Unmanned Aircraft Systems

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1 Introduction

Defence forces around the globe are becoming increasingly reliant on unmanned systems to carry out missions that are dull, dirty, dangerous or difficult to provide in any other way. In particular the use of the unmanned aircraft systems (UAS) by armies will be discussed here.

It has been estimated that 77 percent of the global UAS research budget is spent in the USA and 69 percent of the global procurement budget (Zenko, 2012). There are a greater number and variety of UAS available to the US defence force than to that of any other nation and with the daily operational use of these systems in various theatres around the world it makes sense to focus a good portion of this work on their systems and the operations thereof. UAS from other nations will also be discussed.

The results of the apparently successful utilisation of UAS by the US Army has been reflected in the US Army Roadmap for UAS 2010-2035 (U.S. Army UAS Centre of Excellence, 2010) in which they project that the majority of their airborne assets carrying out surveillance, C3 (command, control and communications), armed reconnaissance, attack and sustainment /cargo roles will be unmanned by 2035.

"There have been many technologies introduced during this eight-and-a-half years of war. However, I don't think any has made a greater impact than UAS. It's always important when you have a game changer like this that you step back, take some time to think about it and lay out your future. That's what we've tried to do in this very first UAS Roadmap." Gen. Peter Chiarelli, Army Vice Chief of Staff (Chiarelli, 2010).

Cognisance is taken of the fact that the SA Army operates under different circumstances, in a different environment, with a smaller budget and has operational priorities different from those of the US Army, nevertheless an understanding of the UAS in operation with the US Army should provide the reader with an understanding of where and how these assets can be used and will be used in the future.

2 UAS Categories

There are approximately 680 different UAS available internationally (Zenko, 2012) covering a wide variety of missions. With this wide range of platforms, UAS classifications have been introduced as below.

European UAS groups have suggested classifying UAS in terms of range and altitude, from handheld to space systems, presented below up to the MALE system. In contrast the US DoD has, over the past few years, introduced the following UAS categories for use in Joint Unmanned Aircraft System roadmaps (U.S. Army UAS Centre of Excellence, 2010). We will use the US DoD system further.

Table 1: Comparison between EU and DoD UAS Classification

EU Cat.	Ceiling	Range		DoD Grp	Ceiling	Max Speed	MTOW
	[ft]	[km]			[ft]	[kn]	[kg]
Handheld	2000	2		1	1200 AGL	100	9
Close	5000	10		2	3500 AGL	250	25
NATO Std	10’000	50		3	18’000 MSL	250	600
Tactical	18’000	160		4	18’000 MSL	Any	Any
MALE	30’000	200		5	Any	Any	Any

Note : Upper limits are shown, unless otherwise specified

3 Overview of current Army UAS in use

3.1 Group 1 UAS

The typical advantages of the Group 1 UAS are that they are lightweight (man portable) systems that can be easily transported, rapidly assembled and quickly launched to provide situational awareness at battalion level. The logistic footprint is very low. They emit a very small audible signal and minimal heat making them hard to detect and their small size makes them difficult to shoot down.

The limitations of these UAS are currently the limited flight duration and range. The typically lower resolution of the smaller camera systems is offset by the lower operating altitude.

3.1.1 RQ-11B Raven

The handheld UAS role in the US Army is currently filled by the AeroVironment RQ-11B Raven, a 1.3 m span 1.9 kg electrically powered airframe. It cruises at approximately 60 km/h and has an endurance of up to 80 minutes. The operational range is typically limited to a line of sight but may extend up to 10 km.

Figure 1: AeroVironment RQ-11B Raven UAS

The Raven is designed for rapid deployment and high mobility. The army requirements are for low-altitude reconnaissance, surveillance and target acquisition (it is capable of IR laser illumination of ground targets). It can be operated manually or programmed for autonomous operation utilising GPS navigation. It delivers real-time colour or infra-red imagery to the ground control system (GCS) and remote viewing stations

3.1.2 Lockheed Martin Desert Hawk III

Figure 2: Lockheed Martin Desert Hawk III

The Desert Hawk III, utilised by the UK Army, is slightly larger than the Raven at 1.4 m wingspan and 3.2 kg. It can stay airborne for up to 90 minutes and can operate up to 15 km from its base station cruising at about 80 km/h at a typical altitude of between 100 and 160 m. Due to its larger size it can carry a more powerful and better stabilised daylight or infrared camera system (controlled independently of the aircraft) than the Raven. It is also reportedly a quieter and more stable platform.

The DH3 uses an Xbox-like controller familiar to most of the troops. The operators do not control the DH3 directly but they can change its flight path while it is flying a mission, or command it to circle a location designated on the ground display. The video from each flight is simultaneously recorded and transmitted back to the operator who views it on a handheld controller or laptop computer.

The UAS is launched using a large elastic rope (bungee) and lands conventionally at low speed on its belly.

3.1.3 Elbit Skylark

In a similar class to the Raven is the 2.4 m span, 5.5 kg, electric powered Skylark. It is designed as a hand launched, back packable system for tactical surveillance and reconnaissance. The payload consists of a daylight CCD or optional 700 gram FLIR system for night operations. During operation, it sends real-time video to a portable ground station. The airframe can operate at ranges of up to 10 km with an endurance of 1,5 hours. Recovery involves a deep stall manoeuvre, landing on a small inflatable cushion.

Figure 3: Elbit Skylark

The newer version, Skylark II, has a range of 60 km and was designed to be operated by a two-person crew

3.2 Group 2 UAS

There are no operational Group 2 systems in the US Army and none will be discussed here.

3.3 Group 3 UAS

The advantages of the Group 3 UAS are that they are large enough to carry an array of sensors and possibly precision guided munitions. They can take off from, and land on, unimproved surfaces.

The limitations of these UAS are the reduced endurance when carrying the full array of sensors and additional weapons and their larger logistical footprint.

3.3.1 RQ-7B Shadow 200

The Group 3 UAS (<600 kg, ,18000 feet operating altitude) role is currently filled by the RQ-7B Shadow 200, a 4.3 m span 170 kg powered by a 28 kW rotary engine. It cruises at approximately 166 km/h, has a dash speed of 218 km/h and has an endurance of six hours at a service ceiling of 15,000 ft. The operational range is limited to approximately 125 km by ELOS (Electronic Line Of Sight) to the ground control unit.

Figure 4: RQ-7B Shadow 200

The Shadow 200 is used to locate, recognise and identify targets up to a range of 125 km from a brigade tactical operations centre. The system recognises tactical vehicles by day and night from a typical altitude of 8 000 ft and at a slant range of up to 3.5k m. Imagery and telemetry data is transmitted in near-real time from the Shadow ground control station to common ground stations, analysis systems and to the army field artillery targeting and direction system. 22 soldiers are typically required to operate a Shadow 200 system, including the surveillance analysts.

The Shadow combined mission times have exceeded 100 000 hours in support of the war in Iraq. Its overall usage amounts to 600 000 hours, with incidents down to 29 per 100 000 flight hours. (Curry, 2011). Under a new configuration, wing span is increased to 6.7 m, endurance time has been increased to almost 9 hours and the service ceiling is now 18 000 ft.

3.3.2 Watchkeeper 450

The Watchkeeper 450, in service with the UK army, is an 11,3m span, 450 kg , Wankel-rotary engine powered airframe. It has a top speed of approximately 175 km/h, a range of 200 km and an endurance of 17 hours. The airframe can operate with a 150 kg payload and is based on the Israeli Hermes 450 UAV.

Figure 5: Watchkeeper 450

3.4 Group 4 UAS

The typical advantages of the Group 4 UAS are that they are large enough to carry an array of sensors and possibly precision guided munitions and still maintain a lengthy flight duration.

The limitations of these UAS are their larger logistical footprint (similar to those of manned aircraft) and they generally require improved runways. Not all Group 4 UAS are fitted with the satellite communication systems needed for beyond line of sight operations.

3.4.1 MQ-5B Hunter

Figure 6: MQ-5B Hunter

The MQ-5B Hunter is a 9 m span 884 kg 4 stroke heavy fuel engine powered system. It cruises at approximately 130 km/h and has a range of an endurance of 21 hours. The airframe can operate with a 270 kg payload at ranges of up to 260 km.

3.4.2 IGNAT/IGNAT-ER

Figure 7: IGNAT-ER

The IGNAT /IGNAT-ER is a 17 m span, 1040 kg, 4-stroke engine powered craft. It cruises at approximately 130 km/h and has a maximum endurance of 40 hours at an altitude of 8000 m. The real-time line-of-sight communications range (without using air-to-air relay capabilities) is 250 km.

The air vehicle takes off from an 800 m hard surface and lands under pilot control with a 320 m stopping distance. An automatic landing capability is in development.

The air vehicles can carry custom and off-the-shelf payloads for surveillance, reconnaissance, electronic warfare, voice and data communications relays and air-to-air data relays. The air vehicle can also be fitted for air delivery of equipment or supplies.

For reconnaissance missions the air vehicle is fitted with an Electro-Optical and Infrared (EO/IR) payload that provides streaming video to the GCS. Surveillance payloads include radar, forward-looking infrared, colour video, low-light-level surveillance video and a synthetic aperture radar.

3.5 Group 5 UAS

There are no operational Group 5 systems in the US Army and none are discussed here.

4 Alternative airborneplatform options - Rotary winged UAS

The short range ISR requirement can also be provided by rotary wing UAS. Two quite different systems are discussed which can provide a stationary airborne presence.

4.1 Schiebel Camcopter

Produced by the Austrian company Schiebel, the Camcopter has a maximum take-off mass of 200 kilograms and an endurance of 6 hours (typically not in hover). It has a maximum speed of 220 kilometres per hour and a ceiling of 18,000 ft (again typically not in hover). It is powered by a 55 horsepower engine and can carry various payloads, such as electro-optics and infrared sensors.

Figure 8: Schiebel Camcopter

The launch customer for the S-100 is the UAE Army, which ordered 40 aircraft with an option for 40 more.

4.2 Honeywell RQ-16 T-Hawk

Figure 9: RQ-16 T-Hawk

The T-Hawk mass is 8,4 kg and it has a maximum horizontal speed of 130 km/h, ceiling is 10 500 ft. Its operating range is 11 km, and endurance is 40 min (most likely not in hover) and the propulsion is provided by a piston engine of 3 kW. It can carry small sensors including one forward and one downward looking daylight (or infrared) cameras. The system is relatively noisy.

For rotary wing systems a larger rotor diameter system will typically provide a higher efficiency and less noise than that of a ducted fan system. If the mission duration of the system can be compromised a ducted fan system could be chosen as a safer option when operating near troops or important assets due the enclosed rotor blades. The choice of such a system could thus be a trade off between mission duration versus safety.

5 Ground Control Systems – Current and the future

GCS, also called Ground Stations, Ground Control Stations or Ground Control Units are, in their most basic form, a system with a means to communicate with the flight vehicle(s). Typical GCS also add a means to display or relay the received sensor information and a means to control the flight vehicle(s). The larger systems may utilise an airframe operator and a payload operator although for the smaller UAS a single operator may fulfil both roles. There are typically a large number of video analysts required for most modern surveillance systems. The smaller UAS may have a simple rugged laptop based unit or a suitcase sized system such as illustrated below.

Figure 10: Typical small UAS Ground Station

There has also been a strong move to open architecture systems approach for Ground Control Units and indeed NATO has addressed the need for commonality through STANAG (Standardization Agreement) 4586 whose goal is to enable allied nations to share information obtained from UAS through a common ground control station technology.

One of the safety limitations of the currently available CGU is that the operator is hampered with a limited situational awareness with respect to other aircraft and ground based items. The view from the airborne system via its video feed is typically through a lens of relatively high focal length offering the operator a very small view of the environment around the UAS. Some systems now provide a synthetic view , a Google Earth type environment, added on displays on either side of the video feed display to provide the operator with an apparent wider field of view to provide an improved situational awareness.

There has been a shift in UAS control philosophy from direct flight control of the UAS by the airframe operator in the GCS to the implementation of smarter mission control software where the controllers provide a particular level of mission control and the UAS flies as required accomplishing that mission.

Clarity as to who in the command structure gets to command the UA flight path and altitude, who commands the sensor look direction and magnification, and who receives what information typically requires a decision by the operating service. Typically these answers are not intuitive and the decisions need to be based on experiences gained through modelling and simulation with the operator-in-the-loop.

Recently there has been some investigation into autonomous UAS that will identify and attack targets with minimal (if any) intervention by the operator(s), apart possibly from the final decision to fire – this is no longer man-in-the-loop operation but rather man-on-the-loop and it has both moral and legal implications.

6 Powerplants and Fuel

Lithium polymer batteries commonly used on the smaller UAS have a power density (expressed in kJ per kg) approximately 5% that of a fossil fuel. Electrical propulsion is thus not nearly as efficient for long duration flights as the typical petrol /diesel engines, and the typical fixed wing hand launched UAS is limited to flight times of one to one and a half hours. Current advances in lithium battery technologies are providing power densities 60 % larger than those in the field. Fitted with these batteries, some small electric UAS would be capable of flight times of more than two hours.

Fuel cells are now available that produce sufficient energy for the small hand launched UAS to operate for periods of six to ten hours. This provides a much enhanced surveillance capability and overcomes one of the major limitations of the small UAS.

Numerous UAS manufacturers are upgrading their systems with diesel engines both from the reduced logistics trail, safety and the slightly higher performance obtained. There are now a number of the larger engine manufacturers developing diesel engines for UAS.

7 Sensors

The UAS sensor market is currently worth almost three billion US dollars (Mortimer 2011). The intelligence surveillance and reconnaissance (ISR) requirements of the UAS mission will dictate the type of sensor that should be chosen and how it should be integrated. Typically these options include:

- Visual camera for viewing (and possibly storing) live video
- Electro-Optic/Infra-Red (EO / IR) for day and night surveillance and thermal imaging
- Radar - usually one of two types; Synthetic Aperture Radar (SAR) for large area scans and/or moving target indication (MTI) Radar.

The international increase in demand for border monitoring is driving the need for EO payloads both for medium altitude long endurance (MALE) as well as tactical UAS.

Synthetic Aperture Radar (SAR) is one of the fastest changing market segments. Until recently SAR systems could only be mounted on large aircraft. These are now being miniaturised and installed on tactical UAS. EADS produces the MISAR, K band, mini-SAR with a mass of only 4 kg and power requirement of les than 50 W. SAR systems are typically however very expensive.

The size of airborne sensors is rapidly decreasing along with their mass. This is enabling smaller UAS to provide similar mission effectiveness to those of larger systems produced a few years back.

The requirement for high definition video feeds drives huge data link bandwidth requirements and a large number of video or image analysts. A novel approach is to incorporate the image processing on board the UAS and relay only the threat areas identified by the system to the operators. These images would be relayed in high definition but contain only the objects of interest and possibly the local surrounding areas if requested thus reducing bandwidth requirements.

8 Weapons

It was only a matter of time after the development of large unmanned combat Aerial Vehicles (UCAVs) that the same approach was focussed on the small UAS. The AeroVironment Switchblade is a small, expendable, tube-launched, man-portable UAV that contains an explosive payload that can be guided by a soldier to a target via a wireless video feed. The UAS weighs less than 2 kg and has an endurance of 40 minutes. (Dillow, 2011).

Figure 11: AeroVironment Switchblade with GCS

9 Nano UAS

Nano UAS are becoming popular with various armed services in the risk reduction role for the dismounted soldier. They would typically be used to reconnoitre out of view places, such as the insides of a building, before the troops entered. They could also be used to provide persistent surveillance when perched (no longer flying) but with their sensors and transmitters active. Two of the latest systems, which are not yet operational but show huge potential, are presented.

9.1 AeroVironment Hummingbird

Figure 12: Hummingbird

Hummingbird is a bird look-alike unmanned aircraft equipped with a camera. It can fly at speeds of up to 18 km/h for up to 8 minutes. Remote controllable, it can fly in all three directions while maintaining a given body orientation, or it can rotate maintaining a fixed position.

9.2 PD-100 Black Hornet nano-helicopter

Figure 13: PD-100 Black Hornet

A complete PD-100 PRS System, including the base station, has a mass of less than 1 kg and can fit in a soldier's pocket.

The air vehicle mass is 15 g, with a rotor span of 120 mm.. Its maximum forward speed is 10 m/s and it has an endurance of up to 30 minutes. The sensor is a steerable, electro optic video camera that canpan andtilt, and its digital data link has a range of 1000 m. Using the video data it can be flown by remote control or it can navigate a series of waypoints using it onboard GPS navigation system.

10 Current UAS developments

One of the limitations of all UAS is that of the range being limited by the requirement for a line of sight link between the GCS and flight vehicle. A GCS with radio mast and steerable directional antennas will typically improve the range of the larger UAS although the possibility of placing directional antennas and patch antennas onto a steerable platform for small UAS has also been achieved. Not only is reception thus improved but the line of sight distance is greatly improved.

Small UAS are also being used as communications relay platforms to improve the line of sight range for the larger systems. One limitation of this method is that the relaying airframe generally cannot be orientated in a way that persistently points the directional antennas at the UAS requiring an expensive stabilised antenna system.

One approach to ubiquitous surveillance and reconnaissance is through the use of a large number of UAS that interact with each other (swarm) and relay messages via each other to provide an improved situational awareness with a reduced number of ground stations.

Convoy protection is currently being provided by small UAS that navigate largely autonomously, following the convoy whose position is determined through a GPS location transmitted by the lead truck. When the convoy is travelling at a lower speed than the loitering speed of the UAS it will autonomously determine a loitre pattern that will provide the required coverage.

Embassy and high profile individual protection is now being done via the provision of ISR via UAS.

UAS are already being used in the anti piracy role, requiring relatively long endurance UAS with EO and IR payloads.

There are systems under development that will determine the origin (the distance and direction) of gunshot, artillery and mortar fire by triangulating the origins of the sound. These systems have been demonstrated on a UAS. The Avisa system (see Figs. 14,15) uses proprietary 'acoustic vector' sensors to pinpoint the location of the gunshot and slaves a video camera to focus on the area from where the gunshot originated. The next logical step would be to illuminate that location with a laser designator.

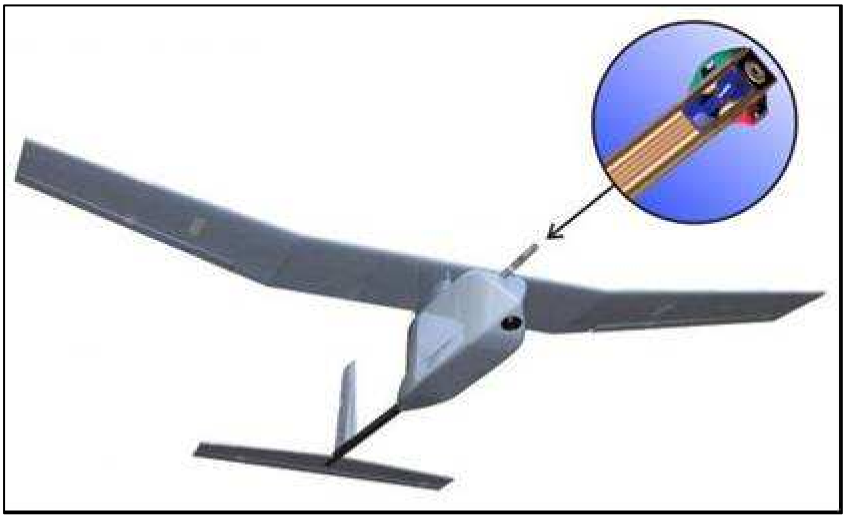

Figure 14: Microflown Avisa system

Figure 15: Avisa target location identification

Research in the USA is currently being directed in a number of areas that will ultimately improve mission effectiveness:

- Determining the optimal distribution of tasks amongst a group of UAS with time and equipment constraints and formulating an optimal sequence and distribution of activities between systems to maximize mission effectiveness
- Sensor fusion, the combining information from different sensors for use on board the vehicle for improved flight authority and target detection and identification
- The coordination and communication between multiple systems in the presence of incomplete and imperfect information
- Determining the optimal path for UA to follow while meeting mission objectives and constraints, determining an optimal manoeuvre to follow a given path or to go from one location to another and the specific control strategies required to constrain a vehicle within some tolerance to a trajectory

11 Modelling and Simulation for UAS missions

One of the most important issues to be determined in specifying a UAS is who, and what level of command, will control what part of the system /mission. In other words who controls the sensor and who controls the airframe and ultimately who receives what transmitted information.

Use is made of interoperability environments and mission simulations (such as the IDE at the CSIR) to model the complete mission and evaluate mission effectiveness based on various command and control structures to evaluate various concepts before committing to acquisition.

Mission level simulations can be used for training purposes. The airframe and payload operators, image analysts and others in the command chain can then enact simulated missions over simulated terrain and threats. Failures of the various sub-systems can be simulated as part of the training to evaluate trainee skills levels before committing the team to costly hardware.

One of the outcomes of the simulations will be clarity on a number of sensor requirements and their relative importance to the intended mission:

- In what portion of the electromagnetic spectrum the sensor(s) should operate.
- Temporal value of the information -whether the image(s) should be relayed in real time to the ground unit or stored on-board due to limited bandwidth capabilities – or both?
- For what duration is the sensor required to be over the target?
- How often should the target area be visited?
- What are the image contrast and resolution requirements?
- What is the required minimum image view angle and area of coverage
- Which is preferred video or high resolution fixed images?
- Are there requirements for motion detection and possibly moving target identification?
- Is there a requirement for relaying of target coordinates and or range to the GCS?
- Is any recording of sound required – and location of origin of the sound?
- Are there requirements for detection of chemical compounds or biological agents?

12 Future UAS missions and requirements

Very high definition image capturing systems such as the Sierra Nevada “Gorgon Stare” technology can capture live video of an entire city but the large amount of imagery (80 mega pixel images at 30 frames/s) requires approximately 2 000 analysts to process the data feeds from a single UAS, compared with typically 19 analysts per UAS today. The solution will lie in smarter image processing software detecting the required information autonomously and relaying the results to a smaller group of analysts than would otherwise be the case.

Small UAS may be used to dispense small ground-based sensor systems at an area of interest far from the operators These sensors relay signals indicating a detection (ground vibration, chemical, biological agents etc.) to the circling UAS. The information is then relayed with GPS location back to the GCS some distance away Persistent sensors would provide data over an extended period on vehicle traffic. This information would be uploaded on request by an overflying UAS Additional roles for army UAS in the near future may include soldier medical resupply, unmanned freight transport to high risk areas.

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