CONSIDERATIONS FOR A ROADMAP FOR THE OPERATION OF UNMANNED AERIAL VEHICLES (UAV) IN SOUTH AFRICAN AIRSPACE

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DECLARATION

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ABSTRACT

Unmanned Aerial Vehicle (UAV) technology is classified as being disruptive since it has the potential to radically change the utilization of airspace. Most unmanned vehicles are aimed at military applications, yet civilian applications of unmanned aerial vehicle technology could benefit South Africa considerably.

At present, the lack of UAV regulations and standards precludes UAVs from being certified to operate on a file and fly basis in un-segregated civilian airspace. The inability for UAVs to be certified because of a lack of standards creates a "chicken and egg" – "stale mate" situation. If principles such as "equivalence", initially proposed by Eurocontrol are adopted in South Africa, it then follows that equivalent standards used by manned aircraft could be used by UAVs. UAVs must therefore be tested and evaluated in order to prove compliance with equivalent existing manned aircraft regulations in the foreseeable future until UAV regulations and standards become available.

It has been suggested that specific UAV missions such as maritime patrol, border control, search & rescue, and cargo transport could fulfil current requirements. Design considerations and possible concepts of UAV operations, maintenance and training that will enable UAVs to satisfy the immediate South African strategic requirements whilst complying with existing airspace and airworthiness regulations have been proposed in this document while further UAV specific standards and regulations are being developed.

UAV testing is an essential part of proving the enabling technology, and part of the process of gaining acceptance into wider airspace. Fortunately, flight test methods and procedures applicable to manned aircraft are directly applicable to UAVs, while systems unique to UAVs can be adapted from existing procedures applied to missiles and military UAVs.

Once UAVs are developed and tested, it will be necessary to start full scale operations. Some considerations will be necessary during mission planning. Air traffic management regulations however will prohibit some UAVs from operating in all airspace until enabling technology is developed and tested, while some existing UAVs will never be permitted to "file and fly". This study also analyses existing airspace and UAV platforms in order to identify the airspace

and platforms that will have the most chance of being successfully permitted to “file and fly” in civil airspace.

For South Africa to advance as a UAV operating and manufacturing nation, it is therefore essential to compile a roadmap that will guide the process of developing, certifying and operating UAVs. The roadmap must include an interim process, as well as stating the end objective, which is “file and fly”.

This South African UAV Roadmap proposal is based on international research that uses documentation and lessons learned from elsewhere to guide the process for creating UAV regulations and standards, while allowing existing UAV operations to expand into the existing airspace in order for further UAV research to take place. This roadmap proposal is the conclusion of a 3 year study, and references to the applicable literature are made throughout the document.

OPSOMMING

Onbemande Vliegtuig (OV) tegnologie word geklassifiseer as ontwrigtend omdat dit die vermoë het om die gebruik van die lugruim drasties te verander. Die meeste OVs word gebruik vir militêre doeleindes, maar die siviele gebruik van OV tegnologie kan tot besonderse voordeel wees vir Suid Afrika.

Die afwesigheid van OV regulasies en standaarde verhoed OVs tans om gesertifiseer te word en te funksioneer op ’n “liaseer-en-vlieg” basis in die nie-gesegregeerde siviele lugruim. Die onmoontlikheid om OVs te sertifiseer, weens ‘n gebrek aan standaarde, veroorsaak ’n “hoender en eier” – “skaakmat” situasie. As beginsels soos “ekwivalensie”, wat oorspronklik deur Eurocontrol voorgestel is, deur Suid Afrika aangeneem word, kan die ekwivalente standaarde waaraan bemande vliegtuie moet voldoen ook op OVs toegepas word. Dit volg dat OVs ook in die nabye toekoms getoets en geëvalueer moet word in ooreenstemming met die ekwivalente huidige bemande vliegtuig regulasies, totdat OV regulasies en standaarde beskikbaar gemaak word.

Daar is reeds voorgestel dat spesifieke OV missies soos maritieme patrollie, grensbeheer, soek en redding, en lugvragvervoer huidige behoeftes bevreedig. Hierdie proefskrif maak voorstelle aangaande die ontwerpsoorwegings en moontlike konsepte vir die operasionele gebruik van OVs, hul instandhouding en nodige opleiding wat dit moontlik sal maak vir OVs om die onmiddellike Suid Afrikaanse strategiese vereistes te bevredig. Op hierdie wyse sal die huidige lugruim en lugwaardigheidsregulasies ook nagekom word terwyl verdere OV-spesifieke standaarde en regulasies ontwikkel word.

Die toets en evalusie van OVs is essensiëel om die hierdie magtigingstegnologie mee te bewys, en is 'n belangrike deel van die proses om toegang tot die groter lugruim te verky. Daar word gewys dat vlugtoets metodes en prosedures wat toepaslik is op bemande vliegtuie direk op OV toegepas kan word, terwyl stelsels wat uniek is tot OVs hanteer kan word deur die oordrag van prosedures vanuit die missiel en militere OV toetsomgewing.

Wanneer OVs ontwerp en ontwikkel is, kan volskaal operasies begin. 'n Paar oorwegings sal nodig wees wanneer missies beplan word. Lugverkeerbeheerregulasies sal sommige OVs

verhoed om binne beheerde lugruim-areas te funksioneer, totdat die spesifieke tegnologie ontwikkel en beproef word. Sommige OVs sal nooit toegelaat word om te “liaseer-en-vlieg” nie. Hierdie studie analiseer die bestaande lugruim en spesifieke Suid-Afrikaanse OV platvorms, ten einde die platvorms te identifiseer wat die grootse kans sal he om toegelaat te word om te "liaseer-en-vlieg" binne die siviele lugruim.

Om Suid Afrika as ‘n OV-gebruikers en vervaardigingsnasie te ontwikkel, is dit noodsaaklik om ‘n Roetekaart saam te stel wat die prosesse van ontwikkeling, sertifisering en operasionele gebruik van OVs sal lei. Die Roetekaart moet die nodige tussenprosesse insluit, en dit moet die einddoel stel, naamlik “liaseer-en-vlieg”.

Hierdie Suid Afrikaanse OV Roetekaart voorstel word gebaseer op internasionale navorsing wat omskryf word in dokumente, prosesse en lesse wat elders geleer is, ten einde die proses vir die samestelling van regulasies en standaarde te lei. Intussen laat die Roetekaart voorstel dit toe dat huidige OV operasies verder uitbou, sodat OV navorsing binne die bestaande raamwerk voortgesit kan word. Hierdie Roetekaart is die uitset van ’n drie jaar studie, en daar word deurgans na die betrokke literatuur verwys.

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ABBREVIATIONS, DEFINITIONS AND ACRONYMS

ACSA	Airports Company of South Africa
AECMA	European Association of Aerospace Industries
AFB	Air Force Base
AGL	Above Ground Level
AMTS	Advanced Manufacturing Technology Strategy
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
ATNS	Air Traffic and Navigation Services
BIT	Built In Test
CAA	Civil Aviation Authority
CASR	Civil Aviation Safety Regulation
CI	Critical Issue
COTS	Commercial off the Shelf
D^3	Dull, Dirty and Dangerous
D3	Dull, Dirty and Dangerous
DEF-STAN	Defence Standard
DGA	Delegation Generale pour l'Armement
DOD	Department of Defence
DT&E	Developmental Test and Evaluation
EEZ	Exclusive Economic Zone
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
ERAST	Environmental Research Aircraft and Sensor Technology
EU	European Union
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FAR	Restricted Airspace
HALE	High Altitude, Long Endurance
HIRF	High Intensity Radiated Fields
Hp	Pressure Altitude
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System

JAA	Joint Aviation Administration
JAR	Joint Aviation Regulations
Kg	Kilograms
KIAS	Knots Indicated Air Speed
kJ	Kilo-Joules
MAA	Military Airworthiness Authority
MALE	Medium Altitude Long Endurance
MIL-STD	Military Standard
MOE	Measure of Effectiveness
MOP	Measure of Performance
MSL	Mean Sea Level
NAS	National Air Space
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NTCA	Non Type Certified Aircraft
OT&E	Operational Test and Evaluation
OTB	Overberg Test Range
QT&E	Qualification Test and Evaluation
ROA	Remotely Operated Aircraft. This is the term used in the USA and is essentially the same as UAV and RPV.
RPV	Remotely Piloted Vehicle. This is a type of UAV that requires a ground pilot to control the aircraft.
RSA	Republic of South Africa
RTCA	Radio Technical Commission for Aeronautics
SA	South Africa
SAAF	South African Air Force
SADC	Southern African Developing Countries
SSA	System Safety Assessment
TFDC	Test Flight and development Centre
TMA	Terminally Controlled Area, Terminal Manoeuvring Area, or Terminal Area
UAS	Unmanned Aircraft System
UAV	Unmanned/Uninhabited/Unpiloted Aerial Vehicle
UAV-S	Unmanned Aerial Vehicle - Surrogate
UCAV	Unmanned Combat Aerial Vehicle
UK	United Kingdom
US	United States
USA	United States of America
USAR	UAS System Airworthiness Requirement
USICO	UAV Safety Issues for Civil Operations

TERMINOLOGY

Airworthiness:	A physical state of an aircraft that deems the aircraft to be safe for operations.
Certification:	A process of certifying that compliance with regulatory requirements has been shown.
Contingency:	Procedures that the UAV must perform if the on-board systems should fail.
Large UAV:	Generally used in this paper to describe any UAV heavier than 150kg (>95KJ impact energy)[i,ii].
Light UAV:	Generally used in this paper to describe any UAV lighter than 150kg (<95KJ impact energy)[i,ii].
Qualification:	The process of carrying out tests, examinations, etc., to show compliance with specified requirements which may include regulations and/or standards.
Regulations:	A set of legislative prescriptions which must be complied with prior to, as well as during the operation of a UAV in national airspace, e.g. FAR[iii].
Segregated Airspace:	Airspace that is reserved for the exclusive use by a specific user e.g. FAR 147.
Standard:	A prescribed accepted minimum requirement with which compliance must be shown to achieve certification or qualification status e.g. RTCA 178B[iv].
Termination:	An immediate end to the UAV flight.
Type Certification:	The process by which an aviation regulating authority certifies that a new type design has been evaluated and complies with prescribed airworthiness regulations[v].

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1.INTRODUCTION

1.1. BACKGROUND

The use of Unmanned Aerial Vehicles (UAV) for tasks that have traditionally been executed by manned aircraft is becoming more common. Unfortunately, the widespread use of UAVs in civil airspace has been curtailed because of the lack of processes to allow their operation. To determine the reasons for this, it is necessary to look into the historical use of UAVs, their progress, mostly because of developments in military technology, and their applications. In order to justify why UAVs should be permitted to share the airspace with other aircraft, it is also important to analyse their potential uses and benefits. This South African UAV Roadmap is based on international research that uses documentation and lessons learned from elsewhere to guide the process for creating UAV regulations and standards, while allowing existing UAV operations to expand into the existing airspace in order for further UAV research to take place. This roadmap is the conclusion of a 3 year study, and references to the applicable literature are made throughout the document.

1.1.1. UAV History

UAVs have been employed for a number of military applications since the First World War, where they were usually used for target practice[1]. The first widely used application of UAVs was by the USA during the war in Vietnam.

In the late 1970's and early 1980's, spending on UAVs was reduced because of the emergence of spy satellites[2]. This changed when Israel started to use UAVs during operations in Lebanon[2]. Since then, UAVs have mostly been used for reconnaissance, forward air observation for artillery and as target practice drones.

More recently UAVs have carried out deep strike missions, where precision guided bombs and missiles are dropped deep inside hostile territory. As such, they were used effectively in Afghanistan and Iraq.

It is foreseen that UAV technology will increasingly be used for tasks that are "dull, dirty and dangerous"[3] (D^3)[4], and the potential uses of UAVs for civil operations has increased as the enabling technology has become more affordable.

1.1.2. UAV Applications

Because UAVs can be configured for specific functions, they can be utilized for a number of additional missions. These include[1]:

- Maritime Patrol/Border Patrol/Search and Rescue
- Reconnaissance/Survey/Surveillance/Aerial Photography
- Atmospheric/Environmental Research
- Telecommunications
- Agricultural Applications
- Cargo Transport

Most of these applications have either not been exploited fully in the past, or have been fulfilled using other more expensive technology, such as satellites. Satellites are however expensive to operate, have a limited life, spend little dedicated time over the target and cannot be repaired. Manned aircraft are also limited by their mission time and various other human factors.

In South Africa, UAVs have traditionally been operated by the military and government. In more recent times, there has been a shift towards civil applications. Civil aviation regulations however prevent UAVs, including military UAVs, from operating freely in civil airspace. Some South African UAVs include:

- Denel Dynamics Seeker - surveillance UAV (see Figure A-1).
- ATE Vulture - artillery forward air observation UAV (see Figure A-2).
- Denel Dynamics Skua - high speed target drone UAV (see Figure A-3).
- Denel Aerospace Systems Bateleur (under development) - MALE UAV for surveillance (see Figure A-4).

Although it might be perceived by some manned aircraft operators that UAVs will be replacing them, and although this is in many cases technically possible, it is neither desired nor economically feasible. Within the existing aerospace arrangements, there are a number of factors prohibiting the economically viable use of UAVs for many applications. There are situations however, where the cost of human life far outweighs the cost of the UAV and when the use of a UAV becomes much more attractive.

Other benefits of UAVs include the ability for some UAVs to be invisible and inaudible at low heights above the ground and the ability for some UAVs to be able to operate from unprepared surfaces.

1.1.3. Dull, Dirty and Dangerous Tasks

The term "dull, dirty and dangerous"[3] or D^3 originates from the military, where UAVs would be preferred for operations where the loss of human life would be too costly, or could have moral or ethical consequences.

- Dull, refers to operations that will be too monotonous or require excessive endurance for human occupants (e.g. orbiting above a city for 24 hours while re-broadcasting radio information).

- Dirty, refers to hazardous missions that could pose a health risk to a human crew (e.g. monitoring nuclear radiation).
- Dangerous, refers to missions that would result in the loss of human life (e.g. deep strike military missions where there is a high risk of hostile fire).

This terminology can easily be applied to civilian operations such as long range maritime patrol missions where the risk to the onboard crew makes the use of manned aircraft unfeasible, e.g. between South Africa and Antarctica during winter.

1.1.4. Cost Advantages of UAVs

The US DOD UAV Roadmap[3] compares the costs of manned air vehicles with UAVs and states that acquisition costs are very similar. Although UAVs save developmental costs in human interface equipment (cockpit), they have extra procurement costs, such as the costs of a ground station and reliable and secure communications and data links.

A significant advantage of UAVs includes the use of innovative technologies that would be too difficult to install on larger manned aircraft, for example the use of adaptive wing technology and limited life-low maintenance engines[5], and reduced operational and support costs.

The US DOD UAV Roadmap[3] also states that at least 90% of operational costs of manned systems result from aircrew currency training, a component which can be reduced during UAV operations by using simulators. UAV operators can more easily be trained on simulators by using exactly the same equipment, but replacing the actual UAV with a simulated UAV, and/or by using a limited amount of UAVs for training multiple operators. Actual UAVs, rather than simulators, would only be used for training where UAVs interface with manned flight, e.g. during formation flying or in-flight refuelling.

Ground stations could also be standardized for many UAVs so that very little bridging training of personnel would be required between different types of vehicles. Using advanced "fly-by-wire" autopilots, different UAVs of the same category could be programmed to respond similarly in order to give the UAV pilots the same response, regardless of the UAV type.

1.2. CURRENT STATUS OF UAV CERTIFICATION

The main reason why UAVs are prevented from operating in civil airspace is because of the lack of UAV specific policy and regulations. It is believed that the lack of a desire to proceed with allowing UAVs to operate in civil airspace, together with the lack of a clear path, has led to stagnation in the process. Understanding the current state of affairs and historical stumbling blocks will enable us to avoid these pitfalls when determining a way forward.

1.2.1. "Chicken and Egg" Situation

UAVs have been caught in a "chicken and egg" situation[1,6] where the regulating authorities are waiting for evidence of acceptable safety from users before they create regulations. On the other hand, industry is waiting for UAV specifications and regulations before being able to sell certified UAV technology. Users are in turn waiting for certified UAV products before being able to operate them, which would then provide the required evidence of safety.

1.2.2. Current Status of UAV Regulations

Present regulations for manned aircraft were derived historically and were modified after air crash investigations and were not based on a total system approach[6]. Partly for this reason, manned aircraft regulations are not always suitable for unmanned air vehicles. However, in order to gain access into airspace that is dominated by manned aircraft, UAVs will have to fit into the existing structure until such time as the manned airspace environment evolves[1] and until new policy and regulations for UAVs are created.

In South Africa, work was started by the Air Traffic and Navigation Services (ATNS) as early as 2002 in order to regulate UAV operations, but only a very brief draft document[7] was created and no further discussions took place. Many of the discussion documents and research documents presently available were not available at the time, and although the document has some common ground, some of the ideas suggested in this document are no longer considered to be feasible.

In order to integrate UAVs into the manned aircraft infrastructure in a more structured manner, certain principles should be agreed upon before proceeding:

The principles proposed by the Joint Aviation Authority (JAA)/Eurocontrol UAV Task Force[8] for creating of UAV regulations are, *fairness*, *equivalence*, *responsibility* and *transparency*, and could be used throughout the industry. The benefits of using these existing principles are that once the principles have been agreed upon by both manned and unmanned airspace users, the process of creating UAV regulations and policy will be quicker, and that it will be easier for manufacturers wishing to export UAVs to gain acceptance in other countries that apply the same or similar principles.

It has been stated that the countries that take the lead in UAV certification will become the leaders in UAV technology[4,9]. Although Europe, under the leadership of the JAA and EUROCONTROL, has been taking a lead[8], no UAV specific regulations have yet been published. Australia has created a set of UAV regulations[4,10] which could be used in developing South African UAV regulations, but these regulations are limited in their scope.

The roadmap proposed by this document suggests a way forward for South Africa to become a significant role player in the international UAV community.

1.2.3. Existing Air Traffic Arrangements

At present, airspace in most countries is divided into different classes (See Appendix F). Each class of airspace usually has requirements for procedures, on-board equipment and manoeuvring. Usually, aircraft that can comply with these requirements will be permitted into the appropriate class of airspace. Although UAVs are not officially recognized as a separate category of aircraft, UAVs are not exempt from complying with these requirements. An example of this would be the requirement to have a transponder installed when operating in a terminally controlled area (TMA), otherwise known as Class B airspace (see Appendix F), in order to assist the ATC with separation.

In areas where the expected traffic congestion is the most severe, the requirement for on-board equipment increases, and the responsibility for aircraft separation shifts from the pilot to the ATC. The implication of this is that because the function of aircraft separation shifts from the pilot to the ATC in controlled airspace, UAVs will more easily fit into most controlled (segregated) airspace provided that they have the required equipment on board.

Conversely, airspace that requires almost no on-board equipment provides the most challenges for UAVs since the responsibility for avoiding other air traffic shifts back to the pilot. For manned aircraft, the pilot's ability to see other traffic is sufficient, while UAVs are currently required to possess a similar "detect and avoid" capability in order to operate in this airspace, which does not exist at present.

It is therefore foreseen that only larger UAVs that have the available payload capacity to have the required ATC equipment installed, will be permitted to operate in heavily congested, highly regulated airspace, while smaller UAVs will be best suited to airspace that has fewer requirements for onboard equipment, provided that a "sense and avoid" solution can be found. Until such technology is developed, UAVs will probably only be permitted to operate in specially segregated airspace, and their operations will have to be published in a notice to airmen (NOTAM).

Another alternative is to design and use UAVs that pose little threat to existing air users and people on the ground. However, apart from existing radio controlled airfields, special airspace and regulations have not been set aside for UAVs and small UAVs wishing to operate in any airspace not reserved for radio controlled aircraft will be required to obtain a special airworthiness permit from the Civil Aviation Authority until relevant UAV regulations have been published.

1.3. THE WAY FORWARD

The way forward is to firstly analyse the past, and to learn from previous mistakes. An end objective must be defined so that a path can be determined. Although there are many possible paths, it was decided to do research in order to determine the paths followed in various countries, each with their unique circumstances, and to initiate a similar process in South

Africa, but taking into consideration all the unique South African requirements and idiosyncrasies.

1.3.1. The End Objective of Creating Regulations ("File and Fly")

The end objective for creating UAV specific regulations is so that the "file and fly" principle[11] can be applied. This will require military and commercial UAVs to be type-certified in accordance with the relevant airworthiness regulations.

Because South Africa is not currently a major role player in the aerospace manufacturing industry, it is unlikely that efforts in creating regulations for UAV operations in South Africa will be adopted by Europe or the United States of America, and it would therefore be prudent to adopt and adapt regulations used by these countries. A number of organizations in these countries have started the process of creating regulations that will enable the certification of UAVs.

Any aircraft wishing to fly in controlled airspace must be airworthy and must also comply with design, safety, maintenance and operations regulations applicable to that country (e.g. FAR[12] in the USA). Provided that the conditions of ICAO are met[13], countries recognize each other's regulations[8] and for this reason there is usually much commonality in regulations. This enables the regulating authority of one country to accept aircraft that were registered by a foreign government's regulating authority. Although not mandatory, using internationally recognized standards and principles will therefore be advantageous[1].

1.3.2. The Process that was Followed in Creating this Roadmap

Before simply creating regulations and standards, it was determined that creating a structured process would be the most logical way forward. This process is depicted in Figure 1 and includes:

- Identifying the real requirements and determining exactly what was preventing UAVs from being certificated.
- Studying as much literature as possible, while paying special attention to: academic studies, policy documents, roadmaps, regulations, standards and

other officially published government documents. Case studies were also investigated to try to determine the strengths and weaknesses of the various models that were already proposed or implemented.

- Once the literature study was complete, elements of the model for the certification of UAVs in South Africa were constructed.
- Peer reviewed papers[14,15,16,17] were published in order to test if the logic of the proposals were sound. These peer-reviewed papers were distributed to the leaders in the South African UAV industry and to personnel within the SA CAA.
- Feedback from the SA CAA and the UAV industry was studied and the model was modified where necessary.
- The final proposal for the roadmap was constructed from a combination of the literature study, the published papers and the feedback that was received.
- The final version of the roadmap was submitted to the South African UAV Coordination Committee as a proposal for the process that could be followed for South Africa to integrate UAVs into its existing airspace and to create regulations and standards that will assist the UAV industry with the manufacture of certifiable UAVs.

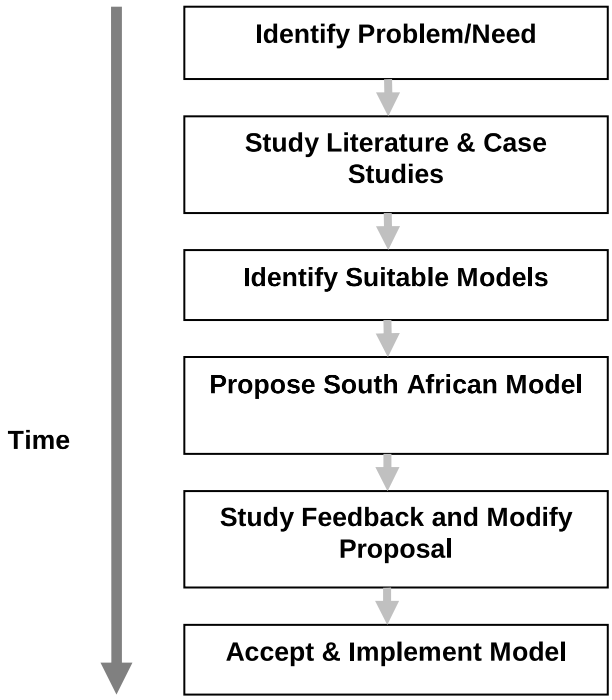

Figure 1: Process Followed while Creating the Roadmap

1.3.3. South African UAV Co-ordination Committee

After years of informal discussions at various conferences about the issue of UAV certification, the SA Civil Aviation Authority convened a meeting on 28 July 2006 to establish a co-ordination committee[18] that would bring together all role players in the UAV industry, including air traffic control, manufacturers and academia in order to provide the inputs that would be required when formulating UAV policy and documentation for South Africa.

Because of the research being done on UAV regulations and certification, an invitation was received from the SA CAA to attend the inaugural co-ordination committee meeting. An academic paper on UAV certification[14] was presented at the meeting, and it was proposed and accepted that the research already done would be used as a guideline when determining the future strategy.

It was later decided that the purpose of the co-ordination committee would also be to co-ordinate the efforts of sub-committees, and to promote the safe usage of UAVs in South African airspace[19]. Owing to the knowledge obtained whilst studying UAV regulations and certification, an offer was made during the meeting to serve on the co-ordination committee as a representative from the academic community.

1.3.4. South African UAV Sub-Committees

During a later UAV co-ordination committee meeting, it was decided to create sub-committees that would address issues of airworthiness and operations. This was later expanded to include: Airworthiness and Standards, as well as Operations and Training[20].

During a discussion on airworthiness, it was stated that total airworthiness covers aspects of operations and training, however it was decided to continue with these sub-committees in order to split the work load, and that it would be the responsibility of the co-ordination committee to ensure that the necessary cross correlation took place.

The UAV sub-committee on airworthiness and standards decided to develop an interim policy that would regulate the airworthiness of UAVs until more substantial regulations are available. A draft proposal[21] was submitted[22] for review. This document covered a wide range of issues including: UAV policy, UAV airworthiness and airspace regulations pertaining to the use of UAVs. It was suggested that this document be used as an interim document, but that it would become a working document that would be modified and eventually be separated into the three separate documents of policy, regulations and standards.

1.3.5. Existing Process

It was stated during the first UAV Sub-committee meeting[23] that a process was already used by Kentron (Denel Dynamics) to operate UAVs in segregated airspace or temporarily reserved airspace. The process is described in Appendix D. This process however only ensures the use of military and ex-military UAVs in segregated airspace.

Although this process would be suitable for the future use of UAVs that fall into the same category, the requirement to operate in segregated, or even temporary segregated airspace would be restrictive, and many new UAV designs would not fall into the military and ex-military category.

A more permanent arrangement or at least a temporary arrangement, such as the Access 5 approach[9] will be necessary for non-military UAVs in order for a wider scope of UAVs to operate within existing South African national airspace.

1.3.6. The "Access 5" Approach

It was suggested[14,15,16] that since generating UAV regulations and standards at once seems to be difficult and unlikely, a more suitable approach would be to allow the use of UAVs in specific areas while development of the enabling technology is being executed and as the technology matures and a safety record is produced, the airspace where the UAVs are permitted to operate could be expanded incrementally to other areas.

The remainder of this "roadmap", is dedicated to identifying the potential areas of operation, the types of missions that would be suitable, the research areas that will require design innovation in order to fulfil these missions, the test procedures required during the design in order to ensure that safety of operations can be proven, what process needs to be followed in order to certify the UAV in order to be permitted to fly, and finally what airspace regulations the UAV will need to comply with in order to operate in the same airspace alongside manned aircraft.

1.3.7. Proposed Roadmap

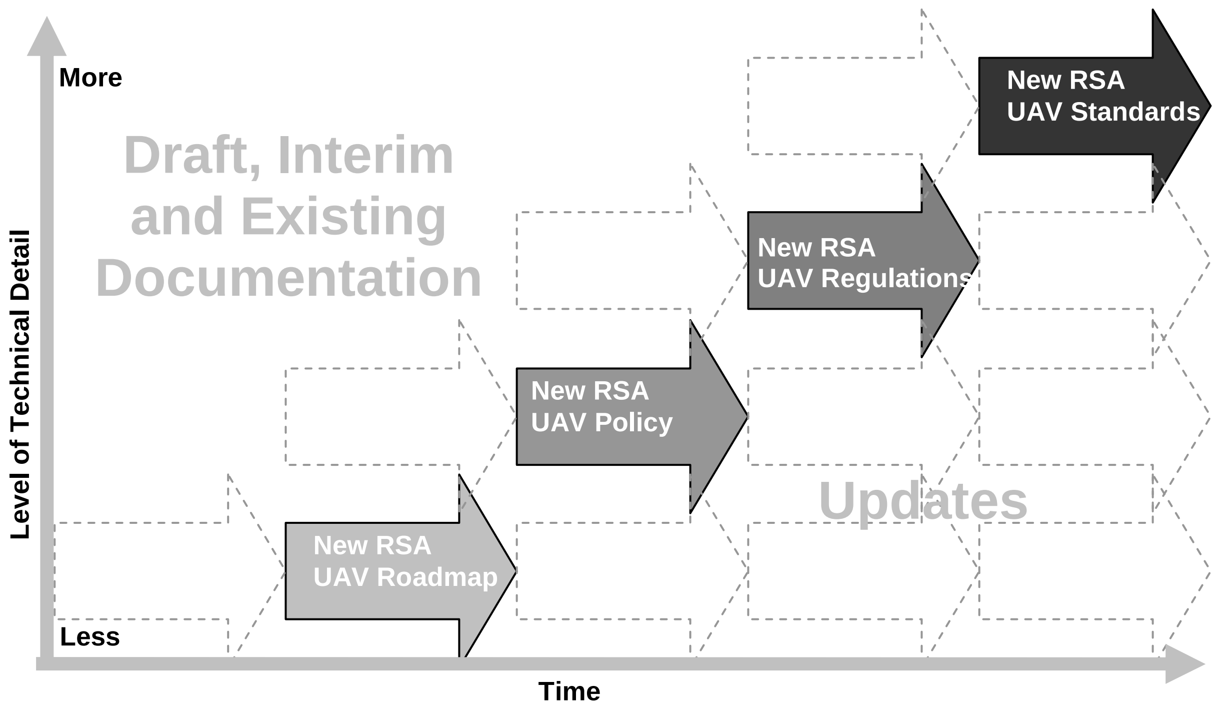

Figure 2: Process for Creating Policy, Regulations and Standards Documents

Because the present lack of published guidelines, policies, standards and regulations has prevented UAVs from operating in civil airspace, a process needed to be initiated in South Africa that would guide the rest of the process of creating the relevant policies, regulations and standards (See Figure 2). Using the knowledge obtained from the research done while creating this roadmap, a preliminary interim roadmap process (Appendix C) was proposed at the South African UAS Co-ordination Committee[24] in order to initialise the process.

The proposed interim roadmap process recognizes the importance of continuing to support existing UAVs in South African airspace by means of temporary special airworthiness permits for operations in segregated airspace, while also placing emphasis on creating a more permanent process for the use of future UAVs that will require certification to operate in South African un-segregated airspace.

1.3.8. Contributions made by this Research

During the course of this study, the following contributions towards the aerospace industry were made:

- Three papers were authored, and one was co-authored in local and international journals. These have subsequently been used by South African and International companies wishing to operate UAVs in South African civil airspace.
- Six presentations were made at national and international conferences where the research was presented to an international audience.
- A roadmap proposal was generated that proposes a method to integrate UAVs into South African civil airspace using a phased approach that uses existing airspace and UAVs to do fundamental research in the mean time, and expanding the area of operations once the technology has been proven.
- Based on the recognition received from publishing papers and giving presentations, inputs regarding UAV certification and testing were requested at various governmental forums, including the UAV co-ordination committee and sub-committees.
- Areas requiring further research were identified, and proposals were made for further research to be executed.

1.4. SUMMARY

UAVs have been used for almost as long as manned aircraft (excluding unmanned balloons and kites which precede manned flight), but because of their limited use, airspace regulations have followed the progress of manned aircraft, but not that of UAVs, and is now preventing UAVs from operating freely.

In order to be permitted to operate on a "file and fly" basis, regulations will need to be modified in order to accommodate UAVs. In order for UAVs to operate in the interim, UAVs will have to comply with existing regulations.

The development of regulations and standards is underway in many countries. In South Africa, a committee was formed to address the issues relating to operating UAVs in civil airspace. As part of this process, a roadmap would have to be created in order to guide the process forward.

As an initial step, it was proposed that airspace should be set aside where research and development can take place, and using the Access 5 approach, when the UAV technology matures and has been proven, the airspace can be expanded to other areas within South Africa.

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2. UAV AIRWORTHINESS REGULATIONS & STANDARDS

2.1. INTRODUCTION

It was stated in the previous section that the lack of regulations and standards was preventing the widespread use of UAVs in civil airspace. It was also stated that in order to create a process or roadmap it would be important to analyse the current status of UAV certification and to learn from work that has been done elsewhere. It would be sensible to learn from the efforts made by other governments, organizations and agencies in creating UAV policy documents. The motivation behind creating unique South African standards and regulations must also be determined so that the correct strategy for the certification of future UAV designs can be determined.

2.1.1. Work Done by International Governments, Organizations and Agencies

The International Civil Aviation Organization (ICAO) was established during the Chicago Convention in 1944[25] in order to set up rules and regulations for contracting states. ICAO has retained this position to date and South Africa is one of the contracting states. The Chicago Convention[25] is used as a basis which has been updated and translated by means of various editions. Although the Chicago Convention[25] does not specifically refer to UAVs, it does make provision for "pilotless" aircraft[25,26]. The Chicago Convention contains articles that address most of the issues relating to civil aviation. More recently, because of the requirement to operate UAVs in civil airspace, ICAO held an exploratory meeting[27] in 2006. At this meeting it was concluded that ICAO was an obvious choice for coordination and reaching consensus on UAV technical and performance specifications and standards, and a questionnaire was issued to attending states and organizations and the results were published[28]. During a later meeting[29], it was noted that ICAO would use the work of RTCA, EUROCAE and other organizations as a basis for ICAO Standards and Recommended Practices (SARPs) and a number of critical issues were addressed. It was also stated that it was still too early to address the regulatory issues, but that there was a need for harmonization of various aspects where ICAO could act as a focal point, but not as a leading regulatory authority.

The FAA is the world's leading agency in aircraft and airspace regulations, and many nations base their own regulations on the FARs. The FAA Flight Plan 2004-2008[30] states that one of its objectives is to develop policies, procedures and approval processes to enable operation of unmanned aerial vehicles. The FAA does however rely on the industry and UAV organizations such as NASA/ERAST Alliance and the now cancelled Access 5 to provide it with the requirements for UAV regulations.

The NASA/ERAST Alliance Certification Project[31] document is a concept document that proposes an overview of a particular class of UAV (High Altitude Long Endurance) in the US National Airspace (NAS) in 2002 and beyond. The organization included the US government, industry and academics.

Access 5 was an initiative sponsored by NASA and the US industry with participation from the US DOD and FAA to introduce HALE UAVs into the US NAS. It proposed to develop standards, regulations and procedures, to demonstrate technology and implement infrastructure that would be necessary to make it possible to fly HALE UAVs in the US national airspace, routinely, safely and reliably by using a specified four step process.

The US Department of Defence, Office of the Secretary of Defence, UAV Roadmap[32] document aimed to stimulate the planning process and to provide a forum for mutual discussion. The document stated that it did not intend to seek concurrence with the services or impose any requirement for funding. It highlighted the trends and future needs that would need to be in place if UAVs were intended to be used for future military applications. The document is described as being "descriptive" rather than "prescriptive" of what must be done in the future and highlights areas of research required in order to make UAVs feasible. It was the first document to describe the concept of "the dull", "the dirty", and "the dangerous".

The US Air Force also published a separate document in 2005, The U.S. Air Force Remotely Piloted Aircraft and Unmanned Aerial Vehicle Strategic Vision[33] that generally describes the benefits of UAVs to the USAF, lists the challenges which includes; reliability, weather, cost, the risk of jamming and airspace integration issues, and provides recommendations how to address these issues.

The JAA/EUROCONTROL Concept of European Regulations for Civil UAVs[34] is a detailed document representing the final report of the UAV Task Force established to address the development of a concept for the regulation of civil unmanned aerial vehicles, with respect to safety, security, airworthiness, operational approval, maintenance and licensing. The document stated that it did not address military UAV certification, but assumed that the military would benefit from the document. The final report also did not develop a concept for the air traffic management of civil UAVs. This document was the first to address the issues of fairness, equivalence, responsibility and accountability.

The Euro UVS Vision of the Future[35] highlighted the need for future application of civilian UAVs. The document addressed the requirement for the

JAA/EUROCONTROL to be a multinational effort, to consist of all major stakeholders, to be a European initiative in which the FAA and US industry were participating and was a one year study to formulate the outline and guiding principles to further the establishment of UAV related airworthiness rules.

EASA published a Policy for UAV Certification[36] where various options for the certification of UAVs were presented and general guidelines were provided. The principles proposed by the JAA/EUROCONTROL[34] were used as guiding principles, and the safety target level and the airworthiness codes approaches to certification were discussed and a proposal was made to map existing manned aircraft regulations (CS 23 and CS 25) onto future UAV regulations (CS-UAV 23 and CS-UAV-25).

The UK CAA has published a document, CAP 722[37], which provides a "signpost" for UAV operators. It does not replace existing regulations and only acts as guidance for UAV operators and manufacturers, who will be intending to operate and certify UAVs and discusses existing regulations, procedures and addresses issues that will still need to be researched. A further document[38,39] was issued by the CAA that further clarified the UK CAA's position, and presented methods for determining the level of airworthiness that needs to be applied by reference to existing codes of airworthiness for manned aircraft.

The French Flight Test Centre presented the framework of the USAR[40] that used a system safety assessment (SSA) to map the JAR/FAR directly with proposed UAV regulations. A subsequent study[41] was concluded in 2005 where the content of the EASA CS-23 (JAR 23) were mapped to each USAR, using the approach proposed the UAV Task Force Final Report[34], and was specifically intended for the certification of military UAVs. This document stated which paragraphs of the EASA CS-23 (JAR 23) document were not applicable to UAVs, modified the relevant paragraphs to accommodate UAVs and includes a means of compliance statement.

At the time that this study was done, Australia was the only country that had officially published a set of UAV regulations, the Australian Civil Aviation Safety Regulation 1998 (CASR) Part 101[42]. These regulations are applicable to tethered balloons and kites, unmanned free balloons, UAVs, model aircraft, rockets and fireworks. These documents include advisory circulars[43,44,45] detailing how compliance with the regulations must occur. Although these regulations are very comprehensive, they do not correspond directly with equivalent manned aircraft regulations.

The American Society for Testing and Materials[46] was given the task to develop standards for UAVs by involving the relevant market place, manufacturers, users, regulators, trade associations, consultants and academics. The reason for the ASTM developing the standard was because of its standing in the industry, as well as the hidden benefit of tax savings as it is a non-governmental organization. A committee (F38) was formed to deal with UAVs, and is divided into three sub-committees viz. Airworthiness (F38.01), Flight Operations (F38.02) and Operator Qualifications (F38.03).

2.1.2. Steps toward the Implementation of UAV Regulations

Figure **3** illustrates the role of the various documents in achieving the eventual aim of "file and fly".

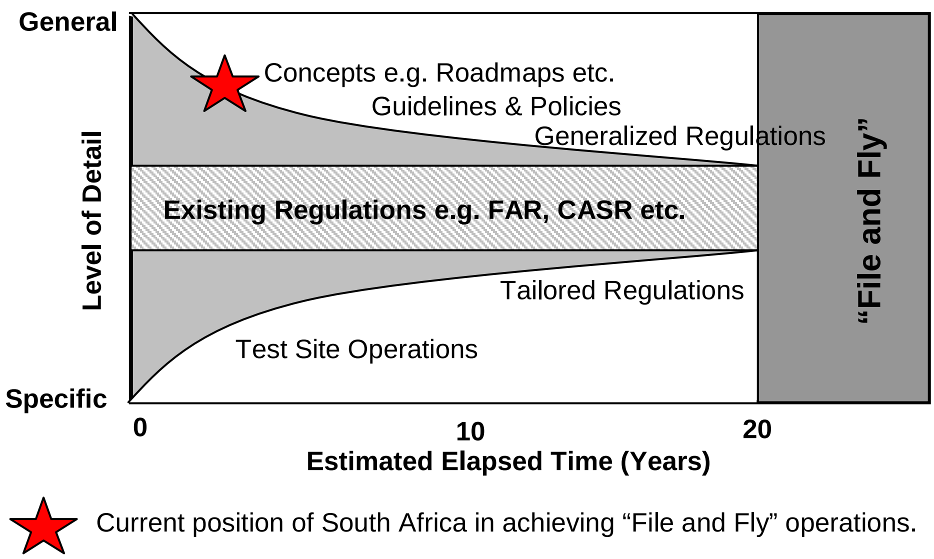

Figure 3: Steps toward the Implementation of UAV Regulations[47]

Conceptual documents and roadmaps, such as the NASA/ERAST Alliance Certification Project[31], are usually the first step in the process of generating regulations and standards.

Thereafter, more detailed documents emerge, such as the CAP 722[37], which are not regulatory documents or standards themselves, but refer to existing procedures and documents and indicate what procedures need to be followed in order to allow UAVs to operate within the existing civil airspace regulations.

Generalized regulations, such as the Australian Civil Aviation Safety Regulation 1998 (CASR) Part 101[43,44,45], are almost complete regulations, but do not include specific details of airworthiness standards and airspace usage requirements, and do not automatically allow “file and fly” operations to take place.

Test site operational documents include documents, such as the Wallops Flight Facility UAV User’s Handbook[48], that regulate the specific operation of UAVs on and around test facilities, but do not regulate the use of UAVs outside these boundaries.

Because of the experience gained during flight testing at flight test centres, these regulations can be refined, and can almost resemble the final version of regulations and standards for UAVs, and these documents, regulations and standards can be merged into the final UAV regulation and standard documents.

Figure 3 also illustrates the importance of executing UAV research at test centres whilst developing UAV regulations and standards in parallel so that lessons learned during flight testing can be applied to new regulations.

This document, the proposal for the South African UAV Roadmap, could be the country’s first step in the process of allowing UAVs to “file and fly”.

The estimated elapsed time in Figure 3 is based on the time that it has taken for the various documents to emerge so far, and by using the diagram[47], a rough graphical extrapolation was made in order to estimate how long it will take to achieve “file and fly” operations in South Africa. The illustrated time frame of approximately 25 years indicates the importance of finding an alternative path for certifying existing UAVs while fully comprehensive regulations, standards and UAVs that will comply with these requirements are being developed.

2.1.3. Necessity for South African Regulations and Standards

Because of its war on terrorism, the USA renewed efforts to encourage the use of lower cost technology for surveillance[31,49]. In addition to this, countries like South Africa are being expected to fulfil regional duties by providing military support and humanitarian aid within Africa and to provide maritime surveillance and search and rescue capabilities off the coast of Southern Africa, all the way to Antarctica. This has provided more of an incentive to exploit UAV technology in South Africa.

In addition, the South African Government has launched the Advanced Manufacturing Technology Strategy (AMTS) and the Aerospace Industry Strategic Initiative (AISI) which partly aims to establish South Africa as a major player in the world aerospace industry. South Africa can therefore not afford to lag behind in the key area of UAV technology.

The South African Civil Aviation Authority is in the process of investigating the possibility of allowing UAVs to operate in civil airspace[50] for tasks such as crowd monitoring, border protection and maritime patrol[51,52]. A number of issues preventing the widespread use of UAVs were identified and include the lack of regulations and standards, the development of sense & avoid equipment and the lack of a history evidence of safety of operations[51,53].

Owing to the fact that South Africa has two major UAV manufacturers and potentially many smaller private UAV manufacturers, South African authorities must encourage the manufacturing and operation of UAVs. This will in turn create manufacturing jobs and will create opportunities for UAV service providers for numerous tasks that cannot be accomplished at present with the current resources in South Africa. There is now a sense of urgency to integrate UAVs into South African civilian airspace and to utilize UAVs for the numerous civilian and humanitarian applications.

If South Africa does not create its own regulations and standards, when a UAV manufacturer wishes to certify a UAV, the manufacturer will be required to apply for certification in another country that does possess relevant regulations for UAVs. Since the process of creating regulations in foreign countries is slow, the South

African UAV industry will have to wait for these regulations to become available. Furthermore, the manufacturer will find it more difficult to communicate with foreign countries than with its own CAA. The creation of South African specific regulations, even if they are a compilation of foreign regulations, is of national importance for the survival of the South African UAV industry.

Airworthiness authorities such as the FAA and South African CAA are however indicating their preference to refer to standards[51,53] such as RTCA DO-178B[54] for airworthiness, rather than to include the technical detail within the regulations. Because few standards for UAVs exist, and while standards are in the process of being developed by organizations such as ASTM, it will be necessary for the SA CAA to investigate the suitability of existing standards and to develop new and possibly unique South African standards which will in turn be referenced in South African airspace regulations[50].

Historically, UAV manufacturers have built UAVs to meet their own standards and have obtained special flight permits[55] to operate in South African airspace in accordance with SA CAR 91, which is similar to FAR 91[30]. In order to be permitted to “file and fly”[51,56], it will be necessary for UAVs to be certified in accordance with appropriate regulations[51,52,55].

Once standards are available for all classes of UAVs, they will facilitate the design, manufacture and qualification of UAVs which may eventually lead to certification of UAVs for “file and fly” operations in un-segregated civil airspace.

UAV technology can typically be used for D^3 tasks. With this concept, the nature of maritime patrol with long endurance over vast expanses of ocean makes UAV technology ideally suited.

Since South Africa has to fulfil its duties for maritime surveillance, and search and rescue all the way to Antarctica, an opportunity exists to use UAVs. Because of the location of South Africa, with no controlled airspace to the south of the country, the question must be asked if it is necessary for aircraft, manned and unmanned (provided that no fare paying passengers are on board), to comply with the same regulations that are required over built up areas, and in controlled airspace.

This is an opportunity that few other countries can afford to take purely because of their geographical location and density of their population. If South Africa uses the opportunity that is being presented, it could become a world leader in UAV operations. This does not mean that UAVs should be permitted to fly over the sea in an un-regulated manner. Rather, a pragmatic approach should be taken to use the opportunity to prove the UAV technology where there is little or no risk while providing useful insights into UAV operations in general and obtaining data into UAV safety and reliability.

In order to achieve this, an initial investment will be needed in the UAV industry. Since UAV products are already available, the investment can contribute to an existing need for maritime surveillance, with the objective of certification research taking place in the background.

2.1.4. Future Requirements for Regular UAV Operations in South Africa

South Africa has one of four options:

- Create its own regulations independently.
- Wait for regulations to be created by ICAO, the FAA, EASA or any other authority.
- To collaborate with other countries and organizations so as to speed up the creation of UAV regulations and to adopt those regulations.
- To create an alternative plan for the operation of UAVs.

Creating indigenous regulations without a reference to draw from could be risky. The regulations might not be recognized, and in the interest of the aviation industry, would have to change to internationally accepted regulations. However, Australia has followed this route and is already, in a sense, leading the industry.

Waiting for regulations to be developed could take some time, and in the mean time, the South African UAV industry will loose its competitive edge to other countries who are closer to the FAA or EASA.

Taking part in the international regulation development process is the method that has been adopted by most of the European and American industry. The reason for this is because they have no choice other than to collaborate with the hope that the joint effort will pool resources and add pressure to the regulating authorities. The disadvantage is that the large organizations have an inertia which slows down the process.

The last option for South Africa is to explore alternative methods of utilizing UAVs, while gaining sufficient experience in UAV operations, design and manufacture, before developing UAV regulations[57], and then to create its own regulations.

2.2. GUIDELINES FOR CREATING REGULATIONS AND STANDARDS

When creating standards and regulations, it is essential for all stakeholders to agree on a set of guiding principles. This will then create a framework within which the various sub-groups can set about generating their own regulations and standards. Understanding the purpose of standards and regulations, and where UAVs fit into the world of aviation, will also assist with defining regulations and standards that are appropriate for UAVs, and will place UAVs in the correct position relative to manned aircraft.

2.2.1. UAV Regulation Principles

The first of the principles discussed in the JAA/EUROCONTROL Concept of European Regulations for Civil UAVs[34] is fairness. It would be unfair to allow UAVs not to have to comply with certain regulations that manned aircraft would have to comply with, and likewise, it would be unfair to create stringent regulations that are only applicable to UAVs and not to their manned counterparts purely because the technology exists to do so. Application of regulations to UAVs must be done fairly, with the acknowledgement of their unique differences. One issue that still needs to be debated is how strictly the regulations will be applied to UAVs, when even manned aircraft sometimes cannot comply with the existing regulations. For example, when certifying autopilot software, it is required to comply with very strict standards such as RTCA DO-178B[58]. The reality is that even a human crew can become incapacitated, as was the case in the Helios Airways Boeing 737, flight 522, which crashed and all 121 people on board died. It would be unfair to expect UAVs to have a perfect accident record, when manned aircraft also do not even meet the same levels of safety.

The second principle is equivalence[34]. Regulations that apply to manned aircraft must be applied equally to UAVs. It must be remembered that the application and environment of UAVs will be different to manned aircraft, and the regulations would therefore be applied differently. A certain regulation could be applied to a manned aircraft for a specific mission and environment. The same regulation could also be applied to a UAV for a different mission and environment. The regulation must however be applied in a manner such that it is not applied more, or less strictly to a UAV than it would be to a manned aircraft. For this reason, an equivalent measure should be defined e.g. safety of people on the ground and/or in the air, so that the regulations can be applied effectively. These measures must include all relevant factors that make up the overall safety of the system, i.e. UAVs have a less proven safety record, but will probably, for some time at least, not carry people on board.

The third principle is responsibility and accountability[34]. A method or approach must apply to UAVs which ensures that the responsibility and accountability of all aspects i.e. design, manufacturing, maintenance and operations, is equivalent to that of a manned aircraft. For this reason, it is foreseeable, that a UAV system will always require a person who is accountable, such as a mission commander or UAV pilot. Because of this restriction, a responsible human will always have to be in the loop even though fully autonomous missions are already possible. Only once UAV technology with a human in the loop has been proven, will the effective technology be able to progress to human outside the loop[53], or even full autonomy.

The fourth principle is transparency[34]. Airspace operations must appear to be exactly the same for all users of airspace. UAVs must therefore appear to other users of airspace in exactly the same manner as manned aircraft appear. ATC, for example, should be able to apply exactly the same rules to UAVs as they would to manned aircraft. This however does present a paradox since even though UAVs can appear to interact the same as manned aircraft, they will still physically look very different.

Inconsistencies within manned aircraft operations[53], such as radio blanking, radio un-serviceability, pilot non-cooperation or non-compliance makes air traffic management with existing regulations difficult, and it would therefore be unfair to expect UAVs to achieve a perfect record, when even manned platforms cannot achieve this.

2.2.2. Standards Based Regulations

Many regulatory authorities are moving towards standards based regulations[53]. The benefit of using standards as a basis for regulations is that aircraft designers can also use the standards as design guidelines. In addition to this, the standards can be updated without having to follow the long legal process of changing the regulations. It is partly this long process of changing the existing regulations that presently makes the integration of UAVs into the national airspace so time consuming and problematic. The standards can be developed by organizations consisting of specialists in the specific field of design, such as the Radio Technical Commission for Aeronautics (RTCA) DO178B[59].

It is most likely that South Africa will adopt existing standards, although as an interim measure, local standards could be developed by the local UAV industry and prescribed by the SA CAA. It is advisable however that these standards should not be less strict than the proposed international standards, as numerous certified UAVs may be classified as un-airworthy when the international standards are promulgated, which could pose a risk to the South African UAV industry.

2.2.3. UAV Categories

Because of the equivalence principle, and because many radio controlled aircraft are essentially UAVs, some authorities[34,37,45,53] have decided to permit UAVs that are similar to radio controlled aircraft to continue to be operated as radio controlled aircraft, provided that they operate within existing arrangements of radio controlled aircraft. These restrictions include not being able to operate higher than 120m (400ft) AGL[45]. Most authorities base the cut off for the classification of radio controlled aircraft on kinetic energy or mass.

Generally, UAVs lighter than 150kg are classified as light UAV systems[34,60]. These UAV systems do not qualify as model aircraft, but also do not necessarily have to comply with the same regulations as manned aircraft but are still required to operate within certain restrictions, e.g. daylight operations within visual range of the pilot in segregated airspace below 120m (400ft) AGL[34]. A measure of kinetic energy below 95 kJ has been proposed as a cut-off[34]. Although there is still some debate about the reasoning behind this cut-off, it has already been adopted in some countries and for reasons of interoperability, it would be sensible for South Africa to use the same mass as a cut-off.

UAVs heavier than 150kg or with a kinetic energy above 95KJ that are to operate in non-segregated airspace will most probably have to be classified according to existing manned aircraft regulations[37].

Owing to the principle of equivalence[34], it seems evident that UAVs will be expected to comply with the relevant regulation for the existing equivalent class of aircraft that it will be classified within (e.g. helicopter, balloon etc.)[34].

Also, the "rules of the air" that determine right of way are determined by the manoeuvrability of the platform, rather than how big or how many people are on board. Classifying UAVs into the same existing categories as manned aircraft makes sense. The reason for this is because the intent of the classification of air vehicles into these categories is primarily for the pilots of other aircraft to decide what type of evasive action to take based on what they perceive the category of the aircraft that they are on a collision course with to be. If sub categories of UAVs are to be created, pilot training will have to be changed and it is doubtful that pilots will be able to determine if aircraft that they are on a collision course with are manned or unmanned, especially at long ranges and in poor visibility

When complying with existing manned aircraft regulations, the regulations pertaining to human interfaces (e.g. oxygen supply for aircrew) will obviously not be relevant[31]. As a result, manned aircraft regulations will need to be modified where necessary, to include UAVs. Lastly, new regulations specific to UAVs (e.g. data link integrity) will need to be created where manned aircraft regulations are completely unsuitable[34].

Eventually, a new set of regulations could evolve that refers to aerospace systems in general and does not separate inhabited from uninhabited systems. Since the South African Civil Aviation Regulations (SA CAR) are in the process of being promulgated, this would be the ideal time to take the necessary action to include UAVs in the SA CARs.

2.2.4. Difference between Standards and Regulations

Much confusion exists about the difference in purpose between regulations and standards. A regulation is by definition[52] a set of legislative prescriptions that must be complied with prior to, as well as during the operation of a UAV in national airspace, e.g. the Federal Aviation Regulations[30]. A standard is by definition[52] a prescribed accepted minimum requirement with which compliance must be shown to achieve certification or qualification status e.g. RTCA DO-178B[54].

Regulations are therefore prescribed by a government agency tasked to manage the safety of aviation in that country. A country's aviation authority may use regulations from other countries, such as the FAR[30], in order to avoid duplication and to ensure interoperability in order to satisfy the requirements of ICAO[25]. Similarly, when creating new regulations it is usually done by mapping the new regulations to a standard regulation such as the FAR[30].

Standards however are usually created by a professional body or organization that is considered to be an expert in that field. It is therefore possible that a number of different standards from various organizations may exist for a particular aspect. It is also possible that different sub-systems of a total aircraft system or UAV will each comply with various standards that were created by specialists from various professional bodies in each specific field of expertise, such as RTCA DO-178B for software certification, RTCA/DO-160D/E[61] and MIL-STD-461E[62]/462D for EMC/EMI and HIRF testing, and ASTM F2505[63] for airworthiness requirements.

2.2.5. Purpose and Application of Standards and Regulations

Historically, regulations are primarily intended by the government of a country to protect people and property on the ground[34,64]. They now also protect civilian passengers who utilise commercial air transport as well as the safety of the crew operating the aircraft[53]. In the case of UAVs, the focus will again shift closer towards protecting people and property on the ground[31].

Regulations therefore concentrate on the safe use of aircraft in civil airspace by means of "Rules of the Air" such as FAR 91[30], and provide the minimum allowable requirements for aircraft in order to prevent aircraft colliding with each other, and to remain airworthy so that they do not "fall out of the sky" and kill or injure passengers or people on the ground.

In most cases, regulations are general and specify only a desired outcome. Some regulations are more technical than others in order to dictate a minimum technical requirement. There is however a tendency for regulatory authorities to keep the regulations general, and to rather refer to standards[51,53]. This also simplifies the process of keeping regulations updated, since the process of changing government regulations is long and slow, while the creation and modification of standards is much quicker and is done by the professional body that created the standard.

Unless referred to in a regulation, standards are not mandatory and are mutually exclusive from regulations. All airspace regulations are however mandatory for specific airspace in a particular country.

Compliance with both standards and regulations is however proven in a similar manner, usually by means of testing. Regulatory authorities usually insist on appointing their own representatives to test or observe compliance with their regulations, while standards are often used merely as a tool for engineers themselves to measure their design against. If a standard is specified in a contract, it is usually required from the supplier to prove to the client by means of test data that the product did indeed meet the specification that was contracted.

Standards are therefore usually technical in nature and provide designers with more guidance, and provide a reference to test against in order to determine if their design was successful. Once standards for UAVs become available, and if designers comply with the standards required by regulatory authorities, the process of certifying the UAV will be simpler.

Although the choice of standard is sometimes governed by airworthiness regulations, it is often specified in a contract in order to ensure a minimum level of quality. Standards could also be used to ensure a level of interoperability between systems by ensuring that the interface and architecture is the same. Standards such as the USA Military Standard (MIL-STD) and UK Defence Standard (DEF-STAN) are examples of this.

A standard could also be used as a quality grading system, where designs or parts that comply with aerospace standards are classified as complying with a minimum specification. It is important to note however that as manufacturing techniques are improving, some components that did not comply with a minimum standard previously may now be of a better quality than components that are currently certified against a certain standard. However, the costs of components complying with appropriate standards may be higher due to the quality control process required in order to ensure that each component indeed complies with that standard.

The choice of the correct standard for the correct reason is therefore very important since the wrong selection can lead to unnecessary testing and high costs, while the choice of the correct standard can significantly lower the work required for certifying a UAV.

2.3. ISSUES REQUIRING FURTHER RESEARCH

Many lessons have been learned over the years of developing manned aircraft regulations and standards, which can be applied while developing UAV regulations and standards. However, a number of issues and technologies are unique to UAVs and need to be researched in order to obtain a greater understanding of these issues before new or adapted regulations can be proposed.

2.3.1. Collision/Conflict Avoidance

One of the major concerns for UAV certification is detect and avoid, particularly in un-segregated airspace that is shared by aircraft such as parachutes or balloons that do not have the manoeuvrability to avoid UAVs even if the pilot of these platforms have detected the UAV. Presently, provision is made for the pilot in command of the other aircraft to be responsible for “see and avoid”. Without a pilot in the loop, airspace regulators and manned aircraft operators are reluctant to permit UAVs to operate in civil airspace.

This is however a dilemma, because manned aircraft depend on the integrity of the pilot to detect and avoid other aircraft. Much is left to the pilot’s discretion, e.g. the pilot must regularly report on his position, and look out for other aircraft. The pilot’s field of view is in turn also limited by factors such as the size of the windscreen. When the requirements for UAVs are created, fairness will dictate that the limitations of manned aircraft should also be considered[56] when determining the equivalent requirements for UAVs.

Detect and avoid can be applied to UAVs as well as to manned aircraft in a number of different ways, each with their own advantages and disadvantages. Although some detect and avoid technology is available for manned and unmanned aircraft today, work still needs to be done to develop the technology before such systems are proven, qualified and affordable.

The challenge of UAV collision avoidance is however seen as a technical challenge that must be overcome before UAVs may be permitted into civil airspace, rather than a regulatory or legal challenge.

2.3.2. Accountability and Autonomy

A number of UAVs have proven that it is already possible for a UAV to complete a mission autonomously from start to shutdown with all the necessary information such as navigation waypoints downloaded prior to launch. At this point in time, most UAVs will however require a human in the loop to execute some of its operations. The purpose of the human in the loop can range from directly controlling the aircraft via remote control, to higher level functions such as mission planning, navigation or voice communications with ATC, or merely monitoring, pressing a termination button, and accepting responsibility for decisions taken.

It is therefore clear that because of the difficulty of integrating UAVs into existing airspace, it will always be necessary to have a human in the loop until the technology has been developed to take over all the human functions. Since manned aircraft may be certified to fly with an autopilot, UAVs should have no problem being certified to be able to fly en-route using much the same manned aircraft autopilot regulations[38,39], provided that all other issues, including detect and avoid, and control authority restrictions are resolved. Takeoff and landings from busy airports will require more human interaction between ATC, other aircraft and the UAV pilot, and will therefore probably initially result in most UAV designs being remotely piloted.

The long term goal would be to certify UAVs for autonomous takeoff through landing. At present, only a few UAVs have successfully demonstrated full autonomy. Full autonomous takeoff and landing will reduce risks associated with pilot induced loss of control and communications/data link loss etc. This will require a far greater degree of design integrity. The technology is however available, and it will be a matter of time before most UAVs will at least have the capability of autonomous takeoff from, and landing at controlled airfields. Certification and regulatory requirements would have to be in place in order for this to occur. Regulations are presently in place to allow civil passenger aircraft to takeoff and land in Category 3 ILS[30] conditions, which should also allow UAVs to land in the same airspace in similar conditions with equivalent (but not necessarily the same) onboard equipment.

Since most of the technology required to automate many of the UAV’s functions is available, the challenge is less technical and more of a legal challenge relating to who will accept responsibility in the event of a failure of the automatic systems.

2.3.3. Flight Termination and Contingencies

When manned aircraft experience a problem, it is sometimes required that the aircraft must divert to the closest airfield, announce the emergency, and execute an emergency landing. This procedure becomes more difficult if the specific airfield is far from the ground station and is unknown to the pilot and not programmed into the UAV database.

The interaction with VFR traffic in the local pattern must also be considered carefully. Possible alternatives include building special airfields specifically for UAV diversions, or in the extreme, utilize a flight termination system such as a parachute.

A unique concept to UAVs is flight termination. This can be accomplished in a number of different ways, but always implies a near immediate end to the UAV flight. Flight termination can be achieved either by means of a ground command or by some autonomous means when a system test reveals a fatal, unrecoverable error. Depending on the kinetic energy of the UAV, an appropriate means can be provided to bring the UAV back to earth without loss or damage to humans.

Flight termination however is not suitable as a primary landing method, and should only be used as a backup method in order to lower the damages resulting from a crash.

2.3.4. Continued Airworthiness, Maintenance and System Monitoring

During manned aircraft missions, the pilot or flight engineer would usually monitor the on-board systems, and take action in the event of a failure. Because the UAV operator resides on the ground, the system information either needs to be transmitted to the ground or an on-board decision making process needs to be in place.

Furthermore, because of the ability for UAVs to execute extended missions longer than those of manned aircraft, continued airworthiness and maintenance of these systems would be different from aircraft operating for shorter periods of time.

Developments in health monitoring systems will be required in order to monitor and rectify faults in on-board systems so as to identify and prevent any failure that could result in the loss of the UAV during extended missions.

2.3.5. Air Traffic Management

At present, the airspace is dominated by manned aircraft, and is managed in most countries in accordance with FAR 91[30] or equivalent requirements. The airspace has naturally evolved in a way that favours manned aircraft operations. When integrating UAVs into the national airspace system, it would be prudent to do so in a transparent way that would create the least disruption and risk to human life.

Research would be required in order to determine the feasibility of gradually increasing the frequency of UAV operations into the national air space or to create separate UAV operating areas and to gradually merge the two.

It seems nevertheless obvious that creating a completely new system in South Africa, with manned and unmanned aircraft operating together from the beginning, is neither feasible nor recommended.

Information first needs to be collected on operating procedures of UAVs in airspace using separate "pilot project airfields" and then to slowly integrate UAVs into the national airspace as the confidence in their operations builds. At the same time, the current air traffic management regulations and procedures will have to be reviewed in order to accommodate UAVs[34,53].

2.3.6. Ground Station

Much attention is devoted to cockpit design and ergonomics in manned aircraft regulations[30]. In removing the human from the aircraft, some of these requirements will not be relevant to the air vehicle, and new requirements will need to be created in order to regulate the design of the ground station[31,34].

Many of the manned aircraft regulations were introduced to reduce workload of the pilot, so that the duties of the pilot could be executed safely and effectively. These requirements remain the same for UAVs.

The benefit of a ground station is that weight and size are no longer limiting factors. This not only makes it easier to add safety features such as redundancy, it also allows additional safety features to be added that might not have been economical because of the size-weight-cost playoff in manned aircraft.

Regulators must however guard against requiring additional equipment, which would not be regarded as equivalent when compared to manned aircraft just because weight is not an issue. This does however allow designers to lower the cost of the equipment because of the lack of requirements to save weight by using expensive materials.

2.3.7. Data Link Integrity

The required level of data link integrity will in part be dependant on the level of autonomy. UAVs relying on a high level of ground based human control will require a secure and redundant data link in order to counter the threat of intentional and non-intentional attacks on system integrity. Countering intentional and non-intentional attacks must become part of the design and should include testing for EMC, EMI, HIRF and loss of signal control logic.

Fully autonomous UAVs will however require on-board fault diagnostics, proven contingency logic, and autonomous detect and avoid systems. As computer processors become faster and more powerful, on-board processors could replace many processing functions that presently require data links[65].

2.3.8. Operator Competency

Along with ground station design, the experience and qualifications of the operators must also be investigated[34,53]. Depending on the level of autonomy and automation, the workload and responsibility of the operator can vary greatly. The operator can take the form of a person who merely presses a launch button, to a pilot who actively flies the aircraft.

All of these factors must be considered when deciding on the licensing requirements of the operators. Because space and weight are no longer factors, tasks that were usually required to be performed by one person can be divided, and the licensing requirements will also have to accommodate this.

2.3.9. Security

Security of the ground station, as well as the command link to the UAV was been raised as an issue in many UAV documents[34,53]. Because of the ability for the UAV (or any aircraft) to be used as a missile, control needs to be exercised over whom may have access to the control centre (cockpit). In an airliner, the passengers can be screened before the flight, and once airborne there is little risk of anyone else climbing on board. The UAV ground control centre is however vulnerable at all times, not only for direct attack, but also for jamming etc. These risks can be reduced by using a greater degree of autonomy as well as encoded and frequency hopping data link technology that can reduce the risk of interference.

A certain level of fairness and equivalence must be applied however, since it is possible at present to interfere even with manned aircraft instruments in certain conditions and to use false beacons and radio broadcasts to mislead aircraft during instrument flight conditions.

2.4. OVERVIEW OF EXISTING REGULATIONS CURRENTLY USED IN SOUTH AFRICA

South Africa does not currently have an aircraft industry that requires the civil certification of new aircraft. Most aircraft designs presently are either experimental aircraft that fall into the non-type certified aircraft (NTCA) category, are modifications of existing designs, or are military aircraft. For this reason, the SA CAA has mostly used the FARs or JARs during certification. Although unique South African regulations have been drafted, the SA CAA still appears to prefer to use the FARs and JARs as guidelines. It is therefore important to understand the relevance of these existing regulations, and to analyse their benefits and shortcomings.

2.4.1. ICAO

South Africa is a contracting state to the Chicago Convention[25] and has therefore agreed in principle to comply with its contents. The Chicago Convention however does not prescribe specific regulations, but rather provides guidelines by means of its various articles. ICAO however leaves the regulation of aircraft and airspace to each contracting state provided that the individual state's regulations comply with the Chicago Convention.

Specific guidelines regarding UAV airworthiness have however not been created, and the only reference to UAVs is provided in Article 8 of the Chicago Convention where it states that: "No aircraft capable of being flown without a pilot shall be flown over the territory of a contracting state without special authorization by that State and in accordance with the terms of such authorization. Each contracting state undertakes to ensure that the flight of such aircraft without a pilot in regions open to civil aircraft shall be so controlled as to obviate danger to civil aircraft."[25,26]

2.4.2. Federal Aviation Regulations

The Federal Aviation Regulations[30] (FAR) are regulations contained in the Code of Federal Regulations[30] which is specifically intended to promote aviation safety within the United States of America. These regulations have been adopted and adapted by many countries and have in a sense become a standard for regulations. Because many USA aircraft operate outside US borders, and because many aircraft manufactured within the USA are certified with the FAR, many other regulatory authorities such as the South African Civil Aviation Authority have agreed to accept aircraft certified by the FAA, and also strives to regulate airspace operations within its borders by ensuring minimum compliance with the FAR, thereby satisfying the requirements of ICAO[25,51]. The reverse is also true that manufacturers and aircraft operators wishing to operate within the USA must also prove compliance with the FAR[30]s. Organizations such as the Civil Aviation Authority of China (CAAC) therefore often choose to use the FAR for certification and operational reasons within its own borders.

The shortcoming of the FAR is that they have evolved over time during the development of manned aviation from accident investigation and as a result, did not cater for technical challenges that have been created by the sudden requirement for UAV operations. Although the FAR could be modified to include UAVs, the process is long and slow and due diligence must be taken to ensure that the inclusion of UAVs does not affect the safety of aircraft that already comply with the FARs. It has rather become the responsibility for UAV manufacturers and operators to prove that their UAVs comply with the minimum requirements of the FAA before being permitted to fly in un-segregated airspace.

The FAR[30] is divided into parts that regulate items such as airframes, engines and propellers. FAR Part 91 provides regulations for airspace control, and is used by most nations.

2.4.3. Joint Aviation Regulations

The JAR of Europe is an equivalent manned aircraft regulation that closely maps to the FAR. There are a number of differences and exceptions, but the FAR is used as a basis for these regulations thereby allowing them to comply with the IACO requirements[25] for interoperability across international borders.

The "Etude sur la Réglementation et les Codes de Navigabilité applicable à des Drones Civils" (NAVDROC) JAR Paragraph Analysis[66] is a document prepared by French aerospace companies and analyses each paragraph of the JAR and comments on changes required to the JAR in order for the JAR to accommodate UAVs.

2.5. ANALYSIS OF EXISTING STANDARDS

Although it can be argued that the FARs and JARs are a combination of both regulations and standards, the new philosophy of referring to standards within regulations necessitates closer scrutiny of existing and proposed standards. Many of these new standards have been initiated by the requirements by regulating authorities to create standards in order to regulate UAV manufacture and design. It is important to emphasize that these standards pertain specifically to the airworthiness and design on the air vehicle and related systems, while the regulations relating to the use of the airspace remains within the airspace regulations. Standards are often not all encompassing and each specialist professional organization is responsible for the generation of standards relating to its own field. The regulations will therefore have to refer to a number of different standards. The process of creating one all encompassing standard for a complete UAV system must still be initiated.

2.5.1. UAV System Airworthiness Requirements

The USAR[67] is an airworthiness requirement developed by the French DEG. The USAR[67] maps existing FAR[30] and JAR regulations to new UAV requirements by using a safety case approach[51,68]. Some UAV manufacturers are presently using these requirements as a standard rather than a regulation in order to qualify their UAVs for special flight permits in civil airspace[55].

2.5.2. South African Civil Aviation Standards

The South African Civil Aviation Authority has drafted Civil Aviation Regulations and Technical Standards for the airworthiness and operation of non-type certificated aircraft, Parts 24[69], 94[70] and 96[71], but these regulations have not been promulgated.

It has been proposed that these standards be used for UAVs[72]. Part 24 classifies UAVs as a class of Non Type Certified Aircraft (NTCA). UAVs could therefore be certified in accordance with these regulations. However, limitations on the use of these aircraft for commercial operations could be problematic.

Also, the classification of certain aircraft such as ex-military aircraft within the NTCA category has been problematic and the SA CAA may be reluctant to certify all UAVs as NTCA, especially larger UAVs.

2.5.3. ASTM Standards

The American Society for Testing and Materials[46] was given the task to develop standards for UAVs by involving the relevant market place, manufacturers, users, regulators, trade associations, consultants and academics. The reason for the ASTM developing the standard is because of its standing in the industry.

A committee (F38) was formed to deal with UAVs, and is divided into three sub-committees viz. Airworthiness (F38.01), Flight Operations (F38.02) and Operator Qualifications (F38.03).

F2411-04e1 Standard Specification for Design and Performance of an Airborne Sense-and-Avoid System[73] summarizes the existing requirements for sense and avoid by extracting relevant information from the FAR[30] and by quantifying the current abilities and failures[74] of a manned aircraft sense and avoid system (the pilot) into one document. This standard is relevant to manned and unmanned airborne systems. F2584-06 Standard Practice for Maintenance and Development of Maintenance

Manuals for Light Unmanned Aircraft System (UAS)[75] provides general guidelines for creating maintenance manuals for light UAVs. This includes the content and scope of the manual as well as competencies and authorities of the people who must execute the work.

An additional document, F2505-06 Standard Practice for Application of Federal Aviation Administration (FAA) Federal Aviation Regulations Part 21 Requirements to Unmanned Aircraft Systems (UAS)[76], has extracted the content of FAA Part 21 and has modified it for use for UAVs weighing less than 1225 kg with the intent that this standard could be used as a pathway for creating new FAA Part 21 regulations. This standard is comprehensive enough to be used in South Africa, however being a transcription of the original FAR Part 21, numerous references to the FAA within the standard would need to be changed for it to be usable as a South African standard.

New standards have been proposed by F38.01 but are still in progress. These include: Standard Guide for Mini-UAV Airworthiness; Recommended Practices for Unmanned Aircraft System Design, Manufacture and Test; Standard Specification for Design and Performance of an Unmanned Air Vehicle (UAV) Data Link System; FAR Part 21 Review For Civil Unmanned Aircraft (CUA) Requirements; FAR Part 27 Review For Civil Unmanned Rotorcraft (CUR) Requirements; Quality Assurance in the Manufacture of Unmanned Airplane Systems (UAS); Continued Operational Safety Monitoring of the Light Unmanned Airplane Systems (UAS); Standard Practice for Maintenance and the Development of Maintenance Manuals for Light Unmanned Aircraft System (UAS); UAV Embedded Software; Standard Practice for Design and Manufacture of Reciprocating Engines for Unmanned Aircraft Systems; Standard Specification for the Design and Performance of a Pneumatic UAS Launch System; Standard Practice for Design and Manufacture of Turbine Engines for Unmanned Aircraft System; and Standard Practice for Design and Manufacture of Compression Ignition Engines for Unmanned Aircraft System.

2.5.4. RTCA Standards

RTCA concentrates its activities mostly on issues relating to communications, navigation, surveillance, and air traffic management. These issues are mostly equally applicable to manned as well as unmanned aircraft since very few of the RTCA standards deal with human interface issues. A number of RTCA standards such as RTCA DO-178B[54] have been mandated in regulations such as FAR[30] Part 23/25 §1301/§1309 for software certification.

A sub-committee of the RTCA (SC-203) has been tasked to develop the Minimum Aviation System Performance Standards (MASPS) for UAVs. The sub-committee is working on producing two documents. "Guidance Material and Considerations for Unmanned Aircraft Systems" will possibly become the basis for FAA guidance, while "UAS MASPS" will be released later and will cover command, control and communications for UAVs. A further document will include sense and avoid systems. It is planned that the FAA will use these documents along with documents from other organizations in drafting their UAV regulations.

2.5.5. SAE Standards

The SAE S-4 Unmanned Systems Committee is tasked with developing standards for UAVs. AIR5665, was initiated in September 2005, entitled Architecture for Unmanned Systems and is still in progress.

2.5.6. NATO Standards

STANAGS are standardization documents designed to ensure and ensure interoperability between NATO signatory countries.

NATO standards are addressed in the document: STANAG 4586 - Standard Interfaces of UAV Control Systems (UCS) for NATO UAV Interoperability - NATO Standard on UAV Interoperability and STANAG 4671 - Unmanned Aerial Vehicles Systems Airworthiness Requirements (USAR)[77]. STANAG 4671 is presently the only standard that addresses interoperability in UAVs[78].

Many UAVs are currently being designed to be STANAG 4671 compliant[78]. A number of issues and potential problems have however been identified when using the STANAG 4671, that need to be taken into account during the design phases[78].

2.6. THE CREATION OF UAV STANDARDS IN SOUTH AFRICA

Learning from other organizations, and compiling them into one South African standard would simplify the task of both the SA CAA as well as the UAV industry. For this reason, it is necessary to determine which existing standards are suitable, to analyse the necessity for the standards and to propose a method for generating these standards. Once the standards are created, it will be important to ascertain who will be responsible for complying with these standards, who will enforce them, and who will be responsible for maintenance of the standards.

2.6.1. Applicability of Existing Standards for South Africa

Since all standards are not mandatory unless prescribed by regulations, such as RTCA DO-178[54] which is prescribed by the FAR[30], the choice of standard is arbitrary. Some standards however are easier to work with, and others contain valuable design information.

There is however no standard that comprehensively covers all aspects of UAV design and operation. Presently, if a UAV manufacturer wishes to use standards for a particular UAV design, it will be necessary to apply a number of different standards that are published by the relevant professional organization for each of those fields.

It would be more desirable if South African UAV manufacturers could obtain a fully comprehensive standard from a South African standards authority such as the South African Bureau of Standards (SABS). These standards would not necessarily be original, could use the basis of standards from other organizations, and would be available in a single document.

2.6.2. Requirements for Standards

Once South African standards are created, they would act as design guidelines for the UAV industry. Compliance with the standards, although not mandatory, should result in a quicker qualification process for type certification of the UAV with the SA CAA.

2.6.3. Proposed Methodology for Creating South African Standards

Traditionally, standards are created by professional organizations to ensure that the work of their members and people subscribing to that standard are of a known acceptable quality. Standards must therefore be based on known professional experience and practices in that field.

It follows therefore, that a standard must contain an achievable level of quality. Research must therefore be conducted to determine what is indeed achievable, and what is considered to be 'best practice'. This is usually done by manufacturers themselves.

The converse that a manufactured UAV that has a proven level of safety and performance sets a standard is also true. It would therefore not be incorrect to start with a draft standard by listing the safety and performance specifications of an existing UAV with a proven track record. Unknown issues such as 'sense and avoid' could be added later.

The proposed method of integrating existing standards into a South African UAV Standards is illustrated in Figure 4:

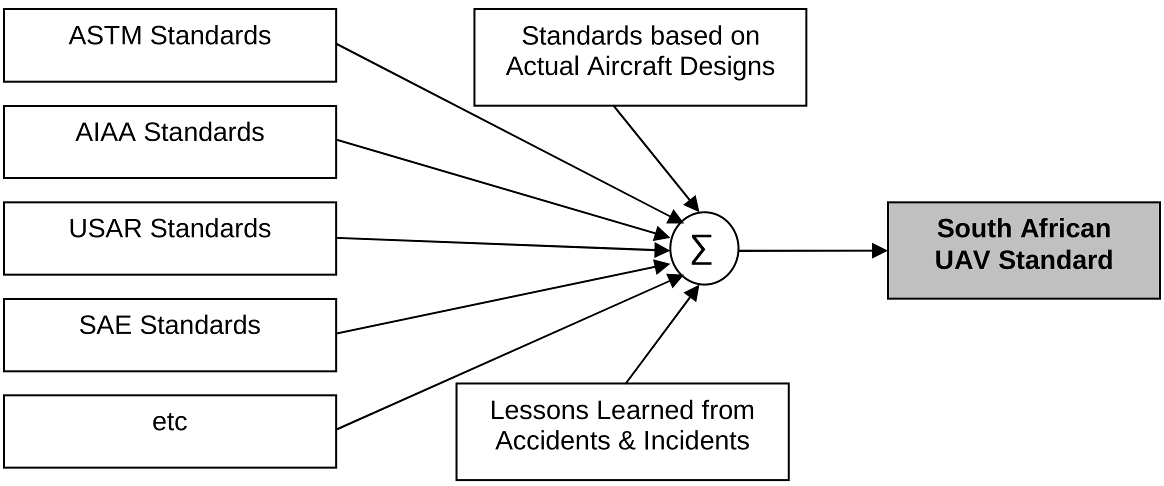

Figure 4: Compilation of Standards into a South African UAV Standard

2.6.4. Responsibilities

Once South African standards have been published, it will be the responsibility of the UAV manufacturer or organization wishing to certify a UAV to prove an equivalent compliance with that standard.

2.6.5. Maintenance of Standards

Since technology evolves, standards must also be reviewed regularly in order to keep up to date with technology, and with developments such as accident investigations.

South African standards must therefore be maintained by a suitable professional organization, standards organization or the regulating authority.

2.6.6. Accessibility

It is essential that the latest South African standards must be readily available. All persons or organizations wishing to certify a UAV in accordance with a relevant South African standard bust have access to the standards database.

2.7. SUMMARY

Because of the urgent requirement for UAVs to be integrated into civil airspace, a number of organizations have created plans and policy documents on how to achieve this. Few countries have however published regulations.

In order to measure the level of UAV compliance with existing aircraft regulations, principles were proposed in order to ensure that UAVs were not unduly subjected to harsher requirements than manned aircraft. These principles, if adopted in South Africa, will ensure that UAVs will be able to be integrated into civil airspace and will assist with identifying issues that must be addressed at the technology level before it will be possible for UAVs to be integrated into civil airspace.

A number of technical challenges must therefore still be researched and solutions must be found in order to create the technology for UAVs to have the same functionality as manned aircraft.

The development of UAV standards is a critical step in the process of regulating the design and operation of UAVs. Standards are being produced by many international organizations, and in order to create a comprehensive South African standards document, it may be necessary to combine standards from various sources. Once the standards are available, UAV regulations could then refer to these standards.

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3. UAV DESIGN & OPERATIONAL REQUIREMENTS

3.1. INTRODUCTION

In order to determine where to prioritise and focus the efforts of generating regulations and standards, it is necessary to determine the current UAV strategic, design and regulatory requirements. These requirements are the drivers in determining the path that the roadmap proposes. It is also essential that the roadmap must be relevant, and more importantly - feasible. Analysing these requirements will ensure that the roadmap is directed at UAV applications that have the greatest chance of success so that efforts can be focussed on integrating these UAVs into the existing civil airspace efficiently and cost effectively. Conversely, ensuring that future designs take these factors into account will then speed up and simplify the certification.

3.1.1. Strategic Requirements

Before undertaking research on UAVs, funding would be necessary and it would therefore be important to identify the requirements of potential investors. Since the government agencies would be the largest potential investor, and since the national security would be the main driver for the SA CAA to permit UAV flight in civil airspace, it is sensible to start by identifying the national strategic requirements.

Also, in order to determine the location where potential missions would be the most suitable for UAV research to take place with the aim of eventual certification, it is once again necessary to analyse the strategic requirements of South Africa so that the effort can be focussed on creating policy documents in order to satisfy these strategic requirements. Once the strategic requirements are satisfied by UAVs, and the regulations and standards are in place, other potential users can use the same regulations to certify and operate their UAVs in other areas.

Information regarding the strategic requirements was obtained from papers presented at various symposia[79,80,81]. This analysis of the operations will discuss the feasibility of the suggested UAV missions and will identify airspace where the integration of UAVs that can fulfil these missions can be done so that the creation of policy documents can be expedited.

3.1.2. Regulatory Requirements

One of the challenges facing UAV operations worldwide is the lack of published regulations and standards that should enable the design, manufacture and regular use of UAVs in civilian airspace[82].

The creation of regulations and standards is a long process that is currently underway in most major countries and aviation administrations, but complete regulations and standards may only be available in a number of years. Until these regulations are approved and published, methods need to studied where UAVs can satisfy the strategic requirements whilst complying with existing, albeit restrictive, regulations[83].

The most sensible approach for South Africa at present seems to be that UAVs should comply with existing manned aircraft regulations for the specific class of aircraft[83,84] e.g. light aircraft, balloon, helicopter etc.

Certain manned aircraft regulations will obviously not be relevant to UAVs e.g. oxygen supply for aircrew, and new regulations will have to be created for UAVs where manned regulations are insufficient[84,85]. Eventually both manned and unmanned regulations could be merged, and a new set of regulations could evolve that are equally applicable to manned and unmanned aircraft[83].

In South Africa, because of the type of UAVs presently available and the environment within which UAVs will be required to operate, the method – concept of operations[85] – should also be different to other countries. It will not be necessary to operate at extremely high altitudes to avoid commercial traffic as is the case in the USA, and if the strategic requirements for maritime patrol, border control and search & rescue are addressed, UAVs could operate at various altitudes between South Africa and Antarctica without posing a threat to manned aircraft operations or human inhabitants. Eventually the information obtained from research on maritime patrol, border control and search & rescue operations can be transferred to operations over land.

3.1.3. Design Requirements

Classical system engineering principles[86] as well as lessons learned in the USA[87] indicate that it is essential for UAV functional[88] and mission requirements to be determined before developing a new UAV rather than blindly developing UAVs and finding uses for them.

It was therefore also necessary for research to be done in South Africa in order to determine the strategic requirements as well as the UAV regulatory requirements so that the future South African UAV designs can satisfy both of these requirements. These regulatory constraints will become the boundaries within which the UAV systems must be designed and may operate in order to satisfy the strategic requirements.

It was also stated[89] that many of the perceived regulatory and certification challenges are indeed merely design challenges and that it would be the responsibility for design engineers to innovate systems that can assist UAVs to comply with the existing airworthiness requirements of manned aircraft.

The traditional systems engineering design process[86] applied to aircraft, excluding phasing out and disposal, is illustrated very generally in Figure **5**. This process starts with the user requiring a specific service or product. Inherent in this design process are the certification requirements, such as the requirement to comply with FAR[90] 23 or RTCA DO-178B[91].

Once certified, the aircraft will be required to operate in accordance with airspace requirements such as FAR[90] 91. For manned aircraft, this process is well established, but must still be instilled in UAV manufacturing and operations since most UAVs operating in South Africa are essentially prototypes operating with special airworthiness permits in specially allocated airspace.

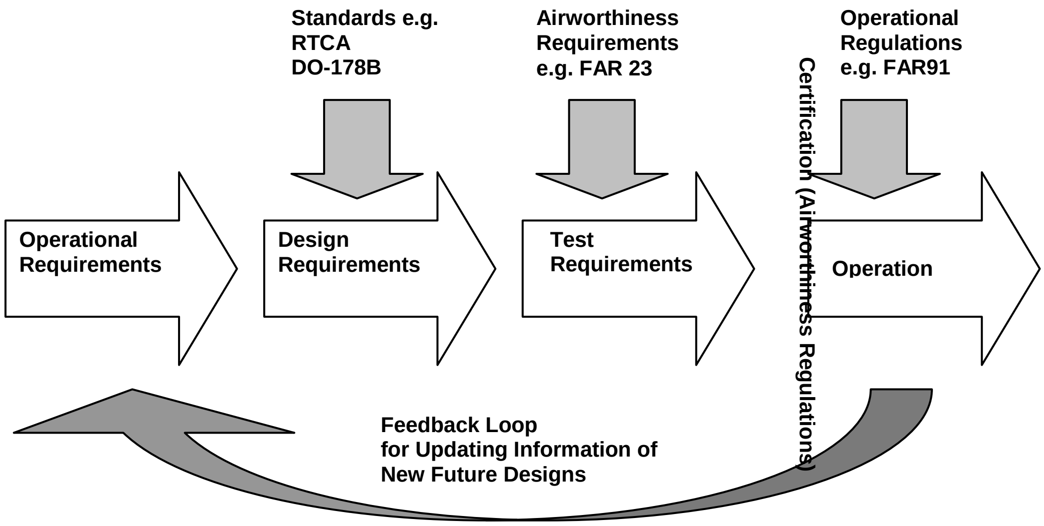

Figure 5: Modified System Engineering Process

3.2. UAV OPERATIONAL CONSIDERATIONS

Analysing the strategic requirements, the environment and the existing infrastructure will give an indication of what missions are required and will give an indication of what the mission profiles will look like. This in turn will drive the design of future technologies where current technologies cannot fulfil all of the requirements.

3.2.1. Strategic Analysis

Incidents of piracy have been recorded along both the Eastern (e.g. Somalia) and Western (e.g. Nigeria) African coastlines[92,93,94]. One of the major contributing factors to piracy is the lack of policing in pirate occupied territory. Pirates are usually heavily armed and well equipped, making unarmed manned missions dangerous. Surveillance platforms will enhance the policing capability of South Africa, which will in turn deter pirates from operating in South African territory.

Anti-terrorism has become a major requirement for South African law enforcement and intelligence agencies[94]. It has become important to monitor inflow and outflow of cargo that could be related to terrorist activities. UAVs could play a vital role in port control where individual suspicious containers could be tracked.

Poaching, especially abalone is also a major problem on the South African coastline which requires persistent monitoring[95,96]. Manned anti-poaching crews have come under small arms fire by poachers when they are detected, and the ability for UAVs to stay airborne, undetected, for long periods of time makes them very suitable for anti-poaching operations[97].

If necessary, UAVs could also be used for civil defence missions to monitor accidents at nuclear power stations, gas leaks, and chemical and oil spills.

UAVs can provide the platform for the dull, dirty and dangerous missions[97,98] (D^3) and tasks required for surveillance of the vast uninhabitable areas of South Africa[97].

Furthermore, because of the national requirement to boost the South African economy, the use of UAV technology will also create work, improve transportation infrastructure, and improve technical and scientific skills[99,100].

Because large UAVs with the capacity to be equipped with on-board navigation equipment have the best possibility of complying with most existing regulations, maritime patrol, border control, search & rescue, and cargo transport UAVs were proposed[97] as the most suitable type of UAV to conduct this research. South Africa is ideally placed in the world to allow certain UAV operations within the current manned aircraft airspace with limited risk to the public by mitigating existing manned aircraft regulations.

The research and development of maritime patrol, border control and search & rescue UAVs should be considered as part of the national and international obligation for South Africa to defend its borders up to the exclusive economic zone[101] (EEZ). It was suggested that this could also serve as an opportunity to conduct research on UAV design and operations, which would be necessary in order to create the relevant standards and regulations[102].

It is however essential that the operation and design of UAVs in this environment must be structured, and even with the lack of regulations and standards, the UAV design and operations must conform to correctly researched international trends[97]. As such, when officially published international standards and regulations become mandatory, the UAV operations and designs will automatically be compliant with these regulations and standards.

The concept of operations must therefore be developed that will satisfy the strategic requirements, will utilize the existing South African infrastructure and will comply with existing and possible future regulatory guidelines.

The missions that are deemed to be the most suitable to satisfy the South African strategic requirements are therefore: maritime patrol and border control; search & rescue; cargo transport; pipeline, power line and railway line patrol; and security monitoring. These missions must therefore be used to drive future UAV design and operation and for creating policy documents, especially since most other conceivable missions will have similar mission requirements.

3.2.2. Operating Area

Figure **6** illustrates the South African exclusive economic zone[101], and includes the Marion and Prince Edward Islands. There are almost no human inhabitants except for the occupants of ships operating in these areas and researchers temporarily living on the islands. There are also no scheduled air traffic routes between South Africa and Antarctica at present, making the operation of UAVs in this region very feasible.

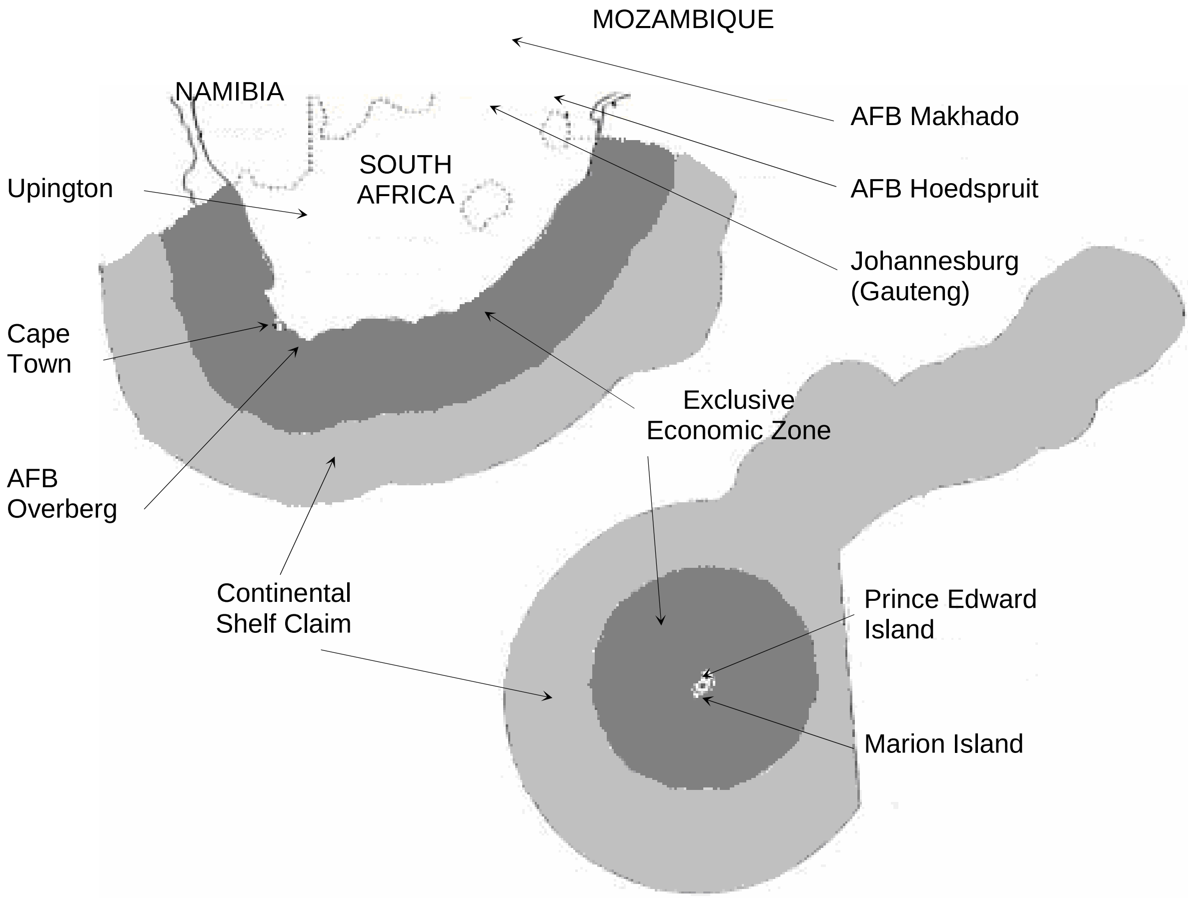

Figure 6: South African Exclusive Economic Zone[101]

The two leading concerns in UAV operations with regard to public safety are mid air collisions with other aircraft and ground impact[103,104]. Potential UAV air transportation routes that would minimize these risks could exist between coastal cities by using off shore routes.

Although the interior of South Africa is populated, the West Coast regions and the Northern Cape regions potentially provide the opportunity for UAV operations to take place between Cape Town and Gauteng. Contingencies will have to be studied carefully, but because of the relatively lower air traffic, this region could be used at a later stage to determine the impact of combined manned aircraft and UAV operations.

Once most of the operational issues have been resolved over uninhabited areas, and a concept of operations has been established at a test airfield, the operations could be expanded to other more populated areas of the country using the Access 5 approach[105,106].

3.2.3. Environment

Because of the lack of suitable infrastructure in many African countries, and the various hostile areas that need to be over-flown, High Altitude Long Endurance (HALE) or Medium Altitude Long Endurance (MALE) UAVs hold many benefits because of their ability to stay airborne for long periods of time at high altitudes.

South Africa is ideally placed for UAV operations. To the south, there is a large ocean with minimal air traffic. As part of the exclusive economic zone (EEZ), South Africa is now required to defend the coastal waters from illegal fishing, protect its mineral rights and other legal responsibilities. As such, South Africa has been involved in operations as far as Antarctica and Australia[107] and could benefit from UAV technology over these large distances.

The large uninhabited areas and the few air corridors, in comparison to countries such as the European Union, will make it more feasible to operate UAVs in South Africa than in the USA or Europe. Because the South African airspace is well controlled and regulated by both the SA CAA and the Air Traffic and Navigation Services (ATNS), the infrastructure exists in which UAVs can be accommodated.

Because of the large areas with no air traffic and few human inhabitants, like the ocean off the Southern Cape coast or the desert in the Northern Cape, together with the formalized aerospace structure, it should be possible to create areas where UAVs could operate between large cities such as Cape Town and Johannesburg, or Cape Town and Durban along the coast, as was done in places such as Alaska[108].

Generally, South Africa has a moderate climate suitable for most types of aviation, with few extremes in weather. Although the wind speed does affect the speed and endurance of the UAV, the size and power of the UAV can however be adjusted to accommodate this.

Even though weather conditions such as wind would restrict the platform, the restrictions on the sensors, especially visibility in cloud, would impose more severe limitations on the platform.

Owing to flight control automation, the UAV pilot will essentially fly the UAV in instrument conditions at all times making operations at night similar to day time operations. The UAV pilot will therefore be required to hold a valid instrument rating.

Because larger aircraft generally have a greater tolerance for poor weather conditions, and because they have a longer endurance, larger UAVs would therefore be preferable as a platform for persistent maritime patrol.

3.2.4. Available Infrastructure

Initially operating from an airfield within segregated or restricted airspace will allow the UAV to take-off and land without interfering with civil manned aircraft operations, thus avoiding issues such as collision avoidance and ATC transparency[84].

Places, such as air force bases, where the security requirements[97] can be met without additional infrastructure expenses will be preferable. Although domestic airports managed by the Airports Company of South Africa (ACSA) could satisfy most of the security requirements, the operation of UAVs from these airports would only be feasible once the UAV regulations are in place, UAVs are certified and once UAVs are permitted to “file and fly”.

The Test Flight and Development Centre (TFDC) located at Air Force Base (AFB) Overberg (see Figure **6** and Appendix E) would be ideally suited for maritime UAV operations. As well as being restricted airspace (FAR 147), the airspace around AFB Overberg is also south of all air corridors making it free from regular commercial operations. Furthermore, the infrastructure and facilities are suitable for UAV operations, and military UAVs have frequently operated there in the past.

AFB Overberg is also situated within a reasonable distance from the Cape Town based industry and universities, making the support of UAVs and related research feasible. The approximately equal distance from AFB Overberg to each end of the South African coastline also makes AFB Overberg an ideal base for HALE and MALE UAVs.

The Upington Airport (see Figure **6** and Appendix E), situated adjacent to the Gariep river (Orange river), is situated in the centre of the Northern Cape and was used for many years as an alternative test airfield for aircraft, UAVs and missiles. Although the airport has commercial traffic, the density of operations is low, and the population density also makes it attractive for future inland UAV operations.

Air force bases at Makhado (Louis Trichardt) or Hoedspruit (see Figure **6** and Appendix E) are proposed for UAV operations in order to completely service the eastern part of the country.

The airspace to the north of South Africa is used by aircraft travelling between Johannesburg and Europe, the Middle East, the Far East and Asia. This factor would make UAV operations more difficult, however once detect and avoid technology is available, and when UAV regulations are in place, operating from these air force bases could become a possibility. A further consideration is that operations in these areas could be executed by manned aircraft and would not necessarily classify as D^3 missions, unlike the maritime patrol mission that does classify as a D^3 type of mission.

3.3. PROPOSED UAV MISSIONS

With the strategic requirements analysed, and with an indication of the existing infrastructure and environment, the mission profiles satisfying the strategic requirements can be expanded, which in turn will become a design driver.

3.3.1. In-Shore Maritime Patrol Mission

The in-shore maritime patrol mission would operate within a short distance from the coast using a mission profile illustrated in Figure 7. The purpose of this mission would be to monitor fishing activities along the South African coastline. For this reason, the UAV would be required to operate at lower altitudes in order for the imaging sensors to monitor the fishing activities.

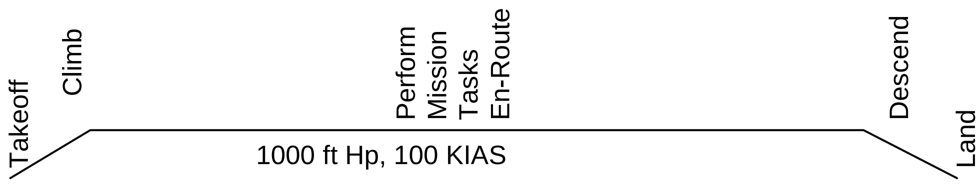

Figure 7: In-Shore Maritime Patrol Mission Profile

Light UAVs could be used effectively for this mission, and operate within visual range by deploying a number of UAVs at strategic positions along the coast line, such as at harbours and at known poaching sites, and would provide a low cost persistent surveillance platform.

Large UAVs could also be used for this mission, and would be necessary where factors such as weather conditions, payload and range necessitate their use.

A combination of both types of platforms would provide low cost persistent surveillance over strategic areas, while providing a less persistent, but longer range capability in-between.

(Note: Geo-survey operations[109] could also use a similar mission profile in certain areas.)

3.3.2. Long Range Maritime Patrol and Search & Rescue Mission

The long range maritime patrol mission will require the UAV to operate over the sea over long distances with the purpose of monitoring the major shipping traffic in order to provide intelligence on shipping activities as illustrated in Figure 8. A further requirement will be to fly to remote fishing areas and perform in-shore maritime patrol over islands such as Marion Island (see Figure 6). A similar mission profile would also be applicable for maritime search & rescue.

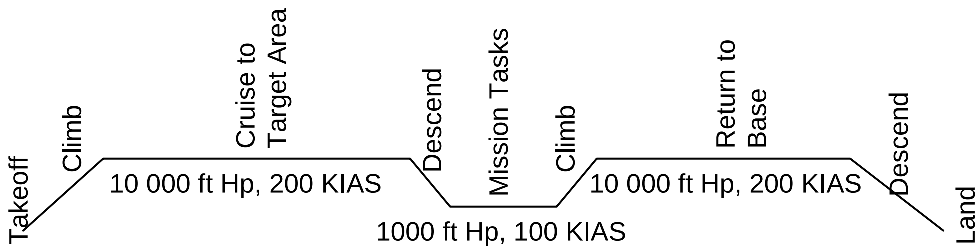

Figure 8: Long Range Maritime Patrol Mission Profile

Because of equipment requirements for longer-range data communications, which includes a satellite data link, as well as weather and endurance requirements, this type of mission profile would necessitate employing large UAVs. Using longer range data communication, beyond visual range, would prevent light UAVs from being able to be utilized for this mission and will promote the operation of large UAVs from fewer, but better equipped, base stations.

3.3.3. Cargo Transport Mission

The cargo transport mission profile as illustrated in Figure 9 is similar to the long range maritime patrol mission profile, in that the route would be along the coast and would use the same airspace as other maritime patrol UAVs, at a distance far enough to avoid manned air traffic, but in this case the sensor payload would be replaced with cargo.

Figure 9: Cargo Transport Mission Profile

Because of payload requirements, large UAVs would be used which will lower the number of base stations required, but will necessitate more complex mission planning. The use of modified ex-airline aircraft should not be excluded, however this is not foreseen in the near future, but is being mooted for the longer term. Since most airliners comply with existing manned aircraft airworthiness regulations, the transition from manned to unmanned aircraft should become possible once the pioneering work is complete and regulations are in place to allow UAVs to "file and fly".

3.3.4. Pipeline, Power Line and Railway Patrol

The pipeline, power line and railway patrol mission profile as illustrated in Figure 10 is similar to the long range maritime patrol mission profile, but the UAV would follow the pipeline, power line or railway line instead of the coastline.

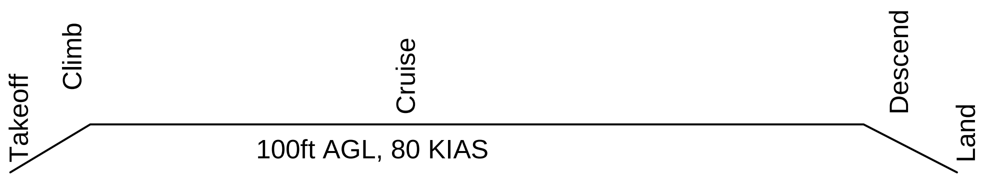

Figure 10: Pipeline/Power Line/Railway Patrol Mission Profile

These missions would primarily be executed in low population density areas where regular patrols of the required infrastructure would be difficult because of its remoteness.

The risk to the UAV during these missions however, is that general aviation aircraft presently use roads, pipelines, power lines and railway lines for navigation, especially in remote areas where other features are lacking.

Limiting the size of the UAV and limiting the operating envelope to a small space around the feature can mitigate this problem. In addition to this, general aviation aircraft are limited to 500 ft above ground level, so UAVs operating below this height should not pose a threat.

3.3.5. Security Monitoring

The security monitoring mission profile is illustrated in Figure 11. There is a large commercial requirement for airborne monitoring of security residential estates, crowd monitoring of sports events and patrolling of areas where hijackings occur frequently.

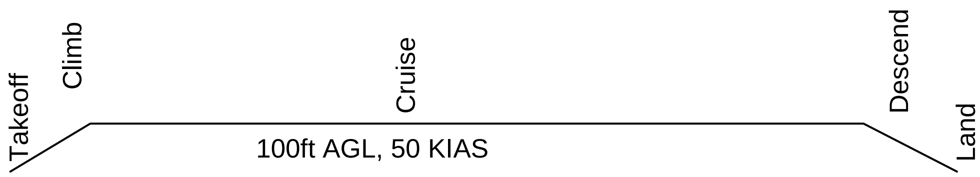

Figure 11: Security Monitoring Mission Profile

In order to make these missions feasible, light UAVs would have to be used in order to mitigate the risk of damaging property on the ground after a terminal failure. Although it would be desirable for the UAV to stay airborne as long as possible, other factors like not being detected by criminals would be beneficial, but would also limit the size and power and therefore the payload of the UAV.

Since these UAVs would operate in densely populated areas, a safety case approach for certification would be the most appropriate since there would be a reasonable probability of failure. However, the consequences of such a failure would determine the feasibility of the platform for this mission. Being small, the UAV might not be required to comply with existing manned aircraft regulations, however new regulations similar to radio controlled aircraft regulations would have to be promulgated so that the UAV could be used in airspace outside of the existing radio controlled aircraft airspace.

3.4. UAV DESIGN CONSIDERATIONS

Based on the mission profiles and the strategic requirements, certain system requirements become visible where more research and development is necessary before UAV operations will become possible. Many of these requirements are unique to UAVs, however wherever possible, it is desirable to find commonality with manned aircraft in order to simplify the design and support of the system, but more importantly, to satisfy the proposed certification principles.

3.4.1. UAV Launch and Recovery Platform

Most light UAV systems require a dedicated launch and recovery platform and cannot land at existing airfields without advance preparation and would therefore have to return to the same place that it was launched, halving the maximum possible range and making them less suitable than other UAVs that could land at the many existing airfields.

Regular maritime patrols using light UAVs would therefore require a considerable infrastructure with many base stations along the coast in order to cover the long ranges. Because of the current designs of the launch and recovery platform, allowing the UAV to takeoff and to land over short distances, and operating from moving platforms such as ships would present some advantages for light UAVs over large UAVs, but these operations would in turn be restricted by the availability and location of the launch platform or ship.

Because of the lower weight, light UAVs should not require full certification, but would then also not be permitted to operate outside visual range, below 400 ft AGL, or within un-segregated airspace. If it will in the future only be necessary for light UAVs to comply with radio controlled aircraft regulations[84,110], as proposed in many countries, then the advantage will be that certain procedures such as maintenance and air traffic control will also become less complicated. Mission profiles for this class of UAV will therefore have to take into consideration the regulatory requirement to operate within visual range of the UAV commander[83,84,110,111]. Light UAVs will therefore only be suitable mostly for inshore coastal patrol and surveillance.

Longer range UAVs will inevitably weigh more than 150kg, and will therefore be unsuitable for unconventional landings and will need to land at prepared runways and possibly at existing airfields. Large UAVs will also be the most suitable for maritime surveillance in South Africa because of their long range and long endurance but will require civil certification if they should wish to operate on a "file and fly" basis in un-segregated airspace[83,84,110,111].

3.4.2. Ground Station Design and Operation

One of the benefits of UAVs over manned aircraft is that a single ground station can replace several manned aircraft cockpits. Furthermore, the same ground station design could be used for many different types of UAVs[112].

There is also a suggestion that ground station designs should be standardized[87,113]. The standardization will simplify the certification requirements of many future UAVs. Since the ground station must be designed in order to comply with various security and certification requirements, it could be used for the operation of many other UAVs thereafter.

This modular approach will simplify the design of the total UAV system since future UAV manufacturers in South Africa and elsewhere will only need to design their UAVs to interface with existing control centres. Operator licences would also be simplified since operators could typically qualify for one UAV license, and only require bridging training for each type of UAV.

Initially, the existing flight test control centres at OTB and at TFDC could be set up to be used as command centres during UAV test missions, and more permanent command centres can be erected as the design of command and control centres evolves.

3.4.3. Security

In order to prevent UAVs from becoming targets of terrorists and groups with similar intentions, especially since UAVs would be used against such organizations, it will be necessary to control UAVs from a secure location[83,84].

Operating UAVs from military units will provide the necessary security for UAV operations. Although special authority will need to be obtained in order to operate from military units, choosing to initially use UAVs to satisfy national strategic objectives, such as maritime patrol, should provide the necessary motivation to obtain the necessary authority to operate UAVs from national assets like air force bases.

In addition to physical security of the platform and control centre, the security of the data link and especially the command link to the UAV must be ensured since a false signal, or even jamming the signal, could allow terrorists to intercept UAVs for their own intentions.

3.4.4. Fuel & Power Supply

The type of power supply and fuel must be considered during the design. Battery powered UAVs will require strictly controlled battery charging processes in order to ensure that equivalent[114] airworthiness standards that are applied to manned aircraft batteries are maintained.

It may also be preferable for UAVs to use similar fuel to the fuel available at existing airfields because the storing and transporting of non-standard fuel at existing airfields can be problematic. The use of diesel engines that can run on kerosene is becoming popular with general aviation aircraft for this reason.

It also is essential that backup power must be supplied for a sufficient length of time in case of an engine failure in order to activate the necessary recovery systems and in order to maintain flight stability. The backup power must also include the transponder for the purposes of ATC transparency[114,115]. This will necessitate a reliable battery backup in addition to the normal power supply.

3.4.5. Engines & Motors

The development of special engines for UAVs has been recognised by engine companies such as Rolls Royce[116].

The requirement exists for the development of limited life engines[116]. It is argued that if regular maintenance can be eliminated, the maintenance parts of the engine can be eliminated and in so doing, the weight and cost of the engine can be decreased. This has an implication on manufacturing techniques used to manufacture engines.

Likewise, the maintenance of UAV engines can be simplified to a simple replacement of the whole engine, rather than regular maintenance of specific components, which will have benefits for UAV users with limited technical ability. This philosophy is already applied with many electrical motors. Hydrocarbon burning fuel engines could operate using a similar philosophy.

3.4.6. Payload Design

Owing to the many requirements placed on UAVs, and the seemingly endless design alternatives, future UAVs will probably be required to be re-configurable by means of payload attachments or re-configurable fuselages.

This enhancement will allow the UAV airframe to be certified, while the payload can be changed as required. It will however be essential to ensure that the payload remains separate from the air vehicle so that it will not result in the whole air vehicle being re-certificated as a result of a small change on the payload.

Payloads that can be dispensed during flight must also comply with the relevant airspace and airworthiness requirements, and in most cases will only be permitted when the UAV is classified as a combat vehicle, which is then not subjected to civil certification.

3.4.7. General Maintenance

Maintenance is a fundamental part of the system engineering design process[86]. This therefore necessitates that UAV maintenance must be done together with the air vehicle design. In order to comply with sound system engineering practices, UAVs will need to be designed with consideration of the functional requirements[86], which in the case of UAVs will be the requirement to comply with relevant regulations and standards.

Although the ASTM standard for maintenance of light UAVs exists[117], the lack of applicable UAV standards for the remainder of UAVs, and the principle of equivalence[84] will however necessitate that UAVs must either be designed, manufactured and maintained in accordance with existing manned aircraft requirements and standards, or each UAV design must be considered by means of a safety case approach in order to achieve the same levels of safety as those prescribed for manned aircraft.

3.4.8. Ground Based Maintenance

Because of the requirement to maintain UAVs to the same level of safety as manned aircraft, an amount of infrastructure development and personnel training will be required in order to service UAVs, especially for large long-range UAVs.

Most maintenance would therefore be done in a controlled environment, and it would be sensible to do this at a centralized location, close to the UAV operations.

Between, before and after flight maintenance will also have to be performed in the same manner as with similar types of manned aircraft in order to achieve equivalent safety standards to manned aircraft[84].

3.4.9. In-Flight Maintenance

In-flight maintenance poses some challenges. Usually, during manned flight, system failures are often identified and rectified by the aircrew. Decisions are also taken by the crew whether or not to continue with the mission. UAVs will probably not have the capability to do in-flight maintenance.

UAV systems will have to monitor their own health by using built in tests (BIT), and will either have to notify the ground station of any failures, or in the case where data communications are not possible, will have to be pre-programmed with decision criteria on whether or not to continue with the mission.

3.4.10. Maintenance Records

Almost all airspace regulations and standards require records of maintenance to be kept[90,117]. This is not only to ensure that the correct maintenance procedures are indeed carried out, but also to assist in accident investigations. For this reason, persons responsible for design and maintenance must ensure that the maintenance procedures are carried out correctly, and that the documentation is kept up to date.

3.4.11. Compatibility with Existing Infrastructure

For UAVs operating at existing airfields, ground handling and flight line maintenance procedures should be similar to those of manned aircraft in order to comply with the principle of transparency[84].

During certain activities, such as towing, additional procedures must be created to compensate for functions that were accomplished by humans, such as lookout and emergency braking.

It has already been mentioned that it will be beneficial if UAVs use similar consumables to those of manned aircraft. Operating from most military airfields will necessitate the use of kerosene rather than Avgas. The use of kerosene will also increase the safety of the platform and extend the range of operations. Although some manned aircraft still use Avgas, the requirement to use kerosene will enhance the operations of especially large long range UAVs.

3.5. SUMMARY

South Africa clearly has a requirement for UAVs to carry out tasks that classify as “dull, dirty and dangerous (D^3)”. Many of these tasks are in areas that have a low population density and are not in areas that have high air traffic density. UAV development could therefore concentrate on fulfilling these mission requirements and develop the airspace regulations in parallel. Once the UAV technology has been proven in this airspace, it can be expanded and moved to more densely populated areas when the airspace regulations are in place.

Although the subject of UAV design is outside the scope of this document, it does have a direct impact on the generation of Standards and is conversely affected by the regulations in force when the UAV is designed. It is therefore vital that UAV designers familiarize themselves with current airspace regulations since it can significantly influence their design.

Further research into UAV designing must be executed in order to ensure that when standards are transferred from manned aircraft, or when new UAV design standards are proposed, that they are relevant and correct. The future design of UAVs will probably break new barriers that were not possible with manned aircraft, mainly because of the human limitations, and it is inevitable that new designs, standards and regulations will be created in order to accommodate this.

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4. UAV FLIGHT TESTING

4.1. INTRODUCTION

Although flight-testing is usually a small, but very expensive part of the total design, much work needs to be done for UAVs to gain acceptance into existing airspace. This can only be achieved through extensive flight-testing. Together with flight-testing go many risks, including the risk of proving the opposite of what was intended, which is that UAVs are indeed safe to operate in existing airspace. As with most aspects of air vehicle design, flight testing is a specialist field which has evolved over many years with some of its procedures seeming to be unnecessary, until the reasons for the procedures are understood, which usually came about after a significant number of lives were lost owing to the lack of procedures. Once UAVs have proven that they are indeed safe to operate in civil airspace and the ground breaking technology has been developed and proven, the flight testing phase proposed in this roadmap can be cut back to only testing that is necessary for certification to take place, however the present lack of knowledge in the UAV community compared to the years of flight testing experience in the manned aircraft industry necessitates a specific section in the roadmap.

4.1.1. Necessity for Formal UAV Flight Testing

The range and endurance of UAVs is increasing in order to satisfy mission objectives, and the requirement to be certified to fly in civilian airspace will therefore result in UAVs having to be designed to comply with both air traffic management and airworthiness requirements. As became the case with manned aircraft testing, the complexity of systems increased and specialist skills were required for testing aircraft. UAV manufacturers will soon also not necessarily have the time or specific training to test their own designs and specialist flight test skills will be necessary in order to execute flight tests that will comply with the various regulations.

In the South African aerospace industry, UAV flight-testing has been done within the respective companies, while the major flight test organizations have been conducting mostly manned aircraft flight tests. With the present re-structuring of the South African aerospace industry and the disruptive nature of UAVs[118], the focus could shift from manned aircraft systems to unmanned aircraft systems, and flight testing organizations should be prepared to reorganize themselves to accommodate this shift.

It has now also become possible for radio controlled aircraft builders to manufacture light UAVs and as such, the design and testing of these UAVs has in some cases been done in a similar manner to the methods generally used by radio controlled aircraft builders. So far, this has been an acceptable low cost method of proving UAV technology since UAV builders were responsible for testing their own products, but the requirement to operate these UAVs in un-segregated airspace will necessitate certification and formal flight-testing.

Historically, UAVs have proven to have higher reported loss rates than manned aircraft, especially during takeoff and landing[119]. This may be ascribed to the fact that, because UAVs are unmanned, their loss could sometimes be regarded by UAV test personnel and managers as acceptable. However, the risks to the project and the safety of personnel resulting from an accident will become more important as the cost of a UAV platform increases, or as the payload weight and sophistication increases. As such, based on the principle of equivalence, it would probably become necessary to achieve the same accident and safety record as manned aircraft. In order to limit UAV losses, it would therefore be sensible to apply the same testing principles and procedures to testing UAVs as those principles and procedures applied to testing manned aircraft that have evolved over the years.

Also, the USA DOD has stated[120] that future planning is for UAVs to replace manned aircraft performing dull, dirty and dangerous (D^3)[121] tasks[118,120,122], especially where the human crew was a limiting factor. These UAVs must therefore have equal or better effectiveness than existing combat aircraft. The method of proving the effectiveness of manned aircraft has been through rigorous flight-testing. These UAVs will have to comply with similar operational requirements, and must therefore be subjected to similar or even more stringent flight tests than existing combat aircraft in order to prove that UAV technology can indeed replace manned aircraft.

Lastly, the South African government is creating strategies to develop its economy. The Advanced Manufacturing Technology Strategy[123] (AMTS) has identified UAVs as one key area that the South African aerospace industry should develop, especially for the export market. In order for the South African built UAVs to be accepted internationally, the quality of UAVs manufactured must be of a high enough standard so that they can satisfy the requirements of the export market. Flight-testing of UAVs in order to improve the quality of the design and prove compliance with international standards and regulations will therefore be essential.

Because of its location adjacent to the sea, away from commercial traffic, the Test Flight and Development Centre (TFDC) near Cape Agalhas, South Africa was proposed as the most suitable place for executing UAV operations and research[122]. It was suggested that operations should initially take place from TFDC where most of the infrastructure is readily available[122].

4.2. UAV TEST PREPARATION

In order to lower the risk during testing, test preparation has become a major part of the testing process. The correct planning of the test also eliminates the necessity to do testing at a later stage that was left out during the initial campaign and correct planning can significantly speed up the certification process because data is collected systematically, enabling the report to be structured and aimed at the specific purpose of the test.

4.2.1. Systems Engineering Approach to UAV Testing

Unlike manned air vehicles that are self contained, for reasons such as communication with ATC, mission management, remote sensor operation and flight termination, UAV platforms will be dependent on a network of remote systems in order to make operations possible[122,124].

Testing and evaluation will therefore need to be executed on the entire system[125], and not only on the air vehicle platform[122,124]. This could raise the task from testing a relatively uncomplicated UAV platform to that of testing a highly complex integrated system. It is therefore essential that the correct system engineering concepts be applied to UAV design. Testing and evaluating the system as a whole will ensure that the UAV is capable of performing its required function[126].

4.2.2. Classifications of Flight Tests

Flight test & evaluation is commonly divided into two main groups: developmental testing & evaluation (DT&E) and operational testing & evaluation (OT&E)[127].

DT&E usually forms part of the design process and is used to confirm engineering calculations, which can assist with optimising the design[127]. It is the data collected during DT&E that is usually submitted to the certification agency when applying for certification.

The end user usually executes OT&E in order to determine if the product can perform the intended task. This type of testing often does not require engineering data and is done by simulating mission task elements for the specific mission, such as takeoff and landing from a ship for a maritime UAV mission. In order for the results to be valid, people with similar expertise as the final user must preferably execute these tests using production-representative equipment[127].

The inclusion of the human in the loop for many UAV missions[122], for practical and legal reasons[118], also necessitates that a reasonable amount of OT&E must be executed to ensure that the total system, with humans in the loop, functions correctly. It must also determine the suitability of the total UAV system for use by the end users, especially operators and maintainers[125]. It is therefore essential that the personnel executing the tests must have a good understanding of the intended mission that the UAV will be required to perform[127]. Suitably qualified test personnel who have previously been involved with similar manned aircraft operations would be ideal for testing these UAV missions[125].

A third category, qualification testing and evaluation (QT&E), is sometimes required where DT&E has been completed, and where only proof of compliance with a specification or regulation is necessary. QT&E usually tests pass/fail criteria required by regulations in order for an air vehicle to be certified or in order to prove compliance with a contracted specification, and could form part of the DT&E process and may even include certain OT&E elements[127]. This may be necessary where a military system must be certified for civilian use or where a commercial off the shelf (COTS) UAV system must meet the specifications and regulations of a new user.

4.2.3. Testing against Regulations, Standards and Specifications

Many aircraft acquisition contracts include specifications, which ensure that a product with an acceptable minimum standard is supplied. Often, a recognized standard is used such as Mil Spec, Def Stan or RTCA DO-178B[128]. Over the years, the military standards have become overly restrictive, resulting in excessive costs and the exclusion of suitable suppliers because of non-compliance with such specifications. More recently, it has been suggested that less restrictive civilian standards should be used.

Airworthiness is however usually contained in regulatory documents such as FAR[129]. Apart from countries like Australia[130], specific civil regulations for civil UAVs are still in the process of being developed. There is a tendency to favour the use of civilian standards, such as RTCA DO-178B[128], within the regulations[118,124,131] and it has been suggested[118] that South African UAV specifications and regulations should try to use existing standards and regulations[118] wherever possible. Compliance with the regulations, standards or specifications must then be proven by means of testing.

4.2.4. Regulatory Requirements for Various Types of UAVs

All UAV systems will require developmental tests to be conducted in order to optimise the design. Some certification agencies and regulatory bodies[118, 124,130] have proposed relaxed regulations for academic institutions, research organizations and UAV developmental organizations that design and test UAVs provided that these UAVs do not pose a threat to people and property on the ground.

This classification of UAVs could be adopted by the South African authorities and, as such, light UAVs[118,124,130] weighing less than 150kg with a kinetic energy of less than 95kJ might not be required to be type certified[118,124,130] provided that they will operate as radio controlled aircraft within visual range in un-segregated airspace for missions such as aerial photography. This could inevitably lower the cost of development of these UAVs.

Large UAVs weighing more than 150kg with a kinetic energy more than 95kJ[118, 124,130], and light UAVs flying in un-segregated airspace or outside the visual range of the pilot will be required to be certified in a similar manner to that of manned aircraft if principles such as equivalence[118,124] are applied. Operational testing would be done at the discretion of the user and could be extensive depending on the mission, cost risks or allowable safety margins.

4.2.5. Defining Test Requirements

In accordance with system engineering principles, it is essential that the operational requirements must be determined first[126,132]. As far as practicable, test requirements must be determined as early as possible in the development process of a UAV and preferably as soon as the operational requirement has been determined. Correctly determining the test requirements at an early stage will ensure that it will be possible to measure whether the UAV design will indeed meet the operational requirements during each step of the design[133].

Measures of effectiveness (MOE) determine how effectively the UAV will be able to perform its mission. Measures of performance (MOP) indicate how well the UAV will match the desired performance requirement[127]. Both MOE and MOP must first be determined. From each of these measures, test objectives can be determined. These objectives ensure that the correct parameters will be measured so that it can be determined if the UAV system will meet the specification, and will therefore be able to perform the desired mission.

For already designed, or COTS UAV systems, the same process should be followed, except that most of the test and performance data will already be available. It will therefore only be required to determine if the UAV system will satisfy the measures of effectiveness. These measures of effectiveness will always vary between missions, environments and factors such as the experience of the user.

4.2.6. Certification and Airworthiness

The final objective of flight-testing a UAV should be to demonstrate a satisfactory airworthiness standard so that the UAV can be certified to operate in un-segregated airspace. In order to certify the UAV, the certification authority may provide a list of requirements and will require visibility into the testing process throughout the development program[134]. It will therefore be prudent to contact the certification agency as early as possible in the development phase of the UAV. The certifying agency may request to observe certain tests, which would have to be repeated if they are involved too late.

Qualification is the process of obtaining evidence, which must be presented to the certifying agency in the form of test reports[122]. The manufacturer usually executes qualification testing because the acquisition contract often requires a certified product to be delivered.

Once the evidence of successful testing is provided to the certifying agency, and the UAV complies with applicable regulations, the UAV can receive a type certificate[135]. All future identical copies of that UAV design would then be certified provided that the UAV manufacturer holds a production certificate[135]. The design essentially becomes frozen, and any future changes must go through a similar process and either a new type certificate will be issued or a supplemental type certificate may be issued[135].

The certified UAV will then be permitted to operate in airspace, with any restrictions that may apply. Although the UAV may have received a type certificate, it would still be necessary for the individual UAV to remain airworthy throughout its life, and periodic maintenance and airworthiness checks will be necessary in order to obtain a certificate of airworthiness[135].

4.2.7. Lessons Learned from Accidents during Testing

Because of the 'chicken and egg' situation[118,124] where certification agencies require evidence of a safety record for UAVs before being willing to certify a specific UAV design, there may be a tendency for UAV designers to hide their accident data. It was also stated that because of military secrecy, many UAV data on accidents are unavailable, however most of these accidents occurred during testing[136]. Also, personnel who are not always familiar with manned aircraft test principles sometimes manage UAV flight test projects, and because many UAV accidents do not necessarily result in the loss of life, some accident data may be lost.

Because manned aircraft regulations evolve as accident investigations recommend modifications to them, it will be valuable to include the lessons learned from the experiences and accident investigations from UAV manufacturers and operators, in developing these regulations.

Manned aviation has evolved a principle of divulging relevant information that will limit the possible loss of life or injury, for the benefit of all aviators. This attitude needs to be encouraged in UAV flight testing, and once UAVs share airspace with other manned aircraft, this culture will become essential.

4.2.8. Test Planning

One of the most essential elements of flight testing is test planning which is to ensure that all the correct safety procedures are put in place, and that all possible contingencies for failures have been considered and catered for. In order to achieve this, a test plan document must be compiled that provides a detailed description of exactly what will be tested, how it will be tested, and by whom it will be tested.

In addition to this, test planning must ensure that the desired outcome of the test will indeed be achieved most efficiently and that the test method is sound. This process is ensured by having a technical review of the test plan which must include a safety review of all the procedures that will be executed, including provision for failure.

Once the test plan has been compiled and approved, it is usually distributed to all the test executors, support services and other interested parties in order to ensure that the test takes place as efficiently as possible.

4.2.9. Technical and Safety Reviews

Part of standard flight test practice is to hold technical and safety reviews to approve test plans and procedures. When holding safety reviews, it is essential that a pre-determined quorum must be present in order to prevent last minute panic decisions. It is important that this quorum must consist of objective personnel with experience in the field of testing, and technical experts from outside the program should be brought in to offer an objective opinion[137]. Part of the safety review process should include reviewing the test hazard analysis and safety procedures that will be followed if a failure should occur.

4.2.10. Flight Test Principles

Over the many years of manned flight-testing, lessons learned from accidents have resulted in standard flight test procedures being created. In fact, most flight test centres worldwide use similar processes and procedures. With the proliferation of UAVs, it will be essential that the correct flight test procedures be applied to UAV testing so as to avoid the same catastrophic failures that were experienced during the early days of manned flight-testing.

The ‘build up’ approach is an important principle, which emphasises the importance of moving from the known to the unknown where knowledge and experience from previous testing is used to progress to the next test point. This is especially applicable to UAVs where implementation of automation results in more complexity[138]. More complex UAVs utilizing integrated systems could result in many unknowns. A combination of a well planned test matrix together with a build up approach, making one change at a time and progressing through the matrix from the known to the unknown, will make the process more controllable.

Another good principle to adopt is that once the test plan has been approved, it becomes a binding document. Only tests that were approved in the test plan may be executed in accordance with the method detailed in the test plan. All safety procedures must be adhered to and no deviations from the plan are permitted without a safety review.

4.3. UAV TEST METHODOLOGY

Although UAVs are generally different to manned aircraft, the test methods applied to manned aircraft can be transferred directly to UAVs. The reason for this is partly because manned aircraft flight-testing is procedural, rather than technical, and the procedures are independent of the platform. Complying with the same procedures used by manned aircraft will simplify the process of obtaining authority to execute tests and will also assist with the presentation of data during the certification process.

4.3.1. General UAV Test Methodology

Flight-testing of manned aircraft is traditionally divided into three main categories: Performance testing; Handling qualities & stability testing; and Systems testing. Although these categories are relatively arbitrary, and some tests could fall into more than one category, it seems prudent to apply similar categorization to UAVs.

As an initial approach, it is therefore suggested that similar test methods used by manned aircraft should be used for testing UAVs[139]. UAV testing however poses unique challenges, especially when testing exotic designs with highly augmented stability and integrated systems, and many of these flight test challenges are still being researched.

4.3.2. Performance Testing

Performance flight testing[140,141,142,143] includes aspects such as level flight performance and climb performance, and usually results in graphs being compiled for publication in the aircraft's documentation for planning and operating purposes.

During manned flight testing, the aircraft is usually flown very accurately in still air and data are collected either manually or electronically using on-board recording equipment using calibrated reference instruments during stable test points. If performance testing of UAVs is executed in a similar fashion to that of manned aircraft performance tests, the UAV tests will therefore also comply with the requirements of manned aircraft regulations and standards.

During performance testing, accurate pitot-static data is required for the pilot to obtain the correct flight conditions, and pitot-static system testing is often included during performance testing.

4.3.3. Handling Qualities and Stability & Control Testing

Handling quality testing[140,141,144,145] generally assesses whether the response of the platform to control inputs is satisfactory, while stability testing assesses the tendency of the aircraft to return to a stable flight condition.

Handling quality and stability testing is usually much more dynamic than performance testing and often requires qualitative test-pilot statements. Methods such as the Cooper-Harper handling quality rating scale[144,146,] ADS-33E[147], and the Bedford workload rating scale[144] have been developed to quantify the pilot statements. Studies into UAV handling qualities have been done and have defined new boundaries[148] and standards[149] for stability of UAVs, which are generally wider than manned aircraft equivalents owing to the system architecture of the UAV[149] and the absence of a human in the loop.

In general, UAVs possess the type of stability and control augmentation systems and navigation systems usually found only in larger, more advanced commercial aircraft.

However, latencies in aircraft response[150] and display[151], and the lack of flight cues pose problems to a remote pilot[149].

Owing to airspace requirements, amongst other things, pilot in the loop control will be necessary in the near future[118,149] and UAVs will therefore have to comply with the relevant handling control standards and regulations in order for the UAV to be certified. Proving compliance with these standards can be done using simulators and ground based tests, but will usually conclude with flight tests.

Parameters that cannot be measured because of the lack of an on board test crew, such as stick force[125], need to be measured using alternative methods, but the use of the autopilot negates some of these stability and handling quality tests, however system effectiveness and reliability must still be demonstrated.

Although stability can be measured with reference to a pilot on the ground, the lack of physical feedback could result in certain flying qualities of the UAV being overlooked, resulting in an unsafe flight condition being reached such as during wind gusts in critical phases of flight such as takeoff and landing, especially where there is a large degree of coupling between the pilot and the aircraft. It will be even more difficult to evaluate the handling qualities of UAVs with command directed autopilots.

A simple design philosophy would be to design a highly stable platform, but when manoeuvrability is required or where stability margins become small, successfully evaluating handling qualities can become difficult. In addition to this, the small input forces and the high sensitivity and small control deflections also makes accurate measurement of the parameters difficult[125].

4.3.4. System Testing

System testing has become the largest part of flight-testing as systems are becoming more complex. Indeed, aspects previously covered in performance and handling qualities are becoming automated, such as engine management systems and auto pilot systems, and can now also be treated as systems. The amount of automation required by a UAV is largely dependent on these systems and the operation of the whole UAV must be regarded as a system[125].

Failure mode testing of UAV systems is a critical part of UAV testing. Testing the failure of the communications link, resulting in flight termination, is particularly important especially when testing the reliability of the autopilot[125].

As with manned aircraft testing, system testing can become very involved and specific test techniques for each system under test must be developed. In most cases, test techniques applicable to manned aircraft will be applicable to unmanned aircraft and UAVs will have to comply with manned aircraft regulations where they exist.

Due to the highly integrated nature of many UAVs and because of pressure to meet project deadlines, it is often necessary to perform concurrent tests on many systems at the same time. Testing all possible aspects of the final integrated system consisting of many sub-systems poses additional challenges to flight testers. Very careful planning is necessary to ensure that all sub-systems are tested thoroughly, and that the necessary preparations are made to ensure that complete testing of the final integrated system is done correctly and on time.

System testing of UAVs must therefore include the whole system, including those parts of the system that communicate by means of a data link.

4.3.5. Control Station and Simulator Testing

It is important that the flight simulator should mirror the UAV operation as accurately as possible so as not to induce negative training[137].

If the principal of equivalence[118,124] is to be used, testing of the control station must be similar to that of testing a cockpit of a manned aircraft. Since the UAV operations and simulations can be executed from the same control room but operating in different modes, the perceived differences between the modes can be minimized.

Ergonomics and human machine interface testing[152] could be done in a similar fashion as manned air vehicle systems. Test pilots and flight test engineers who are trained in evaluating ergonomics, displays etc. can be very helpful for identifying design and operational deficiencies early on in the developmental cycle.

4.3.6. Human Machine Interface Testing

Although the ultimate objective is for UAVs to operate autonomously, there will always be a requirement for a human interface with the UAV system. Applications that may require UAVs to be remotely piloted, operations where airspace is shared with other users and where interaction will be required with manned aircraft, and operations that are presently too complex for unqualified flight control systems[125] will require a human in the loop. Human machine interface testing will be necessary on such systems.

It is important to note that pilot error is often cited as a cause of accidents, but failure of humans to acknowledge this weakness is also part of the problem, and more attention needs to be paid to pilot workload. Issues relating to fatigue, work overload, situational awareness, ergonomics, crew co-ordination as well as boredom can affect pilot workload[153].

Also, some UAV accidents have been attributed to the lack of attention to detail of the crew station, especially when under high workload situations resulting in a lack of situational awareness[153]. Additional artificial sensory information, such as sound[137,154], is sometimes created in order for the pilot to receive the same sensory information that he would receive in a cockpit of the aircraft. It is therefore essential that proper evaluations of human machine interfaces must be done[137] in order to minimize UAV losses.

4.3.7. Developing and Testing Procedures for UAV Operation, Training and Maintenance

One of the traditional requirements during the design, and especially flight test phases of any air vehicle, is the creation of procedures. For safety reasons, aviation is highly regulated and it is expected of personnel to follow these procedures religiously. During the flight test phases, procedures often do not exist and must be created. All procedures should be tested in order to ensure their correctness so that they can be released together with the documentation of the final UAV product.

Once procedures are in place however, it is essential that test crews must follow these procedures since it has been proven that properly formulated procedures can effectively prevent aircraft losses[137] under conditions of high workload. Where new flight regimes are being explored, it is important that new procedures must be created in parallel with testing.

4.3.8. Telemetry Data Link Testing

Because manned aircraft have not been dependent on a data link to sustain flight, it has not been necessary to certify the integrity of the data link. It is however essential that integrity of the UAV data link, especially for command directed UAVs, must be tested and evaluated.

A large amount of expertise about data links resorts with the flight test telemetry personnel at flight test centres such as TFDC/OTB.

A data bus often manages modern aircraft systems, and it is possible to include the parameters of most on-board systems in the data stream transmitted by the data link. A large amount of these data could be used for flight test data, and other flight test instrumentation parameters could be included in the data transmitted by the data link, eliminating the need for a dedicated telemetry transmitter.

4.3.9. EMC/EMI and HIRF Testing

Because UAVs must rely on a data link when being piloted remotely, on an on-board system when flying autonomously, and must receive termination signals and commands to re-direct during flight, testing for Electro Magnetic Interference (EMI), Electro Magnetic Compatibility (EMC) and High Intensity Radiated Fields (HIRF) will be essential. Since EMC/EMI and HIRF testing is independent of the human crew or operator, standards used by manned systems can be applied directly and a standard such as RTCA DO-160D/E[155] or MIL-STD-461E[156]/462D could be used.

4.3.10. Software Testing

Because of the parallels with manned flight, software testing should be similar to software testing of manned aircraft. A software standard such as RTCA/DO-178B[157] that is used for testing software on manned aircraft should be used. The software certification process is however based on a safety hazard analysis, and a different safety criticality may be assigned to a UAV owing to factors such as weight and airspeed. This could result in a different software certification requirement than a manned aircraft used for a similar task.

4.3.11. Weapons Testing

Because of the risks associated with the requirement to carry armament, armed UCAVs are not permitted to be tested in civil airspace. A suitable test range such as TFDC/OTB must therefore be utilized, where the necessary facilities and safety procedures are in place for the handling and discharging of weapons.

The testing of UCAV weapon systems will therefore be the same as the testing of manned military systems, and it is unlikely that civil UAVs will carry such weapons in the foreseeable future in South Africa.

4.3.12. Testing Integration of UAV Systems into Existing Airspace

Since UAV systems will interact with other air users, it will be necessary to prove that the operation of UAVs will be transparent[124] to ATC and other aircraft.

Using the approach similar to Access 5[158] as described earlier, the concept of integrating UAVs into the national airspace must first be proven at a test site and only once proven to be safe should the UAV system be transferred into un-segregated airspace.

Issues such as “sense and avoid”, visibility and interaction with other aircraft must be tested in order to prove compliance with applicable airspace regulations such as FAR 91.

4.3.13. Multiple UAV and UAV Network Testing

Depending on its complexity, testing of a single UAV air vehicle could be a relatively simple task, however when UAVs are required to co-operate with each other, the situation can become more complex[159].

Standard system design principles must be used, and test objectives must be defined in the early stages of development so that the complexity of testing the integrated system at a later stage can be reduced.

Issues such as the allocation of frequencies must be addressed and the correct choice of test location will be necessary during these tests[137].

Apart from chase aircraft and formation flying on manned aircraft, testing of multiple UAVs, formations and swarms of UAVs is a new field of testing which will be network oriented and a build up approach would be essential.

4.3.14. Testing of Ground Support, Maintenance and Infrastructure

As is the case with manned aircraft, and using the principle of equivalence[124], unmanned aircraft wishing to operate in the same airspace must comply with equivalent maintenance and support regulations[118,122].

Ground support and maintenance must also comply with the relevant regulations and standards[160], and tests must be executed in order to prove compliance with these requirements.

Evaluations of relevant operations, maintenance and training documentation will also be necessary.

4.3.15. Flight Termination System Testing

One major difference that separates unmanned from manned aircraft is the ability to terminate flight abruptly[125]. Testing of flight termination is therefore not done on manned aircraft, however testing of flight termination will be essential for all categories of UAVs in order to ensure that the UAV does not violate airspace restrictions or endanger human life during flight termination.

Testing of the termination system of the UAV must include tests to ensure that airspace boundaries are not exceeded, as well as tests to determine the human machine interface aspects such as the ability to programme these boundaries, and other automated fail-safe flight termination functions[125].

The boundaries of the test safety zone should be calculated by means of the predicted impact point[137], and all flight-testing must be done within this zone with the safety margin.

Parachutes however, should not be used as primary flight termination device and other methods are required to bring the aircraft safely to the ground, however once a terminal failure has occurred, a parachute could be use to limit the damage resulting from impact.

4.4. UAV TEST EXECUTION

The test execution phase of any flight test is the most dangerous phase of any new development campaign, but the safety records of international flight test centres proves that if the correct test planning is applied, the risks can be reduced to below that of steady state operations. The correct use of procedures during test execution will contribute to the lowering of this risk. Lastly, the maintenance of configuration control documents and data will greatly assist with the reporting process, which will in turn speed up the certification process.

4.4.1. Flight Test Facilities

At present, only Overberg Test Range (OTB) situated next to TFDC, as shown in Figure **12,** is certified as a test range in order to execute experimental testing.

The test range at OTB/TFDC has a low population density in the surrounding areas, is away from commercial aircraft corridors and provides direct access to the Indian Ocean where long range tests can be executed without any risks to humans.

OTB/TFDC airspace is also restricted to commercial and civil traffic, allowing UAVs to be tested without risk of collision with commercial aircraft.

Many other locations in South Africa would be suitable for UAV testing, however present regulations require that special authority must be obtained from the South African Civil Aviation Authority for the specific test programme.

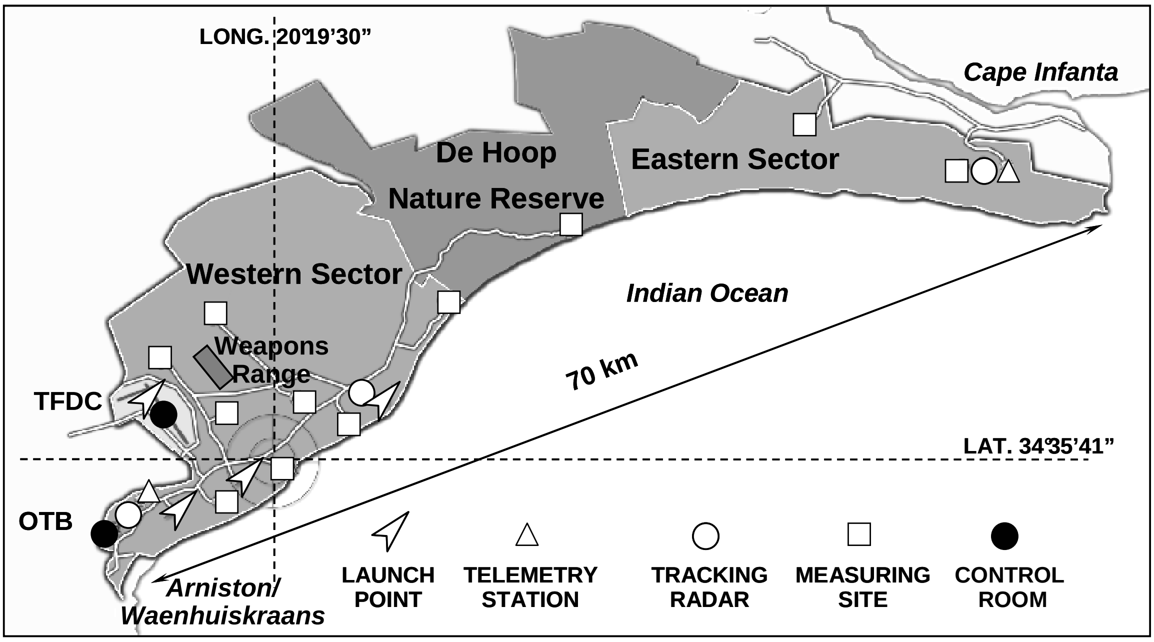

Figure 12: TFDC & OTB Test Range Layout[161]

DT&E of UAVs should therefore only be executed where civil airspace regulations permit the use of uncertified UAVs, but further considerations such as the relative cost of the UAV development versus the cost of using the test range and the costs of travelling the distance to the range must also be considered[125].

The unavailability of telemetry and data link frequencies can also be a limitation if the correct test location is not chosen[137].

OT&E should be conducted in the same physical and system environment that the UAV is intended to operate in. The selection of the correct location for UAV OT&E is therefore essential[125].

Light UAVs that are permitted to operate using radio controlled aircraft regulations should be able to execute flight tests at radio controlled aircraft fields, but must operate within the radio controlled aircraft restrictions such as operating within visual range and below 400ft AGL. If the test envelope exceeds radio controlled aircraft limits, then the UAV must comply with existing airspace regulations such as SA CAR 91 or FAR 91, and must obtain the necessary approval for executing flight tests.

Fortunately, because of the small nature of some UAVs, a considerable amount of testing can be done in a wind tunnel in order to reduce test range costs, but a number of tests cannot be tested in a wind tunnel[125] and must be tested in actual conditions.

UAVs that do not possess a type certificate, must obtain a special flight permit from the South African Civil Aviation Authority for the planned tests[135]. Only when tests are executed at a certified flight test centre, can the flight test centre issue their own approval for flight tests to take place, but civilian UAVs must nevertheless obtain a special flight permit from the SA CAA for the air vehicle itself.

4.4.2. Atmospheric Conditions

The lack of an on board person to judge the weather conditions could lead UAV operators to fly into adverse weather conditions that could be beyond the capabilities of the UAV. For this reason it has been stated[162,137] that atmospheric data must be collected before and during test flights.

The most important condition is wind, but precipitation and icing are also important[137,162]. Other factors such as temperature variations with altitude must be considered because many electronic components and batteries cannot withstand the extremely cold temperatures experienced at very high altitudes[162].

It is therefore important that the developmental test location must be chosen where the atmospheric conditions are most suitable for UAV testing, and the time of day and year must be chosen that best suits UAV operations.

OT&E must however be executed at a location that represents the intended operational conditions which may include testing in adverse weather.

4.4.3. Usefulness of Simulators and Surrogates for Flight Testing

Since one underlying driver for UAV technology, especially light UAVs is low cost, the use of simulators can significantly reduce costs, eliminate delays resulting from variables and unknowns such as weather, and will become an important part of UAV testing in the future[163,164,165].

Data from wind tunnel tests, mathematical models and limited flight tests could be used in order to develop computer simulators that can predict the response of the actual UAV to given signal inputs. Such simulators can be used to develop systems such as automatic flight controls.

Likewise, simulated inputs could be given to the actual UAV systems, such as the air data system, in order to measure the response of the actual UAV to simulated flight conditions.

Testing of a ground control centre could be executed by providing the ground control centre with simulated UAV inputs in order to emulate the flight of a UAV so that aspects such as human factors and human machine interface can be evaluated without the use of an actual UAV.

Airborne type simulators, such as in-flight simulators[166,167] and UAV surrogates[168,169] (UAV-S), including optionally piloted UAVs, could also be used very effectively during UAV testing, especially when physical limitations or airspace restrictions prevent the use of an actual UAV or where the safety of test crew or other airspace users is questionable. This type of testing will be particularly relevant for evaluating unqualified systems such as ‘detect and avoid’ systems[168,170] in un-segregated airspace.

4.4.4. Pre Flight Activities

Because safety is the primary concern during flight-testing, all tests must be planned properly before execution. All testing must be executed in accordance with the approved test plan.

Test cards must be written for each flight and the test must be executed, point-for-point, strictly in accordance with the test card. Test points are usually specified in the test plan, but it is sometimes necessary to further break down test points in order to manage the test more effectively.

A briefing must be held before each flight to ensure that all personnel are aware of their duties during the test, and must also address safety procedures that must be followed whether or not a failure occurs.

Go, No-Go criteria must be established based on pre-determined minima that have been imposed during a safety review. These criteria must be adhered to strictly, and cannot be changed during flight.

Issues such as minimum crew composition must be determined based on workload, and are best defined in a simulator before actual flight testing[137] in order to lower the risk.

Data such as weight & balance and endurance must also be determined and recorded before flight. Records of the weight and balance must be kept for each flight, even if no changes have been made since the previous flight.

4.4.5. Data Management and Configuration Control

Because modern flight test instrumentation recording equipment is capable of recording large quantities of data, the process of managing data becomes more critical and is sometimes the driver of a flight test programme[135].

It is essential that information and data obtained during the flight must be recorded carefully so as to prevent the loss of data, and to prevent the necessity to repeat test flights unnecessarily. The preservation of data is ensured by implementing the correct configuration control procedures, as well as by de-briefing after each flight in order to record all relevant observations and deviations from the plan so as to correct any deficiencies in future planning. It is advisable that all documentation and reporting must be completed as soon after the test flight as possible, preferably before the end of a test day and before commencing the next test flight[137].

During flight test programmes, it is also sometimes necessary to make changes to hardware, aircraft configuration and software. It is essential that these changes are recorded in parallel with the measured data so that the correct conclusions can be made by relating the data to the specific configuration of the UAV for that flight[137]. This data could also be used at a later stage for determining the service life of components.

4.4.6. Qualifications of Test Personnel

The training and qualification of flight test personnel has traditionally been well established in South Africa and the licensing and rating of aircrew is regulated by the Civil Aviation Authority[135].

In order for UAVs to operate in civil un-segregated airspace, UAV pilots would also be required to hold an equivalent licence and rating to that required for manned aircraft.

Mostly non flight test qualified personnel have up to now executed tests of UAVs in South Africa. This may have been because so far, it has not been required to certify UAVs to fly in un-segregated civil airspace.

Evidence in the USA however suggests that UAV manufacturers with little flight test operational experience were more prone to mishaps than experienced flight test personnel[139].

UAV pilots and maintenance crew must also have the appropriate licenses and ratings[125] because of the requirement for UAVs to comply with existing manned aircraft regulations.

Training courses for test pilots and flight tests engineers, as well as specialized UAV flight test training, are available at internationally recognised civilian test pilot schools such as the National Test Pilot School (NTPS) in the USA.

4.4.7. Test Reporting

The purpose of test reporting is to state whether the test objectives have been met, to provide data and supporting evidence as proof, to state whether the system will perform the intended mission safely, to conclude on the compliance with the initial test objectives, and to recommend any changes if necessary.

In the early stages of design, the report should be used by designers to rectify failures, while in the later stages the data presented in the report should be submitted as proof of qualification for certification. Flight test reports are often used many years after the tests have been completed, especially for accident investigations where proof that tests were conducted are necessary, or where flight test data are required in order to draw conclusions.

4.5. SUMMARY

Flight testing practices are well established for all classes of aircraft. These practices were designed to be applicable to all flying platforms and can easily be applied to UAVs.

Because UAVs have not been required to be certified, and because UAVs are now no longer being designed and built only by traditional aerospace companies, the concept of testing UAVs correctly must be transferred to these non-traditional aircraft manufacturers in order to ensure safety, and quality.

Apart from the necessity to flight test UAVs in order for them to be certified, it is also necessary to prove during flight testing that the developmental testing will not endanger life or property during the testing phase.

For this reason, extra ordinary measures are needed that are not common practice during normal aircraft operation in order to ensure safety and to determine the required safety procedures that will be applicable to the specific platform after certification.

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5. UAV OPERATIONS IN CIVIL AIRSPACE

5.1. INTRODUCTION

Although the section on *Design and Operational Requirements* assessed the strategic requirements and assessed eventual operations, it was aimed mainly at identifying the design aspects relating to these requirements. Once UAV regulations are in place, and UAVs are accepted into national airspace, then "steady-state" airspace procedures will need to complied with. Some of these procedures and regulations are already in place since manned aircraft procedures are equally applicable to UAVs, while in other cases existing procedures will need to be modified and new procedures and regulations must be created, however based on regulations from ICAO, it seems clear that it will not be possible for UAVs to create their own regulations and will be required to fit into existing airspace arrangements.

5.1.1. Current Airspace Usage

Once any aircraft is designed, built and certified to fly, it will be required to comply with existing airspace regulations. Depending on the type of certification that the aircraft receives and the equipment that it has onboard, it will be permitted to operate in certain categories of airspace.

Typically, aircraft that are permitted to fly in un-segregated airspace have the lowest requirement for on-board equipment. Segregated airspace that is controlled by ATC will require additional navigational equipment which is intended to provide both the ATC as well as the pilot the ability to navigate more accurately. The more congested the airspace becomes, the more stringent the requirement for navigation equipment becomes.

UAVs however usually have reasonable amounts of navigation equipment on-board merely to control normal flight. This enables UAVs to operate effectively within segregated airspace where the positions of all air vehicles are known. However, in un-segregated airspace where aircraft often have the absolute minimum required navigational equipment, the position of other aircraft is often not known, and the pilot is required to use on-board equipment to detect other aircraft.

The requirement for equipment on board the air vehicle is intended to assist air traffic personnel with directing and separating aircraft from each other. Together with the requirement for equipment, are rules that the pilot of the vehicle must comply with.

The principle of transparency[171] however suggests that UAVs must integrate seamlessly into existing airspace so that other airspace users and air traffic controllers will not need to create or apply new regulations or techniques to UAVs. Complying with this principle will indeed assist UAVs in being integrated into existing airspace since the process of changing regulations globally to allow UAVs will in all likelihood take longer than the time that it will take to develop enabling technology for UAVs to comply with existing airspace regulations.

5.1.2. Rules of the Air

Rules of the air are contained in FAR 91[172]. There rules are the same in most countries and specify right of way.

Because of their lack of manoeuvrability, airships and balloons have the highest priority and have right of way over all other aircraft. It can be assumed that UAV balloons will have similar manoeuvrability to the manoeuvrability of manned balloons and likewise, fixed wing manned aircraft will also have similar manoeuvrability to similar sized unmanned aircraft.

Therefore, it seems logical that for airspace management purposes and right of way, the category of UAV will be the same as the corresponding manned aircraft. The management of UAVs in the national airspace should therefore be same as manned aircraft.

5.2. OPERATION OF UAVS

There are a number of aspects relating to the operation of UAVs that are specific to UAVs and are not included in manned aircraft regulations. In order for UAVs to gain full acceptance into the national airspace, procedures and regulations must be created before “file and fly” operations can take place.

5.2.1. Mission Planning

One of the most important issues in UAV operations will be mission planning. Although the final objective is “file and fly”, mission planning will still be essential in order to plan for contingencies, safe termination points and general route planning so as to avoid populated areas.

Fortunately, because of the repetitive (“dull[171]”) nature of the proposed UAV operations, the mission profiles and routes can be planned well in advance. This will aid transparency since the UAVs can be handled using similar procedures as IFR flights, thereby lowering the workload of the ATC.

The depth of mission planning would however increase as the level of automation[173] increases because more contingencies will have to be pre-planned.

In order to minimize the impact that UAVs will have on manned civil operations, it is necessary to study the intended mission profiles and routes. If the UAV is pre-programmed to follow a specific route with pre-programmed contingencies, it may be possible to allow the UAV to operate exclusively for this mission with these factors certified as part of the design.

Until approved "detect and avoid" technology is available and the safety of UAVs has been proven, the cruise phase of the mission should be done so as to avoid any potential obstacles and hazards, while also considering contingencies.

5.2.2. Takeoff and Landing

In order for UAVs to be permitted to takeoff and land at manned aircraft airfields within populated areas, evidence of the safety and reliability of the UAV will have to be provided by UAV manufacturers. In order to allow South African UAV manufacturers the opportunity to collect this evidence, it will be necessary to initially avoid taking off over populated areas and to execute takeoffs and landings from suitable airfields that are accustomed to the experimental nature of UAVs. This will allow the necessary time for South African UAV manufacturers to collect evidence in order to prove equivalence of safety[171].

Airfields must be chosen so that the takeoff and departure flight paths are preferably over the sea, or over uninhabited areas. A dedicated UAV research airfield that is familiar with UAV operations would be beneficial. The UAV must then climb to cruising altitude in order to avoid manned aircraft, and route directly to the operational area. It should be attempted to achieve the operating altitude and airspeed as soon as possible after takeoff so as to avoid complicated manoeuvres within manned airspace.

Once operations are proven to be safe and airworthiness certification is granted, UAVs could then operate from other airfields.

5.2.3. Collision Avoidance

Collision avoidance is the major issue preventing certification of UAVs in civil airspace from taking place.

Effective collision avoidance can be achieved by means other than on-board systems, provided that the UAV retains direct communications with the control centre, and that the control centre has access to radar data and real time on-board sensor information. It could be argued that this method would be equivalent to manned aircraft collision avoidance. It has also been stated that the probability of collision can be reduced significantly if UAVs are operated away from airways and major flight levels[174].

Larger UAV sizes will also be advantageous for collision avoidance since they will be easier to detect by manned aircraft in un-segregated civil airspace, especially if they will be painted in colour schemes that are easier to detect.

5.2.4. Air Traffic Control

Evidence also suggests that strategies such as procedural separation of UAVs from other aircraft in controlled airspace can reduce the risk of collision[174].

It is however envisaged that UAVs will eventually operate in the same airspace as manned aircraft. When operating in un-segregated airspace, so as to satisfy the principle of transparency[171], UAV operations will need to fit in with manned aircraft operations.

It would therefore be preferable if additional measures could be introduced such as creating airspace where it will be generally accepted that UAVs will operate without restricting either manned or unmanned air vehicle operations and so that UAV missions can be accomplished with minimal risk of collision with manned aircraft.

5.2.5. Airfield Operations

In order for the UAV operations to be transparent to manned airfield operations[171], it will be necessary for the UAV to be operated in a similar manner to that of manned aircraft. The ability to taxi to-and-from the takeoff point from a safe initial start up position will be essential. The ground operations will typically be directed by the ground traffic controller, and although collision avoidance will be the responsibility of the UAV commander, it will be necessary for the ground controller to clear the UAV for any movements only where it will be safe to manoeuvre. Also, to comply with the principle of transparency[171], it will be necessary for the UAV to vacate the active runway after landing without additional ground support.

5.2.6. Flight Authorization

Eventually, the objective is for UAVs to "file and fly". Until regulations and standards are developed that will enable this, UAVs will either have to apply for authorization every time they fly and will have to remain within restricted airspace reserved for flight testing, or special airspace will have to be created in which UAVs can operate exclusively.

During the research phase of the UAV operation concept, flight test restricted airspace could be used. This will enable the UAV commander to obtain authority only from the test centre.

During intense UAV operations, where more than one UAV is being operated at once, research suggests that a single mission commander would be needed as a point of contact in order to ensure a logical chain of command[175].

Once testing of UAVs has proven that UAVs can operate safely, including airfield operations, the airspace restrictions on UAVs should be lifted to allow UAV operations outside the restricted airspace.

5.2.7. Flight Termination

UAV flight termination has the potential to significantly reduce human fatalities during impact, thereby lowering the hazard and lowering the risk[174]. Because of the uncertainty of failure, flight termination could happen at any time.

The route of the mission must be chosen so as to avoid human occupants on the ground if the flight is terminated. It is therefore essential that control communications be maintained over critical populated areas so that a termination signal can be received by the UAV.

If it cannot be guaranteed that both manual and automatic flight termination over populated areas will be executed safely, then it will be essential to ensure that the area where any loss of signal can occur is uninhabited in case a terminal failure should occur during this phase. The UAV flight path must then be monitored and it must be confirmed that the signal was re-acquired when expected.

Failure to re-acquire the signal by the UAV should trigger either an automatic termination, or an alternative operational procedure. An acceptable procedure to re-acquire the signal, or procedures such as return to a pre-defined waypoint, or a return-to-base procedure, could be used in order to minimize the risk to the inhabitants on the ground.

5.2.8. Level of Flight Control Automation

The level of flight control automation should be determined by factors such as UAV stability and control, uplink and downlink limitations, mission requirements, emergency contingencies required[176] etc.

Maritime patrol UAVs will fly at long ranges from the control room and radio transmitters and will also fly over uninhabited areas so that the benefit of automation could be exploited fully, without the concern that failure in automation will result in the loss of human life.

5.2.9. Environmental Impact

There is little difference between the environmental impact of UAVs and manned aircraft[177].

ICAO[178] makes no distinction between manned and unmanned aerial vehicles. However, there are no requirements for aircraft with takeoff distances shorter than 610m because it was assumed that aircraft with a short takeoff capability would climb to altitude quickly and would not pose a noise problem[177]. Jet powered UAVs however will usually operate with takeoff distances less than 610m, and the noise factors must be considered.

Operating from remote airfields will mitigate this problem, but when operations move closer to built-up areas, consideration must be given to inhabitants.

5.2.10. Airworthiness, Registration, Identification and Certification

Because of the principles of fairness, equivalence and transparency[171], airworthiness, registration and identification will need to be similar to that of manned aircraft.

During the research phase at the test airfield, the UAV will require a special airworthiness permit.

When eventually operating outside the test airfield restricted airspace, type certification will typically be required.

5.2.11. Maintenance & Maintenance Manuals

Depending on the eventual categorization of UAVs, it is likely that large UAVs will be required to comply with equivalent manned aircraft maintenance requirements, however standards for light UAVs are already available[179].

5.3. UAV OPERATOR CONSIDERATIONS

Although it is understood that UAV are unmanned, in the foreseeable future there will always be a requirement for a human in the loop, at the very least to accept responsibility. There are arguments for- and against higher levels of automation. Nevertheless, where a human is involved, either in the operation of the UAV or during the maintenance of the UAV, there will be training, licensing and medical requirements. Many of these requirements are transferable from manned aircraft, however it is important to identify which at which level this can be done.

5.3.1. Aircrew Training and Qualifications

In order to comply with the principles of responsibility and transparency[171], it will be necessary for the UAV to be piloted or at least commanded by a human. According to the equivalence principle, the aircrew training and qualifications will have to achieve the same level of safety as manned aircraft. Depending on the level of automation, the qualifications and training will have to be based on the required competencies of the function that each crew member will be required to perform[173,180]. The overall safety performance of the UAV system must then be proven to be equivalent to that of manned aircraft carrying out the same missions. A minimum crew requirement for each UAV should also be included in the flight manual[181].

A study by Access 5[182] did however state that the pilot skills, knowledge and abilities required to operate a low autonomy UAV were no more than a private pilot with an instrument rating[183]. It was also concluded that there would be minimal training required to bridge the gap between the training provided to manned aircraft pilots and the training that is unique to either system[183] and that a separate UAV rating would probably not be necessary[183]. This argument could possibly be used as proof of equivalence[171] in order to speed up the process of training UAV pilots in South Africa.

5.3.2. Simulators and Ground Station Training

Because it will be invisible to the UAV crew whether or not an actual UAV is being used, it has been suggested that simulation will be an effective means for crew training[186,184] and that ground stations could double as simulators, eliminating the need to design and manufacture separate simulators for training[186] especially during the initial phases of UAV development.

Once UAV operations have been proven at the test site and the operations are expanded into the rest of South Africa, cheaper dedicated simulators could be used for training at a training site. The use of these simulators would eliminate the need for actual aircraft, further lowering the operating costs, and reduce the loss of human life during training.

5.3.3. Maintenance Personnel Training and Qualifications

Because of equivalence requirements[171], the training and qualifications of maintenance crew of large UAVs will be equivalent to the same class of manned aircraft used for the same type of mission.

5.3.4. Operating Crew Medical Requirements

Medical requirements will vary, depending on the degree of automation and the mission task that the crew member would be required to perform[173,185]. Further studies of this field should be done whilst conducting the proposed research.

5.3.5. Accident Reporting

The United States Department of Defence has stated that 70% of all non-combat losses, e.g. training, have been attributed to human error, and a large percentage of other losses have human error as a contributing factor[186,187]. Indeed, many of these accidents occurred during takeoff or landing with the human pilot in control[188].

It was stated that when modifications to aircraft were made, the accident rated due to mechanical failure decreased noticeably[136], while when training procedures were modified, the accident rate did not decrease[186] as much. With the human out of the loop, UAV mishap rates can be decreased and after each mishap, corrective action can be implemented that will permanently eliminate the particular problem. As the system matures, it is possible that mishaps could be almost completely eliminated. Mechanical failure would still occur, but this would be no different from manned aircraft.

Accident reporting is therefore extremely important, and the subsequent investigation must be executed by qualified aviation safety personnel in accordance with relevant SA CAA requirements to determine the cause of the accident. It is essential that the necessary changes must be made to the air vehicle, ground station, crew training and procedures based on the outcome of the accident investigation.

5.4. CASE STUDIES OF SOUTH AFRICAN AIRSPACE

The assumption of "file and fly" is that UAVs will have unrestricted access to all classes of airspace. Some UAVs will however never qualify for this. Also, until procedures and regulations are in place, an interim arrangement must be found to accommodate UAVs during the testing phases. It is possible that as technology matures, UAVs will be permitted into the national airspace using the Access 5 approach, however, the procedures developed during the interim phases of UAV testing should still be applicable for all UAVs in the future. Therefore the analysis of existing airspace for UAVs during the interim phase will also allow future UAVs that cannot receive full certification access into the national airspace.

5.4.1. Cape Town/Overberg

The airspace around AFB Overberg has been proposed as the most suitable for commencing UAV operations. Most UAV research activities can be executed at the Test Flight and Development Centre (TFDC) and at the Overberg Test Range (OTB), and when the UAV system is mature, the operations can be expanded to other airspace classes.

The major advantage of AFB Overberg is that the airfield is situated within restricted airspace FAR147[189]. This restricted airspace is limited to 19500 ft (FL195) AGL. This will allow UAVs to climb into class A airspace within controlled and restricted airspace, negating the necessity for sense and avoid equipment. Once in Class A airspace, UAVs could then access all parts of South Africa provided that they have the necessary navigation and communication equipment on board and the ability to maintain altitudes above 17500 ft above MSL.

Pilots operating UAVs in this airspace would be required to hold a current instrument rating with the relevant license.

A further advantage of the airspace around AFB Overberg is that numerous opportunities are available to fulfil the strategic requirements such as maritime patrol and anti-poaching while the research on UAVs is being executed.

5.4.2. Upington/Kimberley

Although the airspace near Upington and Kimberley does contain restricted airspace, FAR 25[190], which is also limited to 19500 ft (FL195), the airports themselves are not within restricted airspace, the UAV would be required to be certified at a location such as AFB Overberg before being permitted to takeoff and land at the Upington and Kimberley commercial airports. In addition to this, UAVs that are unable to reach class A airspace, and that do not possess sense and avoid equipment would not be able to transit to FAR 25. Therefore, the only UAVs that might be able to operate from FAR25 would be UAVs with a moveable launch and recovery system. However the inability for these UAVs to land elsewhere and to reach class A airspace would make this option unfeasible.

5.4.3. Johannesburg

Although Johannesburg airspace is not suitable for the interim use of UAVs, it has been included in this study to illustrate the reasons for this.

The airspace around Johannesburg and Pretoria contains numerous restricted and danger segregated airspace. The primary disadvantage of this airspace is that the limit of the airspace is between 10000ft and 14000ft, which prevents UAVs from reaching class A airspace without transiting through Johannesburg CTR[191]. Although this airspace is also controlled and segregated, the volume of commercial air traffic increases the risk of collision for uncertified UAVs operating with a special airworthiness permit, and will require UAVs to be certified before commencing with regular operations.

5.4.4. Makhado/Hoedspruit

The use of Makhado and Hoedspruit air force bases was proposed mainly because of the benefit of security of the ground station, and because of its proximity to the borders of South Africa, where UAVs could be used for regular border patrols and surveillance.

The disadvantage of this airspace is that it is over-flown by commercial air traffic travelling to Europe and to the Far East. The restricted airspace FAR71[192] will however make it possible to transit from the runway into class A airspace, which would in turn allow access for UAVs without sense and avoid equipment to the rest of the country, but neither of the airfields themselves are within restricted airspace, making it difficult for UAVs to operate without a special airworthiness permit and a NOTAM or without having first been certified at a place such as AFB Overberg.

5.5. CASE STUDIES OF SOUTH AFRICAN UAVS

Eventually, new UAVs will be designed using technology still under development in order to gain unrestricted access into the national airspace. However, the development of the regulations, standards, procedures and technology will take some time and an arrangement must be found for existing UAV platforms to gain access to the existing airspace. Because of current restrictions however, the various categories of UAVs available in South Africa will be restricted to specific classes of airspace, or even limited to temporarily allocated airspace. These UAVs may however still operate long into the future under these temporary arrangements. Future UAVs that do not qualify to operate unrestricted should also be permitted to comply with the same requirements as existing UAVs, however most UAVs should fall into one of the categories of existing South African UAVs.

5.5.1. Denel Dynamics Seeker

The Seeker (see Appendix A-2) has been used for many years by the military and police for surveillance intelligence gathering. The procedure that was used to obtain authority to fly in civil airspace is described in Appendix D. The Seeker UAV was however never certificated and a type certificate was never issued.

Because of its weight, the Seeker is outside the category of radio controlled aircraft and that of light UAVs. For this reason, Seeker would have to be certified in accordance with an equivalent airworthiness regulation such as FAR[172] 21 or FAR[172] 23.

Included in this requirement would be the necessity to comply with RTCA DO-178B[193] for software certification, which should include the software of the ground based flight controls.

The benefit of Seeker is that it can takeoff and land conventionally, making it suitable to operate from existing airfields, also making the ground operation of the Seeker transparent to ATC. The lack of sense and avoid equipment would make Seeker unable to operate in un-segregated airspace (class G airspace) without special arrangements, however, it could takeoff and land within segregated airspace and climb and operate either in restricted airspace, segregated airspace or in class A airspace while doing surveillance.

The possibility of Seeker being operated from a central ground station with various relay stations around the country could provide the Seeker with the ability to provide continuous surveillance with multiple platforms over long ranges. The weight of the Seeker also will permit operation in adverse weather conditions, and with the potential benefit of nationwide coverage, the UAV could be diverted to contingency airfields where conditions would be suitable for safe landing and takeoff.

5.5.2. ATE Vulture

Although the ATE Vulture (see Appendix A-3) can perform a similar function to Seeker, its weight allows it to fall within the light UAV category, but still heavier than the maximum permissible for radio controlled aircraft. This could possibly allow Vulture to comply with less stringent airworthiness requirements, but may be limited in the airspace in which it operates owing to the limited equipment. Although Vulture could try to comply with the more stringent requirements of the FAR[172] 23, the cost of the vehicle would increase, possibly making it unviable to compete with UAVs such as Seeker.

The catapult method of takeoff makes the Vulture only suitable for operations from a dedicated position. However, the ability to deploy to remote places makes Vulture suitable to be used for specific operations.

The lack of sense and avoid equipment, the lower weight, and service ceiling below that of class airspace limits the operation of Vulture only to specific operations during favourable weather using a special airworthiness permit from the CAA and with an applicable license to operate. With a special airworthiness permit and having a NOTAM issued for the airspace that it intends to operate in, the Vulture would however be able to operate in both segregated and un-segregated airspace with lower risk to civilians on the ground.

5.5.3. Denel Dynamics Skua

The Denel Skua (see Appendix A-4) is mostly a target drone with few other uses. Like most target drones, it is used for very specific military applications within restricted airspace. As such, there would be no requirement to certify the Skua for use within civil airspace. In addition to this, the high weight and high impact energy would preclude the Skua from complying with most airworthiness regulations and airspace airspeed requirements.

5.5.4. Denel Dynamics Bateleur

As with the Seeker, the mass of the Denel Bateleur (see Appendix A-5) is above the 150kg threshold of a light UAV and would have to be certified in accordance with an equivalent regulation such as FAR[172] 23.

Because of its mass and payload, the Bateleur would be capable of carrying all the on-board navigation and communication equipment required for all controlled airspace. In addition to this, it could be technically feasible to install detect and avoid equipment once it becomes available, allowing it to operate in un-segregated airspace.

Also, because of the ability for its data link to communicate via satellite, it is not limited in its area of operation. The Bateleur could therefore takeoff and land from an airfield in segregated, controlled and restricted airspace, such as AFB Overberg, and transit to the required operating area in Class A airspace, as is done with the Predator UAV in the USA.

The large payload also creates the opportunity for the Bateleur to be configured for various tasks that are strategically required by South Africa. Furthermore, the engine of the Bateleur could be converted to a diesel engine and could easily operate from most airfields that supply Jet A1 or Kerosene.

RTCA DO-178B[193] software qualification of both the air vehicle and ground station will be a major requirement for the Bateleur to qualify for “file and fly”. It is strongly recommended that new systems such as Bateleur implement the necessary procedures for software certification using standards such as RTCA DO-178, even though regulations are not in place. When the regulations do become mandatory, these UAVs will then automatically comply with the regulations. The procedure of retro-actively certifying software is extremely complex and can prevent UAVs that were not originally designed using the correct software qualification procedures from being certified.

Until issues relating to sense and avoid are resolved, with the necessary navigation and communication equipment on-board, the Bateleur UAV could operate in all segregated or controlled airspace once certified.

5.5.5. Stellenbosch University SLADE

The Stellenbosch University SLADE (see Appendix A-6) is an example of a purpose built UAV that has very specific applications. Because of its low weight, it could operate in the radio controlled aircraft category, provided that it complies with the radio controlled aircraft requirements, and operates in airspace segregated for radio controlled aircraft use. If it is intended for SLADE to operate for commercial gain within civil airspace, a license will be required, however as a research platform, a license is not necessary. Potential military applications for SLADE should be carried out under the authority of the military airworthiness authority within restricted military airspace such as at AFB Overberg in FAR147 airspace (See Appendix E).

5.5.6. Baird Micro Turbines HALCAT

The Baird Micro Turbines HALCAT (see Appendix A-7) is similar to the SLADE in that it is purpose built and has limited applications outside of its design. Owing to its mass, it could operate within the radio controlled aircraft category.

In addition to this, HALCAT was assembled using off the shelf radio controlled aircraft components. This illustrates the potential for radio-controlled aircraft to be used as UAVs. The off the shelf radio controlled aircraft components do not usually comply with recognised airworthiness regulations and the use of a HALCAT type UAV outside of radio controlled airspace would be extremely restricted, and could only be done with special approval from the SA CAA.

An additional consideration for the HALCAT type of UAV would be that the speeds that it is intending to operate at are outside those permitted by both the airspace and the categorization of radio controlled aircraft. The HALCAT would therefore only be permitted to operate under special authority from the SA CAA or military airworthiness authority in restricted airspace intended for the exclusive use of this specific UAV, such as at AFB Overberg in FAR147 airspace (See Appendix E).

5.6. SUMMARY

The ultimate goal of UAV certification will be to operate freely in un-segregated and segregated airspace. Rules of the air must be complied with, and it would be easier to develop technology in order to do this rather than to try to change the internationally recognized rules of the air.

Once this is achieved, a number of considerations unique to UAVs must be taken into account, such as termination and contingency planning. A number of other factors unique to UAVs must be addressed, however owing to the equivalence and transparency principles, a number of regulations and procedures can be transferred directly from manned aircraft.

Ultimately, there should be no difference between the operation of UAVs and manned aircraft except for those activities that are unique to UAVs.

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6. CONCLUSIONS & RECOMMENDATIONS

6.1. INTRODUCTION

The conclusion of this study, which includes over 3 years of research of international trends and documentation on the certification and operation of UAVs in civil airspace, is a roadmap that proposes a method of introducing UAVs into South African civil airspace using a phased approach. During the course of the study, the following contributions were made:

- Three papers were authored, and one was co-authored in local and international journals. These have subsequently been used by South African and International companies wishing to operate UAVs in South African civil airspace.
- Six presentations were made at national and international conferences where the research was presented to an international audience.
- A roadmap proposal was generated that proposes a method to integrate UAVs into South African civil airspace using a phased approach that uses existing airspace and

UAVs to do fundamental research in the mean time, and expanding the area of operations once the technology has been proven.

- Based on the recognition received from publishing papers and giving presentations, inputs regarding UAV certification and testing were requested at various governmental forums, including the UAV co-ordination committee and sub-committees.
- Areas requiring further research were identified, and proposals were made for further research to be executed.

Based on the abovementioned research, the following conclusions were made, and recommendations were proposed that would enable UAVs to operate in South African civil airspace using a phased approach:

6.2. CONCLUSIONS

In general, it is concluded that without a roadmap, the path to generating regulations and standards will be long and difficult. Lessons learned by other organizations can contribute to creating an effective roadmap, and analysing the South African strategic requirements will focus the energy of regulatory bodies and UAV developers into technologies that have the greatest potential for eventual "file and fly" operations. Extensive testing will be necessary to develop new technologies and to prove that UAVs have the potential to operate in the same airspace as manned aircraft. Because it is based on international trends and is built on existing principles, this roadmap will streamline the process of creating the processes to generate regulations and standards so that existing UAVs can satisfy existing strategic needs, and so that future UAVs with new technologies can operate on a "file and fly" basis. Further conclusions are as follows:

- The routine application of UAVs for many missions, military and civil, will become a reality around the world and in South Africa in the foreseeable future.
- No fully comprehensive UAV standard exists at present.
- UAV regulations still need to be developed in South Africa.

- Certain principles and standards that have been developed by other organizations could be used in the South African regulations so that they will be internationally recognized.
- It will probably be necessary to comply with existing radio controlled aircraft and manned aircraft regulations, and where these regulations cannot accommodate the differences between UAVs and their inhabited counterparts, new regulations will have to be created.
- Using the principle of equivalence, maintenance and training could be performed in a similar way to that of the same category of manned aircraft.
- Standards are not intended to replace regulations, but can be used as design guidelines.
- Regulations may refer to standards if a desired level of performance is required.
- Each professional body should create relevant standards for UAV equipment in their own field of expertise.
- A fully comprehensive design standard for various categories of UAVs will enable the manufacture of quality UAVs in South Africa.
- The situation of South Africa is ideally suited to allow UAV operations in areas where there is almost no risk to humans.
- South Africa has a requirement for Maritime Surveillance that can be satisfied by UAV technology.
- If South Africa takes the opportunity to use UAV technology for maritime surveillance, there is a good possibility that the technology will reach the world market at a critical time when there is a demand for UAV technology once other governments formalize their own UAV certification requirements.
- Because of the economical and leadership role that South Africa plays in SADC and the rest of the African continent, South Africa should at least become the true African Centre of Excellence in UAV Technology, strengthening its position internationally, further boosting the South African economy.

- The lack of regulations and standards should not be seen as an impediment, and it is still possible for certain UAV operations to take place with acceptable risks to humans if UAVs are used for missions such as maritime patrol, border control, search & rescue and cargo transport.
- The international trends in UAV regulations and standards have now been researched, and it should be possible to design UAVs so that these UAVs will comply with regulations and standards when they become available.
- Maritime patrol UAV operations over the sea, away from civil air traffic, could satisfy strategic requirements while posing limited risk to other airspace users until regulations and standards become available.
- Light UAVs could be used for shorter range applications, within visual range, to satisfy requirements for persistent surveillance such as over harbours and known poaching sites.
- Large UAVs such as a Medium Altitude Long Endurance (MALE) UAV would be the most suitable maritime surveillance platform for the South African environment because of range, visibility and weather requirements.
- Military airfields such as AFB Overberg are the most suitable for certain UAV operations because they can satisfy the requirements for security, can allow takeoff and landing in restricted airspace and have most of the infrastructure required for UAV operations.
- The correct mission planning will further lower the risk to human life by ground or air-to-air collisions by avoiding inhabited areas and frequently used airspace.
- Although there are few short term cost benefits that UAVs have above manned platforms, UAVs have the potential to reduce costs over the long term standardizing ground stations, and using the ground station as a simulator for training.
- The objective of UAV testing will be to prove compliance with the applicable regulations so that UAVs will eventually be permitted to 'file and fly'.
- Existing standards for testing UAVs could be used.

- Light UAVs that do not have to be certified could be tested at radio-controlled airfields provided that they comply with radio controlled aircraft regulations.
- Formal flight-testing of large UAVs and light UAVs that operate beyond visual range will be required in order to prove compliance with regulations.
- As the complexity of UAV systems increases, testing will become a significant part of UAV development and the UAV must be tested as a complete system.
- Test requirements must be defined as early as possible by first determining the measures of effectiveness and measures of performance.
- If manned aircraft regulations are used, testing of UAVs will be similar to testing of manned aircraft and the same principles could be applied.
- Testing of exotic designs with highly augmented stability and integrated systems poses unique flight test challenges that must be explored further.
- Existing flight test facilities in South Africa will be suitable for UAV testing because of the location, availability of telemetry systems and the availability of exclusive use airspace.
- Testing of UAVs is driven by factors such as cost and weather and a suitable test location should be chosen.
- Categories of aircraft are determined by the rules of the air for right of way purposes based on manoeuvrability, and UAVs should fit into these existing categories.
- Requirements for equipment on board UAVs will be determined by airspace requirements, rather than airworthiness requirements.
- The fewer the airspace requirements for on-board equipment, the more difficult it will be for UAVs to operate within this airspace.
- In order for “file and fly” operations to take place, a number of pre flight activities will be required, such as filing a flight plan and declaring contingency airfields.
- Evidence of safe UAV operations needs to be collected before UAVs will be permitted to operate over built up areas.

- Some existing UAVs might never qualify for "file and fly" operations.
- The airspace around TFDC/OTB is the most suitable for future operations of all UAVs, while airspace around Upington/Kimberley and Makhado/Hoedspruit is only suitable for certificated UAVs.
- Of the existing South African UAVs, only one has the potential to operate on a "file and fly" basis anywhere in South Africa. All other UAVs would require special concessions from the SA CAA.

6.3. RECOMMENDATIONS

It is recommended that the SA CAA and other organizations wishing to create a process for allowing UAVs to operate on a "file and fly" basis in the national airspace adopt this roadmap. It is also recommended that this roadmap be used as a reference document to co-ordinate the activities of the various role players wishing to eventually certify UAVs for "file and fly" operations. It is lastly recommended that organizations currently manufacturing UAVs or wishing to manufacture UAVs use this document to formulate their internal processes in order to create UAVs that will have the potential to fulfil the strategic requirements and in so doing, should maximize their chances of success in being permitted to operate within the national airspace, albeit only in temporarily allocated airspace. Further recommendations are as follows:

- A process for creating South African UAV certification requirements must be initiated.
- Existing principles and regulations should be used for the development of these requirements.
- A fully comprehensive design standard for various categories of UAVs should be made available for UAVs in South Africa.
- South African standards should be compiled from existing standards, but using proven UAV designs as a basis.

- Widespread technologies need to be investigated for use on UAVs in South African airspace.
- Research projects must be initiated and funded to research outstanding issues such as collision avoidance, data link integrity, continued airworthiness, ground station design/operation and operator qualifications, ground and flight testing criteria, etc.
- Regulations must be developed in parallel with the development of technology in order to eventually certify UAVs in un-segregated airspace.
- A special operating area should be created where UAVs can be utilized, without interference to or from other aircraft so that the necessary research can be executed.
- An operational and maintenance concept for UAV utilization within South Africa must be developed.
- UAV operations should not be prevented merely because of the lack of UAV dedicated regulations, and operations that do not pose a safety threat to humans in the air or on the ground should be permitted in order for research to be conducted.
- Academic research should focus on developing UAV technology for maritime patrol, border control, search & rescue and cargo transport missions in order to satisfy immediate strategic requirements.
- Airfields should be chosen where UAVs can takeoff, land and reach the operating altitude within restricted airspace, so that it will be possible for UAVs to execute D^3 missions (where manned operations are not suitable) without interfering with manned aircraft operations.
- Mission profiles should be designed and approved for regular UAV operations where there will be acceptable risk to inhabitants on the ground, or to humans in the air.
- Dedicated UAV corridors should be considered for UAV operations until suitable detect and avoid equipment becomes commercially available.
- Light UAVs should be used for persistent surveillance over harbours and known poaching sites, taking off from dedicated zones.

- Large UAVs should be used for longer range applications where necessitated by payload, could be used in areas in-between light UAV operations, and would use existing airfield infrastructure.

- The concept of operations, training and maintenance should be expanded during the research phase so as to resolve any problems before integrating UAVs into civil un-segregated airspace.

- Once the mission profiles, concept of operations, maintenance and training have been studied and proven to be safe at the test airfield, the operating area of UAVs should be expanded to un-segregated civil airspace.

- Academic institutions and research organizations that will not require their UAVs to be certified should ensure that their UAVs remain in the light category so that they can operate from radio controlled aircraft airfields.

- Appropriately qualified flight test personnel should test large UAVs at a suitable test location.

- Existing regulations and standards should be used wherever possible, and personnel with experience in operating and testing similar manned aircraft systems can significantly reduce the risks and consequently the costs associated with testing UAVs.

- UAV testing must include testing of all relevant sub-systems, including ground based systems, and must be tested as a complete system since the UAV cannot be tested as an independent air vehicle as is the case for manned aircraft.

- Measures should be taken during UAV testing in order to limit the costs associated with testing UAVs by using simulators wherever possible.

- Further development of test methods must be done in order to research the unique challenges of testing exotic designs with highly augmented stability and integrated systems.

- Correct determination and forecasting of weather must be done before flight-tests to ensure that the test UAV does not enter weather where the response of the UAV is unknown.

- Correct procedures must be followed during testing of UAVs and during emergencies experienced during UAV testing so that the correct operational procedures can be developed using experiences from flight tests.
- Correct configuration and control must be exercised, and the results of tests must be reported on correctly so that the data and reports can be used as evidence for certification which could ultimately result in 'file and fly'.
- Correct reporting of UAV incidents and accidents should be encouraged so that the correct evidence of suitability for the integration of UAVs into the national airspace can be obtained.
- Creating new categories for UAVs should be avoided since this will create a conflict with existing right of way categories.
- When designing and certifying UAVs, the type of airspace that the UAV is intending to use must be determined so that the minimum on-board equipment can be determined.
- UAVs should attempt to access highly regulated airspace (Class A) first, and later attempt to access less regulated airspace, once "detect and avoid" equipment becomes commercially available.
- Pre flight activities must be researched and developed before "file and fly" can take place, with possible pre-planned missions that include contingencies.
- Initial testing and operations should be executed from airfields next to the sea, or in uninhabited areas.
- UAVs that will not qualify for "file and fly" operations should make use of temporarily segregated airspace and special flight permits to operate as required.
- Future operations of UAVs should be planned to operate from TFDC/OTB airspace, while access to the rest of South African can be achieved within Class A airspace.
- In order for "file and fly" operations to be become a reality in South Africa, effort should be focussed on a HALE/MALE type of UAV, while existing smaller UAVs must continue to apply for special flight permits until the enabling technology is developed that will allow them into classes of airspace in which they wish to operate.

APPENDIX A: EXAMPLES OF UAVS

DENEL DYNAMICS SEEKER

Figure A-1: Denel Dynamics Seeker[i]

Table A-1: Denel Dynamics Seeker Table of Specifications

Denel Dynamics Seeker[ii,iii,iv]	
Mass	240 kg
Endurance	10 hours
Controllable Range	250 km
Cruise Speed	176 km/h
Service Ceiling	18000 ft
Payload	50 kg
Takeoff Method	Conventional

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i. Online: http://www.global-defence.com/2000/pages/kentron.html
ii. *Complete Guide: Drones*, Armada International, Issue 3, Zurich, 2006
iii. *Complete Guide: Drones*, Armada International, Issue 5, Zurich, 2001
iv. MEREDITH, A.P., *The Utilisation of Unmanned Aerial Vehicles in the Role of Long Range Maritime Patrol Aircraft*, APM/AMS/UAV/RES/01, Pretoria, 2007

ATE VULTURE

Figure A-2: ATE Vulture UAV[v]

Table A-2: ATE Vulture UAV Table of Specifications

ATE Vulture UAV[vi,vii,viii]	
Mass	125 kg
Endurance	3 hr
Controllable Range	200km
Cruise Speed	161 km/h
Service Ceiling	16000 ft
Payload	*****
Takeoff Method	Catapult/Parachute

v. Online: http://commentary.co.za/archives/2006/08/14/vultures-take-flight/
vi. *Complete Guide: Drones*, Armada International, Issue 3, Zurich, 2006
vii. *Complete Guide: Drones*, Armada International, Issue 5, Zurich, 2001
viii. MEREDITH, A.P., *The Utilisation of Unmanned Aerial Vehicles in the Role of Long Range Maritime Patrol Aircraft*, APM/AMS/UAV/RES/01, Pretoria, 2007

DENEL DYNAMICS SKUA

Figure A-3: Denel Dynamics Skua[ix]

Table A-3: Denel Dynamics Skua Table of Specifications

Denel Dynamics Skua[x]	
Mass	*****
Endurance	85min
Controllable Range	200 km (line of sight)
Cruise Speed	M0.85
Service Ceiling	12000m
Payload	80kg (140kg external)
Takeoff Method	Catapult/Parachute

ix. Online: http://www.global-defence.com/2003/kentron_03.htm
x. *Skua High Speed Target Drone*, Denel Brochure: Broc0144.

DENEL DYNAMICS BATELEUR

Figure A-4: Denel Dynamics Bateleur[xi]

Table A-4: Denel Dynamics Bateleur Table of Specifications

Denel Dynamics Bateleur[xii,xiii]	
Mass	1400kg
Endurance	24 hr
Controllable Range	1890 NM (estimated)
Cruise Speed	135 knots (estimated)
Service Ceiling	25000ft
Payload	500kg
Takeoff Method	Conventional

xi. Online: http://navy.org.za/pages/denel-uav

xii. MEREDITH, A.P., *The Utilisation of Unmanned Aerial Vehicles in the Role of Long Range Maritime Patrol Aircraft*, APM/AMS/UAV/RES/01, Pretoria, 2007

xiii. LYNN, M., *The DENEL Aerospace Systems Bateleur Male UAV*, Ad Astra Magazine, 4th edition, 2007

STELLENBOSCH UNIVERSITY SLADE

Figure A-5: Stellenbosch University SLADE

Table A-5: Stellenbosch University SLADE Table of Specifications

Stellenbosch University SLADE	
Mass	15 kg
Endurance	10 min
Controllable Range	5000 m
Cruise Speed	40 km/h
Service Ceiling	500 ft AGL (Sea Level)
Payload	5 kg
Takeoff Method	VTOL

BAIRD MICRO TURBINES HALCAT

Figure A-6: Baird Micro Turbines HALCAT

Table A-6: Baird Micro Turbines HALCAT Table of Specifications

Baird Micro Turbines HALCAT[xiv]	
Mass	60 kg (estimated)
Endurance	30 min (estimated)
Controllable Range	1km LOS (Takeoff & Landing) – Autonomous Flight (Unlimited)
Cruise Speed	500km/h (estimated)
Service Ceiling	10000 ft
Payload	30kg including fuel
Takeoff Method	Conventional

xiv. Since permission was not obtained to publish data on this specific UAV, it is being used only as an example of this type of UAV. The specifications are estimated only as an illustration to be used as a case study.

BOEING GLOBAL HAWK

Figure A-7: Lester Ingham with Global Hawk (Edwards AFB - 1998)

Table A-7: Boeing Global Hawk Table of Specifications

Boeing Global Hawk[xv]	
Mass	25600 lb (empty)
Endurance	42 hours
Controllable Range	14000nm
Cruise Speed	454 mph
Service Ceiling	65000 ft
Payload	1900 lb
Takeoff Method	Conventional

xv. http://www.airforce-technology.com/projects/global/specs.html

APPENDIX B: TEST HAZARD ANALYSIS EXAMPLE

TEST HAZARD ANALYSIS

TEST HAZARD ANALYSIS WORKSHEET[i,ii,iii]

TEST TITLE:
FOR UAV DEMONSTRATOR

AIRCRAFT/SYSTEM:
SLADE

SUBJECTIVE PROBABILITY OF OCCURRENCE

Hazard Category	frequent	probable	uncertain	remote	improbable
catastrophic		*HIGH*			
critical					
marginal			*MEDIUM*	X	
negligible					*LOW*

HAZARD:
Loss of Control of UAV

CAUSE:
Loss of radio signal
Loss of control by operator

EFFECT:
Crash
Fire

MINIMISING PROCEDURES:
Remain within safety footprint
Monitor trajectory of the UAV at all times

EMERGENCY PROCEDURES:
When leaving safety footprint: Deploy parachute.

PREPARED BY	SIGNATURE	DATE
L. Ingham		

Risk Level (after minimizing procedures taken into account)

High Medium Low X

Figure B-1: Example of a Test Hazard Analysis

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i. *Flying Qualities Flight Testing*, National Test Pilot School, 1st Edition, Mojave, 1997.
ii. *Rotary Wing Stability and Control*, Empire Test Pilot School. Boscombe Down, 1993.
iii. WEIBEL, R. E., AND HANSMAN JR, R., *Safety Considerations for Operation of Different Classes of UAVs in the NAS*, MIT International Center for Air Transportation, ICAT-2005-1, Massachusetts, 2004.

APPENDIX C: PROPOSED UAV ROADMAP DIAGRAM

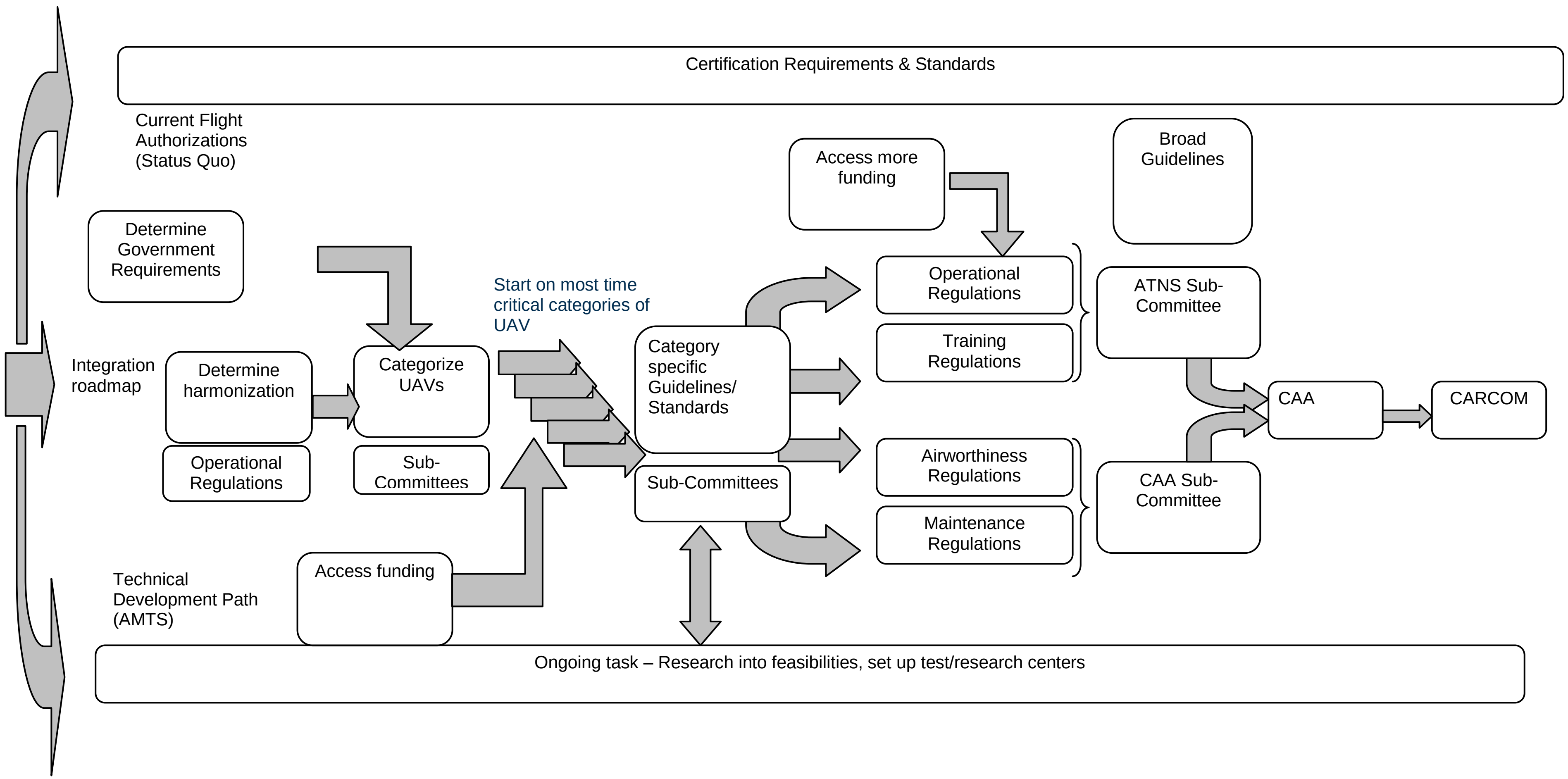

Figure C-1: UAV Roadmap[i]

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i. *Progress Report of the National Unmanned Aerial Systems Policy Co-ordination Committee (NUASP Co-com)*, 2007.

APPENDIX D: PROCESS USED BY DENEL DYNAMICS FOR FLYING SEEKER 1 IN SOUTH AFRICAN AIRSPACE

PROCESS FOLLOWED FOR FLYING SEEKER 1 SYSTEM IN RSA AIRSPACE

1. Present safety case for airworthiness to fly over build-up areas to the then Military Aviation Board (MAB).

2. Implement recommendations by MAB e.g. dual elevator control and get formal authority to fly.

3. Applied for "Authority to Fly" to CAA by:

    - Applying for the registration of UAVs as "ex military" aircraft in terms of Part 24.01.2.D1.after presenting MAB authority.
    - Mark UAVs in terms of requirements.
    - Presenting proof of crew proficiencies in terms of approved training policy.
    - Presenting prove of "Certificate of Insurance" to cover any 3rd party losses.
    - Present information in terms of Annex A to Form CAR 47A for special flight permit plus mass and balance sheet results for each registered UAV.
    - Present overall Flight Safety Plan.

4. Received "Private Operation Authority to Fly" for a specified period and specific restrictions in terms of Part 24.02.03.

5. Applied for specific operational deployments by:

    - Presenting operational deployment plan.
    - Presenting Flight Specification.
    - Presenting Flight Test Instruction.
    - Presenting specific Safety Plan.

6. During this whole process we also submitted the required Operations Manual and AMO Manual of Procedure in an effort to utilize the UAV for commercial applications.

APPENDIX E: AEROSPACE MAPS

Figure E-1: Cape Town/Overberg Airspace[i]

i. *World Aeronautical Chart: Cape Town (3422)*, Chief Directorate Surveys and Land Information, Third Edition, Cape Town, 1995.

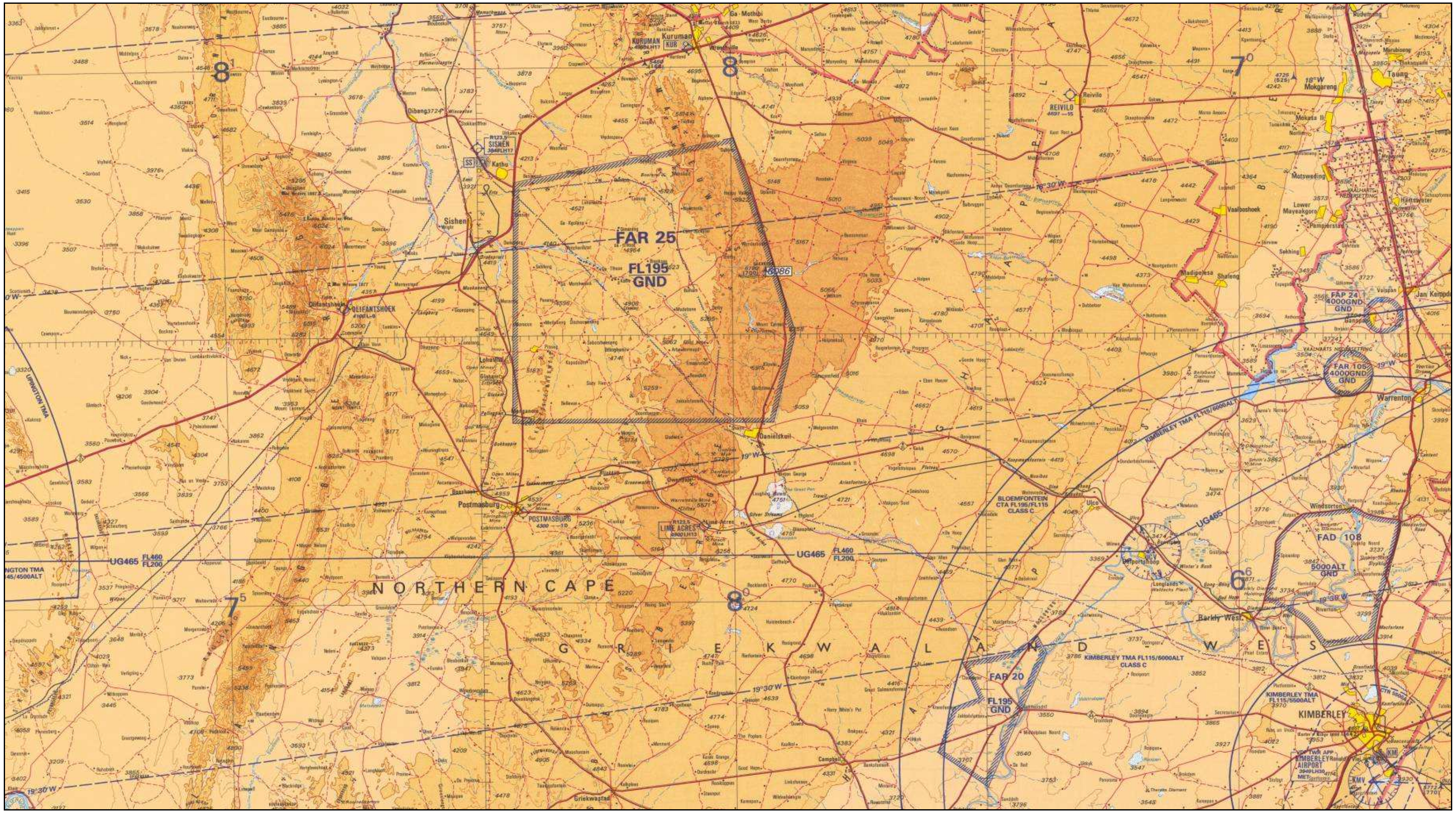

Figure E-2: Upington/Kimberley Airspace[ii]

ii. *World Aeronautical Chart: Kimberley (2722)*, Chief Directorate Surveys and Land Information, Third Edition, Cape Town, 1995.

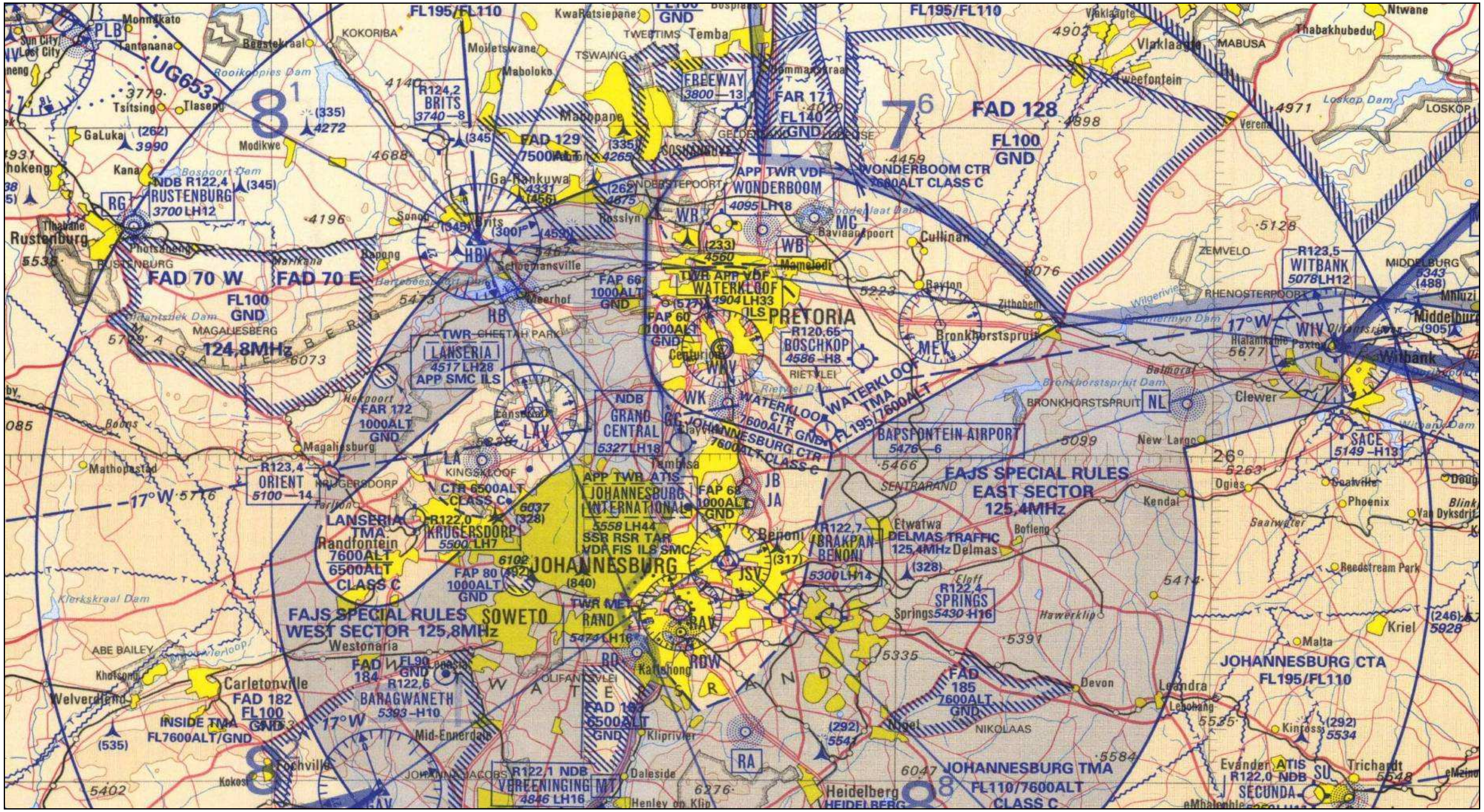

Figure E-3: Johannesburg Airspace[iii]

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iii. *World Aeronautical Chart: Johannesburg (3300)*, Chief Directorate Surveys and Land Information, Fifth Edition, Cape Town, 1998.

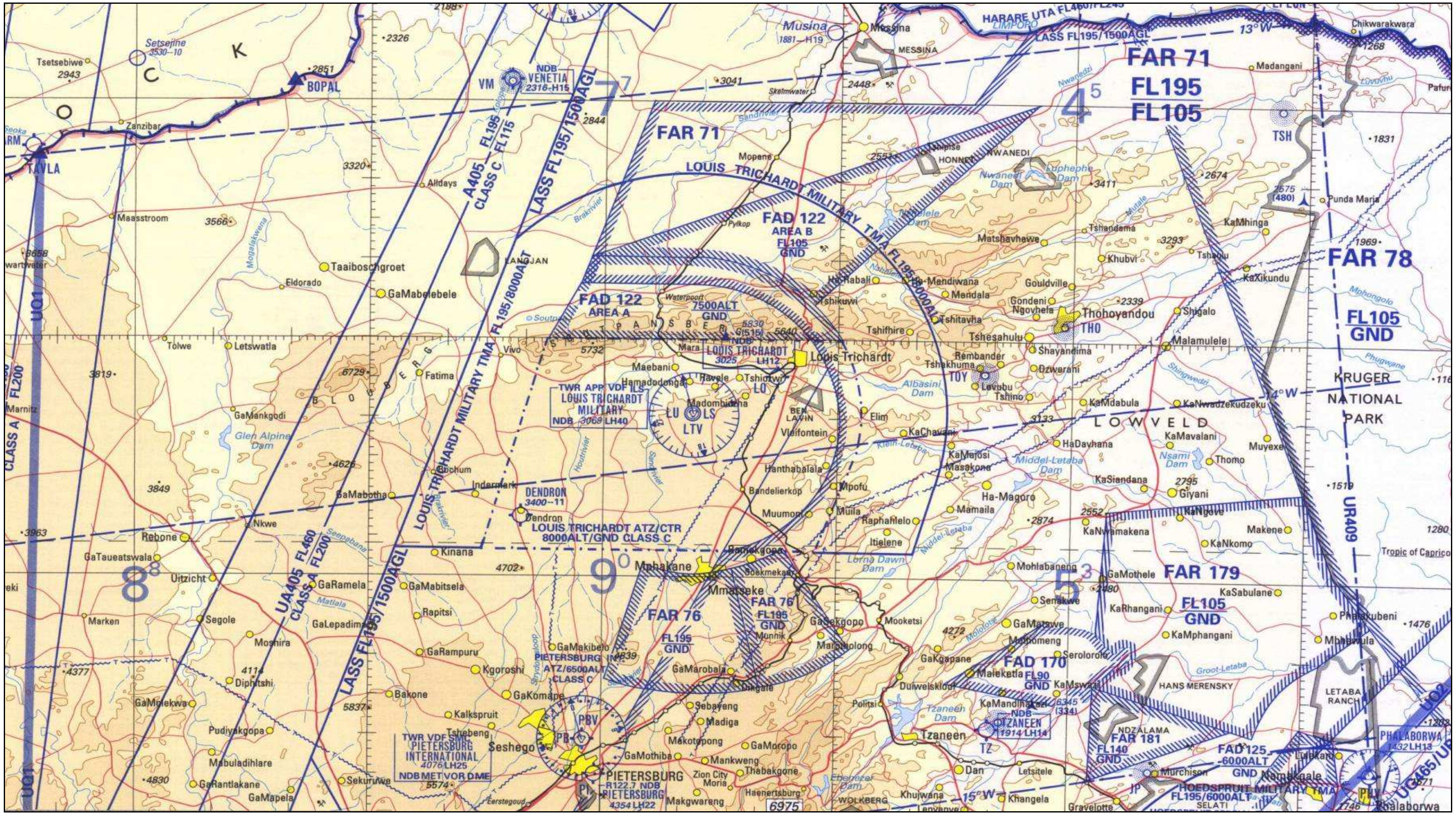

Figure E-4: Makhado Airspace (Louis Trichardt)[iv]

iv. *World Aeronautical Chart: Bulawayo (3275)*, Chief Directorate Surveys and Land Information, Fourth Edition, Cape Town, 1996.

APPENDIX F: CLASSES OF AIRSPACE

DESIGNATION OF AIRSPACE ADOPTED BY ICAO[i]:

Classes of airspace designated by ICAO is as follows:

Class A

All operations must be conducted under Instrument Flight Rules (IFR) or Special Visual Flight Rules(SVFR) and are subject to ATC clearance. All flights are separated from each other by ATC.

Class B

Operations may be conducted under IFR, SVFR, or Visual Flight Rules (VFR). All aircraft are subject to ATC clearance. All flights are separated from each other by ATC.

Class C

Operations may be conducted under IFR, SVFR, or VFR. All flights are subject to ATC clearance. Aircraft operating under IFR and SVFR are separated from each other and from flights operating under VFR. Flights operating under VFR are given traffic information in respect of other VFR flights.

Class D

Operations may be conducted under IFR, SVFR, or VFR. IFR aircraft are subject to ATC clearance. VFR aircraft require radio contact prior to entering airspace (Not to be confused with ATC clearance). Aircraft operating under IFR and SVFR are separated from each other, and are given traffic information in respect of VFR flights. Flights operating under VFR are given traffic information in respect of all other flights.

Class E

Operations may be conducted under IFR, SVFR, or VFR. Aircraft operating under IFR and SVFR are separated from each other, and are subject to ATC clearance. Flights

i. Extracted from: http://en.wikipedia.org/wiki/Airspace_class under VFR are not subject to ATC clearance. As far as is practical, traffic information is given to all flights in respect of VFR flights.

Class F

Operations may be conducted under IFR or VFR. ATC separation will be provided, so far as practical, to aircraft operating under IFR. Traffic Information may be given as far as is practical in respect of other flights.

Class G

Operations may be conducted under IFR or VFR. ATC separation is not provided. Traffic Information may be given as far as is practical in respect of other flights.

Classes A to E are referred to as controlled airspace. Classes F and G are uncontrolled airspace.

Separation: Maintaining a specific minimum distance between an aircraft and another aircraft or terrain to avoid collisions, normally by requiring aircraft to fly at set levels or level bands, on set routes or in certain directions, or by controlling an aircraft's speed.

Clearance: Permission given by ATC for an aircraft to proceed under certain conditions contained within the clearance.

Traffic Information: Information given by ATC on the position and, if known, intentions of other aircraft likely to pose a hazard to flight.

As of 2004, ICAO is considering a proposal to reduce the number of airspace classifications to three, which roughly correspond to the current classes C, E and G.

DESIGNATION OF CONTROLLED AIRSPACE IN THE UNITED STATES

The designation of airspace classes in the United States is as follows (See Figure F-1 and Table F-1):

Class A

Generally, that airspace from 18,000 feet MSL up to and including FL600, including the airspace overlying the waters within 12 nautical miles of the coast of the 48 contiguous States and Alaska. Unless otherwise authorized, all persons must operate their aircraft under IFR.

Class B

Generally, that airspace from the surface to 10,000 feet MSL surrounding the nation's busiest airports in terms of IFR operations or passenger enplanements. The configuration of each Class B airspace area is individually tailored and consists of a surface area and two or more layers (some Class B airspace areas resemble upside-down wedding cakes), and is designed to contain all published instrument procedures once an aircraft enters the airspace. An ATC clearance is required for all aircraft to operate in the area, and all aircraft that are so cleared receive separation services within the airspace. The cloud clearance requirement for VFR operations is "clear of clouds."

Class C

Generally that airspace from the surface to 4,000 feet above the airport elevation (charted in MSQ surrounding those airports that have an operational control tower, are serviced by a radar approach control, and that have a certain number of IFR operations or passenger enplanements. Although the configuration of each Class C airspace area is individually tailored, the airspace usually consists of a surface area with a 5NM radius, and an outer circle with a 1 ONM radius that extends from 1,200 feet to 4,000 feet above the airport elevation. Each person must establish two-way radio communications with the ATC facility providing air traffic services prior to entering the airspace and thereafter maintain those communications while within the airspace. VFR aircraft are only separated from IFR aircraft within the airspace.

Class D

Generally, that airspace from the surface to 2,500 feet above the airport elevation (charted in MSQ surrounding those airports that have an operational control tower. The configuration of each Class D airspace area is individually tailored and when instrument procedures are published, the airspace will normally be designed to contain the procedures. Arrival extensions for instrument approach procedures may be Class D or Class E airspace. Unless otherwise authorized, each person must establish two-way radio communications with the ATC facility providing air traffic services prior to entering the airspace and thereafter maintain those communications while in the airspace. No separation services are provided to VFR aircraft.

Class E

Generally, if the airspace is not Class A, Class B, Class C, or Class D, and it is controlled airspace, it is Class E airspace. Class E airspace extends upward from either the surface or a designated altitude to the overlying or adjacent controlled airspace. When designated as a surface area, the airspace will be configured to contain all instrument procedures. Also in this class are Federal airways, airspace beginning at either 700 or 1,200 feet AGIL used to transition to/from the terminal or en-route environment, en-route domestic, and offshore airspace areas designated below 18,000 feet MSL. Unless designated at a lower altitude, Class E airspace begins at 14,500 MSL over the United States, including that airspace overlying the waters within 12 nautical miles of the coast of the 48 contiguous States and Alaska. Class E airspace does not include the airspace 18,000 MSL or above.

Class G

(Uncontrolled airspace) Airspace not designated as Class A, B, C, D, or E.

Controlled Airspace - Airspace of defined dimensions within which air traffic control service is provided to I FR flights and to VFR flights in accordance with the airspace classification.

Note 1 - *Controlled airspace* is a generic term that covers Class A, Class B, Class C, Class D, and Class E airspace.

> **Note 2** - Controlled airspace is also that airspace within which all aircraft operators are subject to certain pilot qualifications, operating rules, and equipment requirements in FAR Part 91 (for specific operating requirements, please refer to FAR Part 91). For IFR operations in any class of controlled airspace, a pilot must file an IFR flight plan and receive an appropriate ATC clearance. Each Class B, Class C, and Class D airspace area designated for an airport contains at least one primary airport around which the airspace is designated (for specific designations and descriptions of the airspace classes, please refer to FAR Part 71).

Service - A generic term that designates functions or assistance available from or rendered by air traffic control. For example, Class C service would denote the ATC services provided within a Class C airspace area.

Special VFR Operations - Aircraft operating in accordance with clearances in Class B, C, D, or E surface areas in weather conditions less than the basic VFR weather minimum. Such operations must be requested by the pilot and approved by ATC.

Surface Area - The airspace contained by the lateral boundary of the Class B, C, D, or E airspace designated for an airport that begins at the surface and extends upward.

Terminal VFR Radar Service - A national program instituted to extend the terminal radar services provided to instrument flight rules (IFR) aircraft to visual flight rules (VFR) aircraft. The program is divided into four types of service referred to as basic radar service, terminal radar service area (TRSA) service, Class B service and Class C service. The type of service provided at a particular location is contained in the Airport/Facility Directory.

Basic Radar Service - These services are provided for VFR aircraft by all commissioned terminal radar facilities. Basic radar service includes safety alerts, traffic advisories, limited radar vectoring when requested by the pilot, and sequencing at locations where procedures have been established for this purpose and/or when covered by a letter of agreement. The purpose of this service is to adjust the flow of arriving IFR and VFR aircraft into the traffic pattern in a safe and orderly manner and to provide traffic advisories to departing VFR aircraft.

TRSA Service

This service provides, in addition to basic radar service, sequencing of all IFR and participating VFR aircraft to the primary airport and separation between all participating VFR aircraft. The purpose of this service is to provide separation between all participating VFR aircraft and all IFR aircraft operating within the area defined as a TRSA.

Class C Service

This service provides, in addition to basic radar service, approved separation between IFR and VFR aircraft, and sequencing of VFR arrivals to the primary airport.

Class B Service

This service provides, in addition to basic radar service, approved separation of aircraft based on IFR, VFR, and/or weight, and sequencing of VFR arrivals to the primary airport(s).

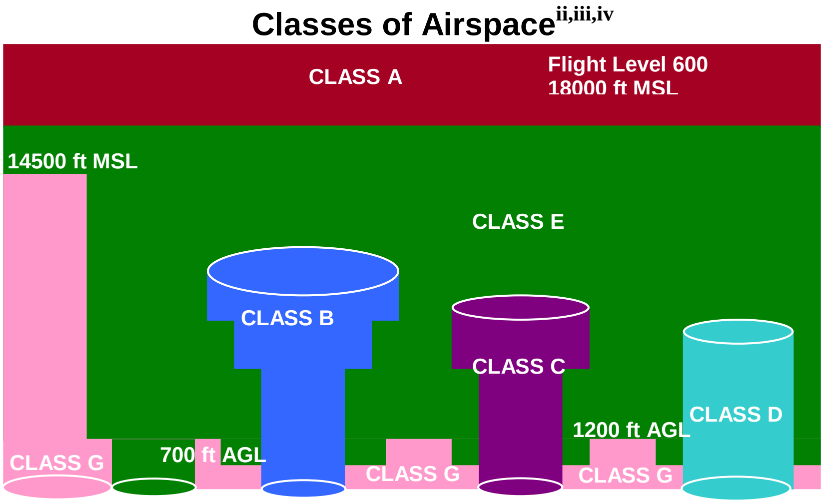

Figure F-1: Diagram of Classes of Airspace

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ii. Extracted from: http://en.wikipedia.org/wiki/Airspace_class_(United_States)

iii. Extracted from: http://www.atlasaviation.com/AviationLibrary/usairspaceclasses/usairspaceclasses.htm

iv. WEIBEL, R. E., AND HANSMAN JR, R., *Safety Considerations for Operation of Different Classes of UAVs in the NAS*, MIT International Center for Air Transportation, ICAT-2005-1, Massachusetts, 2004.

Table F-1: Classes of Airspace

Classes of Airspace[v,vi,vii]						
Airspace Features	Class A	Class B	Class C	Class D	Class E	Class G
Entry Requirement	ATC Clearance	ATC Clearance	Prior two Way Communi-cations	Prior Two Way Communi-cations	None	None
Minimum Pilot Qualification	Instrument Rating	Private or Student Certificate Location Dependant	Student Certificate	Student Certificate	Student Certificate	Student Certificate
Two Way Radio Communi-cations	Yes	Yes	Yes	Yes	Not Required	Not Required
Special VFR Allowed*	No	Yes	Yes	Yes	Yes	Yes
VFR Visibility Minimum	N/A	3 Statute Miles**	3 Statute Miles**	3 Statute Miles**	3 Statute Miles**	1 Statute Mile**
VFR Minimum Distance From Clouds	N/A	Clear of Clouds	500 feet below, 1000 feet above, 2000 feet horizon-tally**	500 feet below, 1000 feet above, 2000 feet horizon-tally**	500 feet below, 1000 feet above, 2000 feet horizon-tally**	Clear of Clouds **
VFR Aircraft Separation	N/A	All	IFR	Runway Operations	None	None
Traffic Advisories	Yes	Yes	Yes	Workload Permitting	Workload Permitting	Workload Permitting
Former Airspace Equivalent	Positive Control Area (PCA)	Terminal Control Area (TMA/TCA)	Airport Radar Service Area (ARSA)	Airport Traffic Area and Control Zone	General Controlled Airspace	Uncontrolle d Airspace

*** Authorized by an ATC clearance and conducted within the lateral boundaries of the surface area.**

**** Flight visibility and cloud clearance requirements differ for operations below 1,200 feet AGL, above 1,200 feet AGL but below 10,000 feet MSL, above 10,000 feet MSL, day, night, or student pilot. See FARs 61.89 and 91.155 for specifics.**

NOTE: IFR operations in controlled airspace require filing an IFR flight plan and an appropriate ATC clearance.

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v. Extracted from: http://en.wikipedia.org/wiki/Airspace_class_(United_States)
vi. Extracted from: http://www.atlasaviation.com/AviationLibrary/usairspaceclasses/usairspaceclasses.htm
vii. WEIBEL, R. E., AND HANSMAN JR, R., *Safety Considerations for Operation of Different Classes of UAVs in the NAS*, MIT International Center for Air Transportation, ICAT-2005-1, Massachusetts, 2004.

DESIGNATION OF CONTROLLED AIRSPACE IN SOUTH AFRICA

Controlled airspace in **South Africa** is similar to that of the USA, but only uses the following airspace classes:

Only classes A, C, F & G are used in South Africa.

Within class F Airspace, radio communication is required for VFR flight.