Considerations for UAV design and operation in South African airspace

L. A. Ingham, T. Jones and A. Maneschijn
Faculty of Engineering
Stellenbosch University
South Africa

ABSTRACT

At present, the lack of UAV regulations and standards precludes UAVs from being certified to operate commercially in un-segregated civilian airspace. Because of strategic, economical and security requirements, it is necessary to devise a method to operate UAVs in South African airspace within existing regulatory arrangements. This paper suggests specific UAV missions, *viz*; maritime patrol/boarder control, search and rescue, and cargo transport, together with design considerations and possible concepts of UAV; operations, maintenance and training, that will enable UAVs to satisfy the immediate South African strategic requirements whilst further UAV standards and regulations are being developed.

ABBREVIATIONS

AFB	air force base
AGL	above ground level
ATC	air traffic controller
BIT	built in test
CI	critical issue
D^3	dull, dirty and dangerous
EEZ	exclusive economic zone
FAR	Federal Aviation Regulation
FAR?	restricted airspace
HALE	high altitude long endurance
Hp	pressure altitude
IFR	instrument flight rules
KIAS	knots indicated air speed
MALE	medium altitude long endurance
MOE	measure of effectiveness
MOP	measure of performance
RTCA	Radio Technical Commission for Aeronautics
TFDC	Test Flight and Development Centre
UAV	unmanned aerial vehicle
USA	United States of America

TERMINOLOGY

Airworthiness:	a physical state that deems an 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)[1,2].
Light UAV:	generally used in this paper to describe any UAV lighter than 150kg (<95KJ impact energy)[1,2].
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[3].
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[4].
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[5].

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1.0 INTRODUCTION

1.1 Design requirements

Classical system engineering principles[6] as well as lessons learned in the USA[7] indicate it is essential for UAV functional and mission requirements to be determined before developing a new UAV. It is therefore necessary for research to be done in South Africa so that the strategic requirements as well as the UAV regulatory requirements can be determined. By doing this it will be possible for future UAV designs to satisfy the strategic requirements as well as the regulatory 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.

1.2 Regulatory requirements

One of the challenges facing unmanned air vehicle (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[8].

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 should 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[2].

Considerable work has been done by many organisations:

Eurocontrol has proposed equivalence, fairness, accountability/responsibility and transparency as guiding principles when deriving UAV regulations. It was suggested that South Africa could adopt similar principles[2].

In the USA, the Access 5 initiative[9] proposed a method of allowing UAVs into the national airspace in four steps. Preference was given to high altitude long endurance (HALE) UAVs by allowing them access to airspace exceeding that of most manned aircraft[10] and commercial traffic, and to gradually lower the UAV operating altitude. Eventually when the operating altitude was to be lowered, other UAVs would have enjoyed the same freedom as HALE UAVs.

Australia has published regulations, but these regulations do not address system specifications[11].

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[1,2] e.g. light aircraft, balloon, helicopter etc.

Although UAVs could be arbitrarily divided into a number of different sub-categories, in order to allow more flexibility for academic research UAVs, the development of experimental UAVs, and the operation of UAVs that will not pose a threat to people on the ground, special provision has been made by some authorities[1,11] for light UAVs under 150kg (95KJ) provided that they operate with similar restrictions to radio controlled aircraft e.g. daylight operations within visual range of the pilot in segregated airspace below 120m (400ft) AGL[1,11].

It has been proposed that a similar approach for light UAVs could be adopted by the South African authorities[2]. It was also proposed that large UAVs heavier than 150kg (95kg), or light UAVs that will operate outside the regulations for radio controlled aircraft, should be required to comply with equivalent manned aircraft regulations[2].

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[1,9]. 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[2].

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[9] — should also be different to other countries. It will not be necessary to operate at extremely high altitudes to avoid commercial traffic, and if the strategic requirements for maritime patrol/boarder 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/boarder control and search and rescue operations can be transferred to operations over land.

The South African approach could therefore be similar to Access 5, but instead of operating above commercial traffic, and gradually lowering the operating altitude, South Africa could operate UAVs in areas where there is literally no air traffic, and gradually expand this airspace towards more frequently used airspace.

1.3 Strategic requirements

Incidents of piracy have been recorded along both the Eastern (e.g. Somalia) and Western (e.g. Nigeria) African coastlines. 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. 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. 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[16].

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

UAVs can provide the platform for the dull, dirty and dangerous missions (D^3)[2,12] and tasks required and for surveillance of the vast uninhabitable areas of South Africa[2].

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.

Owing to its possibility of complying with most existing regulations, maritime patrol/boarder control, search and rescue, and cargo transport UAVs have been proposed[2] 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/boarder control and search and rescue UAVs should be considered as part of the national and international obligation for South Africa to defend its boarders up to the exclusive economic zone (EEZ). 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.

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[2]. 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.

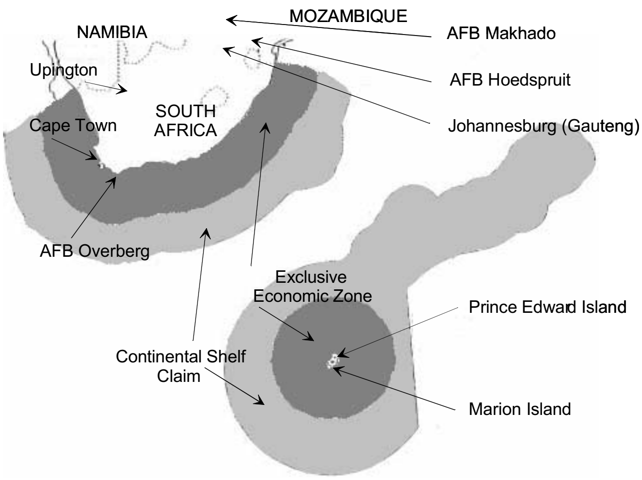

Figure 1. South African exclusive economic zone.

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

This document will continue to focus on the requirements for maritime patrol/boarder control, search and rescue, and cargo transport UAV design and operation.

2.0 UAV OPERATIONAL CONSIDERATIONS

2.1 Operating area

Figure 1 illustrates the South African EEZ[13], 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.

The two leading concerns in UAV operations with regard to public safety are mid air collisions with other aircraft and ground impact[10]. Potential UAV air transportation routes that would minimise 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 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.

2.2 Environment

The South African Air Force has been conducting maritime patrol operations for a number of years and much can be learned from these operations.

The operating altitude will be between sea level and the height required by the sensors to have the necessary coverage, as well as for the communications link to have sufficient range.

Although weather conditions, e.g. wind, would restrict the platform, the restrictions on the sensors, e.g. visibility in cloud, would probably impose more severe limitations on the platform.

Owing to flight control automation, the UAV pilot could essentially fly the UAV in instrument conditions at all times making operations at night similar to day time operations.

Because larger aircraft usually have a greater tolerance for weather and have longer endurance, larger platforms would therefore be preferable for persistent maritime patrol.

2.3 Security

In order to prevent UAVs from becoming targets of terrorists and groups with similar intentions, it will be necessary to control UAVs from a secure location[1,2]. 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, the UAV operations for maritime patrol will be executed in the interest of national security, and the necessary authority should be granted.

2.4 Available infrastructure

Initially operating from a segregated or restricted airfield 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[1]. In order to satisfy the security requirements[2], air force bases will be preferred.

The Test Flight and Development Centre (TFDC) located at Air Force Base (AFB) Overberg at the southern tip of Africa (see Fig. 1) would be ideally suited for maritime UAV operations. As well as being restricted (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, making support of UAVs feasible. The 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 Fig. 1), situated next to the Gariep river (Orange river), is situated in the centre of the Northern Cape and has been 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 Fig. 1) 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 which does classify as a D^3 type of mission.

2.5 UAV launch and recovery platform

Most light UAV systems require a dedicated 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

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the coast in order to cover the long ranges. Operation from movable platforms such as ships would however present some advantages for light UAVs over large UAVs, but these operations would in turn be restricted by the availability and location of the platform or ship.

Because of the lower weight, light UAVs should not require certification, but would then not be permitted outside visual range or within un-segregated airspace. If it will only be necessary for light UAVs to comply with radio controlled aircraft regulations[1,11], the advantage will be that the maintenance procedures, air traffic controller (ATC) etc. 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[1,2,11]. Light UAVs will therefore 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 takeoff and landing zones, and possibly at manned aircraft airfields. Large UAVs will also be the most suitable for maritime surveillance in South Africa because of their long range and endurance but will require civil certification if they should wish to operate on a 'file and fly' basis in un-segregated airspace[1,2,11,14].

2.6 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 of 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 experimental airfields. This will allow the necessary time for South African UAV manufacturers to collect evidence in order to prove equivalence of safety[1].

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.

2.7 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[10].

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.

2.8 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[10].

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[1], 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, so that UAV missions can be accomplished with minimal risk of collision with manned aircraft.

2.9 Airfield operations

In order for the UAV to be transparent to manned airfield operations[1], it will be necessary for the UAV to be operated in a similar manner as 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[1], it will be necessary for the UAV to vacate the active runway after landing without additional ground support.

2.10 Flight authorisation

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 authorisation every time they fly, 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. Once the testing of UAVs has been proven that UAVs can operate safely, including airfield operations, the airspace should be opened further to allow UAV operations outside the restricted airspace. 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[15].

2.11 Flight termination

UAV flight termination has the potential to significantly reduce human fatalities during impact, thereby lowering the hazard and lowering the risk[10]. 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 are 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 minimise the risk to the inhabitants on the ground.

2.12 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[16], 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.

2.13 Ground station design and operation

One of the benefits of UAVs over manned aircraft is that one ground station can replace several manned aircraft cockpits. Furthermore, the same ground station design could be used for many different types of UAVs. There is also other evidence that suggests that ground station designs should be standardised[7,18]. The standardisation will simplify the certification requirements of many future UAVs. The ground station must be designed in order to comply with the security and certification requirements, and could then be used for the operation of all 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 license, and only require bridging training for each type of UAV.

3.0 UAV MISSION CONSIDERATIONS

3.1 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[2]') 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[18] increases because more contingencies will have to be pre-planned.

In order to minimise 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.

Simplified mission profile diagrams have been used to illustrate some of the missions that are discussed further in more detail:

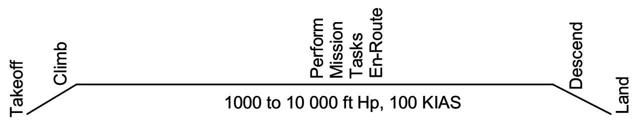

Figure 2. In-shore maritime patrol mission profile.

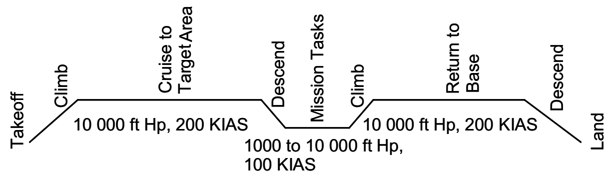

Figure 3. Long range maritime patrol mission profile.

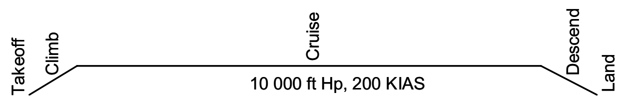

Figure 4. Cargo transport mission profile.

3.2 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 Fig. 2. The purpose of this mission would be to monitor fishing activities along the South African coast line. For this reason, the UAV would be required to operate at lower altitudes in order for the imaging sensors to monitor the fishing activities.

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 e.g. weather conditions, payload, range etc. requirements 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[16] could also use a similar mission profile in certain areas.)

3.3 Long range maritime patrol and search and rescue mission

The long range maritime patrol mission would require the UAV to operate over the sea over long distance with the purpose of monitoring the major shipping traffic in order to provide intelligence on shipping activities as illustrated in Fig. 3. A further requirement will be to fly to remote fishing areas and perform in-shore maritime patrol e.g. Marion Island (Fig 1). A similar mission profile would also be applicable for maritime search and rescue.

Because of equipment requirements for longer range data communications e.g. satellite, 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 utilised for this mission, but will enable the operation of large UAVs from fewer base stations.

3.4 Cargo transport mission

The cargo transport mission profile as illustrated in Fig. 4 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.

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.

4.0 UAV MAINTENANCE CONSIDERATIONS

4.1 General maintenance

Maintenance is a fundamental part of the system engineering design process[6]. This necessitates that UAV maintenance must be done together with the air vehicle design. To comply with sound system engineering practices, UAVs will need to be designed with consideration of the functional requirements[6], which in the case of UAVs will be the requirement to comply with relevant regulations and standards.

The lack of applicable UAV standards at present, and the principle of equivalence[1] 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.

4.2 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 centralised 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[1].

4.3 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.

4.4 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[1].

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

It will be beneficial if UAVs use similar consumables to that of manned aircraft. Operating from most military airfields will necessitate the use of kerosene rather than Avgas. The use of kerosene will however 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 not be essential, but will enhance the operations of especially large long range UAVs.

5.0 UAV TRAINING CONSIDERATIONS

5.1 Accident related costs

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[7,8]. Indeed, many of these accidents occurred during takeoff or landing with the human pilot in control[17]. When modifications to aircraft were made and training procedures were modified, the accident rate did not decrease[7]. With the human out of the loop, UAV mishap rates can be decreased and after each mishap by implementing corrective action 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.

5.2 Aircrew training and qualifications

In order to comply with the principles of responsibility and transparency[1], 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[18,19]. 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.

5.3 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[2,7] and that ground stations could double as simulators, eliminating the need to design and manufacture separate simulators for training[7] especially during the initial phases of UAV development.

Once UAVs 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 human losses during training.

5.4 Maintenance personnel training and qualifications

Because of equivalence requirements[1], 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.

6.0 ADDITIONAL CONSIDERATIONS

6.1 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[18,20]. Further studies of this field should be done whilst conducting the proposed research.

6.2 Airworthiness, registration, identification and certification

Because of the principles of fairness, equivalence and transparency[1], 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.

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6.3 Test and evaluation

Critical issues (CI), measures of effectiveness (MOE) and measures of performance (MOP) required for test and evaluation[16,21] must also include the regulatory constraints associated with the design and operation of the UAV so that it can be determined if the newly designed UAV did indeed satisfy the original regulatory and strategic requirements.

7.0 CONCLUSIONS

- 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, boarder control, search & rescue and cargo transport.
- If the international trends in UAV regulations and standards are researched, it could be possible to design UAVs so that the 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 requirements 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.
- UAV operations have the potential to reduce costs over the long term in comparison to manned operations, e.g. by using the same ground station for operations, and as a simulator for training.
- Using the principle of equivalence, maintenance and training will have to be performed in a similar same way to that of the same category of manned aircraft.

8.0 RECOMMENDATIONS

- It is recommended that 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, boarder control, search and rescue and cargo transport missions 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, and 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.

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