The UCAV Ascendancy:

What are the Problem Issues?[1]

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Abstract. This paper explores a number of fundamental technology issues which will present obstacles to Uninhabited Combat Aerial Vehicles fulfilling a broader portion of the mission spectrum currently performed by manned combat aircraft. These obstacles are then discussed in the context of Australia's AIR 6000 program.

In the context of Australia's public debate on program AIR 6000[2]*, the UCAV frequently assumes mythological proportions. Indeed, a former Minister of Defence advocated UCAVs as a possible alternative to manned aircraft.*

There can be no doubt that much of the enthusiasm for UCAVs as manned fighter replacements in Australia stems from budgetary pressures to which the RAAF, and the ADF as a whole, are being subjected. The prospect of 'robot fighters' which do not incur the large cost overheads of fast jet pilot training and retention, or the difficulties in recruiting suitable candidates for pilot training, is clearly attractive to many participants in this debate. The essential argument for the UCAV is centred on a perceived lower cost of ownership and fleet operation, in theory allowing the RAAF to field a substantial combat force without the budgetary grief traditionally associated with manned fighters. With the RAAF facing very significant funding challenges in fielding the AIR 5077 Wedgetail 'Pocket AWACS', the AIR 5402 tanker replacement, and ultimately the AIR 6000 F/A-18A replacement, any alternative which is perceived to yield a major reduction in 'bucks per achievable bang' will inevitably develop a following.

This paper will explore some of the fundamental technological issues which present obstacles to UCAVs assuming roles currently performed by manned fighters.

Roles and Missions

The essential starting point for any comparative discussion of the merits of manned aircraft against UCAVs, or vice versa, must be roles and missions to be performed. A necessary and essential condition for the replacement of any capability with an

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[1] Paper prepared for the `UAV Australia' conference, 8&9 February, 2001, Melbourne, Australia.

[2] AIR 6000 aims to replace the F/A-18A Hornet and possibly the F-111 Aardvark. Refer Figure 1.

alternative is that the substitute can effectively do the same job, and ideally do it either better for the same expense, or cheaper.

Figure.1 AIR 6000 aims to replace the F/A-18A Hornet, and possibly the F/RF-111C/G tactical fighters (Author).

If we consider the role spectrum performed at this time by the F/A-18A Hornet in Australian service, we will find that the aircraft is primarily used for counter-air operations, with secondary strike roles in which it supplements the larger F-111C/G. These roles can be further subdivided thus:

- Offensive Counter-Air - flying Combat Air Patrols into contested airspace to destroy opposing fighter aircraft, and supporting assets.
- Defensive Counter-Air - flying Combat Air Patrols over the air-sea gap or Australian territory to destroy opposing aircraft and cruise missiles.
- Maritime Strike - supplementing the F/RF-111C/G and P-3C as Harpoon ASCM delivery platforms, and providing fighter escort for the former in contested airspace.
- Close Air Support / Battlefield Air Interdiction - supplementing the F/RF-111C/G in striking at opposing ground forces either in contact with or in the proximity of Australian ground forces, and providing fighter escort for the former in contested airspace.
- Defence Suppression - supplementing the F/RF-111C/G in striking at opposing air defences, and providing fighter escort for the former in contested airspace.

- Interdiction and Strike - supplementing the F/RF-111C/G in striking at opposing strategic assets and road/rail communications, and providing fighter escort for the former in contested airspace.

In essence, the F/A-18A will fight for control of the air, and once this is achieved, swings to supplementing the F/RF-111C/G in attacks on surface targets.

The role spectrum for the F/RF-111C/G is no less challenging in its breadth and its depth:

- Offensive Counter-Air Strike - destroying hostile aircraft on the ground, air bases and other supporting infrastructure.
- Defence Suppression - destroying hostile air defence assets, especially radars, C3 and SAM/AAA systems.
- Strategic Strike - destroying hostile strategic military assets, such as ballistic missiles, C3, port facilities, fuel supplies etc.
- Maritime Strike - destroying opposing maritime surface assets using the Harpoon, AGM-142E and guided bombs.
- Close Air Support / Battlefield Air Interdiction - striking at opposing ground forces either in contact with or in the proximity of Australian ground forces.
- Interdiction - striking at opposing road/rail communications.
- Defensive Counter-Air - interception of opposing maritime patrol aircraft and transports at large operating radii.

Both the F/A-18A and the F/RF-111C/G will rely heavily upon the Wedgetail AEW&C aircraft and aerial refuelling tankers.

The capability goals in the December 2000 White Paper are quite specific, in that they define the geographical footprint for such operations to encompass the air-sea gap to Australia’s north and north west, and for strike operations any base or asset within the region which could be used to threaten Australia or ADF forces operating in the region.

A UCAV replacement for either or both the F/A-18A and F/RF-111C/G would therefore have to cover an exceptionally broad role spectrum, and do so with no loss in flexibility, over a geographical footprint which necessitates aerial refuelling on almost every single mission profile. This is no mean feat by any measure.

Figure 2. Cyberdyne T-800 Terminator, the central protagonist of James Cameron's `Terminator' sci-fi thrillers, is perhaps the best contemporary popular representation of the self-aware autonomous robot warrior (Photo copyright Universal).

Wherein do the Obstacles Lie?

There are no fundamental technological obstacles in aerodynamics, structures, propulsion, flight controls and low observables technology which would preclude the design of a UCAV capable of matching or exceeding the aerodynamic performance, load carrying capability and combat radius of either the F/A-18A or the F/RF-111C/G. Given the dictates of Breguet's equation, such a UCAV would be similar in size and weight to the aircraft it is replacing, given that the weight and volume of the pilot and mission avionics are not substantial in relation to the gross weight of combat aircraft in this category. To deliver an F-111 sized payload to the radius of an F-111 will require a roughly F-111-sized UCAV, at a similar cost in airframe technology.

The much bigger issue to be resolved here is that of replacing the decision-making entity, which is the pilot or pilot and navigator, and the mission avionics used to support the flight crew.

Current UCAV literature identifies two idealised extremities in implementation. One is a 'dumb RPV' wholly controlled in every respect by a remote human operator over a datalink. The alternative is a wholly autonomous 'robot fighter' which in the manner of James Cameron's 'Terminator' is assigned a target to kill, and does so with the cunning of a human pilot, and the error free precision hoped for of true artificial intelligence (AI). Refer Figure 2.

To wholly replace a modern manned multirole fighter across its role spectrum, a UCAV must in the limit conform to either of these hypothetical paradigms[3].

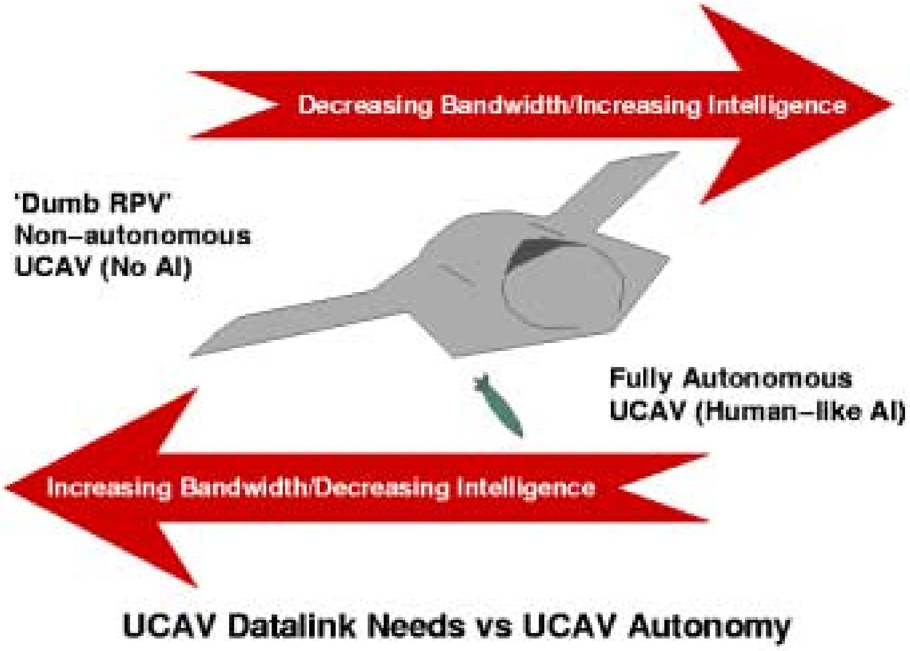

Figure.3 With increasing autonomy the demands for datalink capacity and thus bandwidth to a UCAV will decrease. In the limit, a UCAV with human-like cognitive and reasoning ability would require no more datalink bandwidth than a manned combat aircraft (Author).

The 'dumb RPV' model essentially amounts to using a digital pipe to transfer what the pilot of a manned aircraft sees from his cockpit over hundreds of nautical miles or more into the remote cockpit of an operator in a controlling aircraft, or ground installation. It must do so without loss of information, thus imposing challenging demands in bandwidth, and also do so with exceptional reliability in a hostile jamming environment, thus further exacerbating bandwidth needs.

To establish a reasonable bound on required data channel capacity, a throughput of the order of a high definition television (HDTV) picture would arguably be reasonable. Using lossy compression techniques, this is typically of the order of tens of Megabits per second, per UCAV. Using lossless techniques for mission critical imagery and data, the capacity demand could be much higher. If we assume an aggressive jamming environment, a spreading ratio of the order of 1000 or more for a noiselike modulation may be required. This imposes bandwidth requirements of the order of 10 GHz per UCAV. Such bandwidth requirements are arguably not

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[3] The alternative could be argued to be some balance between the non-autonomous and fully autonomous extremes. The difficulty in such a hybrid is where to set the `datum point' for splitting the decision-making intelligence between the UCAV and the remote controller.

implementable over satellite microwave links, given the established antenna and transmission technology base, and the need for both redundancy and the concurrent support of multiple UCAVs in a given area of operations.

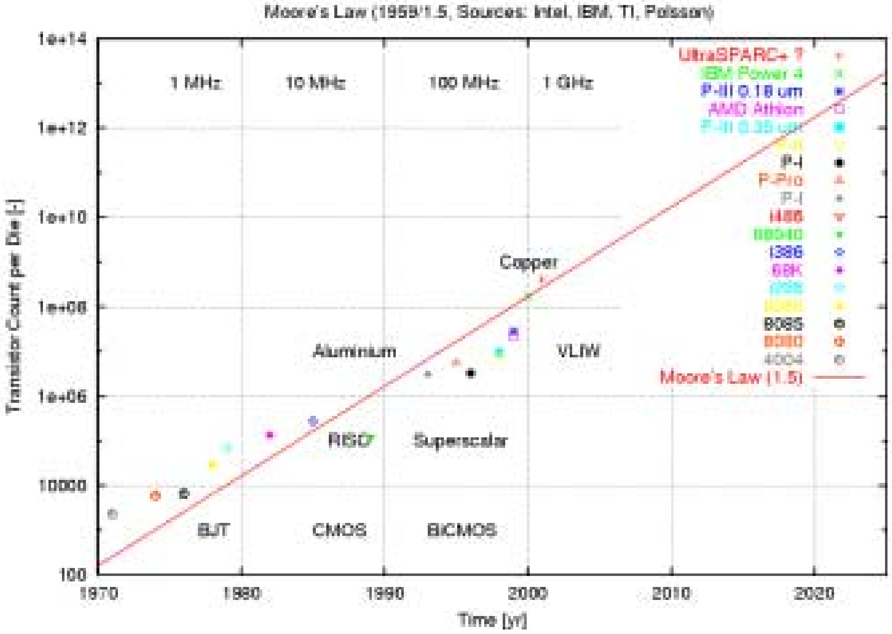

Figure 4. Moore's Law for microprocessor transistor counts, on a logarithmic scale. The exponential growth rate in component complexity is plotted here for a range of commercial processor chips. Transistor counts around 1 billion can be expected around 2005 (Author).

Tropospheric propagation constraints are not conducive to the use of millimetric band channels of such bandwidth over the distances associated even with Low Earth Orbit satellite channels. Propagation delays of milliseconds preclude genuine real-time control loops, and thus operator inputs must amount to commands to an autopilot in the UCAV.

In the limit, the 'dumb RPV' would not appear to be economically implementable if it were to wholly replace a modern manned multirole fighter.

The 'robot fighter' model essentially replaces a human 'wetware' brain with true artificial intelligence, implemented with software running on digital computer hardware. Full autonomy, assuming such an AI can be eventually built and packaged into the required volume, has other implications. The 'robot fighter' UCAV will require the whole sensor package carried by an equivalent manned fighter, since the AI would require access to all of the same inputs a human pilot (or navigator) would.

To predict the emergence of true AI technology within a bounded timescale is wholly speculative at this time. Moore's Law can provide robust predictions of transistor counts in single chip processors. Given that fundamental science based predictions frequently do hold over single decade timescales, then it is reasonable to predict processor chips within this decade with a billion or more switching elements. Arrays of hundreds of such processor chips would thus provide a comparable number of switching elements to characteristic neuron counts in human brains.

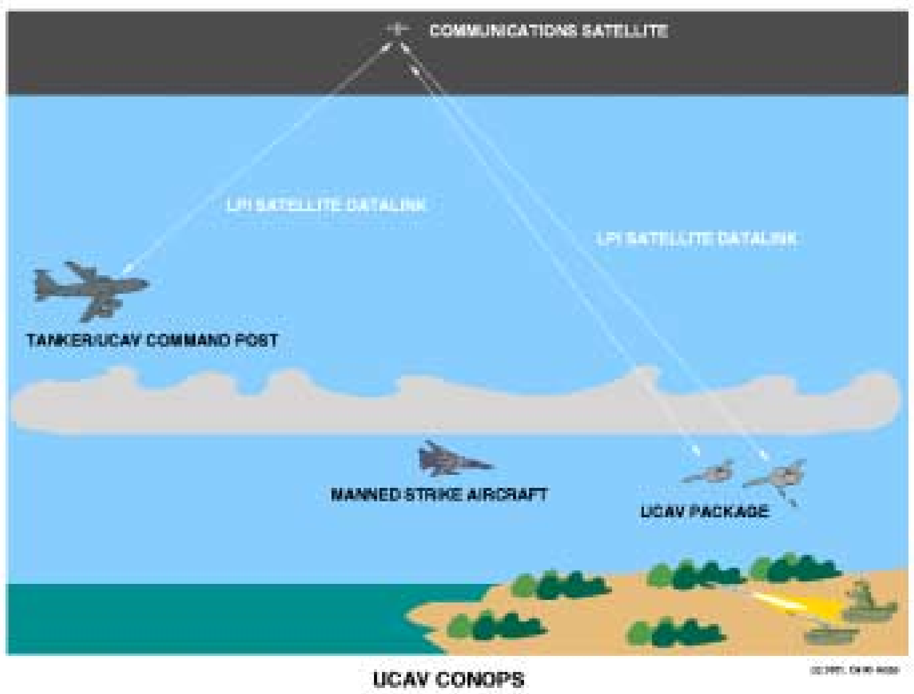

Figure 5. CONOPS for a SEAD/DEAD and fixed target strike UCAV. The UCAV supplements manned aircraft in situations where prohibitive risk of aircrew loss occurs (Author).

However, the assumption that piling together the number of switching elements contained in a human brain will result in an entity which exhibits the reasoning and cognitive capabilities of an experienced combat pilot does not follow.

What does follow, is that until the Computer Science research community solves the problem of creating a true AI, a wholly autonomous ‘robot fighter’ which can match or exceed the tactical skills of a competent combat pilot is simply not implementable.

The essential consequence of this argument is that the expectations of many in the Australian defence community, that UCAVs can wholly replace manned fighters, are not reasonable given the established technology base and the technology base which can be reasonably expected over the coming decade, which is the decision timescale for AIR 6000.

Should a breakthrough in the computing sciences occur in coming decades, such that a genuine AI can be produced, then other consequences will follow. Perhaps the most important of these is that wholly autonomous ‘robot fighters’ matching the capabilities of manned fighters will be no cheaper than manned fighters. Whatever economies may be achieved in removing pilots are likely to be rapidly absorbed by the overheads in programming/training and maintaining man-like machine intelligences.

Figure 6. Boeing/DARPA UCAV demonstrator, here depicted dropping a pair of GBU-32 JDAM GPS/inertial guided bombs (Boeing).

The assumption that such a machine intelligence will be devoid of the complicated internal behavioural oddities which we term ‘psychology’ in ‘wetware’ intelligence cannot be supported at this time. Indeed, current experience in software engineering would suggest that any systems which comprise many millions of lines of software represent serious reliability and maintainability challenges.

Does this prognosis rule out the UCAV as a viable combat asset for the RAAF?

The answer is critically contingent upon what our expectations of a UCAV are. If the expectation exists that a UCAV is to wholly perform the complex and frequently rapidly evolving role spectrum performed by manned fighters, then the answer is yes. If the expectations of a UCAV role spectrum are less ambitious, and it is to be a supplementary asset for particular niche roles only, then UCAVs can indeed be very useful combat assets if properly supported.

UCAVs and the RAAF

Current reasoning in the US UCAV community, described in the AFSAB and DARPA references, realistically accepts current technology limitations and constrains the role spectrum of UCAV technology demonstrations to SEAD/DEAD[4] and fixed target strike roles.

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[4] Suppression of Enemy Air Defences, Destruction of Enemy Air Defences.

Figure 7. Northrop-Grumman UCAV Proposal. This design evidently exploits the low observable design rules devised for the B-2 bomber (Northrop-Grumman).

Both are roles which have been successfully performed by expendable munitions, SEAD/DEAD by the Northrop AGM-136 Tacit Rainbow loitering anti-radiation drone, fixed target strike by autonomous cruise missile types such as the BGM-109 and AGM-86. A UCAV performing such roles is thus a reusable equivalent of established ‘expendable’ technology used in these roles.

The aim of such UCAVs is to supplement manned aircraft in situations where extremely high risks to aircrew exist, without the prohibitive costs incurred by the sustained use of expendable weapons of the required complexity. A reusable Tacit Rainbow or Tomahawk offers greater lethality than the expendable weapon, and the sustainability of a manned aircraft in a protracted campaign. Refer Figures 5, 6, 7 and 8.

The algorithms required for a stealthy UCAV to evade threats such as emitting SAM systems, and deliver relatively autonomous weapons such as GPS guided bombs or antiradiation missiles are also well within the reach of current technology.

Should the RAAF aim to pursue a UCAV based solution for addressing SEAD/DEAD and some fixed target strike roles, other issues do arise.

The first of these is achieving the range performance characteristic of a large fighter which is refuelled in flight. Should an off-the-shelf UCAV with 600-800 NMI combat radius be available, some scheme for aerial refuelling would be required to match the radii of available manned aircraft. A UCAV would need the capability to rendezvous with a tanker and then hook up to take on fuel, a task which is not entirely trivial to perform even by an experienced combat pilot.

Figure 8. Lockheed-Martin UCAV proposal. This design exploits some of the low observable design rules devised for the X-35 JSF (Lockheed-Martin).

The second issue is that no economies will exist in the provision of pre- and post-strike targeting intelligence, against manned aircraft. The same overhead in satellite or Global Hawk imagery intelligence will be incurred regardless as to whether the warhead is delivered by a cruise missile, manned fighter or UCAV.

Perhaps the most difficult issue is that of providing the necessary satellite channel capacity and coverage footprint for operations over the required geographical extent. If we conservatively assume that such a UCAV requires no more than one Megabit/s of data channel capacity, a strike package of two dozen such UCAVs requires of the order of tens of Megabits/s of capacity over a radius which could be as great as 2,500 nautical miles, given recently declared strategic capability goals[5]. With provisions for channel redundancy and noiselike modulations with high spreading ratios, this is a demanding requirement, alone well in excess of satellite capacities extant and planned for by the ADF.

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[5] Refer the December 2000 White Paper, `Defence 2000'.

Clearly technological solutions do exist. A geosynchronous satellite with a large steerable antenna capable of flooding a spot of several hundred nautical miles in diameter is not an unreasonable proposition, and near real time control of the spot position is also feasible. Line of sight datalinks between tankers and UCAVs are also a perfectly reasonable proposition.

However, none of this technology is cheap, and thus important questions must be raised as to whether the use of such UCAVs to fulfill niche roles is justified, given that these niche roles can be accommodated by manned fighters with the role specific overheads of specialised munitions and aircrew training.

Conclusions

One of the principal virtues of modern air power is its unparalleled flexibility, which in a large part is the reason why air power is progressively displacing naval and land power as the preferred means of firepower delivery. That flexibility mostly derives from the presence of a competent aircrew in the cockpit of a combat aircraft. Currently envisaged UCAVs, by design specialised assets for niche roles, are by their nature inflexible assets, and thus divert resources from manned aircraft without the flexibility which the very same resources would yield if expended on manned aircraft.

To build a case for an RAAF UCAV capability, it will be necessary to prove that the cost of the UCAV force, its supporting satellite capabilities, and other necessary supporting capabilities, are lesser than or equal to the costs incurred by using some fraction of the manned combat aircraft force to fulfill the very same niche roles equally well.

Even given the potential for unexpected breakthroughs in artificial intelligence, this will be no mean feat to perform.

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About the Author

Carlo Kopp attended the University of Western Australia, and graduated in Electrical Engineering with First Class Honours, in 1984.

After more than a decade in industry engineering positions, in 1996 he completed a research Masters degree in Computer Science. More recently, he completed a PhD degree. His thesis dealt with long-range microwave data links, exploitation of phased array technology and mobile computer networks. Both degrees were completed at Monash University in Melbourne.

Carlo Kopp is best known publicly in Australia as a trade journal writer. Writing for Canberra based *Australian Aviation* journal since 1980, he has specialised in military aviation, technology, and strategic issues. More recently, his work has been published by the US *Journal of Electronic Defence*, UK *Jane's Missiles and Rockets*, and Amberley based *Air Power International* journal. He has also written monthly computer technical features for Sydney based *Systems* and *Commsworld*, since 1994, covering computer systems, software and networking issues.

His other professional interests include air warfare strategy, doctrine and information warfare. His work in this area has been published by the Royal Australian Air Force, the United States Air Force and he has contributed to Winn Schwartau's book on Information Warfare, published in 1996 in the US. His most recent works are a 140 page study on aerial refuelling aircraft, published by the RAAF, and a technical study paper proposing a range of new guided weapons for the US F-22 and JSF fighters, published by USAF *Aerospace Power Chronicles*.

Carlo Kopp enjoyed competition aerobatics and display formation flying until 1994. He was issued a low level aerobatic approval in 1992, and has qualified for a night multi-engine rating. At this time he is working on regaining his currency. He has flown the RAAF PC9/A twice and the F-111C simulator on three occasions.

He is a member of the IEEE, AIAA and AOC professional societies, and currently teaches computing topics at Monash University.