AR-008-372

DSTO-GD-0044

Unmanned Aerial Vehicle Technology

K. Cameron

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ABSTRACT

This document reviews the individual technologies that may be applicable to Unmanned Aerial Vehicles (UAVs). In addition an overview of UAV systems as a new technology and their integration into the existing ADF structure is considered. Despite there having been considerable interest in UAVs for at least twenty years they have not as yet become a significant factor in operations, outside Israel and possibly the Gulf war. The number of operational systems is limited as is the specific technology base of UAVs. This may be due to the need for a significant market before industry will make the investment needed and to the users not being able to acquire suitable systems. Therefore it is likely that slow progress will be made until a 'critical mass' is achieved when industry will make the needed investment to produce the range of UAVs required by the users.

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DEPARTMENT OF DEFENCE

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DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

Published by

DSTO Aeronautical and Maritime Research Laboratory
PO Box 4331
Melbourne, Victoria 3001, Australia

Telephone: (03) 626 7000
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AR No. 008-372
February 1995

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EXECUTIVE SUMMARY

This document reviews technologies relevant to unmanned aerial vehicles (UAVs) in the context of the Australian Defence Force (ADF). There have been a number of studies carried out on behalf of the ADF by DSTO looking at particular applications. A general review of the information collected during these studies is presented in this document. Whilst it is primarily a review of UAV system technologies some consideration is given to the wider implications of introducing a UAV system to the ADF.

UAVs have been used overseas, primarily by Israel and in the Gulf war, but have not achieved general acceptance as military systems. There have been many systems under development, some for up to twenty years, but few successful deployments. However, UAV systems appear to offer great potential as military systems and there is considerable interest and activity in many countries about them. In this context the ADF has been assessing the possibilities for the acquisition of a UAV system, in particular for the army. The most likely role would be in the area of reconnaissance and surveillance using electro-optical sensors, although a number of compatible payloads (in size, mass etc.) may also be options. The ranges considered are in the close to short categories (e.g. out to say 300 km) and the vehicle would be relatively small, propeller driven and fixed wing. The vulnerability of a UAV to countermeasures in the context of a low level conflict is considered both from the point of view of actions to damage the UAV system and measures that would otherwise degrade its effectiveness. Launch and recovery methods are looked at as these are a problem with all UAV systems and may be more so in the Australian context where there is a lack of sealed runways, or even roads, in the most likely operational areas. The Australian situation is different from most overseas scenarios and it would be difficult to base UAV operational concepts on overseas experience. Therefore while the acquisition and deployment of a current UAV system may not add much to present ADF capabilities it would generate an experience base from which to assess future systems. This may be sufficient justification for acquiring a UAV system because the introduction of UAVs appears to be inevitable in the longer term and the establishment of the supporting infrastructure (logistics, command structure etc.) would assist in the acquisition and introduction of future systems.

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Keith Cameron obtained a B.Sc. (Hon) in aeronautical engineering from the City University London while working for the UK Defence Department. He then studied at the Cranfield Institute of Technology and was awarded a M.Sc. in aerodynamics in 1975. On returning to Australia in 1975 he joined the Department of Transport's Flying Unit as a flight operations engineer. He moved to the then Aeronautical Research Laboratory (ARL) in 1976 to partake in remotely piloted aircraft development. During his time at ARL he has worked on systems aspects of a number of projects including Ikara and Nulka. This work has include aerodynamic testing, development of data acquisition systems, autopilot development, trials and studies at both systems and operational levels. He is curreny working in the area of instrumentation and data acquisition systems for aircraft trials and wind tunnels.

1.0 Introduction

The primary purpose of this document is to review the individual technologies that may be applicable to unmanned aerial vehicles (UAVs). The flight vehicle will be referred to as a UAV and the overall system (flight vehicle plus ground control station (GCS) launch and recovery equipment etc.) will be referred to as the UAV system. The term GCS will be used although in some instances the UAV may be controlled from a ship or airborne platform. This document, based on information gathered in support of the studies described in References 1, 2 & 3, reviews the technology required by small UAV systems. The information presented here is more general than that in the above references and may be of use in considering the potential of UAV systems. In addition section 2.0 provides an overview of UAV systems as a technology new to the ADF and their integration into the existing ADF structure.

A UAV system may provide new capabilities to carry out existing functions more efficiently, or offer some other advantage over existing practices (e.g. reduce risks to personnel). The context for the work described here is Australian Defence Force (ADF) applications; principally for the land force but with some consideration of naval requirements. The technologies and specific types of equipment relevant to UAV systems are identified and then examined for their applicability both in their current form and short term future forms. There is some emphasis towards surveillance and reconnaissance type missions as these are seen as the most likely ADF application in the near term.

The studies described in References 1 & 2 determined a number of requirements and methods of operation for UAVs operating with the ADF. These studies also determined the type of UAV system required and, from a market survey, identified a number of suitable candidate systems. A compendium of information (magazine articles, reports and manufacturers' data sheets) has been collected to support this study and the earlier studies [1 & 2]. This compendium provides the input from which this document has been compiled.

2.0 UAV System Implications for the ADF

In order to justify the acquisition of a UAV system, the UAV must perform some function (either existing or planned) more cost effectively than current systems. For example in the surveillance and reconnaissance role it could provide real-time images of a number of locations using multiple air vehicles. While the same result could be achieved using sensors mounted on other platforms, such as manned helicopters, the advantage in using a UAV may be in cost effectiveness, vulnerability reduction, covertness or some other reason that justifies the acquisition of UAVs.

Although the ADF currently operates a number of UAVs in the form of target aircraft these have little in common with surveillance and reconnaissance UAV systems. Therefore the acquisition of a UAV system principally for surveillance and reconnaissance or related missions such as radio relays would involve the introduction of a totally new technology (at the system level) to Australia.

UAV systems range in capability from small units that are man-portable and capable of limited daylight surveillance to very large systems capable of operating multiple sensors day and night over long ranges. The cost of acquisition of a UAV system ranges from around $50,000 (single air vehicle man-portable system) to tens of millions of dollars for a large system. Operational costs also depend on the type and size of system acquired.

When considering the acquisition of a UAV system, interfacing with existing defence systems is an important issue, particularly in the following areas:

i. Human resources required: although the UAV is unmanned the UAV system will require a number of personnel to operate it. Therefore it is necessary to determine a number of factors such as, where they are to come from, the number, the skills required, the type of command structure and support services that are needed (e.g. fuel, spare parts, maintenance and repair, food and shelter). Also should such personnel be dedicated to the system or shared with other systems?

ii. Logistics: whilst some parts of a UAV system may be common to existing non-UAV systems (e.g. ground vehicle parts), the majority of the parts will be different and require additional support services.

iii. Command: a UAV system needs to be integrated into the existing command structure in order to make full use of its capabilities. This requires an understanding of UAV system effectiveness relative to existing systems to enable decisions to be made on when and where to deploy a UAV rather than some other system. Under some circumstances the UAV may provide capabilities that cannot be provided by alternative systems.

iv. Information: an effective UAV system will acquire large amounts of data probably in the form of real-time video images although other data may also be acquired. To be of use, information extracted from these data must be passed to the areas within the ADF where it is needed and methods for feeding information into the existing information network need to be developed. The format for transferring the information must be considered as raw data, such as real-time video, requires wide bandwidth data links for transfer. Therefore transferring real-time data from a number of flight vehicles would occupy a number of wide bandwidth communications channels between nodes in the command structure, and these channels may not be available. Although this problem may be alleviated by the use of data compression techniques the wide dissemination of raw data is unlikely to be practicable.

v. Operational safety: air traffic control and general flight safety will be of concern in areas where other aircraft are operating and also where personnel on the ground may be at risk. Part of the philosophy behind UAVs is that they do not need to use 'human rated' equipment due to the absence of a pilot. This does not take into account the risk that in-flight equipment failures may endanger the operators and other people on the ground within the area of operations. Risks to other airborne platforms arise because the UAV operator is incapable of detecting them, unless they are in the sensor field of view which may be narrow and looking downward. The UAV itself is inherently difficult to detect and therefore other aircraft are unlikely to be aware of its presence. To avoid a situation that may result in an accident, close coordination between UAV operations and normal air operations would be required.

3.0 UAV System Technology

Any UAV system, other than basic UAVs limited to a few kilometres range, relies on a wide range of technologies to collect, analyse and disseminate information. These technologies include:

- airframe and propulsion systems for the vehicle;
- control systems and sensors to fly the vehicle;
- launch and recovery systems;
- electro-optic and other sensors to gather information;
- data links to transfer information to and from the vehicle; and
- ground control equipment.

3.1 Payloads

The payload is the most important part of the UAV system. The rest of the UAV system exists to place the payload in position and in most cases to collect, process and disseminate the information gathered by the payload. The flight vehicle specification is determined from payload mass/size, vehicle endurance, operator field of view and speed over the ground requirements. These must be considered along with mission requirements, such as range/endurance and operational requirements such as vulnerability. An examination of manufacturers' data on UAVs indicates that generally the all up mass (AUM) of the flight vehicle is around four times the AUM of the payload. Large vehicles require large support systems, such as launch and recovery equipment, all of which add to the cost and complexity of the overall system. Therefore while system payload performance requirements must be met it is also important to minimise payload mass.

3.1.1 Sensors

The most common UAV sensors are electro-optical sensors that return a real-time video image to the GCS. These include daylight TV and/or forward looking infrared (FLIR) which together provide 24 hour coverage. Other sensors may be used to gather different types of data, for example electronic support measures (ESM) or radar. The choice of sensor(s) depends on application requirements, vehicle carrying capacity and costs. A charge coupled device (CCD) daylight camera is both light/small and relatively cheap. This can result in a small relatively cheap UAV (e.g. AeroVironment's Pointer has a mass of 4.7 kg and costs around $US50,000) but with limited range/endurance and daylight-only capability. Stabilised TV/FLIR sensor packages can give 24 hour coverage but require flight vehicles weighing hundreds of kilograms and costing millions of dollars.

CCD TV

CCD TV provides a black and white or colour television picture during daylight hours but has no night vision capability. CCD cameras are available with very low masses and costs.

Low Light TV (image intensified TV)

LLTV is essentially a CCD TV with the addition of an image intensifier to provide a measure of night vision capability. As with normal TV imaging the LLTV relies on ambient light but the highest gain systems will work at light levels down to that of a clear starlit night. The addition of the image intensifier adds a little to the mass and the images are monochrome. The cost of the image intensifier is currently quite high ($1K to $20K depending on performance) although it may fall in the future.

Infrared Systems

IR systems that operate in the near IR detect reflected IR light with wavelengths shorter than about 1.5 μm. Thermal IR systems detect longer wavelength thermal radiation emitted by objects. Objects that have different thermal emission characteristics from the background stand out. Except for the pyro-electric vidicon, thermal imaging systems require cooling to low temperatures in order to operate. The cooling and insulation requirements add to the mass of the imaging system making it considerably heavier than the CCD and LLTV systems. IR systems also tend to be relatively expensive.

Film Camera

A film camera may be used to get high quality images but there are some problems with this approach. A method of aiming the camera at the desired target is needed and the image is not available to the user until after the UAV has been recovered and the film processed. The loss of the UAV results in the loss of the pictures.

Radar

Small radars, both conventional and Synthetic Aperture Radar (SAR), are available for use in UAVs. By lifting the radar the UAV provides a means of extending the radar horizon, which depends on altitude of operation. Also the UAV can carry the radar to locations that give improved coverage (e.g. further forward or around an obstacle such as a mountain). Radar payloads are quite large and heavy although not much more so than current IR systems. The UAV must be configured to accommodate the radar antenna. The Israeli Aircraft Industries (IAI) Searcher UAV can operate a SAR supplied by the ELTA division of IAI.

Electronic Support Measures (ESM)

As with the radar case the advantage of mounting the ESM system on a UAV is the increased horizon and mobility it provides.

Nuclear, Biological and Chemical (NBC) Sensors

NBC sensors are an ideal payload for a UAV in that they are compact, and intended to operate in hazardous environments. The UAV can sweep an area searching for NBC hazards without putting personnel directly at risk.

Sniffer

Sniffer sensors have been used in the past as fixed ground sensors (e.g. Vietnam) to detect the presence of humans or their activities. Also environmental sensing has been carried out using such sensors for air pollution monitoring on a UAV. This could be considered as an extension of NBC monitoring to airborne particles and gases in general. Depending on size, sensitivity etc., sniffer sensors are potentially a useful option for a surveillance/reconnaissance UAV.

Magnetic

Anti-Submarine Warfare systems use magnetic sensors to look for magnetic anomalies and such a sensor may be useful in a maritime UAV.

3.1.2 *Non Sensor Payloads*

A UAV provides a method of transporting equipment such as jammers and radio relays to otherwise inaccessible areas.

Jammers

A UAV could be used to carry a RF jammer(s) to interfere with an opponent's communication and other systems. The UAV extends the range of the jammer and allows flexibility in jammer positioning. The positioning flexibility is especially useful as the power required to jam a signal increases with range (approximately proportional to range squared). Additionally, removing the emitter from the UAV user's position aids concealment.

Radio Relays

Radio Relays are used to extend communication link ranges either between ground stations or between a ground station and another airborne station. Currently in the ADF such relays are set up on high ground and permanently manned. A UAV relay would be more flexible and probably less vulnerable.

Decoy

Decoys for use against weapon systems (such as anti-ship missiles) and search systems (e.g. radar) are currently deployed by means such as helicopters. A UAV may be a more cost effective means of deploying decoy payloads.

3.1.3 *Payload Stabilisation*

Electro-optical sensor payloads (CCD TV and IR) require stabilisation to compensate for the effects of vehicle motion and vibrations. In order to make full use of the available resolution the image motion at the focal plane during image frame time must be less than one pixel width. This level of stabilisation plus the ability to steer the sensor about two axes requires a high quality stabilised, steerable gimbal system for the sensor. Typically the gimbal system weighs three times as much as an IR sensor and many times more than some other electro-optical sensors. Reducing the mass of the stabilisation system significantly would pay large dividends throughout the whole UAV system. Logistic support, manning level and maintenance considerations would all benefit from a reduction in payload mass. Replacing the onboard mechanical stabilisation system with image processing onboard or in the ground station has the potential for great savings. This would reduce the airborne requirement to a steerable mount which may be much lighter and cheaper than a stabilised system. Alternatively, optical stabilisation (like that employed in automatic levels) may be useful because of reduced mass by comparison with full mechanical stabilisation.

3.2 Data Link

The data link provides communications between the flight vehicle and the ground control station. It may also, as in most current systems, be the basis of the UAV's navigation system.

3.2.1 *Functions*

For real-time sensing the data link transfers control signals to the vehicle from the GCS, sensed data from the UAV and vehicle condition parameters to the GCS. If the vehicle can operate autonomously the data link may be shut down temporarily. The main functions of the data link are as follows:

i. Control of the UAV
The control of the UAV from the ground provides flexibility and real-time planning of UAV activities unavailable with preprogrammed drone flights.

ii. Control of the payload
Independent control of the payload is desirable, for example an electo-optical payload should be steerable and have zoom control.

iii. Status of the UAV
It is necessary to monitor the condition of the UAV and its systems and to have access to parameters such as fuel level and engine temperature.

iv. Status of Payload
The condition of the payload also needs to be monitored to ensure its optimum performance .

v. Sensed Information from Payload
In the case of a sensor payload the data gathered, such as a TV image, needs to be transferred to a ground based receiver, usually at the GCS.

3.2.2 *Data Link Implementation*

Conceptually there are a number of methods for implementing the data link, ranging from high frequency (HF) radio through higher frequencies to light beam links and finally physical links such as optical fibre. While some UAVs use the very high frequency (VHF) band, currently most systems operate data links in the ultra high frequency (UHF) band.

HF

HF data links are not limited to line of sight transmission ranges. However, the range over which they will work is variable from day to night and day to day; the bandwidth available is too narrow for the transfer of video data at real-time rates; the long transmission range means that stations many thousands of kilometres away may interfere with the signal and the link is far from secure. Developments in the areas of HF data links combined with data compression and the use of reduced frame rates may make this type of data link viable in the future.

VHF, UHF or Microwave

These higher frequency data links have sufficient bandwidth to carry real-time video signals but are limited to line of sight. They are used in the vast majority of current UAVs that are controlled from the ground and return real-time images. The aerial on the flight vehicle is usually omni-directional while, in order to get longer ranges, a high gain tracking antenna is used by the ground station. Having a narrow uplink beam helps make the uplink more secure while the omni-directional downlink can be intercepted over a wide area. To add similar security to the downlink would require a directional aerial on the vehicle which would need to be kept pointing at the ground station. With directional aerials at both ends the link is difficult to intercept/jam and lower powers may be used but the need for a steerable antenna on the vehicle is a major impediment to this arrangement.

Satellite

Using a satellite data link removes the range limitation set by the need to remain in line of sight of the ground station for a terrestrial data link. The problems with satellite systems are: the UAV must know where the satellite is at all times; a steerable antenna large enough to contact the satellite must be carried; the down links from the satellite, at both ends, can be intercepted over a wide area; and conversely, signals can be injected into such a link from over a wide area (possibly beyond Australia) either to jam or corrupt the data link.

Optical

An optical link is similar in concept to UHF data link but uses light (visible or other) as the transmission medium. This is clearly a line of sight link requiring directional transmitters and receivers at both ends in order to achieve a useful range. Laser beams are well suited for this purpose. Range capability depends on features such as beam power, divergence, wavelength and atmospheric conditions. Ranges of hundreds of kilometres may be possible in heavy installations. Optical links may provide a secure link without concern for scarce frequency allocation. Whilst directional 'aerials' are needed these may be physically smaller than those needed for VHF/UHF, and hence more compatible with a small air vehicle. The use of narrow beams presents a problem in the event of a temporary loss of contact as re-establishment of the data link may prove difficult. However, given a good onboard navigation capability and a fixed GCS if should be possible for the UAV to direct its transmissions to the GCS. Once the GCS detects these transmissions it should be able to direct its own transmissions to the UAV.

Fibre Optics

A fibre optic data link is both fully secure and has a large bandwidth capability. However the UAV must carry and pay out many kilometres of optical cable. The mass of cable required for reasonable ranges (more than a few kilometres) is excessive for small UAVs and the cost is currently prohibitive. Also experiments by AeroVironment raised the environmental effect of draping kilometres of difficult-to-recover fibre optic cable across the landscape.

3.2.3 *Data Compression*

The problems caused by the high bandwidth requirements of electro-optical sensors may be alleviated by compressing the data prior to transmission. There are a number of compression techniques that may be applicable, such as Discrete Cosine Transforms (DCTs) or fractal compression. The benefits of using data compression are that narrower bandwidth can be used for transmission, and more data can be stored in a given storage capacity.

A combination of compression and reduced frame rates may even make the use of HF data links feasible, at the cost of loss of picture detail and/or frame rate. The criterion for judging the quality of images after decompression is based on the viewer's perception of loss of picture detail. In the UAV case the fine detail may be important. In the case of automatic target detection systems the lost detail may be vital for maximising detection probabilities.

3.3 Flight Path Management

In order to manage a UAV mission the operator must know where the UAV sensor information is coming from (e.g. the centre of the FOV in the case of an electro-optical sensor). Therefore UAV position and sensor pointing angles are needed to enable the operator to direct the sensor in the required direction. This process may be automated in some of the larger and more sophisticated systems.

3.3.1 Navigation

Knowledge of the UAV position is essential for all but the most trivial of missions. Apart from very short range vehicles (1 to 2 km) where the operator can see the vehicle at all times, a navigation system is required. The accuracy required is mission dependent and would be a major input to deciding which system to adopt.

Sensor Information

With an electro-optical sensor operating over a well known area it may be possible for an operator to determine the UAV position from the video image returned. However, due to the limited field of view and unusual viewing angles this is difficult and not likely to be practicable in most situations. Radar payloads may also provide information useful in determining the UAV's position. However, this is unlikely to be sufficient as a stand-alone navigation system.

Dead Reckoning

This method relies on using the UAV air speed and direction to determine position. This combined with the information coming from the primary sensor (to provide periodic fixes) may prove adequate over a limited area. However, as a general area navigation system it is unlikely to be reliable and could impose a significant work load on the operator.

Data Link

The data link may be used to obtain the range and bearing of the UAV from the ground station. This information is sufficient for a fairly accurate fix (typically 100 m error at 50 km) to be obtained in real-time. This provides an effective navigation system and is widely used in small UAVs. Loss of the data link at any time deprives the UAV of navigation information and a fall back system is required.

Satellite Navigation System

The Global Positioning System (GPS) based on a constellation of American satellites provides position and time information to suitably equipped users. The accuracy of the position information depends on whether the user has access to the precision 'P' code or not. Without the 'P' code, accuracy is about 100 m and with 'P' code the accuracy improves to around 20 m.

Because the errors introduced into the GPS system are common over large areas a knowledge of the errors at one location can be used to correct a GPS derived 'fix' at a different location. A reference GPS system in a UAV GCS could be used to acquire the GPS errors for the area of operation and the UAV position errors can then be corrected to get a more accurate UAV position. This technique is known as differential GPS.

Conceptually it is possible to jam the system locally; the area covered by jamming is dependent on a number of factors such as jammer power and terrain type. The simple light cheap GPS systems most suitable for a small UAV are the easiest to jam. However, in the low level contingency situation such jammers may be difficult to deploy due to their having to be carried and provided with significant power. In addition the presence of a UAV may be hard to detect and the operation of a jammer may itself give away positional information.

The Russian Glonass system is an alternative to GPS but it may not be competitive.

Inertial

Inertial navigation systems are self contained, do not need to emit signals and do not depend on external signals except during initialisation. The drawbacks in the UAV context are that existing systems are heavy, expensive, require accurate pre-flight alignment, consume significant power and the position errors increase with time. However, laser gyro-based systems are now being introduced that may be sufficiently light, low-powered, compact and priced to be compatible with UAVs.

Terrain Matching

Terrain matching correlates the ground profile being traversed (measured using a radio altimeter together with a barometric altimeter) with a profile derived from a digital map of the area. This provides information which when combined with a primary navigation system such as a low grade inertial system, forms an accurate low drift navigation system. The total cost of the primary navigation system plus the terrain navigation system should be less than for a good inertial system. However, the need for a primary navigation system plus radio altimeter may make this system heavier and more expensive than is desirable for a small UAV.

Scene Matching

The matching of a picture from the primary sensor with a known view could be used to improve the accuracy of a primary navigation system, as with terrain matching. However prior knowledge of scenes is required and this is currently only practical for a limited number of views.

Radio Location

Position may be determined from observation of a number of known radio transmitters such as commercial radio stations. This relies on their continued operation during the period of UAV use; see References 4 & 5.

3.3.2 *Vehicle Control*

Vehicle control stabilises the vehicle, and controls speed, altitude and direction. In nearly all UAVs this function will be highly automated. Possible exceptions may be very short range vehicles that could be controlled like radio controlled model aircraft.

3.3.2.1 Control Parameters

In order to control the vehicle the onboard control system (autopilot) requires information on the UAV attitude, speed and height. These parameters may be measured using dedicated sensors or in some cases obtained from other onboard systems. For example an inertial navigation system may provide all parameters apart from airspeed and altitude, and a GPS system does not provide any control parameters although height above a datum may be available. Altitude may be obtained in a number of ways. A barometric altimeter is simple to implement and can use the static pressure line associated with an airspeed system while a radio (or possibly laser) altimeter measures height above local terrain. Airspeed is an essential flight control parameter as aircraft flying characteristics are related to airspeed rather than speed over the ground. While there are many ways of measuring airspeed such as using ultrasonics or thermocouple based methods the classical pitot-static system is probably the best for a UAV and static pressure also provides altitude information. Vehicle attitude may be obtained from an inertial navigation system or a combination of discrete gyroscopes and accelerometers. The latter methods work for straight and level flight, but may not function after prolonged circling in one direction. Circling may be used to maintain a point on the ground in view but the direction must be periodically reversed in order to maintain accurate attitude reference. Rather than circling to maintain a point within the sensor field of view a pattern such as 'figure eight' is preferable as this averages out over a complete cycle to be equivalent to level flight. Flight direction may be obtained from an inertial navigation system or by using a magnetometer to sense the earth's magnetic field. As the magnetometer requires the air vehicle to be in level flight for accurate heading measurement a directional gyro may be needed to provide a heading reference during manoeuvres. Continuously turning flight will degrade the heading reference as the gyro drifts and a similar limitation on manoeuvres as for the attitude system above applies.

Whilst the mission's primary sensor (TV FLIR etc.) gathers information for people outside the UAV ground control unit, this information may also be of use to the UAV operator. Vehicle attitude and altitude may be estimated from the sensor output, and navigation updates may be obtained by recognition of known features.

3.3.2.2 Flight Path Adjustments

Except in the most basic of systems the onboard autopilot will be responsible for controlling the vehicle so that the measured parameters closely follow the demanded values. Essentially the throttle, via the power plant, controls the total energy of the vehicle while the control surfaces are used to control the attitude of the vehicle and the balance between potential and kinetic energy.

While it is possible for the primary sensor to be strapped to the vehicle's airframe and aimed by pointing the vehicle this is generally unsatisfactory, especially for imaging sensors. A much better system is to have an independently steerable sensor mount which may be stabilised in order to achieve clear high resolution pictures.

3.3.3 Guidance

Guidance is the part of the system that ensures the vehicle follows the desired flight path. Information defining both the flight path desired and the vehicle position must be available. The changes required in vehicle parameters to keep the vehicle on track may then be deduced and corrections passed to the control system. All, some or none of these functions may be contained within the flight vehicle.

3.3.3.1 Launch Phase

The need for control during the launch phase depends on the type and duration of the launch phase. Take off from a runway requires accurate guidance over a considerable distance and time. The major problem in runway operations is to obtain a sufficiently accurate spatial reference for the flight path control system. 'zero length launchers' provide direct physical constraints in the form of guide rails during the launch phase.

Direct Operator Control

Take off under direct operator control is similar to model aircraft operations: the operator observes the vehicle visually and sends commands directly to the vehicle control surfaces to vary the flight path. Variations on this could include some degree of auto stabilisation in the vehicle control system and/or the operator may observe the UAV via a video link.

Ground Control Station

Control of the take off process from the GCS may be quite feasible in the case of zero length launchers where flight speed is attained near the end of the launcher. Control of take off from a runway would be more difficult due to limited information available to the GCS operators and the narrow field of view from the UAV sensors. After lift off the main task is to maintain a stable climb which could be an automatic task similar to that required at other stages of the flight. Therefore it should be possible to take off from a runway under GCS control. A white line marking the centre of the runway plus other markings such as distance references would aid this task.

Fully Automatic

This may be quite practical where a zero length launcher is used as flight is achieved quickly. In the case of unassisted take off from a runway, a fully automatic take off may be impractical due to the lack of spatial references suitable for the accurate guidance of the vehicle on or near the runway/ground.

3.3.3.2 Mission Phase

The mission phase constitutes the bulk of the flight, starting once the vehicle has been launched and ending at the commencement of the landing or other recovery phase. This may include periods beyond data link range under automatic control carrying out pre-planned manoeuvres or the execution of procedures to recover from data link loss.

Direct Operator Control

Operation is limited to visual range or at most a few kilometres.

The AeroVironment Pointer is controlled in this manner and has a maximum range of 5 km. One operator controls the vehicle using a directional control and an altitude control. A second operator points the data link antenna at the vehicle and therefore must be able to see it at all times.

Ground Station Control

The principal GCS supports a number of UAV functions including mission planning, data analysis and vehicle control. Direct control of the vehicle, while possible, is undesirable and the lowest level of control should be entering direction, speed and altitude commands. A step up from this to enter waypoints for the vehicle to pass through and for observing objects, steering the sensors and having the vehicle fly holding patterns that provide the required sensor field of view would be appropriate. From the mission point of view the gathering of information using the onboard sensor is the function to be controlled and control of the vehicle is only a means to support this function. Mission planning goals are concerned with placing the sensor so that it may acquire the required information and return it to the GCS in the most efficient manner. Ultimately this mission planning may be automated as part of the GCS systems.

Auxiliary Ground Station Control

In some situations the UAV may be required to operate over an area too large to be covered by one GCS and one or more auxiliary GCSs may be used. In this situation, control of the UAV is passed from one GCS to another. An auxiliary GCS would have many of the capabilities of the main GCS but need not require functions such as launch and recovery .

Remote Operator Control

Small units (e.g. reconnaissance patrol) may have a requirement for localised control of a UAV in a small area. This may only require a very basic GCS providing short range control, possibly using direct observation of the UAV and sensor data as in the direct control method above, but using the higher level control functions of the UAV system. Such a GCS may even be man portable.

Fully Automatic

At present fully automatic control is used in reconnaissance drones which are preprogrammed to fly a particular flight path to gather information and return with it. The control function is in the vehicle and entails flying the preplanned flight path with reference to an area navigation system. This system lacks flexibility and as there is generally no data link, no data are obtained until the vehicle returns.

In the future it may be possible to install more computer power onboard the UAV, thereby making functions such as automatic target detection practicable. The next step would be to have the vehicle respond to sensor input and guide itself according to this sensor input. This type of operation has a number of attractions. The principal emissions from both the vehicle and the GCS are due to the data links; eliminating these would improve UAV survivability and effectiveness (the data link would be activated only when there are useful data to be passed). The load on the GCS and its operators would be greatly reduced and possibly more UAVs could be controlled from one GCS. Areas that could not be reached under GCS control, either due to range or terrain masking, could be examined.

3.3.3.3 Recovery Phase

Recovery of UAVs without damage to the vehicle or equipment on the ground (or ship) is a major problem which inhibits their acceptance in many applications, especially at sea. Recovery requires precise guidance and control and is often complicated by the presence of wind and turbulence. No completely satisfactory solution to this problem has yet emerged.

Direct Operator Control

As with direct operator control of take off mentioned above the UAV is flown in a mode similar to a model aircraft. This could include control of a vehicle after deployment of a parafoil or other controllable parachute.

Landing Guidance System

Landing aids such as an instrument landing system (ILS) are unlikely to be available unless the UAV operates from a major airfield. However, simple techniques such as using the onboard sensor to home in on a light beacon behind a recovery net are quite feasible. This method of homing in on the light may be 'human-in-the-loop' or fully automatic.

Ground Control Station

The control of the UAV from the GCS relies on sensor input from the UAV and possibly other sources such as the data link (UAV range and bearing). Generally the information available is not adequate for the precise control of the UAV needed for landing.

The view from a UAV TV sensor is usually narrow and lacking in depth information that would be available to the pilot of a manned aircraft. This may make the landing task too difficult to be carried out from the GCS: usually the GCS would bring the UAV back from its mission into an area where control would be taken over by an external pilot or automatic landing system for recovery.

Fully Automatic

Fully automatic landing is similar in many ways to fully automatic take off mentioned above and with the possible exception of net recovery is not practicable at present. In the net recovery case the UAV is flown straight into the net which absorbs the UAV kinetic energy.

3.4 Power Plant

Generally the smaller UAVs of the type likely to be acquired by the ADF would be propeller driven although rocket assisted take-off may be possible. The efficiency of small propellers is not good (as low as 60% - 70% compared to 80% - 90% for larger propellers) and this coupled with other installation problems make the propeller a significant factor in overall power plant considerations.

3.4.1 Propeller Efficiency

Propeller installations on many small UAVs are far from optimal. The propellers are small, compared to manned aircraft, and operate at low Reynolds numbers. Because the primary sensor needs a clear forward view the propeller is usually used in a pusher configuration. This places a small propeller in the wake of a relatively large body and the resulting efficiencies are low compared to those of full size aircraft. Low propeller efficiency leads to a requirement for greater installed power and fuel consumption.

3.4.2 Internal Combustion Engines

Almost all UAVs are powered by some form of internal combustion engine; small UAVs either by two stroke or four stroke petrol engines, and large ones by gas turbine engines.

Two Stroke

Small two stroke engines have good power to mass ratios and are of relatively simple construction. This makes them attractive from a mass and cost point of view for UAVs. However the specific fuel consumption is greater than for equivalent four stroke engines, especially if compared at part-open throttle settings. Small two stroke engines are readily available in power outputs starting at fractions of a kilowatt up to many tens of kilowatts.

Four Stroke

The four stroke engine's lower power to mass ratio is offset by better specific fuel consumption. As flight time is increased the total mass of the engine plus fuel becomes less, relative to an equivalent two stroke engine plus fuel, and at some point is less in absolute terms. The four stroke is more complex and costly than the equivalent two stroke engine and less readily available. Nevertheless, suitable engines are available to cover the power range from less than a kilowatt up to many hundreds of kilowatts.

Gas Turbine

Gas turbine engines are generally unsuitable for small UAVs, except possibly rotary wing vehicles. They have a good power to mass ratio but the smallest engines produce more power than small UAVs require and as gas turbine engines are reduced in size they become less efficient. These UAVs operate at slow to moderate speeds where jet propulsion is relatively inefficient. Therefore a turbine driven propeller or rotor would be required, and as the small engines run at high rotational speeds a large ratio and therefore heavy reduction gearbox is required.

Fuel

UAV gas turbine engines use the same fuel as turbine powered aircraft. However the vast majority of two and four stroke engines use Avgas which is not generally used by other military engines (except piston engined aircraft). Therefore UAVs require a supply of Avgas to be provided specially for their operations. This is undesirable from a logistics point of view and Avgas is a more dangerous fuel to store and handle than the fuel oil used by the majority of military piston engines. Because of this there is currently a considerable research effort to develop piston engines for UAVs that will run on the generally available fuel oil. It is likely that in the future it will be a requirement that UAVs operate on fuel oil rather than Avgas.

3.4.3 *Electric Propulsion*

Internal combustion engines are by far the most common power plants for UAVs of all types and sizes. However electric power is an alternative that is used in a small number of UAVs, and may become more prevalent in future. The main obstacle to electric propulsion is the lack of a suitable power source; none of the sources described below come close to the energy density of liquid fuels, or they are tied to a ground based energy source.

Electric Motors

An electric motor is an ideal power plant for a UAV as it can be matched to the propeller, easily integrated into the airframe and there is little vibration or noise emitted and no exhaust gases. Electric motors are easy to control, start reliably, and may be stopped/restarted in flight. However the provision of the necessary electric power onboard a flight vehicle is a problem which has not yet been satisfactorily solved. In a small number of UAVs the limitations of electric power sources have been accepted but until a suitable power source becomes available electric propulsion will not be generally accepted.

Batteries

Batteries come in two types: either primary batteries which are made fully charged and can only be discharged once; or secondary batteries that once discharged can be recharged electrically, and for which the charge/discharge cycle can be repeated many times. The two main measures of battery suitability are energy density and power density. The energy density indicates the total stored, recoverable energy to mass ratio of the battery, and the power density the rate at which the energy may be extracted. The energy density of even the best batteries (at about 20% that of hydrocarbon fuels) is much lower than that of fuels for internal combustion engines. Also the batteries with the highest energy densities have the lower power densities, and this limits the power available during critical flight periods such as take off. In addition, for any given battery, as the discharge rate is increased the energy density falls.

Fuel Cells

Fuel cells differ from batteries in that the reactive part of the cell (usually a liquid) can be replenished so that power may be produced continuously. The reactant is considered to be a fuel as it is pumped into the cell somewhat like petrol into an internal combustion engine. The exhaust product is the depleted reactant.

There are many prospective fuel cell configurations and types of fuel. The power and energy densities are similar to batteries at the current stage of development. There does not appear to be much general usage, or availability, of fuel cells; probably because batteries are as good and are an established technology. However, fuel cells are used in a number of special applications where it appears they are custom designed for the application (e.g. space craft). Unless fuel cell performance outstrips that of batteries it is unlikely that they will displace batteries in general portable power applications. In some applications where a quick recharge is essential (such as electric vehicles) the fuel cell may have the necessary performance advantage provided the basic energy and power densities can be achieved. Research and some development into fuel cell technologies continues but off-the-shelf fuel cells suitable for UAV applications are unlikely to be available in the near future. There is also the issue of having to provide and store a non-standard fuel. As in the case of Avgas, mentioned above, this is undesirable from a logistics point of view.

Long Lead

Power may be provided to a flight vehicle via a cable from the ground. However, this restricts both the range and manoeuvrability of the vehicle. Such vehicles have been built and they operate in much the same manner as a balloon by hovering above a ground station that supplies the power. The reaction time (time to launch) is likely to be much better than for a balloon as is the stability and ability to operate in adverse weather conditions (especially high winds). Endurance is indefinitely long. Such a vehicle provides an elevated observation platform from which the local area may be kept under surveillance. It may also be used to support an elevated antenna.

Microwave

The long lead above may be replaced by a microwave link that transmits power to the air vehicle. Experiments have shown that this system works, but no UAVs using this system are known to have been developed. While it extends the range of operation relative to the long lead, the microwave link is probably inefficient and would emit a strong signal for enemy ESM systems to detect.

3.5 Configuration

Many configurations have been proposed for UAVs at various times. However, all real vehicles, both developments and in service, could be considered conventional by manned aircraft standards. These vehicles are either fixed wing with a tailplane (although a number of developments have been just flying wings) or rotary wing.

In addition at least one company has been experimenting with some small lighter than air vehicles.

3.5.1 Fixed Wing

The majority of UAVs fall into this category including all those currently known to be in service around the world.

Because the primary sensor is usually configured for a forward view, many designs operate with pusher propellers either at the back (usually flying wings), between the twin tail booms, or mounted high in the centre above the fuselage. Some vehicles are modified target drones and retain their tractor propellers. Aerodynamic efficiency does not appear to have been pursued to great lengths as most vehicles have moderate aspect ratio wings and lack extensive streamlining in other areas. This results in UAVs with installed power which appears to be excessive for the performance achieved.

Propulsion installation designs also appear to result in less than optimum efficiency, and there is clearly scope for improvements in this area which could lead to increases in capabilities such as range and endurance. The electric powered Pointer is one of the more aerodynamically efficient UAVs, presumably due to the limited power available from batteries, and indicates what can be achieved.

Many UAV designs appear to be aimed at getting robust and reliable vehicles at minimum cost. To achieve this in some cases modified target drones are used, and in others components from assorted sources (manned aircraft sensors, chainsaw motors, etc.) have been used.

It is possible that as UAVs become more accepted and widespread more efficient configurations will emerge. This in part depends on the availability of a support industry able to provide components designed for UAV use (such as power plants, sensors, etc). However, the situation is not likely to improve in the near future as the demand for UAVs would not support the development of such components for UAVs alone.

3.5.2 Rotary Wing

The rotary wing configuration appears to solve a number of problems that arise with fixed wing UAVs, in particular the launch/recovery problem. The abilities to hover and point the sensor in any direction and to back track during surveillance missions are inherent. Despite these advantages there are no rotary winged vehicles currently in service.

There have been some extensive development programs (one lasting over 20 years) resulting in vehicles that have had service trials but none have progressed to operational use. There appear to be a number of reasons for this; firstly the in flight performance (in terms of speed, endurance, vibration levels etc) is less than for an equivalent fixed wing vehicle; the vehicle complexity is greater leading to higher initial and operational costs; power requirements are greater leading to the use of gas turbine engines instead of relatively cheap piston engines; and hot and/or high altitude conditions adversely affect performance more than for fixed wing vehicles. Even in the naval case where it would appear that a rotary winged vehicle could operate from a platform on small ships, difficulties arise in adverse conditions.

The US Department of Defence has recently cancelled a number of development programs aimed at developing vertical take off UAVs (effectively rotary winged vehicles) primarily intended for naval use. The one remaining rotary wing UAV is the Canadair CL227 which has been around for over 20 years in one form or another without going into service.

3.5.3 Lighter Than Air

Lighter than air (LTA) UAVs would appear at first sight to have some advantages, notably an ability to remain airborne without consuming much energy. However the lack of airships either manned (other than for commercial TV coverage and advertising) or unmanned in the skies suggests that they have significant disadvantages. There are some tethered LTA systems used to elevate radar systems and one very small experimental LTA UAV equipped with a video camera.

The disadvantages of airships/balloons seem to be: they are bulky and cumbersome to deploy, especially in high winds; have a low airspeed capability; are large and hence can be seen at long range (possibly transparent envelopes would alleviate this); and buoyancy varies with temperature making altitude control difficult. Although free flying LTA UAVs have not emerged as yet there may be specific applications (possibly in the context of monitoring unattended ground sensors) where they would be appropriate.

3.6 Structure

The purpose of the vehicle structure is to carry and protect all the sub systems associated with the vehicle. There may be other constraints on the structure such as minimisation of radar reflections, and the structure may perform secondary functions such as providing electromagnetic shielding for the internal components.

3.6.1 Fixed Wing

In the case of the smaller UAVs being considered the structure required to resist the aerodynamic forces could be very light, for example as in model aircraft. However, in the case of a functional UAV the design must cater for ground handling and launch/recovery. Therefore the UAV structure may need to be much stronger, stiffer and heavier than the flight regime would indicate in order to withstand handling and launch loads. In some cases the structure may be designed either to come apart under excess loads or to deform so as to absorb energy, for example on crash landing.

3.6.2 Rotary Wing

For a rotary wing vehicle the lift and control forces are usually generated by the rotor or rotors (UAV designs usually use contra rotating rotors rather than a tail rotor). These rotor(s) and their attachments are the structurally critical parts of the vehicle. The cyclic nature of the forces associated with the rotor make material fatigue a major consideration for these parts and to a lesser extent for the vehicle plus sub systems as a whole. The body of the vehicle may be kept compact, having a good volume to surface area and an efficient structure.

Rotary wing UAVs have a limited manoeuvre capability which in turn limits the maximum forces applied to the structure by air loads. Take-off and landing are relatively well controlled compared to fixed wing UAVs and the forces generated during these processes are normally modest. Therefore while flight critical rotor components may suffer from fatigue the vehicle structure as a whole tends not to be subjected to excessive loads during operations.

3.6.3 Materials

The choice of materials is between traditional aircraft metals (aluminium) or composites such as glass fibre or kevlar reinforced plastics. The majority of UAVs appear to be constructed mainly from composites. This is presumably due to their good structural properties: light, strong and with appropriate design stiffness and damage resistance. Also most UAVs appear to be manufactured in small numbers for which composite airframe construction is more efficient than metal. In thin sections composite materials can be made radar transparent although this may not always be an advantage: see sections 3.7.2 and 3.8.2.

3.7 Vehicle Emissions

Emissions from the vehicle that may be detected by an opponent contribute to the vulnerability of the vehicle: they need to be identified and if possible reduced in order to minimise vehicle detectability.

3.7.1 Direct Emissions

Direct emissions are taken to be those which are generated by systems onboard the UAV. These systems either deliberately send signals to the outside world or leak energy from internal processes. In both cases the emission potentially reveals the UAV's presence and location.

Thermal

All onboard activities produce heat as a waste product which must be transferred to the environment. The major source of heat in most UAVs is the propulsion system. Even if electric power is used for propulsion the motor and batteries will probably still be the main sources of waste heat although at a lower level than for an equivalent internal combustion engine.

The cooling fins and especially the exhaust system on an internal combustion engine attain temperatures well above ambient. In order to mask thermal emissions these components need to be shielded and cooled with plenty of air to keep temperatures down. The associated ducting affects vehicle design, particularly in the area of aerodynamic drag reduction.

Acoustic

As with thermal emissions the main source of acoustic emissions is the power plant and propeller: using electric power would greatly reduce such emissions. Detectability of these acoustic emissions depends on terrain and the background noise in the operational area. In remote areas acoustic emissions are those most likely to reveal the UAV's presence and it is therefore important to minimise such emissions. An omni-directional acoustic sensor designed to filter out the background noise and search for frequencies associated with engines may be able to detect a UAV at a considerable distance. Neither acoustic nor other sensors specifically designed to counter UAVs appear to be commercially available at present, but they would be easy to develop.

Optical Radiation

It is unlikely that there will be any detectable optical radiation from a UAV, especially during the day, unless some form of illuminator is used by the UAV. This illuminator could be a laser designator or night area illumination to aid the search sensor. It is possible that a data link to the GCS could use an accurately aimed laser diode.

Electro Magnetic

There are many sources of electro magnetic emissions from any UAV, some intentional and others unintentional. With appropriate electronic design and shielding, the unintentional emissions such as thermal radiation from onboard electronics should be at a low level and difficult to detect at practically significant distances from the UAV. The intentional emissions such as the data link are, in general, omni-directional and could be easily detected by an opponent who may be much closer to the UAV than is the GCS.

It is possible to take action to avoid detection by using techniques such as spread spectrum to hide the data link signal in the background noise. If and when automatic target detection becomes available onboard a UAV, the data link may be closed down until a target is found, thereby avoiding detection of the data link during the search phase.

Engine Exhaust

The exhaust from an internal combustion engine may be detected by visual means in the case of smoke and by sniffer sensors (including the human nose). Visible smoke emissions are particularly easy to detect if they form a line contrasting with the background. Even low concentrations of exhaust gases may be detectable using appropriate gas detectors. A relatively simple improvement in detection capability might be achieved using a trained dog due to dogs' much keener hearing and sense of smell.

3.7.2 *Indirect*

Indirect emissions are taken as those where an externally generated energy field is disturbed by the UAV (e.g. the earth's magnetic field, radar waves etc.)

Radar Reflection

UAVs are generally small compared to manned aircraft and are therefore harder to detect using radar. Also many UAVs use composite material in their construction which further reduces their radar signature. One consideration with composite construction is that while the structure may no longer reflect radar signals its transparent nature allows internal components to become radar reflectors. Components such as the engine and in particular long strips of metal (control rods or wiring etc.) may act as dipole aerials and provide a strong radar return. Under such circumstances a reflective skin would shield these components and reflect the radar signals less efficiently, scattering a weaker signal in a number of directions. With some care the radar signature of a UAV can be made much lower than that of a manned aircraft.

Light Reflection or Obstruction

A UAV with glossy light-reflecting surfaces may give off 'glints' of reflected sunlight as it manoeuvres in clear daylight. Also the casting of a shadow on the ground may attract attention and lead to detection of low-flying UAVs.

The glint problem may be reduced or eliminated by ensuring that there are no glossy surfaces on the UAV.

3.8 Vulnerability

Once the presence of the UAV is discovered by opponents, they may attempt to take action either to reduce its effectiveness or to destroy it altogether. Vulnerability of UAVs to various countermeasures is currently an important issue as there is little experience on which to base assessments. There are many claims (particularly by manufacturers) that UAVs are very difficult to counter. However, more general experience indicates that while a new system may enjoy a period in which countermeasures are ineffective, in time, effective countermeasures are developed. The effectiveness and cost of countermeasures relative to UAV system cost may ultimately determine the overall viability of UAV systems. The vulnerability of a UAV to such action is discussed below by reviewing the options open to an opponent.

3.8.1 Passive Action

While passive action does not result in loss or damage to the UAV itself, from a mission point of view, it may exploit a system vulnerability and may be even more effective than destroying the UAV. Given that the UAV mission is to detect a hostile presence, any action against the UAV that reveals a hostile presence actually assists the UAV in conducting its mission. Conversely any action that prevents detection, such as concealment, negates the usefulness of the UAV, unless the action taken to avoid the detection undermines an opponent's mission.

3.8.2 Direct Action

Direct action is action taken against the flight vehicle with the aim of physically damaging the vehicle as a whole or damaging some operationally critical vehicle component. Such action would be successful if the UAV could not continue effectively with its mission (e.g. could not gather and/or send useful information to the GCS).

<u>Mechanical</u>

Physical damage to the UAV may either degrade it and force the mission to be ineffective or aborted, or destroy the UAV altogether. It appears that it is difficult to hit a UAV either with gunfire or missiles. The use of missiles against a UAV may not be cost effective due to the cost of the missile relative to the cost of the UAV and the probability of success. Also in the context of low level conflict, ground to air missiles are unlikely to be freely available to an intruding force.

Laser

It is unlikely that lasers capable of destroying a UAV will be operationally available in the near future, especially to small ground force units. However, the UAV sensors may be vulnerable to low power lasers that are already available. There would be a need to aim the laser beam at the UAV sensor while it was looking in the general direction of the laser operator. Damage to, or total destruction of, a UAV sensor could make continuance of the UAV mission pointless.

Other

It may be possible to damage or interfere with the UAV's electronics by such means as the electro magnetic pulse from a nuclear detonation (unlikely in the Australian context) or by illuminating the UAV with a high power radio transmission (e.g. radar at close range). For example the radar of a ship being examined at close range by a UAV may be able to affect the UAV's systems. A radar absorbing or reflecting skin would provide some protection for internal systems.

3.8.3 *Indirect Action*

Indirect action is action against parts of the UAV system other than the air vehicle. This action may either physically damage part of the system or cause disruption which degrades mission performance.

Ground Control Station Vulnerability

Action against the GCS may be a viable alternative for an opponent, in that the GCS is less mobile than the UAV and it also emits strong electromagnetic signals. The signals are usually narrow beam but strong enough for an omnidirectional receiver on the UAV to operate at ranges up to 100 km. Techniques, such as spread spectrum, may reduce the probability of detection. However, the base station, once located, is larger than the UAV and potentially is an easier target.

Data Links

The relatively complex system of data links associated with UAV operations could possibly be disrupted. There is an uplink for vehicle control, a downlink for sensor data, and a downlink for vehicle parameters. In addition the UAV system may use other data links to disseminate information obtained from the flight vehicle. Any or all of these data links are potentially vulnerable to jamming.

The uplink to the vehicle would seem to be the most vulnerable when the vehicle is close to an adversary and far from the GCS. In this situation the signal from the GCS is at its weakest, and the adversary operating a disruptive system such as a jammer may be very close to the UAV. As the flight vehicle usually carries an omni-directional aerial it is easier for a jamming signal from nearby to overpower the signal from the GCS. This may be countered to some extent by the UAV being able to operate autonomously for a period in the absence of the control signal from the GCS. In theory it would be possible to take over control of the UAV in these circumstances so that encryption of command signals may be needed to avoid commands from any source other than the GCS being obeyed.

The jamming of the downlinks and other data links with a ground based jammer is much less likely. This is due to the narrow beam width of the GCS antennas, the elevation of the UAV providing spatial separation (and possible terrain masking of the jammer) between itself and the jammer, and the fact that both UAV and jammer are likely to be at comparable ranges from the GCS.

Navigation

Currently many UAVs use the data link to determine position for navigation purposes. Therefore as discussed above jamming of the data link is a possibility and this would also interfere with vehicle navigation. In the future, navigation is likely to be based on systems such as GPS. These are radio signal based systems, whose radio signals come from an array of satellites. They are therefore potentially jammable.

In the case of GPS its susceptibility to jamming is considerably reduced by using the military 'P' code system which also provides better accuracy than the generally available 'C/A' code. As a UAV would almost certainly have a secondary navigation capability (either speed and heading or possibly low grade inertial) the loss of GPS signal due to jamming would degrade the UAV's capability rather than result in its loss. A more subtle approach than jamming would be to corrupt the GPS signal (possibly by re-transmission of the real signal) to produce a navigation error in the UAV.

3.9 Launch and Recovery

3.9.1 Launch

Getting the flight vehicle airborne is one of the critical areas of UAV operation. In most applications operation away from airfields and/or prepared sites is a major requirement. Launch becomes more difficult when operation from confined areas is required. Various methods have been developed and used successfully, but none could be considered ideal in all situations.

Hand Launch

Hand launch has been used for some very small UAVs, notably AeroVironment's Pointer which has an all up mass of less than 5 kg. Pointer has a maximum range of 5 km and maximum endurance of one hour.

Bungee Launch

In principle a stretched elastic cord (bungee) could be used to launch a UAV. In its simplest form a bungee would have one end staked to the ground and the UAV attached to the other end of the stretched cord. On release the energy store in the bungee cord would be used to accelerate the UAV to flight speed. There are some potential hazards to personnel with this system such as the cord 'whipping around' or the stake coming out of the ground. No current UAVs appear to use this type of 'open air' bungee launcher.

Mechanical Launcher

Mechanical launchers are usually truck or trailer mounted launch rails with a catapult mechanism to accelerate the UAV to launch speed. The power source for the catapult varies and may be a spring, or compressed air, or even a bungee cord as above. In this application the bungee cord is restrained within the launcher structure and the hazards mentioned above are eliminated.

Rocket Assisted Take Off (RATO)

RATO involves attaching a small rocket to the UAV to provide acceleration up to flight speed. RATO has been used operationally both on land and at sea. Whilst it provides a simple compact launch system there are some difficulties in the handling and storing of pyrotechnics. The operating cost is higher (a new rocket motor is used for each launch) than for other methods although the capital cost may be less. Emissions from the rocket exhaust may reveal the launch site.

Runway

A UAV equipped with an undercarriage can take off from a runway in the same way as a manned aircraft. This method is used extensively by the Israelis with their numerous types of UAV. While minimising launch equipment this approach requires an undercarriage with its associated weight and drag penalty. Because the vehicles and the undercarriage, including the wheels, are small the runway needs to be sealed. Israel is a small country with plenty of sealed runways. Australia has large areas with few sealed runways, and this makes this method of operation less attractive.

Vertical Take Off

Vertical take off would appear at first to be the solution to the UAV take off problem and indeed there have been a few vertical take off (rotary winged) UAVs built; notably the ML Aviation Sprite and the Canadair CL227. The problem with this type of vehicle appears to lie in other areas such as performance (see section 3.5).

Air Launch

The air launch of UAVs has been used by the USAF with their Teledyne Ryan BQM drones. UAVs being considered by the ADF are mainly smaller and much slower, and these features make it difficult to successfully deploy such a UAV from a manned aircraft. Control of the UAV from an aircraft would presumably be possible although such a control station would be a very expensive option. It would however provide a flexible deployment capability and have good data link ranges even over rough terrain.

3.9.2 Recovery

Recovery is perhaps the most difficult part of UAV operations and is the greatest single factor inhibiting their wider acceptance. Various methods have been proposed from crash landing to conventional runway landings. This is an area that warrants R&D effort as the payoff for a successful solution to the recovery problem would be considerable.

Crash Landing

Small UAVs in many cases can be flown straight on to the ground at minimum flight speed without suffering structural or equipment damage. This is partly due to low minimum flight speeds, and partly due to light weights combined with materials design in the contact areas giving a high strength to mass ratio. Also, areas likely to be damaged in such crash landings are made easily replaceable. Examples of such UAVs are Pointer (4.7 kg AUM) and Cyclops (110 kg AUM).

Parachute

A step up from crash landing is to deploy an unguided parachute to reduce the ground impact speed. This tends to reduce the accuracy of the landing so that a larger landing area is required and the UAV may be dragged along the ground in strong winds. Also the parachute must be carried throughout the flight resulting in a loss of payload/fuel carrying capacity.

Parafoil

A parafoil restores the guidance capability lost when a simple parachute is used and in some cases level flight, or even gentle climbs, are possible. Therefore a controlled accurate landing may be accomplished, although strong winds may complicate the procedure and drag the vehicle after landing.

Net

A net (usually in the vertical plane) is deployed at the landing site and the UAV is flown into it for recovery. The net must be large enough to ensure that the UAV can be flown into it reliably.

Arrester

The UAV hooks onto an arrester system (say a horizontal wire) using a hook on the end of an arm or cable deployed below the vehicle and is decelerated to a standstill. The advantage of this over a net is that there is one predictable point of contact between the UAV and the arrester system. This results in a known load path within the UAV for the deceleration forces. Therefore the risk of damage to the UAV is reduced relative to a net recovery. In addition should the UAV miss the arrester system it will be able to continue flying and go round for another attempt.

Runway

A UAV can land on a runway in the same manner as a manned aircraft and the other aspects of this are as for the take off from a runway mentioned above.

Vertical

Vertical landing is more difficult than vertical take off, the difficulties increasing as high winds, turbulence, visibility, and in the naval case, ship motion effects are added. The need for some form of guidance during the landing phase becomes apparent, and a capture mechanism may be required (as in the case of the CL227 operating from a ship).

4.0 Discussion

Over at least the last twenty years there has been increasing interest in and considerable development effort expended on UAVs, primarily for military applications. Despite this, with the exception of the Israeli UAVs, few UAV systems have reached the in-service stage of development. Attempts to define and then build the optimum system to meet a pre-defined set of requirements (e.g. the US Aquila) have failed. This failure was probably due to the lack of a suitable technology base and experience in UAVs in general. The alternative method (Israeli UAVs) of developing a basic UAV (Scout) and then building up to more sophisticated UAVs (Pioneer and Searcher) has been successful. UAVs that have gone into service, with the exception of the Israeli UAVs, have had limited deployment and could possibly be considered as experimental from a user's point of view. Despite this lack of progress the promise of UAV systems to be more cost effective (plus other benefits) than existing systems has sustained interest in them. The successful widespread use of UAVs has always appeared to have been waiting for the development of some key technology such as: light robust sensors (TV and in particular FLIR); navigation systems; power plants; data links etc. The Israeli success was built on necessity in that their situation demanded action rather than continuing analysis and experimentation. Therefore they built the best they could with the available technology and continued to improve their systems in the light of experience as the technology became available. There have been many UAV projects in the USA most of which have been abandoned prior to the production stage. However, the US Department of Defense is still interested in UAVs and there are ongoing UAV developments including one based on Israeli technology called Hunter.

This review of technologies related to UAVs indicates that there is a wide range of different technologies involved and that the system as a whole must be considered. A reasonably capable UAV system is more complex than some basic manned aircraft systems. The technology needed falls in an area between model aircraft and manned aircraft and technology drawn from both these areas has been used. Small target aircraft have also been used as the starting point for UAV developments. Equipment certified for manned aircraft tends to be overly expensive whilst that intended for model aircraft use tends to have inadequate performance and/or reliability. At present there does not appear to be any industrial base to support UAV developments; therefore, each UAV development requires that sub systems be developed from scratch, or at least adapted from manned aircraft (or possibly model aircraft) equipment. This situation presumably arises because the market is as yet too small to interest industry.

The current interest in UAVs is based partly on the perceived capabilities of UAVs and partly on their contribution in recent conflicts in the Middle East. It is to be expected that once the capabilities of UAVs are generally accepted as providing significant advantages to the operator the numbers in service will increase rapidly.

This will create a market and from among the large number of companies that have little more than dabbled up to now a few will emerge offering service-ready UAV systems. Also a support industry supplying equipment specifically for UAVs should develop. Until such time (which is difficult to predict) the current situation is likely to continue where only the Israelis (driven by domestic requirements) offer a range of fully developed UAV systems. Elsewhere UAV technology developments based heavily on technology adapted from other areas (model aircraft, targets and manned aircraft) are likely to progress slowly.

The availability of good UAV systems will only be the start of their actual application, as their integration into existing systems is likely to be a difficult task. The actual operational control (deciding where, when and how to deploy UAVs plus air safety considerations etc.), and methods for the handling the information stream generated will need to be developed. The vast majority of the literature on UAVs concentrates on the basic UAV system (primarily the flight vehicle) with little consideration of the impact of UAV technology as a whole. There would appear to be considerable scope for studies into the integration of UAVs into existing systems and their operational control.

The first step in assessing technologies required for an ADF UAV system is to define the capability that such a UAV system is expected to provide. The system technology should then be examined to determine whether a UAV system is the only means of providing this capability or alternatively the most cost effective. Alternative methods of providing the capability and the comparative advantages of UAVs versus these other methods should to be considered. If it is determined that a UAV system is the best method of providing the required capability then interfacing to existing ADF structures needs to be examined. This aspect of a UAV system is examined in section 2.0.

Having established that a UAV system is the best way of acquiring the required capability, the characteristics of such a system may be determined by examining the technology available and selecting that which is needed to meet the system requirements. The starting point is to consider the functions the UAV is expected to perform, such as surveillance/reconnaissance. In surveillance or reconnaissance, the first consideration is the sensor plus its stabilisation and steering requirements. From this and the other UAV technologies a UAV system could be designed to provide the required capability.

Given that there are few mature UAV systems available it is unlikely that there would be one that exactly matched the ideal design. Therefore an assessment of available systems must be made both at the system level and at the individual subsystem levels. This will lead to trade offs and an assessment of the technologies, their applicability, current stage of development, scope for further development, and possible alternative technologies. Fortunately there is a degree of modularity in most UAVs that would allow alternative subsystem components to be used (e.g.

primary sensors) and also a range of launch and recovery methods. The overview provided in this document should be useful in this process although a more focused and deeper assessment of the specific technologies proposed for a specific UAV system would be needed at a later stage.

The situation where only one country, Israel, has been successful in fully developing and operating UAVs over an extended period may be an indication of their applicability in general. Israel is a small country with a reasonably high population density, good infrastructure (airfields in particular) and close to unfriendly countries. This contrasts starkly with Australia and in particular the areas where the ADF would be likely to operate UAVs. Here there are vast sparsely populated areas with little (high quality) infrastructure (sealed airfields or roads) and a benign security environment. It is possible that UAVs, at least at their present state of development, are not the best way of fulfilling ADF requirements. However, continuing development and the fielding of more and better UAVs is highly probable.

It would therefore be prudent to continue to monitor and assess UAV capabilities. The acquisition and fielding of a less than optimum system would enable the ADF to develop operational concepts and gain experience in the operation of UAVs. However, the danger in this approach in that the failings of such a system might produce a negative attitude to UAVs in general.

5.0 Conclusions

Despite a prolonged interest and considerable R&D effort UAVs are not yet widely accepted as military systems. Israel appears to be the only country to have fully developed operational systems although some other countries have deployed systems; the most successful of these having acquired their UAVs from Israel or developed them from Israeli UAV technology (e.g. Hunter).

The potential of UAVs is such that despite the lack of general success so far their development is being pursued by many countries, and their appearance as significant military systems seems to be inevitable. It is in this context that the ADF should view its approach to UAVs and consider where current UAVs, modified current UAVs, and future developments are likely to enhance its ADF capabilities.

The acquisition and deployment of a currently available UAV system may not add a great deal to ADF operational capabilities. However, such an acquisition would provide an experience base for assessing future UAVs, developing operational concepts and provide a framework for the introduction of more capable UAVs in the future. The Australian situation is vastly different from overseas situations for which current UAV systems have been designed. Therefore it will be difficult to develop operational concepts from paper studies alone. Assessments of the contribution UAV systems can add to ADF capabilities cannot be carried out in the absence of those operational concepts.

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DOCUMENT CONTROL DATA

PAGE CLASSIFICATION
UNCLASSIFIED

PRIVACY MARKING

1a. AR NUMBER AR-008-372	1b. ESTABLISHMENT NUMBER DSTO-GD-0044	2. DOCUMENT DATE FEBRUARY 1995	3. TASK NUMBER ADL 93/061

4. TITLE

UNMANNED AERIAL VEHICLE TECHNOLOGY

5. SECURITY CLASSIFICATION (PLACE APPROPRIATE CLASSIFICATION IN BOX(S) IE. SECRET (S), CONF. (C) RESTRICTED (R), LIMITED (L), UNCLASSIFIED (U)).

DOCUMENT	TITLE	ABSTRACT
U	U	U

6. NO. PAGES
43

7. NO. REFS.
3

8. AUTHOR(S)

K. CAMERON

9. DOWNGRADING/DELIMITING INSTRUCTIONS

Not applicable.

10. CORPORATE AUTHOR AND ADDRESS

AERONAUTICAL AND MARITIME RESEARCH LABORATORY
AIR OPERATIONS DIVISION
PO BOX 4331
MELBOURNE , VIC 3001

11. OFFICE/POSITION RESPONSIBLE FOR:

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14. DESCRIPTORS

Pilotless aircraft
Australian Defence Force

15. DISCAT SUBJECT CATEGORIES

010310

16. ABSTRACT

This document reviews the individual technologies that may be applicable to Unmanned Aerial Vehicles (UAVs). In addition an overview of UAV systems as a new technology and their integration into the existing ADF structure is considered. Despite there having been considerable interest in UAVs for at least twenty years they have not as yet become a significant factor in operations, outside Israel and possibly the Gulf war. The number of operational systems is limited as is the specific technology base of UAVs. This may be due to the need for a significant market before industry will make the investment needed and to the users not being able to acquire suitable systems. Therefore it is likely that slow progress will be made until a 'critical mass' is achieved when industry will make the needed investment to produce the range of UAVs required by the users.

PAGE CLASSIFICATION
UNCLASSIFIED

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16. ABSTRACT (CONT).

17. IMPRINT

AERONAUTICAL AND MARITIME RESEARCH LABORATORY, MELBOURNE

18. DOCUMENT SERIES AND NUMBER DSTO General Document 0044	19. WA NUMBER 40 8660	20. TYPE OF REPORT AND PERIOD COVERED July 1993 - June 1994

21. COMPUTER PROGRAMS USED

22. ESTABLISHMENT FILE REF.(S)

M1/9/15

23. ADDITIONAL INFORMATION (AS REQUIRED)