Human Factors Implications of RPA Flight in Non-Segregated Airspace

A Use Case based Methodology applied to Military RPA operators

Customer

NATO FINAS

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EXECUTIVE SUMMARY

Human Factors Implications of RPA Flight in Non-Segregated Airspace

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Safety-related and legislative issues are now preventing effective use of NATO Remotely Piloted Aircraft Systems (RPAS) to operate within other member states' airspace. NATO guidelines to allow the cross-border operation of Remotely Piloted Aircraft (RPA) in non-segregated airspace are therefore needed. As part of this effort to develop these guidelines, a method is needed to 'diagnose' Human-System Integration (HSI) challenges that are specific for RPAS.

Description of work

A 'Use Case' based methodology is developed that systematically identifies HSI challenges in RPA operations in non-segregated airspace.

Results and conclusions

Based on the theoretical underpinnings of the NATO Architectural Framework (NAF) and the Human View (HV), the developed methodology takes a stepped approach that captures, analyses & interprets system requirements for safe RPA flights. In several NAF HV work sessions, Human Factor (HF) experts and Subject Matter Experts (SMEs) walk through typical flights that could potentially be performed in non-segregated airspace. The pilot sketches a 'successful' scenario, from flight phase to flight phase as well as a number of alternative scenarios. Each alternative scenario is characterized by a non-nominal event, like loss-of-link, an intruder aircraft causing loss of separation, or a human error. For each flight phase, the so-called Use Case diagrams are constructed. On the basis of this information, an HF identification is performed to identify (potential) HSI challenges. Specifically complex or multi-facetted issues are subsequently broken down using an Operational Risk Management method: Bowties. The Bow-Tie models present a comprehensive overview of the (HF) events and the surrounding situational aspects.

Applicability

The use case based methodology allows for standardized identification of the Human Factors implications of RPA flight in non-segregated airspace. This methodology can in turn be used to develop a NATO wide database of HSI issues related to integrating RPAs in non-segregated airspace, accessible for all NATO Flight In Non-segregated Air Space (FINAS) participants.

The methodology supports and complements the required safety assessment facilitating safe and seamless integration of RPAS in non-segregated airspace. In addition, it provides clarity about the requirements that RPAs have to meet to acquire access to all relevant International Civil Aviation Organization (ICAO) airspace classes.

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Summary

This document aims to identify presently unidentified Human Factors (HF) that support, lead or incur occurrences impairing Remotely Piloted Aircraft (RPA) system safety. Analyzing existing RPA System (RPAS) procedures during all phases of flights and focusing on the pilot as the “controlling entity” of such NATO RPA operations in non-segregated airspace, potential HF issues will be identified, described and stored in a database.

The methodology to be applied is the Use Case methodology. Focusing on the interactions of RPA pilots with the Remote Pilot Station (RPS) and RPA, Use Cases will assist experts and specialist teams in developing functional requirements. Since there is also a need to take specific subsystems into account, specifically the Sense And Avoid (SAA) system, the Use Cases will be framed at individual flights of air vehicles (use case terminology: ‘sea level’) and major subsystems (use case terminology: ‘fish level’). This approach will provide added value to deliver requirements for RPA to safely and seamlessly access non-segregated airspace (airspace classes A to G as defined by ICAO).

The Use Case methodology allows precise diagnosis of Human-System Integration (HSI) challenges (in other words: HF problems) that are specific for RPA. In this context, the meaning of ‘diagnose’ is that those challenges will be detected and detailed in the scenario descriptions of RPA flight in non-segregated airspace.

Human Factors that were specifically complex or presented unacceptably high risks were further analyzed using the Bow-Tie Occupational Risk Model (ORM).

Content

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Abbreviations

Acronym	Description
ACAS	Airborne Collision Avoidance System
AGS	Alliance Ground Surveillance
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Service
AVO	Air Vehicle Operator
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CRM	Crew Resource Management
CSO	Collaboration Support Office
DODAF	Department of Defense Architectural Framework
DUO	Designated UAV Operator
FINAS	Flight in Non-Segregated Airspace
HF	Human Factors
HFM	Human Factors Medicine Panel
HFST	Human Factors Study Team
HMI	Human Machine Interface
HSI	Human-System Integration
HV	Human View
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IT	Information Technology
JCGUAV	Joint Capability Group on UAVs
METAR	Meteorological Aerodrome Report
MC	Mission Commander
MODAF	Ministry of Defense Architectural Framework
MRM	Maintenance Resource Management
NAF	NATO Architectural Framework
NAFAG	NATO Air Forces Armament Group
NATMC	NATO Air Traffic Management Committee
NATO	North Atlantic Treaty Organization
NOTAM	Notice to Airman
NLR	National Aerospace Laboratory

NSA	**Non Segregated Airspace**
ORM	**Operational Risk Model**
PO	**Payload Operator**
RF	**Radio Frequency**
RLOS	**Radio Line Of Sight**
RPA	**Remotely Piloted Aircraft**
RPAS	**Remotely Piloted Aircraft System**
RPS	**Remote Pilot Station**
RTG	**Research task group**
SA	**Situation Awareness**
SAA	**Sense And Avoid**
SME	**Subject Matter Expert**
ST	**Study Team**
STANAG	**NATO Standardization Agreement**
TRM	**Team Resource Management**
UC	**Use Case**
UML	**Unified Modelling Language**
USAR	**UAV System Airworthiness Requirements**
VFR	**Visual Flight Rules**
VLOS	**Visual Line Of Sight**

1 Introduction

1.1 Introduction to NATO FINAS

In 2003, NATO Air Forces Armament Group (NAFAG) Air Group 7 (AG7) recognized the need for military RPA systems approved for operation by a NATO country to be acceptable for similar operations in other NATO nations, as is already the case with manned military aircraft. However, there were significant safety-related and legislative issues that had to be addressed.
To this end, at its 9th meeting, in November 2003, AG7 agreed to create the Flight In Non-Segregated Air Space (FINAS) working group to progress these issues. Initially, FINAS worked directly for AG7, but on 1st January 2006, NATO restructured its Armament Groups along capability lines. Now FINAS reports to the Joint Capability Group on UAVs (JCGUAV), which is the result of a merger between AG7 with the RPA land and naval groups NATO FINAS WG (2009).

The FINAS mission is ”...to recommend and document NATO-wide guidelines to allow the cross-border operation of Remotely Piloted Aircraft (RPAs) in non-segregated airspace.”
FINAS members also hold relationship with other RPAS bodies, including EUROCONTROL; EUROCAE WG-73; NATO Air Traffic Management Committee (NATMC); NATO Alliance Ground Surveillance (NATO AGS); JCGUAV and RTCA SC-203.

FINAS is currently engaged on a number of pieces of work of differing levels of maturity. These include:

- A RPA System Certification Standard (see STANAG 4671/4702/4703/4746)
- Functional Requirements for a Sense & Avoid (SAA) System;
- Recommended Guidance for the Training of Designated UAV Operator (DUO);
- RPA System Security Guidelines.

A key document lists the functional requirements of Sense and Avoid (SAA) system. FINAS has identified two distinct but complementary functions that a SAA system must possess:

- Collision Avoidance - a “don’t scrape paint” function that is self-evidently required at all times, in any class of airspace, under any flight rules.
- Separation Provision - a “don’t scare other pilots” function that operates as the primary means of keeping aircraft apart. The responsibility for this function lies with either Air Traffic Control (ATC) or the crew in the Remote Pilot Station (RPS). The class of airspace, the flight rules in force and the ATS being provided determines where this responsibility lies.

1.2 NATO FINAS Human Factors Study

The JCGUAV/FINAS Working Group issued Terms of Reference for a Human Factors Study Team 4685 (FINAS, 2009)[1].

The aim of the Study Team (ST) is to investigate the influence of Human Factors (HF) on RPAS safety and mission effectiveness and make recommendations for RPAS design and development. Objectives of the study are to:

- Define levels of automation to be applied and the corresponding degree of human engagement.
- Identification of an agreed automation level for different phases of the mission. These phases include ground operations, terminal operations, en route, on task, and contingencies/emergencies. Contingencies and emergencies that should be covered include conflict resolution, loss of link, loss of voice communications, diversion and go around.
- Identify the transition between planned and unplanned changes in automation level.
- Recommend the best practice from existing literature, operating experiences and those resulting from the discussions of the ST.
- Production of a draft Study report which may lead to the publication of a Ratification Draft STANAG 4685.

In terms of scope, the study will initially limit itself to considering Class 2 (150 to 600kg) and Class 3 (> 600kg) RPA Systems. The period of operation is from system activation to shut-down, or "chock-to-chock"

1.3 Use Case subgroup activities

1.3.1 Aim

The Use Case subgroup tries to identify presently unidentified Human Factors that support, lead or incur occurrences impairing RPA system safety. This approach will provide added value in delivering requirements for RPAS to safely and seamlessly access non-segregated airspace (airspace classes A to G as defined by ICAO).

In detail, the goal of the Use Cases is to 'diagnose' Human-System Integration (HSI) challenges (in other words: Human Factors problems) that are specific for RPA. In this context, the meaning of 'diagnose' is that those challenges will be detected and detailed in the scenario descriptions of

[1] A revised Terms of Reference document for the Human Factors Specialist Team was drafted later, however it is unknown to the authors whether the revised document was approved.

RPA flight in non-segregated airspace. The aim is to provide a data base with HSI challenges that will be accessible to the FINAS stakeholders.

1.3.2 Approach

The subgroup's prime concern is analyzing existing procedures with NATO RPA operations in non-segregated airspace, separated by type and kind of RPA operation, to identify potential HF issues. The methodology to be applied is the Use Case methodology, which focuses on the interactions of RPA pilots with the Remote Pilot Station (RPS) and RPA establishing Use Cases to assist functional area experts and specialist teams in developing requirements. Since there is also a need to take specific subsystems into account, specifically the Sense And Avoid (SAA) system, the Use Cases will be framed at individual flights of air vehicles ('sea level' use cases) and major subsystems ('fish level' use cases). All phases of flight will be covered by the Use Case scenarios, that is, from flight preparation (from receiving the applicable NOTAMs and METAR) to engine shut-down.

1.3.3 Assumptions

<u>SAA</u>

It is assumed that a fully functioning SAA system is operational available to the individual RPA type. A fully functioning SAA system implies three levels of SAA requirements, first the establishment of situational awareness, second the ability to detect potential conflicting traffic in order to avoid such traffic and third, the last resort of collision avoidance.

<u>Airspace classifications</u>

It is assumed, that the classes of airspace (A to G) in line with ICAO Annex 2 will be implemented on the state level in accordance with the described requirements of ICAO. In any case, national deviations or derogations are considered not to have a significant effect on the identification of HF issues.

1.4 Goal and scope of this document

The goal of this document is to provide methodological guidance for the Human System Integration (HSI) community. The target audience may consist of specialists involved in any of the process steps from RPA requirements via design and development to RPA operation, including related processes in acquisition, Verification & Validation (V&V) and personnel training. These specialists may benefit from a common NATO database representing requirements for representative RPAS configurations to access non-segregated airspace.

The next chapter (Chapter 2) discusses the used methodologies within the context of the NATO Architectural Framework. Thereafter (Chapter 3), illustrative examples of the proposed methodologies are provided. The final Chapter (Ch.4) provides conclusions and recommendations. All relevant source material, on which the examples are based, is included in the appendices.

2 Methodologies applied

<u>Objectives – What do we want to achieve?</u>

The goal of the Use Cases based methodology is to 'diagnose' Human-System Integration (HSI) challenges (in other words: HF problems) that are specific for RPAs. In this context, the meaning of 'diagnose' is that those challenges will be detected and detailed in the scenario descriptions of RPA flight in non-segregated airspace. Specifically, knowledge from the RPA field will be captured. Knowledge (including lessons-learned) about HSI challenges in manned aviation will supposedly be covered by the other efforts of the HFST.

At this stage, it is not a goal of the Use Cases to resolve the challenges that are encountered. The aim is to provide a data base with HSI challenges that is accessible to the FINAS stakeholders.

<u>Methodology</u>

To diagnose HSI challenges a stepped approach is used that captures, analyses & interprets system requirements for safe RPA flights. On the basis of this information, a HF identification is performed to identify (potential) HSI challenges.

2.1 System requirements identification

In order to ultimately identify HSI challenges, the missing criteria or requirements that qualify unmanned aircraft systems to operate in the various classes of airspace (A..G) need to be identified first. This includes for example, the see-and-avoid criteria to prevent collisions, traditionally provided by the on-board pilot. From this, the function that compensates for the missing criteria or requirement, e.g. an Automatic Collision Avoidance System (ACAS) can be defined. With this complete picture of what would be involved in operating such a (complete) system in non-segregated airspace, HSI challenges can be identified.

To identify these system requirements, Use cases are constructed that capture the functional requirements of a system. The Use Case method is a standardized method that originates from software and system engineering and is embedded in the NATO Architectural Framework (NAF) and the NAF Human View.

<u>Use Cases within NATO</u>

In the choice for tools and techniques for the current purposes, it would be preferable to come up with something that is already embraced by NATO. NATO has adopted a so called Enterprise Architecture Framework, called the NAF. This is basically a framework to describe architectures such as a C4ISR system, an RF spectrum management system, or any large Information Technology (IT) system. The NAF is based on MODAF and DODAF. The framework consists of layers or so-called views. The NAF includes, for example, a technical view, a systems view and an operational view.

In addition, a research task group (RTG) under the Human Factors and Medicine (HFM) panel (of NATO Collaboration Support Office - CSO) developed a Human View, to supplement the existing views, to represent the human and to document the unique characteristics that humans bring to system design. The NATO Human View Handbook advocates the use of Use Cases to identify Human Factors problems in systems with large integration and interoperability challenges.

The NATO Human View (HV) specifically tries to capture the human requirements of a system and specify how humans interact within systems. By integrating Human System Integration (HSI) into the early design phases of architectures, it ensures that human roles are considered in the final product. Through the structured approach, Human Factors engineers and System engineers can coordinate effectively.

The NATO Human View consists of eight products, depicted in Figure 1.

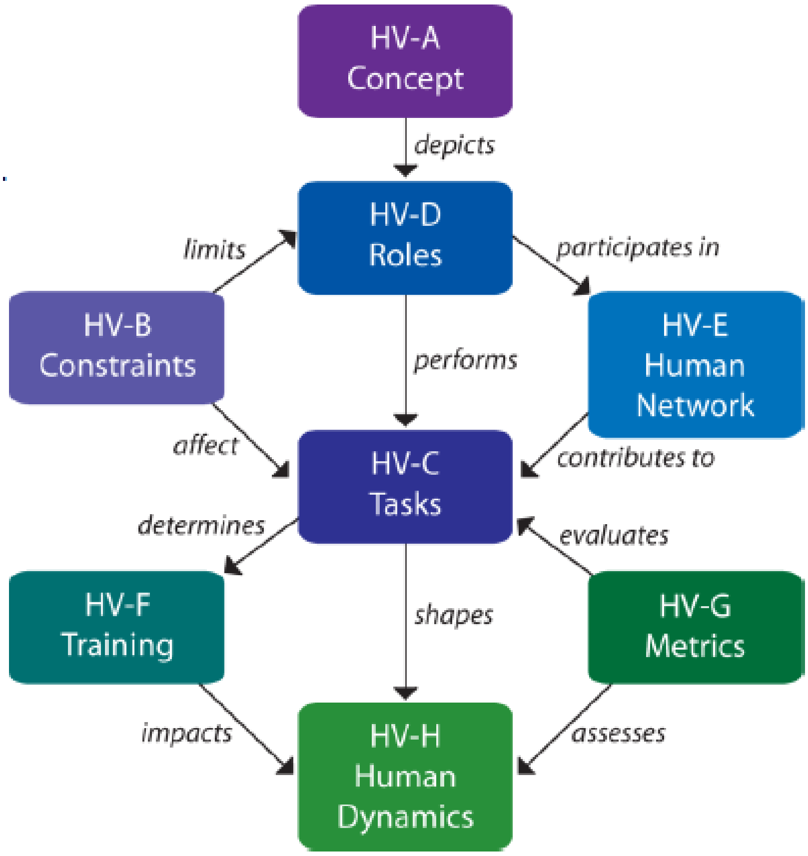

Figure 1: NATO Human View products (Adapted from: NATO Human View Quick Start Guide)

The additional products are represented in a structured way to document the information needed to specify human activity. Given the scope and the demands of this identification, only the conceptual dimension of the Human View (HV-A) will be addressed. "The HV-A is a conceptual, high-level representation of the human component of the enterprise architecture framework. Its purpose is to visualize and facilitate understanding of the human dimension in relation to operational demands and system components".

Within the Human View, Use Cases are constructed to identify the role of the human in the system, and as such are suitable to identify HSI issues.

<u>What are Use Cases?</u>

Use Cases (UC) are a technique for capturing the functional requirements of a system. "Properly written, they accurately detail what the system must do". Use cases contain a number of scenarios in which a user of the system (in this case the remote pilot) is the central actor. Moreover, the scenarios in a Use Case are tied together by a common user goal. The primary scenario is the 'main success scenario' which, in this case, describes a successful flow for flying RPAs in non-segregated airspace. Hence the objective is: safe RPA operation in non-segregated airspace (e.g. from location A to location B).

From the viewpoint of the user, Use Cases can be constructed at different abstraction levels. In use case terms these are 'cloud', 'kite', 'sea', 'fish' and 'clam' level. For example, in RPA terms, taken the pilot as the user, the 'cloud' level may be the ATM-level, the 'kite' level is the mission level, and possibly addressing multiple flights simultaneously. The 'sea' level is at the level of the individual flight, addressing the interaction of the pilot with the air vehicle through the RPS. The 'fish' level is addressing subsystems such as a RPA SAA system. Finally, at the clamp level you can zoom in at specific components of an SAA system, such as the utilization of an IR sensor. Use Cases are tools within the UML and SysML, hence standard tools for software development and system development.

<u>Scope of the Use Case activities</u>

The focus of the Use Case activities will be on the interactions of the remote pilot with the RPS and RPA. Since there is also a need to take specific subsystems into account, specifically the SAA system, the Use Cases will be framed at the 'sea' level (individual flights of air vehicles) and 'fish' level (major subsystems). All phases of flight will be covered by the Use Case scenarios, that is, from flight preparation (from receiving the applicable NOTAMs and METAR) to engine shut-down.

<u>Use case methodology</u>

For Use Cases at 'sea' level, the following methodology is used to derive functional use cases:

- HF expert(s) sit around the table with pilot(s) of a currently operational platform. Such a face-to-face session typically takes four to six hours, depending on the complexity of the scenarios.
- Both agree, possibly beforehand, to walk through a typical flight that could potentially be performed in non-segregated airspace (through different classes (A..G) of airspace). This could, for example, be an actual mission, a training flight or a ferry flight.
- The HF expert provides the pilot with the functional characteristics of the (future) SAA system with which the specific RPA should be equipped in order to perform the flight.
- The pilot then sketches a 'successful' scenario, from flight phase to flight phase. For each flight phase, the HF expert notes the tasks, the subtasks and specific information (information exchange, timing, waiting conditions, etc.).

- Subsequently, the pilot sketches a number of alternative scenarios. Each alternative scenario is characterized by a non-nominal event, like loss-of-link, an intruder aircraft causing loss of separation, or a human error. Again, the HF expert notes the tasks, the specifics and any contingency measures required to resolve the non-nominal situation.
- After having dealt with the most salient or significant alternative scenarios (there is some subjective element here), the session is adjourned. For each flight phase, the so-called Use Case diagrams are constructed.

2.2 Human Factors identification

The developed use cases are then carefully analyzed by a team of HF experts and Subject Matter Experts (SMEs) to identify where Human Factors issues are possible to occur.

2.2.1 Bow-Tie diagrams

Human Factors that are specifically complex or may present high risks are further analyzed using the Bow-Tie Occupational Risk Model (ORM).

<u>Bow-Tie Risk Model:</u>

The relationship between an accident and its possible causes is often given as a fault tree. The relationship between an accident and its potential consequences is often depicted as an event tree. The two trees combined, create a Bow-Tie shaped diagram. This structure has proven a valuable concept in analyzing past accidents (Ale et al. 2008).

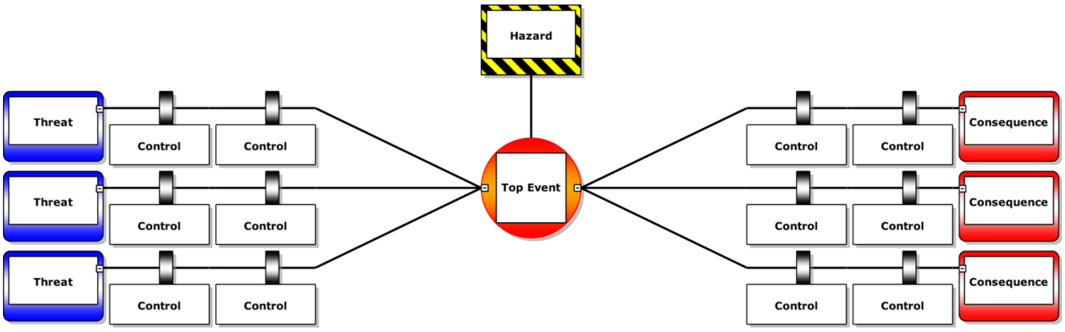

Figure 2: Topology of a Bow-Tie model

The Bow-Tie model will be explained by three practical examples out of RPAS operations, the potential of loss of link; mode confusion and unintentional take off.

A Bow-Tie model consist of several parts, the hazard that is present, the event that can occur within this hazardous environment, the threats that cause the event (as depicted in blue), and the consequences (as depicted in red) that can come out of this event. On the left of the model are depicted the threats. A threat is any possible cause that will potentially release a hazard and result in an undesirable top event. Consequences deriving from the top event are depicted on the right hand side of the model. To prevent top events from developing, and top events from developing into consequences, control measures can be put in place. Such control measures can be best explained by Reason's Swiss cheese model (1997). In line with the Swiss Cheese model, threats can develop straight into events when preventive barriers are not in place. These preventive barriers are presented in Figure 2 as control measures, and could prevent a threat from developing into an event. Control measures could also prevent an event from developing into consequences. Second, it can be a measure to limit the severity of the consequence of the top event.

Control measures themselves are also vulnerable. Factors influencing the effectiveness of these control measures are called escalation factors (see yellow boxes in Figure 3, 4 and 5). Escalation factors can, in turn, also have control measures to prevent their effects.

The Bow-Tie model presents a comprehensive overview of the (Human Factors) events and the surrounding situational aspects.

3 Examples of Human Factors of RPA Flight in non-segregated airspace

The Human Factors analyses of the developed use cases result in the identification of several human factors issues that can potentially affect flight safety. Three exemplary human factors cases that are specifically tied to RPA flight in non-segregated airspace are presented below. For more context, the reader is referred to the Use Cases in appendices A and B.

3.1 Loss of control link

The first Human Factors example featured is the loss of control link between the remote pilot station and the RPA (top event). There are several threats that can cause this event to occur, among which RPA maneuvering, undeliberate Air Vehicle Operator (AVO)[2] input and errors/malfunctions in RPA, data connection or RPS[3]. Most of these threats can be overcome by automatic recovery of the control link (e.g. when the aircraft maneuvers into other airspace) or by careful crew monitoring (e.g. to avoid 'loss of link prone' areas).

[2] Air Vehicle Operator (AVO) equals the term Remote Pilot used throughout this document.
[3] Remote Pilot Station (RPS), formerly called Ground Control Station (RPS)

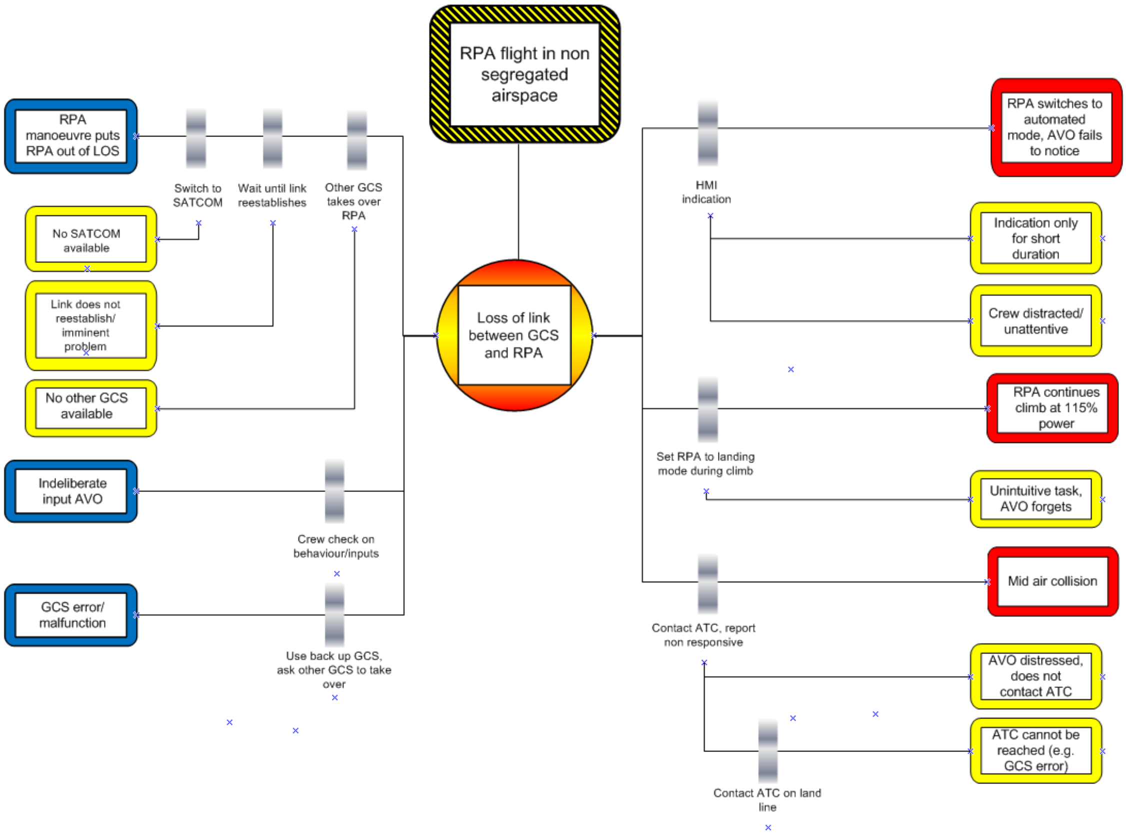

Figure 3: Loss of control link Bow-Tie

The most catastrophic consequence of RPA loss of link is a collision with obstacles or other aircraft. To prevent this, the RPA operator can contact Air Traffic Control (ATC) which can provide additional separation between the RPA and other traffic. In case the loss of link duration is only short, the event might not even be noticed by the flight crew. The loss of link could however trigger automated processes in the RPS such as flight mode changes. This can be dangerous, as the mental model of the operator(s) is now incongruent with reality. A recovery measure in this case can be to provide the operator with a visual/auditory indication on the Human Machine Interface (HMI) such as clear flight mode annunciations.

3.2 Mode Confusion

Large RPAS capable of flying in non-segregated airspace are highly automated machines, performing maneuvers in a variety of different flight modes. Mode confusion can occur when the automation or the remote pilot puts the RPA in a different flight mode. Subsequently, the remote pilot may no longer be aware that the RPA is in a certain mode or switches modes. This can put the operator, located at a distance of the aircraft, at risk of suffering mode confusion.

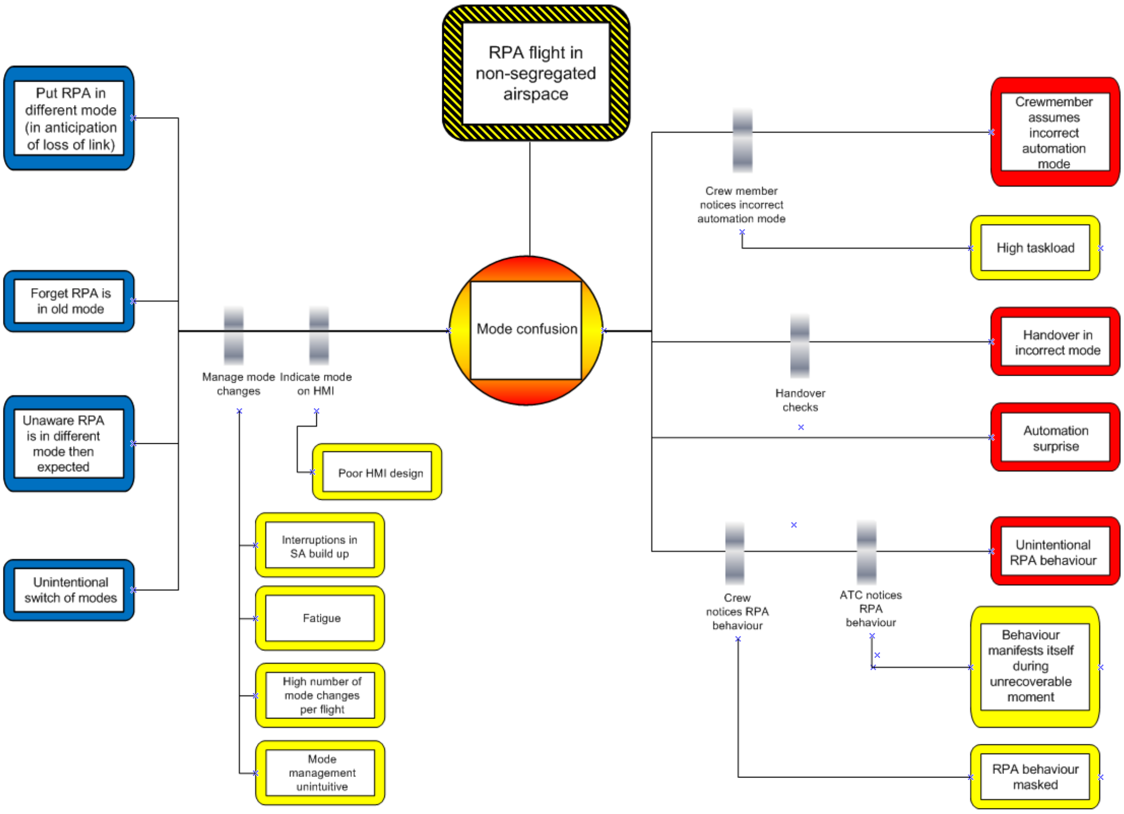

Figure 4: Mode confusion Bow-Tie

These mode changes can be managed, but this relies on the effectiveness of the remote pilots, which is inherently fallible. Fatigue, Situation Awareness (SA) interruptions and unintuitive designs can all have major effects on the remote pilots' capability to safely manage mode changes and thereby preventing the top event (mode confusion). Consequences of mode confusion may include unexpected RPA behavior, leading to the flight crew counteracting the automated systems and potentially leading to loss of control. Furthermore, RPAs sometimes need to be handed over to different crews/other teams. Handover in incorrect modes can set the other team/crew up for errors. Recovery measures such as careful monitoring and performing checks can intercept consequences of mode confusion, but are also vulnerable to human error.

3.3 Unintentional take off

As a consequence of mode confusion, the RPA can potentially perform an unintentional take off. This has occurred at least once before, resulting in the catastrophic loss of the RPA. The Bow-Tie below does not represent findings of the accident report but is the interpretation on the basis of the use case method.

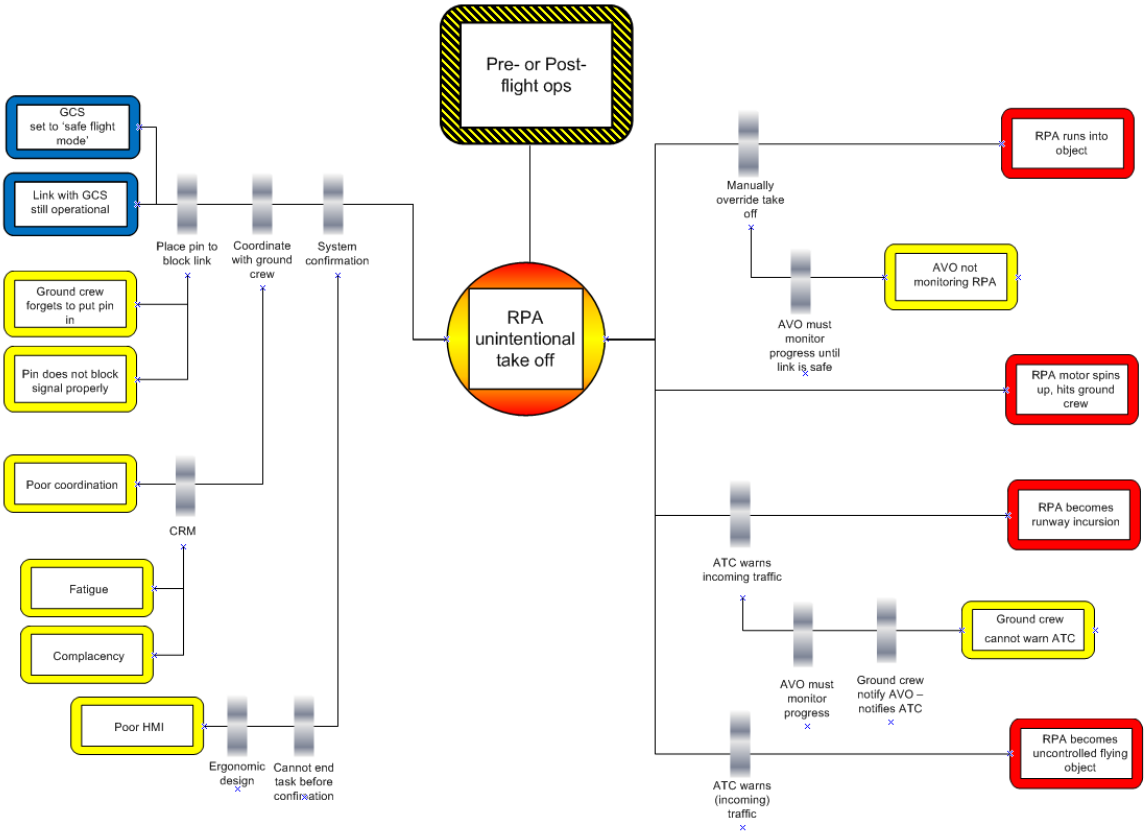

Figure 5: Bow-Tie of RPA unintentional take-off

Causes of unintentional take-off are setting the RPS in safe flight mode (meaning availability of full RPA engine power) in anticipation of connecting with another RPA. When the link with the first RPA is still operational when the operator puts the RPS in 'safe flight mode', the top event of unintentional take off can occur. To prevent this from happening, a safety pin can be inserted to block the data link between RPS and aircraft. Close coordination between flight crew and ground crew should take place. These barriers are vulnerable to human error and human fallibility. The consequences of unintentional take-off are obvious; a collision with objects or other aircraft, an accident with ground crew surrounding the aircraft during the occurrence. The RPA operator can prevent these consequences from unfolding by manually overriding the RPA behavior. To manually interrupt the process, the operator needs to be actively monitoring the RPA behavior. This is especially crucial when ground personnel are present in the vicinity and AVO reaction times are thus limited.

3.4 Summary of findings

Not unsurprisingly, RPA operations incur human factors that are not always repeating HF issues that can be found in manned aviation, but also incur new, unique issues. The proposed methodology, as an initial approach, seems promising.

The Bow-Tie methodology is a powerful technique in risk and control measures assessment. It is a qualitative technique. It combines causes and consequences into one diagram. The theory behind the Bow-Tie could be found in the Swiss cheese model of Reason and concepts of layers of protection. At this stage, we propose to use the Bow-Tie model in a descriptive, rather than in a normative manner. By following the proposed method, several HSI challenges were unearthed, as presented in the exemplary Bow-Ties.

HF issues specific to RPA flight that have been identified so far include:

- Human factors of loss of (control) link
- Time delay in detecting aircraft maneuvers due to a lack of 'seat of pants' cues resulting in a lack of capability to exert reflexes or even exert skill based behavior (unintentional take-off)
- The need for a new approach for team coordination in RPA operations within the RPS but also within the larger team including ground crew, crews in other RPSs and ATC (CRM/MRM/TRM) (unintentional take-off/mode confusion/loss of link).
- 'Keyhole' perspective prevents crew from building a multi-modal situational awareness. Even more than in manned aviation, the crew relies on flight mode information (mode awareness).
- Detect and Avoid System, absence of 'Eyeball Mark I' information
- Unintuitive procedures related to concepts specific to RPA operation (unintentional take off)
- Operations of RPAS, especially following business opportunities for small RPAS, will be performed by operators and remote pilots with no vast aviation experience.

4 Conclusions and Recommendations

The need for FINAS is a set of functional requirements that allow (safe and seamless) RPA integration in non-segregated airspace meeting ICAO airspace classification requirements. This methodology reflects the human centered approach for RPAS operations in non-segregated airspace. It can be applied to identify and analyze the HSI issues that are inherent to the integration of RPAs into the various classes of airspace that are penetrated during a flight. The methodology starts with subject matter expert consultation, followed by drafting the Use Cases. On this basis, Use Case diagrams can be developed, portraying the interactions between the system elements and actors, involved in the particular flight phase. The Use Case diagrams hint at potential HSI problems which are further detailed by the use of 'Bow-Tie' risk models. The latter graphically represent the relation between the event of interest, the hazard and the corresponding environmental conditions and consequences.

The following is recommended:

- Use this methodology as a harmonized approach to identify HSI issues (see blue box) relevant to FINAS;
- Increase the number of examples for RPAS operations at the 'sea' level (flights) and 'fish' level (major subsystems);
- Establish a common NATO FINAS database representing Use Case examples, accessible to NATO stakeholders (designers, certifiers, end-user agencies);
- Establish a common NATO FINAS database representing requirements for individual RPAs to access relevant airspace classes according to the ICAO airspace classification scheme.

- Determine HSI problems and highlight solutions through a stepwise approach:
    1. Determine the missing criteria or requirements that qualify RPAs to operate in the various classes of airspace (A..G), for example, the see-and-avoid capability to prevent collisions, traditionally provided by the on-board pilot;
    2. Define the functions that compensates for the missing criteria or requirement, e.g. an ACAS;
    3. Determine potential HSI problems within the aforementioned functions by building Use Cases at the 'sea' and 'fish' level around this function. This way, a focus on HSI problems that are specific for RPAs is implied in the methodology.

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Appendix A Use Case Heron

Executive summary

Use Cases (UC) are a technique for capturing the functional requirements of a system. “Properly written, they accurately detail what the system must do”. Use cases contain a number of scenarios in which a user of the system (in this case the remote pilot) is the central actor. Moreover, the scenarios in a Use Case are tied together by a common user goal. The primary scenario is the ‘main success scenario’ which describes a successful flow for flying RPAs in non-segregated airspace, hence the objective is: safe RPA operation in non-segregated airspace. Table A.1 positions this Use Case in the larger scope of RPAS operations in an ATM environment.

Table A.1: Airspace classification and potential types of RPAS operations

Class of Operation	Type of operation	Segregated Airspace	Non Segregated Airspace						
			Controlled Airspace					Uncontrolled Airspace	
		segregated	class A	class B	class C	class D	class E	class F	class G
VFR	VLOS		N/A						
	E-VLOS		N/A						
	B-VLOS		N/A						
	RLOS	Heron Germany, Afghanistan	N/A		Heron Germany *)				
	B-RLOS		N/A						
IFR	VLOS								
	E-VLOS								
	B-VLOS								
	RLOS	Heron Germany, Afghanistan			Heron Germany *)	Heron Germany *)			
	B-RLOS	Heron Germany, Afghanistan			Heron Germany *)				

**) assumed for the purpose of potential flights in non-segregated airspace*

The airspace classes are colour coded, indicating the likelihood of usage for RPA operations, depending on the provision of Air Traffic Services and separation as well as the radio communication requirements, facilitating safety. Green indicates the highest level of safety facilitation.

The following types of operations are distinguished (ERSG, 2013):

1. Non-standard RPA S operations in VFR or IFR, below the typical IFR and VFR altitudes for manned aviation: i.e. not to exceed 500 ft. above ground level; they comprise:
    A. **Visual line of sight (VLOS)** in a range not greater than 500 meters from the remote pilot, in which the remote pilot maintains direct unaided visual contact with the remotely piloted aircraft;
    B. **Extended Visual Line of Sight (E-VLOS)** where, beyond 500 meters, the pilot is supported by one or more observers, in which the crew maintains direct unaided visual contact with the remotely piloted aircraft;
    C. **Beyond VLOS (B-VLOS)** where the operations are also below 400 ft but beyond visual line of sight requiring additional technological support.
2. **Standard RPA S operations in VFR or IFR,** above 500 ft above ground level and above minimum flight altitudes; they comprise:
    A. **IFR (or VFR)** operations **in radio line-of-sight (RLOS)** from the RPS in non-segregated airspace where manned aviation is present. The key capability of 'detect and avoid' (D&A) is required in relation to cooperative and non-cooperative nearby traffic (otherwise specific procedures and restrictions would apply);
    B. **IFR (or VFR)** operations **beyond radio line-of-sight (BRLOS) operations,** when the RPA can no longer be in direct radio contact with the RPS and therefore wider range communication (COM) services (including via satellite) are necessary. In this case COM would typically be offered by a COM service provider.

The altitudes that are identified for the above mentioned operations are of a generic nature not taking into consideration national differences and exemptions.

Further, this document describes alternative scenarios, which are potential failure flows, with events such as imminent loss of separation, imminent collision risk, an emergency resulting in a loss of functionality or human error.

The descriptions of the scenarios will reveal specific human factor issues associated with both success and failure flows, such as issues associated with the hand-over procedure of the RPA between pilot and maintenance crew, or issues related to auto pilot mode switching.

The purpose of this document is to understand functional requirements for operations of RPAs in non-segregated airspace in order to ensure safe operations, with levels of safety that do not decrease the levels of safety that are achieved with manned operations to date, in the ATM system. HSI implications of such requirements are considered, such as implications for manpower, training, RPS design and use of automation. To acquire the information, interviews with an RPA (Heron) operator were performed.

Although such systems are currently not certified for use on RPA s, it is assumed that the RPA is equipped with a functioning sense-and-avoid system that replaces the human see-and-avoid obligation to fly in non-segregated airspace.

Use cases reflect a portion of the total set of requirements to be imposed on a system. These are further identified by means of use case diagrams. Based on this Use Case approach, HSI issues will be further detailed using so called ‘bow-tie’ models.

Safe IFR flight through segregated airspace in Germany

Scope

The availability of the sense and avoid system supports flying IFR and VFR operations in airspace class C. Note that in class C, separation for VFR flights is only provided towards IFR flights. Hence, traffic avoidance between VFR flights is a responsibility of the pilot using the SAA system. The advantage of a VFR flight is that the pilot enjoys more flexibility in selecting a route (assumed that the flight plan is accepted by ATC), while IFR flights proceed along prescribed routes.

Level

This use case is written on ‘sea level’ but has ‘fish level’ information where more detailed information is needed.

Summary

The use case starts when a ferry flight is tasked to the Mission Commander (MC). The mission commander performs the necessary steps to gather relevant information and relays this to the planning crew (Air Vehicle Operator (AVO) and Payload Operator (PO)). After planning and pre-flight preparations, the ground crew prepares the RPA for take-off. During the take-off, departure and en-route phases of the mission, the AVO is in close contact with air traffic control to ensure separation and collision avoidance. The AVO requests ATC clearance of RPA maneuvering (e.g. climb to flight level 090) and entering of airspaces. Upon arrival at the location of the training, the RPA performs reconnaissance functions to support ground elements. The RPA returns after the training following the flight path permitted by ATC. The use case ends after completion of flight, when the RPA has been handed over to the ground crew and the RPA operators debrief the mission or training.

Actors

Primary actor:

Air Vehicle Operator (AVO)

The Air Vehicle Operator (AVO) is the main actor. The AVO controls the RPA and is responsible for ensuring separation and collision avoidance from other aircraft.

Secondary actors:

Air Traffic Controllers

Air Traffic Controllers are coordinating all controlled air traffic in their area of responsibility. They are responsible for aircraft separation in accordance with the current airspace class requirements.

Air traffic controller - Area Control (ACC)

The Area Control (ACC) air traffic controller manages all controlled air traffic en-route.

Air traffic controller – Approach Control (APP)

The Approach Control (APP) air traffic controller controls all air traffic to and from the airport or airfield in an approximately 60-100 km radius. The APP controller then hands air traffic over to ACC (after departure) or tower control (before landing).

Air traffic controller – Tower Control (TWR)

The Tower Control (TWR) air traffic controller controls all traffic taking off and landing, as well as ground traffic on the airport. The TWR controller receives or hands over air traffic to APP.

Mission Commander (MC)

The Mission Commander has responsibility of the mission. The MC holds overview of mission and is in contact with other assets in the area of operation. The MC can command multiple RPAs but the MC can also be performed by the AVO (double role) in less complex missions.

Payload Operator (PO)

The Payload Operator (PO) handles the payload of the RPA, typically electro optical or infrared surveillance systems. The PO also assists in flight planning.

Ground crew

The ground crew handles the RPA before take-off and after landing. The ground crew has control of all technical and engineering issues concerning the RPA on the ground. The ground crew has control of the RPA on the ground and tows the vehicle to and from the runway.

Preconditions

The use case has as precondition that the Unmanned Aircraft System is equipped with Sense And Avoid (SAA) system[4]. The SAA system consists of:

- Situation Awareness function
  - Providing the pilot with traffic information relevant to his flight path at a certain distance/ time ahead
- Traffic Avoidance function:
  - Provides sufficient information for the pilot to ensure traffic avoidance. This becomes particularly relevant whenever ATC separation is not provided (including warning of pending loss of separation)
- Collision avoidance function (the following characteristics are neither fully agreed nor in line with NATO / EASA / ICAO documents):
  - detects both cooperative and non-cooperative aircraft
  - detects all traffic in all lighting and WX conditions, in IFR/VFR and in IMC/VMC
  - provides autonomous collision avoidance[5] (as well as pilot override & return to course capability)
  - ensures interoperability with Airborne Collision Avoidance Systems (ACAS) of manned aircraft

The SAA equipment requirements have been derived from the NATO sense and avoid requirements for unmanned aerial systems operating in non-segregated airspace document (PFP (NNAG-JCGRPA) D (2008) 0002 dated 23 April 2008) in appendix C.

Postconditions

The use case successfully ends when safe and efficient flight in non-segregated IFR and VFR airspace has been performed and the RPA is safely on the ground and in control by the ground crew.

Success end state

RPA executed the ferry flight in accordance with IFR/VFR through (non-)segregated airspace applying to current ATM regulations.

[4] A Ground Based Sense And Avoid (GBSAA) system could be used as an alternative technology to airborne Sense And Avoid system.

[5] Both this and the next function are not yet integrated in any UAS. The USN TRITON and the USAF Reaper will probably be amongst the first types with such a capability.

Failed end state

The use case will have failed when unsafe situations occur, or are likely to occur, in the execution of the IFR flight through segregated airspace.

Trigger

The use case starts when a ferry flight tasking is received by the Mission Commander (MC).

Main Flow

There are four main flows presented in this document, assigned to two use cases. Each use case is triggered by the (training) flight assignment from command. The use case ends after completion of flight, when the RPA has been handed over to the ground crew and the RPA operators perform the debrief of the mission or training. Use case 1 concerns a training flight in German airspace. Three different main flows are presented, representing a flight in IFR segregated airspace, IFR non segregated airspace and VFR non segregated airspace, respectively. Use case 2 concerns an operational MALE RPA S mission over Afghanistan in segregated airspace.

Use Case 1, Training Mission in GER:

In order to practice and develop procedures for Joint Fire Support (JFS) a mechanized infantry group is ordered to the military training area Munster in Northern Germany to train with a MALE RPA based in Schleswig with Tactical Reconnaissance Wing (TRW) 51. The Joint Fire Support Team (JFST) is equipped with the ROVER display and a PRC 117 secure radio. The JFST will direct the fire of the Howitzer 2000 from the Artillery Training Squad. TRW 51 personnel will support with a MALE RPA which has electro optical and infrared sensors, secure radio and an ICAO RPA Cat 2 rating.

Flight path and times are requested with ATC two weeks in advance.
After pre-flight inspection and flight plan acceptance the RPA is towed to the number one position on the RPA runway at Schleswig. The AVO takes control of the aircraft and takes off after clearance from tower.

The aircraft flies the pre-programmed standard departure route and climbs to 2500 feet within Schleswig airspace D. After talking to Bremen radar, the RPA is cleared to climb to flight level 90 in the lateral limits of the restricted airspace ED-R 148 and furthermore to FL 120 within the TRA ED-R201N.

The flight continues to the naval airbase Nordholz, which serves as an emergency alternate, into a holding where the AVO waits for ATC clearance to cross the temporary restricted corridor to ED-R 32 north of Munster. After clearance is received, the HERON descends to FL110 and enters ED-R 32 at FL 080. The AVO checks out with Bremen radar, changes the frequency to contact the JFST, and can now only be reached by Bremen radar via land line.

The payload operator (PO) checks in with the JFST and they switch to a secure channel. After confirmation of a good ROVER picture the training starts.

During the next 3 hours the airplane maneuvers between FL 040 and FL 100. The AVO steers the aircraft to the holding pattern and positions requested by the PO. The PO is in constant contact with the JFST which uses the ROVER data to request fire support from the howitzer. During the actual weapon release, the AVO moves the aircraft out of the projectile's trajectory.
After the training is complete, the pilot switches back to the ATC frequency and climbs to FL 120 within ED-R 32. After he receives his clearance, he flies the planned route back to Schleswig airbase within the temporary restricted corridor and informs the tower already via telephone about his estimated time of arrival. Because the ETA of a Tornado has changed tower requests the HERON to arrive 45 minutes later. The RPA has enough fuel left so a holding of 45 minutes above ETNS is incorporated into the mission plan and coordinated with Bremen radar.
After the PA-200 has landed the AVO is cleared to descend into Schleswig airspace D and after his descend and landing checks the pilot initiates the automatic landing. The aircraft stops on the runway and is towed back into the hangar where the post flight inspection is done.
Once the initial mission debriefing within the crew is complete, a video conference is initiated with the JFST and the supported unit in the training area for a complete debriefing of the operational part of the mission.

Main flow 1: flight in IFR segregated airspace

Task assignment

The first phase of the mission, the task assignment starts with when the Mission Commander (MC) receives a tasking for a mission or training that requires a ferry flight through German airspace. This task is analysed by pilots and mission essential personnel. Mission aspects are determined such as goal, destination and course of action. On the basis of this, a mission flow is designed that comprises a mission (game) plan, mission (navigation) route, contingency plan, frequency management plan and sensor plan. An Air Traffic Control flight plan is then created and filed by the MC with ATC 24 hours before desired take off.

Planning Phase

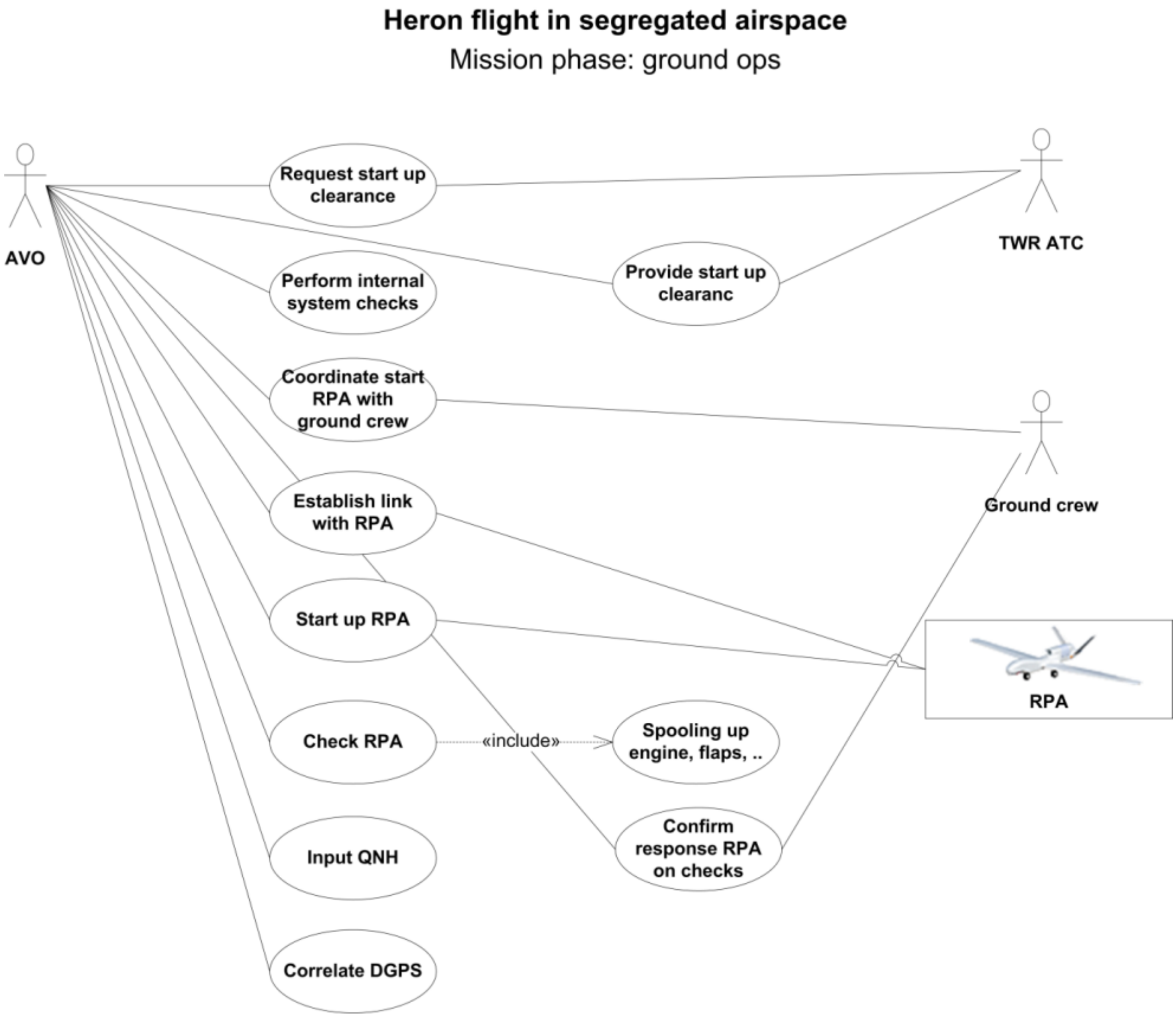
According to the task analysis and mission flow, the MC checks the personnel flight times to determine which crews are available. The MC tasks the Air Vehicle Operator (AVO) with creating a contingency plan on the basis of the mission, which incorporates holdings and extra fuel. The finalized mission plan is verified by the Pilot In Command (PIC) prior to uploading the mission. The mission plan is subsequently loaded in the RPA.

Pre-flight operations

As part of the pre-flight operations the AVO performs a (visual) pre-flight inspection of the RPA, and signs out the maintenance log if no anomalies are detected.

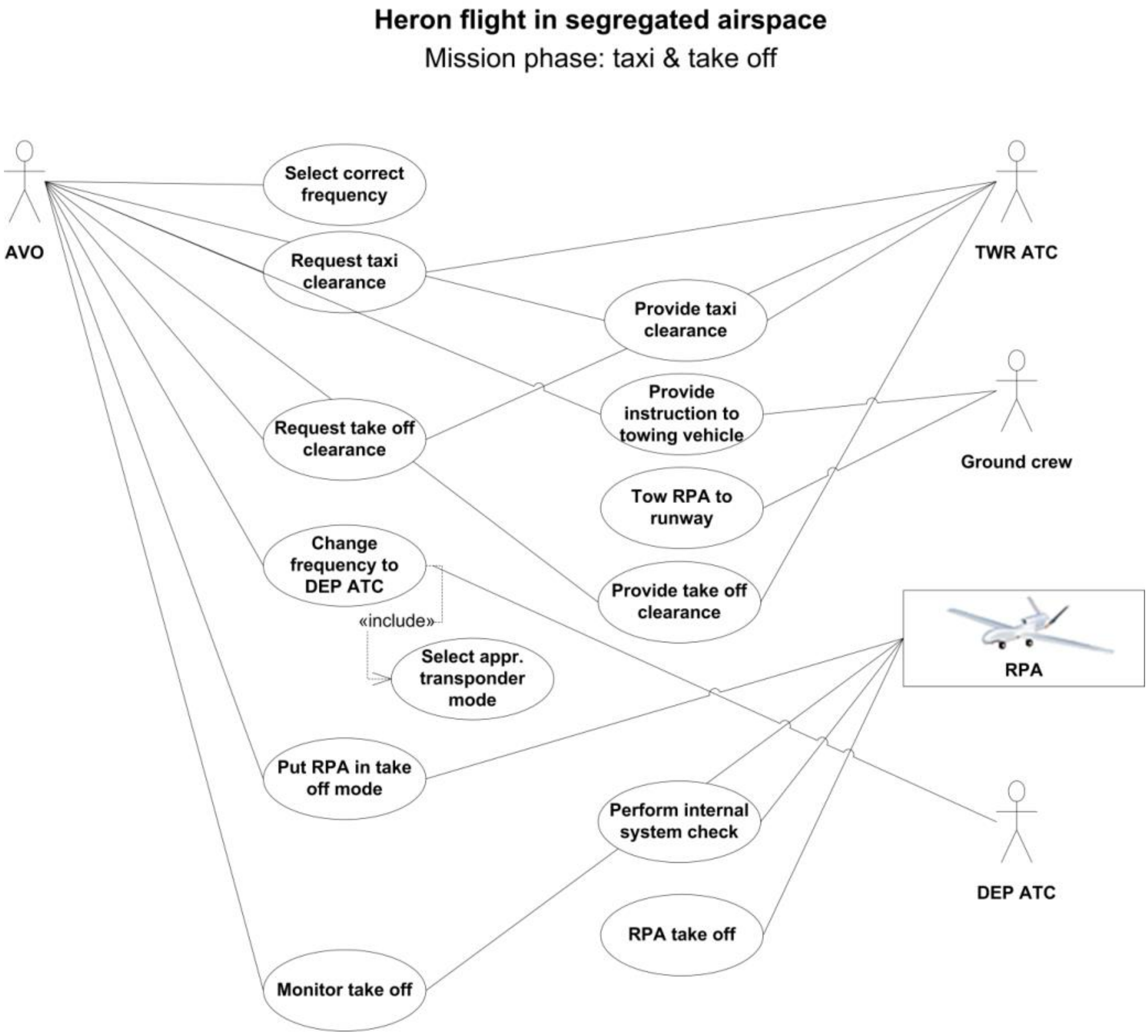
Ground ops

After planning and pre-flight preparations are completed, the AVO gets start up clearance from ATC and checks internal systems. This requires coordination of activities with ground personnel over radio. Ground personnel prepares for AVO control by removing the pin that blocks the link with the RPS. When internal systems are checked, the AVO establishes link to the RPA and takes control over the RPA. The AVO proceeds to start up the RPA and checks responsiveness by spooling up the engine, checking the flaps, etc. The corresponding effects on the RPA of the checks are confirmed to the AVO by the ground crew. The AVO proceeds to input the QNH and correlate the Differential GPS (DGPS) data.



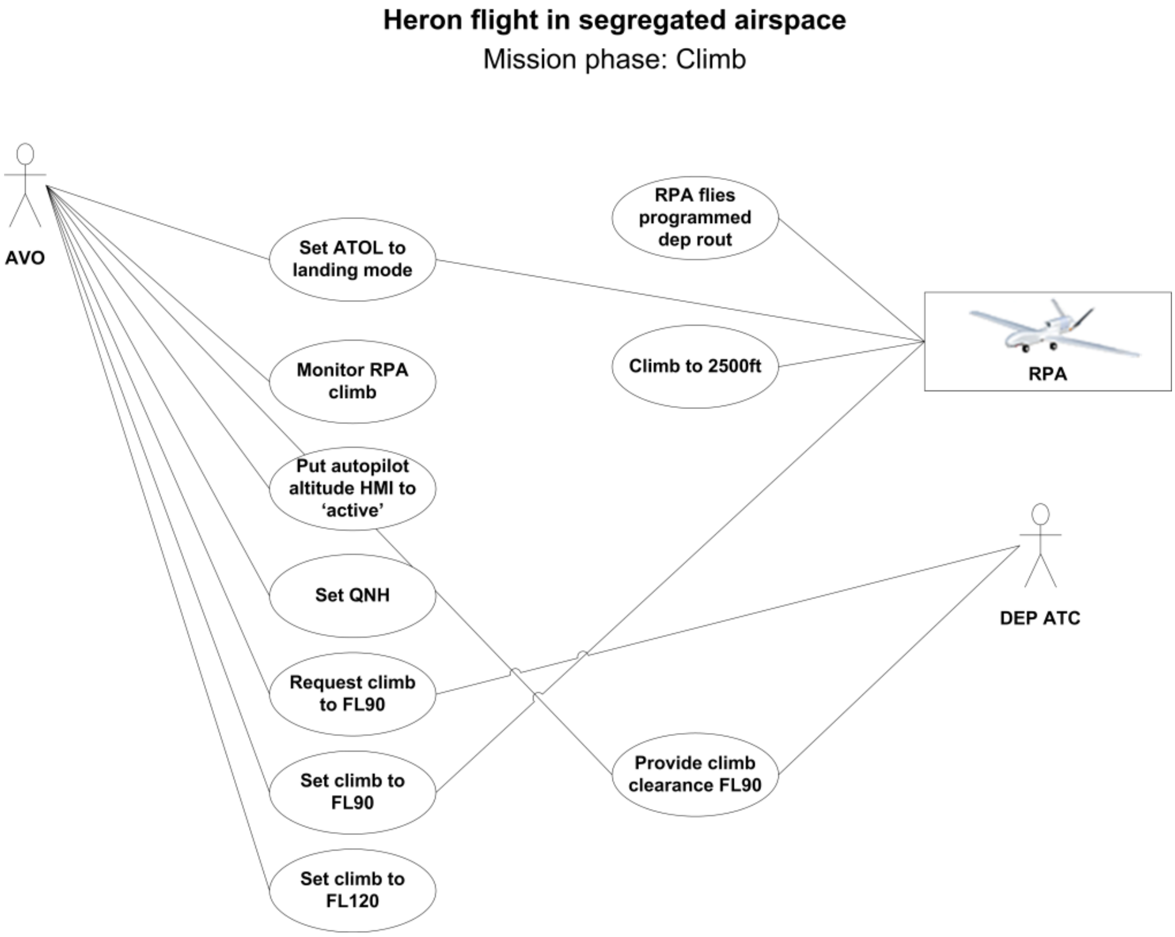
Taxi and take off

After completion of the ground ops, the AVO selects the correct channel/frequency and contacts tower control for taxi clearance. Upon confirmation of taxi clearance, the AVO provides instructions to the ground crew to tow the RPA to the appropriate runway. During this time, the tower (ATC) has no contact with the towing vehicle, all communication proceed through the AVO. After the RPA has towed to the appropriate runway, and the towing vehicle has egressed from the runway, the AVO changes frequency to Departure control and requests take-off clearance. After receiving take-off clearance, the AVO puts the RPA in take-off mode upon which the RPA performs a 10 seconds automatic system check. The RPA then proceeds to take off, changes to the departure route and independently flies in accordance with the cleared departure route. The AVO monitors the take-off of the RPA.



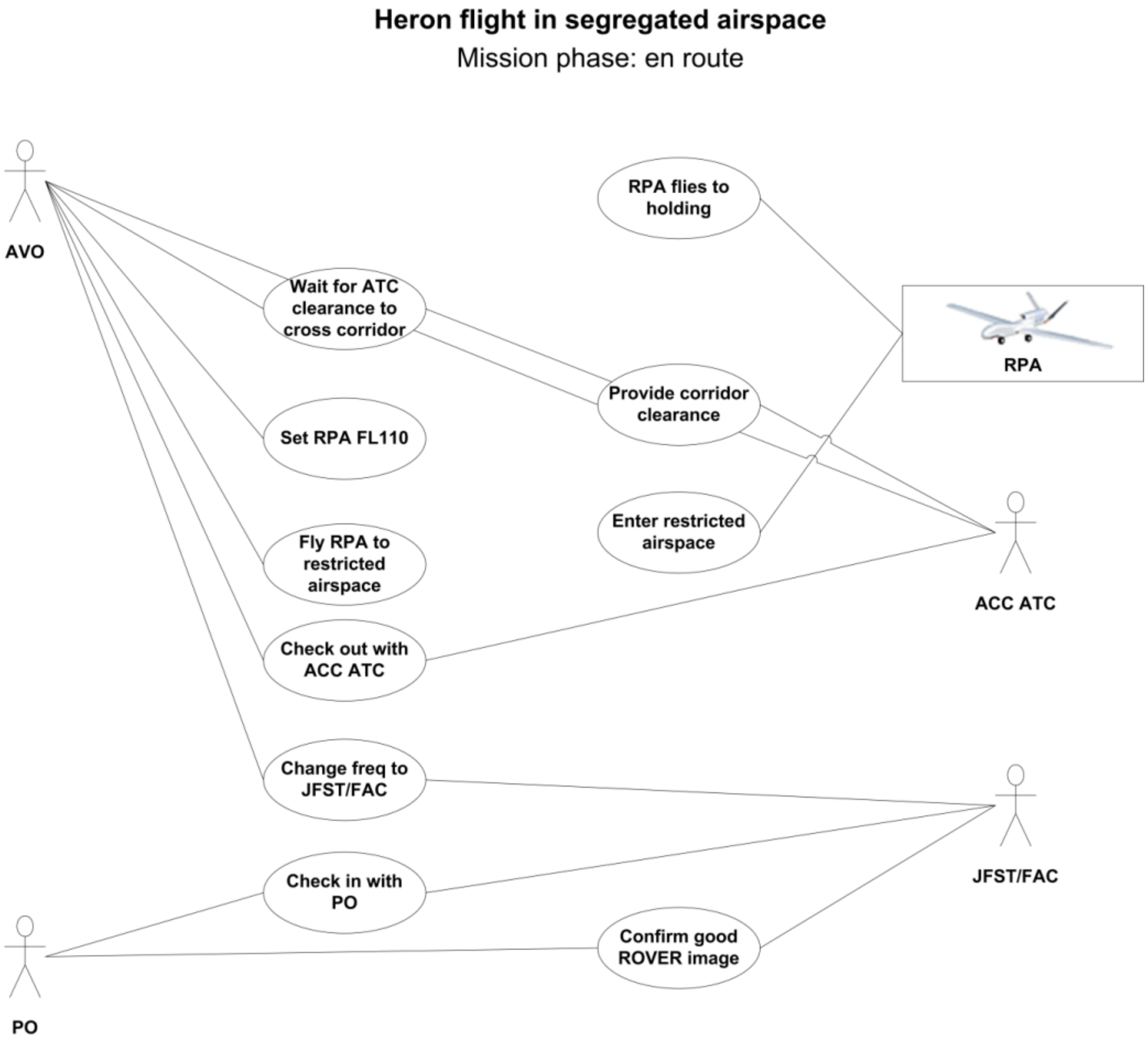
Climb

After taking off, the RPA flies the programed departure route. AVO proceeds to set the Automatic Take-off and Landing system (ATOL) back to landing mode in case of emergencies. AVO monitors RPA flight while the RPA climbs to 2500 feet. The AVO proceeds to put auto pilot altitude system HMI to active' and set QNH to standard atmosphere. The AVO then requests and receives clearance for climb to FL90 and sets climb to FL90, corresponding to the lateral limitations of the restricted area (ED-R). When the RPA is within the Temporary Restricted Area (TRA), the AVO sets climb to FL120.



En route

After climbing, the AVO flies the RPA towards a holding area. The AVO requests to cross a temporary restricted air corridor to another restricted airspace and waits to receive clearance. When the AVO receives clearance, the AVO sets a descend to FL 110. The RPA proceeds to enter the restricted airspace (ED-R) at FL080. The AVO proceeds to check out with the supervising ATC and changes AVO changes frequency to contact the Joint Fire Support Team (JFST, also known under Forward Air Control (FAC)). As there is only one frequency available, the AVO can now only by reached by the supervising ATC via land (telephone) line. The PO checks in with JFST and coordinates on the (training) task at hand.

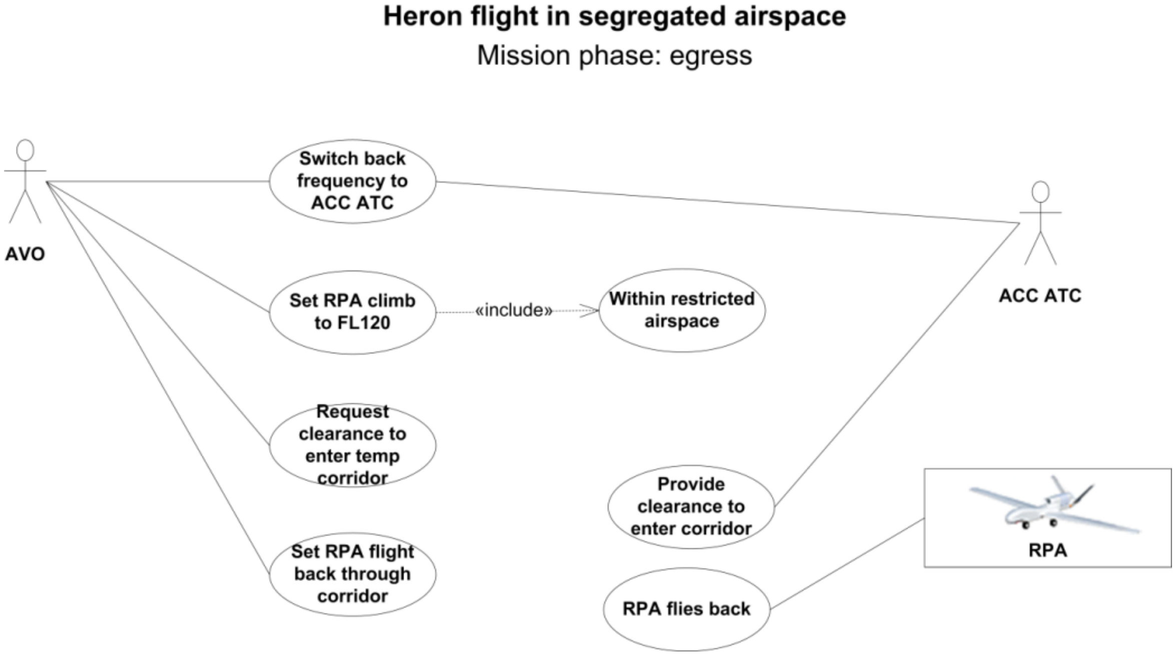


Training Task

As the PO coordinates with the JFST/FAC, the AVO steers the aircraft to the holding pattern and positions requested by PO. The PO talks to JFST to coordinate the fire support. Upon request, the AVO moves the aircraft out of (Fire Support) projectile's way.

Egress

After completion of the training task, the AVO switches back to the ATC frequency of the supervising ATC. The AVO proceeds to climb the RPA to FL120 within the restricted air space. After requesting clearance to enter the temporary air corridor, the AVO flies the RPA back according to the planned route.

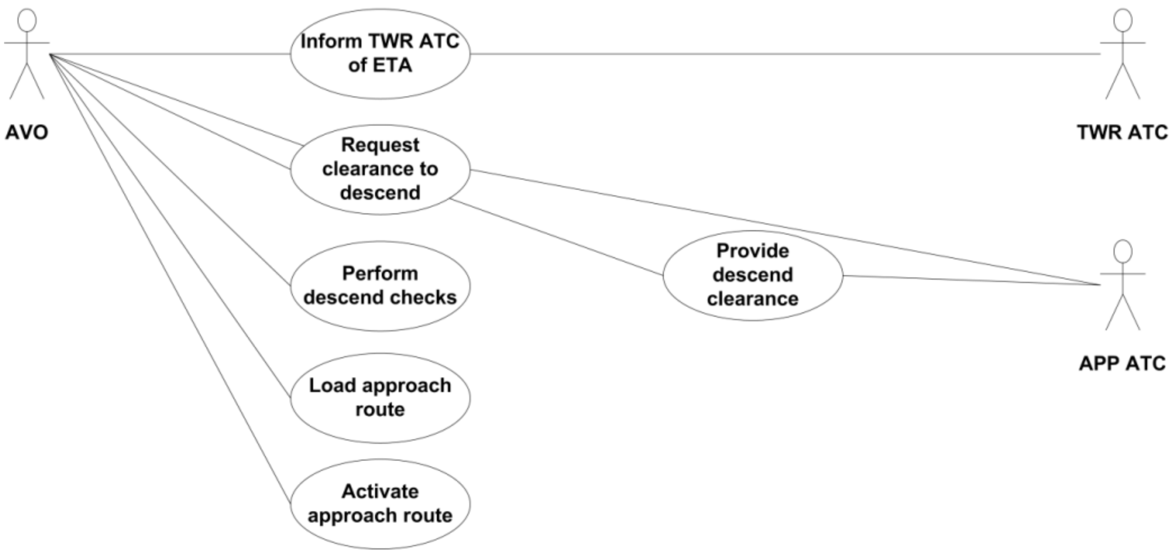


Approach

After egressing, the AVO informs the tower about the Estimated Time of Arrival (ETA) via radio and informs ground crew via land (telephone) line. The AVO receives clearance to descend from approach ATC. The AVO performs the descend checks and loads and activates the approach route.

Heron flight in segregated airspace

Mission phase: approach

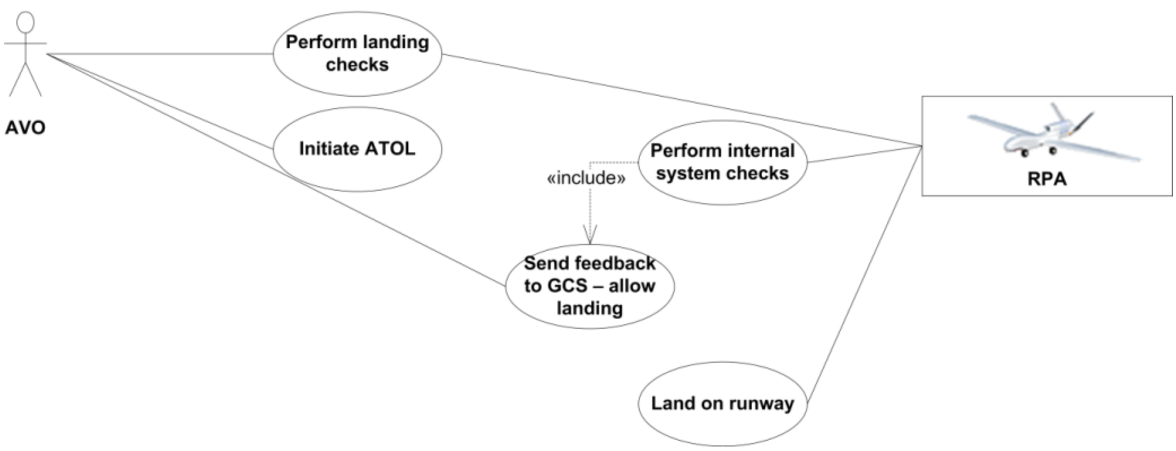


Landing

When the RPA is within landing distance, the AVO performs the landing checks. The RPA also checks internal system and landing parameters and allows landing when the landing criteria are met. After successful completion of landing checks, the AVO initiates the ATOL system automatic landing. This landing is DGPS based but has laser guided back up. The RPA lands and stops on runway.

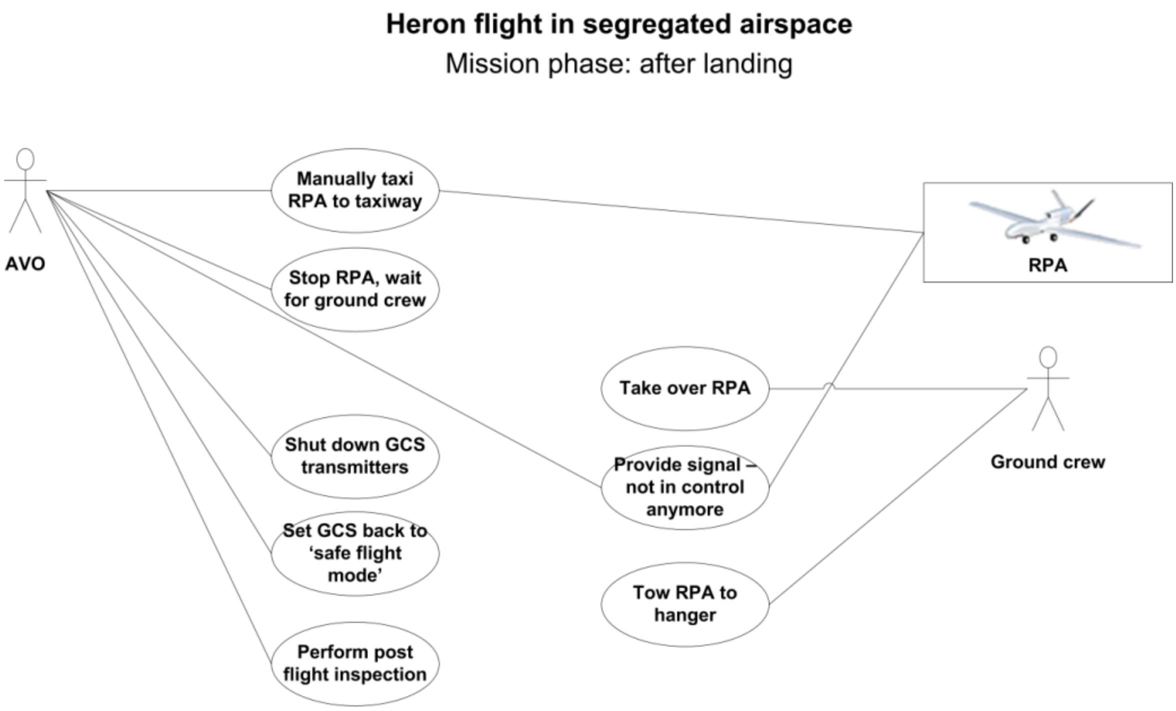
Heron flight in segregated airspace

Mission phase: landing



After landing ops

After landing, the AVO manually taxies the RPA to the taxiway, where it stops and waits for the ground crew to take over the RPA. After the ground crew have taken over control over the RPA by reinserting the control link pin, the AVO receives a system signal that he/she is not in control anymore. The AVO proceeds to shut down the RPS transmitters and set back the RPS to 'safe flight mode' to prevent a situation in which the RPS should unintentionally take over another RPA and turn off the engines of the now taken over RPA. The ground crew tows the RPA back to hangar, and the AVO performs a post flight inspection.



Debrief

After completion of the flight phases and after landing ops, there is a debrief with the crew, and with the JFST/FAC and other supporting units via video conferencing.

Failure flows of MALE RPA (Heron) flight in segregated airspace

Failure flow 1: Loss of link with RPA

During the en route mission phase: when the RPA losses link with the RPS, the RPA continues on the planned route as filed and cleared by ATC. The RPA indicates this by squawking (setting transponder code) 7600 as standard NORDO procedure. The RPA completes mission as planned but does not proceed into landing. The RPA goes into a pre-designated holding near the air base. AVO can then regain control using back up RPS and/or with a backup UHF signal. The AVO then proceeds to land the RPA according to standard landing procedures.

Failure flow 2: delay due to other traffic

During approach phase: due to a Tornado with a changed Estimated Time of Arrival, the TWR ATC requests a 45 min late arrival. The AVO proceeds to put the RPA in a holding.

Failure flow 3: Missed approach

During (automated) landing, the RPA can detect dangerous landing conditions (e.g. due to heavy cross winds). The RPA aborts the landing and performs a missed approach. The RPA then flies to a predetermined holding point. The AVO can then put the RPA back in landing mode upon which the RPA will follow the arrival route and retries the landing.

Failure flow 4: Ground crew forgets to put in pin, do not take over control of RPA

During post flight ground ops: when the ground crew forgets to insert the pin to block the RPA link with the RPS, the AVO does not receive system signal, but still puts RPA in safe flight mode. The RPA proceeds to accelerate out of control. The AVO sees the RPA taxiing on panoramic camera; engine spinning up. The AVO proceeds to apply the brakes, pulls back engine to idle. The AVO then contacts ground crew to take over RPA.

Main flow 2: flight in IFR non-segregated airspace

Task assignment

The first phase of the mission, the task assignment starts with when the Mission Commander (MC) receives a tasking for a mission or training that requires a ferry flight through German airspace. This task is analysed by pilots and mission essential personnel. Mission aspects are determined such as goal, destination and course of action. On the basis of this, a mission flow is designed that comprises a mission (game) plan, mission (navigation) route, contingency plan, frequency management plan and sensor plan. An Air Traffic Control flight plan is then created and filed by the MC with ATC 24 hours before desired take off.

Planning Phase

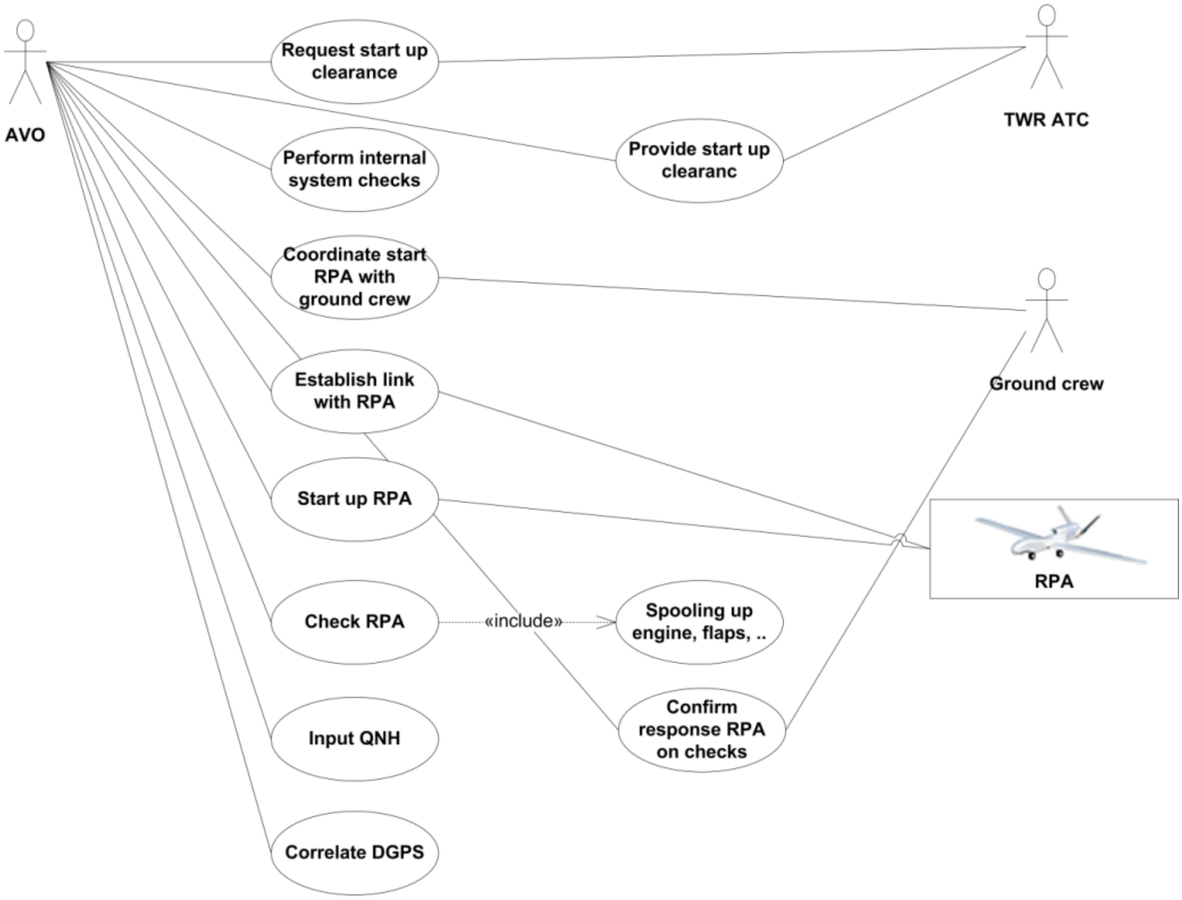
According to the task analysis and mission flow, the MC checks the personnel flight times to determine which crews are available. The MC tasks the Air Vehicle Operator (AVO) with creating a contingency plan on the basis of the mission, which incorporates holdings and extra fuel. The finalized mission plan is verified by the Pilot In Command (PIC) prior to uploading the mission. The mission plan is subsequently loaded in the RPA.

Ground ops

After planning and pre-flight preparations are completed, the AVO gets start up clearance from ATC and checks internal systems. This requires coordination of activities with ground personnel over radio. Ground personnel prepares for AVO control by removing the pin that blocks the link with the RPS. When internal systems are checked, the AVO establishes link to the RPA and takes control over the RPA. The AVO proceeds to start up the RPA and checks responsiveness by spooling up the engine, checking the flaps, etc. The corresponding effects on the RPA of the checks are confirmed to the AVO by the ground crew. The AVO proceeds to input the QNH and correlate the Differential GPS (DGPS) data.

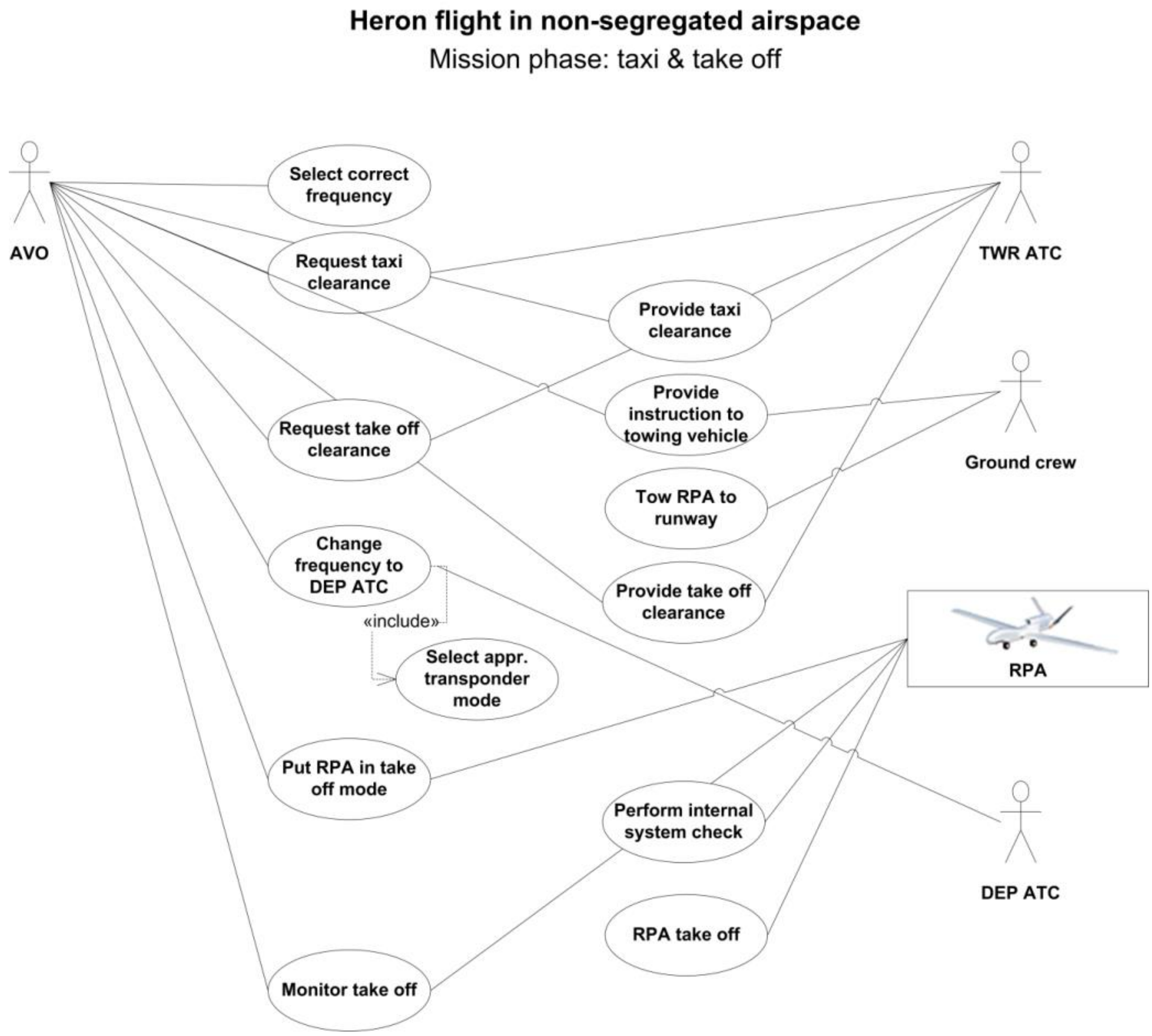
Heron flight in non-segregated airspace

Mission phase: ground ops



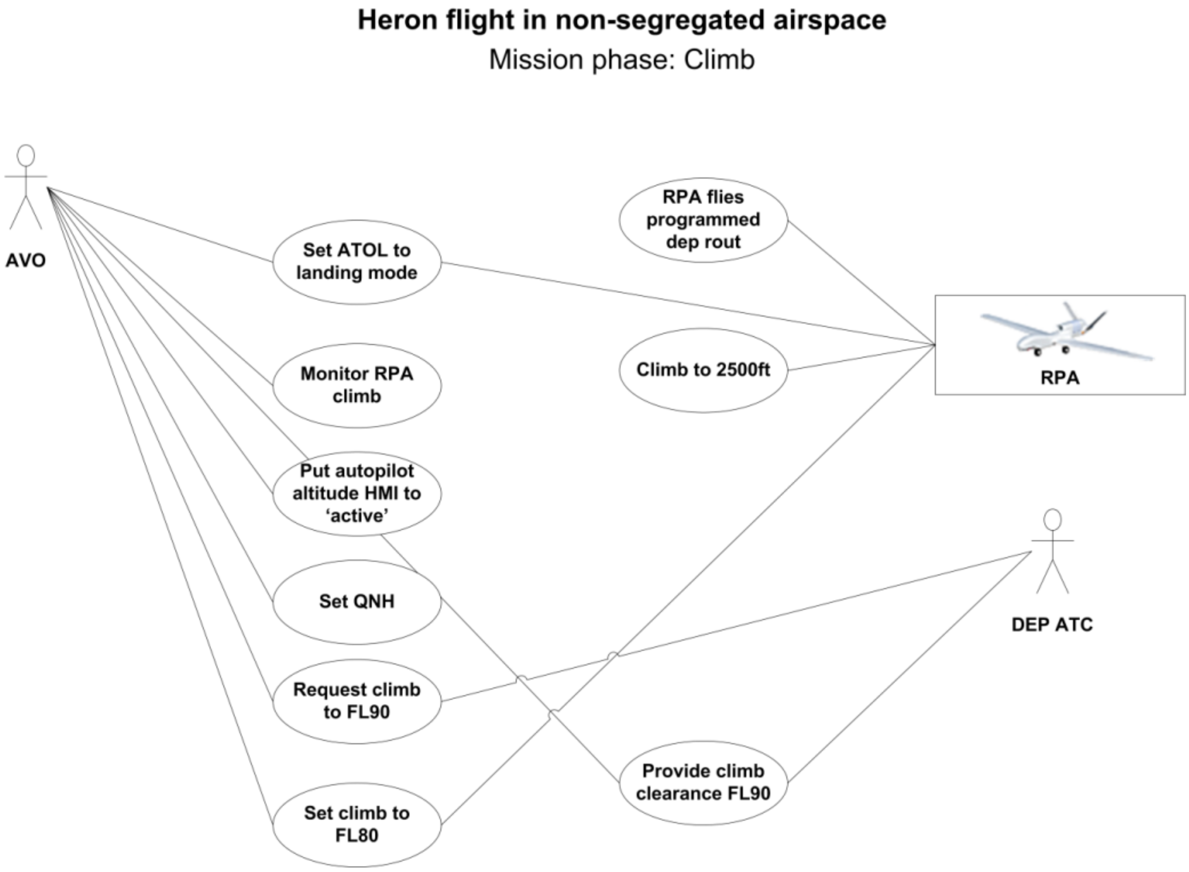
Taxi and take off

After completion of the ground ops, the AVO selects the correct channel/frequency and contacts tower control for taxi clearance. Upon confirmation of taxi clearance, the AVO provides instructions to the ground crew to tow the RPA to the appropriate runway. During this time, the tower (ATC) has no contact with the towing vehicle, all communication proceed through the AVO. After the RPA has towed to the appropriate runway, and the towing vehicle has egressed from the runway, the AVO changes frequency to Departure control and requests take-off clearance. After receiving take-off clearance, the AVO puts the RPA in take-off mode upon which the RPA performs a 10 seconds automatic system check. The RPA then proceeds to take off, changes to the departure route and independently flies in accordance with the cleared departure route. The AVO monitors the take-off of the RPA.



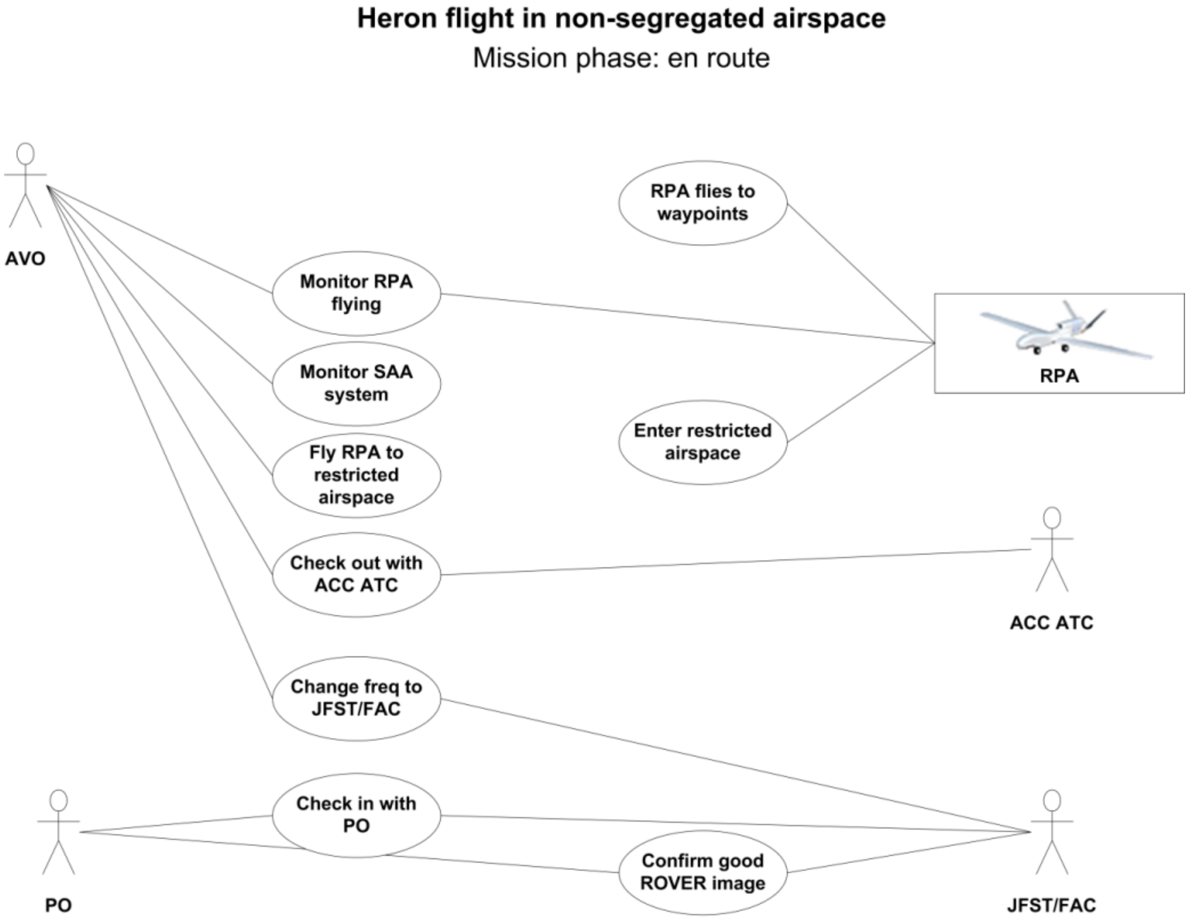
Climb

After taking off, the RPA flies the preprogramed departure route. AVO proceeds to set the ATOL back to landing mode in case of emergencies. AVO monitors RPA flight while the RPA climbs to 2500 feet. The AVO proceeds to put auto pilot altitude system HMI to active' and set QNH to standard atmosphere. The AVO then requests and receives clearance for climb to FL90 and sets climb to FL90. The AVO then sets climb to FL080 within the lateral limits of the restricted airspace.



En route

After taking off the AVO flies the RPA the first waypoints. The AVO monitors the RPA flying to the waypoints, and monitors the Sense and Avoid system for traffic. If VFR traffic crosses, the AVO informs ATC about this. Upon arrival at the training area, the AVO proceeds to check out with the supervising ATC and changes frequency to contact the Joint Fire Support Team (JFST, also know under Forward Air Control (FAC)). As there is only one frequency available, the AVO can now only by reached by the supervising ATC via land- (telephone-) line. The PO checks in with JFST and coordinates on the (training) task at hand. The JFST/FAC reports the quality of the ROVER image to the PO.

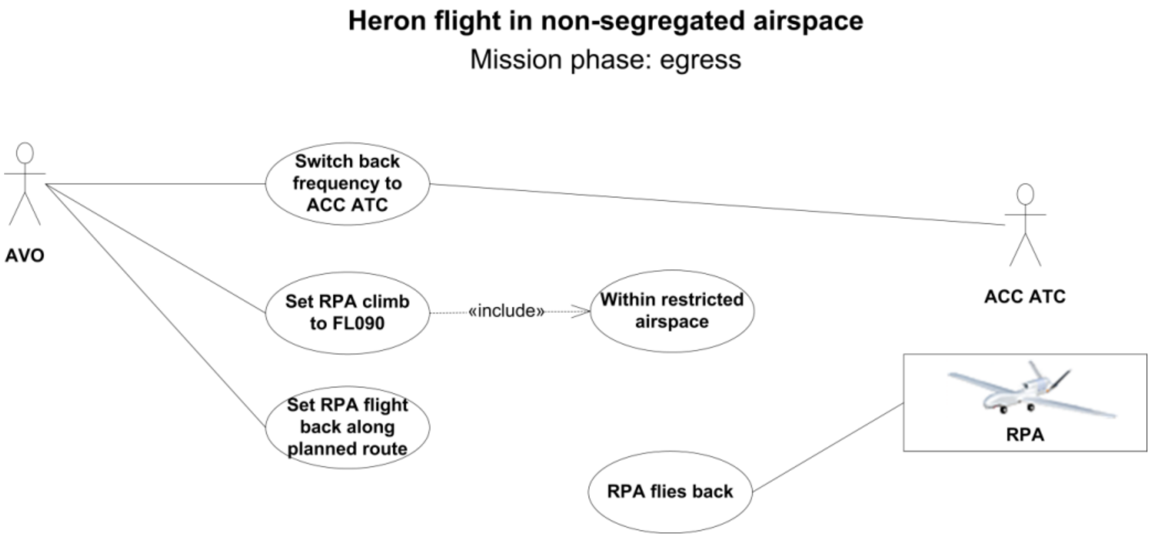


Training Task

As the PO coordinates with the JFST/FAC, the AVO steers the aircraft to the holding pattern and positions requested by PO. The PO talks to JFST to coordinate the fire support. Upon request, the AVO moves the aircraft out of (Fire Support) projectile's way.

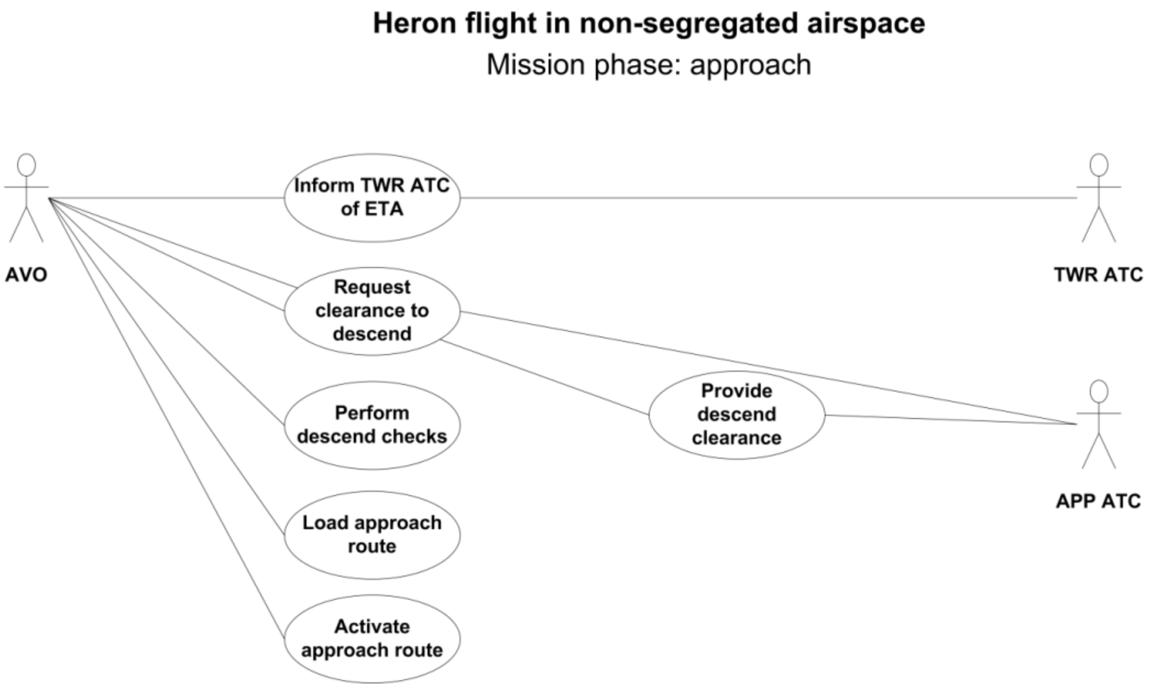
Egress

After completion of the training task, the AVO switches back to the ATC frequency of the supervising ATC. The AVO proceeds to climb the RPA to FL090 within the restricted air space. The AVO flies the RPA back according to the planned route, all the while monitoring the RPA and SAA system.



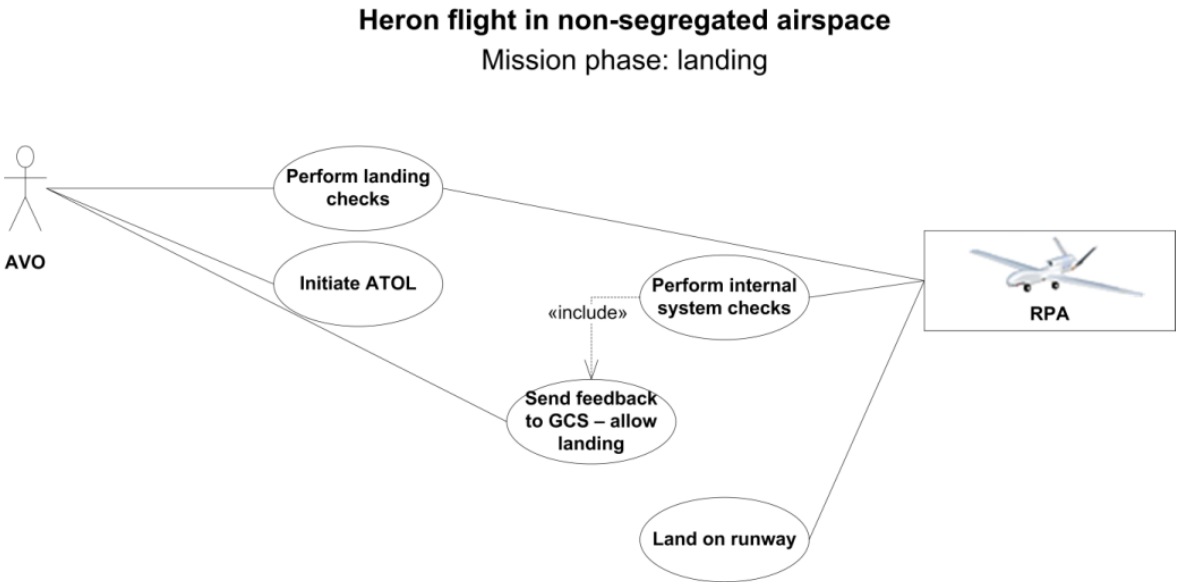
Approach

After egressing, the AVO informs the tower about the Estimated Time of Arrival (ETA) via radio and informs ground crew via land (telephone) line. The AVO receives clearance to descend from approach ATC. The AVO performs the descend checks and loads and activates the approach route.



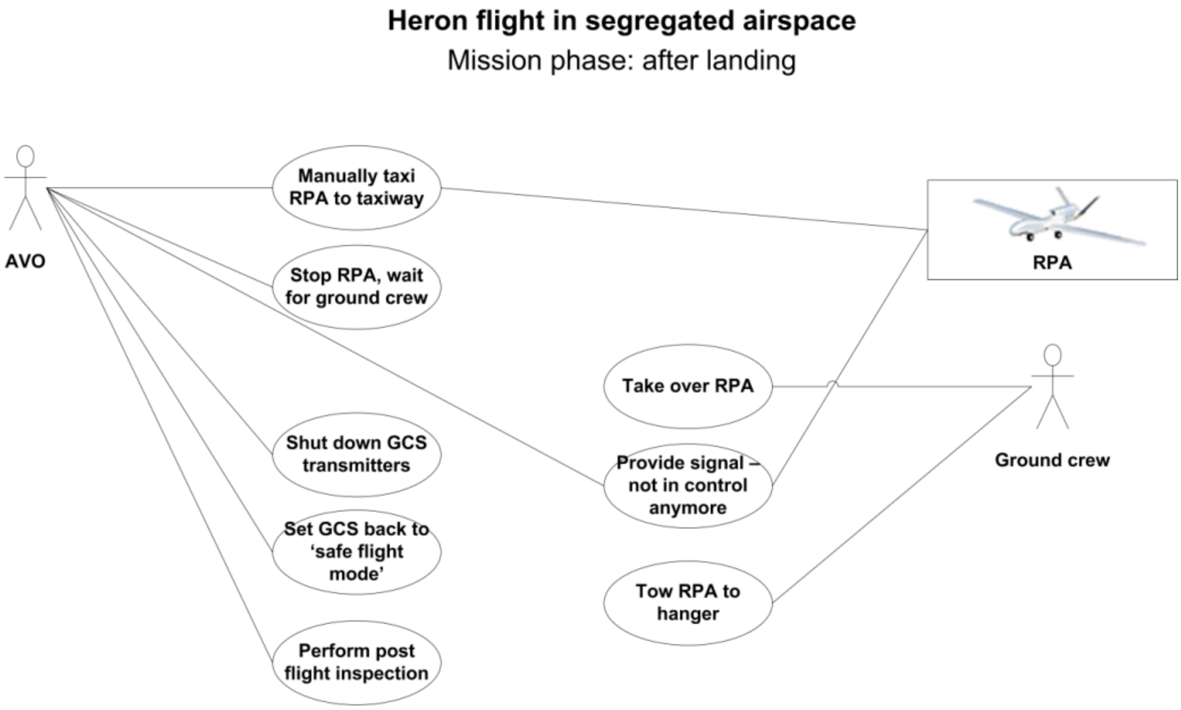
Landing

When the RPA is within landing distance, the AVO performs the landing checks. The RPA also checks internal system and landing parameters and allows landing when the landing criteria are met. After successful completion of landing checks, the AVO initiates the ATOL system automatic landing. This landing is DGPS based but has laser guided back up. The RPA lands and stops on runway.



After landing ops

After landing, the AVO manually taxies the RPA to the taxiway, where it stops and waits for the ground crew to take over the RPA. After the ground crew have taken over control over the RPA by reinserting the control link pin, the AVO receives a system signal that he/she is not in control anymore. The AVO proceeds to shut down the RPS transmitters and set back the RPS to 'safe flight mode' to prevent a situation in which the RPS should unintentionally take over another RPA and turn off the engines of the now taken over RPA. The ground crew tows the RPA back to hangar, and the AVO performs a post flight inspection.



Debrief

After completion of the flight phases and after landing ops, there is a debrief with the crew, and with the JFST/FAC and other supporting units via video conferencing.

Failure flows of MALE RPA (Heron) IFR flight in non-segregated airspace

Failure flow 1: Other traffic during en route phase – separation issue

When the RPA is en route to the waypoint Nordholz, other traffic may be encountered. ATC will inform the AVO about the other traffic, which requires a route change. The AVO puts the auto pilot system heading HMI on 'active' and manually steers the RPA to the designated route.

Failure flow 2: Loss of link with RPA during en route phase

When the RPA is en route to the training area, a loss of link can occur. The RPA will continue to keep flying the programmed route. The AVO contacts ACC that the RPA is unresponsive. ACC follows the normal 'non responsive aircraft' procedures that are also used on manned aircraft. ACC navigates other traffic away from the RPA. When the AVO regains control of the RPA (e.g. by using a different signal or by a maneuver made by the RPA), the AVO resumes the normal mission flow.

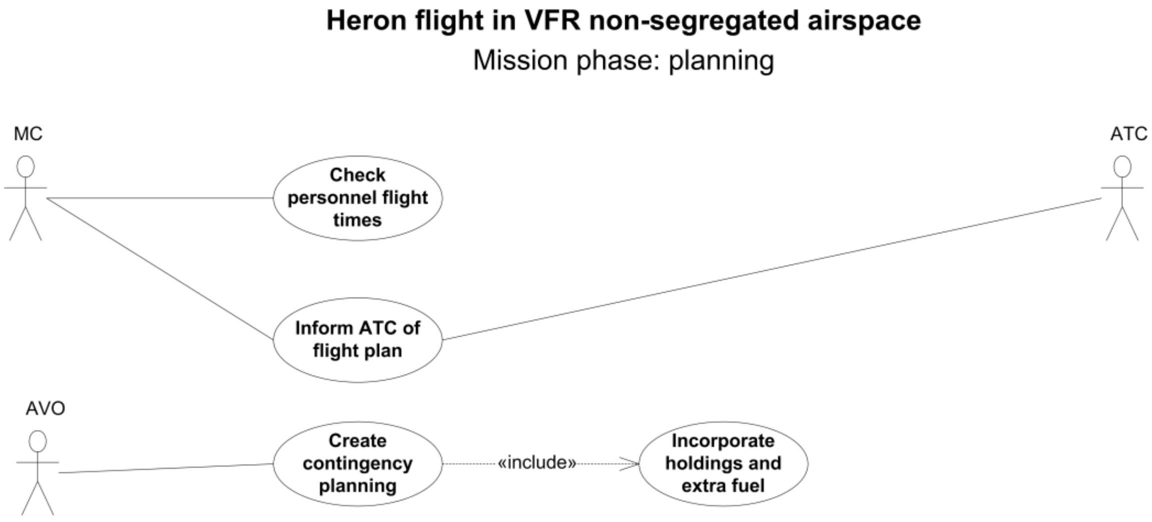
Failure flow 3: VFR traffic with wrong QNH setting – flying on same FL

It is possible that ATC contacts the AVO to inform that VFR traffic is crossing 500ft below. When this other aircraft has incorrect QNH setting, it is possible the two aircraft are actually on the same FL. In this situation, the AVO will be informed about the separation issue by the RPA 'seperation provision system'. The AVO subsequently informs the ATC that VFR is on the same FL and requests a heading or FL change. After confirmation of the request is received, the AVO puts the auto pilot system heading HMI on 'active' and manually steers the RPA to avoid the other aircraft. When the AVO is unable to take action, e.g. due to a loss of link or due to low levels of alertness, the RPAs SAA system will analyse the situation. The situation is interpreted by the SAA system movement of the other aircraft and the distance marker. The SAA system will autonomously instruct the RPA to take evasive measures. When the AVO is able to regain action, the AVO takes over control from the autonomous system. The RPA subsequently goes back to the programmed course. The AVO can override this behaviour if necessary.

Main flow 3: flight in VFR non-segregated airspace

Planning

The planning for a training flight in VFR starts by the MC checking the personnel flight times to plan the crew rosters. The MC then informs ATC about the flight plan. A contingency plan is created by the AVO, which incorporates flight relevant information to ATC.

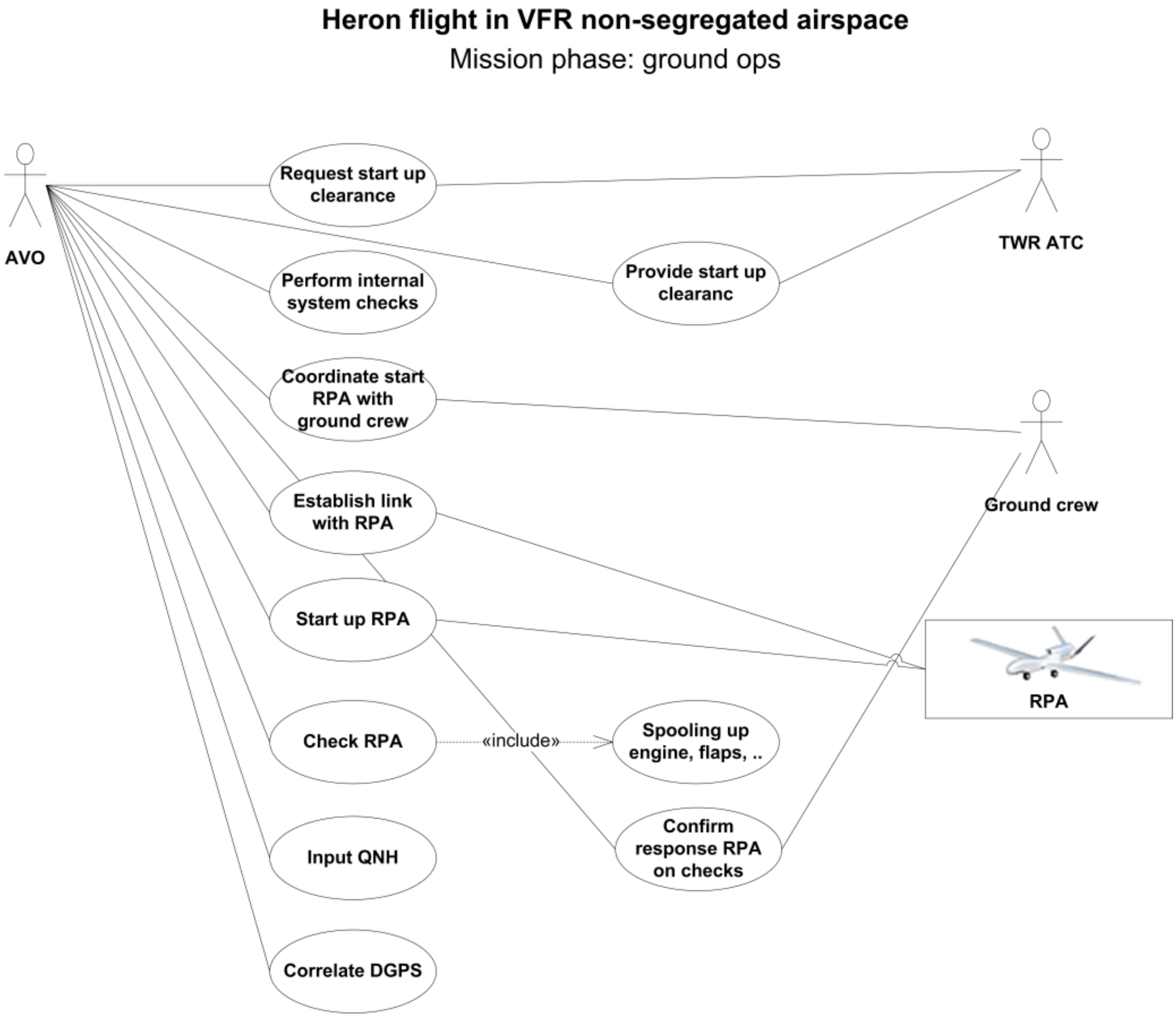


Pre flight

On the basis of the flight plan, the AVO creates a mission route in the RPS. Actual current NOTAMS are incorporated into the route. A visual inspection of the aircraft and RPS is subsequently performed by the AVO. When the aircraft and RPS have passed inspection, the maintenance log is signed out by the AVO.

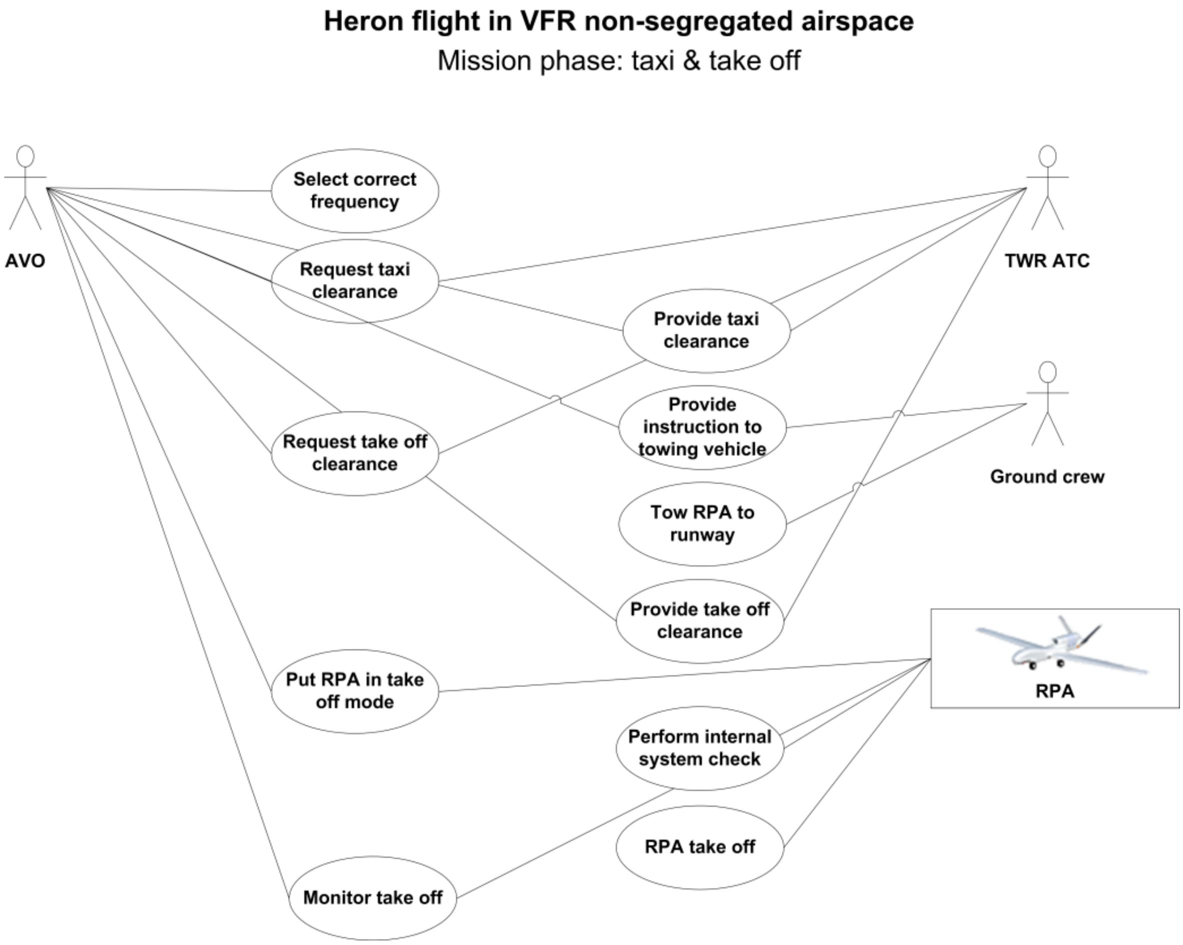
Ground ops

The ground ops phase starts with the AVO receiving clearance from tower control to start up the aircraft. The AVO performs an internal system check (in the RPS). The AVO then establishes a link to the RPA, thereby taking over control of the aircraft. The AVO starts up the aircraft and checks aircraft response by performing the aircraft specific pre-flight checks. These checks are confirmed by the ground crew who are present near the aircraft. When checks are performed, the AVO inputs the QNH and correlates the DGPS data.



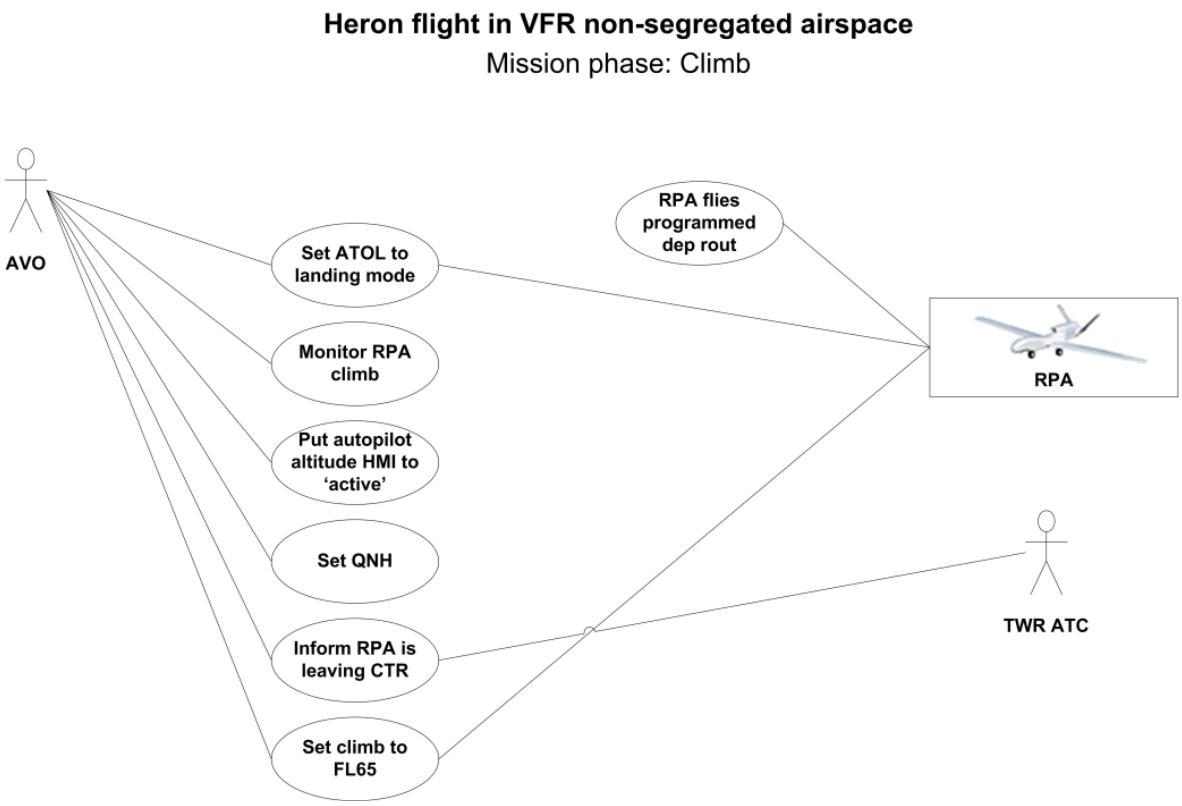
Taxi and Take off

When ground ops are complete, the AVO contacts tower control for taxi clearance. After receiving clearance, the AVO coordinates and provides instructions to the towing vehicle (runway number, crossing of runways) to maneuver the vehicle to the start of the designated runway. The towing vehicle is not in direct contact with ATC during this period. When the aircraft is at the designated waiting position, the AVO requests take off clearance. Upon receiving clearance to take off, the AVO puts the RPA in take-off mode. The aircraft subsequently performs a 10 second automatic system check to confirm the system is in proper working order. When the internal systems check is complete, the aircraft takes off (in take-off mode, at 115% engine power) and puts itself on the pre-planned departure route. The AVO monitors the take-off, and puts the aircraft in departure mode as soon as possible.



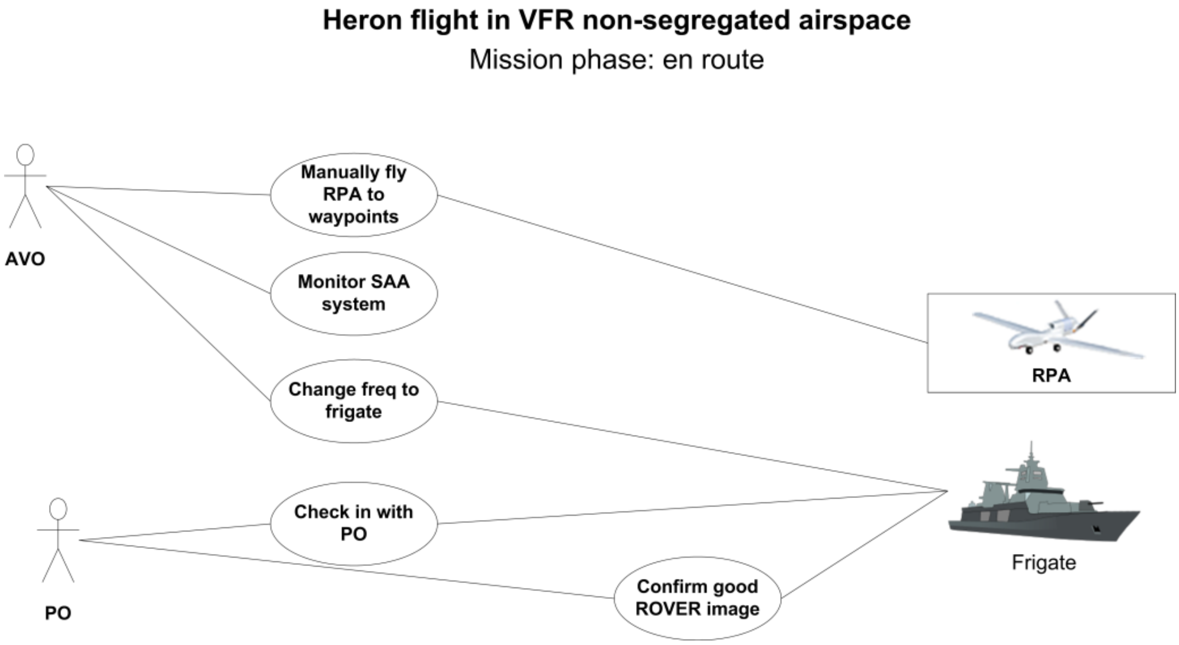
Climb

After the AVO has put the RPA in departure mode, the aircraft flies the programmed departure route. The AVO sets the Automatic Take-off and Landing (ATOL) system back to landing mode so the aircraft can land when a loss of link occurs. The AVO monitors the flight and puts the auto pilot altitude system HMI to ‘active' and sets the QNH to standard atmosphere. The AVO informs the tower that the RPA is leaving the CTR. When leaving the CTR, there is no longer any radio contact with TWR. The AVO sets climb to FL65. The AVO contacts the ACC.



En route

During the ‘transition period’ from the departure phase to the enroute phase, the AVO keeps the HMI in ‘active’ mode to be able to react faster on potential problems. The AVO manually flies the RPA to waypoint Nordholz and on to the next waypoints using headings. To avoid other traffic, the AVO monitors the SAA system. When approaching the training area (North Sea), the AVO changes frequency to contact the frigate. Bremen radar can now only be reached by land line. The PO checks in with the frigate and receives confirmation of the RPA ROVER image.



Training

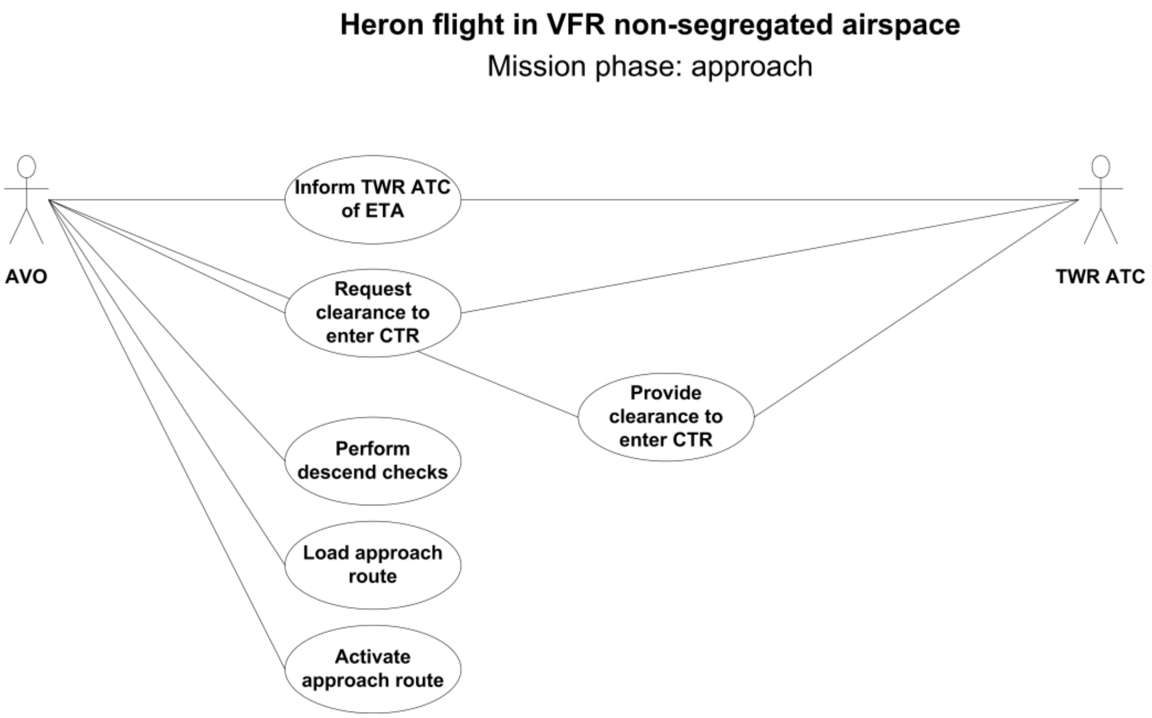
For the training exercise, the AVO steers the RPA to a holding pattern and positions requested by the PO. The PO communicates with the frigate to coordinate the RPA actions. If the RPA has illuminated a target, the AVO moves the aircraft out of the way of weapon trajectories so the frigate can commence with actual weapon release.

Egress

After the training, the AVO flies the RPA back according to the planned route. The AVO monitors the SAA system during the egress phase to remain separated from other traffic. AVO changes frequency back to ACC.

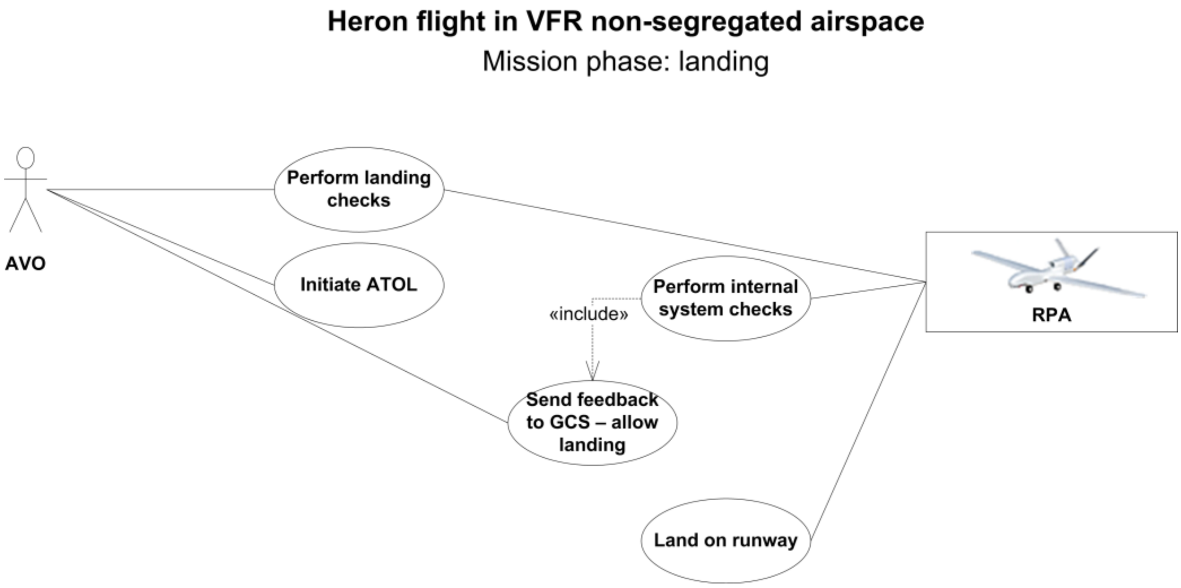
Approach

Upon approaching the air base, the AVO informs the tower about the Estimated Time of Arrival (ETA). The AVO also informs the ground crews using the land telephone line. The AVO flies the RPA to the entry point, contacts TWR to receive entry clearance to enter CTR. The AVO subsequently receives clearance from tower control to enter the CTR. The AVO performs the descend checks and loads and activates the approach route. The approach route brings the aircraft into the landing cone (brings the RPA within the landing parameters). No ground based landing assistance is needed.



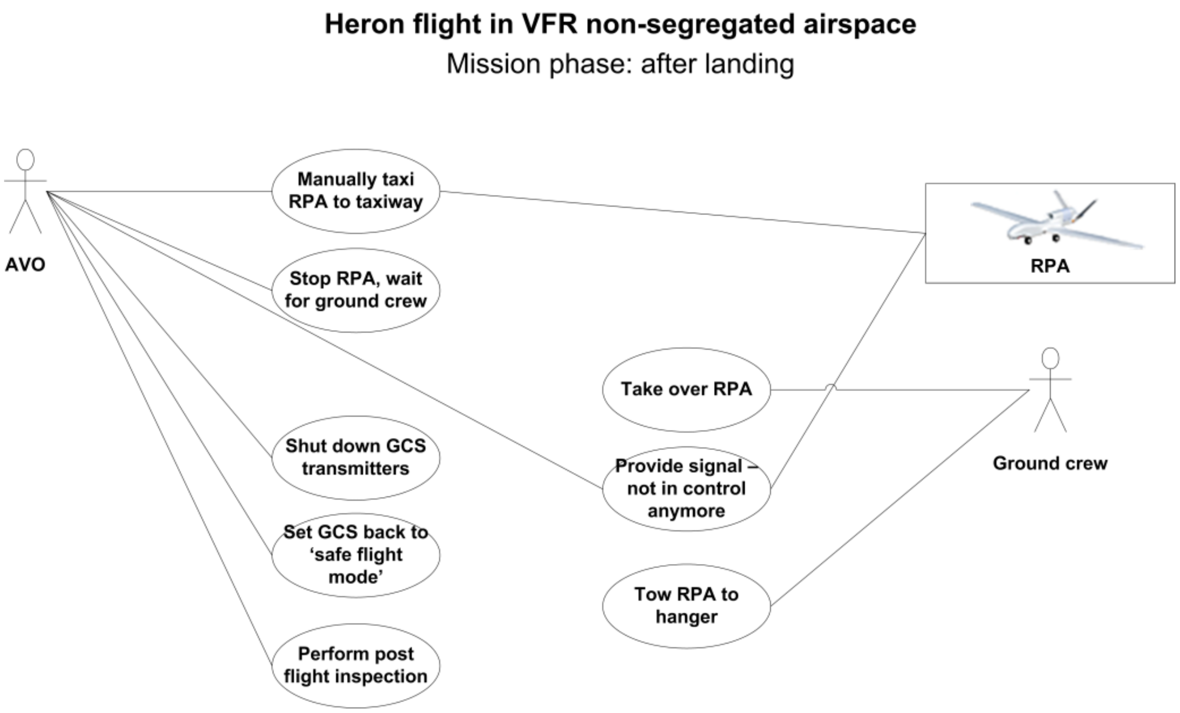
Landing

When approaching the runway, the AVO performs the landing checks. The RPA also checks internal systems and landing parameters. If checks are completed, the RPA allows landing to commence. The AVO initiates the automatic landing systems, upon which the RPA lands and stops on the runway.



After landing

After landing, the AVO manually taxies the RPA to the taxiway. The AVO stops the RPA and waits for the ground crew to take over the RPA. The ground crew takes over the RPA by disconnecting the link with the RPS by inserting a pin in the RPA. The AVO receives a system signal that he/she is not in control anymore. The AVO shuts down the RPS transmitters and puts the RPS back in 'safe flight mode', in case the RPS unintentionally takes over other RPAs. The Ground crew subsequently tows the RPA back to the hangar. The AVO performs a visual post flight inspection of the aircraft.



Debrief

After the flight, a debrief is performed with the crew. A video conference is held with the frigate crew.

Failure flows of MALE RPA (Heron) flight in VFR non segregated airspace

Failure flow 1: Loss of link with RPA during en route phase

When the RPA is en route to the training area, a loss of link can occur. The RPA will continue to keep flying the programmed route. The AVO contacts ACC that the RPA is unresponsive. ACC follows the coordinated 'non responsive aircraft' procedures. ACC keeps safe separation for all other air traffic to the RPA. When the AVO regains control of the RPA (e.g. by using a different signal or by a maneuver made by the RPA), the AVO resumes the normal mission flow.

Failure flow 2: Landing missed approach

If during the landing phase the RPA detects dangerous landing conditions (e.g. heavy crosswinds), the RPA will abort the landing. The RPA will proceed to fly to a predetermined holding point. The AVO then proceeds to put the RPA back in landing mode. The RPA will commence with the normal arrival route and retry the landing.

Failure flow 3: ground crew does not take over RPA – RPA out of control

When the RPA has landed, the ground crew has to take over the RPA to prevent an unintentional input from the RPS and the subsequent dangerous situation to the ground crew on or around the aircraft. When the ground crew does not cut off the link with the RPS (e.g. by forgetting to put the pin back in, or by not correctly inserting the pin) the RPA can still receive input from the RPS. If the AVO will not receive a system signal, but still puts the RPS in safe flight mode, the RPA will accelerate out of control. The pilot can detect this by seeing the RPA spool up the engines on the RPA panoramic camera or be attended to the actions of the RPA by the ground crew. The AVO applies the brakes and puts the engine back to idle. The AVO subsequently contacts the ground crew to take over the RPA.

Use Case 2, Operational Mission in AFG:

J2 at RC North has information that a group of insurgents (INS) is located near Aq Tappeh (30 km northwest of PRT Kunduz) and tries to disrupt the work of the local security forces by threatening and blackmailing the civilian population in order to bring the area back under insurgent's control.
The decision is made to send a Task Force Kunduz squad to patrol the area, talk to the locals and key leaders to gain their trust that the ISAF and ANSF is able to provide security and stability for the area. In case of contact with INS they are to be detained and handed over to the ANSF.
Analysing his task the squad leader TF KDZ realizes the necessity of area reconnaissance and writes an ISR request to the ISR Manager RC North. The ISR Manager tasks TE HERON EG MeS (the unit's name in German) to support the squad.

This task is received by the mission commander (MC) TE HERON EG MeS 24 hours before the mission and he immediately contacts the TF KDZ to discuss all the necessary details like area of operation, frequencies, callsigns, available JTAC´s, FAC´s, planned tactics etc.
After this he hands over all the information to the planning crew (normally the air vehicle operator (AVO) and payload operator (PO) taking off this mission) and books the necessary airspace with air traffic control.

The day before the mission the aircraft and shelter are checked and the status is reported to the MC. If everything is fine, he signs the flight order. An hour before take-off the aircraft and sensors are checked one more time and after take-off while still within MeS airspace the payload operator (PO) makes sure the sensors can be used without any restrictions.

During transit to the area of operation the higher headquarter of the tasked squad is contacted via ISAF secure line, to get the latest updates like change of callsigns, frequencies or times.
Arriving at the area of operation contact to the JTAC or FAC is established via radio.
During the mission there is a constant exchange of information between the troops on the ground and the aircrew about the situation, planned moves and what the PO sees and all mission relevant data. Furthermore the airspace booking is constantly adjusted to the mission needs by the AVO. The flight crew is exchanged every 4 hours and a quick handover briefing is given to the new crew. This is done to give the squad the best support possible.

After the squad has finished their mission and ISR support is no longer needed the JTAC releases HERON and the plane transits back to MeS.

With ATC clearance the AVO activates the automatic landing and the aircraft lands while monitored by the AVO. After landing it is towed back into the hangar and the post flight inspections are done. This concludes the mission.

Main flow 4: flight in (military) segregated airspace in Afghanistan

Planning

The planning if a military flight in segregated airspace in Afghanistan begins with an ISR request by the Task Force Kunduz to the ISR manager. The MC receives the task from the ISR manager and establishes contact with the ISR requester (TF Kunduz). The MC discusses the details with the requester, including the area of operation, frequencies, call signs, available JTACs/FACs, tactics, etc. When all necessary information is collected, the MC hands over the information to the planning crew, normally constituting of the AVO and PO. The planning crew subsequently plans the mission and books necessary airspace with ATC.

Pre-flight ops

A day before the mission, the MC checks the aircraft and shelter. The MC signs the flight order and, one hour before take-off, checks the sensors.

Take off and climb

The aircraft automatically takes off and climbs to the designated flight level.

Enroute

During the enroute phase, the PO checks the sensors again and makes sure the sensors can be used without any restrictions. The PO contacts higher headquarters via the ISAF secure line and gets the latest updates on callsigns, updated frequencies and updates times.

In theatre

When arriving in theatre, the PO contacts the JTAC/FAC via the radio frequency. Relevant information about the situation is exchanged between the PO and the troops. This includes the situation, planned moves, what the PO sees as well as all other mission relevant data. The AVO simultaneously (constantly) adjusts airspace booking. Every four hours, a flight crew change is necessary. Each crew change is preceded by a quick handover briefing about the situation.

Egress

When the JTAC does no longer needs RPA support, he ‘releases’ the RPA. The AVO then proceeds to transit back to the airbase.

Landing

When approaching the airbase, the AVO contacts ATC and requests landing clearance. ATC permits the landing clearance and the AVO activates the automatic landing system. The aircraft proceeds to land, continuously monitored by the AVO.

Ground ops

After landing, the aircraft is towed back to the hanger. The AVO performs the post flight inspections to the aircraft.

Debrief

After the flight, a debrief is held with the crew.

Appendix B Use Case EuroHawk

Executive summary

Use Cases (UC) are a technique for capturing the functional requirements of a system. “Properly written, they accurately detail what the system must do”. Use cases contain a number of scenarios in which a user of the system (in this case the remote pilot) is the central actor. Moreover, the scenarios in a Use Case are tied together by a common user goal. The primary scenario is the ‘main success scenario’ which describes a successful flow for flying RPAs in non-segregated airspace, hence the objective is: safe RPA operation in non-segregated airspace. Table B.1 positions this Use Case in the larger scope of RPAS operations in an ATM environment.

Table B.1: Airspace classification and potential types of RPAS operations

Class of Operation	Type of operation	Segregated Airspace	Non Segregated Airspace						
			Controlled Airspace					Uncontrolled Airspace	
		segregated	class A	class B	class C	class D	class E	class F	class G
VFR	VLOS		N/A						
	E-VLOS		N/A						
	B-VLOS		N/A						
	RLOS	EURO HAWK Germany	N/A		EURO HAWK Germany				
	B-RLOS		N/A						
IFR	VLOS								
	E-VLOS								
	B-VLOS								
	RLOS	EURO HAWK Germany			EURO HAWK Germany	EURO HAWK Germany			
	B-RLOS	EURO HAWK Germany			EURO HAWK Germany				

The airspace classes are colour coded, indicating the likelihood of usage for RPA operations, depending on the provision of Air Traffic Services and separation as well as the radio communication requirements, facilitating safety. Green indicates the highest level of safety facilitation.

The following types of operations are distinguished (SJU, 2012):
Non-standard RPAS operations in VFR or IFR, below the typical IFR and VFR altitudes for manned aviation: i.e. not to exceed 400 ft. above ground level; they comprise:
Visual line of sight (VLOS) in a range not greater than 500 meters from the remote pilot, in which the remote pilot maintains direct unaided visual contact with the remotely piloted aircraft;
Extended Visual Line of Sight (E-VLOS) where, beyond 500 meters, the pilot is supported by one or more observers, in which the crew maintains direct unaided visual contact with the remotely piloted aircraft;
Beyond VLOS (B-VLOS) where the operations are also below 400 ft. but beyond visual line of sight requiring additional technological support.
Standard RPAS operations in VFR or IFR, above 400 ft. and above minimum flight altitudes; they comprise:
IFR (or VFR) operations **in radio line-of-sight (RLOS)** from the RPS in non-segregated airspace where manned aviation is present. The key capability of 'detect and avoid' (D&A) is required in relation to cooperative and non-cooperative nearby traffic (otherwise specific procedures and restrictions would apply);
IFR (or VFR) operations **beyond radio line-of-sight (BRLOS) operations,** when the RPA can no longer be in direct radio contact with the RPS and therefore wider range communication (COM) services (including via satellite) are necessary. In this case COM would typically be offered by a COM service provider.

The altitudes that are identified for the above mentioned operations are of a generic nature not taking into consideration national differences and exemptions.
Further, this document describes alternative scenarios, which are potential failure flows, with events such as imminent loss of separation, imminent collision risk, an emergency resulting in a loss of functionality or human error.

The descriptions of the scenarios will reveal specific human factor issues associated with both success and failure flows, such as issues associated with the hand-over procedure of the RPA between pilot and maintenance crew, or issues related to auto pilot mode switching.

The purpose of this document is to understand functional requirements for operations of RPAs in non-segregated airspace in order to ensure safe operations, with levels of safety that do not decrease the levels of safety that are achieved with manned operations to date, in the ATM system. HSI implications of such requirements are considered, i.a. implications for manpower, training, RPS design and use of automation. To acquire the information, interviews with an RPA (EURO HAWK) administrator and an operator were performed.

Although such systems are currently not certified for use on RPAs, it is assumed that the RPA is equipped with a functioning sense-and-avoid system that replaces the human see-and-avoid obligation to fly in non-segregated airspace.

Use cases reflect a portion of the total set of requirements to be imposed on a system, namely the human behavioural requirements. To formulate these requirements, one needs to ask
‘What does the user need to do, to actually perform each step of each scenario in the use case?’
‘What is the human backup to system operation?’
‘What legal (e.g. RPA personnel licensing, RPA airworthiness) and what political (e.g. on border crossing operations) requirements are there?’
‘What are the human consequences of creating a system that is able to perform these scenarios’?
‘What are the training requirements for personnel involved?’
‘What assumptions and dependencies are there on the human environment?’

These questions have not yet been answered in this document, but will be addressed in subsequent activities.

Safe IFR flight through segregated airspace in Germany

Scope

The availability of the sense and avoid system supports flying IFR and VFR operations in airspace class C. Note that in class C, separation for VFR flights is only provided towards IFR flights. Hence, traffic avoidance between VFR flights is a responsibility of the pilot using the SAA system. The advantage of a VFR flight is that the pilot enjoys more flexibility in selecting a route (assumed that the flight plan is accepted by ATC), while IFR flights proceed along prescribed routes.

Level

This use case is written on sea level but has fish level information where more detailed information is needed.

Summary

The use case starts when a ferry flight from Schleswig (GER) to Manching (GER) is tasked to the Mission Commander (MC).

Planning Phase

Due to the fact that mission planning lasts several weeks it will be done by various persons. The mission is planned by qualified personnel. They create a mission plan, which includes all contingencies. The finalized mission plan is verified by the Pilot In Command (PIC) prior to uploading the mission. A flight plan is created as an excerpt of the mission plan and sent to ATC. The MC requests confirmation from Air Traffic Control (ATC) that the flight plan is accepted. The mission is loaded in the RPA.

Taxi and Take-off Phase

After planning and pre-flight preparations are completed, the pilot in the LRE[6] gets start up clearance from ATC and checks internal systems. When internal systems are checked, the LRE-pilot coordinates with ground personnel and takes over control of the RPA by establishing a communication link. Part of the ground preparations are to configure and check all available communication links (RLOS and B-RLOS). This is accomplished together and in concert with the MCE[7] pilot. Prior taxi clearance the LRE-pilot as well as the MCE-pilot has to establish a communication link to the EURO HAWK. The RPA will taxi autonomously to the runway. After receiving T/O clearance the LRE-pilots puts the RPA in 'take-off mode' upon which the RPA takes off autonomously. The LRE-pilot monitors the take-off aided by another pilot in the Hawkeye[8] vehicle.

[6] LRE: Landing and Recovery Element, only LOS capable.
[7] MCE: Mission Control Element, BLOS and full mission capable ground control station.
[8] Hawkeye is a qualified EURO HAWK pilot in a car, monitoring all ground activities up to and including the T/O run.

Climb Phase

The pilot then selects the appropriate aircraft configuration; the RPA automatically flies the programmed departure route. With support of Ground Based Sense And Avoid System (GBSAA), the EURO HAWK RPA climbs inside segregated airspace until, reaching controlled airspace class C. Throughout the climb both pilots check the validity of the communication links (LOS and BLOS) and coordinate the handover from LRE to MCE.

En-route Phase

Once arrived at cruising altitude, the pilot ensures that the RPA maintains the proper flight level. The pilot keeps a close watch on the traffic picture using the Sense And Avoid (SAA) system. En-route, the pilot monitors the RPA flight from waypoint to waypoint to maintain Situation Awareness (SA).

Descend & Approach Phase

When arriving near the destination airfield, the pilot receives clearance for descending into lower levels. The pilot prepares for descent by performing the necessary checks, setting the correct configurations and activating the appropriate route portion. This is coordinated with Approach (APP), which brings the RPA into the segregated airspace. The MCE-pilot hands over the RPA to the LRE-pilot at the destination.

Landing & Taxi Phase

The use case ends after the RPA initiates and completes the automatic landing. After landing, the RPA automatically taxies to the taxiway monitored by the destination Hawkeye element and the LRE-pilot. The LRE pilot shuts down all communication links and hands the RPA off to the ground crew who performs an orderly shutdown.

Engine Start-Up as well as Shutdown is completed by the ground-/ maintenance crew. In the first case (Start-Up) because the LOS communication links cannot be configured until the aircraft runs on its own power and in the second case (Shutdown) to give the ground crew the chance to perform maintenance duties & tasks prior the aircraft becoming “de-energized”.

Post-ops Phase

A debriefing is performed to analyse the mission.

Actors

Primary actor:

Remote Pilots

The LRE and MCE pilots are the main actors. The pilots control and monitor the RPA during all respective phases of flight and are responsible for collision avoidance from other aircraft.

Secondary actors:

Air Traffic Controllers

Air Traffic Controllers are coordinating all controlled air traffic in their area of responsibility. They are responsible for aircraft separation in accordance with the current airspace class requirements.

Air traffic controller - Area Control (ACC)

The Area Control (ACC) air traffic controller manages all controlled air traffic en-route.

Air traffic controller – Approach Control (APP)

The Approach Control (APP) air traffic controller controls all air traffic to and from the airport or airfield in an approximately 60-100 km radius. The APP controller then hands air traffic over to ACC (after departure) or tower control (before landing).

Air traffic controller – Tower Control (TWR)

The Tower Control (TWR) air traffic controller controls all traffic taking off and landing, as well as ground traffic on the airport. The TWR controller receives or hands over air traffic to APP.

Hawkeye

A qualified remote pilot in a supervisory function who monitors all ground movements. At a later stage, the monitoring of ground activities may be reassigned to technical devices (security cameras).

Operations Officer

A qualified remote pilot in a supervisory function, coordinating all RPA activities in the squadron.

Mission Commander (MC)

The Mission Commander has responsibility of the mission. The MC holds overview of mission and is in contact with other assets in the area of operation. The MC can command multiple RPAs but the MC role can also be performed by the remote pilot (double role) in less complex missions.

Payload Operator (PO)

The Payload Operator (PO) handles the payload of the RPA, typically electro optical or infrared surveillance systems. In the EURO HAWK, this role is taken over by sensor operators and analysts at a remote location connected by a landline wide band data-link to the MCE.

Ground crew

The ground crew handles the RPA before take-off and after landing. The ground crew has control of all technical and engineering issues concerning the RPA on the ground. If the RPA does not taxi automatically, they tow the vehicle to and from the runway to the parking position or the hangar.

Preconditions

The use case has as precondition that the Unmanned Aircraft System is equipped with Sense And Avoid (SAA) system[9]. The SAA system consists of:

Situation Awareness function

Providing the pilot with traffic information relevant to his flight path at a certain distance/ time ahead

Traffic Avoidance function:

Provides sufficient information for the pilot to ensure traffic avoidance. This becomes particularly relevant whenever ATC separation is not provided (including warning of pending loss of separation)

Collision avoidance function (the following characteristics are neither fully agreed nor in line with NATO / EASA / ICAO documents):

detects both cooperative and non-cooperative aircraft

detects all traffic in all lighting and WX conditions, in IFR/VFR and in IMC/VMC

provides autonomous collision avoidance[10] (as well as pilot override & return to course capability)

ensures interoperability with Airborne Collision Avoidance Systems (ACAS) of manned aircraft

The SAA equipment requirements have been derived from the NATO sense and avoid requirements for unmanned aerial systems operating in non-segregated airspace document (PFP (NNAG-JCGRPA) D (2008) 0002 dated 23 April 2008) presented in Appendix C.

Post conditions

The use case successfully ends when a safe and efficient flight in non-segregated airspace has been performed and the RPA is safely on the ground and the engine has shut down. This EURO HAWK flight may be performed in compliance with IFR and/or VFR in IMC and/or VMC.

[9] A Ground Based Sense And Avoid (GBSAA) system could be used as an alternative technology to airborne Sense And Avoid system.
[10] Both this and the next function are not yet integrated in any UAS. The USN TRITON and the USAF Reaper will probably be amongst the first types with such a capability.

Success end state

RPA executed the ferry flight in accordance with IFR/VFR through (non-)segregated airspace applying to current ATM regulations.

Failed end state

The use case will have reached a failed end state when unsafe situations occur or are likely to occur in the execution of IFR/VFR flight through (non-)segregated airspace.

Trigger

The use case starts when a ferry flight tasking is received by the Mission Commander (MC). The crew converts this tasking into a mission plan, which serves as the basis for the flight plan.

Main Flow

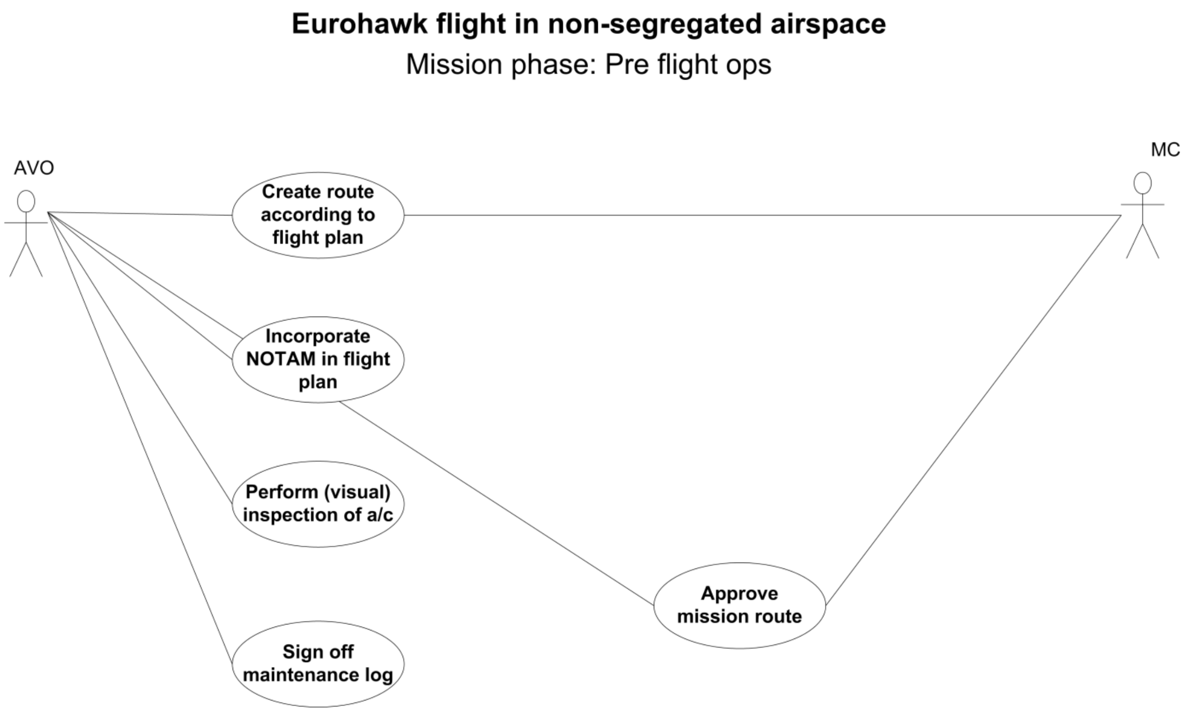
All main flows are based on a EURO HAWK ferry flight in Germany.

Task assignment

The start of any RPA mission is the assignment of a (generic) task. This task is analysed by pilots and mission essential personnel. The outcome of this task analysis determines the destination, goal and course of action (how do we get there). On the basis of this, a mission flow is designed that comprises a mission (game) plan, mission (navigation) route, contingency plan, frequency management plan and sensor plan. On the basis of this mission flow, the AVO generates an ATC flight plan. This plan is filed with ATC 24 hours before desired take off.

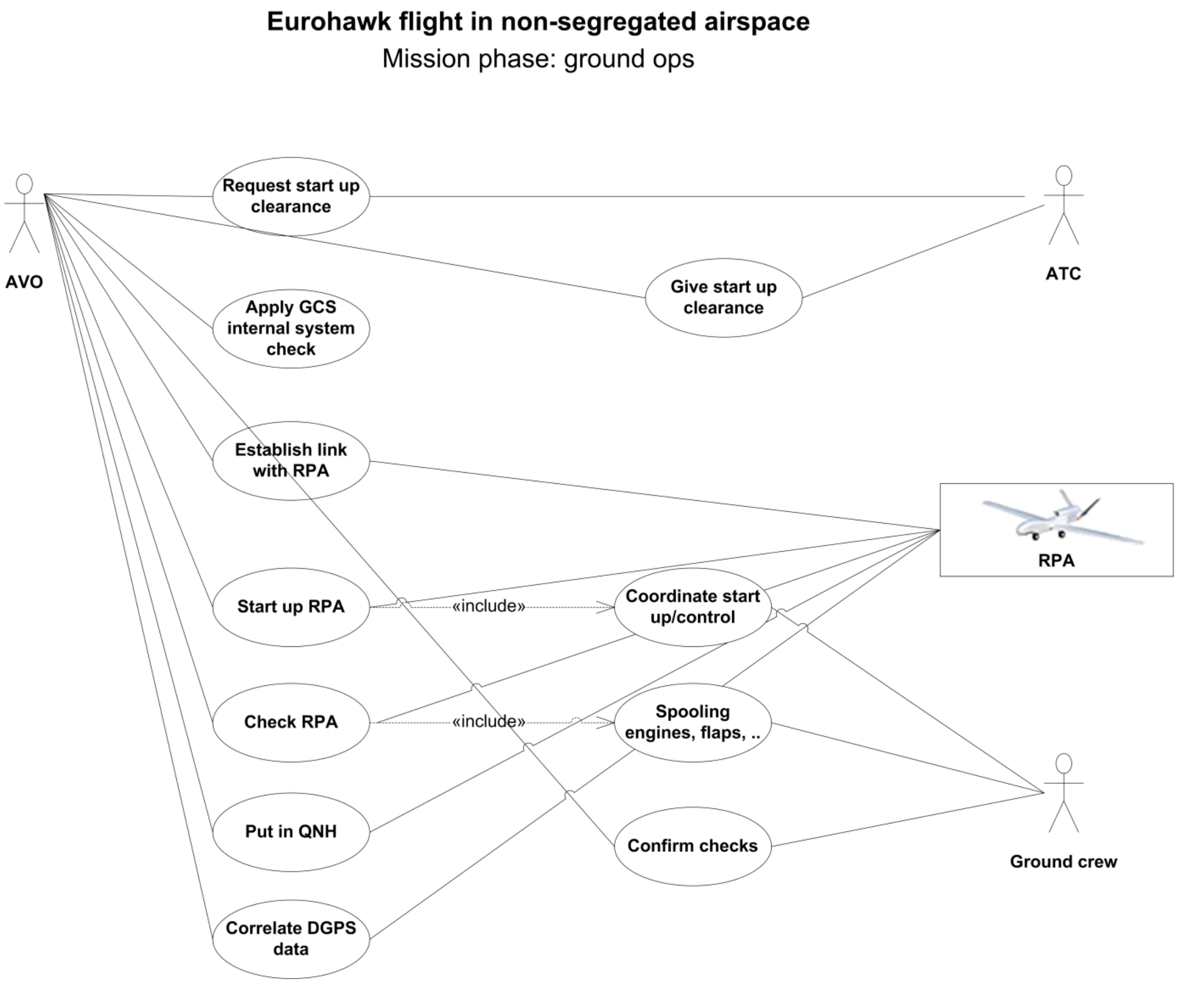
Pre-flight ops

Before flight operations can commence, several pre-flight operations need to be performed. The AVO incorporates the latest Notice to Airman in the flight planning. These NOTAMs are provided by the Aeronautical Information Service (AIS). Incorporating the NOTAMS is performed in the RPS itself. The AVO subsequently performs a visual pre-flight inspection of the RPA and RPS. If no discrepancies are found, the AVO signs off the maintenance log.



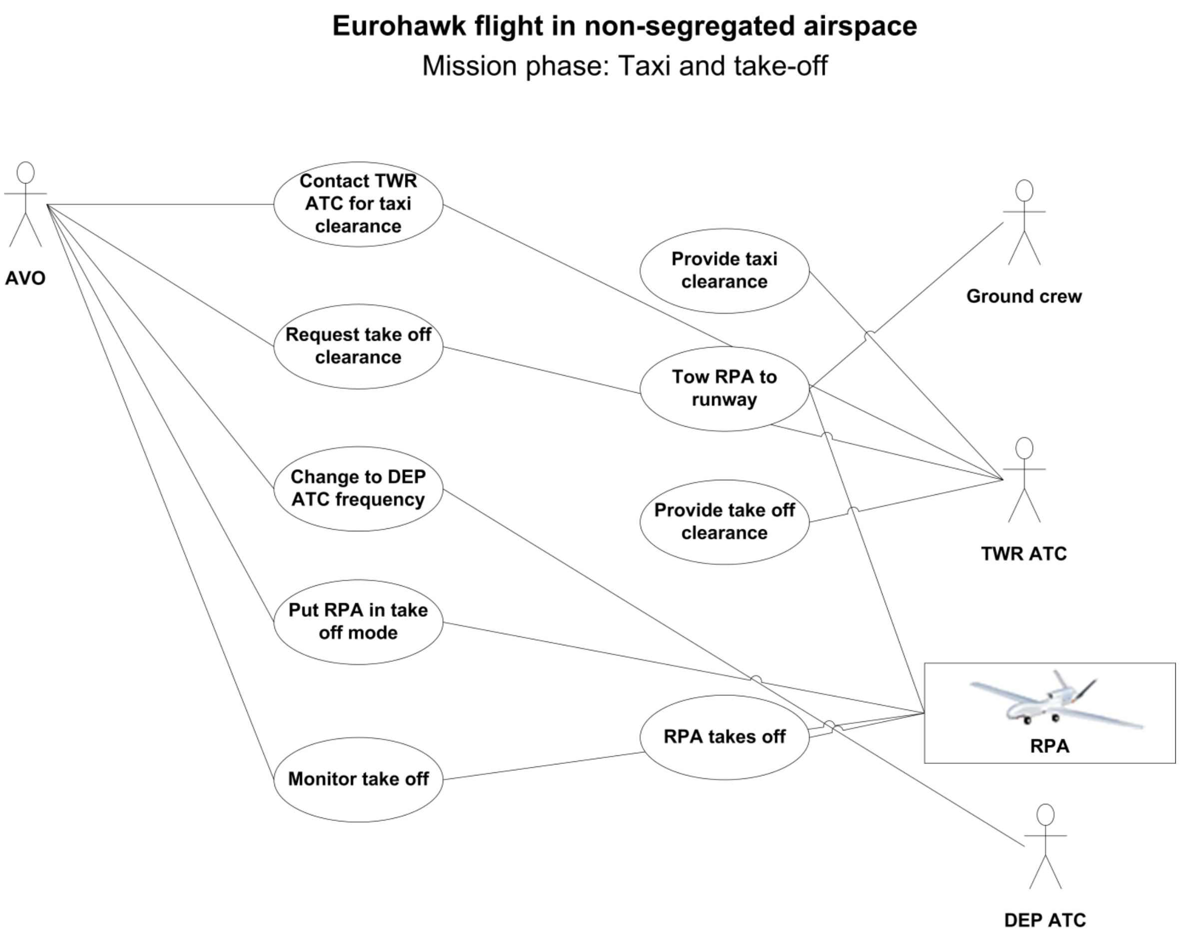
Ground ops

After completion of the pre-flight ops, the AVO gets start up clearance from the tower. The AVO proceeds with a final internal system check. After a successful systems check, the AVO establishes a control link to the RPA and thereby takes over control of the RPA. The AVO coordinates over radio with personnel next to the RPA that control is now with the AVO and start up will commence following. The AVO then proceeds to start up the RPA from the RPS. The AVO checks the RPA by spooling up the engine, checking flaps, etc. The corresponding effects on the RPA of the checks are confirmed to the AVO by the ground crew. The AVO proceeds to input the QNH and correlate the Differential GPS (DGPS) data.



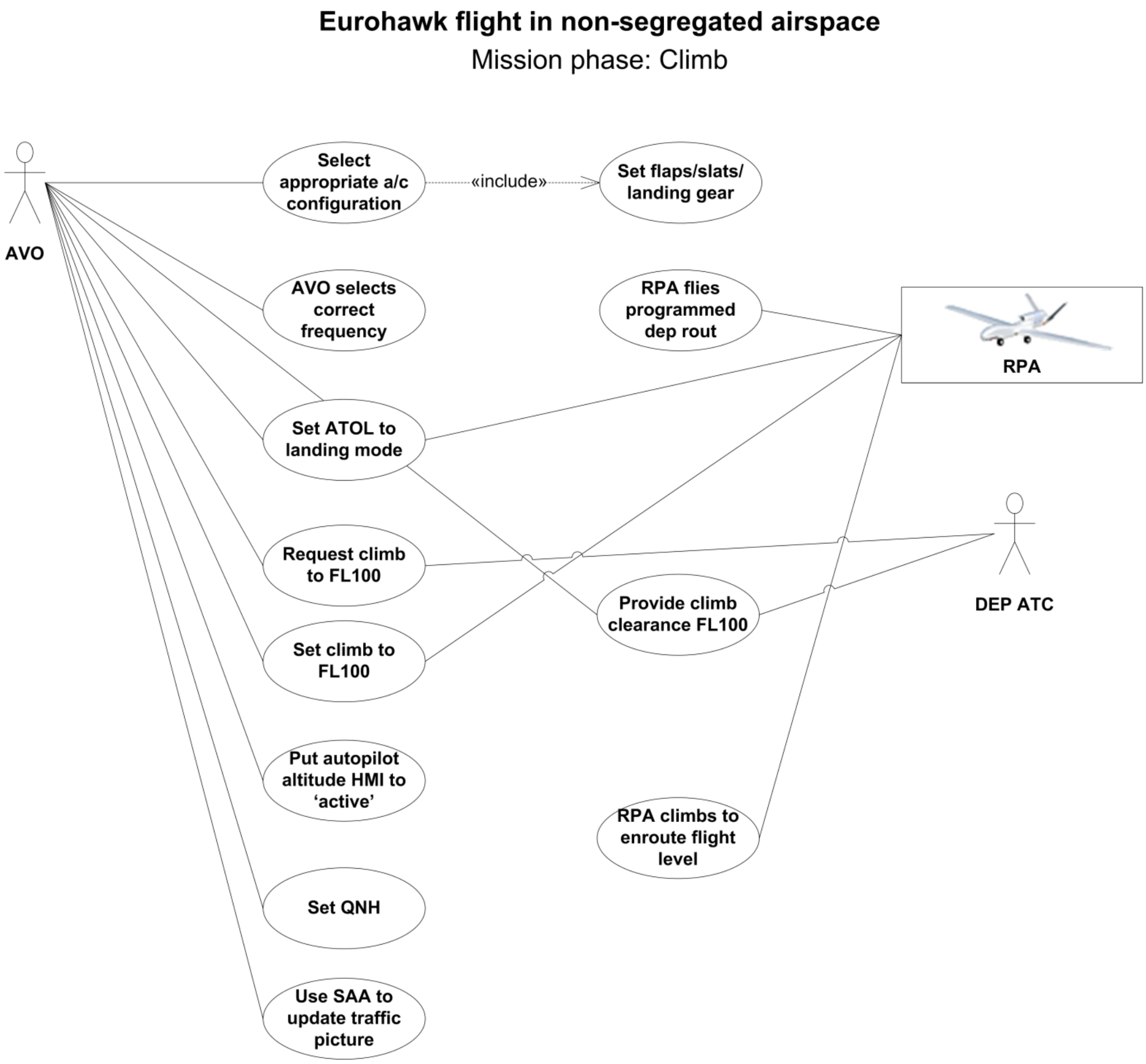
Taxi and take off

After completion of the ground ops, the AVO selects the correct channel/frequency and contacts tower control for taxi clearance. Upon confirmation of taxi clearance, the AVO provides instructions to the ground crew to tow the RPA to the appropriate runway. During this time, the tower is in constant contact with the towing vehicle to provide assistance or intervene if necessary. After the RPA has towed to the appropriate runway, and the towing vehicle has egressed from the runway, the AVO changes frequency to Departure control and requests take-off clearance. After receiving take-off clearance, the AVO then selects the appropriate transponder mode. The AVO puts the RPA in take-off mode. The AVO selects the appropriate aircraft configuration (flaps/slats/landing gear), the RPA performs a self-system check. The RPA then proceeds to take off and independently flies in accordance with the cleared departure route. The AVO monitors the take-off of the RPA.



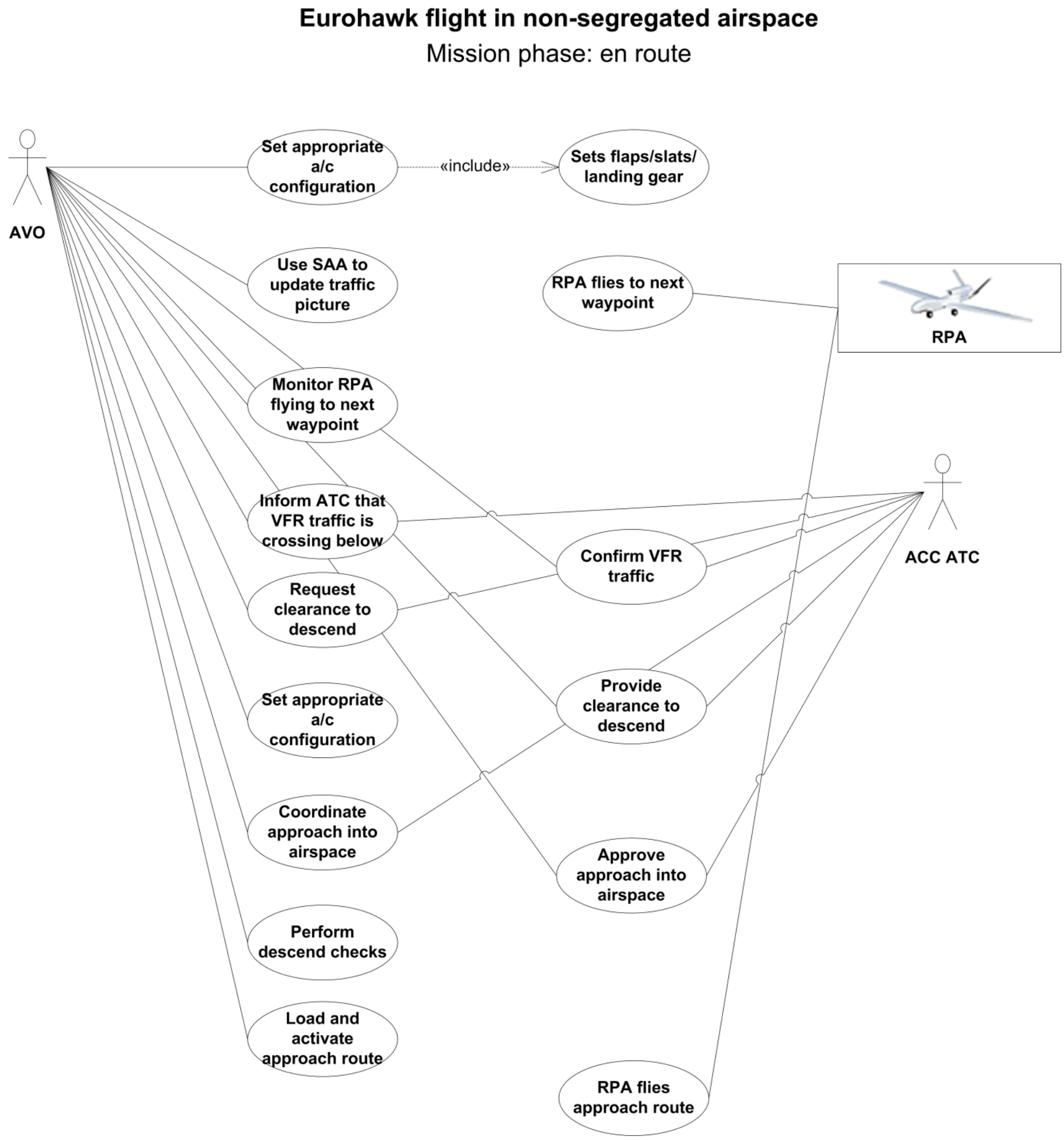
Climb

After taking off the AVO selects the appropriate aircraft configuration and sets flaps, slats and retracts the landing gear. The RPA proceeds to fly the programmed departure route. The AVO then proceeds to set the Automatic Take-off and Landing (ATOL) system back to landing mode, in case a loss of link with the RPA takes place. The AVO sets climb speed, attitude/pitch angle and heading, upon which the RPA climbs via initial cleared altitude/flight level(s) to the assigned en-route altitude/flight level. At transition altitude, the AVO puts the autopilot altitude system HMI to 'active' and sets the QNH to standard atmosphere. To stay separated from other air traffic, the AVO updates the traffic picture, checking for potential interfering traffic via the Sense and Avoid (SAA) equipment.



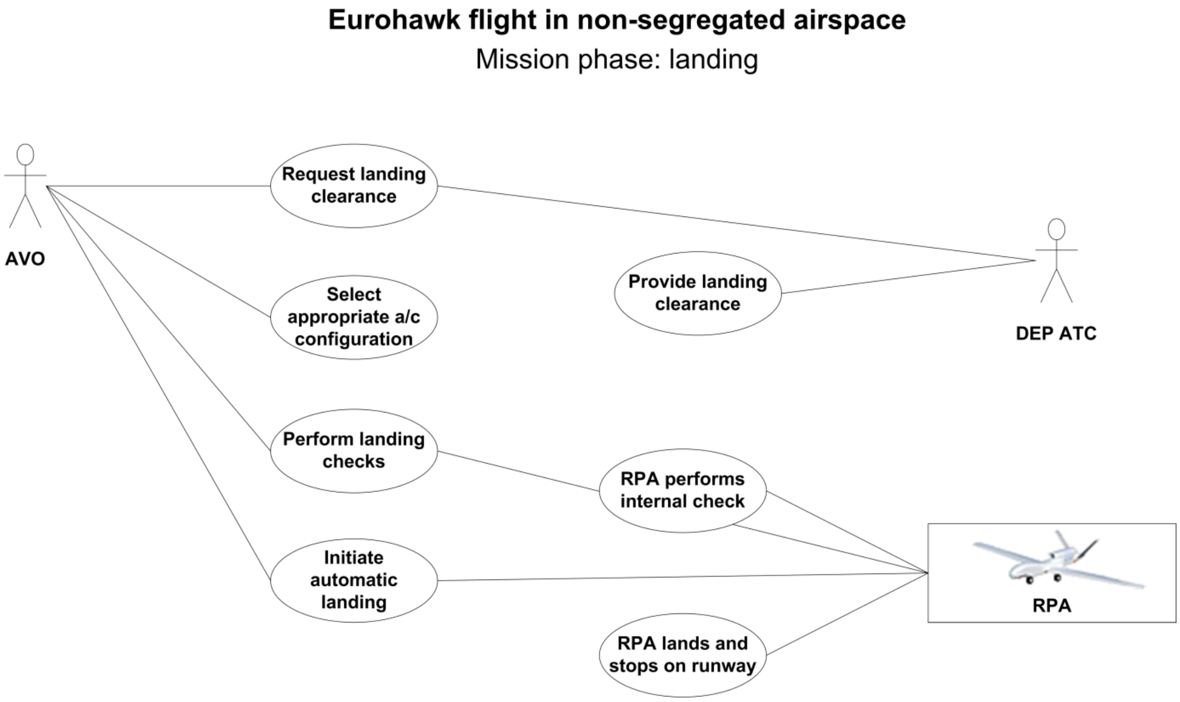
En route

After the RPA has reached the appropriate en route flight level, the AVO again sets the appropriate aircraft configurations. The main responsibility of the AVO at this point is to maintain Situation Awareness (SA) by updating the traffic picture (checking the SAA equipment) and monitoring RPA flight to the next waypoint.



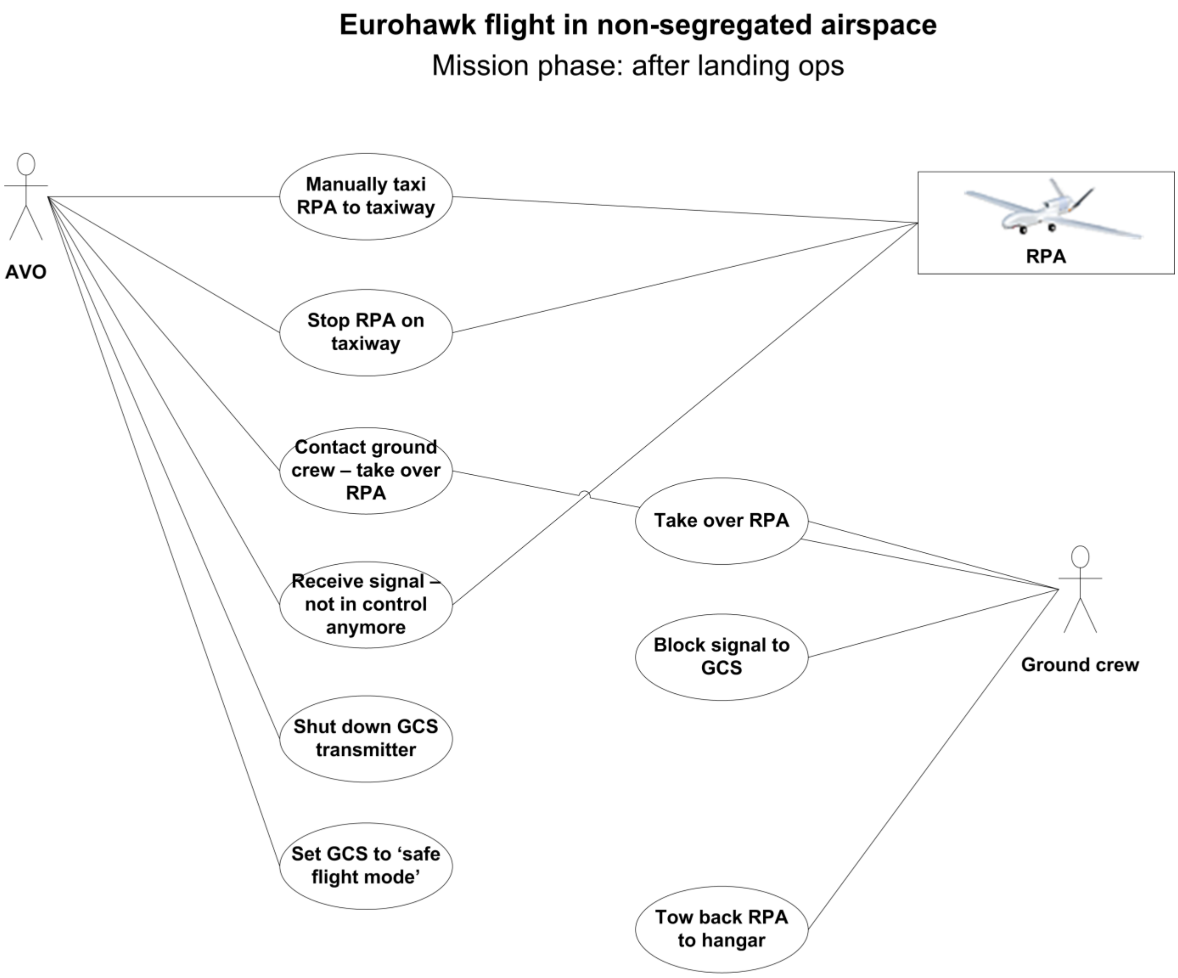
Landing

After flying the approach route, the AVO requests and receives landing clearance from the Tower Control. The AVO proceeds to select the appropriate aircraft configuration and sets flaps/slats/landing gear. The AVO performs landing checks. The RPA also checks internal system and landing parameters. If internal system and landing parameters are ok it will allow landing. The AVO initiates the automatic landing procedure in the RPS, upon which the RPA lands and stops on runway.



After landing ops

After landing, the AVO manually taxies the RPA to the taxiway. The AVO stops the RPA, contacts ground crew to take over RPA and waits for ground crew to take over control of the RPA by manually inserting a pin in the RPA that blocks the control signal from the RPS. The AVO receives system signal that he/she is not in control anymore. The AVO shuts down the RPS transmitters and sets RPS back to 'safe flight mode'. The ground crew proceeds to tow the RPA back to the hangar. Finally, the AVO performs a visual post flight inspection of the RPA.



Debrief

The final phase of the mission is a mission debrief within the crew.

Alternative Flows

Besides the identified failure flows, no other alternative flows have been elaborated in the use case.

Failure Flows

During the en route phase of flight, a failure can occur: a loss of (communications) link with the RPA.

Failure: Loss of link

When a loss of link occurs, the RPA will perform a contingency procedure, depending on the most mission phase and situation. There are four contingency procedures (C1-C4): C1=Lost Command & Control. C2=Return to Base, C3=Land Now, C4=Go Around/ Take-off Abort. The AVO contacts the responsible Area Control (ACC) that the RPA is non-responsive. ACC then follows the standard procedures for non-responsive' aircraft, and separates other traffic away from the RPA. When the AVO regains control of the RPA (e.g. when link is re-established by using a different signal or by a maneuver of the RPA), the main flow continues.

Failure: VFR traffic with wrong QNH setting

Within the main flow, VFR traffic can cross the flight path of the RPA. Normally IFR traffic is separated vertically by 1000ft while VFR traffic is separated by 1000+500 ft. (VFR traffic is only allowed to fly in the 500 ft between Flight Levels (FL)). Semicircular separation is also provided (separation by 1000ft) depending on flight direction. Above FL100 (airclass A), no VFR traffic is allowed in Germany. When VFR traffic crosses the RPA flight path, ATC will inform the AVO. In this scenario, a failure can occur: VFR traffic with wrong QNH setting, thus flying on same FL as the RPA. In this scenario, the RPA 'separation provision system' informs the AVO about the separation issue. The AVO then informs ATC that VFR traffic is on same flight level. The AVO proceeds to request avoiding action, for example a heading change. ATC clears the avoiding action; provides a heading change. The AVO steers the RPA manually to avoid other aircraft in accordance with the given clearance.

Within this scenario of avoiding other traffic, a failure can occur: the AVO is unable to take avoiding action, e.g. due to loss of link, or because the AVO does not physically intervene due to incapacitation, overload, etc.

Failure: AVO is unable to take avoiding action

If the AVO is unable to take avoiding action, the Sense and Avoid (SAA) system evaluates the conflict by interprets situation by movement of other aircraft and distance marker (bubble) by laser. Upon properly evaluating the conflict, the SAA system commands the RPA to take evasive action. Depending on the configuration of the conflict between UAV and aircraft, the corresponding part of the SAA (either separation provision or collision avoidance) will react. When the AVO is again able to take action, he/she retakes control from the autonomous RPA system. The RPA goes back on course autonomously, although the AVO can override if deemed necessary.

After the RPA has flown the en route phase of the mission, the AVO prepares for the landing phase. The AVO requests clearance from ACC to decent from upper into lower airspace. The AVO proceeds to select the appropriate aircraft configuration. The AVO requests and receives clearances from approach (APP) for approach into TMA airspace. The AVO then performs the descend checks and loads and activates the approach route for the RPA. The RPA proceeds to fly the programmed approach route.

Appendix C SAA requirements for unmanned aerial systems operating in non-segregated airspace

NATO OTAN	North Atlantic Council
	Conseil de l'Atlantique Nord

17 February 2011 PFP(NNAG-JCGUAV)D(XXXX)0001

NATO NAVAL ARMAMENTS GROUP
JOINT CAPABILITY GROUP ON UNMANNED AERIAL SYSTEM

SENSE AND AVOID REQUIREMENTS FOR UNMANNED AERIAL SYSTEMS OPERATING IN NON-SEGREGATED AIRSPACE

Reference:
PFP (NNAG-JCGUAV) D (2008) 0002 Dated 23 April 2008

Related Documents:

STANAG 4670 Ed 1 - Recommended Guidance for the Training of Designated UAV Operator
STANAG 4671 Ed 2 - UAV System Airworthiness Requirements (USAR)

PREAMBLE

1. This document was developed and is maintained by the NATO Unmanned Aircraft Flight in Non-segregated Airspace (FINAS) Military Working Group. FINAS is dedicated to overcoming barriers for cross-border operations by military unmanned aircraft. Other work toward this end has included training standards and extensive development of NATO airworthiness standards which have received wide application. FINAS is a subordinate activity under the Joint Capability Group for Unmanned Aerial Vehicles (JCGUAV), with reports, through the NATO Naval Forces Armament Group, to the NATO Conference of National Armament Directors. Access to terms of reference of these councils, groups and working bodies as well as the other work of the JCGUAV is encouraged through respective national representatives.

AIM

2. The aim of this document is to define functional requirements for the design of a Sense and Avoid (SAA) system for Unmanned Aircraft Systems (UAS) operating in non-segregated airspace. This document should be read in conjunction with the related documents above. It is a revision of the earlier edition, Reference A above. As its principle intended use this document will bridge the activities of system developers working to realize capabilities that are compatible with national & ICAO airspace structures. This includes standards and recommended practices, and application of those systems engineering processes undertaken during system acquisition to integrate a see-and-avoid capability in the context of the total weapon system. Every mission system has its own concept of operation and expected behaviors in non-segregated airspace. Hence, this document supports requirements decomposition and use-case analysis on the path to developing sense and avoid capabilities and system responses compatible with routine operations in civil airspace. It intends to place the sense and avoid system for military state unmanned aircraft in the context of the civil international air traffic system while providing advantages in military controlled airspace as well, as a derivative outcome. Application of this document does not preclude considerable additional engineering planning, integration, modeling, and test for applications on specific aircraft weapons systems.

SCOPE

3. This document only addresses conventionally powered, fixed wing, UASs with a maximum take off weight of greater than 150kg that require integration with other airspace users. It is not intended to be a Minimum Operating Performance Specification (MOPS) or to articulate technical system requirements. It does not propose technical solutions for a SAA system nor does it address Air Traffic Management (ATM) procedures, Concept of Operations (CONOPs) or Tactics, Techniques and Procedures (TTPs) information, which will be found elsewhere. Furthermore, these requirements are specifically intended to apply to the airborne Sense and Avoid function and not intended for taxi operations or ground obstacle avoidance. Where current regulatory guidance already exists, such as ICAO Annex 2 - Rules of the Air, Chapter 3, paragraph 3.2.2 “right-of-way rules”, such guidance is not repeated herein. The requirements provided in this document are based on the most authoritative international standards. When an international standard was not available, the requirements were based on those national standards deemed most appropriate. In the cases where no standard currently exist, FINAS subject matter expert (SME) analysis was used. Background information for the derivation of each functional requirement can be found in Annex A.

AGREEMENT

4. If this document is translated into a STANAG, then participating nations agree to employ these functional requirements as the basis for designing SAA systems for UASs operating in non-segregated airspace.

TERMS AND DEFINITIONS

5. Acronyms and Terms used in the document are defined in Annexes C.2 & C.3 for the purposes of this document only.

GENERAL

6. Military and/or civil authorities may not allow UASs access to all classes of airspace until the UAS can demonstrate, *inter alia*, an acceptable means of compliance with the applicable Rules of the Air. Furthermore, the operation of UASs in non-segregated airspace shall present no greater risk to other airspace users than currently exists in manned aviation.

7. The safety context of the SAA function is imperative and intended to support applicable benchmarks depending on the airspace in which the UAS is operated. FINAS has determined that there are two levels of safety for the avoidance of aerial collisions. The most stringent can be derived from the need for operations with Commercial Air Transport in Airspace Classes A through D where the rate of a mid-air collision (Λ_{MAC}) must be equivalent to, or better than **5×10^{-9} per aircraft flight hour** [11]**.** For all other operations in Airspace Classes E, F and G the P_{MAC} mid-air collision rate must be equivalent to, or better than **1.07×10^{-6} per aircraft flight hour which is the level of risk associated with mid-air collisions in those classes of airspace** [12]. However due to the anticipated technical advancements that are expected to decrease the overall rate of MAC, FINAS recommends that the target level of safety (TLOS) be **1×10^{-7} per aircraft flight hour.**

8. Having respect for these TLOS is a matter of assuring separation from other airspace users as an element of a UAS's CONOPs. Without a SAA function, the separation needed for this level of assurance currently hinders operations in shared airspace. This reduces the military utility of UASs by requiring extraordinary and time-consuming planning arrangements, as well as reducing the airspace available to other users. The SAA function described herein is intended to reduce these limitations.

9. Achievement of this goal, however, is not a matter of technology alone. The SAA function must be considered as part of a total system CONOPs which must also take into account the airspace environment, training, airworthiness, and other technologies (e.g. secondary surveillance radar systems).

10. **Target Safety Level**. A fundamental requirement is that a UAS must achieve a "target level of safety" comparable to that for a manned aircraft.

In simplistic terms, for any mid air collision (MAC) to occur the following sequence of events must happen:

- There must be two aircraft on a collision course, and
- There must be a failure in separation provision, and
- There must be a failure of the UAS collision avoidance function, and
- There must be a failure of collision avoidance in the other aircraft (since both aircraft are responsible for collision avoidance)

Each event has a discrete rate (Λ) or probability (P) of occurring. The risk of a MAC occurring (Λ_{MAC}) is the product of the rates and/or probabilities of the above events. This can be described by the following expression:

[11] Konstantinos Dalamagkidis, Kimon P. Valavamus and Les A.Piegl, On Integrating Unmanned Aircraft Systems Into the National Airspace System (Springer-2009) 68,Table 5.4
[12] Dalamagkidis, Valavamus and Piegl, 68,Table 5.4

Λ_{MAC}[13] $= \Lambda_{\text{Collision course}} \times P_{\text{Separation failure}} \times P_{\text{UAS Collision Avoid failure}} \times P_{\text{Conflicting A/C Collision Avoidance failure}}$

SENSE-AND-AVOID SYSTEM REQUIREMENTS

11. The basic goal of any SAA system is to provide sufficient information to maintain aircraft separation and collision avoidance functions. As such, any Sense and Avoid (SAA) system must, when required, be capable of performing two distinct but complementary functions:

a. **Collision avoidance.** Collision avoidance applies when the separation provision has failed and an imminent risk of collision exists. It applies at all times, in any class of airspace under any flight rules. Notwithstanding that the flight is being made with ATC clearance, it shall remain the duty of the Designated UAV Operator (DUO) to take all possible measures to ensure that his UAS does not collide with any other aircraft.

b. **Separation provision.** Separation provision is the routine act of keeping aircraft apart, in order to mitigate the risk of collision. The responsibility for separation provision lies with either the Air Traffic Control (ATC) controller or the DUO. The class of airspace, the flight rules in force, and the Air Traffic Services being provided determines where this responsibility lies.

12. The proposed SAA requirements have been written in relation to these two specific functions. The requirements are also either Mandatory or Desirable:

a. **Mandatory.** Requirements using the verbs “shall” or “must” are mandatory and may only be departed from under specific national exemptions.

b. **Desirable**. Desirable requirements are those using the verbs “should” or “may” and are believed to improve the performance of an SAA system beyond a base level of safety. Desirable requirements must not prejudice the ability to meet the mandatory requirements.

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13 Where:

$\Lambda_{\text{collision course}}$ = The ambient risk of collision dependant on air traffic density…
$P_{\text{separation failure}}$ = The probability of loss of separation (by the DUO, other pilot/DUO or ATC)
$P_{\text{UAV Collision Avoid failure}}$ = The probability of the failure of the UAV’s collision avoidance function
$P_{\text{Conflicting A/C Collision Avoidance failure}}$ = The probability of failure of the collision avoidance function in the conflicting aircraft.

COLLISION AVOIDANCE AND SEPARATION PROVISION FUNCTIONAL REQUIREMENTS

COLLISION AVOIDANCE

CAS1. Cooperative – Non-cooperative Aircraft. The collision avoidance system shall detect both cooperative and non-cooperative aircraft.

CAS2. Lighting Conditions. The collision avoidance system shall detect aircraft in all lighting conditions in which the UAS is approved to operate.

CAS3. Flight Rules. The collision avoidance system shall detect aircraft when the UAS is flying under Visual Flight Rules (VFR) or Instrument Flight Rules (IFR).

CAS4. Flight conditions. The collision avoidance system shall detect aircraft when operating in Visual Meteorological Conditions (VMC).

CAS5. The collision avoidance system should detect aircraft when operating in Instrument Meteorological Conditions (IMC).

CAS6. Class of Airspace. The collision avoidance system shall detect aircraft in all classes of airspace in which the UAS is approved to operate.

CAS7. Collision Volume (CV). The collision avoidance system shall avoid other aircraft by a minimum of 500 feet in the horizontal plane and 100 feet in the vertical plane.

CAS8. Independence from ATC Separation Provision Function. The collision avoidance system shall not rely on ATC input or intervention to protect the UAS from collisions with other aircraft.

CAS9. Automatic Manoeuvring. If the Unmanned Aircraft (UA) does not receive a DUO command input owing to lost link or latency issues to resolve an imminent collision hazard (defined as an intruder that will violate the CV), the UA shall manoeuvre automatically to avoid conflicting traffic.

CAS10. The system should warn the DUO of the pending manoeuvre and incorporate an override capability, time and conditions permitting.

CAS11. Technical Reliability. The UAS based collision avoidance system shall have a minimum mean time between critical failures of 1 in 10^5 flight hours.

CAS12. System Status. The collision avoidance system shall have a means of indicating to the DUO the status of the system.

CAS13. System Failure. When CAS 11 or CAS 12 (e.g. due to lost link) cannot be met, the UAS shall automatically declare a malfunction by use of an agreed transponder code.

CAS14. Post Manoeuvre Recovery Action. After conflict resolution, the collision avoidance system shall provide a “clear of conflict” advisory to the DUO.

CAS15. The collision avoidance system should seek DUO approval to conduct a "return-to-course" manoeuvre**.**

CAS16. The collision avoidance system shall automatically return to last cleared altitude and routing in a lost link scenario unless another conflict is detected.

CAS17. **Field of Regard (FOR).** The field of regard of the onboard CAS sensor shall be a minimum of +/-110° horizontally with respect to the longitudinal axis of the UAS, a minimum of +/-15° vertically with respect to the flight path, and provide sufficient coverage to enable detection of conflicting air traffic during expected manoeuvres.

CAS18. The field of regard of the onboard CAS sensor should provide 360° horizontal coverage around the aircraft.

CAS19. **Compatibility with Existing Collision Avoidance Systems.** The collision avoidance function shall not increase the collision risk of aircraft utilizing existing collision avoidance systems.

SEPARATION - WHERE SEPARATION RESPONSIBILITY RESTS WITH THE DUO

SPS1. **Cooperative – Non-cooperative**. The separation provision system shall detect both cooperative and non-cooperative aircraft.

SPS2. **Lighting Conditions**. The separation provision system shall detect aircraft in all lighting conditions in which the UAS is approved to operate.

SPS3. **Class of Airspace**. The separation provision system shall provide the DUO with sufficient information to separate the UAS from other aircraft in any class of airspace where ATC separation is not provided to all aircraft.

SPS4. **Flight Rules.** The separation provision system shall provide the DUO with sufficient information to separate the UAS from other aircraft whenever VFR operations are being conducted and ATC is not providing separation.

SPS5. **Separation Standard – Distance**. The separation provision system shall, except for airfield operations, provide the DUO with sufficient information to separate the UAS from other aircraft by a minimum of 0.5 NM horizontally or by a minimum of 500 ft vertically when, under the rules of the air, the UAS has the responsibility to give way to the intruder aircraft.

SPS6. **Manoeuvre Authorization**. The separation provision system shall warn the DUO of a pending loss of separation so that the DUO may initiate a manoeuvre whenever the UAS is obliged to so under the Rules of the Air.

SPS7. **System Failures**. The separation provision system shall provide the DUO with a system status indication. Any change in the system status should be clearly obvious to the DUO.

SPS8. **Post Manoeuvre Recovery Action**. The separation provision system shall provide the DUO with a “clear of conflict” advisory once appropriate separation has been reestablished.

SPS9. **Field of Regard**. The field of regard of the onboard sensor system shall be a minimum of +/-110° horizontally with respect to the longitudinal axis of the UAS, a minimum of +/-15° vertically with respect to the flight path and provide sufficient coverage to enable separation of conflicting air traffic during expected manoeuvers.

Annexes:

C.1 Derivation of Collision Avoidance and Separation Provision Requirements.
C.2 List of Acronyms
C.3 Glossary of Terms

Appendix C.1 DERIVATION OF COLLISION AVOIDANCE SAFETY STANDARDS

(5 x 10^{-9} and 1.07 x 10^{-6} mid-air collisions per aircraft flight hour)

It was seen by the FINAS WG that the most stringent level of safety facing the sense and avoid requirement, while operating in non segregated airspace, is the mixing of UASs with Commercial Air Transport (CAT). Regulatory guidance from many countries define an acceptable TLOS on the order of 5 x 10^{-9} collisions per flight hour in controlled (Classes A - D) airspace. Further research has shown that many regulatory agencies consider the risk of the occurrence of a catastrophic event (FINAS considered a mid-air collision as a catastrophic event) could be no greater than 5 x 10^{-9} collisions per flight hour. Furthermore, ICAO has stated that an acceptable TLOS for separation of aircraft is 1.5 x 10^{-8} collision per flight hour during RVSM operations[14], which also applies to controlled airspace. Given the variety of standards applicable and to allow for greater acceptance of UAS operations in non-segregated airspace, **FINAS recommends that the TLOS for the avoidance of a mid-air collision in Class A - D airspace should be 5 x 10^{-9} collisions per flight hour.**

FINAS noted from many sources that the actual mid air collision rate for manned VFR operations, outside controlled airspace was on the order of 1 x 10^{-6} collisions per flight hour. As such the minimum required TLOS for operations in Class E, F and G airspace would be 1 x 10^{-6} collisions per flight hour. However, in order to reduce the numbers of near mid-air collisions, allow for greater acceptance from airspace regulators/users and provide for future technical advances which could result in reduced rates of aircraft mid-air collisions, **FINAS recommends a TLOS in Class E, F and G airspace of 1 x 10^{-7} collisions per flight hour.**

It must be understood that TLOS described above is not the safety level required of the UAS's Sense and Avoid system equipment, but rather includes the various procedures, methodologies and technologies available to prevent mid-air collisions. This includes prevailing air traffic density, procedural separation, ATC separation, current airborne collision avoidance systems (ACAS) the human see and avoid capability in manned aircraft and finally the UAS sense and avoid function. Accordingly, the UAS Sense and Avoid system is but one part of the overall collision avoidance solution.

DERIVATION OF COLLISION AVOIDANCE FUNCTIONAL REQUIREMENTS

CAS1. Cooperative – Non-cooperative Aircraft. Current collision avoidance systems are designed to operate between aircraft equipped with transponders. However, these systems are only mandated for particular categories of aircraft operating in specific classes of airspace. As UASs may be operated in areas that contain aircraft without cooperative collision avoidance systems/ACAS, a SAA system must provide information on both cooperative and non-cooperative aircraft.
Requirement. The collision avoidance system shall detect both cooperative and non-cooperative aircraft.

CAS2. Lighting Conditions. Collision avoidance is a responsibility of the pilot of a manned aircraft whether it is day, night or in transition. Exterior aircraft lighting systems are specifically mandated so as to assist pilots of conflicting aircraft with the separation of their

[14] AFI Reduced Vertical Separation Minimum (RVSM) Safety Policy - April 2006

aircraft in low light conditions. As with aircraft lighting regulations, these requirements should be published in the appropriate operating regulations.
Requirement. The collision avoidance system shall detect aircraft in all lighting conditions in which the UAS is approved to operate.

CAS3. Flight Rules. The ICAO Rules of the Air [15] state that "It is important that vigilance for the purpose of detecting potential collisions be not relaxed on board an aircraft in flight, regardless of the type of flight or the class of airspace…." This therefore mandates that a collision avoidance system must work under any flight rules in force. Note that there is no relaxation for the situation when a pilot is flying IFR.
Requirement. The collision avoidance system shall detect aircraft when the UAS is flying under Visual Flight Rules (VFR) or Instrument Flight Rules (IFR).

CAS4. Flight Conditions. Flight conditions can be described as VMC or IMC. As there are no impediments to visually acquiring conflicting traffic under VMC, a pilot, and in-turn a SAA system must have the ability to do so. However, when IMC prevails, a pilot is required to concentrate on his flight instruments at the direct expense of a visual lookout.
Requirements. The collision avoidance system shall detect aircraft when operating in Visual Meteorological Conditions (VMC).
CAS5. The collision avoidance system should detect aircraft when operating in Instrument Meteorological Conditions (IMC).

CAS6. Class of Airspace. As stated above, the Rules of the Air also require vigilance to be maintained irrespective of the class of airspace in which the aircraft is operating. This therefore mandates a collision avoidance system to function in any class of airspace that the UAS could operate.
Requirement. The collision avoidance system shall detect aircraft in all classes of airspace in which the UAS is approved to operate.

CAS7. Collision Volume (CV). There are no prescribed ICAO collision avoidance minima for manned aircraft other than the Rules of the Air state that aircraft should not be operated in such proximity to other aircraft as to create a collision hazard[16]. RCTA/DO-185A does mandate the Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II), but the equipage of TCAS II is only mandated for certain classes of aircraft. TCAS II uses the parameter of time to CPA and is defined by range divided by range rate. However, owing to the wide variations in UAS sizes, capabilities and control link latencies, it would not be feasible to dictate a time to CPA that could be applied to all UASs. Therefore, a basic miss distance was determined. The 500 ft horizontal requirement was derived from current regulations on approved hemispheric altitudes, guidance on near miss reporting[17], examination of aircraft dimensions and existing standards for other collision avoidance systems[18]. However, it was deemed that a 500 ft vertical separation would not be appropriate, as it could lead to false collision avoidance manoeuvres for aircraft that were within legal separation criteria. The 100 ft limit is based on the same principles/specification used in the current TCAS MOPS[19].

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[15] ICAO Annex 2, Rules of the Air, "*Right of Way Rules*". International Civil Aviation Organization, Ninth Edition, July 1990.
[16] ICAO Annex 2, Section 3.2.1Rules of the Air, "Right of Way Rules". International Civil Aviation Organization, Ninth Edition, July 1990
[17] FAA Order 8700.1, Change 3, Chapter 169, § 5A
[18] DO-185a
[19] DO-185a - Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II) Airborne Equipment

<u>Requirement.</u> The collision avoidance system shall provide the capability to ensure that other aircraft are avoided by a minimum of 500 feet in the horizontal plane and 100 feet in the vertical plane.

CAS8. Independence from ATC Separation Provision Function. As per manned aviation the responsibility for collision avoidance is distinct from that of separation provision. This provides redundancy by utilizing for two separate methods of preventing aircraft from colliding. As such, a collision avoidance system for UASs must also be independent from the separation provision provided by ATC.
<u>Requirement.</u> The collision avoidance system shall not rely on ATC input or intervention to protect the UAS from collisions with other aircraft.

CAS9. Automatic Manoeuvring. UASs are unique in that their DUO is not physically located in the aircraft. This then allows for the isolated possibility that at some point the DUO may not have control of the UAS due to various communications failures either within the UAS Control Station (UCS) or the air vehicle itself. As collision avoidance is a full time responsibility the UAS must perform this function automatically should the communications links fail. Furthermore, due to potential latencies of the control link, there may be insufficient time from the point of detection to the point a manoeuvre must be initiated allow the DUO to successfully avoid a collision. In this case the UAS must automatically take over and ensure a collision is averted.
<u>Requirements.</u> If the Unmanned Aircraft (UA) does not receive a DUO command input (owing to lost link or latency issues) to resolve an imminent collision hazard (defined as an intruder that will violate the CV), the UA shall manoeuvre automatically to avoid conflicting traffic.

CAS10. The system should warn the DUO of the pending manoeuvre and incorporate an override capability, time and conditions permitting.

CAS11. Technical Reliability. Depending on interaction with other flight critical systems, in many situations the SAA system will be considered a flight critical system and as such must meet integrity standards and mean time between critical failures associated with similar flight critical systems. Failure rates of flight critical systems are required to be “Extremely Remote” or as a minimum 1 in 10^5 per flight hour[20]. This technical reliability requirement applies specifically to the failure of the UAS’s SAA system equipment and does not account for failure of the conflicting aircraft’s ACAS, pilots see and avoid capability, or a failure of ATC separation provision. These issues are related to the overall TLOS which is addressed earlier in the document.
<u>Requirement.</u> The UAS based collision avoidance system shall have a minimum mean time between critical failures of 1 in 10^5 flight hours.

CAS12. System Status. The DUO must be fully aware at all times of the serviceability status of the SAA system. A failure of the SAA system must be presented in such a manner that the DUO is immediately notified (visually and/or aurally). This notification must include all on and off boards systems involved in the SAA process. A self-test mode to ensure that the system continuously checks its functionality and a method of relaying this information would likely allow the system to provide the DUO with advance warning of potential failures.
<u>Requirements.</u> The collision avoidance system shall have a means of indicating to the DUO the status of the system.

[20] STANAG 4671 – NATO UAV System Airworthiness Requirements

CAS13. System Failure. Any system failure or emergency that compromises the collision avoidance function should be treated as an aircraft in distress, since the UAS is no longer capable of complying with the Rules of the Air and would require special protection from other air users. The UAS shall automatically declare a system malfunction by use of an agreed upon transponder code. Although FINAS considered mandating of the use of a discrete transponder code for these situations, this was deemed inappropriate at this time because such a code has not been established.
Requirement. When CAS 11 and CAS 12 (e.g. due to lost link) can not met, the UAS shall automatically declare a malfunction by use of an agreed transponder code.

CAS14. Post Manoeuvre Recovery Action. After a collision avoidance manoeuvre has been executed and the risk of collision has passed, barring additional ATC or DUO instructions, the UAS shall automatically return to the last cleared or pre-planned routing and altitude. The post manoeuvre recovery must not create another risk of collision.
Requirements. After conflict resolution, the collision avoidance system shall provide a "*clear of conflict*" advisory to the DUO.

CAS15. The collision avoidance system should seek DUO approval to conduct a "return-to-course" manoeuvre.

CAS16. The collision avoidance system shall have the ability to automatically return to last cleared altitude and routing in a lost link scenario unless another conflict is detected.

CAS17. Field of Regard (FOR). The FOR of a SAA system should be consistent with the Right of Way requirements already established for manned aircraft operating under VFR. To comply with the Right of Way obligations the horizontal FOR must be a minimum of +/-110°[21] off the nose of their aircraft. This requirement is further articulated in numerous state and regulatory documents. However, in some cases, in order to meet the required TLOS stipulated in paragraph 7 or comply with right of way rules, it may be necessary to increase the FOR. In the case of UAS, FINAS recommends the FOR in the horizontal plane should be increased to +/-120° off the nose of the UA[22]. Additionally, there may be situations, depending on aircraft performance, that a further increase of the FOR in the horizontal plane to 360° may be needed, particularly when trying to achieve the TLOS for small, slow moving UAs.
Requirements. The field of regard of the CAS sensor shall be a minimum of +/-110° horizontally with respect to the longitudinal axis of the UAS, a minimum of +/-15°[23] vertically with respect to the flight path, and provide sufficient coverage to enable detection of conflicting air traffic during expected manoeuvres.

CAS18. The field of regard of the CAS sensor should provide 360° coverage, horizontally, around the aircraft

CAS 19. Compatibility with Existing Collision Avoidance Systems. In order to ensure that the introduction of a UAS collision avoidance system does not negatively impact the level of safety provided by current collision avoidance systems, the UAS collision avoidance system must not interfere with existing systems such as ACAS. Although there are several burgeoning technologies with regards to collision avoidance systems this requirement is

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[21] ICAO Annex 2, Rules of the Air, "Right of Way Rules". International Civil Aviation Organization, Ninth Edition, July 1990
[22] FAA AC25.733-1
[23] ASTM F 2411-07

intended for existing, mandated technologies.
Requirements. The collision avoidance function shall not increase the collision hazard to aircraft utilizing existing collision avoidance systems.

DERIVATION OF SEPARATION PROVISION FUNCTIONAL REQUIREMENTS

SEPARATION PROVISION FUNCTIONAL REQUIREMENTS - WHERE SEPARATION RESPONSIBILITY RESTS WITH THE DUO

Note: When the separation provision function is provided by ATC, then there is no technical requirement for a separation provision system to be installed on the UAS. ATC will apply standard separation minima between the UAS and known traffic.

Note: There will be occasions where both ATC and the DUO will have separation responsibilities for different aircraft simultaneously. For example, a flight conducted under IFR, while operating under VMC, within airspace where ATC does provide separation from VFR traffic.

SPS1. Cooperative – Non-cooperative. Unlike collision avoidance systems, there is currently no additional separation provision capability designed for the pilot of a manned aircraft when separation is not provided by ATC or the ATM system. Any separation provision system cannot solely rely on encoded transponder returns from cooperative aircraft; it must be able to work with non-cooperative aircraft.
Requirement. The separation provision system shall detect both cooperative and non-cooperative aircraft.

SPS2. Lighting Conditions. Provision of separation is a responsibility of the pilot of a manned aircraft when it is not provided by ATC or the ATM system, whether it is day, night, dawn or dusk. Exterior aircraft lighting standards are specifically mandated to assist pilots of both aircraft involved with the separation of their aircraft in low light conditions. It is expected that the UAS collision avoidance system would provide, as a minimum, the ability operate in the same lighting conditions as a manned aircraft.
Requirement. The separation provision system shall detect aircraft in all lighting conditions in which the UAS is approved to operate.

SPS3. Class of Airspace. Although somewhat dependant on the specific nations' regulatory requirements, ATC/ATM separation services are generally provided to all aircraft operating in Class A and B airspace. In Class C, D, E, and in some countries, Class F airspace separation services may be provided based on whether aircraft are operating under IFR or VFR. In Class G airspace, separation provision may be provided for IFR flights but normally not provided to VFR traffic. When operating under IFR, under control of ATC, ATC is responsible for providing separation between aircraft. As such, for the purposes of aircraft separation, the DUO may not deviate from the approved flight path without clearance from ATC.
Requirement. The separation provision system shall provide the DUO with sufficient information to separate the UAS from other aircraft in any class of airspace where ATC separation is not provided to all aircraft.

SPS4. Flight Rules. When the flight rules in force in that class of airspace require the DUO to exercise separation provision, the DUO shall utilize standard procedures (e.g. Semi-circulars, quadrantals etc) and other information sources (radio traffic, NOTAMs etc) to build sufficient information to maintain adequate separation from all traffic known to the DUO. When flying VFR he will need technical assistance to maintain adequate separation with the same degree of assurance as a manned aircraft flying VFR.
Requirement. The separation provision system shall provide the DUO with sufficient information to separate the UAS from other aircraft whenever VFR operations are being conducted and ATC is not providing separation.

SPS5. Separation Standard – Distance. Standards are only currently available for the acceptable vertical separation required between aircraft. In many countries, based on IFR hemispheric flight levels and those altitudes recommended for VFR flights, aircraft may routinely be separated by as little as 500 feet vertically. However there are no prescribed ICAO horizontal separation minima for manned aircraft where responsibility for separation rests with the pilot. Several authoritative organizations quote or imply that 500ft is an appropriate and acceptable all round miss distance for UASs. In the USA, the FAA[24] view of 'well clear' (i.e. so as to not represent a collision hazard) is a minimum separation of 500ft between aircraft. However, while use of 500ft vertical separation is routine between manned aircraft and should not therefore cause undue concern to other airspace users, the application of 500ft lateral separation could generate a heightened sense of collision risk. An increase in lateral separation to 0.5 NM would reduce this perception and also the risk of collision itself, and is therefore preferable. This lateral limit has some precedence based on the value used for simultaneous close parallel approaches used in the United States[25]. These minima would only apply away from airfields.
Requirements. The separation provision system shall, except for airfield operations, provide the DUO with sufficient information to separate the UAS from other aircraft by a minimum of 0.5 NM horizontally or by a minimum of 500 ft vertically when, under the rules of the air, the UAS has the responsibility to give way to the intruder aircraft.

SPS6. Manoeuvre Authorization. UASs are unique in that their DUO is not physically located in the aircraft. This then allows for the isolated possibility that at some point the DUO may not have control of the UAS due to various communications failures either within the UCS or the air vehicle itself. As separation provision is subordinate to collision avoidance, then provided the aircraft is equipped with an automated collision avoidance system, a fully automated separation provision system may not be required.
Requirement. The separation provision system shall warn the DUO of a pending loss of separation so that the DUO may initiate a manoeuvre whenever the UAS is obliged to do so under the Rules of the Air.

SPS7. System Failures. As the separation provision system would be subordinate to the collision avoidance system, a system failure of the separation system alone would not constitute a critical system failure. Loss of the separation provisions system should not be considered an emergency and therefore no specific transponder code should be generated for simply a loss of separation capability. The system should however inform the DUO of any such failure so that ATC can be informed. A lost link scenario would result in the inability of the AV to provide the status of the separation provision system.

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24 FAA Order 8700.1 Change 3, Chapter 169, Section 5A.
25 FAA Order 8260.39B - Close Parallel ILS/MLS Approaches

Requirement. The separation provision system shall provide the DUO with a system status indication. Any change in the system status shall be clearly obvious to the DUO.

SPS8. Post Manoeuvre Recovery Action. After a separation provision manoeuvre has been executed, separation has been achieved and the risk of collision has passed, barring additional ATC or DUO instructions, the UAS will be required to return to the last ATC cleared or pre-planned routing and altitude. The recovery manoeuvre must not create another risk of collision.
Requirements. The separation provision system shall provide the DUO with a "clear of conflict" advisory once appropriate separation has been reestablished.

SPS9. Field of Regard (FOR). As the provision of separation is required in the same sections of airspace relative to the nose of the aircraft, then the standards already provided for the collision avoidance system shall be utilized for the separation provision system. However, in some cases, in order to meet the required TLOS stipulated in paragraph 7 or comply with right of way rules, it may be necessary to increase the FOR. In the case of UAS, FINAS recommends, as published in FAA AC25.733-1, the FOR in the horizontal plane should be increased to +/-120° off the nose of the UA. Additionally, there may be situations, depending on aircraft performance, that a further increase of the FOR in the horizontal plane to 360° may be needed, particularly when trying to achieve the TLOS for small, slow moving UAs.
Requirements. The field of regard of the onboard sensor system shall be a minimum of +/-110° horizontally with respect to the longitudinal axis of the UAS, a minimum of +/-15° vertically with respect to the flight path at normal cruise speed, and provide sufficient coverage to enable separation from conflicting air traffic during expected manoeuvres.

Appendix C.2 LIST OF ACRONYMS/ABBREVIATIONS

ACAS	AIRCRAFT COLLISION AVOIDANCE SYSTEM
ATC	AIR TRAFFIC CONTROL
ATM	AIR TRAFFIC MANAGEMENT
CV	COLLISION VOLUME
duo	DESIGNATED UAV OPERATOR
FAA	FEDERAL AVIATION ADMINISTRATION
FINAS	FLIGHT IN NON-SEGREGATED AIRSPACE
FOR	FIELD OF REGARD
ICAO	INTERNATIONAL CIVIL AVIATION ORGANIZATION
IFR	INSTRUMENT FLIGHT RULES
IMC	INSTRUMENT METEOROLOGICAL CONDITIONS
MAC	MID-AIR COLLISION
NATO	NORTH ATLANTIC TREATY ORGANIZATION
RVSM	REDUCED VERTICAL SEPARATION MINIMA
SAA	SENSE AND AVOID
TCAS	TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (SEE ACAS)
TLOS	TARGET LEVEL OF SAFETY
UCS	UAS CONTROL STATION
USAR	UAV SYSTEM AIRWORTHINESS REQUIREMENTS
VFR	VISUAL FLIGHT RULES
VMC	VISUAL METEOROLOGICAL CONDITIONS

Appendix C.3 GLOSSARY OF TERMS

Aircraft Collision Avoidance System	Airborne collision avoidance system (ACAS). An aircraft system based on secondary surveillance radar (SSR) transponder signal which operates independently of ground-based equipment to provide advice to the pilot on potential conflicting aircraft that are equipped with SSR transponders. (*ICAO Annex 10, vol. IV (Aeronautical Telecommunications - Surveillance and Collision Avoidance Systems), Fourth Edition, July 2007 – Definitions)*
Air Traffic Services	The national or international authority governing flight in any airspace. For example, Eurocontrol, FAA or ICAO.
Automated Operation	Pre-programmed flight that does not require human intervention for normal operation. Can include all operations from takeoff to final landing or any portion thereof.
Controlled Airspace	Airspace of defined dimension within which air traffic control service is provided to flights in accordance with the airspace classification. *(Federal Aviation Administration - Pilot/Controller Glossary)*
Cooperative Collision Avoidance Systems	Systems (such as ACAS) designed to communicate with the on board systems of other aircraft in order to facilitate the detection and resolution of potential mid air collision scenarios.
Collision Volume	Collision Volume is the volume of airspace around the UA that, if penetrated, results in a mid-air collision or near mid-air collision.
Cooperative Traffic	Traffic that broadcasts position or other information, which assists in detecting and assessing conflict potential. *(Access 5)*
Designated UAV Operator	The UAS system Operator in the UCS tasked with overall responsibility for operation and safety of the UAS system. Equivalent to the pilot in command of a manned aircraft. *(STANAG 4670)*
Detection Distance	The distance at which a SAA system can detect an aircraft on a potential collision course.
Instrument Flight Rules	A set of procedures prescribed by the appropriate controlling authority for conducting flight operations under conditions not meeting the requirements for visual flight or in certain types of designated airspace. Under IFR, the controlling authority is responsible for flight separation with other IFR aircraft. Separation from VFR aircraft is only provided on a workload-permitting basis.
Non-segregated Airspace	Regions open to all traffic, including the various ATS airspaces, in which, no temporary or permanent airspace reservation is established for the use of special aircraft activities.
Segregated Airspace	Airspace of defined dimensions wherein activities must be confined because of their nature and / or wherein limitations are imposed upon flights that are not part of those activities.
Search Volume	The area capable of being viewed by a SAA sensor specified in terms of azimuth, elevation, and range from the UAS.
Target Level of Safety	A generic term representing the level of risk which is considered acceptable in particular circumstances. (ICAO 9574)
Unmanned Aircraft	A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be remotely piloted, can be expendable or recoverable, and carry a lethal or non-lethal payload. Ballistic or semi-ballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles.

Unmanned Aircraft System	The UAS comprises individual UAS elements, consisting of the unmanned aircraft, the control station, guidance and control links and any other UAS elements necessary to enable flight such as the launch and recovery element.
UAS Control Station	The facility or device from which the UAV is controlled and/or monitored for all phases of flight. May include the subsystems designed to plan the mission, employ the sensor employment and connectivity with the appropriate airspace controlling authority. *(STANAG 4671)*
Visual Flight Rules	A set of procedures prescribed by the appropriate controlling authority for conducting flight operations under conditions meeting the requirements for visual flight or in certain types of designated airspace. Under VFR, the designated operator is responsible for flight separation from other aircraft.

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