research Laboratory was to provide the design of the Air Data Unit to ASTA.

AWA dramatically restructured the Full Scale Engineering Development phase program in order to contain costs within the approved budget. This led to the deletion of the fire control system development, and the requirement to comply with a stringent design disclosure documentation system — NWS10. The number of delivered rounds was reduced, several overseas and local consultants were removed, and flight trials restructured. System effectiveness modelling by DSTO and all its support to the contractors were removed. The scope of work was reduced and DSTO support disappeared, along with Computer Sciences Australia.

However, to offset the price reductions, the Commonwealth agreed to supply 200 000 hours — approximately 125 man years — of effort from the DSTO laboratories. DSTO's Henry d'Assumpcao had been 'persuaded' by the minister to save the project. Some of these hours were allocated to specific tasks with the Advanced Engineering Laboratory becoming responsible for launcher and canister design and Guided Weapons Division for a simplified fire control system for trials. However, the majority of hours were to be directed to specific tasks by AWA over the contract period. The prime contractor now controlled DSTO activities and oversaw the transfer of technology from that organisation.

The start of the Australian Full Scale Engineering Development phase contract was already seven months behind the schedule.

Awarding the United States payload the Full Scale Engineering Development phase contract

Under terms of the joint agreement, the payload was to be developed and manufactured by a United States company and integrated by the Australian developer. The United States Project Office had started the contracting process in June 1986, much earlier than its Australian counterpart, but took a more ambitious approach.[24]

Two short-listed companies were contracted in April 1987 to bid for the payload development and also build and deliver two working prototype payloads as part of the competitive 'fly-off' process within 14 months. General Instruments of Long Island, New York, and Lockheed Martin Sippican of Marion, Massachusetts, started work in May 1987.

The United States Navy was responsible for the payload, but Australia did all it could to assist. For example, the Electronic Warfare Division supplied a data pack on the Australian Condev payload. This data was held at NRL and made available to the competing Nulka payload contractors on an equal and limited time basis. There was no obligation on the bidders to use the data, but it summarised the existing state-of-the-art. The data pack included details on microwave designs including the antenna and fabrication details. It also included measured performance from the Condev development. Most of the material was from Ken Harvey's work. John Curtin and others from the Australian Project Office participated in the Preliminary Design Reviews for Lockheed Martin Sippican and General Instruments in October 1987.

Lockheed Martin Sippican managed to deliver one payload and a box of components while General Instruments delivered two payloads. The efforts of both companies were extremely good, given the short timeframe, but the ensuing three months of testing at NRL were to show that the Lockheed Martin Sippican design on payload performance and its approach on interoperability with radars of friendly ships was much superior than its competitors.

6-3 : Peter Terrill had an association with the Nulka program prior to his appointment as the first civilian Nulka Project Director in 1988. Eight years later, after leaving the Australian Project Office, he became the Australian Defence representative in Europe assisting the Melbourne Nulka group at British Aerospace to market the system.

In October 1988, Lockheed Martin Sippican was awarded the contract to proceed to develop the payload on the basis that the design had a more robust antenna and packaging which provided better performance on one of the critical specifications and for its design approach to interoperability. The contract called for delivery of 103 payloads over an 18-month period for the decoy test and evaluation program. These payloads were to be at a fixed price defined in the proposal submitted two years earlier, before the design could be prototyped and built and tested at the Naval Surface Warfare Center, Crane. Lockheed Martin Sippican had won a contract which expanded its business beyond the sonobuoys business of its past, but at a price that introduced it into a high-risk development at a fixed price, which was the new acquisition policy introduced in the late 1980s in the United States. It led to near-disaster for Lockheed Martin Sippican, and for the Nulka program, within a few years.

Nulka under new managers

On Christmas Eve 1987, immediately following the agreement on the AWA contract, Captain McNally was transferred from the position of Nulka Project Director under a cloud of controversy concerning conflicts between the project office and DSTO. His replacement, Peter Terrill, commenced as Nulka Project Director in February 1988 in his capacity as Assistant Controller Materiel, the Navy branch responsible for Nulka.

Peter Terrill recalled:

There were some serious issues at the time, with conflict between DSTO, Navy and Defence Central, and the project was in some jeopardy. In particular, DSTO was feeling alienated from the project, and others perceived they were far too close to the United States Navy project office. I was able to provide some much-needed focus and discipline to the project, resulting in my appointment in May 1988 as First Assistant Secretary, Project Development and Communications Division. This was a new organisation, to take over some indigenous projects including Nulka and Jindalee, where the previous departmental structures had been found unsatisfactory.

In May 1988, Peter Terrill relinquished the day-to-day project director role to Jim Smith, who was joined by John Brentnall as the Director Systems Engineering. The naval operations aspects were to be managed by Commander Les Pataky. The group residing in Adelaide remained under Brian Edwards. Meanwhile, in DSTO, Henry d'Assumpcao, then Chief Defence Scientist, transferred Warren Harch to a role in the project office as the Nulka Project Scientific Advisor, and gave Nulka a priority within DSTO over all projects except Jindalee[25]. The time-critical nature of the project was to create numerous problems for the project office. However, creation of the Scientific Advisor Branch assisted with the quick resolution of technical issues by short circuiting the formal process to the research authorities.

6-4 : Warren Harch joined the Nulka Project Office from DSTO as the first Nulka Project Scientific Advisor. He provided practical and sound advice and acted as a conduit to the DSTO laboratories during the difficult times of the engineering development.

The Full Scale Engineering Development phase commences

The Nulka Full Scale Engineering Development phase officially commenced on 16 January 1988, 16 years after Scot Allison's insight into the need for an active off-board decoy, and nearly 11 years after Alan Smith presented his analysis showing a hovering rocket was the most viable decoy vehicle solution. Importantly, it was only 16 months after the Memorandum of Agreement with the United States had been signed.

6-5 : Barry Watson started as the Nulka Program Manager for AWA Defence and Aerospace with nothing but a bank account and the contract to develop the Active Expendable Decoy system. He managed the contractor teams through exciting but turbulent times, culminating in successful trials for the system. He maintained a watch on the Nulka team in Melbourne when he became the AWADI general manager for defence projects in October 1993.

Both Lockheed Martin Sippican and AWA had entered into a very high-risk development at a fixed price.

Remarkably in hindsight, AWA entered a fixed price contract, worth A$57 million, to bring a unique concept to full production standard within a little more than four years. The fact that the production goal was achieved — albeit 13 months late — testified to the determination, the abilities and the faith of the people involved.[26] Those people firmly believed that Nulka remained the most successful defence development project undertaken within Australia because of what was achieved, and because of the circumstances under which those achievements were made.

Responsibilities and governments

The Defence and Aerospace Division of AWA Limited was the prime contractor for the Full Scale Engineering Development phase of the Nulka system, and Barry Watson was appointed its Program Manager. As prime contractor, AWA's role was to provide overall project management, systems engineering, systems integration, test and trials management, and integrated logistics support services, including management of several subcontractors responsible for development of individual hardware and software elements. AWA also retained responsibility for developing the launch sub-system, comprising the Launcher Interface Unit and the Casualty Fire Control Unit.

ASTA was responsible for design development and manufacture of the Flight Control Unit and the Spin Control Unit, as well as final assembly and integration of the decoy. ASTA also had responsibility for managing development of the Air Data Unit by the Aeronautical Research Laboratory. The Air Data Unit was an integral part of the Flight Control Unit design and the Aeronautical Research Laboratory had developed this sensor system during the earlier Winnin Concept Development phase.

ASTA also participated in aspects of the development of the Thrust Control Unit and the electrical looms for the rocket motor. In addition, the subcontract called for ASTA to supply systems engineering staff to an AWA project office to develop and manage the overall system design.

Responsibility for propulsion units — the rocket motor and the Thrust Control Unit — was subcontracted to the Explosives Factory, Maribyrnong, which had also been involved in the earlier Concept

Development phase. During Winnin, the design capability for the motor had effectively migrated from DSTO to the Explosives Factory, although the latter retained the ability to access propulsion specialists within DSTO. This differed from the Aeronautical Research Laboratory Air Data Unit situation, where that migration was intended to commence with the Nulka contract.

Bob Scott's involvement with the Winnin-Nulka program started in 1979 with the 'Hoveroc' test vehicle and continued through the Concept Development phase. He continued his role as the Nulka Project Manager at ASTA to February 1991.

The Ordnance Factory, Maribyrnong, became responsible for manufacturing canisters to house and protect the decoy, which were to be designed by the Weapons System Research Laboratory in Salisbury, South Australia. The latter was also responsible for design of the launcher. Concepts for the launcher had been considered, but no significant progress had been made on the canister. Responsibility for manufacturing the launcher, which ultimately devolved to the Ordnance Factory, Maribyrnong, was not assigned at the time of contract signature.

The Commonwealth was responsible for providing to AWA the electronic warfare payloads as government furnished equipment. These were to be designed, developed and manufactured by the United States company, Lockheed Martin Sippican, under contract to the United States Project Office.

All of AWA's subcontractors were government-owned establishments. ASTA was government owned, but was then being restructured along commercial lines. The dispersal of the Explosives Factory, Maribyrnong, had started within days of Barry Watson's employment. AWA was the only non-government organisation on the flight-vehicle project. The initial responsibilities and the structure of the subcontracts changed considerably as the contract progressed.

The contract between AWA and the Commonwealth of Australia established the formal relationships, but the involvement of the United States government, through the United States Navy, had a major and continuing effect on the conduct of the project and on contract management issues because it prevented adequate communication between AWA and Lockheed Martin Sippican and limited the effective integration of the payload with the vehicle. The United States Navy had no formal role within the contract structure, but exercised a major influence on the project, as might be expected from an interested party that was contributing the major proportion of the funds.

6-6 : David Mann managed the difficult formalities of scheduling the Full Scale Engineering Development phase and then became the Nulka Program Manager at AWADI in 1993. This role expanded rapidly as the Nulka Active Missile Decoy project started and another international defence development program began. Mann's defining moment was to provide a new world-class manufacturing facility to improve product reliability issues that threatened the Nulka program. In 10 years from 1993 he negotiated contracts to generate a four-fold increase in the size of the Melbourne office and retired as a member of the company executive committee.

Up and running

A major part of the recruiting campaign by AWA was to acquire promised personnel through secondment from DSTO in accordance with the contract. Barry Watson approached the directors of each of the DSTO laboratories to make arrangements for secondment of engineering staff to support the AWA project team. The response was not encouraging. Several of the laboratories were unaware of the commitment made on their behalf by their Chief Defence Scientist. Support was eventually provided, but there were serious issues from AWA's perspective about its timeliness and the match between what DSTO could and would offer, and what the project team actually needed. There were four DSTO people in the team by the end of 1988, an average maintained over the first few years, with each person staying for periods between nine and 15 months. Henry d'Assumpcao's response to Professor Tom Fink in October 1989 showed how the tension continued for at least two years: 'You know we have a disagreement; although an amicable one, with AWA. They seem to think there are unlimited resources here at DSTO'.

None of the DSTO secondees to the AWA office had previous experience on the Winnin program. This was unfortunate for the program because, if they had, it would have been an ideal way of transferring the expertise from the earlier Winnin work into the fledgling project. Many DSTO personnel involved in subcontracted work packages experienced difficulties in delivering outcomes within the timescales allowed in a commercial environment and using recognised system engineering processes for decision-making, traceability and documentation standards.

Fortunately some of those involved in the DSTO subcontracted work packages had prior experience from the Winnin program and certainly were important in meeting the aggressive 'success oriented' schedules. However, these were often the people who had a role as the Research and Development Authority and hence were advisers to the project office as well. This dual role presented many dilemmas for the individuals and was often a concern for AWA.

Engineering work begins

AWA was soon to learn, in fact, at the first formal meeting with the Commonwealth in Canberra on 10 and 11 February 1988, that the latter expected a fresh approach to the design of Nulka. The view of

6-7 : Alan Smith (left) and Barry Watson address the AWA new team. Alan Smith had made a defining contribution to the 'hovering rocket concept' in 1977 and returned to make a similar contribution to the Full Scale Engineering Development phase. As System Engineering Manager, he adroitly managed the designs and the development of all the major elements, but in a way that allowed the subcontractors freedom to meet their requirements. Smith's leadership in making engineering trade-off decisions and his drive to find the cause of test failures in difficult circumstances, most notably the first decoy flight test of November 1990, were an inspiration to his team.

those in the Nulka Project Office was that the work of the previous six years of Condev was for information only and that AWA had to review and make its own decisions. AWA argued that the time and money had not been included in the contract to reconsider such a major item within the system. In reality AWA was actually working according to the government view.

An unrealistic schedule for the program

The Full Scale Engineering Development phase schedule was aggressive and 'success oriented', with no allowance for a failure requiring a repeat activity. The system Preliminary Design Review was to be completed by month 10 and the System Critical Design Review was to be completed by month 16. The launch sub-system was to be ready for the first flight trials (DT-IIA) at month 22. Payloads were to be delivered for the DT-IIA-D flight trials within 20 months, and the first flight trials at Woomera (DT-IIA) were planned for month 26.The first flight trials from an RAN ship (DT-IIB) were to follow in month 29, and the first flight trials from United States Navy ship (TECHEVAL) were to be completed by month 40. The final operational evaluation trial from United States Navy ships (OPEVAL) was to be completed by month 45, and the Production Readiness Review and project completion were scheduled for month 50.

It was immediately obvious that the schedule did not allow time for establishing teams and facilities. Nor did it permit the development

6-8 : Prior to Mal Crozier joining the AWA team, he had been involved almost continuously on the decoy, and particularly decoy flight control since its inception in 1977. As in earlier phases, he was supported by a small group that specialised in aerodynamics, sensors, stability and control, modelling, software and flight performance. This experience was behind Crozier's participation in United States Navy ship trials and the subsequent reviews and investigations.

6-9 : Warren Kidd's 22 years' experience in flight control and airflight vehicle developments expanded in 1988 when he assumed the senior systems engineer role for the development of the Launch Interface Unit: the centrepiece of the Nulka shipboard equipment. It was a most challenging task. He became the system engineering manager after Alan Smith in 1993 and became the driving force for the four years to 1997 for the design of the new shipboard system for launching decoys for the Australian Navy.

of new processes and procedures required for accreditation to the AS1821 quality standard. The AWA defence and aerospace procedures were found wanting for this project. The schedule underestimated the time for dealing with the new concepts and requirements of the insensitive munitions testing. And everything was virtually guaranteed to take much longer than envisaged as the customer pressed for substantial compliance with requirements of the large number of United States military standards and specifications required by the contract.

The Preliminary Design Review for the system

The first and most tumultuous gathering of those involved in the new project was the Preliminary Design Review for the system. This took place over five days from 24 October 1988. There were 58 participants, including seven from the United States Project Office, 11 from the Australian Project Office, six from DSTO, as the Research and Development Authority, and four from Lockheed Martin Sippican. AWA and the subcontractors had prepared 30 hours of presentation material 'in general accordance with the military standard' and their contract. However, AWA found that the United States Navy, in particular, had a checklist of favourite topics that all good project design reviews required, and especially 'offshore' reviews. Jim Smith summed up on the fifth day by listing the deficiencies in the AWA review: there were no design trade-off studies; no top down analysis; no risk analysis; no program for the 'illities'— referring to subjects like reliability and availability; and insufficient error budgets. The intake of breath was audible, as it was during Alan Smith's opening presentation when he said, 'It wasn't intended to present overall system error budgets'.

The other underlying theme that recurred in this and later meetings was that AWA had contracted for the project based on existing technology, and was going to change only if this was assessed as unviable to meet the trials date. The Project Office took the approach that the baseline technology was a guide only, and that a full top down evaluation of all options was required.

Project Design Review chairman Jim Smith concluded that AWA had failed the review, partly because it had not followed the same process it applied to its subcontractors, and partly because the proffered solutions were not good enough. AWA had 40 substantial actions to complete before the second review four months later.

However, one good outcome from the review was that AWA and the customer realised there were benefits in Lockheed Martin Sippican having face-to-face discussions with the decoy team under supervision of the United States Project Office, though the United States Navy remained apprehensive that this might generate an increase in the Lockheed Martin Sippican workload, and thereby raise project costs. The second Project Design Review in February 1989 had a much more satisfactory outcome.

The requirements of the Preliminary Design Review were far more stringent than AWA had foreseen.

The engineering baseline for the Nulka Full Scale Engineering Development phase

The Full Scale Engineering Development contract, in part, required AWA 'to take the validated concepts and technologies and to develop the system to a point where it is capable of being produced, by any competent manufacturer.' Barry Watson and David Mann's analysis was that the previous Winnin development represented a few concepts but few technologies, and it could reasonably be said that the rocket motor and the spin control method were the only 'validated' technologies. The Aeronautical Research Laboratory Air Data Unit was the only other item where hardware resembling the technology was ever built. The starting point for the Nulka development program fell far short of what was generally considered to be 'validated technology' for a Full Scale Engineering Development. Funding of the design and flight testing of an 'Advanced Development Model' had been rejected during the Winnin program, and the idea that the previously flown 'Hoveroc' vehicles of 1981 had 'proven it all' was misguided, though current among some. The 'Hoveroc' vehicle was irrelevant to Nulka. The feasibility of certain concepts and functions had been examined on paper, but the Concept Development phase was incomplete in several important respects, and many elements of the system had simply not been considered. It took the management team probably a year before it fully understood the extent of the extra effort required.

AWA decided in mid 1989 to change the baseline and develop the Pressure Air Data Assembly system as an alternative to the Air Data Unit. By that time, the technical risk of the Air Data Unit was found to be unacceptable, and both ASTA and AWA believed funding the development of the Pressure Air Data Assembly provided the cheapest and most affordable prospect of a successful outcome. This meant the change could occur without a protracted discussion about additional funding from the government.

6-10 : Peter King's work on the mortar launch in 1983 was validated by others in tests completed in 1987. Then King rejoined the Nulka program in 1988 to coordinate the design of the launcher, the canister, the propulsion unit, and the mechanical aspects of almost everything else. He assumed direct responsibility for these items as the Full Scale Engineering Development phase design teams disbanded and the program transitioned to production. He was a key player in preparations for trials and decoy assembly facilities.

6-11 : Having been on many trials at Woomera, Jervis Bay, and at sea, and having managed a development laboratory, Ian Turner was most competent to join the AWA team in charge of the Nulka test and trials program. The number and scope of tests undertaken by contractors and Turner's group was immense and often arduous. Ian Turner was of great assistance to the program in planning the most arduous of these tests, the Woomera flight trials. The customer regarded the hundreds of test reports delivered as the most crucial output of the program.

The quantum change represented by the Full Scale Engineering Development phase specifications was necessary to meet operational performance requirements, and pre-conditions for shipboard use, but the real magnitude of the change was considerably greater than many had foreseen. This was not simply a matter of taking a developed concept and re-engineering it to meet production, reliability and support requirements. The task facing most of the project teams was to take a concept that was at the 'view graph slideshow' level of detail, and to develop it into a high performance operational flight vehicle and ship system. All this was to be delivered with a fixed amount of funding, without contingency funds, and within a schedule that was, to say the least, challenging.

Advanced vehicle control

Vehicle control remained a major focus of engineering effort during the Full Scale Engineering Development phase. The Nulka flight control system was more sophisticated than conventional systems for winged vehicles because all three axes of orientation were completely omnidirectional. The control algorithms included many coordinate transformations, as small angle approximations were not sufficient. The task of deriving the three angles of vehicle orientation in space, from the four angles provided by the two displacement gyroscopes, was regarded as critical, difficult, and prone to error.

The characteristics of the Thrust Control Unit, in particular, were highly non-linear and its control system included inverse functions, rather than gain scheduling, in attitude and height control. The use of three tabs to control three axes of motion — pitch, roll and height — required a matrix to decouple loops and needed careful use of limiters to deal with competing demands from the height and attitude control loops. The control laws needed to provide the desired transient responses over a large angle range, which invoked cross coupling between, say, azimuth and pitch. The launch phase was particularly challenging because of the cross coupling of key parameters that were changing over a wide range due to rapid changes in vehicle kinematics. Once that transient period was past, the controls faced a more benign kinematic environment.

Mal Crozier, Winston Furlong and Dave Taunton completed the majority of the control system algorithm design for the Nulka vehicle during 1988.

A replacement for the Air Data Unit

In March 1989, 15 months into the Full Scale Engineering Development phase, the Aeronautical Research Laboratory team provided to AWA the wind tunnel data on expected errors and the software algorithms for the Air Data Unit. The aim was to use these error tables to calibrate the device, dependent on other variables. The algorithms required knowledge of the angle of attack of the impinging airstream — airflow incidence angle — and the airspeed, in order to eliminate large errors present in some conditions. The basic problem was that the airflow incidence angle was unknown, or at least could not be estimated accurately. This correction process introduced a new input into the behaviour of the sensor and the resulting interdependencies had a destabilising effect on the height control system in rapidly changing motions.[27] Additionally, these algorithms required considerable computing resources in the flight control unit.

Both AWA and ASTA became concerned with Air Data Unit issues. AWA examined the earlier tunnel test data from 1987 and carried out an error analysis for an alternative concept, which used multiple pressure sensors known as the Pressure Air Data Assembly. An Australian company, Invetech, was contracted to survey all candidate pressure sensors and ASTA and Invetech prepared general layout drawings for the pneumatics and electronics for this new sensor. The details of a viable alternative to the Air Data Unit emerged quickly, to the point where Laurie Harris (ASTA) drafted a patent application for the Pressure Air Data Assembly in July 1989.

The 'pressure distribution' method was based on the potential flow theory, which held that the position around the cylinder where the pressure was equal to the ambient atmospheric static pressure was a known position from the direction of the airflow — around 32 degrees. Speed and height could be derived from the distribution of pressure over the leading 64 degree sector. More than a dozen separate measurements of pressure were needed to obtain a good pressure distribution profile so the sensors could not be too expensive. The advantage of the pressure distribution technique was that its height and speed estimate depended only on the pressures over one sixth of the circumference and was not affected by pressures around the remainder of the cylinder. This remainder was affected by airstream turbulence, airflow incidence and surface

The report by ASTA proposing that work begin on a pressure distribution sensor as an alternative to the Air Data Unit was the final report from the 'Risk Reduction Studies' of 1987. The technical content was made available to AWA, but the material was unfortunately not part of the contract negotiations of late 1987. The formal report was delivered in February 1988.

6-12 : Pressure Air Data Assembly.

6-13 : Professor Tom Fink retired as Chief Defence Scientist of DSTO in 1986 after nine years' service and was a consultant to AWA on a range of engineering issues. He was well placed to improve the gaps between DSTO and the AWA teams.

6-14 : Ian Mitchelhill (ASTA) and Leon MacLaren (seconded from the Aeronautical Research Laboratory to AWA) seen here with the Pressure Air Data Assembly fitted to a decoy in the low speed wind tunnel at ARL. These were the final tests to establish the performance of the assembly prior to flight tests. Ice shapes are visible as a pink patch on the decoy for these tests.

effects and was the source of the large errors in the Air Data Unit. The Pressure Air Data Assembly was inherently less likely to suffer from these issues.

The selection of a pressure sensor with acceptable performance, weight, size and cost was achieved after an intensive search. Then began a comprehensive series of tests of the Pressure Air Data Assembly at Edinburgh Airfield on the back of a truck. The results of the vast majority of the tests were extremely good, but there were cases when the flow around the cylinder was asymmetrical, causing unacceptable errors in the estimated airspeed direction measurement. Professor Tom Fink, a retired Chief Defence Scientist of DSTO, was engaged by AWA as a consultant on this and other Nulka engineering and management issues. He solved the airstream turbulence problem by employing a dimpled surface finish around the Pressure Air Data Assembly analogous to the dimples used on golf balls to create some turbulent flow in the airstream.

By February 1990 the Pressure Air Data Assembly and its accompanying software were ready for final tests in the low speed wind tunnel at the Aeronautical Research Laboratory. Kwong San Yin and Alan Rankine, with Leon MacLaren, monitored the Pressure Air Data Assembly results in real-time and confirmed the performance by effectively flying the unit in the tunnel. The work on defining the position of the static pressure-point angle from the earlier tunnel and the truck test data was confirmed to be accurate and the Pressure Air Data Assembly was considered suitable for the forthcoming flight trials. The first flight test of 7 November 1990 confirmed that assessment. Subsequent flight tests showed its height accuracy to be considerably better than specified.

The canister

A canister to protect the decoy and act as the launch tube was envisaged prior to the Condev program and was inherent in all launcher concepts. However, the canister's importance was not appreciated, and development did not start until after the Full Scale Engineering Development phase began. The canister influenced the handling and transport of the decoy, in addition to its reliability and its launch. Fundamental to the canister concept was the mortar launch, whereby the initial burn of the rocket motor created pressurised gas that propelled the vehicle from its launch tube. A need for an explosively-jettisoned top cap also posed difficult challenges. The design of the canister proved more difficult than expected. The eventual success of the canister development was due largely to the excellent cooperation between the teams at the DSTO Guided Weapons Division and the Ordnance Factory, Maribyrnong, which concurrently had responsibility for both the design and the manufacture.

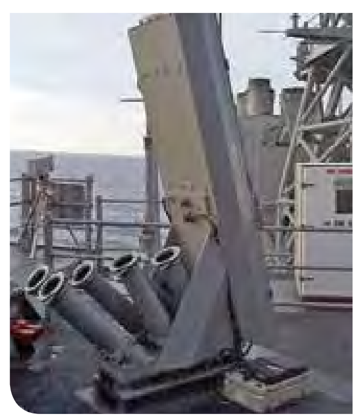
6-15 : Two decoy canisters are shown fitted to the launcher before the launcher doors are closed.

The launcher

Differing views held by the United States and Australian navies regarding launcher designs arose during the Condev phase and was noted above. The United States Navy was driven by the desire to integrate Nulka with the Super Rapid Bloom Off-Board Chaff launcher, whereas the Royal Australian Navy had identified handling and storage issues with this approach and, instead, opted for the 'four round in line' flat-cabinet launcher design — the flat pack launcher proposed by Advanced Engineering Laboratory and later by the Guided Weapons Division team. The feature of this design was that it could be fitted permanently to the ship and rounds could be brought to the launcher from another ready-use locker or from the dock. The launcher also had to withstand underwater shock, green seas loading and solar radiation. The first design failed an internal Project Design Review due to its unacceptable weight, and this led the team to propose an open frame structure with a canvas awning for sun shielding. The United States Navy and its Nulka Project Office

6-16A : Waymon Humphries and launcher.

6-16B : Stand-alone launcher.



6-16C : Launcher with RBOC barrels.

In 1994, the United States Navy developed a two-barrel, fixed, launcher box to either stand-alone, designated the Mark 137 Mod 10 (left and centre photographs) or piggy back with the Mk 137 Mod 4 chaff launcher (right photograph), designated the Mark 137 Mod 7.

Photograph on left shows Waymon Humphries with the stand-alone launcher on a United States ship during trials. An aerospace engineer from the Tactical Electronic Warfare Division at NRL, Humphries was the test director for the technical evaluation of the Nulka system in the United States Navy and the test coordinator for several follow-on at-sea tests; the most notable involving two AEGIS cruisers. Humphries was the lead engineer for the development of the majority of passive chaff decoys in service in the United States Navy and around the world. He has won many innovation and distinguished service awards for his work in off-board counter measures.

6-17 : Ian Jolley of AWA operating the simple scissor mechanism to cause the launcher to tilt from vertical stowed position for launching.

vigorously rejected this design at the Preliminary Design Review. ADI Bendigo finally came to the rescue and proposed a lightweight aluminium monocoque structure housing four decoys which was suitable for location in gangways and against bulkheads.

The ADI Bendigo launcher was used on all the Full Scale Engineering Development phase sea trials, though the United States Navy was to design its own simple two round box and fit it to the back of its preferred chaff launcher as first proposed in 1984. However, all RAN and Canadian Navy ships were fitted with the Australian launcher after the Canadians expressed their interest in Nulka.

Launch control

The Nulka system need for information about the threat, and when, and in which direction to deploy a decoy, was addressed during the Full Scale Engineering Development phase. These functions were determined to be provided by dedicated interface and control systems on board the ship, as described below.

6-18 : Loading a decoy canister into a launcher was exercised many times during flight trials on land and later on board ship, and then later during training courses for Navy personnel.

Early studies of the launch control architecture showed the need for two interface units to be associated with the Nulka launcher: a Nulka Launcher Interface Unit associated with each of several launchers, and a central unit referred to as a Decoy Launch Processor to be connected directly to the system for detecting the attacking missile. The majority of United States Navy ships – and Australian Navy FFG frigates – were to use the AN/SLQ-32 as the detecting system. The SLQ-32 on the United States trials ship was modified for the United States Navy tests so the operator could initiate a Nulka decoy launch. The Decoy Launch Processor made decisions on which launcher to use, and the Launcher Interface Unit defined the commands to the decoy and controlled the communications and launch sequence to the appropriate decoy in its launcher.

During the Full Scale Engineering Development phase it was determined that the primary function of the launch controller was to initiate the manoeuvre demands for the decoy to achieve the required tactical decoy trajectory. The Decoy Launch Processor determined the launcher to be used to suit the threat missile and to define the appropriate trajectory for the decoy. The Launcher Interface Unit computed the optimal demands for the decoy to achieve this trajectory, taking into account such constraints as flying around the ship rather than over it. To do this it required information from the ship about the latter's motion and measurements of wind speed and direction. Additionally, it executed the algorithms for inhibiting launch in unsafe conditions and provided the decoy control system with a measure of its orientation relative to the horizon. It provided the circuits to ignite pyrotechnic charges to eject the canister top cap, start the batteries, and ignite the rocket motor. The Launcher Interface Unit had safety issues because it controlled the pyrotechnic devices. Consequently, extra layers of safety modes had to be incorporated. Clearly the Launcher Interface Unit was a crucial part of the Nulka self-defence system.

6-19 : David Hogue, from NSWC Dahlgren, became the Project Manager for the United States Navy Decoy Launch System in 1996. He was the test director for the second flight trial at Dahlgren (DT-IIF) also in 1996, and afterwards managed many upgrades to the United States launching system. Hogue was a principal designer of the Processor Power Supply Unit for the United States Navy. He worked closely with the BAE Systems team on flight demand algorithms and system performance.

The software for the Launcher Interface Unit ultimately contained an immense amount of intellectual property that was key to deploying the decoy to defend the ship. The core of the system was the flight demand algorithms for computing the optimum trajectory demands for the decoy. It provided demands to the decoy that met the tactical requirements while being constrained by the need to be compatible with the decoy flight characteristics. The tactics for deploying decoys were derived by Gino Beltrame and Cos Melino. AWA systems engineers Warren Kidd and Oliver Collins devised the means to define the optimum flight demands to be incorporated in the flight demand algorithms. The name of this software belied its importance. A large part of the software developed for the interface unit was later transferred to other units and called the 'Flight Demand Algorithms Common Software', meaning it was common to both the United States Navy and Australian anti-ship missile defence systems for deploying the decoy.

However, a ship system simulator was required for the several trials planned to occur in Australia. A unit known as the Interim Fire Control System was developed to provide a means of inputting ship motion data and the desired tactical trajectory for the decoy. This unit was for use at trials in a non-operational environment and needed to use only commercial standard computers and components.

AWA's development of the shipboard system to control decoy launches required a lot of close management and intellectual effort during engineering development. The shipboard system was redefined after the engineering development phase, and the Royal Australian and United States navies created different systems to meet different operational needs during the 1990s.

6-20 : Those responsible for developing the Launcher Interface Unit and John Brentnall, the Australian Project Office System Engineering Manager, are all smiles after the first major test using the Interim Fire Control System, the Launcher Interface Unit and a decoy.

From left to right: Oliver Collins, Ian Turner, Peter King, John Brentnall, Commander Ron Jemeson, Warren Kidd, and Bernie Charles with Alex Yates and David Chenoweth behind the gimbal rig performance.

A team from the Naval Surface Warfare Center at Dahlgren, Virginia, in the United States, developed the Decoy Launch Processor used in conjunction with the Launcher Interface Units for all flight trials involving a United States Navy ship. The Decoy Launch Processor computed a tactical solution based on the information available from the SLQ-32 system for detecting the attacking missile. It also processed the ship's orientation and wind speed information before passing this to the Launcher Interface Unit.

Insensitive Munitions Testing program

Nulka was required to comply with requirements for munitions safety known as the 'Insensitive Munitions requirements'. These covered a range of tests where there was a need to demonstrate that the rocket motor would not behave 'too violently' when subjected to extreme conditions. These requirements on all munitions within the United States Navy were derived from experience in the Vietnam War and were aimed at minimising the damaging effects of munitions when in a fire or when hit by ammunition. The spread of fire on a ship or in a store was greatly reduced if ordnance did not explode forcefully. Louise Barrington of DSTO was responsible for this major program and worked closely with Barry Murphy at AWA. The tests included a slow – ambient heating, and fast cook-off – oil fire. These tests required the round to be in its shipping container and in some cases there were stacked containers. Other tests included dropping the round from great heights and subjecting it to severe vibration and shock.

Crisis at Lockheed Martin Sippican

Meanwhile, a significant crisis occurred in the United States at Lockheed Martin Sippican, the small employee-owned company that was developing the payload. The Nulka Memorandum of Arrangement had defined that all contracts were to be fixed price: this was at odds with Lockheed Martin Sippican commencing the second phase with an immature design which did not facilitate ease of manufacture. The effect was to require Lockheed Martin Sippican to redesign the internal packaging approach totally, while maintaining the critical antenna/packaging approach demonstrated at the Naval Surface Warfare Center. This led to the incorporation of a T-chassis which had the receiver and transmitter mounted in the mid-body assembly oriented along the payload long axis with the transmit and receive antennas mounted in their own enclosures at the top and bottom of the mid-body assembly. This effort required more than 12 months of intense redesign work, culminating in a Critical Design Review in late 1989 with the United States and Australian project offices. This was the first time that Lockheed Martin Sippican engineers had met their AWADI counterparts Warren Kidd and Ian Turner. Lockheed Martin Sippican passed the review by demonstrating it could manufacture the payload and maintain the previously demonstrated performance. Lockheed Martin Sippican now had a drawing package which could be used to generate accurate cost-to-complete figures for the required 103 payloads. When the cost was identified it became apparent that a small company like Lockheed Martin Sippican could not bear the required level of overruns. Lockheed Martin Sippican announced to the United States Project Office that defaulting on the contract was a certainty, and this led to an approach to the Australian Project Office to agree formally to a Claim for Equitable Adjustment.

The disregard for the protocols of the MOA was officially overlooked, as there was a sense of 'desperate times require desperate measures'.

Lockheed Martin Sippican's plight quickly became known at the highest level because of the international ramifications. Rear Admiral Meinig, who was in charge of weapon systems for the United States Navy surface fleet, took a personal interest and flew to Australia to broker a deal. Ultimately, the parties agreed to halve the number of payloads to be delivered to 51 in order to save the small company, and contract finances were changed to a cost-plus basis, although there was a limit established. Lockheed Martin Sippican would still be short by US$6 million but it had been relieved of an additional US$10 million shortfall. The decisions taken by Rear Admiral Meinig and the United States Project Office were announced at the

6-21 : David Stone joined Lockheed Martin Sippican for the engineering development of the payload starting in February 1986. He had an innate feel for microwaves and immediately grasped the challenges thrown his way by Dr Frank Klemm. The two pursued every decibel of performance and delivered a payload which handsomely exceeded the requirements. However, this led to Lockheed Martin Sippican's brush with bankruptcy and the subsequent 'Request for Equitable Adjustment' claim of 1990.

The photograph shows Lockheed Martin Sippican's lead electronics engineers, Mark Small (left), David Stone and Wes Libby preparing for a payload test at Converse Point in Buzzards Bay, near Marion, Massachusetts. These tests were first done on the oval of a local private school and the penultimate tests used the 100 foot high bell tower at the University of Massachusetts at Dartmouth.

6-22 : Dr Frank Klemm from the Naval Research Laboratory (NRL) was a frequent and active participant in the joint United States Navy and Australian discussions in 1982 and from 1984 onwards. His speciality was the payload issues although his engineering degree was in aerodynamics. He made major contributions to the payload specification based on his depth of experience in electronic warfare and knowledge of the operational environment. Klemm, assisted by Paul Bryant, drove the tradeoffs in the Lockheed Martin Sippican design of the payload to extract the most out of the technology: the result was a product which robustly exceeded the requirements of the specification.

following joint Flag Officers' Review from 10–14 September 1990. The Australian office was a little annoyed because of this unilateral action, which greatly affected the AWA contract and changed the resources available for test and evaluation. The disregard for the protocols of the Memorandum of Agreement was officially overlooked, because there was a sense of 'desperate times requiring desperate measures'. Rear Admiral Meinig was quoted as saying 'this arrangement has been made by consenting adults'.

The global firm Plessey acquired Lockheed Martin Sippican soon after this episode in order to access the Lockheed Martin Sippican share of the United States Navy sonobuoy market, and it effectively took the loss on this contract. The Cold War had ceased by 1993 and the need for sonobuoys plummeted. In turn, GEC Marconi took over Plessey, and Lockheed Martin Sippican was sold back to the management team, principally, Dick Arthur, Bill Walsh and Bernie Mitchell. They and others at Lockheed Martin Sippican showed a remarkable faith in the company and its people, but it meant there was a huge incentive for the Nulka program to succeed, not only in the short term, but onwards into production. This faith in the future was to be severely challenged within two years.

Restructuring the program

Development and operational flight tests of vehicle rounds were required to prove the vehicle design. The significant reduction in the number of payloads from Lockheed Martin Sippican reduced the number of operational flight tests by 28, prompting the Flag Officers' Review of September 1990 to conclude that the operational evaluation (OPEVAL) would have to be downgraded to a lesser evaluation test, referred to as OT-IIA. This meant that a limited rate production, rather than a full rate production, could be authorised. The plan was for a successful OT-IIA to be followed by the development of production and performance improvements to be managed by a Systems Engineering Group along with limited production for the fleet. This, in turn, was to lead to a full OPEVAL trial and then a full rate production decision by the Flag Officers. This represented a dramatic program change, but was common for such programs in the United States to be phased in this way. It added approximately two years to the program before there could be full introduction to the United States Navy fleet. However, the immediate problem was to replan all activities and trials to cope with a slower delivery rate from Lockheed Martin Sippican. The change raised a key question 'Would it be cost effective to reduce the number of decoys built by the Australian contractors?'

The Flag Officers' Review of September 1990 was also memorable for other reasons. The admirals concluded that the isolation of Lockheed Martin Sippican from AWA as prime contractor through the arrangement whereby the Commonwealth provided Lockheed Martin Sippican's payload to AWA was detrimental and precluded effective system engineering at the high level. The intention was that there would be a properly constituted prime contractor for any program beyond the FSED phase. It would, however, be another five years before such a prime contractor would be appointed.

In the meantime, the Joint Project Office proposed forming a Systems Engineering Group, with the aim of it being 'the primary Nulka system problem solver'. A forum was proposed for the interchange of technical, system-level information, and for the discussion of system-level problems and to provide system-level recommendations to the Joint Program Office. Permanent 'voting members' of the group were to be representatives from the United States and the Australian project offices, DSTO and NRL, Lockheed Martin Sippican and AWA. The initial focus for the Systems Engineering Group was to study ways to reduce the cost of the decoy and improve performance and reliability. The AWA management team considered this to be good news and regarded it as the point when the project started to mature. This proposal represented a migration from two development contracts — Lockheed Martin Sippican and AWA — into a combined government/industry team which recognised that all parties had a large investment in Nulka and that success would best be achieved by working closely together. The only problem was that neither project office had funds to spare to finance this group and its activities. These activities did not start until after the Full Scale Engineering Development phase was completed.

Meanwhile, the project's immediate future was to be dominated by flight trials starting two months after this important Flag Officers' Review.

The developmental flight tests

The relationship between AWA and the Australian Project Office had begun to deteriorate with the first Project Design Review, and worsened with the change in scope introduced by the United States Project Office. This meant a delay to the start of the first developmental flight trials due, mainly, to delays in developing the flight control hardware and Launcher Interface Unit.

A total of 66 rounds were fired in these first flight trials. There were five visits to Woomera (DT-IIA/1, DT-IIA/2, DT-IIA/3, Test Analysis and Fix and DT-IIE), one to Dahlgren on the Potomac River in the United States (DT-IIC Prime), one from a RAN ship out of Jervis Bay (DT-IIB), followed by three trials from United States Navy ships out of Mayport, Florida (DT-IIC, DT-IID and OT-IIA).

DT-IIA Phase 1, which did not include the payload, commenced at Woomera in October 1990, with the round mounted in a gimbal rig to test the altitude control system. Peter Anderson was the range manager with Janet Arbon the range sequence count down controller, and Michael Wilsch was responsible for records. Tony Harvey was the senior site and facilities provider and Bruce Henderson the range safety officer. Ian Turner's set-up team included Peter King, Bob Irvine, Jack Walker, Ian Jolley and Barry Murphy — later to become manager of AWADI. The AWA team expanded for the actual testing to include Alan Smith, Mal Crozier and Brad Yelland on flight

Writing after his retirement, David Mann recalled:

From an AWA perspective, the Winnin trials notwithstanding, we had achieved a world first with that one successful DT-IIA flight. Everyone had worked tirelessly to get to the trial, albeit six months late, and we felt we had achieved an essential and fundamental milestone. We knew we still had some very big problems, but most of us had a background in system development and to have had flight failures at this early stage did not come as a total surprise. For the AUSPO team it was different. Very few, if any, had a background in development and none had a background in flight vehicle development. Their expectation was that we would not have flight failures and to have done so was a reflection on the competency of the industry team. Over the years that followed we slowly improved the reliability of the system and, with that, the relationship between the parties also improved. It's a fact of life that you can only cancel out a negative with a thousand positives so we must have done a lot of things right to regain their confidence.

test analysis, Warren Kidd, Oliver Collins, Scott Lanyon and Bernie Charles on the Launcher Interface Unit and Fire Control, supported by Alex Yates on the Interim Fire Control System. Barry Watson and Professor Tom Fink visited. The telemetry receiving station was supplied and manned by Phil Pearson, Col Sparrow, Tony Hind, Greg Barratt and Steve Simmons from Guided Weapon Division, DSTO.

6-23 : Gimbal Firing Test DT-IIA Phase 1 at Woomera.

The Joint Program Office was ready to abandon the trial after two gimbal rig failures due to incorrect test set-ups and an error in the Launcher Interface Unit software. It was persuaded to continue after AWA proposed to rebuild another gimbal round at Woomera from parts recovered from the first two. This test successfully demonstrated pitch and roll manoeuvres and it was then agreed to proceed with flights.

The first flight under DT-IIA Phase 1, took place at Woomera on 3 November 1990. The vehicle failed spectacularly during the launch when it tumbled and crashed to the ground after reaching 50 metres altitude. The cause was found to be a burnt wiring loom to the thrust vectoring tabs caused by an unplugged hole in the lower skirt of the rocket motor. The second flight test occurred on 7 November 1990 and, to the amazement and relief of all, the flight was a complete success.

Flight trials dominated almost every activity during the two years from November 1990. There were five trials at Woomera, one on the Potomac River and three ship trials during this period culminating in the highly successful operational evaluation tests.

The Pressure Air Data Assembly as a height sensor was completely successful. Minor technical issues with sputtering of the motor, excessive tab excursions and problems with the tab position measurement would be attended to in the Phase 2 tests.

DT-IIA Phase 2 tests commenced at Woomera in February 1991 with the aim of completing vehicle tests and testing two rounds with payloads. The 10 flights planned were to have the speed control loops closed – first time – and included a range of flight speeds and manoeuvres. Gino Beltrame from DSTO's Electronic Warfare Division led the group providing the equipment that made the payload believe there was a missile attacking. Six consecutive flight tests were successful, but reliability problems caused the next three to fail. The complexities of flight control appeared to have been solved but the simpler things such as resistor choices and manufacturing quality were deficient. The design team had achieved 90 per cent in a situation where anything less than 100 per cent was considered a failure.

The three failures at DT-IIA Phase 2 meant there were a total of three trials at Woomera in 1991. The last of these was designated as a 'Test, Analyse and Fix' trial, although the process was not significantly different from that adopted for previous trials. The Test Analysis and Fix trial was introduced at the direction of the Joint Program Office to demonstrate over five round firings that the system had sufficient reliability to move to ship trials.[28] The reliability of decoys was considered inadequate and threatened the continuation of the program. Environmental stress screening tests were to be more rigorous and soldering standards had to be improved. In view

6-24 : A sequence of three photographs showing the decoy exiting the launcher during the flight trials of March 1991 at Woomera.

of the many issues, the project would have been cancelled if the Test Analysis and Fix trial had failed. Fortunately, the trial of December 1991 was a complete success and was the beginning of considerable improvement in outlook for the program. Planning for the at-sea trials intensified.

Project activities between trials comprised analysis and investigation of each trial, followed by implementation of any corrective actions and preparation for the next trial. There were periods of intense activity characterised by insightful reasoning, stressed people and organisational management, and brave decisions by all.

6-25 : John Brentnall came from a ship building background to be the System Engineering Manager in the Canberra project office. He worked with five project directors before taking a firm hand at the wheel himself till January 1998. He steered the program through some of its most turbulent years.

Project directors and managers

Life was made more turbulent for AWA by the frequent changes that occurred in the management structure of both the Australian and United States project offices. There were five different Nulka project directors in Canberra between the start of the the Full Scale Engineering Development program in January 1988 and March 1991, when John Brentnall became Project Director. John broke the change cycle and provided much needed continuity and stability through the difficult few years by remaining till 1998. One project director lasted only a month and never met the AWA team. Every change in project directors required a period of adjustment as old ground was revisited and people grew to know each other. Also, a change at the top usually brought about a change in direction, as each incumbent brought new ideas that were not always — though often — beneficial, and established his authority over the program. The Captain in charge of Nulka in the United States changed at least every 18 months, though Project Manager, Carl Espeland, remained through to February 1996. AWA had only one change of program manager in 10 years.

6-26 : As the United States Navy liaison officer, Commander Mike Hedrick introduced selected systems engineering processes to the Australian scene to the benefit of all. He later joined British Aerospace and established a Nulka Washington office to improve the service to the United States Navy customer and manage United States based subcontractors.

However, a beneficial practice adopted by the Joint Program Office from the beginning was the exchange of naval officers. In May 1990, Commander Mike Hedrick joined the Australian Project Office as the United States Navy liaison officer. Hedrick added a great deal of rigour to the Australian operation. His attention to detail sometimes drove the AWA management team to distraction, but there were advantages in having an informed customer. Every line on every project schedule was examined and queried in depth, as were test procedures and test equipment. For both the Australian Project

6-27 : Nulka launch during DT-IIB tests from HMAS *Brisbane*.

Office and AWA, Commander Hedrick was invaluable in bridging the cultural and procedural gaps between the Australian and United States Navy ways of doing business. This was particularly important as the trials program devolved to United States Navy ships, and his knowledge of the United States acquisition processes was invaluable later on as the program entered the production phase. Hedrick returned to the United States Navy in December 1992. He later joined the British Aerospace team after that company had acquired AWA in 1996 and was influential in setting up a decoy assembly facility in the United States.

The Critical Design Review for the system

The Critical Design Review for the system was originally scheduled for month 16 of the Full Scale Engineering Development phase and was to precede the first flight trial by five months. However, following three failures in the DT-IIA phase 2 trials in February 1991, four flight trials occurred before the Critical Design Review in February 1992, the last being the successful Test Analyse and Fix trial of December 1991 which was the beginning of the improved fortunes of the program. The Joint Program Office was well aware of the known design issues before this event from a four-day Test Readiness Review in October 1990, prior to the first flight trial the following month, during which all of the known design issues were presented and discussed.

Every conceivable aspect of the design was included in the presentations for the Critical Design Review with the advantage that the reporting included the results of real flight tests.

The project was heading towards ship trials, which introduced additional issues such as ship clearance safety analysis, hazards analysis and software integrity. Every experienced electrical engineer knew that connecting black boxes with long cables on a ship created concern about ‘grounding’ and ‘earth loops’. Carl Espeland offered the supreme compliment to AWA afterwards by saying to David Mann: ‘That CDR is what I would expect from only the best United States prime contractors’.

The at-sea trials

The teams addressed the schedule for major sea trials with considerable optimism following the success of the Test Analyse and Fix trial in December 1991 and the successful Critical Design Review in February 1992. Four sea trials and one Woomera trial were planned. There were a large number of qualification test programs to be completed in addition to these major milestones, including the Hazards of Electro-magnetic Radiation to Ordnance testing, the round and launch sub-system and component qualification, and the explosive safety classification testing. The re-scheduled trials program for 1992 meant trials were planned to occur within one month of each other over an eight month period.

A trial from a fixed barge in the Potomac River at the Naval Surface Warfare Center, Dahlgren (DT-IIC Prime) took place in April 1992 as a rehearsal for the full at-sea test on a United States Navy ship (DT-IIC).[29] The first at-sea ship firings (DT-IIB) from HMAS *Brisbane* at Jervis Bay followed in May, and DT-IIB2 took place in June.

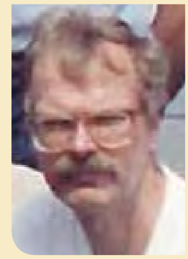
One of the three flights at the Potomac River tests flew with an unexpected error in track direction. An investigation found the software coding error which was corrected for subsequent trials. The testing was completed the day before the special computer used was dismantled and despatched to DSTO. This was the first and last flight control software error in a flight test.

Ten rounds were taken to DT-IIC flight tests from the USS *John Hancock* in September 1992, as preparation for the all-important operational evaluation. Project staff were stunned when the rocket motor case burst on the first round launch.

There had been no indication of the potential for this type of failure after 33 decoy flight tests and at least 100 additional motor firings. There followed one of the bravest decisions in the history of the Nulka program, when Carl Espeland, Director of the Joint Project, decided to proceed with the tests. Eight successful flights followed over two days.

Needless to say, a frantic investigation into the cause of the explosion commenced immediately. Subsequent tests enabled the cause to be identified, and then a design change was made to correct the problem, all within three months.

The following sea trial was to repeat the DT-IIC technical evaluation — renamed DT-IID — and at the same time move to the operational



6-28 : Carl Espeland became the Joint Project Director for the Nulka program after an exposure to the program in the lead up to the joint agreement. He had a major influence on the program till early 1996 while working with five different assistant project directors in the Australian contracting office.

6-29 : Barry Watson saying goodbye after being presented with a Nulka model built by Kevin Kerle.

evaluation trial (OT-IIA). The date had slipped six months to December 1992. Ten consecutive rounds were flown successfully for DT-IID, and were followed by 12 successes from 13 fired for the OT-IIA tests.

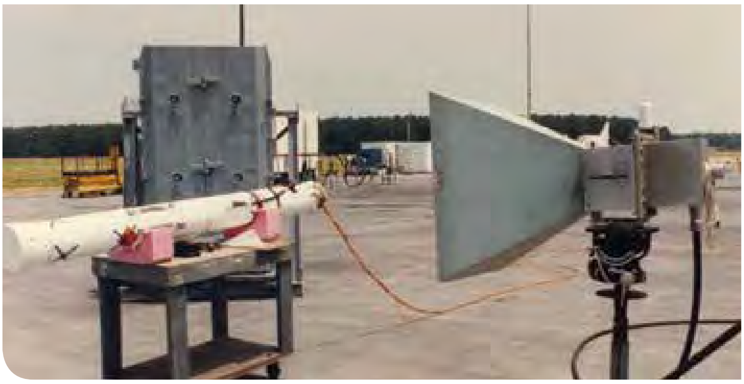
The final trial during the Full Scale Engineering Development phase occurred at Woomera in February 1993. Four rounds were environmentally pre-conditioned to various extreme conditions before flight testing to special flight plans. The results were excellent, although a payload failed to activate on one test that was later found to be due to recurring interface problems between the flight control unit and the payload.

The five trials were completed successfully over a period of 12 months, instead of the impossibly optimistic eight months outlined in the 'success oriented schedule'. The motor failure during DT-IIC tests was another low point in the project, but it had been quickly rectified within three months. Differences between the Nulka motor design and the accepted methodologies in United States industry arising from this event led a few years later to the introduction of an alternative United States supplier for the motor.

The at-sea tests extending over 37 decoy firings, had convincingly demonstrated the potential capability of the system to protect ships. Each test in the United States had used up to eight different missile simulators under the wings of aircraft. The reliability of the product had exceeded the original specified level, further improving its capability.

David Mann believed:

To have developed such a new concept as Nulka and completed the operational flight trials program, only 14 months late, was a major project achievement, when you consider that 21 months of schedule delay were accumulated at the first hurdle, the DT-IIA flight trial. To put it another way, from the point at which the concept was first proven to be feasible (end of DT-IIA), the rest of the program was completed seven months ahead of schedule, in spite of the fact that two United States trials and one Australian trial were added.



6-30A : Testing the system for susceptibility to radar emissions at NSWC, Dahlgren, May 1991.

6-30B : Establishing susceptibility to damage by dropping the decoy in a shipping container from 12 metres.

6-30C : Surviving the corner drop test was mandatory.

6-30D : 20 mm bullet Impact Test Rocket Motor Assembly.

6-31 : The Lockheed Martin Sippican team photograph in 1993 for the delivery of the fifty-first and final payload for the Full Scale Engineering Development program. The team from left to right: top row: Jim Soden, Paul Lavoie, Bernie Mitchell, Everett Williams, Bob Gordenstein, Kevin Loranger, Bob Chismer, Bill Walsh, Con Pierce, Randall Elgin, Mark Small, Tom Benevides, Jim Vernon, Anne Rafferty. Second row: Frank Baptista, Wes Libby, Paul DosSantos, Anita Waagen, Diane Ouellette, Donna Edwards, Rick Becker, Gail Laliberte, Bill St George, Phil Young. Third row: Pat Carbone, Judy Cambra, Wenonah Clarke-Smith, Jim Shaw, Carolyn Rose, Cheryl Souza, Tom Behrendt, Bob Ouellette. Bottom row: Alec Chalmers, Libby Signell, Paul Duane, Dave Stone, Rusty Bodnar, Cheryl Haxton.

6-32 : The AWADI Aerosystems group had been reduced to a minimum number in 1993. The team is, from left to right: back row: Robert Scott, Charlie DeBrincat, Jack Walker, Edward Nichols, Kevin Kerle, Graeme Lewis, Sam Schofield, Tuan Do, Ray Luckins, Brian Chapple, Ian Jolley, Peter King, Robert McNeill, Trevor Atkinson. Middle row: Brad Yelland, Pieter Penhall, Oliver Collins, Scott Lanyon, Sylvia Skonietzky, Elke Giantsis, Kathy Cates, Kevin Jones, Arnold Barker, Neil Barling. Front row: Wayne May, Mike Vowles, William Henderson, John Townsend, Alan Smith, Barry Watson, David Mann, Ian Turner, Warren Kidd, Mal Crozier, Peg Kelly.

Absent: Barry Murphy, Jim Kennedy, Bernie Charles, Kevin Winch, Jodi Dalpiaz.

CHAPTER 7

More obstacles to overcome, 1992–1995

It was to be expected that development projects would encounter a variety of funding and political-level obstacles throughout their lifetime. Nulka was no different. This chapter reviews a major obstacle that threatened to kill the project virtually overnight and the frantic efforts at the political level to continue the project. The dedicated efforts of individuals, including politicians, were vital in keeping the project on track.

The news that the United States Navy would not proceed to production had a devastating impact at Lockheed Martin Sippican. Commodore Terry Roach worked with Bernie Mitchell at Lockheed Martin Sippican to develop support for the Nulka program in the United States. They continued that relationship into 1995 to secure funding for the United States Navy to introduce Nulka into the fleet.

Nulka's future looked assured following the system's Critical Design Review and three consecutive successful flight trials. Despite this outstanding success, the United States Navy launched a bombshell when it announced that Nulka would be unlikely to proceed to fleet introduction and associated production.

At the time, the United States defence budget was under great pressure following the end of the Cold War, symbolised by the Berlin Wall coming down in November 1989, and the aftermath of the Gulf War of February 1991.[30] The letter from Gerrald Cann, the Assistant Secretary Navy Acquisition in the United States Pentagon, to Gary Jones, Assistant Secretary Defence, Canberra, was dated 14 July 1992.

This news came as a severe blow to the chances of the RAN ever obtaining the system, at least at an affordable price. Gary Jones and the minister, Senator Robert Ray, immediately initiated diplomatic and persuasive efforts through the Naval Attaché in Washington, Commodore Terry Roach, that were to bear fruit in 1995. They worked through the Office of the Secretary of Defense as had Defence Minister Kim Beazley, Malcolm McIntosh, Deputy Secretary of the Department of Defence, and Roger Lough in 1985.

The news that the United States Navy would not proceed into production had a devastating impact at Lockheed Martin Sippican. That company needed the production to recover the losses on the development program and remain viable. Lockheed Martin Sippican had succeeded in delivering on payloads after the financial crisis of 1990 and everything pointed towards the decoy exceeding performance expectations, even though technical and operational evaluation tests were yet to occur.

When Bill Walsh and Bernie Mitchell at Lockheed Martin Sippican confirmed this devastating news they made the momentous decision to lobby their local senator for Massachusetts, Ted Kennedy, who was chairman of the powerful Senate Armed Services Committee, and Senator Warner from Virginia.

Kennedy, supported by Bernie Mitchell and Commodore Roach, ultimately prevailed, but it took 15 months to achieve their objectives. The Senate Committee's financial support began in September 1993 by means of 'Unsought Appropriations' within the defence budget.[31]

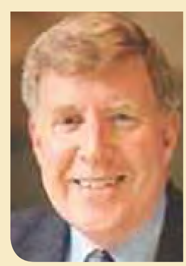
World events involving the United States assisted Nulka's cause. 1992 was the year the United States Senate House Appropriations Committee initiated the US$220 million program called the Ship Self-Defence System to improve the protection of its surface fleet from attack by sea-skimming missiles. The committee noted that the cruise missile attack on the USS *Stark* had been the first indication of the need for drastic improvements for fleet protection. The use of amphibious ships laden with United States marines for the assault on Kuwait in Operation Desert Storm, which were vulnerable to land launched cruise missiles, reaffirmed the need for action.

7-1 : In mid 1990, Bill Walsh, the Chief Executive Officer of Lockheed Martin Sippican, presided over a financial crisis which led to major changes in the contract to deliver payloads. Plessey bought the management-owned company, then later the management team bought the company back from GEC Marconi. The managers' faith in the future of the Nulka program was severely challenged by the announcement that the United States Navy would not proceed to production following the Full Scale Engineering Development phase.

The Applied Physics Laboratory at the Johns Hopkins University executed a series of studies to evaluate the effectiveness of various strategies during 1993: these studies included Nulka and versions of the Sea Sparrow missile.

The excellent Nulka operational evaluation trials of 1992 provided a timely verification of the numbers used in these simulation studies. The House Appropriations Committee's support for Nulka in September 1993 was directly related to the positive outcomes from the Applied Physics Laboratory studies as well as the influence of Senator Kennedy's Armed Services Committee. US$10 million was approved for spending in 1994 and again in 1995.

Additional studies on ship self-protection using Nulka were carried out by NRL, the Applied Physics Laboratory and the Naval Surface Warfare Center, Dahlgren, using the funds appropriated by Congress. Part of the funding was allocated to the new United States Nulka launching system to be compatible with other ship self-defence systems to be developed at the Naval Surface Warfare Center, Dahlgren. By the end of 1993, the United States Navy had declared Nulka a front-line system for ship self-defence.



7-2 : Bernie Mitchell at Lockheed Martin Sippican was instrumental in securing Congressional support to revive the Nulka program in the United States Navy following the Full Scale Engineering Development phase. He then led a campaign to inform all elements of the United States Navy of the merits of Nulka, leading to approvals and budgets to fit the system to the surface fleet from 1997.

The official announcement of the positive outcome of the operational evaluation (OT-IIA) tests in December 1992 had been timely for Congressional support and had a positive effect on the project. John Brentnall provided the momentous news to AWADI in an important letter on 7 April 1993. He officially confirmed these excellent outcomes, and advised that the Commander Operational Test and Evaluation Force was recommending limited fleet introduction 'to support continued program development', as Nulka had been assessed as potentially operationally effective and potentially

7-3 : Wes Libby joined Lockheed Martin Sippican Ocean Systems following the decision in 1985 to diversify and team with Dalmo Victor to develop a payload for the early Active Expendable Buoy program. Libby played a leading role on the Nulka payload development, and during the crisis years of 1994 and 1995 was a key presenter in the campaign to sell the effectiveness of the system to the United States fleet. He mentored many participants on the Lockheed Martin Sippican team.

7-4 : Rear Admiral Meyer, the father of the 'AEGIS weapons control system', had an involvement with the Nulka program from 1993. He had worked as a consultant to Lockheed Martin Sippican and reviewed the Australian facilities and processes on several occasions, the most notable being April 1998 following events on a United States ship trial.

suitable. Furthermore, the intention was to secure Navy funds for advanced low rate initial production with a view to more operational testing and introduction into the United States Navy fleet. This news served to refocus the project after the Full Scale Engineering Development phase activities of the previous five years.

Nulka for the United States Navy

Lockheed Martin Sippican had secured Congressional funding to keep the United States Navy in the program, but this meant nothing unless the Navy was sufficiently convinced of the value of the system to introduce funding for production and service introduction.

A major issue remained with the so-called 'hard kill' proponents in both the United States and Australian navies. While recognising the serious threat posed by anti-ship missiles, a large part of the officer corps of the United States and Australian navies considered a visible destruction of the threat with a 'hard kill' system such as the Rolling Airframe Missile (RAM) or Phalanx to be the best approach. Nulka, as a 'soft kill' system, could not visibly demonstrate that the approaching missile was defeated, and as such was regarded as inferior to the 'hard kill' alternative.

Following the initial success in gaining Congressional support in 1992, Lockheed Martin Sippican embarked on an intensive program to educate the United States Navy about the value of Nulka. The company used the results of all operational tests, assessments and recommendations with results of the comparative assessments by the laboratories. Bernie Mitchell, Wes Libby and John Brokaw made more than 40 presentations to every element of the United States Navy surface fleet, the Pentagon, defence acquisition staff and the laboratories between 1993 and 1995. A surprise supporter emerged in Captain Cassidy from the AEGIS community, that was traditionally known for its emphasis on 'hard kill' weapons.[32] This, in turn, led to support from none other than Rear Admiral Wayne Meyer, the 'Father of the AEGIS' weapons control system for United States Navy ships. Admiral Meyer subsequently followed the program closely and assisted Lockheed Martin Sippican and BAE Systems on many occasions.

During this period, Commodore Terry Roach (RAN) furthered the cause by lobbying the United States Navy through the Office of the Secretary of Defense. He convinced Jim Whalen, an influential

7-5 Nulka launched from HMAS *Newcastle*.

7-6 : Commodore Terry Roach (RAN) was influential in maintaining United States Navy support for Nulka as the program worked towards Navy funding for production and fleet introduction. He subsequently supported Lockheed Martin Sippican in developing commercial opportunities in Australia.

civilian within the Ship Air Defence Systems (United States Navy), that Nulka was important to ship self-defence for both countries. He emphasised that the need was great, particularly in low intensity situations where there was no direct conflict, but where a potential threat to ships might occur. This was apparent in the USS *Stark* incident of May 1987, and even that involving USS *Vincennes* which shot down Iran civilian flight 655 by firing two missiles in the belief that it was under a missile attack. Both were cases where Nulka would have been particularly advantageous: 290 lives would have been saved in the case of the USS *Vincennes* incident.

By 1995, United States Navy fleet commanders were convinced of the system's value and Admiral Cody of Surface Navy Requirements supported the budgeting process for fleet introduction starting in the 1996 financial year: no doubt, colleagues such as Admiral Wayne Meyer had influenced his decision. Lockheed Martin Sippican had won a reprieve with guaranteed funding, but its future and that of other organisations depended on the project's successful introduction. The extent and intensity of Lockheed Martin Sippican's endeavours as it sought to maintain the project became evident only in hindsight.

CHAPTER 8

Towards full scale production, 1993–2001

The operational performance of the decoy exceeded the expectations of many and led to the formation of the Active Missile Decoy program to fit Nulka to Australian Navy ships. In the United States Navy, the adoption of Nulka as a primary ship protection system took much longer because of the need to have the required budgets in place. Many improvements were incorporated and low rate production of decoys began as facilities were reconstructed. The flight trials leading to operational evaluations in the United States Navy were not without drama, but huge improvements were made. Then in 1997, nearly 10 years from the start of the Full Scale Engineering Development phase, a Nulka production contract was signed to supply the navies of Australia, Canada and the United States with decoys. At-sea testing cleared the way to introduce the system into the fleets.

The good results of the OT-IIA operational tests led to the formation in Australia of the new Active Missile Decoy Project Office, which was established soon after the project's approval by the Defence Force Structure and Policy Committee in August 1993. The project became responsible for eventually fitting the Nulka system to 14 Australian ships along with the production and acquisition of several hundred decoys. The project included installation on the ships, training infrastructure, and test and evaluation leading to acceptance into naval service. However, while Australian efforts were being made to fit Nulka to HMAS *Melbourne*, another year passed before contracts for work were finalised. Industry teams dissipated in the meantime.

The Boeing Aircraft Company had by now acquired ASTA, and the new Australian Defence Industries consortium had closed both the Propulsion Development Facility, Salisbury, and the ADI Maribyrnong site for manufacturing rocket motor hardware and canisters. The AWADI Aerosystems team was reduced by half, though Barry Watson was successful in having the AWADI board agree to keep a team together that could spawn a new group as and when the intentions of both navies were funded. The joint project offices recognised the issues and a series of new initiatives was introduced into the original contract to sustain the capability and move towards production and provision of a system for the ships of the two navies.

The AWADI Aerosystems team had been confirmed as the prime contractor for the production of decoys for both the United States and Australian navies by October 1993. The team, now under the leadership of Barry Murphy and David Mann, needed to develop technical skills to complement the management responsibilities on production and integration of the payload. Moreover, there were production facilities for the round and sub-assemblies to create and prove. Essentially, everything that had existed for the Full Scale Engineering Development program had been dismantled.

Many issues related to the production of the decoy were to emerge, including the non-availability of parts. Technology was continuing to accelerate and the major electronic components, which had been selected at least six years earlier, were becoming outdated. There were many analyses and changes that the safety authorities and the Navy operations people would need in order to satisfy the requirements for each milestone review.

The need for an engineering and manufacturing development contract

The program was sustained by Congress appropriating research and development funds for production over the few years starting in 1994 under the Engineering and Manufacturing Development contract. In 1995, the funding went to both AWADI and Lockheed Martin Sippican to develop production capability in readiness for the procurement of rounds for both navies. The budget approval cycle for any new program in the United States typically took approximately three years, and there were several acquisition milestone decisions as part of such a program. Anything was likely to happen in that time based on experience to that time.

8-1 : Chris Edwards of the Nulka Project Office was the driving force behind the Track Requirements Working Group; this was a forum for discussing technical issues related to deployment of the decoy. A problem solving forum such as this was first proposed in the Flag Officers' review of 1990.

Improving system integrity

The substantive issues concerning AWADI and the Nulka Project Office by 1994 related to improving the integrity of the decoy, launcher, and canister designs to go into production. They included canister sealing, the ability of the canister to withstand a burning round, resistance of the launcher to shock, and a range of software safety and integrity issues.

Additionally, there began several jointly-funded tasks, referred to as the Nulka Improvement Program. A range of improvements that shortened the decoy launch sequence timing were the most complex changes introduced to improve the reaction time of key components in the payload. These changes improved the system capability over that of the decoy evaluated in the OT-IIA flight tests of 1992. Further changes were introduced by Lockheed Martin Sippican to reduce the cost of the payload.

Study activities at AWADI begun during 1994 were directed towards understanding what factors might improve the overall effectiveness of the decoy in defending the ship from which it was launched. To this time, Gino Beltrame and DSTO had been the only ones in Australia seriously studying the issue of system effectiveness. Such studies had been deleted from the Full Scale Engineering Development contract with AWADI. The time was right for both parties to understand more fully both the application of the system and the means of developing and improving its effectiveness. Chris Edwards of the Australian Project Office made an important innovation to facilitate this process when he initiated and chaired

8-2 : Oliver Collins built on his earlier role in the development of algorithms for deploying the decoy by extensive use of the decoy computer models and a detailed understanding of Gino Beltrame's work.

regular meetings from early 1994 between AWADI, DSTO and Australian Project Office staff to discuss and understand operational issues related to decoying performance. These discussions later included United States Project Office staff, and those involved became known as the Track Requirements Working Group, although the scope of the subject material was far wider than the name implied. Chris repeatedly reminded everyone that money and schedules were not 'in scope' at these working level forums. Outcomes from these meetings that involved money or schedules were referred to the formal project meetings for future guidance.

The joint project had authorised studies to devise ways of generalising the vehicle flight demand system to cope with a wide range of ship types and launcher positions. The 'Azimuth Study' examined the impact on the Launcher Interface Unit software algorithms of a range of launcher orientations expected in the future. The so-called 'DR line study' was one of the first studies to benefit from the interaction of the Track Requirements Working Group's methodology. Associated with this was the landmark 'Golden Rules' document by Gino Beltrame, which made a valuable contribution to the joint understanding of the system.

The concept of the Flight Demand Algorithms Common Software developed during this period. This term referred to a large section of the software in the Launcher Interface Unit that directly related to decoy flight deployment. The development of the Fire Control System was well underway and it was clear that the United States Navy system would be different. However, it was sensible that functions specific to the decoy embodied in Flight Demand Algorithms Common Software should be common to both and be maintained and developed by the prime contractor. Work on creating this software as a stand-alone package began in mid 1995.[33] The interface was defined so that it would remain common to both the United States Navy and RAN systems, and configuration and the necessary joint approval processes were put into place. Code-testing harnesses were defined as part of the common package, recognising that the compilers were different in each service. The processes implemented to control the configuration of this software were used almost every 18 months afterwards as each upgrade was released.

Agenda topics for the June 1995 meeting of the joint Track Requirements Working Group in Washington DC provided a picture of the range of issues being considered as both navies moved towards flight trials necessary for fleet introduction. Robert Hill, the Project Manager for the United States Navy Decoy Launch Processor, proposed changes to the interfaces so the system could be used with the threat detection system of the Royal Canadian Navy, whose personnel were showing considerable interest in buying the Nulka system. Discussions were held in the expectation that Lockheed Martin Sippican would begin to build the United States Navy Decoy Launch Processor system for the United States fleet. Major changes for the 6 degrees of freedom decoy model known as FORTRAN 6DOF were being jointly defined by NRL and DSTO.

Engineering and manufacturing development

The Engineering and Manufacturing Development contract began in mid 1995 and continued until December 1997, by which time it was expected that both navies would have the funding to begin full scale acquisition of Nulka rounds and equipment. This contract was significant because it was placed directly by the United States Navy to AWADI and became the first United States Navy defence-related development contract to be let outside the United States. It was a significant financial commitment that indicated the United States Navy was finally committed to introducing the Nulka system.

This contract provided the first opportunity for AWADI to exercise its responsibility as prime contractor and to take responsibility for all aspects of the program. The most important and difficult task was to provide engineering support to the United States Navy program to enable Atlantic Research Corporation (ARC) to redesign the rocket motor and to establish a manufacturing production capability for the complete propulsion unit in the United States.

David Mann recalled:

The United States' decision to have their rocket motors built in the United States was based on advice from Government rocket motor specialists at NSWC, Indian Head. In essence they concluded that the Australian design was inadequate, because the propellant did not contain a bonding agent, which is contrary to US practice for all composite propellant rocket motors manufactured for Service use in the Navy, and that no US manufacturer would have designed it that way. It was believed it was going to be difficult to get the propulsion unit through the safety committees.

Charlie Haff at NSWC, Indian Head, triggered much animated debate on case bonding during investigation of the motor burst on the first decoy launch off a US Navy ship under the DT-IIC tests.

8-3 : Maurie Opperman was the system manager for the engineering development of the propulsion unit at ADI. He provided considerable assistance to ARC to facilitate acquisition of this capability after difficult decisions by ADI to support an overseas competitor.

Having an alternative rocket motor manufacturer was a major element in the United States Navy's return to the Nulka program.

Australia did not see the need for a bonding agent in the propellant on the grounds that, unlike the United States Service composite propellant charges which are all case bonded, the Nulka propellant charge is cartridge loaded and not subjected to the same stresses on temperature cycling during normal service life.

The Atlantic Research Corporation (ARC) was well advanced with its task by the time the Engineering and Manufacturing Development contract was signed. Bob Rovitto was the project manager, but Stewart Gould was to take over as the engineering project manager later into the program. Mike Allan was the senior engineer and liaised extensively with Peter King, the engineer in charge at AWADI. Nat Seiden joined the United States Project Office from Indian Head to oversee the development contract. This was the first test for the quality of the Full Scale Engineering Development technical data packs. The question arose: 'Could a second source supplier understand and build to the drawings produced by the designer?' A deliverable for this new program was a data pack that would suit both ARC and ADI. Considerable effort went into this drawing pack along with additional test and fabrication documents.

By its nature, the Nulka motor was critically dependent on the fine tolerances which were driven by the thrust versus time characteristic and the weight. ARC had never before encountered such tight requirements. It bought rocket motor cases from ADI for the initial work because it could not find a contractor to produce the thin walls of the tube accurately enough. Maurie Opperman of ADI provided an immense amount of expertise and assistance to ARC. This saved time and money for the United States Project Office. Understandably, ADI had serious reservations about helping ARC to develop a capability that would eventually compete with their own but, as AWADI had appreciated and ADI came to realise, production for United States requirements was going to be undertaken in that country irrespective of the quality of a foreign product. If ARC failed, the likely outcome would be United States withdrawal from the program or the appointment of another supplier.

The ARC program to 'Americanise' the rocket motor cost more than US$6 million and, apart from a number of relatively minor design features, ended up essentially with what DSTO and ADI had designed in the first place. However, ARC was a good choice as a second source. The company became competent in handling the tough Nulka requirements, provided a depth and breadth of rocket motor engineering expertise, and produced a high quality product. However, ARC had an enormous amount of trouble with the Thrust Control Unit during this development. BAE Systems (formerly AWADI) also learnt many things about the device hitherto probably understood only by ADI and ASTA.[34] One issue was the dramatic change in the Thrust Control Unit test results before and after fitting to the rocket motor. The unit was found to twist when bolted to the motor.

8-4 : Commander Mark Remmers was the first project manager for the RAN Active Missile Decoy program, starting in 1993. He maintained momentum while significant changes were proposed for the shape of the shipboard launching system. He secured contracts for the development with AWADI and CEA (Canberra) and was party to consummating a Memorandum of Understanding on production with the United States Navy and later the collaborative rounds contract for decoys for the Australian, United States and Canadian navies.

Only months before the first flight trials in four years, a propulsion unit on the test stand incinerated a Thrust Control Unit during a firing and the motor burn had to be forcibly terminated. Mal Crozier, Warren Kidd and Peter King joined the failure investigation at ARC in May 1996. At least one tab had been inserted too far and was burnt off. The cause was not definitely established, although failures in the drive electronics were strongly suspected. It did not help that the firing had been rushed because of confusion over the procurement of the correct potentiometer for the Thrust Control Unit.[35] ARC did not object when BAE Systems decided to retain manufacture of the Thrust Control Unit in Australia.

Launch control

Australia and the United States Navy pursued different paths for launch control after the Full Scale Engineering Development phase. As discussed above, a modified AN/SLQ-32 and the Decoy Launch Processor had provided these functions during Full Scale Engineering Development. There appeared to be problems in acquiring the modified software for the SLQ-32 systems fitted to the RAN FFG frigates and it was almost certain the new Anzac frigates would not use the AN/SLQ-32 available only from the United States Navy. Consequently, the Royal Australian Navy preferred to connect the Nulka system to the ship's combat system by means of a new operator's panel, referred to as the Fire Control Panel. This was fundamentally different to the approach taken by the United States Navy. However, the Fire Control Panel would include many functions that were similar to those of the United States Navy Decoy Launch Processor. This configuration had another advantage: it made the Australian system exportable because many navies would need to connect to the combat system.

8-5 : David Mann (left) and Commander Mark Remmers witness the signing of the Australian Navy Active Missile Decoy contract by Barry Watson (left) and Admiral Nick Hammond on 30 June 1994.

The important driver for the United States Navy was to use a two-decoy Nulka launcher box and mount it on the existing chaff decoy launch system.[36] The Americans could not afford the deck space or the money to support Nulka and chaff as two separate systems.[37] Furthermore, they proposed that the software functions of the Launcher Interface Unit – the decoy flight demand algorithms – be shifted to the Decoy Launch Processor, and the rest into a new interface unit called the Processor Power Supply to go with each launcher. In addition, the Processor Power Supply needed to interface with the chaff and infrared decoys as well. So the Dahlgren team began development of a Processor Power Supply and a more capable Decoy Launch Processor in early 1994.[38] The task of defining the Flight Demand Algorithms Common Software for the United States Navy began with discussions with AWADI in June 1995 and Gerry Boynton from Dahlgren worked with Oliver Collins (AWADI) to define the structure and content of the first version. The two-decoy Nulka launcher fitted to the chaff launcher with the Processor Power Supply and Decoy Launch Processor became known as the Mark 53 Decoy Launch System.

Mark Remmers was resolved to complete the RAN launcher control developments speedily in readiness for production, and these were carried out under Phase 1 of the Navy's Active Missile Decoy program. He proceeded to negotiate the Phase 1 contract with AWADI based on the Fire Control Panel and Launcher Interface Unit. The contract included installation to the first ship and a large number of decoys for testing. After three month's debate and negotiation, Admiral Nick Hammond and Barry Watson signed the Active Missile Decoy Phase 1 contract on 30 June 1994. This contract was modified shortly afterwards to place the software functions of the Launcher Interface Unit into the Fire Control Panel, leaving the firing circuits for the pyrotechnic squibs in the decoys to be incorporated into a smaller lighter box.

It was possible to have a single Processor Power Supply that was common to both navies, but the Australian Active Missile Decoy program chose to develop its own unit. Initially both units were intended to be interchangeable, though the Australian unit included the chaff decoy functions.[39] The United States Navy eventually changed the Processor Power Supply to deal with only two active

8-6 : The Fire Control Panel.

8-7 : Remote interface module.

8-8 : The CEA Processor Power Supply.

decoys in the interest of reducing space and cost. Australian parties were relieved and elated that the local program opted for what was considered the best solution and, accordingly, started to make changes to the Active Missile Decoy Phase 1 contract. It was little wonder that the Active Missile Decoy program was to be continually at risk financially. The budget had not envisaged the need for the more complex Fire Control Panel as well as a new unit to replace the Launcher Interface Unit.

However, despite protests from AWADI, the Active Missile Decoy office selected the Australian contractor, CEA, to develop the Processor Power Supply under Colin Davidson as project manager and Ian Croser as design manager.

There continued to be challenges. The safety design constraints were shown to slow down the processor speed significantly at the Preliminary Design Review of the Fire Control Panel in May 1995. There were several other unfortunate restrictions imposed because of safety considerations that reduced the reliability of the product. Fortunately these restrictions were removed for the later development of the new flight control electronics for the decoy.

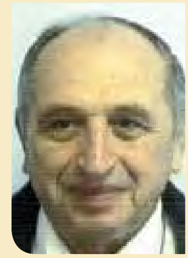
The Preliminary Design Review for the Processor Power Supply had preceded that for the Fire Control Panel by six months and was followed by two sessions for the Critical Design Reviews in November and December 1995. There were many concerns on points of detail and it was clear that CEA was unfamiliar with the extra rigour required for designing safety critical military equipment. The design reviews were torrid and protracted experiences as the two companies failed to agree on many design principles. All parties eventually agreed to the design after the comprehensive test program was completed and AWADI assumed the design authority role and, later, responsibility for maintaining the software.

8-9 : Dr Tony Cant from DSTO led the development of a new Australian Defence Standard for the development of safety critical equipment and its software. He worked with Chris Edwards (AUSPO) and BAE Systems to apply the draft standard to the development of a new flight control computer for the decoy.

The most memorable feature of the Critical Design Review for the Fire Control Panel in January 1996 was the time spent on the man/machine interface. As a member of the Active Missile Decoy project team said, 'To the operator, that interface is the Fire Control Panel'. The importance of this interface had not been apparent in the beginning, as the military standard was the only defined requirement.

System safety and approvals

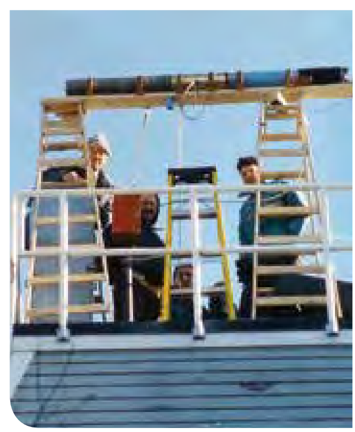
As Nulka team members worked with other companies, government agencies and navies, they began to realise that Nulka had certain unique features, and these led to much scrutiny by safety authorities. The United States Navy's Nulka shared the Super Rapid Bloom Off-Board Chaff round launcher, and was managed by the same United States Navy project group, but it flew far slower and therefore remained close to the ship for far longer than the chaff round. This raised the fear that Nulka would cause damage and fire similar to that of a Tomahawk or Harpoon missile if a mishap occurred. But Nulka did not have an explosive warhead, and had a fraction of the energy contained in a missile motor. Still, Nulka had a flight control system that controlled the vehicle's motion and trajectory like a missile. Because it loitered around the ship, the probability of a collision with the ship was higher for Nulka than for chaff rounds or missiles but, because Nulka carried no warhead, the consequential damage was certainly much less than that caused by a missile. However, the level of scrutiny by the safety community was typically based on the product of the two factors: likelihood and damage. The inherently different operation of Nulka across all these aspects meant the template for assessment by safety authorities had to be revisited and revised many times.



8-10 : Nat Seiden, with extensive experience in rocket motor development, was the natural choice to be the safety officer for the United States Project Office. He oversaw developments at ARC (later Aerojet) and coordinated submissions to the safety committees. In this latter role his Australian counterpart was Chris Edwards.

The process of bringing Nulka into service between 1994 and 1999 came at a time when there was great emphasis on product safety. Computers controlled critical functions in an increasingly large number of systems such as passenger aircraft, air traffic control systems, trains and medical equipment. Both the civil and military safety authorities, on both sides of the Pacific, were assiduously following procedures and generating new ones. Methodologies for ensuring the safety of ordnance and electronics were adapted to software, and research began on methods of improving the integrity of software used in these critical applications.

BAE Systems participated in the United States Navy safety program that was necessary for approvals from the Weapons Systems Explosive Safety Review Board which assessed safety aspects of systems used on United States Navy ships. Additionally, several software system safety technical review panel meetings occurred during this period. Nulka ultimately gained the necessary approvals and status under the guidance of Nat Seiden, the United States Project Office safety engineer.



8-11 : Joint development tests at Lockheed Martin Sippican. Testing of the payload occurred four stories above the ground — referred to as 'up the pole'. This occasion was the first test of a completed decoy jointly conducted by Lockheed Martin Sippican and AWADI. The photograph shows Mal Crozier and Andrew Macaulay working with Mark Small in sub zero temperatures during December 1995. Greg Delios was also present.

More on test equipment

Two important items of equipment were required for trials and tests of the Nulka system. Operational evaluation of the system relied on threat simulators and similar equipment. The Naval Research Laboratory provided this equipment during engineering development, but Australia's Active Missile Decoy program required a simulator in Australia. Additionally, the Winnin Nulka programs were required to carry payloads for long duration tests with ships.

Captive carry units

The DSTO payload captive carry unit served the project well for more than a decade, commencing with the Point Perpendicular tests

8-12 : A payload was attached to the end of a long boom projecting forward from a helicopter for decoying tests and Nulka flight trials with United States Navy ships during 1991 and 1992. Mike Combs from NSWC, Crane, managed its design and building by the Naval Air Test Centre at Patuxent River, Maryland. He was assisted by Craig Ketcham and Ken Myers at Crane. Mike's many trips in the helicopter on tests accounts for his later efforts to build his own light aircraft.

8-13 : Don Northam returned to Naval Research Laboratory in the mid 1990s. One task he had a few years later was to manage the design of this version of a payload captive carry unit, the CCTS. This unit was towed below a Bell helicopter and was developed over the same period as the BAE Systems system. The system was designed to enable the helicopter to land on the deck of a ship by reeling the towed body into a cradle near the helicopter cabin. The reel-in capability was not completed, and the CCTS was only flown as a sling load.

The NRL towed body vehicle was the fifth captive carry unit to be designed. What is striking is the large differences in shape and mode of control between the five units.

in 1986. NRL had also developed captive carry units for the same purpose, although it had a requirement for the helicopter to land on a ship. An early version comprised a mechanism to wind the captive carry unit into a rack under the helicopter, but this was replaced in the early 1990s by a payload which was attached to the end of a long boom projecting forward from a helicopter for decoying tests and Nulka flight trials with United States Navy ships during 1991 and 1992. Mike Combs from the Naval Surface Warfare Center, Crane, managed its design and building by the Naval Air Test Center at Patuxent River, Maryland. He was assisted by Craig Ketcham and Ken Myers at Crane.

NRL developed a second version of a captive carry unit in the mid to late 1990s. It was used for some developmental-payload testing and limited Nulka testing; it was flown on a United States Army, UH-1 helicopter. Around 2000, NRL began the design and development of a third captive carry unit — named the Captive Carry Test System — to support testing of a range of electronic warfare payloads, particularly the Nulka payload. This design was an evolution of the previous captive carry unit design. It is interesting to note that Don Northam, who had worked at DSTO — then the Weapons Research Establishment — in the mid 1970s on what was to become Nulka, returned to NRL in 1996 working in the Offboard Countermeasures Branch headed by Frank Klemm and, by the late 1990s, again became involved with the Nulka project. He was responsible for conceiving and managing the design and development of the most recent Captive Carry Test System. There was no formal program for the system, so its development was funded by support from various programs for electronic warfare payloads, including Nulka. David Mann and Mark Johnson of NRL played key engineering roles in the design, construction, and use of the Captive Carry Test System.

The Captive Carry Test System controlled payload orientation with a three-axis gimbals system, measured and recorded real-time payload and kinematic data, and provided command, control, power, protection, and cooling to the payload. It was designed to be used for both bench and captive carry testing of payloads, so that the same measurement and control system would be used when testing either on the bench or in the field. To expand its on-station support during at-sea testing, the system was designed to be installable on United States Navy SH-60 helicopters with a reel-in/reel-out capability.

The test helicopter would then be able to land on and refuel from navy ships during trials. Development of the Captive Carry Test System did not progress to the point where either automatic control of the payload orientation or a full reel-in/reel-out capability was implemented, although the design supported both. The Captive Carry Test System carried Nulka payloads on Bell 412 helicopters in several wharf-side and at-sea trials of Nulka payloads.

The DSTO captive carry unit came to an unfortunate end in October 1998 during tests in Spencers Gulf with HMAS *Canberra* when one engine failed on the helicopter and it was forced to jettison the unit. To everyone's dismay it did not survive the drop onto land. Fortunately, BAE Systems had commenced the design of a new unit a year earlier. There was a need for a unit that did not require manhandling into a cradle at the end of its journey on the end of a cable under a helicopter. It was highly desirable that the required time for a sortie be increased and it was hoped the setting of the angular position of the payload could be automatic rather than manually aligned prior to flight.

This new design worked well and the system was accepted following the third series of flight tests in May 2001. Ashley Searl and Paul Merlo had had rather more trips in a helicopter than had been planned. The program was managed by Joe Linehan and Cameron Burhop in the Nulka Project Office and supported by the end users, Gino Beltrame and, later, Peter Gerhardy from DSTO.

8-14 : Dieter Adams (leading draftsman), Anthony Schnellbeck (aerodynamics) and Jack Walker (trials officer) preparing for the first airborne tests for the captive carry unit at Monageeta, Victoria.

Threat simulators

The Active Missile Decoy acquisition strategy had identified the need for a device that simulated a missile which could be used to test whether the Nulka decoy was working and, in addition, test the shipboard counter measures system for detecting threats. The United States Navy had provided this facility for all trials activities to 1994. In August of that year, Commander Mark Remmers initiated a task at Tenix Defence — formerly Vision Abell — to develop the concepts and prepare specifications for this threat simulator system. The concept was to have a single-frequency, monopulse radar, with processing to define range gate widths, repetition frequency, pulse widths, and variable gate tracking loop bandwidths. The radar was housed in a pod which was designed to fit on the wing pylon of a Learjet 35A and with an operator console located inside the aircraft.

8-15 : The Tenix Concept Demonstrator for the Generic Threat Simulator fitted under the wing of a Lear jet. The Project Manager, Kim Scott, is shown crouching in front of the development team. Others are from left: Darryl Hickey (Technical Manager), Claude Messina (Integration and Test Team Leader), Mark Testi (Console Team Leader), and Tony Moran (Radar Senior Software Engineer).

The threat simulator was first used with the Nulka decoy from HMAS *Melbourne* in March 1999 and later for operational evaluation testing of Nulka. The Generic Threat Simulator facility provided an excellent and realistic environment to evaluate all aspects of the ship defence system. Kim Scott renewed his association with the Nulka program by becoming the Tenix Project Manager and worked with Paul Room from the Nulka Project Office. Gino Beltrame ably assisted both in the task of specifying requirements.

8-16 : The Barge, *Sir Robert*, used for the DT-IIF flight tests on the Potomac River.

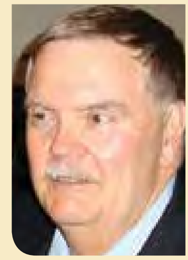
In September 2002, Tenix was awarded a contract to develop a more advanced system, with a radar that could emulate both coherent and non-coherent threats, operate over a wide microwave frequency range, and have programmable power output levels, much higher sampling rates and more advanced electronic protection features. Darryl Hickey became the Tenix Project Manager for this Generic Threat Simulator Mark 1 program and worked with Joe Linehan in the Nulka Project Office. Two Generic Threat Simulator systems were delivered in October 2005.

A return to flight trials

The Active Missile Decoy contract contained an order for 10 rounds to be built, complemented by an additional 10 rounds in the Engineering and Manufacturing Development contract. So, establishing the facilities for manufacturing the components of the decoy began in readiness for the large production order expected in 1997. These initial small batches were intended for flight tests of the

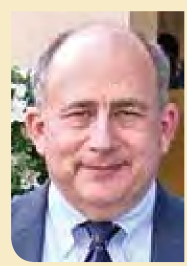
Australian Fire Control System and another operational evaluation test leading to a full rate production decision, referred to as a Milestone III decision in the United States Navy.

There was a return to the Naval Surface Warfare Center, Dahlgren, Virginia, for the DT-IIF flight tests that took place in October 1996 off the barge *Sir Robert* prior to tests on United States Navy ships. The DT-IIF tests used refurbished flight control hardware, payloads and rocket motors from the Full Scale Engineering Development phase, as well as a new ARC motor, a new payload and two newly manufactured flight control units. All flight control units were fitted with a new version (K13) of the flight control software and new 'common design' batteries. The same flight profile was to be repeated five times to facilitate comparisons between new and old hardware. The team was relieved to see all tests completed successfully.



8-17 : Harry Severin joined Nulka as the United States Project Manager in 1996. It is interesting to note that Severin had been the manager of the Phalanx gun system prior to accepting the position on the Nulka program.

8-18 : The Active Missile Decoy suite of shipboard decoy firing and control equipment with instrumentation is set to work at Woomera for final functional testing prior to tests on ship.



8-19 : Ed Settle also joined the United States Navy Project Office in early 1996 and introduced improvements in the planning processes. Six months after Harry Severin's retirement in 2003, Settle was selected to fill the position of the United States Project Manager.

8-20 : Lieutenant Commander Mick McCourt managed the return to the Woomera range after five years for the testing of the Active Missile Decoy launching system.

8-21 : HMAS *Melbourne* was the lead ship for the Australian Navy version of the Active Missile Decoy Nulka system. Although based in Sydney, it was ironic that this ship had the 'freedom of the City of Melbourne', since Melbourne was the base for the Nulka group of BAE Systems.

Tests on the Australian Fire Control Panel

The Australian Fire Control Panel and its interfaces were integrated with an FFG combat system and tested in June 1997 at the FFG Combat Data System Centre, Canberra. The tests produced a good result after several attempts. There was the usual finger pointing at those responsible for either side of the interface for a time but corrections were made by both parties and completed during June 1997. Other laboratory tests followed.

The time finally arrived to fit the pre-production Fire Control Panel and Processor Power Supply to HMAS *Melbourne* at Garden Island, Sydney. The team completed the fitting and testing of this first system on the ship in August 1997.

The first Nulka round production contract

The primary opposition to obtaining approvals in both Australia and the United States for a production contract for Nulka came from the 'hard-kill' proponents. Nulka was cheaper than the Rolling Airframe Missile system and was later to be demonstrated to be cheaper than the other ship self-defence system, the Evolved Sea Sparrow missile. Captain Alan Brecht recalled that as early as February 1994, at a production Memorandum of Arrangement meeting, there was much concerned discussion about the expected cost of a Nulka round. The United States Navy position was that it would not proceed with production if the cost per round exceeded US$200 000, and the target was for the cost to be as low as US$150 000. All customers wanted the lower prices, but Nulka always appeared to suffer from the mentality created in the early 1980s that its price should be related to the price of chaff decoys. The view of many of the Nulka champions was that the real competition and basis for comparison should be the Rolling Airframe Missile system and the Sea Sparrow missile, which were two and three times the price of Nulka.

Along with funding uncertainties was the issue of drafting and agreeing to a new Memorandum of Understanding between Australia and the United States for the production and use of Nulka. This time it was expected that the Memorandum would take at least two years to finalise and require United States State Department involvement. Alan Brecht, as Assistant Secretary Development Projects Management, had the responsibility to negotiate the Memorandum with the United States on Australia's behalf. This became a protracted activity involving several visits to Washington. The sharing of work between the two countries was a major sticking point, as were financial cost sharing arrangements and third party sales and marketing issues. It took two years for the production Memorandum of Understanding to emerge from the committees and the United States State Department. It was signed on 25 June 1996, after Alan Brecht had completed his appointment as Assistant Secretary Development Projects Management.

A production contract for Nulka rounds was still another year into the future. Commitment to production fluctuated within the RAN. The number of rounds required appeared to decrease, with a consequent rise in the unit cost and delays. Continuing uncertainty caused AWADI to grow concerned about the viability of production and

8-22 : The United States Navy Program Director and Nulka contractors attended a function in Washington DC to celebrate the signing of the Collaborative Rounds Contract in June 1997. The group photograph shows (from left) Bill Walsh (Sippican), Harry Severin (United States Program Manager), David Mann (BAE Systems), Bernie Mitchell (Sippican), David Greyard (BAE Systems NA), Mike Hedrick (BAE Systems), Ian Turner (BAE Systems), and front row (from left) Captain Dana Rowland (USN) and David Parker (ARC).

8-23 : Captain Carney, Bernie Mitchell, Mike Hedrick and Bill Walsh celebrating the formal United States government's acceptance of the first production payload in September 1998.

The payloads were built in a secure facility dedicated to payload production and co-located with the Nulka program and engineering support team. The production program delivered more than 1100 payloads through to the end of 2010.

consider laying-off staff. Fortunately, senior Navy and Department of Defence officers, including Allan Hawke and Richard Brabin-Smith, responded positively to AWADI's arguments that the company was ready to go to production and delays would put seriously at risk any future production.

A production contract, referred to as the Collaborative Rounds Contract, was signed by Barry Murphy (BAE Systems) and Ron Bonighton and witnessed by David Mann and Commander Mark Remmers in June 1997, for production of Nulka decoys for the RAN, United States Navy and the Canadian Navy. This was a truly momentous occasion. The contract provided rounds for the RAN to fit to the FFG and Anzac class frigates and enabled the United States Navy to begin fitting to their destroyers and cruisers with the frigates to follow. The Canadians were to fit out their Iroquois class destroyers. This production contract was for US$114 million with options for the United States Navy and Canada for further quantities with a total order that could exceed US$400 million. This contract provided important defence exports for Australia, enhanced cooperation with the United States and Canada, and ensured ongoing support by Australian industry for the Nulka system through to 2002. Three months earlier, in March 1997, BAE Systems had signed the contract to supply the launchers and fire control systems to Canada.

Lockheed Martin Sippican was awarded a production contract in 1997 containing a baseline contract segment of 276 payloads: 200 were earmarked for Australia and the balance was to be distributed to the United States Navy with a small amount earmarked for the Canadian Navy. The contract also contained three yearly options for additional payload deliveries, though these were never exercised. These options were eventually rebid as stand-alone options on a yearly basis. The first production payload was delivered in September 1998 with the final unit being delivered in early 2001.

The team was horrified to learn that the first round tumbled straight into the water and the third hit the ship.

A trials failure and major improvements

Challenges continued to characterise the program. The final activity of the Engineering and Manufacturing Development program involved the DT-IIG2 flight trial conducted on the USS *Stump* in October 1997. This was to be a precursor to the operational evaluation tests necessary to introduce Nulka into service in the United States Navy.

Seventy-three flight tests of Nulka had occurred and the Flag Officers had announced that low rate production could start when, on 28 October 1997, two decoys failed a ship test on the USS *Stump*. The Nulka team was horrified to learn that the first round tumbled straight into the water, the second flew correctly, and the third decoy climbed to about 30 metres, wandered around very slowly, bumped the main mast and the motor dropped to an upper deck, still burning. A minor fire was quickly extinguished and a sailor cut his head while scrambling to avoid the debris.

These failures resulted in the project's most intensive investigation to that time.

David Mann recalled:

We were under tremendous pressure from all sides; even Lockheed Martin Sippican gave me a hard time. The cause, although some disagree, was put down to the presence of swarf in the computer cards of the Flight Control Unit and a failure to maintain cleanliness in the assembly facility for that unit at Edinburgh Park (then Salisbury). I took the view that if we had stuffed up, then we would be upfront and admit our failure to the customer and that's what we did... I would like to think that our approach helped us to recover the confidence of our customers in the months that followed.

8-24 : Barry Murphy, Managing Director of BAE Systems Australia, welcomed past and present participants to the celebration of 10 years of exciting engineering development for the Nulka system. Murphy was well qualified because he had played a leading role in marketing the Nulka system since 1992.

The United States Navy office was impressed by this honest admission and David went on to provide a new world-class assembly facility for the Flight Control Unit to keep the program on track. It is clear in hindsight that David Mann's decision to accept that BAE Systems manufacturing standards were inadequate was critical to the program.

Rob Eddy and David Mann took control of improvements to the assembly processes, implementing a shift from a general electronics workshop to a dedicated clean room facility, and the introduction of cleanliness procedures and training aimed at eradicating 'foreign objects'. Mann had to fight internal company opposition to the separation of Nulka manufacturing from the company mainstream operations, but persisted. As a result a 'world's best practice' facility was built at Edinburgh Park that also handled the Evolved Sea Sparrow missile manufacturing.

David Mann recalled with pleasure the visit of two senior United States Navy representatives:

Admiral (Rtd) Wayne Meyer and Marion Oliver from the United States visited BAE Systems five months after the new facility had been commissioned (April 1998). They reviewed what we were doing in some detail and talked to the staff assembling components and sub-assemblies in the new facilities. Their main message was all about attitude to high quality missile work and 'the devil is in the detail'. They underscored, time after time, that the lives of sailors were in our hands, and that we should never forget that. It was an important and memorable visit.

8-25 : Alan Smith (left) and Murray Evans (retired) renewed connections going back to the 1960s and discussed the developments in the decoy since Evans' involvement in the early 1980s.

Mal Crozier led the failure investigation for BAE Systems, and together with Neil McCoy proposed a major modification to improve the testing of the gyroscope electrics. The May 1998 Active Missile Decoy trial at Woomera tested this refinement. Another five trials followed to August of 1998. There were a total of 24 rounds fired during this time, which included DT-IIG3 flight trials off USS *Peterson* in July 1998, followed by the all-important operational evaluation OT-IIB trials off USS *Peterson* in August 1998. The RAN had started the sea acceptance testing of ships using the Active Missile Decoy fire control system. For the third year in a row, in December, Crozier presented safety case studies and credentials to the United States

8-26 : Ian Turner (left), Maurie Opperman, Peter King and Commander Mark Remmers enjoyed festivities at the 10-year anniversary of the development of Nulka. Maurie Opperman prepared to retire and Mark Remmers relinquished his position as Active Missile Decoy Program Manager.

Navy Software System Safety Technical Review Panel. The Weapons System Equipment Safety Review Board typically met soon after the technical review panel and following the December meeting approved the United States Navy system.

A time to celebrate

Amid this work there was cause for an important celebration on 16 January 1998 at the British Aerospace office in Abbotsford, Melbourne, to mark the tenth anniversary of the signing of the contract to develop the Nulka decoy system. This date had additional significance because it heralded the formal closure of the Full Scale Engineering Development contract. David Mann presented the final invoice to the Nulka Project Director, and John Brentnall relinquished his position to Paul Room after seven years in the position.

The COTF report contained a stunning conclusion to the Nulka community and arguably a disastrous recommendation for the Nulka program.

The saga of the OT-IIB operational evaluations

The RAN Active Missile Decoy tests at Woomera in May 1998 successfully cleared the Australian Fire Control System and decoys for operational at-sea tests. In the United States, the final requirement for Nulka to move to full rate production approval was to achieve a successful independent operational evaluation of suitability and effectiveness that was conducted and assessed by Commander Operational Test and Evaluation Force (COTF). A positive recommendation from COTF following an operational evaluation was required as part of the approval for fleet introduction of the tested system. The testing for this Nulka operational evaluation, OT-IIB, was conducted in August 1998 aboard the USS *Peterson*.

The operational evaluation testing appeared to go well. All the test data was delivered directly to COTF for its analysis upon completion of the testing. COTF had 90 days to produce the concluding report, which then became a primary input to the milestone decision meeting that decided whether a system would achieve Milestone III. The Milestone III decision meeting was scheduled for mid January 1999.

On 30 November, the COTF report was released to the Office of the Chief of Naval Operations. The report stunned the Nulka community with its conclusion that 'the Nulka system effectiveness... is undetermined' and it was unable to conclude that Nulka was 'operationally suitable' for the ship classes on which it was intended to be installed. The ultimate recommendation of the report was that '[a]pproval for fleet introduction is not recommended.' An immediate impact of the recommendation was to jeopardise all United States funding for procuring Nulka decoys. Unless it could be shown that COTF's conclusions were sufficiently incorrect to enable their recommendation to be reversed, the Nulka program would be delayed for at least one to two years until the reasons for Nulka failing the OT-IIB were understood and another operational evaluation could be successfully conducted. Given the problem tests off the USS *Stump* the previous year, cancellation of the United States involvement in the Nulka program was likely.

Background endeavours to reprogram the United States Nulka funding began immediately. Frank Klemm at NRL received a call within minutes of COTF's conclusions being received by the Nulka office. He too was stunned. NRL had not had access to the test data, but based on his understanding of Nulka and the results of the recently completed DT-IIG3 test, Klemm had no doubt the OT-IIB testing should have been successful. This was also the view of the United States Project Office. Klemm immediately began working with Harry Severin of the Project Office and, together, they formulated a plan to address what they were convinced could only have been problems with the analysis performed. The plan was for NRL to perform an assessment of the data and have that assessment reviewed by an independent panel. NRL was confident that its analysis would show what it was certain was the actual outcome of the testing. If that were the case the plan was for the Program Executive Office Theatre Surface Combatants, PEO (TSC), to then have the NRL results reviewed by an independent agent. Unfortunately, it was already the beginning of December and the milestone decision meeting was only a month away, with provision having to be made for the Christmas holidays.

The plan was presented to PEO (TSC) which on 16 December 1998, issued a letter directing that actions, plans, and teams be formed to perform an independent assessment of the operational evaluation that would be reviewed by an independent panel appointed by PEO (TSC) prior to the January Milestone III decision meeting. The panel, referred to in the letter as a 'Blue Ribbon panel', was established to independently 'assess the findings of the OPEVAL, and report their conclusions to Chief Naval Operations, CNO (N91 and N86), and PEO (TSC) during the Milestone process.' The PEO (TSC) was firm that the panel be independent; panel representatives were specified to be from CNO (N2), The Johns Hopkins University/Applied Physics Laboratory, the Center for Naval Analysis, and the Naval Postgraduate School. The panel was to meet on 11 January 1999.

The letter directed NRL to 'independently review all of the data collected from the operational evaluation and provide a separate conclusion of the results of each test engagement' using 'all of the tools they had at their disposal, including engagement visualization, computer-based modelling and simulation…' The letter called for COTF to be kept fully informed of the NRL analysis as it was being performed, and it requested a full time analyst from the former to be at NRL for the duration of the latter's assessment. In addition, the letter requested that simulator experts from Weapons Division of the Naval Air Warfare Center, China Lake, be made available to provide expert guidance to the NRL analysts, relative to key threat simulators used in the operational evaluation.

Time was short for such a critical task. By the start of December, Frank had pulled together his analysis team at NRL, led by Waymon Humphries and, with concurrence of team members, cancelled their Christmas leave. Once the test data arrived at NRL, the team began the arduous tasks of performing detailed analysis of individual test runs in the short time available. In real time, members of the Blue Ribbon panel also reviewed the analysis work being done by NRL and the work that had been done by COTF to enable the panel to provide a solid assessment of the analysis, with particular attention to the manner in which simulator data was employed in determining effectiveness.

NRL applied both its electronic warfare expertise and its state-of-the-art modelling and simulation tools to the task. By mid January 1999, NRL had completed its analysis and had reached the conclusion that the test data had demonstrated that the Nulka decoys had performed

8-27 : In 1998 Commander Andrew Rennie became the Active Missile Decoy Project Director and steered the program to installation of the Nulka system with the Australian Navy. He initiated production and fitout ahead of the completion of qualification tests to bring the completion date forward. He presided over the trials and tribulations of the extensive qualification program and a large number of at-sea tests in the five years to July 2003.

8-28 : Lieutenant Commander Tony Wright worked closely with the BAE Systems team to fit the Active Missile Decoy system to the Navy fleet of FFGs. He later completed an equally active tour of duty as the Nulka Liaison Officer posted at NAVSEA in Washington, DC.

as required and that the operational evaluation had successfully demonstrated the operational effectiveness of the decoy. NRL and COTF delivered summaries of their respective analysis methods and effectiveness results to the Blue Ribbon panel, and both formally briefed the panel. The panel had been reviewing the work of both organisations as the NRL work was being conducted, and this also fed into its review of the two studies. The panel concurred with the NRL methods, results, and conclusions, and reported accordingly to the Program Executive Office Theater Surface Combatants.

On 15 January 1999, COTF issued a revision of its final report based on the analysis performed for the Blue Ribbon panel. The revision was based on 'further analysis of Nulka operational evaluation data', and it recommended limited fleet introduction with full fleet introduction contingent upon successful resolution of eight deficiency issues.

The Milestone III Panel met on 28 January and issued its decision. It had weighed the NRL results and the deficiency issues and decided to approve full rate production for the decoy, contingent on Nulka undergoing a Follow-on Operational Test and Evaluation to resolve remaining issues from the OT-IIB. This enabled United States warships to begin being fitted with the Nulka system.

Over the following six years the Program Executive Office Theater Surface Combatants addressed the issues identified in the OT-IIB report by conducting at-sea development testing with both live-fire and captive-carry testing, by conducting shore-based testing, and by conducting modelling and simulation in support of the testing. Throughout these efforts, the Program Executive Office Theater Surface Combatants maintained a continuing dialogue with COTF regarding the efforts to resolve the issues. In addition, the technical teams at NRL and the Naval Surface Warfare Center, Dahlgren, worked closely with COTF analysts when reviewing development test data collected subsequent to OT-IIB. On 9 May 2005, the Chief of Naval Operations requested a Verification of Correction of Deficiencies. Based on the results of the years of work to address the deficiencies, COTF issued such a verification on 28 July 2005, stating that five of the issues identified in the OT-IIB report were considered to have been corrected, one was determined not to be an issue for Nulka, and two remained outstanding but now were addressed by other acquisition programs. This brought closure to the saga of the OT-IIB.

Provisional acceptance into Royal Australian Navy service

The need became obvious during the latter months of 1998 to deploy Royal Australian Navy frigates to join coalition forces in the Persian Gulf, following cessation of United Nations weapons inspections in Iraq. The Navy was anxious to fit Nulka to the ships to be deployed to the Gulf even though testing was not complete. The Defence Acquisition Review Board did not challenge Commander Rennie's intention to start fitting the system to all 14 combatants, ahead of the Active Missile Decoy Fire Control System qualification testing.

In May 1999, the RAN announced HMAS *Melbourne* would be deployed to the Gulf with Nulka. The BAE Systems team and the Project Office began the enormous task of production, ship fitting and test, while testing and correcting the system as a concurrent activity.

The decision to start production of the fire control equipment and set it to work in the fleet ahead of the completion of the testing program was significant for the project. As a result, the date for the Provisional Acceptance into Naval Service was brought forward by up to three years. Commander Rennie reflected, 'It came down to our confidence in the ability of BAE Systems to complete the crucial hardware and software qualification. I was convinced that the company had the right people, were totally committed and would be successful.' Rennie's assistant, Lieutenant Commander Tony Wright, played an energetic and capable part in ensuring that the ship fitment program was successful.

CMDR Andrew Rennie showed remarkable leadership and initiative when confronted by a shortfall in AMD funding by proposing to sell a number of decoys delivered under the Collaborative Rounds Contract to the USN and Canadian Navy.

However, the more serious issue for Commander Rennie was the shortfall in funding available to complete the Active Missile Decoy program. The reshaped Active Missile Decoy program had cost more than planned, and there were insufficient funds to complete the installation of the Nulka system to the new Anzac frigates being built at Williamstown. The Defence Acquisition Review Board meeting of March 1999 directed Commander Rennie to define ways of solving the problem without a real cost increase. Rennie's proposal to sell several decoys already delivered under the Collaborative Rounds Contract, to the United States Navy and Canada to cover the shortfall, was accepted by Navy headquarters. The Australian Minister for Defence approved this course of action and, fortunately, the United States Navy agreed to the acquisition, as did Canada. The contractors were less than overjoyed by these sales because they effectively reduced the numbers of decoys ordered and built,

8-29 : High speed cameras were used with specially designed instrumentation of the Active Missile Decoy Launching System to find the cause of the occasional failure to launch a decoy. This sequence of photographs was taken on board HMAS *Darwin* during tests in April 2001 to solve this vexing problem.

8-30 : Nulka in flight

but it provided the funds to complete the RAN Active Missile Decoy program. This sale to Canada was a slow process because it involved negotiations with the United States State Department for the first time. These sales to North America proceeded over the period 2000–2002.

HMAS *Melbourne* was upgraded in January 1999 and, two months later, became the first ship to be tested using the Australian generic threat simulator system, and it became the first Australian ship to be sent to an operational theatre fitted with Nulka. Five of the six Australian FFG frigates were fitted with Nulka over the next 14 months and the sea acceptance tests started with HMAS *Darwin*.

There were 19 other successful firings — from 19 attempts — from three RAN ships, four United States Navy ships, one Royal Canadian Navy ship and at Woomera over the three years until Nulka was provisionally accepted into RAN service on five of its six Adelaide Class FFG frigates in a ceremony held in Canberra on 31 August 2001.

During this period, a problem with the HMAS *Darwin* acceptance test led to three instrumented firings in April 2001. This revealed errors in the Processor Power Supply software developed by an Australian

8-31 : The Nulka Project Office team in December 2002, near the end of Commander Rennie's watch.

From left to right: back row; Mark Devlin, Chris Edwards, Nicki Preo, Stuart McLaren, Sommer Parkin, Barrie Miller, Tony Pengelly, Ray Parker, Darren Lysenko, Jason Maynard, Cameron Burhop, Michal Severa. Front row: Jan Maher, Commander Andrew Rennie. Kneeling, left to right: Garry Beales, Lieutenant Commander Ben George, Bob Mays.

8-32 : Commander Andrew Rennie (left) and David Mann signing the Provisional Acceptance into Royal Australian Navy service on 31 August 2001.

subcontractor. Related problems were revealed during the Canadian acceptance tests on 11 September. At this time the last of the FFG frigates, HMAS *Sydney*, was being fitted urgently with Nulka before it proceeded to the Persian Gulf, a region of potential conflict. Realising the need for rapid action, BAE Systems Nulka management chose to forego contractual issues and proceeded with all efforts to correct the software. HMAS *Sydney* was fitted in September 2001 and its acceptance test immediately followed six operational evaluation tests on HMAS *Melbourne* on 17 October 2001.

All decoy firings from HMAS *Melbourne* were successful, after a large number of decoys were used in a range of scenarios against the Generic Threat Simulator carried in a pod under the wing of a Lear jet. Successful sea acceptance tests on four Australian FFG frigates followed. The successes were confirmed by detailed analysis by BAE Systems and by the Navy test and evaluation group. These tests were the final step to the official Provisional Acceptance into Naval Service milestone. This successful trial was a high point for the Active Missile Decoy program as was a demanding evaluation that had occurred with USS *The Sullivans* a month earlier.

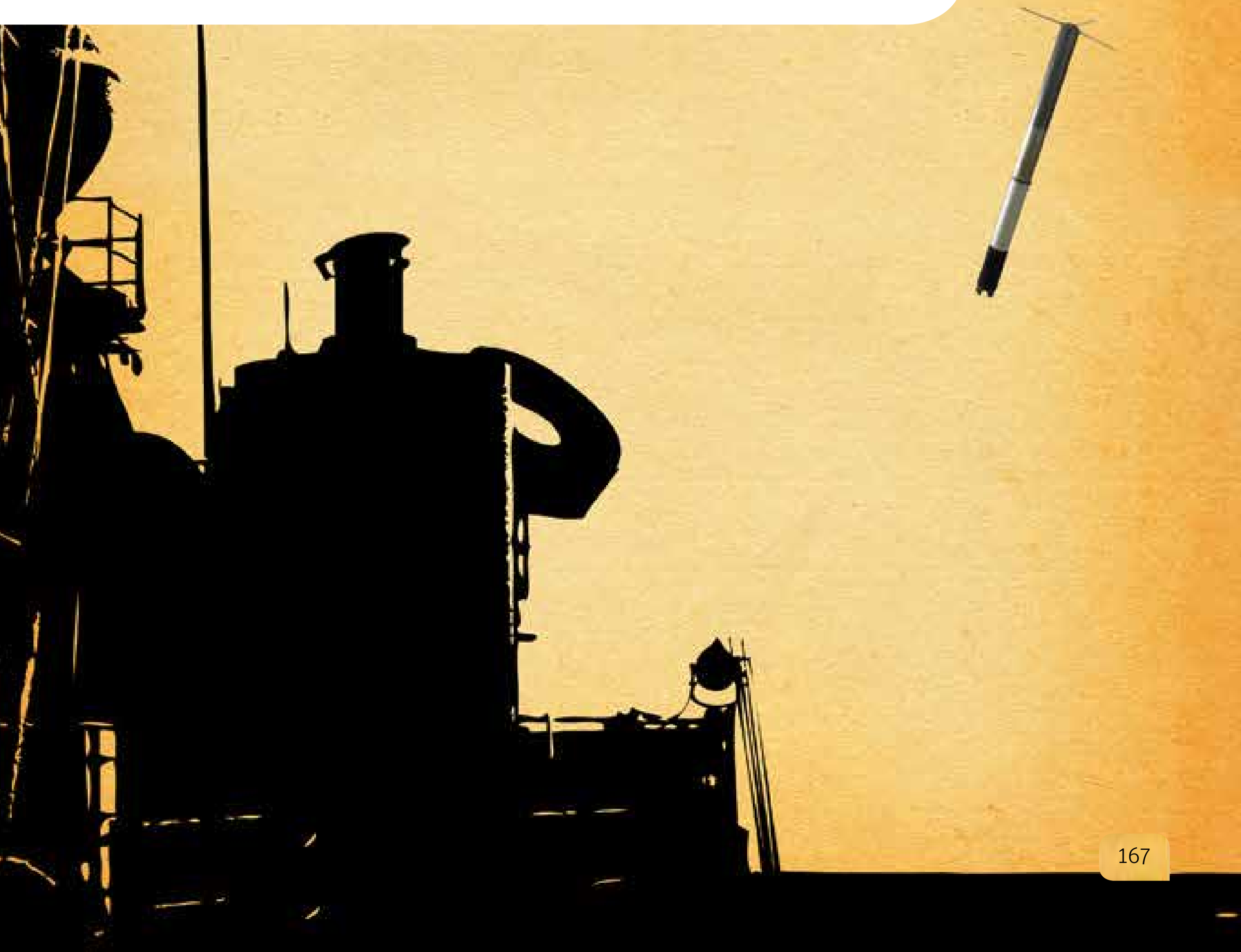
BAE Systems took pride in being prime contractor under several contracts with the RAN to take the Nulka decoy into production, to improve the launcher, to develop the fire control system, test sets and shore-based training facilities, and then to fit and test the system in the fleet.

8-33 : The official party at the ceremony to mark the Provisional Acceptance into Royal Australian Navy service on 31 August 2001. From left to right; front row: Commander Jacqui King for DNWS, Commander Ted Walsh for RANTEAA, Commodore Tony Flint, Director General Maritime Development, Commodore Les Pataky, Commander Navy Surface Combatant Group, Commander Andrew Rennie, Active Missile Decoy Project Director (DMO), David Mann, Domain Manager BAE Systems. Back row: Mark Devlin, Director Platform Electronic Warfare SPO DMO, Mark Reynolds, Director General Electronic Warfare DMO, John Townsend, Active Missile Decoy Project Manager BAE Systems, Rob Eddy, Nulka System Program Manager BAE Systems, Mal Crozier, Nulka System Chief Designer BAE Systems, Paul Room, Nulka Project Director DMO, Steve Onus, Nulka ILS Manager DMO.

CHAPTER 9

A summary of the journey

It is a marvel that the Nulka program ever survived beyond its conception, in view of the social, political, economic and organisational turmoil that was a feature of the 1970s through to the 1990s. Some of the critical decisions and defining moments that shaped the eventual success of Nulka and its introduction into service are reviewed. After 25 years the challenge shifted thankfully to maintaining high quality production and in-service support.



The success of the joint program by Australia and the United States to develop the Nulka decoy was clearly apparent with the celebration by BAE Systems Australia in October 2010 of the production of its 1000th round. Collaboration in electronic warfare with the United States was a world first, and Nulka is now fitted to over 150 warships of Australia, the United States and Canada under a program costing around $1 billion. That it took close to 40 years after the essence of Nulka was conceived as an idea testifies to the complexity of the project and the determination of many people.

The program overcame many powerful challenges in addition to those normal to the acceptance of any new engineering concept. In this case, the concept was a ‘soft kill’ approach to defeating a new and dangerous threat, rather than a ‘hard kill’ concept traditionally favoured by the majority of naval personnel. Electronic counter measures were new, expensive and perceived as likely to be obsolete quickly. So, defence departments were not convinced of the need for an active decoy system, and most did not appreciate that there was such a major deficiency in their capability to defeat missiles approaching at very low altitudes.

The HMS *Sheffield* sinking and the Falklands War appeared to change this perception slowly in several countries, including the United States, but not in Australia. There were already so many shortcomings in Australia’s defence capability in the early 1980s that decision-makers simply pointed to the long list of proffered solutions and directed the project’s proponents to stand in line. A new development proposal was at a huge disadvantage to any established system that could be bought readymade off the shelf.

Interestingly, Nulka is a unique example of an international collaboration program concerning electronic warfare systems where international collaboration was never entertained before. From Australia’s perspective, collaboration was essential to obtain access to critical technologies and overseas funding, and a condition of the Winnin program proceeding beyond the concept development stage. This decision to seek a collaborative partner was made at a time when it would have been considered highly unlikely that a small country like Australia would find such a partner. But the Active Decoy program was a successful collaborative program because of two important factors.

First and foremost was that each party had significant and unique technologies to offer in response to a major emerging threat. The successful United States investment in off-board payload technologies, led by visionaries including Lyn Cosby and John Montgomery, was of critical importance, as was Australia's more modest investments in rocketry and microwave technologies.

The second factor was that each partner trusted the other after many decades of working together on defence matters, and they shared similar cultures and a common language. The significance of Australia partnering the United States in the Korean and Vietnam conflicts should not be underestimated. The tradition of exchanges between the United States and Australia at the navy and technology levels was also significant. Lasting friendships arose from these exchanges which assisted the formal collaboration process.

Finding a collaborative partner followed an amazing confluence of events. It was even more amazing that the defence committees should approve funding at all for the concept development during the 'finding a partner' phase given conditions at the time. The acquisition of the requisite funding was due to sustained efforts and a focus of several key people on the Royal Australian Navy's operational requirements. However, it is fair to say that those who appeared to obstruct these efforts were probably following government policy, or were promoting the acquisition of another of the many defence capability requirements at the time. A fair measure of 'rat cunning' was required to secure support for any particular program over another in a competitive funding environment.

It must also be pointed out that the vast bulk of the early funding was actually provided in the form of the salaries of permanent government employees. So the approval really related to whether these people should be allocated to this program or another, not whether the defence budget was required to increase. There was virtually no money for procurement of equipment and hardware, which was a serious deterrent to rapid progress on the actual development program.

Scarce funding and the search for a collaborative partner required the people's attention in addition to the technical issues of developing a system. So, the early technical achievements were not as organised and efficiently managed as might be assumed when compared to later environment and management structures. The achievements were certainly not as rapid as those during the Full Scale Engineering Development phase. Australia had people skilled and experienced in guided weapons and similar technologies, but they were spread across many organisations. Even within DSTO, the people were spread through three laboratories and two geographic sites. There were research and development authorities and design authorities for each item and all within a traditional stovepipe organisational structure. This was the manner in which projects were organised during the 1970s and 1980s in Australia and around the world. But, from a different perspective, the existence of electronic warfare, propulsion and weapons control technologies grouped within the one research organisation was an advantage at the project's conception because it facilitated communication between the respective experts.

There were alternative management structures, but these cut across organisational boundaries, so a new model was not attempted until 1987 when Alan Smith proposed the idea of a central system engineering and project management office to AWA. This model proved to be efficient and successful for the Nulka application. Even the project office arrangement under Captain Graeme McNally was a new approach within the Department of Defence. The period from 1986–1993 was one of dramatic change in the Nulka program that coincided with the much broader restructuring of most defence institutions and industry in Australia. Commercial and government organisations were being restructured, commercialised, downsized, broken up and, in some cases, went into receivership. Probably more than 100 professionals lost their jobs the moment the Nulka Full Scale Engineering Development program concluded in 1993 as a direct consequence of this new manner of doing business.

Even more dramatic changes occurred in the United States. The controversial Frank Carlucci became the United States Secretary of Defense in 1987 and initiated far reaching changes to the department's procurement system following the Iran-Contra scandal and clandestine international arms deals.[40] All this coincided with negotiations with Australia on Nulka. However, more importantly, Lockheed Martin Sippican attempted to undertake a high risk development of the payload on a fixed price contract that almost destroyed the company. It is interesting to note that the Evolved Sea

Sparrow development program, let in 1994 in the United States, was a return to cost plus incentive contracting.

The best two years for the Winnin program occurred during the 1984–1985 recession in the Australian economy, and the most rewarding period of collaboration and contracts for the Full Scale Engineering Development occurred during the years of extraordinarily high inflation from 1985–1990. The budget estimate for the program was determined in 1985 and three years of the highest ever inflation occurred before the contracting was complete. The timing could not have been worse. The Full Scale Engineering Development program concluded during another recession and amid cutbacks in the United States defense budget, following the end of the Cold War.

The period from 1986–1993 was extraordinarily turbulent in an economic and social sense, and it is astonishing that it coincided with so many momentous happenings on the project. This period of seven years was the time when all aspects of the program came to fruition. The United States/Australian partnership was established, commercial and contractual aspects were agreed upon, and the system was defined and developed. Technical failures occurred but were remedied and successes followed, all against a background of organisational, social and economic change. The program had even been affected directly by social changes such as the renewed emphasis on product safety and an awareness of the potential impacts on the environment.

In the end, it is a marvel that the Nulka program was ever completed. This account has primarily been about recording and recognising the efforts of many people over a long period of time. However, special recognition must be given to the high level of expertise of those who embraced the tasks of steering the program through its many phases. In the formative years there is no doubt that Scot Allison and Bill Dickson were the two upon whom the project depended. Ken Harvey's antenna work was instrumental in demonstrating the feasibility of the payload and giving credibility to the Australian negotiations with the United States. Complementing these was Murray Evans, followed by Bob Scott, Alan Smith, Barry Watson and David Mann, in approximate chronological order. Each had a significant turn at managing the project, as did John Brentnall and Carl Espeland from the government project offices.

Defining moments and milestones

In any project, large or small, there are defining moments which, in hindsight, can be considered to have been so critical as to determine whether or not the project was to succeed of fail. There were many of these critical moments in the Nulka program.

Scot Allison's presentation to the TTCP QTP-11 forum in late 1976, in which he identified the vulnerability of naval ships to modern missiles and proposed active decoys as the effective solution, caused ripples in the international electronic warfare community and represented the symbolic moment of conception of the Nulka program. There was no operational requirement for such a system at the time, and no ready solution.

There followed a significant decision when Bill Dickson and Scot Allison determined to employ a two-pronged approach to make the active decoying concept a reality. Bill Dickson pursued the technical feasibility of the decoy as a solution while Scot Allison highlighted the need for such a device to address an evident deficiency in the RAN and United States Navy operational capability.

The development of the carrier vehicle concept of 'Hoveroc' arising from the DSTO 'think tank' proved vital. Solutions to the thrust vectoring, the rocket motor propellant recipe, the spin control solution, the flight control system, and the height airspeed sensor were all critical to the vehicle's success. The first free flight of the 'Hoveroc' vehicle on 2 May 1981 was definitely another key moment in the project's life. The film record generated publicity and a credibility that sustained the project for several years. The most important viewing of the film occurred at Scot Allison's presentation to a large gathering of senior United States Navy personnel a month after those flight tests. Dr Martin Kamhi's enthusiastic 'That's it' response was regarded as the moment when the psychology of the relationship with the United States Navy changed.

The notion of collaboration with the United States Navy became a possibility because Australia had demonstrated that it could add significant value to the relationship. The demonstration of another critical technology by Ken Harvey, the payload antenna, was essential for potential collaboration with the United States because it showed that the total decoy system was viable.

The sinking of HMS *Sheffield* during the Falklands War had a profound influence on the project, and was particularly important with respect to changing United States Navy perceptions about anti-ship counter measures.

The start of the Surface Launched Electronic Decoy program in the United States Navy under Commander Sam Anderson became another significant event, particularly for those seeking to sign the Collaborative Development Agreement, though Defence Minister Kim Beazley and Malcolm McIntosh certainly had key roles in consummating that collaboration. Revelations in the press of June 1985 about Australia's small participation in MX missile testing and Star Wars also played a role. Prior to the June 1985 revelations, collaboration with the United States Navy had almost been achieved, to the extent that the senior Defence Force Development Committee had assigned the negotiation task to an officer who had the best reputation and experience in defence circles.

It will never be known whether collaboration would have happened without the serendipitous assistance of Kim Beazley and Malcolm McIntosh, but the announcement of the Memorandum of Agreement on 10 August 1986 was certainly another defining moment in the program.

A new group of people became involved in the project who were to learn about it, to negotiate its future, and take measured risks, that were to lead to the contract that was to be the beginning of Nulka. A new management model evolved along with the cooperative arrangements between AWA and the ASTA development teams that were critical to the project's future, as was the appointment of Barry Watson as manager for this new and extremely ambitious program. The signing of the Nulka contract on 16 January 1988 was a defining moment for many people and organisations and the foundation for many momentous events over the ensuing 10 years.

The system Preliminary Design Review of October 1988 qualified as yet another crucial element. The development team endured an aggressive critique that led to several hard decisions that changed the *status quo* and affected and improved the product and the people. The major decisions made were to remove venting of the canister, start a new design for the launcher, and later begin development of the Pressure Air Data Sensor. These changes clearly ensured the final success and outcomes for the program.

The first successful flight test of 7 November 1990 became a major milestone and confirmed the correctness of the design decisions made in the previous three years. However, it was not until the successful demonstration of the complete decoy with its payload in December 1991 that it was evident that Nulka could be introduced to the fleet. This was the crucial trial for the program as the team struggled with reliability issues that could have led to yet another disaster.

Consequently, the joint decision on 5 December 1991 to fit rubber bands to the thrust control unit tabs in order to pass the self test and proceed to demonstrate five successes from five attempts was considered the next crucial moment.

The efforts of Bill Walsh and Bernie Mitchell at Lockheed Martin Sippican to secure funding from the United States Congress via the Senator Kennedy committee was critical. This funding allowed the program to continue after the United States Navy had decided to exclude the Nulka program from the 1993 budget. This support eventually led to Nulka being declared the primary ship self-defence system in the United States Navy and subsequently to production funding in 1996.

Undoubtedly, Carl Espeland's decision to proceed with the United States Navy ship trial on the USS *John Hancock* on 11 September 1992, after a rocket motor had exploded, was decisive. The trial proceeded with all succeeding eight tests being successful. The courageous decision ensured the Nulka program did not stall and enabled the operational evaluation tests to occur only three months later. The good results from those tests played a major part in the program going to production for the United States Navy.

Seventy-three flight tests of Nulka had occurred and the Flag Officers had announced that low rate production could start, when on 28 October 1997 two decoys failed a ship test on the USS *Stump*. It is clear in hindsight that David Mann's decision to accept the inadequacy of BAE Systems' manufacturing standards was another defining moment for the program and led David to provide a new world-class assembly facility for the Flight Control Unit to keep the program on track.

The analysis by the Commander Operational Test and Evaluation Force of the apparently successful OT-IIB operational evaluation test that occurred in August 1998 stunned all those involved in the program and jeopardised the United States funding for procuring Nulka decoys and proved yet another watershed moment. The initiative of NRL's Frank Klemm in addressing the issue, undertaking yet another review, and succeeding in having the Milestone III decision panel approve full rate production saved the project when at the eleventh hour, and enabled United States warships to begin being fitted with the Nulka system.

A final decisive moment in the project related to the decision by the British Aerospace management to forego contractual issues and proceed with all efforts to correct ship equipment from a contractor on HMAS *Melbourne* in time for its planned operational evaluation tests. The successful tests had a positive impact on the program within the RAN, as did similar activities leading to the successful at-sea test on HMAS *Sydney* in the same week while *en route* to the Gulf War.

These defining moments occurred unexpectedly, and it was the ability of key people involved to analyse the problems, innovate solutions, and complete the implementation that proved the worth of all involved. Each critical moment arose from a crisis and the immediate outcome and final success depended on high quality advice and support to those involved in the decision-making. The implementation of this advice and the successful outcome occurred because those involved were convinced that the goal was worth fighting for and they remained motivated to play their part in achieving final success.

Not so quick

Australia and the United States have both recognised that counter measure technologies and missile counter measures will continue to evolve as one system gains superiority over the other. Currently, it is possible to envisage modernised Exocets that could swarm intelligently through networking to penetrate defences. The potential danger remains complacency and a return to a reliance on 'hard kill' defences. As in the 1970s, it is imperative that an integrated weapons/electronic warfare approach to ship self-defence is continued.

It is the ultimate irony that Nulka is Aboriginal for 'be quick' because Scot Allison proposed the need for an active decoy more than 35 years ago. However, the authors hope this history will explain why the development could not 'be quick' and show that delays were not for the want of effort or determination by many people. The authors have the pleasure to report that current challenges concerning Nulka are not so much about finding solutions to concepts, but in maintaining high quality production, supporting the system already in service, and continuing research to meet future threats.

According to many of those who have worked on the concept and engineering development phases, these challenges are as great as those that have gone before. The cost and impact of failure now are enormous. The pressures to ensure all products perform perfectly are high because the Nulka system is deployed on so many naval ships. But that was always the goal from the beginning.

NULKA
A Compelling Story

NOTES

[1] Missile homing sensor.

[2] A travelling wave tube is a specialised vacuum tube used to amplify radio frequency signals to high power, usually as part of an electronic assembly known as a travelling wave tube amplifier.

[3] A method of using two antenna beams to enable a radar to measure a target's angle on a single pulse.

[4] The Technical Cooperation Program (TTCP) is a forum for defence research cooperation between the United States, United Kingdom, Canada, Australia and New Zealand. Sub group Q deals with electronic warfare.

[5] The America Britain Canada Australia (ABCA) forum is a government-to-government information exchange forum for defence issues. ABCA-4 was the group dealing with naval electronic warfare.

[6]The effects on the return signal of radar reflections arriving from multiple paths from surfaces other than the intended target, including the sea surface.

[7] Recorded, along with two versions of the helicopter in a table of options by Phil Pearson of mid 1977. Additionally, a presentation slide records the physical details of this proposal with weight and diameter.

[8] The minimum required by the control system was three, and clearly would require less space. Four tabs were embodied in later design concepts until the performance and requirements were established.

[9] A handwritten report dated 4 May 1977 records this work.

[10] Recorded in a report 'Charge Design for a Solid Propellant Rocket to Support a Hovering Vehicle' in August 1978.

[11] A related but more general patent was granted in a similar range of countries to Bill Dickson and Bill Jolley in 1982.

[12] These tests were reported in October 1978, prior to the official approval for the Advanced Feasibility Study program starting in March 1979. Tests were part of the case for acquiring the approval to proceed.

[13] These eleven tests were reported in December 1983, and formed the basis of performance estimates for the much smaller Winnin operational vehicle.

[14] Radio signals sent from a remote site to enable recording of measurements.

[15] Articles appeared in newspapers e.g. the Melbourne *Age* of 9 May 1984 and *The Australian* of 16 May 1984.

[16] The Clifford-Fairhall Agreement was a framework for information exchange and cooperative developments between Australia and the United States. It was signed in 1968 by Clark Clifford, Secretary of Defense USA, and the Australian Minister for Defence, Alan Fairhall.

[17] The Navy was represented on the FSC by a rear-admiral, so any position on Winnin had to reflect an endorsed Navy office viewpoint and not just that of the Director of Electronic Warfare-Navy (DEW-N).

[18] The planning, the three year duration and cost estimates actually included the interim work of the six months to June 1983. The plans show and refer to three phases.

[19] At the time, the exchange rate was approximately 70 cents (US).

[20] Defence Minister Beazley official press release of 11 August 1986 from San Francisco.

[21] Articles appeared in the Melbourne *Age* and the *Australian Financial Review* on 12 August 1986, and later in the *Engineers Australia* magazine of 22 August 1986 and again in the *Age* of 30 August 1986 and the *Australian Aviation* magazine of November 1986.

[22] The Captain in the USN covered several projects and was referred to as a program manager. He had a project manager to deal with Nulka specifically. In Australia the Nulka specific leader was referred to as a project director. Captain Mike Mulford was the first Joint Program Manager and Captain Graeme McNally the first Australian Nulka Project Director.

[23] This and several other reports were delivered between October 1987 and February 1988. While the reports and hence technical content were made available to AWA, the contract dealings were unfortunately independent of the outcomes of these studies.

[24] Five companies were invited to make proposals in June 1986. They were Lockheed Martin Sippican, General Instruments, Dalmo Victor, Teledyne and Varian. Raytheon and Sanders had worked on payloads over the previous several years but did not bid.

[25] Jindalee was a strategic Australian Defence project for the development of an over-the-horizon radar.

[26] The contract required the project to complete the Operational Evaluation Trial (OPEVAL) in November 1991; it was achieved successfully in December 1992.

[27] The estimates of height and airspeed needed correcting based on the estimate of airspeed and airflow incidence which was also related to airspeed. This loop (speed to error to speed) introduces an uncommon feature into the dynamics of motion known as a 'non minimum phase transfer function'. This makes maintaining stability in flight more difficult. This was identified by the AWA flight control studies.

[28] The Project Director, John Brentnall, advised AWA in a forceful letter on 17 June 1991.

[29] An additional trial introduced in April 1991.

[30] The downturn in the Australian economy meant severe cuts to the Australian defence budget also. The Melbourne *Herald Sun* of 21 August 1991 reported a reduction of 9.1 per cent in the defence budget with cuts on F/A-18 tactical fighters, the Jindalee Over the Horizon Radar and the Collins Class submarines.

[31] *The Journal of Electronic Defence* of September 1993 reported that the United States Congress had given high priority to ship self-defence and approved US$11.7 million to the Nulka Decoy Development.

[32] Aegis is the United States Navy's ship based missile protection system against aircraft and missile attack.

[33] Gerry Boynton of NSWC Dahlgren, and Oliver Collins of AWADI, defined the structure and content of the first version of the FDACS. Boynton devised and created the separate test software to go with the package.

[34] David Berrill, the designer of the Nulka TCU, was seconded from his job with BAE Systems Military Vehicles to join Peter King and assist Mike Allan at ARC. Berrill was able to assure ARC that the tolerances assigned to components were justified and achievable.

[35] Later, in December 1996, Mal Crozier, Stewart Gould, Harry Severin and Ed Settle visited BEI Duncan in San Diego to have a new potentiometer for the TCU designed, tested and manufactured for BAE Systems. The device was needed urgently because production was about to start.

[36] This launcher was designed and built at Naval Surface Warfare Center at White Oak. Gerhard Winkler was the Principal Engineer.

[37] The chaff system is referred to as the Mark 36 Chaff, Infra Red Decoy Launch System. The combined Nulka chaff decoy system is referred to as the Mark 53 mod 2 Decoy Launch System.

[38] David Hogue, Billy Gwin and Eric Morgan were the principal designers for the new PPS. The new DLP was developed by Billy Gwin, Catherine Ray, Gerry Boynton and John Morris.

[39] The Australian PPS was found to be not reliable in firing chaff decoys. Components of the chaff decoys were not provided during the development program and these functions were not tested.

[40] Carlucci followed Caspar Weinberger as Secretary of Defense under President Reagan. He remained 14 months until George Bush senior succeeded Ronald Reagan.

TIMELINE CHART FOR THE WINNIN NULKA PROGRAM

	From the beginning to completion of the Full Scale Engineering Development phase
Early 1970s	Reports of French developing the Exocet missile. French Government announced willingness to sell Exocet to South East Asia.
	NRL demonstrated low cost travelling wave tube technology.
1973	Scot Allison completed his paper on ship defence.
June 1974	Operational evaluation testing of Exocet completed.
Late 1974	TTCP Technical Panel QTP-11 formed to investigate ship defence.
Early 1975	DSTO supported off-board decoy systems study.
February 1977	Inaugural DSTO multi-disciplinary 'think tank' spawned the idea of solid propellant rocket. Alan Smith of GAF was later invited to participate. His analysis showed how a 'Hoveroc' vehicle could work.
March 1979	Winnin Advanced Feasibility Study approved.
2 May 1981	'Hoveroc' successfully flown at Port Wakefield.
August 1981	DSTO's Ken Harvey demonstrated payload antenna feasibility.
1 October 1981	REWSON's Martin Kamhi agreed to exchange information with Australia.
May 1982	An Exocet missile damaged HMS *Sheffield* beyond repair and kindled more interest in ship defence.
March 1983	Winnin Condev approved.
22 May 1984	United States Navy and Australian Department of Defence signed an interim Research Exchange Agreement.
August 1986	Payload successfully demonstrated at Point Perpendicular. Winnin Condev completed.

	From the beginning to completion of the Full Scale Engineering Development phase
11 August 1986	United States and Australia signed Memorandum of Agreement on off-board decoy.
16 January 1988	FSED Contract awarded to AWA as prime contractor.
October 1988	Payload contract awarded to Lockheed Martin Sippican.
October 1990	First DT-IIA trials conducted at Woomera.
February 1991	DT-IIA Trials at Woomera. Six successful, three failures.
December 1991	Test analysis and fix trials at Woomera successful. Turning point in FSED program.
February 1992	Critical design review for the Nulka system. Planning commenced for at-sea trials.
19 May 1992	First Nulka firings from a ship. Tests from HMAS *Brisbane* off Jervis Bay, NSW.
11 September 1992	First tests from a United States Navy ship, USS *John Hancock*. Rocket motor burst on first test but followed by eight successes from eight tests.
December 1992	Highly successful Operational Evaluation tests from USS *John Hancock*.
February 1993	Successful environmentally stressed decoy flight tests at Woomera.
November 1993	Completion of Nulka full scale engineering development.

TIMELINE CHART FOR THE WINNIN NULKA PROGRAM

Production and introduction into service	
April 1993	OPTEVFOR recommended limited fleet introduction to United States Navy.
August 1993	Defence Force Structure and Policy Committee approved formation of the Active Missile Defence Project Office to fit Nulka to Australian ships.
September 1993	United States Congress agreed to some funding to support improvements for production.
March 1994	Start of the Nulka improvement program (NIP) of studies to improve the launch sequence, the payload and deployment of the decoy.
30 June 1994	RAN adopted Nulka as its active missile decoy solution for Project 1229 and awarded contract for phase 1 to AWADI including a batch of test decoys.
June 1995	United States Navy let contract to AWADI for Engineering and Manufacturing Development. Contract covered engineering improvements, support for milestone reviews, test decoys and a flight trial.
25 June 1996	Memorandum of Understanding agreed for production. Signed by Nick Hammond and Admiral Hood (United States Navy).
15 July 1996	Production Readiness Review finalised the commissioning of the new Nulka round assembly facility at Mulwala, New South Wales.
21 October 1996	Five successful flight tests from five at Dahlgren, Virginia, in preparation for operational testing at sea for United States Navy fire control, launcher and modified decoys.
12 December 1996	First of several presentations to United States Navy SSSTRP of the Weapons Systems Explosives Safety Review Board (WSESRB).
March 1997	Royal Canadian Navy and British Aerospace signed the contract for Nulka ship equipment for four ‘Iroquois’ class destroyers.

	Production and introduction into service
June 1997	Contract signed for production and supply of decoys to Australian, United States and Canadian navies. Known as the Collaborative Round Contract.
August 1997	First full ship integration of Nulka system on HMAS *Melbourne* at Garden Island.
28 October 1997	Second flight test campaign off USS *Stump* to qualify United States Navy fire control system. Two of three tests were dramatic failures. Corrective actions included a new manufacturing facility at British Aerospace, South Australia.
April 1998	A new British Aerospace facility commissioned at Salisbury South Australia (Bld 71) for manufacture of flight control units.
12 May 1998	RAN Active Missile Decoy Fire Control System flight tests at Woomera demonstrated system ready for ship testing. Nine successful flight tests and first tested gyroscope modification following the USS *Stump* failures.
17 August 1998	OT-IIB operational evaluation tests off USS *Peterson* successful. Blue Ribbon Panel formed on 16 December 1998 to re-assess results.
28 January 1999	United States Navy Milestone III decision, approved full rate production of decoys. Nulka satisfied requirements for introduction into operational service with the United States Navy.
31 August 2001	RAN provisionally accepted Nulka into service on its Adelaide class frigates.
17 October 2001	Australian Acceptance tests successfully completed on HMAS *Melbourne*.

ABBREVIATIONS AND ACRONYMS*

ABCA	A government to government defence information exchange forum involving America, Britain, Canada and Australia
ABCA-4	The ABCA forum responsible for information exchange in naval electronic warfare
ACTU	Australian Council of Trade Unions
ADF	Australian Defence Force
ADI	Australian Defence Industries
ADM	Advanced Development Model
ADU	Air Data Unit to sense height, air speed and its direction
AEB	Active Expendable Buoy project (US)
AED	Active Expendable Decoy
AEL	Advanced Engineering Laboratory
AFS	Advanced Feasibility Study
AINS	Acceptance into Naval Service
AMD	Active Missile Decoy (phase of the Australian acquisition project)
ANZUS	Australia New Zealand United States Security Treaty signed in 1951
AOC	Australian Ordnance Council
APL	Applied Physics Laboratory (USA)
ARC	Atlantic Research Corporation (USA)
ARL	Aeronautical Research Laboratory
ASCM	Anti-ship capable missiles
ASDPM	Assistant Secretary Development Projects Management
ASTA	AeroSpace Technologies Australia, the restructured form of the Government Aircraft Factories (GAF) at Fishermens Bend, Victoria. It eventually became Boeing Victoria.
ATB	Advanced Techniques Branch, NRL
AUSPO	The Australian Project Office for Nulka
AWA	Amalgamated Wireless Australia
AWADI	AWA Defence Industries (1987-1996)
BAE Systems	British Aerospace and later BAE Systems Australia
BOAT	Back of a Truck Tests of PADA sensor
CCTS	Captive Carry Test System (USA) enabling testing of decoys either in a captive carry mode carried by a helicopter or on the bench
CCU	Captive Carry Unit for testing the decoy payload while mounted under a helicopter

* Unless stated otherwise, all organisations listed are Australian

CDR	Critical Design Review
CFCU	Casualty Fire Control Unit
CIWS	Close-In Weapons System
CNO	Chief Naval Operations (US)
COMOPTEVFOR	Commander Operational Test and Evaluation Force (US)
Condev	Concept Development phase of a project
COTF	Alternative for COMOPTEVFOR
CSA	Computer Sciences Australia
CSE	Central Studies Establishment responsible for providing high level analytical advice to the Australian Department of Defence
DDS	Department of Defence Support
D Trials	Defence Trials group responsible for testing of defence equipment
DESTEC	Defence Science and Technology Committee
DEW-N	Director Electronic Warfare, Navy
DFDC	Defence Force Development Committee
DLP	Decoy Launch Processor
DNOI	Director of Naval Ordnance Inspection
DoD	Department of Defence
DSTO	Defence Science and Technology Organisation
DT-IIA	Nulka Development Tests IIAs; Flight Trials at Woomera (Nov 1990–Feb 1991)
DT-IIB-D	Nulka Development Tests; Flight Trials at sea (May 1992, Sep 1992/Dec 1992)
DT-IIC Prime	Nulka Development Test; Flight Trials on the Potomac River (Mar 1992)
DT-IIE	Nulka Development Test; Flight Trial at Woomera with environmentally-stressed rounds (Feb 1993)
DT-IIF	Nulka Development Test; Flight trials at Dahlgren, Virginia (Oct 1996)
E&MD	Engineering and Manufacturing Development
ECM	Electronic Counter Measures
EFM	Explosives Factory, Maribyrnong
ENEWS	Effectiveness of Naval Electronic Warfare Systems
ERL	Electronics Research Laboratory
ESSM	Evolved Sea Sparrow Missile
ETV	Experimental Test Vehicle
EWD	Electronic Warfare Division
FAS	First Assistant Secretary
FCP	Fire Control Panel

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FCU	Flight Control Unit for the decoy
FDA	Force Development and Analysis
FDA	Flight Demand Algorithms
FDACS	Flight Demand Algorithms Common Software
Fortran 6-DOF	A six degrees of freedom computer simulation of the Nulka flight vehicle prepared in the Fortran computer language
FOT&E	Follow-on Operational Test and Evaluation
FSC	Force Structure Committee
FSED	Full Scale Engineering Development phase
FYDP	Five Year Defence Plan
GAF	Government Aircraft Factories
GTS	Generic Threat Simulator
GWD	Guided Weapons Division DSTO
HERO	Hazards of Electro-magnetic Radiation to Ordnance
HMAS	Her Majesty's Australian Ship
HMS	Her Majesty's Ship
'Hoveroc'	Early hovering rocket during the Winnin phase
IFCS	Interim Fire Control System
ILS	Integrated Logistics Support
INS	Inertial Navigation System
IPN	Iso Propyl Nitrate
IR&D	Internal (or Independent) Research and Development (US), Industry Research and Development (Aust)
JPO	Joint Program Office
LIU	Launcher Interface Unit
LRIP	Low Rate Initial Production
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MX Missile	'Missile Experimental', an intercontinental nuclear-armed ballistic missile developed by the United States c. 1986
NATO	North Atlantic Treaty Organisation
NAVELEX	Naval Electronic Systems Command (US)
NDA	Nulka Decoy Algorithm, tables for deployment tactics
NIP	Nulka Improvement Program

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NPD	Nulka Project Director
NRL	Naval Research Laboratory (US)
NSWC	Naval Surface Warfare Center (US)
Nulka	The Aboriginal based name given to the joint US/Aust off-board decoy program
NWS10	A design disclosure documentation system
OPNAV	Office of the Chief of Naval Operations (US)
ODP	Office of Defence Production
OFM	Ordnance Factory, Maribyrnong
OPEVAL	Operational Evaluation
OPTEVFOR	Operational Test and Evaluation Force (US)
OSD	Office of the Secretary of Defense (US)
OT-IIA	Nulka Operational Test IIAs; Flight Trials at-sea (Dec 1992)
PADA	Pressure Air Data Assembly to sense height, air speed and its direction
PAINS	Provisional Acceptance into Naval Service
PAVO	Early rocket motor propulsion study. Named from a group of stars.
PD	Propulsion Division
PDC	Project Development and Communications Division
PDFS	Propulsion Development Facility, Salisbury
PEO(TSC)	Program Executive Office Theater Surface Combatants (US)
PPS	Processor Power Supply
QTP-xx	See TTCP
RAAF	Royal Australian Air Force
RADM	Rear Admiral
RAM	Rolling Airframe Missile
RAN	Royal Australian Navy
RCS	Radar Cross Section — a measure of an object's ability to reflect electromagnetic energy
RDA	Research and Development Authority
RDT&E	Research, Development, Test and Evaluation
REWSON	Reconnaissance and Electronic Warfare Systems Office Navy (US)
RF	Radar Frequency
RFP	Request for Proposals
RFT	Request For Tender
RMIT	Royal Melbourne Institute of Technology
SAD	Systems Analysis Division

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SADIS	Shipboard Automated Decoy Integration System
SCU	Spin Control Unit for the decoy
SDI	Strategic Defense Initiative (US)
SEG	Systems Engineering Group
SLED	Ship Launched Electronic Decoy
SLQ-32 or AN/SLQ-32	The United States developed shipboard electronic warfare suite with passive and active capabilities
SPAWAR	Space and Naval Warfare Systems Command
SRBOC	Super Rapid Bloom Off-Board Chaff
SSDS	Ship Self-Defence System (USN)
SSN2	Early Soviet surface to surface anti-ship missile c. 1960s-1970s
SSSTRP	Software System Safety Technical Review Panel
TAAF	Test, Analyse and Fix
TCU	Thrust Control Unit
TRR	Test Readiness Review
TRWG	Track Requirements Working Group
TTCP	The Technical Cooperation Program (Government forum of United States, Canada, Britain, Australia and New Zealand)
TTCP Subgroup Q	TTCP forum on Electronic Warfare
TTCP Technical Panel QTP	Focused TTCP forum on a particular area of electronic warfare
T/R	Transmit/Receive
TCU	Thrust Control Unit comprising tab vanes inserted in the hovering rocket exhaust to control the tilt and hence speed and direction of flight
TECHEVAL	Technical Evaluation
TVC	Thrust Vectoring Control
TWT	Travelling Wave Tube (a high power microwave source)
UK	United Kingdom
US	United States
USN	United States Navy
USPO	United States Navy Program Office
Winnin	The Aboriginal based name given to the early stages of the off-board decoy program in Australia (included AFS and Condev)
WRE	Weapons Research Establishment
WSESRB	Weapons System Explosives Safety Review Board (USN)
WSRL	Weapons Systems Research Laboratory

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NULKA

A Compelling Story

David Gambling
Mal Crozier
Don Northam

In October 2010, close to 40 years after Nulka was barely an idea, Australia celebrated the production of the 1000th round of this innovative active missile decoy. This milestone signified the remarkable success of a joint program by Australia and the United States, the first in the electronic warfare domain. By 2013 Nulka had been fitted to more than 150 surface warships of Australia, the United States and Canada. The history of this successful international project, particularly the significant technical breakthroughs, the unique paths taken in technology, politics and engineering and the sheer determination by a number of committed individuals, demanded to be told. This story belongs to the several hundred people who dedicated major parts of their careers to the Nulka project.

Australian Government
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