Roadmap for Unmanned, Autonomous and Remote Systems

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1 Overview

This paper covers the use of unmanned autonomous systems in the military, presenting a strategic threat, capability and needs analysis leading to roadmap proposals for the future.

An assessment of the user needs that drive military technology is discussed. These have traditionally been defence oriented in response to conventional military enemies, however unconventional threats are now emerging. We consider market competition to SA military UASs, current operational capabilities of SA systems and also those of UAS deployments elsewhere in Africa, and set these in the context of a 10-year UAS roadmap.

2 Enemy, Competitor and Threat Benchmarking

Most system engineering method's first order of business is invariably User Needs and Requirements elicitation. For commercial systems this invariably is driven by the Market Opportunity, or the Business Case. However things tend to be more conservative and re-active rather than pro-active in the defence space, typified by the saying

> *Necessity is the mother of invention* [George Farquhar, "The Twin Rivals (1702)"].

In practice, military technology development (where we explicitly exclude aggressor style, 'arms race', military developments) is in reaction to present, suspected or anticipated defence needs. What are the external drivers of these needs? Three sets of these are considered below :-

<u>Enemies</u> are the traditional, military enemies associated with armed conflict. At present, armed militia in the countries where South Africa can and might undertakes peacekeeping operations (incl. anti-piracy) (as per Fig. 1) constitute the closest to military enemies, although classification in these terms is avoided at the diplomatic level.

<u>Competitors</u> are considered to be commercial adversaries, which may be at the state, industry or business level. South Africa's competitors in the military technology area are indicated in Fig. 2. Historically many wars have been fought for trade reasons, and they may have political or religious proponents, but the underlying motivations are often economic, which is further expanded on below.

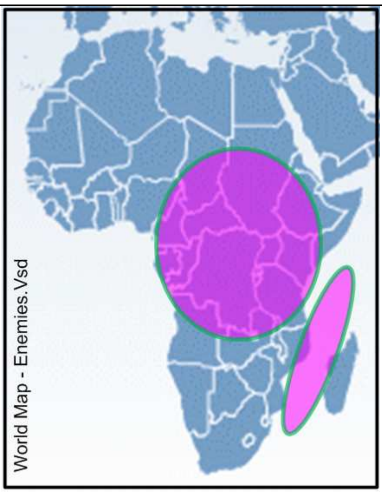

Figure 1: "Enemies"

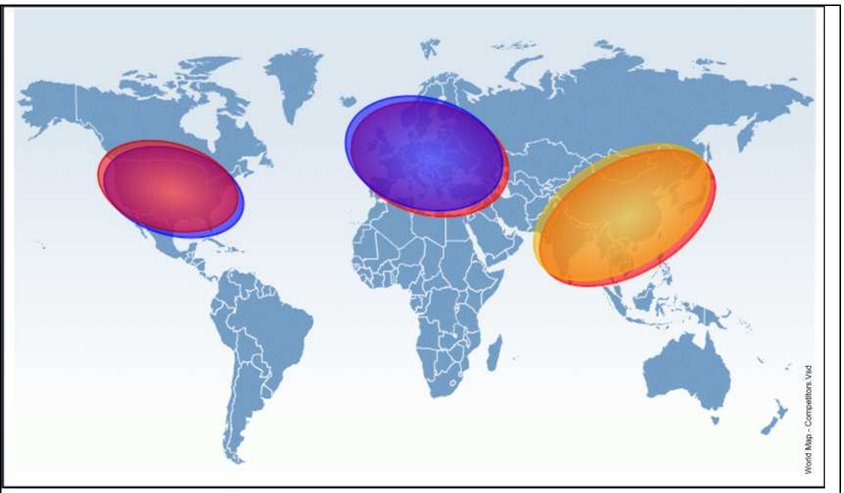

Figure 2: Competitors

Threats are considered to be high level adversaries that do not fall into the two categories above. Fig. 3 indicates threats to the nation as follows : generic economic trade threat (yellow); sovereign debt threat (red: toxic debt triggering global recession); climate change threat (blue: causing sea level rise, water and food scarcity); ideological and terrorist threat (green).

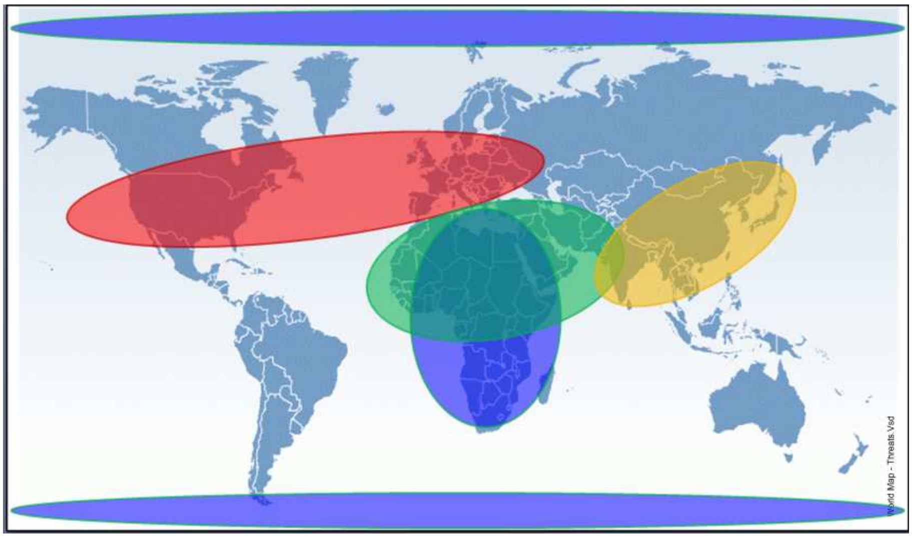

Figure 3: Threats

So what are the appropriate technological responses to the above Geo-political Needs?

There is always a baseline need for sovereign defence against military enemies, for the simple reason that the lack of defence invites aggression. Accurate, thorough and timeous intelligence of potential aggressors is a force multiplier in the defence space, so that all systems that contribute to the surveillance and information gathering effort are cost effective, and unmanned systems have the potential for being extremely cost effective. The last, post World War, conventional military enemies that were opposed by South Africa were foreign supporters for internal political change, acting outside the borders, although this did involve cross-border, conventional military responses by SA. The peacekeeping role that SA undertakes in central Africa bears some resemblance to these military operations, and the benefit of unmanned systems in this theatre of operations has been well exemplified by the use of such in Afghanistan, Iraq and Pakistan, with the exception of detection and defusing of IED devices.

The international market competition to local UAS system developers constitutes short-term tactical adversaries in terms of local GDP, employment and infrastructure development. But open market competition represents a long term, hostile, strategic adversary if it displaces local development completely. Procurement of off-shore, high technology products not only has a negative effect on GDP and balance of payments, but also moves technology and expertise offshore – which cannot swiftly be rebuilt in a time of socio, economic or military crisis.

The international scenario of threats can act over a distance without hostile actors (some *force majeure* threats require no actors at all). Threats can also precipitate unexpected enemies and competitors as the pressure of economic collapse, and scarcity of natural resource or environmental disasters put demographic pressures on society. Ultimately, when individual and national survival is at stake, neither the rules of engagement nor the Geneva Convention are expected to be binding. Unmanned surveillance and intelligence gathering systems represent a key defence against long term and long range threats, since they offer the opportunity for sovereign states to perform their own strategic assessments of global threats, and to prepare contingency plans based on information, situational awareness and knowledge based defence mechanisms. Particular in the area of natural phenomena, which have long time scales and huge inertias to change : *to be fore-warned is to be fore-armed*.

While South Africa intends collaborating with BRICS countries due to their regional importance and market opportunities, it will militarily oppose any designs they may have to become “super powers”. Likewise, South Africa’s relationship with SADC countries is also based on various, complex strategic alliances and competitors. In this light, the technological capabilities of information gathering organisations in South Africa (both military as well as civil defence and commercial) relative to the opposition, whether military enemies, business competitors or global threats, can play a significant role in how future relationships between sovereign states unfolds. This capability comparison is considered in the next section.

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3 SA Army technology competitor assessment

This section considers the subset of African operated UAVs that, in their capability class, are business competitors to the SA offerings. Deployment information is quoted from Jane's UAVs [6].

Denel Seeker II and Seeker 400

Class: Tactical Long Range

Class Competitors
- Northrop Grumman /IAI RQ-5 Hunter
- Elbit Hermes 450

Figure 4: Seeker-400

The RQ-5 Hunter has been deployed by USA, Israel, Belgium and France. By March 2006 it had completed 45'000 flight hours of which 19'000 were in combat operations. It has a geometry similar to the Seeker II, the major difference being both pusher and puller props. It has been weaponised since 2002.

The Hermes 450, with a classical high aspect ratio wing and fuselage but upright V stabiliser, has been deployed by Israel, USA (border surveillance), UK, Croatia, Georgia, Singapore and Mexico since 2001. Weaponisation is believed unlikely given the high wing aspect ratio, single pylon wing mount and catapult launch technique.

Denel Bateleur

Class: Tactical Endurance / MALE

Class Competitors
- AAI Shadow 600
- IAI Searcher II
- Elbit Hermes 900 & 1500

Figure 5: Bateleur

The Shadow 600 has a geometry even closer to the Seeker II, with a single pusher prop and "trailer" front wheel. Supplied in small quantities to Turkey, Romania and suspected also to South Korea. It has not been weaponised.

The Searcher II, also a single pusher with twin boom and vertical stabiliser, has been deployed by Israel, India, Singapore, Sri Lanka, Taiwan and Thailand since 1999. Weaponisation status is not known, but with a 100 kg payload, it is quite likely to have been.

The Hermes 900, similar in profile to the Hermes 450, has been deployed by Israel, Chile and Colombia since 2010. Weaponisation is still unlikely even though the high aspect wing is mated directly to the fuselage.

The Hermes 1500, is similar in form to a conventional, overhead wing, two-seater light aircraft, and has been produced for export only (South Africa, Argentina and Singapore) since 2000. Weaponisation is possible, using centreline hardpoints, given the 350 kg payload capacity.

ATE Vulture

Class: Tactical Endurance Short Range

Class Competitors
RQ-15 Neptune
NATO (Consortium) Flash Mk.105

Figure 6: Vulture

The catapult launched, parachute/skid landing, blended wing/body Neptune was supplied in evaluation quantities to the US Navy in 2003 for operation in the marine environment.

The NATO Flash Mk.105, twin boom, piston pusher prop, forward optical and downward IR sensors, has 20 units deployed in Germany, France and Morocco.

ATE Kiwit

Class: Mini UAV

Class Competitors
RQ-11 Raven,
US-NRL DragonEye,
EADS Tracker,
EMT Luna,
ACR Silverfox

Figure 7: Kiwit

The electric powered, classic wing-body-tail airframe, hand launched Raven has been supplied since 2003 in large numbers to the three main arms of the US military and to its Special Ops Command, and also to the UK, Australia and Italy.

The equivalent twin electric engine, classic wing-body-tail airframe, hand launched Dragon Eye (aka Sea ALL) has been supplied since 2001 in large numbers to the US Navy and Marines.

The Tracker resembles a hand-launched, scaled down version of the CSIR Modular UAV, with very similar geometry and payload pod but a longer endurance. It has been supplied to the French military since 2006.

The catapult launched motor-glider Luna, with net and/or parachute recovery like the Vulture, has been supplied in small numbers to Germany and Pakistan since 2000.

The relatively long endurance, catapult launched Silver Fox, with comparable mass, geometry and GCS to the Kiwit, has been supplied in small numbers to USA and Canada since 2004.

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This section indicates the export challenges for South African UAS system developers, in line with the Competitor assessment in the first section. The early entrants appear to have benefitted from being early to market, both for internal and external markets, while the late starters have either failed to attract funding for development when in competition with products not carrying NRE costs, or are not attractive from the perspective of prospective buyers since they are further down the capability / cost curve. The traditional trade-off of how much investment should be made in military technology development know-how (the competitor and threat response) and how much in procuring high-technology hardware (the enemy response), is a present and future problem that is to be addressed.

4 Current UAS capabilities in South Africa and looking Northwards

From the 1980's to the early part of the last decade, South African UAV developers were amongst the group of trend-setting UAV manufacturers worldwide, along with the US, Israel and European multinationals. South Africa currently has three institutions active in the UAV sector : Denel Dynamics, ATE and the CSIR.

Of the fourteen main UAV designs that have come from these three concerns

Seeker[1], Seeker II, Seeker 400, Skua (strictly a target drone) and Bateleur from Denel;

Vulture[1], Roadrunner and Kiwit from ATE; and

Delta Wing demonstrator, Skyfly, Keen-Eye, Indiza, Sekwa and the Modular UAV from CSIR;

only three have been acquired by the SANDF: the original Seeker, Skua and Vulture.

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[1] Concept and detailed designs for the Seeker and Vulture were both performed at the CSIR, starting in the early 1980's and 1994 respectively.

The CSIR develops prototype UAVs to assist the local industry to keep up with the latest international trends. Indiza is a hand launched UAV, Sekwa a blended wing-body design and the Modular UAV, an electric powered UAV with plug and play aerodynamic and payload components.

Denel Dynamics started UAV development on 1982, with the Seeker being delivered to the SANDF from 1986. Following an incremental development and upgrade process the Seeker II was released in 1999, and from 2009 it was marketing the successor, Seeker 400. The Bateleur MALE was a local equivalent of the Predator, however this still remains a concept design, with only a mockup having been produced for marketing purposes.

ATE had developed the Vulture artillery spotting system in 1998 and from 2006 was delivered to the South African Army. Its hand-launched Kiwit mini-UAV was first displayed in 2006, and has been ordered by an Asian country to equip its Special Forces.

Although the local industry remains innovative, it lacks the support it needs from its local market and the country is probably losing its position amongst the front runners in this booming high-tech sector, not being able to match the significant amount of money that is being poured into UAVs, by the US, UK, Israel and many others.

Despite all the work done on UAVs in this country, the South African National Defence Force (SANDF) only operates the original Seeker system (which can now be regarded as obsolete) and the Vulture. The Kiwit, Seeker 400, and Bateleur would all be of enormous value to the SANDF, to support its peacekeeping deployments, and to patrol the country's borders and maritime frontiers. None have been ordered by the SANDF, nor is there any sign they will be. There is no large-scale local UAV research and development programme to further develop and promote local capabilities, critical mass is lacking with the small, independent projects.

A proposed ten year SA UAS roadmap [1] highlights key development areas of technology, operation, training and airspace integration to halt further lag behind current world-practice, and re-start the local programme with the aim of becoming competitive again. The roadmap further emphasises the importance of user-relevant capabilities as opposed to system performance characteristics. To illustrate this, it introduces the concept of *perimeter surveillance* and *area reconnaissance* as measures of effectiveness. The former capability depends primarily on airframe performance parameters, while the latter depends in equal measure on both airframe and sensor performance. The sensor parameters which are required are not simple field of view, zoom and pixel size parameters – but relate to target detectability and recognisability. They are, in general, not provided by OEMs, for reasons both of security concerns, but also because they are not the result of simple measurements but require characterisation and analysis.

The two depictions below illustrate the difference between these two, and the tables following show these two capability classes for the operational South African UAVs in Section 6.2.

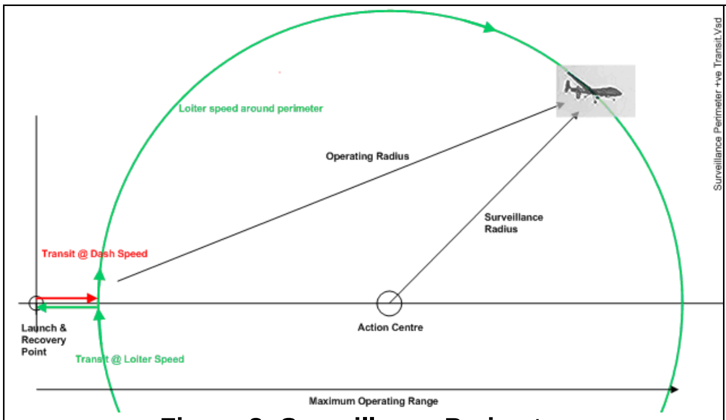

Figure 8: Surveillance Perimeter

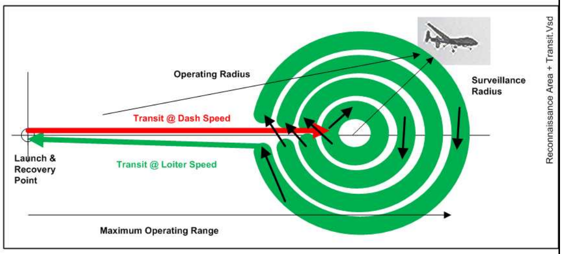

Figure 9: Reconnaissance Area

Sample results from the SA 10 year roadmap [1] are shown below, with three sets of results dependent on the distance of the centre of action from launch (reflected by the transit time). The airframe capabilities are from published OEM specifications, while the reconnaissance area results are shown for level 3/5 daytime perception (80% probability of successful perception using video footage) of a motorcar vehicle, under good visibility conditions. They are estimated based on recorded video footage, and extrapolated as appropriate.

Table 1: Seeker II (Denel) – Airframe Capabilities

Max Transit	Mid Transit	Min Transit	Airframe Capability
0.62	0.11	0.39 *	Transit Time [h]
56.2	112.4	168.7	Perimeter Surv. Radius [km]

* Note : Transit from launch point within surveillance perimeter implies flying away from action centre to reach surveillance perimeter (applies to further tables below).

Table 2: Seeker II (Denel) – Car Perception Level 3/5

Max Transit	Mid Transit	Min Transit	Reconnaissance Capability
0.94	0.33	0	Transit Time [h]
5389	8090	9583	Area [km²]
0.26	0.32	0.35	95% Target Acquis. Time from Random[h]

The individual airframe and reconnaissance tables are combined below for other airframes.

Table 3: Seeker 400 (Denel) – Airframe and Reconnaissance Capabilities

Max Transit	Mid Transit	Min Transit	Capability
0.42	0.29 *	0.99 *	Perimeter Surveillance Transit Time [h]
78.3	156.7	235	Perimeter Surveillance Radius [km]
0.85	0.26	0	Reconnaissance Transit Time [h]
11519	14168	15333	Reconnaissance Area [km²]
0.39	0.43	0.45	95% Target Acquis. Time from Random[h]

Table 4: Vulture Mk II (ATE) – Airframe and Reconnaissance Capabilities

Max Transit	Mid Transit	Min Transit	Capability
0.13	0.13 *	0.38 *	Perimeter Surveillance Transit Time [h]
20	40	60	Perimeter Surveillance Radius [km]
0.3	0.11	0	Reconnaissance Transit Time [h]
445	493	520	Reconnaissance Area [km²]
0.11	0.11	0.11	95% Target Acquis. Time from Random[h]

Table 5: Kiwit (ATE) – Airframe and Reconnaissance Capabilities

Max Transit	Mid Transit	Min Transit	Capability
0.04	0.02 *	0.08 *	Perimeter Surveillance Transit Time [h]
1.5	3	4.5	Perimeter Surveillance Radius [km]
0.07	0.02	0	Reconnaissance Transit Time [h]
7	9	9	Reconnaissance Area [km²]
0.04	0.05	0.05	95% Target Acquis. Time from Random[h]

Table 6: Bateleur (Denel) – Airframe and Reconnaissance Capabilities

Max Transit	Mid Transit	Min Transit	Capability
1.96	0.93	0.11 *	Perimeter Surveillance Transit Time [h]
129.6	259.2	388.8	Perimeter Surveillance Radius [km]
2.91	1.26	0	Reconnaissance Transit Time [h]
1628	11525	18687	Reconnaissance Area [km²]
0.13	0.34	0.44	95% Target Acquis. Time from Random[h]

The following “top ten” list briefly describes the most prevalent UAV deployments (by total number of UAVs deployed) in Africa outside South Africa [Chapter 7 Section 2], together with an identification guide.

1) BAES (UK) Sky Eye R4E-50, Tactical Medium Range, twin boom, piston pusher prop, catapult launch, parafoil skid-landing UAV : 73 units deployed in Egypt and Morocco.

2) Galileo Avionica (Italy) Falco, Tactical Endurance, high wing plus twin boom plus tail, piston pusher prop, catapult /runway launch, runway landing : 50 units deployed in Libya.

3) Meteor CAE (Italy) Mirach 150, Tactical Reconnaissance rocket with 50 kg electronic sensor pod, parachute recovery. 38 units deployed in Algeria and Libya.

4) Northrop Grumman (USA) M324 Scarab, Tactical Reconnaissance rocket with wet film camera only, parachute recovery. 33 units deployed in Egypt and Morocco.

5) NATO (Consortium) Flash Mk.105, Tactical Short Range, twin boom, piston pusher prop, forward optical and downward IR sensors. 20 units deployed in Morocco.

6) ADS (Israel) Aerostar, Tactical Medium Range, twin boom, piston pusher prop, catapult or runway launch, parafoil or wheel-landing UAV : 12 units deployed in Algeria, Benin, Ivory Coast and Rwanda.

7) General Atomics (USA) MQ-1 Predator, Tactical Endurance, pusher piston-prop with classic geometry except for inverted V tail, weaponised UAV. 9 units deployed in Djibouti, Seychelles and Somalia (Algeria requested 3 units – pending).

8) Schiebel (Austria) Camcopter S100, Tactical Short Range classic helicopter geometry. 8 units deployed in Egypt.

9) Fangzhou (China) Airship, equivalent to Tactical Short Range conventional UAV, gas or electric powered, endurance limited by battery life. 6 units deployed in Angola and Egypt (this airship also acquired by South Africa).

9) Hesa (Iran) Ababil-T, Tactical Close Range, cruise missile style geometry, optical and radar sensors, dual suicide role (high explosive warhead). Catapult / rocket launch, skid landing. 6 units deployed in Sudan.

9) Hesa (Iran) Ababil-B, Similar to Ababil-T but without the warhead, and reduced sensor capability (initially B variant was a target drone). 6 units deployed in Sudan.

9) Innocon (Israel) Falcon-Eye M3-S100, Tactical Endurance, unmanned version of a light aircraft. 6 units deployed in Ethiopia and Uganda.

9) Qods (Iran) Mohadjer-2, Tactical Close Range, cruise missile style geometry, catapult launch, parachute /skid /wheel landing, ISR role only. 6 units deployed in Sudan.

In terms of greatest number of countries deploying UAV types, the ADS Aerostar is present in four, the General Atomics Predator is present in three (but with a fourth request from Algeria), and the BAES Sky Eye, CAE Mirach 150, Norththrop Grumman Scarab, Fangzhou airship and Innocon Falcon Eye are all deployed in three countries.

The thirteen UAV types listed above represent 273 (75%) of the 366 UAVs in the 56 African countries outside South Africa. These dominant UAV types are present in fourteen (25%) of these 56 countries. Another five (9%) African countries have other UAV types deployed : Botswana, Kenya, Madagascar, Mauritania and Tunisia.

The implications of UAS deployments in the rest of Africa are two-fold. There is potential shared use of data and intelligence from these systems in joint peacekeeping missions, but conversely there need also be contingency plans for possible hostile use against peacekeeping forces, and also against assets within South Africa.

5 Ten year objectives survey - US Army vs SA UAS roadmaps

The proposed SA UAS roadmap [1] was influenced by the roadmap produced by the US Army in 2010 [3], and by research studies at the University of Stellenbosch in 2008 [4] and 2010 [5]. The US Army roadmap, in turn, was strongly influenced by the roadmap produced by the US Office of Secretary of Defence (OSD) in 2009 [2].

The latter OSD roadmap reflected the benefit of two years of hindsight and lessons learned after the initial 2007 roadmap, embodying the following high level changes in emphasis

- Increase the level of integration to support a greater set of mission areas
- Identify common areas of technology to yield performance improvements in many domains
- Identify the technology enablers to conduct collaborative operations in many domains

These emphases are reflected in the US Army's prime objectives below (applicable to a 25 year time horizon), and these in turn have shaped the proposed SA UAS objectives (for a 10 year horizon) that follow.

<u>US Army UAS Objectives (2010-2035)</u>

1. Improve effectiveness through integration and joint force collaboration [1]
2. Support S&T and R&D to achieve greater autonomy in support of warfighter operations
3. Transfer UAS technology into warfighter operations
4. Increase interoperability between avionics, communications and payloads
5. Develop tactical procedures for safe but effective joint manned /unmanned operations
6. Implement standardized controls for armed UAS, UGV and UGS systems.
7. Ensure test systems are effective and reliable
8. Improve logistic support
9. Develop airworthiness qualification equivalent to manned systems [2]
10. Develop training strategy and aids [2]

Note 1 : The OSD [2] roadmap specifically identified collaboration between combatant commanders of partner nations, which is not reflected in the US. Army roadmap.

Note 2 : These objectives are not present in the OSD roadmap

Apart from the above, the two roadmaps are effectively aligned.

Key goals in a proposed 10 year UAS Roadmap are depicted in Fig. 10 below.

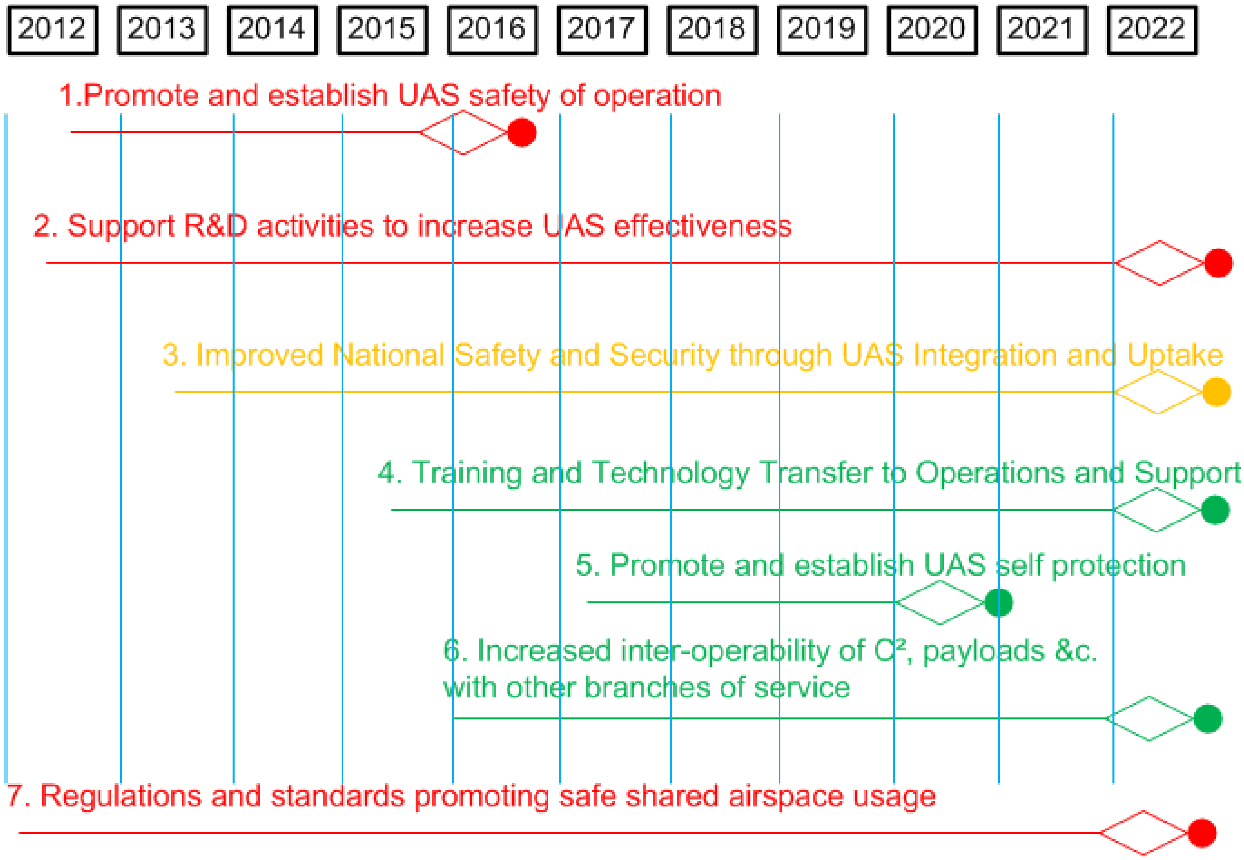

Figure 10: Proposed 10-year SA UAS Roadmap Goals

These goals are expanded on below.

Goal 1 – Safety of operation

- Objective 1(a) – Safety of civilian life and local infrastructure is paramount to commercial uptake
- Objective 1(b) – Safety of operational personnel and materiel is necessary
- Objective 1(c) – Safeguards to prevent hostile takeover of system by antagonists is vital

Goal 2 Increased effectiveness

- Objective 2(a) – Determine key stakeholder requirements
- Objective 2(b) – Promote development effort to achieve stakeholder needs
- Objective 2(c) – Early verification and validation of UAS capabilities with operational requirements

Goal 3 – Improved National Safety and Security

- Objective 3(a) – Conduct and share UAS technology development with all stakeholders
- Objective 3(b) – Participate in test and evaluation exercises

Goal 4 – Training and Technology Transfer

- Objective 4(a) – Develop simulator and training aids
- Objective 4(b) – Develop and actively refine training programmes
- Objective 4(c) – Leverage training aids to promote uptake by UAS systems across military, civilian and commercial applications
- Objective 4(d) – Functional and environmental screening to detect high level of faults
- Objective 4(e) – Test systems field survivability to far exceed deployed equipment

Goal 5 – Self protection

- Objective 5(a) – Self destruct (IP and tech protection) assured by authority-watermark watchdog

Objective 5(b) – Safeguards and systems to prevent command overrule by illicit parties (highly secure command and control uplinks)

Objective 5(c) – Develop capabilities to prevent command jamming and interference

Objective 5(d) – Develop capabilities enhancing self-preservation in the event of loss of command. hostile actions or severe weather.

Objective 5(e) – Secure data and comms relay downlinks (defeat information interception)

Goal 6 – Increased inter-operability

Objective 6(a) – Support harmonization of different UAV and ground control systems and processes by means of common standards and procedures.

Objective 6(b) – Standardise architectures and common command, control and data exchange protocols with UGV, UGS and UUV systems

Goal 7 – Shared airspace usage

Objective 7(a) – Collaboration with international forums for Civ/Com Regulations and Standards.

Objective 7(b) – Support the drafting, adoption and enforcement of commercial and military standards for design, manufacture, testing, certification and operation of UAV systems.

Objective 7(c) – Support increasing levels of autonomy with respect to sense and avoid navigation.

Objective 7(d) – Interim operation of research & military UAS systems operating under exemptions.

The implications of UAS deployments in the rest of Africa are two-fold. There is potential shared use of data and intelligence from these systems in joint peacekeeping missions, but conversely there need also be contingency plans for possible hostile use against peacekeeping forces, and also against assets within South Africa.

6 Miscellaneous Systems (FIBUA, UUVs and Comm. Relays)

This section covers items these classes of items, which do not fit into any of the above sections.

6.1 Systems for FIBUA

This section presents some challenges of unmanned systems used for fighting in built-up areas.

Unique emphases of the challenges of the FIBUA environment are the need to operate against antagonistic opponents with a high degree of difficulty due to terrain obstacles. All systems require high agility, an advanced degree of obstacle avoidance autonomy and typical image recognition capabilities. In particular ground based systems require self-defensive features and airborne systems the ability to manoeuvre rapidly in three axes as well as down to zero speed.

Fig. 11 below illustrates concepts and results for a joint US Army and NASA project [7] examining autonomous navigation in this environment. Two navigation algorithms were developed and tested flying over real, building-dense, terrain and the principal finding was that constructing a full 3D image map and a 3D navigation algorithm were superior to an implementation using 2D slices of the 3D image.

Figure 11: Architecture of US Army / NASA Obstacle Field Navigation system and examples of autonomous flight paths [7]

3D trajectory planning methods require a local representation (map) of the environment to be built. These path planners are generally computationally expensive and their implementation onboard mini and micro UAVs and UGVs is challenging. However, reactive obstacle avoidance algorithms run very quickly and are effective at preventing last-minute collisions. One system has recently been successfully demonstrated, while research on bio-inspired obstacle avoidance methods continues.

Tests in 2011 using LIDAR (light detection and ranging) based reactive obstacle avoidance have demonstrated the effectiveness of a system for infrastructure inspection by an autonomous helicopter at the CSIRO [7]. The perception system used a COTS 2D LIDAR, in combination with customised flight manoeuvres, to address the problem of 3D perception. Simple but effective reactive strategies were used to detect the ground and regulate the height, perform terrain-following, detect and avoidance of frontal obstacles, detect and stop in front of the target, and take high-resolution pictures from a specified viewing angle, illustrated in Figs. 12,13.

Figure 12: CSIRO UAS systems [7]

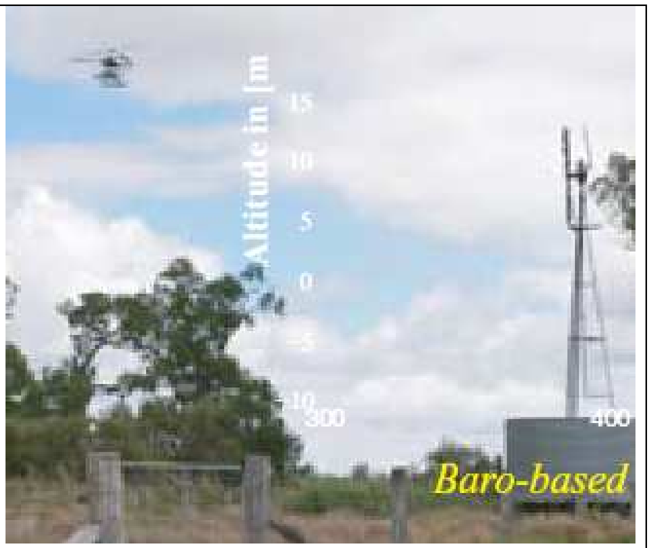

Figure 13: CSIRO UAS flying between obstacles

Visual, bio-inspired reactive methods are not only computationally simple, but have low mass requirements as proven by many flying insects. Many groups are working on applying insect-inspired approaches to obstacle avoidance in small UAS's. In these methods, optic flow is directly used to compute an avoidance manoeuvre, yielding to obstacle avoidance without map building and path planning.

6.2 Unmanned Underwater Vehicles

This section presents a sampling of different UUV systems and news. It is not intended to be representative of all African systems.

IMT's experimental UUV for R&D on navigation and control aspects, with speed to 2,5 kn. Uses a photonic INS system with GPS updates when on the surface and wireless communication via the antenna when surfaced.

Figure 14: IMT UUV

Sebastiaan Swart (NRE) with CSIR's Seaglider 542 after its 5 week, 140 nm trial off West Coast (Feb 2012). Max. system endurance 300 days, 2500 nm.

Figure 15: CSIR scientist with iRobot Seaglider

Maridan 600 remotely piloted bottom explorer (600 m), endurance to 60 hours, speed to 3 kn. In 2001 De Beers became the first client to use this UUV - for undersea surveys of diamondiferous deposits off the West Coast of southern Africa; using imaging and side scan sonars and chirp bottom profilers.

Figure 16: Maridan 600 UUV

Sea Stalker performs ISR and C2 using periscoping sensor masts. Geometry : Fin augmented torpedo body, 5 knots cruise speed. Surface or submarine launch and recovery (but submarine operation – endurance hampered by lithium hazard restriction)

Figure 17: Sea Stalker UUV

Navy Seals deploy an EOD UUV (2009)

Figure 18: Mini UUV deployment

Aeronautic Defence Systems SeaStar (6 tonne, 2500 kg payload : 300 nm Op. range, 10 hour endurance, 45 knot speed) deployed in Angola (2003) and Nigeria (2006).

Figure 19: Seastar ISR and interdiction USV

Upcoming developments include the General Dynamics Surface Mine Countermeasure UUV system, designed to reliably detect and identify mines in high-clutter underwater environments in a single pass, including mines that are suspended in the ocean, resting on the sea floor or buried. Additional capabilities include gathering environmental data that can provide intelligence support for other mine warfare systems.

6.3 Communications Relay UAVs

This section presents a sampling of different relay systems and it is not intended to be comprehensive.

Several existing UAS's have been touted as supporting the Tactical Communication role, for example Northrop Grumman BAMS-D (endurance 35 hours, ceiling 18 000 m), Elbit Hermes 1500 (endurance 24 hours, ceiling 10 000 m) , IAI Heron (endurance 52 hours, ceiling 10 000 m), EADS Surveyor-2500 (endurance 12 hours, ceiling 5 000 m) – and this function even extends to mini UAVs, for example the EADS Scorpio (endurance 2 hours, ceiling 2 000 m)

The potential for fully fledged, high altitude communication relays (as distinct from tactical communication assists in a network-enabled squad of two or more UAVs operating in the same frequency band), was first demonstrated in 2002. Skytower, an AeroVironment subsidiary, used a Pathfinder Plus UAV to act as an "atmospheric satellite" at 20 000 m to relay a high bandwidth HDTV broadcast as well as 3G IMT-2000 cellular communications signals. The 37 m span Pathfinder used high efficiency PV solar cells to generate 12,5 kW electric power for the 8 electric motors. The high operating altitude gives the benefit of a high lookdown angle, reducing the total transmission power requirement to 1 W, a reduction of 40 dB over terrestrial broadcast. The signals were broadcast to an area equivalent to the cities of Tokyo or Los Angeles and delivered very high quality signal-to-noise ratio, typical of fibre optic systems, far superior to what traditional TV broadcast systems can achieve. Further trials used a custom "look down" antenna to relay voice and video without any external antenna and high-speed Internet access with an auxiliary antenna.

Figure 20: Pathfinder Plus UAV carrying Sky Tower Communication Relay Systems

Further developments at AeroVironment are to support day-night operation using a hydrogen-oxygen energy storage system. Excess power from the solar arrays runs an electrolyser that dissociates water into hydrogen and oxygen, which are stored under pressure and used to power fuel cells at night.

Mid term plans for communication relay UAS's include Aurora-Boeing's Orion, a 76 m span, 5300 kg, hydrogen fuelled, piston engined, craft with an endurance of 7 days at 20 000 m ceiling; and AeroVironment's Global Observer, a 40 m span, 4100 kg, hydrogen fuel cell craft, also with an endurance of 7 days but at 18 000m.

Long term plans include DARPA's Vulture Requirements for a solar powered craft flying for 5 years between 20 000 and 27 000 m. Preliminary contenders on this project include Boeing's Solar Eagle and AeroVironment's Helios, depicted in Figs. 21,22.

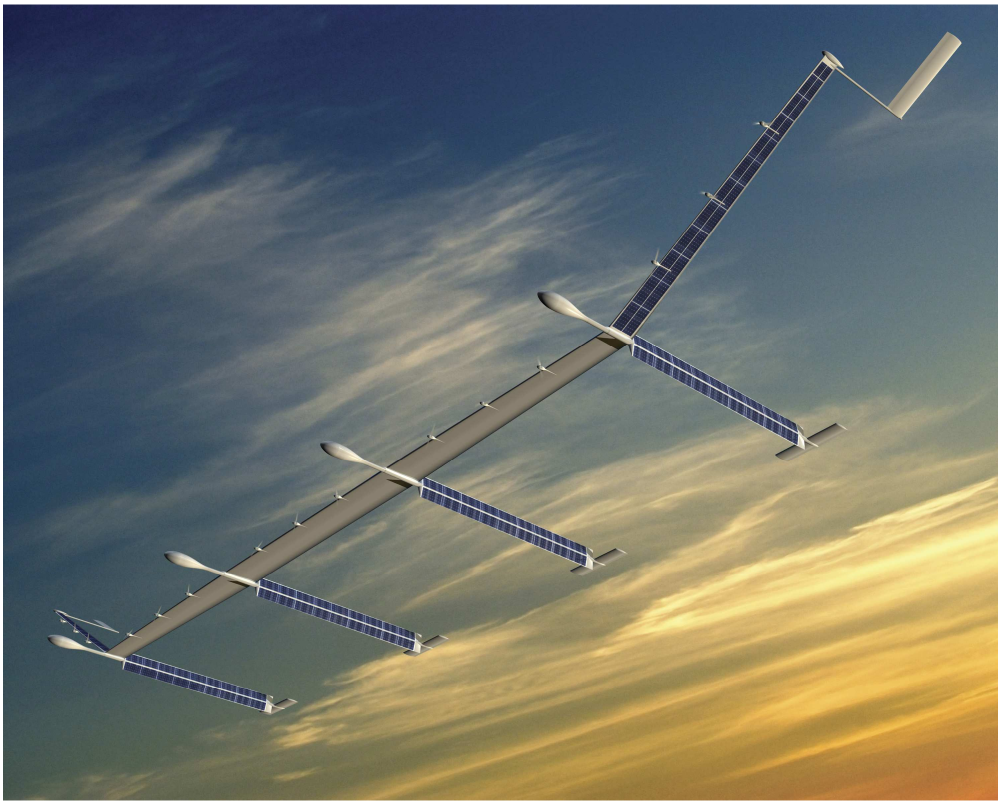

Figure 21: Boeing's Solar Eagle

Figure 22: AeroVironment Helios

7 Conclusions

We have discussed user needs at the state level, considering the interplay between military enemies, market competitors and global threats. Within this context, a ten year roadmap is proposed, building from the current capabilities of SA UAS systems and taking into account international market competition and African deployment patterns.

8 Glossary

ATE : Advanced Technologies and Engineering

C^2 : Command and Control

CSIRO : Commonwealth Scientific and Industrial Research Organisation

DARPA : Defense Advanced Research Projects Agency

EOD : Explosive Ordinance Disposal

FIBUA : Fighting in Built Up Areas

IMT : Institute for Maritime Technology

LIDAR : Light Detection And Ranging

NRE : Non Recurring Engineering (usually in the context of costs)

OSD : Office of Secretary of Defence (US)

TRADOC : Training and Doctrine Command (US)

UAS : Unmanned Aerial System

UAV : Unmanned Aerial Vehicle

UGV : Unmanned Ground Vehicle

USV : Unmanned Surface Vehicle

UUV : Unmanned Underwater Vehicle

9 References

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