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UNMANNED AERIAL VEHICLES AND THE FUTURE NAVY

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The Sea Power Centre Working Paper series is designed as a vehicle to foster debate and discussion on maritime issues of relevance to the Royal Australian Navy, the Australian Defence Force and to Australia and the region more generally.

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Navy 2030

The Royal Australian Navy's (RAN) is examining its existing force structure, what is being proposed over the next thirty years, and how it might go about the transition to the future force. The RAN's Navy Strategic Policy and Futures Branch in Navy Headquarters is conducting a number of Future Fleet Studies, which will form the basis for future concept development across a number of areas. These Future Fleet Studies form part of a wider initiative called *Navy 2030* which is intended to inform the RAN of the strategic, military, economic, technological and personnel developments that will shape it to 2030.

This paper is Future Fleet Study No. 4 and outlines the development of Unmanned Aerial Vehicles (UAVs) to date and considerations for their possible future employment by the RAN. This study is a joint product from the Directorate of Navy Strategy and Futures and the RAN Sea Power Centre as part of the *NAVY 2030* initiative.

Further information regarding the Navy 2030 initiative and the Future Fleet Studies can be obtained from:

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Abbreviations and Acronyms

AAA	anti-aircraft artillery
ADF	Australian Defence Force
AEW&C	airborne early warning and control
BDA	battle damage assessment
DARPA	defence advance research project agency
DNSPF	Directorate of Navy Strategic Policy and Futures
ECM	electronic countermeasures
EO	electro-optical
ERGM	extended range guided munitions
EW	electronic warfare
GPS	global positioning system
HAE	high altitude endurance
IR	infra-red
JORN	*Jindalee* over-the-horizon radar network
LO-HAE	low observable high altitude endurance
MAE	medium altitude endurance
MANPAD	man portable air defence system
MAV	micro unmanned aerial vehicle
NBC	nuclear, biological and chemical
NHQ	Navy Headquarters
RAN	Royal Australian Navy
RATO	rocket assisted take-off
RMA	revolution in military affairs
RPV	remotely piloted vehicle
SAM	surface to air missile
SAR	synthetic aperture radar
SEAD	suppression of enemy air defence
STOL	short take-off and landing
TCS	tactical control system
TUAV	tactical unmanned aerial vehicle
UAV	unmanned aerial vehicle
UCARS	UAV common automatic recovery system
UCAV	uninhabited combat aerial vehicle
UCAV	unmanned combat aerial vehicle
US	United States
USAF	United States Air Force
USN	United States Navy
VHF	very high frequency
VTOL	vertical take-off and landing
WMD	weapons of mass destruction

UNMANNED AERIAL VEHICLES AND THE FUTURE NAVY

Peter Ashworth

The term unmanned aerial vehicle (UAV) has been used to categorise a wide range of air vehicles including cruise missiles and aerial target drones. *ADFP 101–ADF Glossary* defines unmanned aerial vehicles as:

> Powered, aerial vehicles that do not carry a human operator, use aerodynamic forces to provide lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry lethal or non-lethal payloads.

The focus of this study is the application of UAVs to Royal Australian Navy (RAN) operations. Accordingly, the term UAV will generally be confined to the narrower concept of air vehicles deployed on operational missions with the intent of being recovered for near-term re-use. These aircraft would usually carry mission-specific sensor payloads or dispensers. Inclusive vehicles could fly either autonomous, pre-programmed profiles, or be remotely piloted vehicles (RPV). Cruise missiles, unmanned combat air vehicles (UCAV), aerial target systems and drones (manned aircraft types converted for remote piloting) will be covered where relevant.[1]

The non gender-specific term *uninhabited* aerial vehicle is often used in lieu of, or interchanged with, *unmanned* aerial vehicle. Debate regarding which term is more appropriate is semantic. This paper will adopt the more commonly used term unmanned aerial vehicle in accordance with *ADFP 101* and *Janes International Yearbooks*.

The aim of this study is to evaluate the merits of UAV for possible inclusion in the future RAN operational force.

CATEGORIES OF UAV

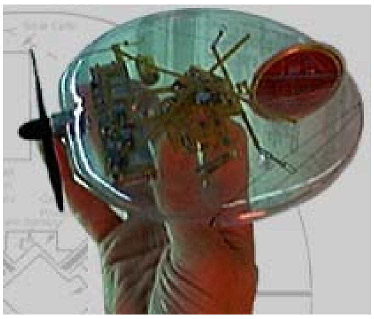
UAVs have been designed to cover a wide spectrum of tasks, from line of sight flights of several minutes duration in direct support of ground troops, to flights of several days duration many thousands of kilometres away from the launch and control sites. UAVs therefore tend to be *de facto* classified according to their operating range and endurance. Given the wide spectrum of capabilities across the categories of UAV, the performance data detailed for each class is indicative.

Micro UAVs (MAV)

The emergent field of micro UAVs represents the smallest class of vehicle. The United States (US) Defence Advanced Research Projects Agency (DARPA) initiated a MAV program in 1997. DARPA stipulated a maximum length of 15 cm in any dimension to reduce size and weight. The goal is for individual soldiers to carry and deploy MAVs for platoon-level surveillance tasks at manoeuvre range. Indicative characteristics include a weight of 50 g, endurance of 30-60 minutes, operating range 3-10 km, controlled from a wallet sized ‘ground station’.[2] The small mass would limit possible payloads to simple cameras or communications relay devices, and the like.

Tactical UAVs (TUAV)

Tactical UAVs are generally designed to operate at a radius of around 100-500 km with about two to seven hours endurance. Four hours time on task at an operating radius of 200 km is a common specification. One representative vehicle is the US *Outrider* TUAV, providing four hours on station at a range of 200 km with an air vehicle comparable in size to the RAN's *Kalkara* unmanned aerial target system. Operational altitude is generally below 15,000 ft. *Outrider* utilises the global positioning system (GPS) for navigation and target reporting, may launch from unprepared ground sites or larger Navy flight decks, and will carry electro-optic (EO) and infra-red (IR) sensors for battlefield surveillance. The entire system, including control elements, is transportable in a single C–130 *Hercules* transport aircraft. Each UAV system would include four air vehicles and cost around US$10 million when in full production.[3] TUAVs are operational in a range of configurations, including rotary-wing (for example, Bombardier CL–327 *Guardian*) and fixed-wing, with other design formats such as tilt rotor (for example Bell's *Eagle Eye* derivative of the V–22 *Osprey*) and 'tip-over' under development.[4] As with manned aircraft, the air vehicle design options tend to be driven by the launch and/or recovery environment, with TUAVs invariably possessing short take-off and landing (STOL) or vertical take-off and landing (VTOL) launch and recovery capabilities.



Black Widow MAV

CL327 *Guardian* TUAV

Outrider TUAV

In February 2000 the US Navy (USN) announced the winner of its vertical take-off and landing (VTOL) TUAV (VTUAV) competition with the letting of a US$93.7 million engineering and manufacturing development contract to Northrop Grumman Corporation for its Model 379 UAV. In essence, this UAV is a remotely piloted variant of the Schweizer 379 light civilian helicopter. For comparison purposes, this aircraft is about 60 per cent of the size of the AS350B *Squirrel* helicopter. Initially, 23 systems will be required for USN and US Marine Corps operations. The system will be used for surveillance and reconnaissance, battle damage assessment, communications support and chemical/nuclear detection missions from any aviation capable ship.[5]

The Model 379 VTUAV in flight, and in comparison to the Sikorsky Seahawk

Endurance UAVs

Endurance UAVs are systems designed to operate at medium to high altitudes with multi-mission payloads, and endurance exceeding 24 hours. The US Air Force (USAF) has determined three categories within this class: medium altitude endurance (MAE) UAV (Tier II), high altitude endurance (HAE) UAV (Tier II+), and low observable high altitude endurance (LO–HAE) UAV (Tier III-). Endurance UAVs tend to represent a significant increase in technology over lower order vehicles, principally due to the complexities of controlling the aircraft and sensors at extended ranges.

Medium altitude endurance UAV

The USAF General Atomics RQ–1A *Predator* MAE UAV is representative of this class. This piston engine, propeller driven aircraft was designed to operate at altitudes below 25,000 feet with a variety of multi-mission sensors, predominantly EO, IR and synthetic aperture radar (SAR). Predator has endurance on station exceeding 24 hours at an operational radius of 500 miles from the launch area (maximum radius 2,000 nm), at airspeeds of 60–110 knots.[6] The aircraft is controlled by line-of-sight ultra high frequency and unencrypted Ku–band satellite links. The USAF considers the *Predator* the most vulnerable of the three US endurance UAVs to hostile threats, given its operating envelope.[7]

High altitude endurance UAV

The only known UAV in this category to date is the USAF Northrop Grumman RQ–4A *Global Hawk* program, in which the Australian Defence Force (ADF) is a collaborating partner under a AUD$30 million agreement announced in March 1999.[8] *Global Hawk* operates at altitudes up to 65,000 feet with on-station endurance of 24 hours at 3,000 nm (5,500 km). The air vehicle can carry a payload of up to 860 kg, including EO, IR and I/J band SAR.[9] Vehicle control is achieved through encrypted satellite links. *Global Hawk* is a large aircraft, its 116 ft wingspan exceeding that of the P–3C *Orion*. This UAV requires 5,000 feet of sealed runway for launch and recovery. Aircraft survivability is enhanced by its high operating altitude (above most fighter and SAM envelopes), limited onboard electronic countermeasures (ECM) and stand-off tactics.[10]

Low Observable–High Altitude Endurance UAV

Similar in concept to HAE, this class would be enhanced by low observable characteristics to 'accomplish a penetration surveillance and reconnaissance mission in an integrated air defense system environment […] low observable characteristics will limit the ability of all but the most advanced hostile SAM [surface to air missile] and aircraft systems to engage it'.[11] The only known UAV in this class was the Lockheed Martin/Boeing RQ–3A *DarkStar*. The USAF cancelled this program in January 1999 after deciding that its military utility would be insufficient to justify completion.

Predator MAE

Global Hawk HAE

Dark-Star LO-HAE

POTENTIAL MISSIONS FOR UAVS

UAV missions fall into two broad categories: non-lethal reconnaissance and surveillance related tasks, and the more advanced concepts of lethal combat air vehicles. Of note, any potential advantages to the RAN from UAV operations could also present as a threat if an opponent exploits UAV capabilities. The following missions therefore present as potential opportunities or threats.

Reconnaissance and surveillance missions

Reconnaissance and Surveillance

The terms 'reconnaissance' and 'surveillance' are often used interchangeably, but there are distinct differences between these tasks. *ADFP 101* defines reconnaissance as a

> mission undertaken to obtain, by visual observation or other detection methods, information about the activities and resources of an enemy or potential enemy; or to secure data concerning the meteorological, hydrographic or geographic characteristics of a particular area.

In other words, this task refers to sourcing general information about an enemy or an area. By contrast, surveillance is the quite specific and systematic observation of a particular area or target, possibly for extended periods of time. UAVs have been used for these missions since their inception. Interestingly, these missions can be quite valid peacetime tasks. For example, US *Predator* UAVs have been used to monitor disputed areas during peacekeeping operations in Bosnia. Tactical UAVs offer the opportunity to provide valuable reconnaissance and surveillance capabilities to RAN ships that do not have direct access to organic air assets, or to augment aircraft operations from aviation capable ships.

Target acquisition, designation and battle damage assessment (BDA)

UAVs can be used to detect, locate, track and identify a target of interest. The Rules of Engagement in any future conflict are likely to mandate positive identification of targets before any strike or interdiction mission. UAVs could meet this requirement, allowing scarce manned air assets to be reserved for combat operations. Smaller UAVs might be able to operate more discretely than their manned counterparts, possibly allowing target acquisition to occur with minimal chance of counter-detection. Should an air strike subsequently be authorised, the surveillance UAV could be used to designate the target for precision strike aircraft, missiles or artillery/extended range guided munition (ERGM) rounds. Following engagement, the UAV could provide near real-time battle damage assessment to the force or mission commander. Accurate BDA can prevent repeat attacks on a target, preventing the wastage of precision and unguided munitions as occurred in the former Yugoslavia and Operation DESERT STORM when targets were repeatedly engaged because the status of the target was unknown. The US General Accounting Office, the investigative arm of Congress, notes that during DESERT STORM unnecessary re-strikes were conducted because complete BDA information was either not available, not utilised, or not properly relayed. Further, insufficient BDA sometimes prevented planners from knowing at what point a target had actually been destroyed, thereby putting pilots and aircraft at risk in conducting additional strikes.[12] The use of UAVs for maritime BDA would allow damage assessment to be conducted at closer range than with manned helicopters, or in the presence of a residual threat, possibly allowing higher quality damage assessment. The aims of BDA would be to determine the status of a target and to prevent unnecessary expenditure of ADF weapons. This is particularly crucial for RAN surface combatants and Task Groups given the finite quantities of embarked weapons and the cost of each round.

Communications Relay
Maritime operations often involve action at considerable distance from a naval unit or Task Group. As is evidenced by current RAN helicopter operations, these stand-off operations usually exceed the range of existing terrestrial very high frequency (VHF)/UHF communications capabilities. UAVs could be employed as simple communications relay platforms to bridge the gap between the scene of action and the force commander. This application would be particularly useful for amphibious operations or maritime service protected/assisted evacuations, allowing embarked force commanders to maintain continuous communications with deployed elements.

Communications and electronics intelligence and attack
The US Department of Defense has conducted communications and electronics intelligence and attack trials using a *Hunter* UAV. The aim is to detect and identify an enemy's emitters, particularly air defence installations, so that strike aircraft or missiles can attack them. The RAN could conceivably use UAVs to locate and identify an enemy warship or shore facility by its emissions. UAVs can also be used to jam emitters. The RAN already has a specialised application of this capability with the *Nulka* anti-ship missile defence system.

Chemical and biological warfare detection
UAVs can be used in these so-called 'sniffer' roles to test an operating environment for contaminants. This capability will be explored further in a later section of this paper.

Combat UAVs

Combat UAVs can be taken to mean UAVs that employ lethal force. Cruise and ballistic missiles are excluded from this discussion in accordance with the definition of UAVs provided at the beginning of this paper.

Land strike. It is quite conceivable that naval forces of the future will have the option of employing UAVs to strike against an opponent's land-based infrastructure. UAVs might prove to be a more affordable option than land attack missiles, and offer the advantage of endurance. As with surveillance UAVs, land strike UAVs can be launched and held overhead a battlefield for many hours until a target presents or is selected. This ability to loiter could significantly reduce reaction times against 'pop-up' threats. Land strike UAVs could be used by warships to enable ingress to an area by ADF or allied strike aircraft.

Maritime strike
Strike UAVs could be used in much the same fashion against maritime threats such as an opponent's shipping, although *Harpoon* and the helicopter launched *Penguin* missile would probably offer advantages over UAVs against shipping. One possible application of maritime strike UAVs is against small, fast attack craft such as 'ram-raid' speedboats. A single UAV could be used to track and then attack such craft before they can threaten RAN or allied shipping. A UAVs small size and greater manoeuvrability compared with manned helicopters would provide a tactical advantage. The UAVs warhead need only be relatively small to neutralise any small craft threat.

Suppression of enemy air defence (SEAD)
One of the first applications of lethal combat UAVs was the use of Israeli *Harpy* UAVs in the SEAD role. This UAV was designed to loiter in the vicinity of known air defence sites waiting for emitters to activate, possibly in response to feints by manned aircraft or drones. When the site activates *Harpy* executes a terminal homing to the transmitter where the high explosive fragmentation warhead explodes. Such a capability is equally applicable against land and sea-based air defence units.

IAI *Harpy* in flight, and attacking an air defence transmitter

OPERATIONAL SUCCESSES

UAVs had some notable but limited operational successes in the 1960's and 1970's. The US BQM–34 *Firebee* reconnaissance RPVs performed well in Vietnam, with increasing use as US losses in aircraft and crews grew. US RPVs flew a total of 3,435 sorties during the Vietnam War, with only 4 per cent losses.[13] The Israelis successfully employed UAVs during the *Yom Kippur* War in 1973 for reconnaissance flights over dangerous areas following pilot losses, and again in the Bekaa Valley in 1982 for reconnaissance, electronic warfare (EW), and to act as decoys to deplete Syrian SAM numbers.[14] UAVs also had numerous operational successes in the 1990s, particularly in the Gulf, Balkan and Kosovo conflicts. The US Navy, Army and Marine Corps deployed six *Pioneer* systems during the 1991 Gulf War, flying a total of 1,698 hours in 545 sorties. Of 40 air vehicles used, 12 were lost and 18 others were damaged, of which 13 were in-field repairable. Operations included day and night sorties with TV and forward looking infra-red sensors for reconnaissance, surveillance, artillery and battleship main gun adjustment of fire, and battle damage assessment.[15] The employment of UAVs during the Gulf War and in the former Yugoslavia was limited due to the very small number of operational UAVs available, and because of the overwhelming air superiority that coalition forces enjoyed in these theatres. Their performance was solid, albeit not startling in these campaigns, but did provide an insight into the future potential of UAVs.

ADVANTAGES OF UAVS

The relative merits of UAVs vary across the different classes. For example, larger Endurance UAVs are capable of supporting relatively large sensor payloads, but require more extensive launch, recovery, control and handling facilities than MAV or TUAVs. MAVs can be deployed by individual soldiers in the field, but are severely limited in range and sensor payload.

Risk

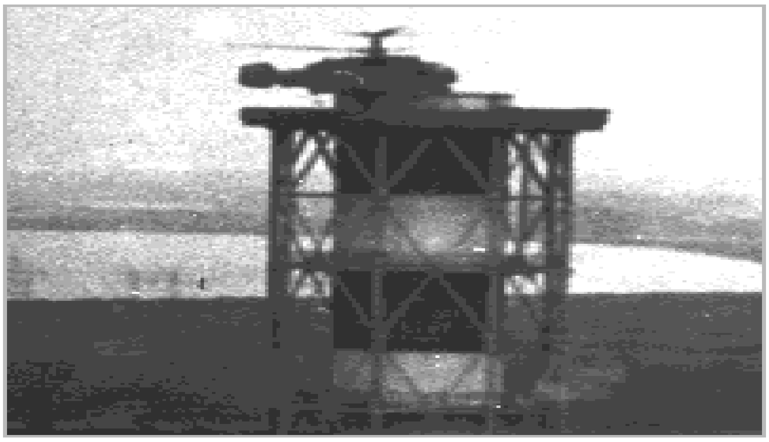
Arguably, the greatest advantage the UAV provides a battlespace commander is the ability to operate in very high-risk areas, where the probability of losing manned aircraft is considered too high. UAVs reduce the likelihood of incurring personnel losses in the form of aircrew killed in action, taken as prisoners of war, or missing in action. As evidenced by conflicts such as the 1991 Gulf War, personnel losses carry likely exposure to adversary propaganda and international media coverage[16]. Casualties and captured personnel might be politically or operationally unacceptable to the Government, the ADF or the Australian public. A sobering example is the footage of bodies from a downed US *Black Hawk* helicopter in Somalia being dragged behind vehicles through streets in Mogadishu.[17] Such events create tension in countries sensitive to casualties on a distant battlefield, undermining the political will to remain engaged in conflicts on foreign shores. Further, the loss of scarce, costly aircraft and aircrew might be unacceptable to a force commander. This is particularly so for medium power nations such as Australia, given the ADF's limited numbers of multi-mission and strike aircraft, few of which can be replaced in the short term.

UAVs offer a viable means of gaining information at lower altitudes where air threat density is markedly increased due to the proliferation of light and heavy calibre small arms, anti-aircraft artillery (AAA) and man portable air defence systems (MANPADS) as well as high-order SAM threats. For example, UAVs were deployed in Kosovo to operate under low and medium level cloud bases that precluded data gathering from more traditional means such as surveillance aircraft or satellite. Lower operating altitudes dramatically increase the number of weapons systems that may be brought to bear on aircraft, and reduce aircrew reaction time and evasion options. Even though coalition forces enjoyed overwhelming air superiority during the Gulf War, eleven coalition aircraft were lost to enemy small arms, AAA and MANPADS whilst operating at low altitude below bad weather in the Kuwait theatre of operations during the final three days of hostilities. Out of 86 coalition aircraft lost or damaged during Operation DESERT STORM, 21 losses occurred in the last seven days.[18] Whilst the requirement for manned combat flights still existed, UAVs may have been able to supplement manned flights for surveillance and targeting sorties at low and medium altitudes. UAVs do not necessarily imply increased survivability in a high threat environment, but they do reduce the risk of losing aircrews.

Environment

Circumstances might arise where environmental hazards prevent ground forces or manned aircraft from entering an area of interest. In particular, the suspected, threatened or confirmed presence of nuclear, biological or chemical (NBC) hazards would place severe constraints in the vicinity of contaminated sites. Such circumstances might arise in times of peace or conflict—the Chernobyl nuclear disaster of 25 April 1986 is an example of a peacetime environmental crisis occurring. Manned helicopters were required to deposit some 5,000 tons of radiation control and sealant material into the reactor well to suppress radioactive release.[19] Many of the helicopter pilots subsequently died from acute radiation poisoning. Potentially, UAVs or remotely piloted helicopters could be used for future such load lifting and contaminant suppression operations.

The possibility of the proliferation of weapons of mass destruction (WMD) within Australia's area of strategic interest, including regions where the ADF has deployed in coalition operations, might increase the risk to manned platforms. UAVs can now be used to sample the environment for NBC agents or industrial pollutants. In March 2000 the US Army *Hunter* UAV successfully completed a series of trials to prove the ability of the platform to 'detect and quantify chemical threat clouds on an active battlefield or in peacekeeping missions'.[20]



A Russian Army helicopter over the Chernobyl reactor well

Long endurance tasks

The growing interest in current information technology based Revolution in Military Affairs (RMA) concepts such as network-centric warfare indicates that the reliance on a qualitative knowledge edge will increase into the future. UAVs could provide the capability for long endurance sensor deployment in a region of interest or in the vicinity of a deployed force, utilised as joint reconnaissance and surveillance platforms. Any future ADF UAV capability would complement other surveillance options including airborne early warning and control (AEW&C) aircraft, the Jindalee over-the-horizon radar network (JORN), naval ships and organic helicopters, and satellite-borne sensors. UAVs offer a distinct advantage over manned platforms by their increasing ability to loiter in an area of interest for extended periods of time. Current trends with personnel retention and aircraft availability indicates that manned platforms might encounter increasing difficulty maintaining sufficient operational tempo for continuous coverage of an area of interest. Combating the effects of crew fatigue on long endurance, mundane or repetitive tasks would be problematic, particularly if a high operational tempo is to be maintained for a prolonged period. Land and ship based UAV control centres offer the opportunity to rotate aircraft controllers and analysts more readily than in crewed aircraft.

Supplementing aircraft numbers

Recent conflicts have highlighted the difficulties that military forces have in meeting concurrent tasking with available aircraft and personnel numbers. UAVs offer one means of relieving the demands on manned aircraft or to supplement platform numbers in a range of tasks, particularly for reconnaissance and surveillance related missions. As an example, the US was forced to rapidly deploy previously unproven UAV systems in Operation ALLIED FORCE in Yugoslavia to supplement North Atlantic Treaty Organisation (NATO) aircraft for surveillance and battle damage assessment, particularly in adverse weather conditions.[21]

Contemporary manned aircraft have a high degree of design complexity imposed by requirements for habitability, reliability and survivability. This comes at a premium of increased research and development and manufacturing cost. It would generally be cheaper and quicker to replace attrition losses from the UAV force than to replace manned aircraft losses, particularly if the crew must also be replaced. This point must, however, be balanced with the recognition that UAV losses are likely to be higher than manned alternatives due to increased operational and operating risks, and with the knowledge that high-end Endurance UAV capability (eg *Global Hawk*) will not be 'cheap' to replace in monetary terms. However, any organic naval UAVs are likely to be the more modest (cost and capability) TUAV systems.

CHALLENGES FOR UAV DEVELOPMENT AND EMPLOYMENT

The mounting, but sporadic, operational successes of UAVs seem to be accompanied by regular predictions that the employment of UAV systems will become widespread 'within the next 5–10 years'. Unfortunately, UAV development programs have generally failed to meet expectations. UAV programs have often been associated with continual failures, setbacks and cost overruns. 'They fly and they crash, but defence ministries keep on pouring cash into UAVs despite a litany of program failures and embarrassing flops.'[22] A case in point is the British Army's Marconi *Phoenix* system:

> Programme delays (six years behind schedule) and development problems (sensor focusing, lack of engine power and damage to sensors during recovery) led, in 1995, to the suspension of the 1985 contract pending resolution of major problems within the following twelve months. Programme cost has escalated from the original £80 million in 1985 to a reported 1998 figure of £227 million.[23]

There are wide-ranging reasons for the litany of UAV development problems.

Technical

UAVs are trying to replicate many of the functions of larger manned aircraft using small air vehicles whose size infer significant performance limitations or capability trade-offs. Projects such as *Hunter* and *Outrider* have suffered from a range of technical difficulties related to payload configuration and weight, engine reliability and power limitations, air vehicle weight growth, datalink reliability and performance, flight control system software flaws, and take-off and recovery mishaps. Technical advances in areas such as component miniaturisation, powerplant development, software design, and composite materials have allowed many problems to be overcome. The reliance on some form of data link for many command and guidance functions creates a natural point of dependence, if not weakness.

Reliability

Manned aircraft have greater reliability than UAVs due to several factors. They are designed with multiple layers of redundancy in vital systems. Their crews are usually able to quickly detect, diagnose and circumvent problems directly. If all else fails they can readily terminate a mission and recover the aircraft. UAVs rely on datalinks to transmit air vehicle health data to a remote site, assuming that the controller has a direct link available. UAVs usually have very little systems redundancy due to weight and size limitations, and because of the mindset that UAVs are expendable. As a general rule, if an aircraft's gross weight is increased by ten per cent due to equipment additions in the form of payload and systems redundancy, and performance is to remain constant, then the wing area, power plant, fuel and structure must be increased by as much as 100 per cent. This is a growth factor of ten. If performance is sacrificed by increasing weight, then you have a poorer aircraft.[24]

Requirements creep

UAV development programs have suffered from ambiguity of purpose and poorly defined requirements. This has led to requirements creep as more is asked of a proposed UAV.

> The more you ask a UAV to do, the harder it becomes to build. UAV system acquisitions need to be protected from what is known as 'requirements creep'. Just because another capability could conceivably be added to a UAV does not mean it should be added as a requirement. Any proposed new requirement should be judged by its overall effect on the acquisition program in terms of cost, schedule, and performance.[25]

One feature of early, successful Israeli and US UAV programs were that the UAVs were relatively simple, single role aircraft. Current programs seem to be seeking multi-role aircraft, which incurs added complexity.

Cost

Most US Department of Defense UAV programs have suffered from cost and schedule overruns which ultimately caused their demise. For example, the US Army *Aquila* program commenced in 1979 with total development and procurement cost estimates of US$563 million for 780 aircraft. It was cancelled in 1988 with cost estimates of US$2,025 million for only 376 aircraft, with many performance requirements still not met. Likewise, the *Hunter* project contract was allowed to expire after cost estimates had doubled to over US$2 billion, again with performance below requirements.[26] The US Government Accounting Office (GAO) estimates that the US Department of Defense has spent more than US$2 billion on eight UAV development programs since 1980, with only a handful of air vehicles ever operationally deployed. *Global Hawk* and *Predator* remain in development and low rate initial production respectively, but have experienced cost and schedule overruns.[27]

Weather

UAVs have had a series of problems related to inclement weather. Many air vehicles are unable to operate in icing conditions because they have insufficient weight and space margins to incorporate anti-icing systems. Some sensors are unable to penetrate rain. Water ingress into systems has led to the damage or loss of command and guidance links, payloads and/or air vehicles. There are significant limitations on take-off and recovery wind envelopes, and on the ability of some UAVs to operate in gusty conditions or with strong cross winds.

Vulnerability

UAVs are generally smaller than their manned counterparts in each category of operations. Their small size and reduced profile mean that these vehicles can usually ingress an area more readily than manned aircraft. However, once detected they can be far more vulnerable to destruction than manned aircraft. UAVs generally operate at low speed with minimal manoeuvring to gain maximum performance from sensors. Their controllers do not possess the same degree of situational awareness that manned aircraft would usually have, so they may not recognise or react to counter-detection or an attack. Strategic assets like *Global Hawk* would utilise a flight and operational profile that makes them considerably less vulnerable than less capable UAV categories, but it remains vulnerable to interception by higher capability SAM/air-to-air missile systems if detected.

UAV CAPABILITY DEVELOPMENT

The replacement of manned aircraft by UAVs has long been forecast. The British Government's 1957 Defence White Paper (the 'Sandys Review') proposed 'that fighter aircraft will in due course be replaced by a ground-to-air guided missile system'.[28] This prediction proved to be somewhat premature, but this error in judgement had serious consequences for the UK aerospace industry, with most major manned combat aircraft programs being cancelled.[29]

Despite costly development failures it would be fair to state that UAVs are now starting to build upon a growing number of successes in system development and operational experience. The US *Pioneer* UAV system alone has accrued a total 20,925 flight hours as of 25 May 2000.[30] Technological advances are allowing UAV air vehicles (airframes and propulsion systems) and payloads to become lighter, smaller and more capable, and are permitting better options for the control of air vehicles. As an example, encrypted satellite radio transponders now permit secure beyond line of sight control of aircraft. UAV systems without access to satellite transponders must rely on pre-programmed navigation systems or the use of relay aircraft to control air vehicles operating beyond terrestrial radio range.

A heightened expectation that UAVs will become increasingly important components of future forces is further fuelling the development cycle. Air warfare systems, in the holistic sense, are becoming more capable. Modern radars and other detection methods are dramatically increasing the probability that aircraft will be detected. Sensors are being paired with ever more lethal anti-aircraft missile systems deployed in land, ship and aircraft platforms. Aircraft manufacturers must counter modern anti-aircraft warfare developments to maintain the survivability of manned aircraft. Designers have to incorporate varying degrees of low observable (so-called 'stealth') characteristics, better long-range sensors, better counter-measures, and longer-range weapons into their aircraft. This in turn is dramatically increasing the complexity and unit cost of new generation combat aircraft. One such example of this is the Lockheed Martin F–22 *Raptor* fighter aircraft, which is expected to cost at least US$84 million unit production cost per aircraft for the USAF, plus support infrastructure costs, if full production proceeds.[31]

To what extent then could technology replace man in the cockpit? Clearly, technology is already replacing many functions within the cockpit that were previously the domain of the aircrew. Tasks such as navigation, systems monitoring, sensor operation and some aircraft flight control modes (such as instrument approaches) in many aircraft have evolved from manual to automatic operation with, at best, aircrew monitoring the systems—manual flight by exception. Other functions are performed or authorised by the flight crew following cues from aircraft systems. An example of such a semi-automatic function might include electronic warfare counter-measures dispensing following an electronic warfare (EW) system alert (in the semi-automatic dispense mode).

The limits of what technology could achieve in a combat aircraft probably would not be set by any aircraft systems requirement. Systems can be developed to operate automatically or via remote monitoring and control from an off-board control station. However, it is the human temporal functions that would be most difficult to replicate. Critical attributes that an adequately trained and experienced human brings to the aircraft, and the fight, are the set of intelligent functions such as situational awareness, rational judgement, instinct, perceptions and intuition, and the flexibility to rapidly respond to changing circumstances. These functions cannot yet be replaced by a computer's pre-defined algorithm set.

Technology would require a quantum leap in processor power and 'artificial intelligence' before these functions could be replicated to any operationally viable extent by the machine. However, to balance the ledger somewhat, technology can compensate for human error such as by prompting a pilot to initiate aircraft safe-flight recovery from potentially fatal circumstances, such as by a ground proximity warning or collision avoidance system alert.

UAV systems are not 'cheap', but their cost must be considered in relative terms. A MAV will cost around US$1,500 per item. This is costly for a simple camera or radio relay if the unit is not recovered, although the tactical utility of a flight in combat circumstances may more than justify the acquisition cost of the system. If a given flight reduces the risks to supporting forces, then the unit cost may be considered as wise and worthwhile expenditure. SEAD and strike uninhabited combat aerial vehicles (UCAV), target drones and other 'first day of the war' UAV types would have to be considered expendable, justifying their cost in terms of the probability of aircrew lives saved and as enablers for future air operations in theatre. However, operators of UAVs would generally want to recover surveillance aircraft in order to re-use the payload and the air vehicle itself, particularly if a unit or force commander does not have recourse to other means of, say, gathering intelligence information. *Global Hawk* is to have a fixed unit price of US$10 million dollars per aircraft for USAF (assuming that the program proceeds), probably higher for export customers such as Australia should the ADF pursue this capability. The loss of any *Global Hawk* air vehicle would significantly erode any operating cost advantage that this UAV might have over manned alternatives such as the AP–3C *Orion*. Before deploying an UAV a commander must make judgements about the tactical or strategic utility of the flight and the unit cost of the vehicle to be employed, given the inherently higher risks of losing unmanned air vehicles when compared with manned alternatives.

UNINHABITED COMBAT AIR VEHICLES (UCAV)

The concept of UCAVs refers to high performance unmanned combat and strike aircraft, as opposed to UAVs with a lethal payload. UCAVs are becoming the focus of attention for many proponents of UAVs, and these aircraft have appeal for a host of reasons. They offer the potential for strikes on heavily defended strategically important targets, to saturate an opponents air defences with multiple targets to deplete weapon stocks, or other similar 'first day of the war' tasks considered too risky for manned aircraft. The presence of a human in the cockpit places limitations on the performance of the machine. For example, the manoeuvrability of an aircraft is limited to a large extent by the ability of the human body to sustain large manoeuvre loads, or 'G-forces'. In general, the human body cannot sustain manoeuvre loads higher than about 10 G without loss of consciousness, even with G-tolerance training. By comparison, missiles are capable of manoeuvring at loads in excess of 40 G due to their compact design. An aircraft will have physical limits to which it can be stressed in-flight by design factors such as the size, mass and structural strength of the air vehicle. If the person was to be removed from the aircraft, along with all associated support and survivability systems, then smaller, more compact aircraft with much higher *flight* performance could be built. However, the question becomes one of whether an unmanned combat aircraft is capable of superior *operational* performance in comparison to a manned aircraft.

Were the UCAV concept to become a reality then military forces could realise significant operating efficiencies from any technologically and operationally mature UCAV system.

UCAV attrition replacement air vehicles could be built to replace combat or operating losses well inside the time it would take to prepare a manned aircraft's replacement crew with sufficient training and experience to go in harms way. UCAVs within a mature system would probably be built at considerably less cost, and therefore probably in greater numbers, than their manned counterparts. However, one must question whether society or Government would be prepared to allow robotic machines to operate relatively autonomously with lethal weapons.

The RAN is unlikely to become involved in operating UCAVs, but warfare officers should maintain an awareness of the development of UCAV capability because they could present as a future threat to surface combatants. Israeli operations in Lebanon and the Bekaa Valley have demonstrated the utility of the concept for saturating air defences and depleting weapons stocks ahead of manned aircraft strikes. Future surface combatants or Task Groups could well be confronted with waves of combat UAVs or drones, each with a lethal warhead, possibly operating as a mixed strike package alongside manned strike aircraft.

UAV OPERATIONS FROM RAN SHIPS

The use of contemporary UAV systems from ships is generally only constrained by the restricted launch and recovery options. Most endurance UAV systems are relatively large fixed-wing aircraft designed to operate from prepared runways, thereby excluding their use from ships. Accordingly, ship-borne systems are currently restricted to TUAV and MAV systems until vertical or short take-off and landing (V/STOL) endurance UAV systems are developed. It would be fair to assume that the performance distinction between TUAVs and lower order endurance UAVs will become blurred as TUAV technology matures over the next decade.

Organic helicopters provide a great deal of operational flexibility to the RAN. To an extent, they are a force multiplier for warships; extending the force sensor horizon and allowing stand-off offensive and defensive capabilities within the constraints of equipment fit. But helicopters can only be embarked in the larger aviation capable ships. Tactical UAVs represent an opportunity for limited aviation capability to be employed from a range of minor war vessels, including patrol boats and mine hunter vessels for limited surveillance, reconnaissance, intelligence collection or communications purposes. Some of the issues surrounding UAV operations from RAN ships will be discussed in the following passages.

Operation of an embarked UAV system

Personnel

UAV systems normally have dedicated personnel to perform the wide range of functions required in order to operate the systems. These functions would include any air vehicle or sensor maintenance, UAV launch and recovery, air vehicle and payload control, and sensor data dissemination or analysis. Personnel requirements vary greatly between the different systems. For example, the newly acquired USN VTUAV system requires up to 18 personnel for an embarked TUAV detachment to cover all maintenance and operating requirements. Only 2–3 personnel are required to support TUAV operations from units that do not embark their own TUAV detachment. These personnel are able to control air vehicles launched from another ship.[32] By comparison, the Canadian Bombardier CL–327 *Guardian* TUAV requires only a crew of two to set up and operate.[33] It would be reasonable to expect that future maritime TUAV systems would require an operating crew of two for pre-flight payload configuration, in-flight air vehicle and payload control, and post-flight data recovery and management. Any decision regarding supplementing ship's crews with specialist UAV personnel as opposed to cross-training existing crew members would need to be considered in light of anticipated operating tempo. In general, it would be preferable to avoid crew supplementation in order to reduce UAV operating costs. Any maintenance requirements beyond basic pre-launch and post-recovery activity might be beyond the scope of minor war vessel crews due to the limited crew sizes. However, technical personnel from major fleet units or their embarked helicopter flights could presumably be trained to conduct field level maintenance.

System integration

The degree of system integration within ships would depend upon the characteristics of any selected system, the cost and complexity of integration (particularly software), and any guidance from an endorsed UAV concept of operations. Integrated systems would allow UAV tracks to be entered into combat data systems quickly; non-integrated systems could be more readily transferred between fleet units. Any dedicated UAV operating consoles would, ideally, be located in the operations room/s of major surface combatants, space permitting. The location of console/s in smaller classes of ship would depend on the availability of space, power supplies and accessibility to radio transmitters and aerials for air vehicle control. The USN has developed common ground control station architecture for the family of UAVs up to and including Medium Altitude Endurance UAVs such as *Predator*. The tactical control system (TCS) will provide command and control of UAV air vehicles and payloads, as well as data dissemination to command, control, communications, computers and intelligence systems. Different types of UAVs and payloads can be controlled from the one console. The USN, Royal Navy, and the Canadian Army have acquired TCS for evaluation.[34] It is possible that emerging and next generation UAV systems would require smaller operating consoles, possibly no larger than a laptop computer.

Tactical Control System (TCS) Ground Station

UAV control

The RAN would need to be quite clear about its intended concept of operations for any future UAV system. RAN warships possess a comprehensive suite of surveillance and targeting systems for operations within their sensor horizon. The RAN would derive greater utility from employing UAVs that could be operated beyond the ships existing sensor capability. However, the more demanding the role for a UAV system then the more demanding the control and/or datalink requirements are likely to be. If a UAV is only required to operate within line of sight of the controlling unit, then control could be effected with a relatively simple UHF or VHF radio transmitter. If the UAV is required to operate by remote control beyond line of sight of the controlling unit it would require a dedicated satellite link or an airborne radio relay facility, such as an aircraft, balloon-borne transmitter or another UAV. Alternatively, many UAV systems are capable of operating beyond line of sight by following a pre-programmed navigation route and storing sensor data for access once the air vehicle is within radio range, or has been recovered. If the force commander requires access to near real-time data from the UAV sensors using satellite datalinks then the RAN would need to gain assured access to sufficient satellite bandwidth from either national or allied satellite systems. This could prove problematic given the high level of demand that is emerging for the limited bandwidth available on LEASAT and OPTUS 1C/D satellites that the ADF will have direct access to. Whilst the US and United Kingdom in particular will have extensive world-wide satellite coverage, ADF access to international satellites must be considered in light of the costs and of our likely priority for high bandwidth access against host nation requirements.

Flight Control

Many less sophisticated UAV systems operate by continuous remote controlled flight, whereby an operator flies the aircraft using controls such as joysticks in a similar fashion to model aircraft or personal computer flight simulator flying. This method of control implies a requirement for a degree of pilot training for the operator. The remote pilot maintains aircraft stabilisation as well as positioning the aircraft for each phase of flight. Arguably, the more expensive or operationally critical the UAV, then the more extensive the training program might need to be in order to cater for a wider range of flight variables. Alternatively, more sophisticated UAV systems employ on-board sensors, and automatic flight control, stabilisation and navigation systems to minimise external flight control requirements. External control then becomes largely one of mission management functions such as altering mission profiles, controlling sensors and data distribution, or as a back-up control method in the event of a system failure.

Launch and recovery options

The launching of UAVs from warships presents less of a challenge than recovery. Vertically launched systems would be operated in much the same fashion as existing helicopter or *Nulka* operations. The ship would manoeuvre, if required, to achieve the launch envelope whereupon the air vehicle would be released and controlled clear of the ship before assuming its flight path for the mission. Fixed-wing aircraft usually need to accelerate to a defined minimum speed before aerodynamic lift and control effectiveness can be achieved. UAVs can achieve this through a variety of catapult options, including rocket assisted take-off (RATO) as used by the USN for embarked *Pioneer* UAV operations. The RAN operates the *Kalkara* unmanned aerial target system that uses RATO to launch the aircraft without any ground run.

Pioneer RATO launch

Kalkara RATO launch

Recovery of unmanned aircraft is more problematic than their launch. Vertical landing aircraft can be recovered using manual remote piloting to a conventional vertical landing, or by automatic landing systems such as the US UAV common automatic recovery system (UCARS) which has been trialed at sea on board the USS *Vandegrift* (FFG–48)[35]. Fixed-wing UAVs are presently recovered by more extreme methods, such as by flying the aircraft into a recovery net, by stopping the motor and ditching the aircraft into the water by parachute for a manual recovery, or by mid-air recovery using a manned helicopter or aircraft. The net recovery method was used by the USN for its RQ–2 *Pioneer* UAV operations from *Iowa* Class battleships, and from LPD class vessels. The 'controlled ditching' method is employed by *Kalkara*. These fixed-wing recovery methods would probably be impractical for smaller warships operating in other than relatively benign operational and environmental conditions.

Pioneer UAV net assisted recovery

CL327 UCARS recovery

UAVS AND THE RAN MISSION

The RANs mission is to:

- Be able to fight and win in the maritime environment as an element of a joint or combined force;
- Assist in maintaining Australia's sovereignty; and
- Contribute to the security of our region.[36]

The wide range of UAV missions, noting the various advantages and disadvantages, demonstrates that there is considerable potential for UAVs to support the RAN's mission in future combat and peacetime operations. In particular, UAVs could augment manned helicopter operations. Accordingly, maritime UAV role requirements would need to be developed to ensure that manned and unmanned maritime air assets achieve synergies rather than duplication of effort. Clearly, the successful introduction of a UAV capability would provide more tactical options and depth to Force Commanders. What is less clear, however, is how or when the RAN could introduce such a capability.

UAV OPTIONS FOR THE RAN

There are a number of options the RAN could adopt regarding the possible introduction of UAV operations. This paper will propose three options.

'Wait and see'
Under this option, the RAN would monitor UAV developments worldwide, particularly those related to embarked operations. Given the large expenditure on UAV development to date, which has yielded only limited operational experience, this might be a prudent path. This approach would give the RAN time to learn from other programs and understand which systems and components are more likely to succeed in service. This option is also the minimum expenditure path. The disadvantage would be that the RAN would not gain experience in UAV operations, and would not be able to mitigate the risk to it's manned air assets in the event that the RAN is exposed to hostile operations in the intervening period.

Trial
Under this mid-range option, the RAN would acquire or lease a mature VTOL TUAV along with largely proven support systems such as UCARS and TCS for a 12–24 month trial period, possibly in conjunction with Army. The trial system could comprise a single system, including four air vehicles and a small selection of sensor payloads. The system could be trialed on a range of ships, commencing with an amphibious transport before trials on progressively smaller classes of ship. A mix of RAN, Army and contractor personnel could man the system.

Capability acquisition
Under this option the RAN, possibly in conjunction with Army, would develop or acquire a full operational TUAV capability comprising a number of complete systems for wider introduction in the fleet. This approach would follow the full major capital equipment acquisition path and include full training and support packages. Any UAV program would have to compete for funding priority against other major capital projects.

Concept of operations

A UAV concept of operations should be developed as a precursor to any UAV capability development or acquisition activity. This document should be quite clear about what the RAN desires of any initial operational UAV system. The concept of operations could in many respects incorporate adaptations of the AS350B *Squirrel* helicopter and JP–7 *Kalkara* aerial target system concepts of operations and operating procedures. Particular consideration must be given to tasking procedures and to sensor data dissemination, particularly if data is to be distributed to operational or strategic level commands.

A number of US and United Kingdom UAV programs have encountered difficulties due to requirement creep. Arguably, this phenomenon has inflicted many ADF acquisition programs to date. It would probably be prudent for the RAN to commence any UAV operations from a relatively simple baseline, then expand operations as experience is accrued. For example, operations could commence using a selected proven VTOL TUAV for a single role within line of sight. As experience and system confidence grows, operations could gradually expand to include over-the-horizon and multi-role missions.

SUMMARY

Unmanned Aerial Vehicles have been employed in a wide range of operational roles since the 1960's, in both lethal and non-lethal roles. However, UAV development reflects a history of program failures due to technical problems that have often generated unacceptable cost and schedule overruns. Despite the setbacks large amounts of money continue to be invested in UAV projects because they are seen as important contributors to future operations. The weight of research and development effort and the sporadic yet increasing operational successes for UAVs are resulting in many of the enduring technical problems being overcome.

The ADF could benefit from the advantages that a UAV offers. In particular, UAVs offer the capability to be employed on missions that are considered tactically important but too risky or too long for manned aircraft—the so-called dull, dirty and dangerous tasks.

The RAN could use UAVs to augment manned helicopters in the future organic aviation force, noting that there are particular challenges associated with operating UAVs from ships underway. Before any UAV trial or acquisition program commences a concept of operations should be developed that accounts for the wide range of personnel, systems integration, command and control and operating factors associated with UAV operations.

Arguably, the RAN does not need to develop a UAV capability immediately. There are benefits to merely monitoring global UAV development until the capability is further developed. Alternatively, the RAN could conduct a trial program to examine the feasibility of UAV operations, either in isolation or under a joint project with Army and/or Air Force.

Notes

1 An example of a drone is the Marconi North America and USN QF–4 program, which uses ex-operational F–4 *Phantoms* as high-speed full-scale aerial targets. Aircraft are converted for remote control or pre-programmed flight profiles.

2 M. Hewish, 'A bird in the hand', *Janes International Defense Review*, Vol 32, November 1999, pp. 22–28.

3 Federation of American Scientists, *Outrider Tactical UAV*, www.fas.org/irp/program/collect/outrider.htm.

4 An example of a proposed 'tip over' VTOL UAV is the Sonacom/Sydney University *Mirli* developmental air vehicle. See www.sonacom.com.au/products.htm.

5 US Navy Program Executive Office (Cruise Missiles and Unmanned Aerial Vehicles) news release, *Navy announces winner of VTUAV competition*, 9 February 2000.

6 Janes Unmanned Aerial Vehicles and Targets (electronic version), UAVs, United States of America, *General Atomics RQ–1A Predator*, date posted: 10 December 1999.

7 US Department of Defense, *USAF UAV Concept of Operations*, www.fas.org/irp/doddir/usaf/conops_uav.

8 J. Moore, *Australia in Pioneering Aviation Research*, Ministerial media release MIN 049/99, 1 March 1999.

9 Janes Unmanned Aerial Vehicles and Targets, *Northrop Grumman RQ–4A Global Hawk*.

10 US Department of Defense, USAF UAV Concept of Operations

11 ibid.

12 United States General Accounting Office, *Operation Desert Storm—Evaluation of the Air Campaign*, GAO Report NSIAD-97-134, Chapter 3, June 1997.

13 A. Noguier, 'Next Mission Unmanned', *RAF Air Power Review*, London, vol. 2, no. 4, Winter 1999, pp. 96–120.

14 ibid.

15 Janes Unmanned Aerial Vehicles and Targets (electronic version), UAVs, International, *AAI/IAI RQ–2 Pioneer*, date posted: 10 Dec 99.

16 Operation DESERT STORM provides recent examples, such as the TV footage of downed Royal Air Force *Tornado* crew members Flight Lieutenants Andy Peters and Andy Nichols. These personnel were seen badly beaten and reading prepared statements condemning coalition operations. The capture and mistreatment, including rape, of US female nursing officer Major Rhonda Cornum following the downing of a combat search and rescue helicopter adds another dimension to the prisoner of war public perception issue.

17 US losses from a failed Special Forces operation attempting to capture a Somali rebel leader on 3 October 1993 in Mogadishu. The US lost two *Black Hawk* helicopters and suffered 18 dead and 77 wounded.

18 United States General Accounting Office, *Operation Desert Storm – Evaluation of the Air Campaign*, GAO Report GAO/NSIAD-97-134, at www.fas.org/man/gao/nsiad97134/index.html, June 1997.

19 See for example the Kurchatov Institute's (Russian Research Centre), *Chernobyl and its consequences (project Polyn)*, at polyn.net.kiae.su/polyn/history.html

20 Alta Vista Live! Business Wire editorial, *TRW's Hunter UAV Adds Chemical Threat Detection as Tactical Tool*, at live.altavista.com/scripts/editorial, 20 March 2000. The UAV carried a payload including a fast scanning fourier transform infrared (FTIR) spectrometer allowing stand-off analysis of a chemical cloud.

21 B. Bender, 'Hunter UAV deployment highlights surveillance shortfalls', *Janes Defence Weekly*, vol. 31, 7 April 1999, p. 4.

22 D. Barry, 'Dull, Dirty and Dangerous', *Flight International*, 11-17 June 1997, p. 58

[23] Janes Unmanned Aerial Vehicles and Targets, *Marconi Phoenix*

[24] E. Heinemann, & R. Rausa., *Combat Aircraft Designer*, Jane's Publishing, London, 1980, p. 218.

[25] United States General Accounting Office, *Unmanned Aerial Vehicles: DOD's Acquisition Efforts*, GAO Report NSIAD-97-134, congressional testimony, 4 September 1997.

[26] ibid.

[27] ibid.

[28] House of Commons, *The Sandys Review*, extracted from *Defence – Eighth Report*, www.parliament.the-stationery-office.co.uk/pa.

[29] The only exceptions were the *Lightening* interceptor, about to enter service, and the ill-fated TSR–2 replacement for the Canberra bomber. See for example www.aemann.demon.co.uk/p42/sandys.html.

[30] US Navy Unmanned Aerial Vehicles Project Office PMA-263, *Pioneer Flight Hours and Statistics*, at www.uav.navair.navy.mil/pioneer/flthrs.htm. *Pioneer* entered service in July 1986.

[31] Aircraft unit cost exceeds US$184 million if full cost recovery of the US$23 billion research and development program is included. Again, this does not include infrastructure and personnel costs. See for example Congressman J. Lewis, US Congress House Defense Appropriations Subcommittee Chairman, *The F–22 Debate*, Online News Hour, 27 July 1999, www.pbs.org/newshour/bb/military/july-dec99/f-22_7-27.html.

[32] US Department of the Navy, Vertical Take-off and Landing Tactical Unmanned Aerial Vehicle (VTUAV)—Concept of Employment, OPNAV N853f Draft G, Chapter 5, 1 June 1999.

[33] Janes Unmanned Aerial Vehicles and Targets (electronic version), UAVs, *Bombardier CL–327 Guardian and CL–427*, 20 August 1999.

[34] US Navy Program Executive Office (Cruise Missiles and Unmanned Aerial Vehicles), News Release, *July a Big Success for TCS*, 26 August 1999.

[35] Janes Unmanned Aerial Vehicles and Targets, *Sierra Nevada UCARS*, date posted 20 August 1999.

[36] *Australian Military Doctrine (RAN Doctrine 1)*, Defence Publishing Service, Canberra, 2000, p. 5.