INVIRCAT Strategies on IFR RPAS Operations in the TMA: Alternatives, Requirements and Effects

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Abstract

This document represents deliverable D4.1 of the INVIRCAT project and is titled “Strategies on IFR RPAS Operations in the TMA: Alternatives, Requirements and Effects". Key findings on alternatives and effects of areas linked to the INVIRCAT project are summarized in the thematic topics of C2 link, communication link, automatic take-off and landing systems, and taxi systems. Each thematic topic is described by its alternative architectures, technologies, and systems, and associated advantages, disadvantages, and gaps. A two-step implementation recommendation is given based on timeframes from the SESAR Joint Undertaking ATM European Master Plan. Effects on safety and efficiency per step are assessed, and the mitigation of these effects is described.

Table of Contents

List of Tables

List of Figures

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1 Executive Summary

This document represents deliverable D4.1 of the INVIRCAT project and is titled "Strategies on IFR RPAS Operations in the TMA: Alternatives, Requirements and Effects".[1] Its purpose is to efficiently summarise key findings on alternatives and effects linked to IFR RPAS integration into the TMA in the course of the INVIRCAT project in the thematic topics of C2 link, communication link, ATOL systems, and taxi systems. Key assumptions of the INVIRCAT project required for the understanding of this work are repeated, and the envisaged timeframe is defined. Afterwards, each of the previously mentioned thematic topics is described by its alternative architectures and/or approaches, and is supplemented with a concise list of advantages, disadvantages, and gaps. These architectures comprise (i) for C2 link: RLOS, SATCOM, and RLOS via Gateway; (ii) for communication link: RLOS, SATCOM, and ground-ground connection; (iii) for ATOL systems: ATOL technologies and ATOL related procedures; (iv) for taxi systems: traditional taxi systems, segmented taxiways, external and on-board taxiing systems, and autonomous taxiing. Further, an implementation recommendation is presented, based on timeframes from the SESAR Joint Undertaking ATM European Master Plan. This implementation recommendation is divided into two steps and subsequently introduces the identified and rated architectures and systems based on their advantages, disadvantages, and gaps. For each step, effects on safety and efficiency are assessed, and the mitigation of these effects is described, if appropriate. The concluding chapter summarizes key findings and statements.

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[1] The opinions expressed herein reflect the author's view only. Under no circumstances shall the SESAR Joint Undertaking be responsible for any use that may be made of the information contained herein.

2 Introduction

2.1 Purpose and Structure of the Document

This deliverable on strategies on remotely piloted aircraft systems (RPAS) operations in the terminal manoeuvring area (TMA) will present alternatives and effects of the reference architecture and various alternatives of infrastructure, systems and sub-systems identified in the course of the INVIRCAT project.

This introduction defines the purpose and scope of the document, the scope of the content of the document, and the relationship with other documents. Chapter 3 summarises necessary assumptions for the understanding of chapters 4 to 7. These chapters are divided into crucial thematic topics for RPAS integration into to the TMA identified in the course of the project, i.e. command and control (C2) link architectures, communication link architectures, automatic take-off and landing (ATOL) systems, and taxi systems. The discussion of each thematic topic will be followed by a clear and concise overview of advantages, disadvantages and gaps per respective chapter. Chapter 8 presents an elaborated implementation recommendation, based on the considered timeframe from chapter 3. This implementation recommendation is divided into two steps and considers effects on safety and efficiency as well as the mitigation possibilities of potential negative effects stemming from the implementation elements. Finally, chapter 9 summarizes the document, derives conclusions, and gives an outlook on upcoming documentation.

The document is complemented with a list of references used during the creation of the document in chapter 0, a list of used acronyms in Appendix A, and a glossary of terms in Appendix B.

2.2 Scope of the Strategies on IFR Operations

This deliverable aims to give a concise overview of findings so far during the INVIRCAT project regarding certain thematic topics, i.e. C2-link and communication link architectures, ATOL systems, and taxi systems. Each thematic topic is also followed by a table advantages, disadvantages, and gaps, so that the reader can easily identify the main aspects of each thematic topic. Requirements are covered extensively and in high detail in the deliverables D2.5 *Preliminary Requirements Definition* and will be further refined in the upcoming deliverable D4.2 *Final Operational and Technical Requirements*, so that the requirements resulting from the presented findings are only described where necessary. Please refer to D2.5 or D4.2, when published, for a detailed requirements definition. The concise overview of advantages, disadvantages and gaps per chapter can be understood as the main outcome of this documentation.

Results from the simulation campaign can only be considered in a preliminary state, as the simulation report D3.4 will be published after the publication of this deliverable. Conclusions from these results will be published in the project's final report D4.3, scheduled for July 2022.

Some parts of this document are not backed up by preliminary findings from the simulation campaign. Due to the coverage of aspects as described in D3.2 *Use Cases Simulation Plan*, not all thematic topics present in this document have been investigated in simulations. Thus, findings presented base on further literature research as a continuation of state-of-the-art analysis in D2.1, and the CONOPS description in D2.3. It should also be noted that the description is not supposed to be understood technical only. Operational aspects are also an important part of the analysis and summarisation.

The authors of this document were careful to not repeat much content that has already been investigated in the research leading to D2.1 *Current State-of-the-Art and Regulatory Basis* [1] and D2.3 *Initial CONOPS 'RPAS in the TMA'* [2]. Reference to this documentation is made when appropriate and necessary for the understanding.

2.3 Relationships with Other Documents

This document can be viewed as a formulation of findings regarding the topics C2-link architectures, communication link architectures, ATOL systems, and taxi systems in the project so far. It builds on the initial research in D2.1 *Current State-of-the-Art and Regulatory Basis* [1] and the concept approach presented in D2.3 *Initial CONCOPS 'RPAS in the TMA'* [2], and also incorporates some early results from the simulation campaigns described in D3.1 *Validation Plan* [3], D3.2 *Simulation Architecture* [4], and D3.3 *Use Cases Simulation Plan* [5]. An extensive analysis of the validation results will be given in D3.4 *Exploratory Research Validation Report*, which is due after the submission of this deliverable.

Parts of the findings presented here will feed content of D4.3 *Final Report: Impacts and Recommendations*, where some statements will be stated more precisely that can only be formulated preliminarily at the current stage of the project and the reporting. Also, some of the findings presented here will, to some extent, have influence on the refined concept in D2.4 *Final CONOPS 'RPAS in the TMA'*.

3 Assumptions

As the strategies on IFR RPAS operations in the TMA and at airports are very much dependent on the type of remotely piloted aircraft (RPA) and the available infrastructure, the scope of this document should be defined. The general assumptions of the INVIRCAT project and the corresponding concept of operations is already extensively described in D2.3 Initial CONOPS 'RPAS in the TMA' [2]. The main assumptions, relevant for the strategies described in this document, are briefly summarized.

The RPAS under consideration are assumed to be of EUROCONTROL's UAS traffic class VI [6], implying certified operations of IFR RPAS. In the scope of INVIRCAT, RPAS are also assumed to

- Have a command and control (C2) link that might also be used for relaying voice communications (R/T) to/from the controlling ATC,
- Have an automatic take-off and landing (ATOL) system operating without assistance of the remote pilot (RPIL) based on visual aids,
- Be able to conduct taxi operations on their own power (besides pushback procedures) and without the support of ground vehicles (e.g. follow-me cars),
- Be highly automated, but not autonomous (as consequence of EUROCONTROL's UAS traffic class VI).

The timeframe considered in this deliverable, especially in chapter 8, is based on the guidelines available in the SESAR Joint Undertaking European ATM Master Plan [7]. In this approach, the RPAS integration is split into three different phases, depicted in Figure 3-1. Phases 1 and 2 correspond to the so-called ICAO "accommodation" period, wherein RPAS can operate in controlled airspace with support or special case-driven adaptations. Phase 3, as a continuation, then is seen as the ICAO "integration" period, where RPAS can enter airspace without special provision.

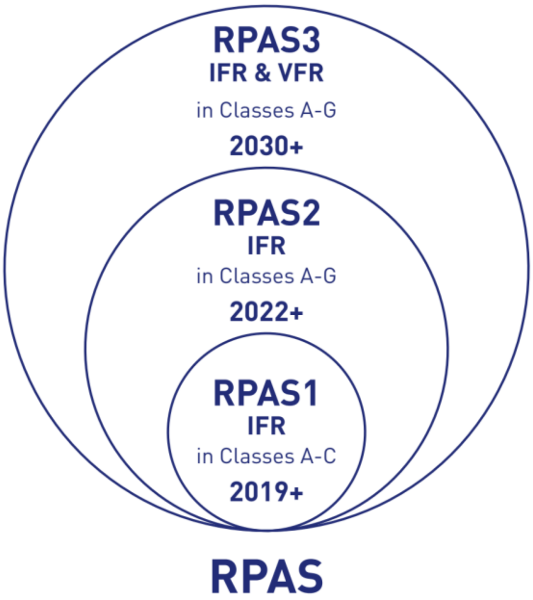

Figure 3-1: SESAR RPAS IFR Integration Plan [7]

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The future development of systems and components of required architecture described in the following chapters cannot be foreseen at present. Where applicable, assumptions are made regarding existing and potential future developments. Currently unknown technologies might have a considerable impact on implementation recommendations described in chapter 8.

4 C2-link Architectures

In order to better understand the different architectures for command and control (C2) of an RPA, it is important to understand the system components and the tasks of the RPIL in the system.

Each RPAS consists of an airborne segment and a ground segment. The airborne segment is the RPA itself. Some of these RPAs resemble conventional aircraft in both appearance and performance, and the pilot on board is simply replaced with a RPIL. However, due to the fact that life supporting systems and equipment are not required, such airborne system might result in drastically different designs as well. In order to comply with the assumption of a Class VI RPA in the INVIRCAT project (Ref. [6]), the RPA, supported by the rest of the RPAS components, will have to comply with the same performance requirements as any other manned aircraft flying in the same airspace. This concerns RNAV capabilities, flying SIDs and STARs and radar vectors, but also take-off and landing (ATOL system in the RPA), CNS (based on ICAO required communication/surveillance performance (RCP/RSP) values) and See-and-Avoid (DAA system in the RPA) capabilities. Chapter 3.1 in Ref. [2] explains in more detail what this means for the RPA systems and also gives examples of the performance characteristic of different types of RPA.

The RPAS ground segment consists of a Remote Pilot Station (RPS), sometimes also called Ground Control Station (GCS). It encompasses all systems for control and monitoring of the RPAS flight. The ground stations differ in set-ups and designs, but they all have in common that a single RPA can only be controlled by a single RPS at a given time. The RPIL is in control of the systems via the C2 link. The systems are divided into critical (with regards to carrying out flight operations) and non-critical systems (e.g. used to monitor and control payload). More details are given in Chapter 3.2 of Ref. [2].

The C2 link is a data communication link between an RPS and an RPA that is used for the purpose of managing the flight. On that link, commands are sent to the aircraft needed for carrying out the intended flight operation and telemetry data is received (including contingency alerts) indicating the current state of the flight and its systems and giving feedback about the execution of the commands. Depending on the type of operation, additional data for carrying out a particular mission may be part of the downlink. This data may either be received in real-time or on command. The C2 link may also include (digital) communication services and the RPA may function as a relay between RPS and ATC. The relevant architectures for voice communication will be described in Chapter 5, though. The current chapter focusses on the different architectures for the control functions of the C2 link and the relevant operational and technical constraints.

Basically, a C2 link may exist in (terrestrial) radio line-of-sight (RLOS), where transmitters and receivers are within mutual radio link coverage, or beyond radio line-of-sight (BRLOS), which is any situation where transmitters and receivers are not in RLOS (see also Ref. [2] in particular chapter 3.4.3.1). As a hybrid option the INVIRCAT project has also been looking at the performance of a combination of ground relay of the communication link towards ground transmitters and receivers which are situated in RLOS with respect to the RPA. This is the so-called RLOS via Gateway option.

4.1 RLOS

In a (terrestrial) radio line-of-sight (RLOS) operation and architecture, the transmitters and receivers are within mutual radio link coverage and thus able to communicate directly. While it means that this operation and architecture is limited in coverage and range and may also be impacted by obstacles (with reflections that can lead to multipath propagation), it is also the least complex form of communication between a transmitter and receiver. The advantage is that a delay of the radio link is low when compared to other architectures where the communication network needs to be extended by relay stations introducing additional delays and increasing the likelihood of equipment failure and data communication loss.

This also means that an operationally more complex ATM situation, requiring quick reaction times of pilots and aircraft, will obviously benefit from the low signal latency in the RLOS architecture, so that RLOS is the preferred architecture to be used in terminal airspace operations. The INVIRCAT Initial CONOPS (D2.3) indicates that literature review has shown that maximum round-trip latencies of the C2 link control functions of about 1 second can be expected for the RLOS architecture [2].

4.2 SATCOM

As can be extracted from D2.1 [1], the C2 link allows a secure and reliable communication between the remote pilot ground control station and the RPA. Ensuring connectivity during beyond radio-line-of-sight (BRLOS) operations could be challenging, as the traditional options such as radio-line-of-sight (RLOS) communications are limited by coverage and range, sometimes, a group of networked terrestrial stations does not exist to provide effective coverage, then a satellite communications link is required. Satellite systems allow greater coverage in situations where the distances between the RPA and the RPS are longer.

The satellite communication C2 link envisioned is subject to design choices incorporating performance goals, limits and failures. C2 link degradation will challenge the ability of the RPIL to effectively command and control the aircraft, especially during a potential loss of well clear encounter when the unmanned aircraft operational situation is changing rapidly and tactical intervention will be required. Satellite communications face an important constraint: the transmission can’t be completed in a timeframe comparable to that of a RLOS system. As it is shown in D2.3 [2], while the maximum C2 link latency (roundtrip) expected with SATCOM is around 2 seconds, the maximum latency for a RLOS system is around 1 second (50% minor), so latency remains as major consideration for SATCOM systems. Due to this issue, although all flight phases can be controlled via satellite, because of the lower latency, RLOS should be used for take-off and landing, if possible, even if SATCOM is used for en-route operations.

As mentioned in [2], RPIL face the unique challenge that their aircraft can fall prey to lost C2 link situations, where the pilots cannot directly control their aircraft and if this happens in an integrated airspace, the ATCO’s workload can increase significantly. Satellite links can suffer from weather related signal fading and signal path obstruction by the RPA airframe can cause signal fading. Mitigations to combat these problems are the use multiple antennas on the RPA, and on the ground, frequency diversity and the use of multiple C2 links. Additionally, according to [8], SATCOM also suffers from propagation loss caused by environmental features such as atmospheric losses or signal absorption. This propagation loss worsens with increasing distance between the RPS (or the transmitter of the SATCOM) and the RPA. Further, satellite connection will most probably not be self-operated but subscribed or bought as a service, and thus depending on the satellite service provider. If a service agreement violation occurs, resulting in a termination of the connection, the C2 link over satellite is lost and must be mitigated by a fall-back satellite solution if no other connection is possible.

As it has been described in reference [1], there are different geostationary augmentation satellites which allow a global coverage, and they are operated by different entities. Besides the well-established geostationary SATCOM, a multi-hop communication system using low earth orbit (LEO) satellites can be foreseen to provide C2 link coverage for RPA [9] while still meeting ICAO RCP/RSP values. This technology reduces the latency of SATCOM communications drastically, by taking advantage of LEO satellites operating at low altitudes of 500 – 2000 km, and hereby reducing the expected end-to-end latency significantly. However, due to the lower altitudes of the LEO satellites the cover range might be reduced compared to geostationary SATCOM systems, depending on the beam sizes of the antennas and the actual altitude of the LEO satellite. Hence, in order to provide C2 coverage over longer distances, a formation of multiple LEO satellites creating a communication bridge/relay to the receiving entity (i.e. RPA) might be required. As a consequence, the use of multiple LEO satellites increases the transmission time between air and ground again, and thereby the C2 link latency. As a result, a trade-off assessment between cover range and acceptable latency has to be made when using this emerging technology.

4.3 RLOS via Gateway

The RLOS via Gateway operation describes a situation where the RPS and the RPA are effectively beyond RLOS. However, data communication via the C2-link is achieved through ground relay stations that allow the connection of the RPS to transmitters and receivers that are positioned at a location where RLOS operations with the RPA are possible. This is the so-called RLOS via Gateway architecture. In the case of TMA operations, this means that transmitters and receivers could be placed as a gateway at airports that are BRLOS for the RPS and allow for coverage of the terminal airspace in RLOS. Additional infrastructure may need to be established for the required connection from the RPS to the gateway.

Regarding the expected end-to-end latency, it would mean that the ground relay would lead to a smaller increase in delay times when compared to satellite communication. The INVIRCAT Initial CONOPS (D2.3) indicates that literature review has shown that maximum round-trip latencies of the C2-link control functions of about 1.5 second can be expected for the RLOS via Gateway architecture [2].

4.4 Advantages, Disadvantages, and Gaps

This section summarizes investigated advantages, disadvantages and gaps regarding C2 link architectures for RLOS (VHF radio), BRLOS (SATCOM) and RLOS via a gateway. More detailed results can be expected in the Validation Report document D3.4 of INVIRCAT, which will be published later this year.

As has been explained above, an RLOS architecture will show the lowest latency values, followed by the RLOS via gateway architecture, which adds a ground network latency component. For BRLOS, a SATCOM connection will work over long distances and have high data rates, but bandwidth is expected to be expensive, reliability to be lower and latency to be higher.

Table 4-1: Advantages, disadvantages, and gaps of RLOS C2 link

RLOS C2 link	
Advantages	+ Lowest latency + Existing infrastructure

Disadvantages	- Short range (albeit sufficient for TMA operations in most cases) - Local weather influences - RLOS spectrum might become congested with additional applications [8]
Gaps	No gaps identified

Table 4-2: Advantages, disadvantages, and gaps of SATCOM C2 link

SATCOM C2 link	
Advantages	+ Long range + Mobility + High data rates achievable (may be asymmetrical in uplink and downlink)
Disadvantages	- High latency - Bandwidth might be expensive (depending on the communication service provider) - Weather related signal fading - Dependent of satellite operator (in case of service agreement violation) - Large and heavy antennas required on the RPA [8] - Signal interference with other terrestrial services [8] - Propagation loss with increased distance (inherent to SATCOM) - May not always be available for certain geo-locations of the RPA
Gaps	* Lower latency with satellites in low-earth orbit possible (if RCP/RSP is met) * Standardized spectrum for RPAS [8]

Table 4-3: Advantages, disadvantages, and gaps of RLOS via Gateway C2 link

RLOS via Gateway C2 link	
Advantages	+ Low latency
Disadvantages	- Slightly higher latency than in RLOS situations - Higher cost than RLOS
Gaps	* Required infrastructure from RPS to gateway

5 Communication Link Architectures

In order to better understand the different architectures for communication between RPIL and ATC, it is again important to understand the system components and the tasks of the RPIL in the system. These have been described in the previous chapter with regards to the C2 link and the monitoring and command & control tasks.

In addition to the functions necessary to fly the aircraft and monitor its state, the RPIL also needs to have radio contact on the appropriate communication channel and establish two-way radio communication with the responsible ATC unit and the ATCO in control. As has been described in Chapter 3.4.3.2 of Ref. [2] in more detail, there are two possibilities for ATC communication: either with or without a relay via the RPA. A relay via the RPA requires the airborne system to carry the necessary VHF radio equipment on board. Generally, just like the C2 link, the communication link may exist in (terrestrial) radio line-of-sight (RLOS), where transmitters and receivers are within mutual radio link coverage, or beyond radio line-of-sight (BRLOS), where transmitters and receivers are not in RLOS. A connection that does not involve the RPA could potentially also be achieved with RLOS and BRLOS architectures. In both cases there will be a link between RPS and ATC, either via standard VHF equipment or using a satellite connection.

Successful integration of RPAS will require that RPAS interactions with the air traffic management system be similar to interactions between manned aircraft and air traffic management. The regulations, however, do not quantify what an acceptable response latency is, stating only that they must not compromise the safe separation of aircraft. RPAS and RPIL response times to ATCO clearances should be equivalent to those that are currently found to be acceptable with manned aircraft.

Finally, the INVIRCAT project also investigated a special option, where a ground connection is used as a direct link between RPS and ATC, and which can be used in combination with the C2 link Gateway via RLOS option.

5.1 RLOS

In a (terrestrial) radio line-of-sight (RLOS) operation, the transmitters and receivers are within mutual radio link coverage and thus able to communicate directly. RLOS communication via the RPA thus means that the RPA is within the coverage range of the RPS. Additionally, there is a possibility to have RLOS communication via the RPA outside the coverage range via a ground network that is still easily accessible and in the proximity of the RPS but where a connection to a remote transmitter is necessary that is within the RLOS coverage area for the RPA. This option will add a delay for the ground network that is considered low, meaning that transmissions will be completed in a comparable timeframe.

Another option for communication between the RPS and ATC in RLOS is to have a direct link between the VHF station of the RPS and ATC, permitting the RPS is within the coverage range of the ATC VHF station or a connected network of VHF stations.

5.2 SATCOM

In a BRLOS operation, the transmitters and receivers are not in RLOS. In the case of satellite communications, large distances can be covered and the RPA could cross different sectors and the RPIL has to contact with different ATC units. In many parts of the world, as it happens over the oceans,

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connections from RPA to ground stations are difficult or even impossible. In those cases, the use of satellite connections may be a complementary or required feature to improve or enable coverage and reliability. Satellite communications allow long endurance flights and large distances, in this case, ATC orders should be redirected to the RPS through satellite communications.

In the case of direct communication between RPS and ATC, remote pilots will act as pilots of manned aircraft do, and they will be responsible for selecting the correct subchannel ordered from ATC unit to communicate. This is not the case of satellite communications, since the RPA is not able to change the ATC channel by its own, autonomous mechanisms and messages to perform the communication should be implemented into the RPA, adding complexity to the system.

Satellite communication links, as opposed to the UHF/VHF radio communications used by pilots of conventional aircraft, lengthen the time to respond verbally by increasing audio set up and signal propagation times. As can be extracted from the estimations shown in D2.3 [2], the latency expected for SATCOM is around 700 ms (one-way), much higher compared to the results obtained in case of RLOS (290 ms) or the ground network (150 ms).

Wherever possible, terrestrial communication should be preferred over satellite communication. Only once in en-route phase, apart from being out of visual contact with the RPAS, communications are conducted with a remote Area Control Centre (ACC).

5.3 Ground-ground Connection

Both the RLOS (VHF) and BRLOS (SATCOM) situation with a direct connection between the RPS and ATC, and thus without relay via the RPA, could be further improved using a direct ground-to-ground connection. While this leads to the lowest latency and the highest reliability when compared to the radio connections, it also requires that new infrastructure (basically the cabling) may need to be created between the RPS and ATC. Due to the high reliability, these wired connections are recommended as a backup means for voice communication between RPILs and ATC when the radio equipment at the RPS or in the RPA fails. Even more so, wired connections between RPS and ATC could become the preferred medium for voice communication in the future (e.g. in Phase 2 of the RPAS Roadmap), especially if it is possible to integrate them with the frequency used by the ATCO to control manned traffic.

5.4 Advantages, Disadvantages, and Gaps

This section summarizes investigated advantages, disadvantages and gaps regarding voice communication architectures. More detailed results can be expected in the Validation Report document D3.4 of INVIRCAT, which will be published later this year.

A study of the state-of-the-art for communication architectures and the different options for voice communication between the RPIL at the RPS and an ATCO at an ATS unit in References [1], [2] and [10] has shown that each of the architectures will lead to different values for end-to-end latency. Generally, with respect to interference, a wired connection is considered more reliable than a radio connection, and a VHF connection again is considered more reliable than a SATCOM connection. This was confirmed by the RPA pilots taking part in the simulations. Their own experience was indeed that SATCOM connections had an increased risk of losing the connection and therefore they always looked at communication links via SATCOM with caution. Wired links were used as backup means at the RPS to establish a direct link with the relevant ATS units.

In order to assess the impact of the latencies introduced with different architectures, some typical values had to be determined first. A literature review as well as stakeholder consultations performed led to the following radio communication latencies that were considered for the simulations (cf. [2]):

Table 5-1: Expected Maximum Voice Communication Latencies (One Way)

RLOS	SATCOM	Ground network
290ms	700ms	150ms

The latencies were introduced in all simulations as a configurable delay in the voice communication systems used at the different simulation platforms. Feedback from ATCOs and RPILs after the simulations showed that none of the one-way latencies, in particular the ground network and RLOS delays, were actually noticed by the participants. Sometimes, they were not even aware of the somewhat larger delay in the case of a SATCOM connection. Even if they became aware of that delay, they said that it had no further impact on their work and they did not apply additional safety buffers. A slight workload increase was noted but manageable.

However, they also stated that a situation with more traffic and a higher frequency load on the VHF radio could render larger communication delays in the range of one second noticeable and undesired. Such a situation could lead to overlapping calls on the frequency that potentially cancel each other out, and thus it would lead to even more delays and, even worse, safety issues. This would especially be true for the ATCO who might notice delays in pilot readbacks and reactions to instructions. For the RPIL, the consequences of communication latency would be less grave, as controller instructions are carried out by the RPIL as soon as they are received without the need of having to wait for voice feedback (such as pilot readbacks to ATC).

Further, in the simulations with BRLOS latency values (SATCOM connection), RPILs also mentioned that the reliability of the link, in real life, was usually the bigger issue. As for the latency, the end-to-end encryption of the signal applied in the real environment would probably add more latency and that again could lead to more noticeable communication delay.

Regarding the backup communication via a phone line, controllers mentioned that mechanisms must be in place to ensure that the call comes from a genuine source, meaning that lines are secure and authenticated users are using the system, so that there is no doubt that the controller is in fact talking to the pilot of the RPA signalling voice communication loss. In addition, when the voice communication link with a specific controller working position is established via a ground network (such as the used phone line), it should be possible to integrate it into the control frequency in order to increase situational awareness (party-line effect). Seamless integration of backup lines into the communication frequency was thus strongly recommended. This comment is relevant for any additional voice communication line that has to be integrated into the control environment. The link has to be verifiably secure and needs to be retransmitted on the frequency. This is especially true, if the backup phone line will become a dedicated voice communication ground link, and other less reliable methods will become the backup solution. Simulations with controllers showed that they were not as worried about R/T loss of an unmanned aircraft as they were about the loss of R/T with a manned flight, as the backup option would always be available. Turning that concept around, and making the (integrated) backup phone connection the primary means of communication, would not change that attitude, as there would still be a redundant means of communication.

As mentioned above, further feedback from controllers and pilots will be contained in the upcoming D3.4 document, the INVIRCAT Exploratory Research Validation Report.

Table 5-2: Advantages, disadvantages, and gaps of RLOS communication link

RLOS communication link	
Advantages	+ No additional ground network connection required, per se + If there is a connection to a ground network of VHF infrastructure, RLOS connections are possible beyond LOS (ground relay) + Low latencies
Disadvantages	- Medium risk of weak signal or signal loss (due to interference).
Gaps	No gaps identified

Table 5-3: Advantages, disadvantages, and gaps of SATCOM communication link

SATCOM communication link	
Advantages	+ Communication beyond LOS possible.
Disadvantages	- Higher risk of weak signal or signal loss. - Higher or increased latencies
Gaps	* Reliability of the link should be improved.

Table 5-4: Advantages, disadvantages, and gaps of ground-ground communication link

Ground-ground communication link	
Advantages	+ Low risk of weak signal or signal loss. + Very low latencies (but will depend on network infrastructure design choices). + ATM ground-ground infrastructure performance requirements are well defined (ATM VoIP).
Disadvantages	- Possibly new infrastructure needed. - Possibly higher network infrastructure latency (see advantages above)
Gaps	* Reliability leads to use as backup communication option. May have to be integrated into frequency for party-line effect (not necessary if already used for regular communication on the frequency).

6 ATOL Systems

The Automatic Take-Off and Landing (ATOL) concept defined in [11] and adopted in the INVIRCAT project provides to an RPAS the capability to automatically perform the operations from “CLEARED FOR TAKE-OFF” to completion of the initial climb and from the beginning of the approach phase to RPA stop on runway, comprising holding, missed approach and rejected take-off procedures.

Even if some of these operations are meant to be initiated automatically by the ATOL and some others to be triggered procedurally by RPIL and ATCO, the RPIL is always considered responsible for the RPAS. The only exception to this is in case of a failure of the C2 link.

As better described in [1] and [11], ATOL concept can be considered as made up of four major concept elements: RPA technical functions, RPS technical functions and rules and procedures for the two environments where the ATOL capability delivers its service by involving remote crew and ATC controllers and airfield personnel. In the next sections, further details on technological and procedural aspect of ATOL will be reported.

6.1 ATOL Technological Concept

Technological aspect of ATOL refers to both airborne and ground functions of the ATOL concept where the airborne are the ones executing automatically several tasks today executed by on-board pilots in manned aviation while the ground are the ones supporting the RPIL, or the remote crew, to track the RPA and to monitor, control and override the ATOL airborne functions.

As reported in [1], each subpart of these functions, which functional architectures are described in [11], rely on different technological elements (e.g. navigation equipment or guidance algorithm) that can be based on various means. The variation on these technological elements from an RPAS to the other can lead to a differentiation in performances.

However, looking at the assumptions reported in chapter 3 ,and defined in [2], as giving a performance baseline for the considered RPASs in executing operations in TMA these possible variations induced by the utilized technological means has not been evaluated in the INVIRCAT project.

Indeed, taking in to account only RPASs belonging to the class VI of the UAV classification by EUROCONTROL [6] assure that the CNS airspace requirements are met and that the airworthiness certification is obtained and so that all of the component of the RPAS, including the ATOL, fulfil the same performance requirements as any other manned aircraft flying in the same airspace.

Moreover, the assumption for the considered RPASs to have an ATOL system able to land without the visual assistance of the RPIL, set in [2] to allow automatic operation down to the ground and also the continuation of the operations in case of a failure of the C2 link, also give a requirement for RPASs that independently from the technological component of its ATOL capability shall allow, with reference to the precision approach systems used in manned aviation as reported in [10], the RPIL to land with “No Decision Height”.

A deeper focus on the technological aspect and the minimum aviation system performance standard for RPAS ATOL can be found in [11].

6.2 ATOL-related Procedures

Procedural aspect of ATOL refers to rules and procedures that establish how RPIL, or remote crew, ATCO and airfield personnel shall coordinate each other during RPAS ATOL operations.

As for assumption set in [2], the considered concept of ATOL system is assuring compliance with the same rules and procedures as the other airspace users without disruption of the current operations. This assumption was respected as much as possible in the definition of the ATOL operations considering the increased level of complexity added to RPAS operations due to the presence of C2 link latency, the possible increase in communication link latency and the introduction of specific RPAS contingencies as C2 link loss.

The flows of activities for each of the procedure considered in the INVIRCAT project, also considering the effect of C2 link and communication latencies, are reported in [10].

C2 link loss is one of the contingencies that differentiate more RPASs to manned aviation and therefore the related procedures have less references within the current regulation, also if as reported in [2] C2 link can be considered equivalent to the linkage between pilot and the control surfaces in a manned aircraft. The proposed procedures in INVIRCAT for this contingency vary depending on the phase of the flight in which the C2 link loss is experienced and on whether or not the link is re-established. To summarise them all, is allowed to the RPA to follow autonomously the pre-defined take-off or landing procedure for a certain amount of time, or until a certain waypoint, before it has to automatically heads to a dedicated circuit, to flight with a pre-defined altitude and speed, waiting for the C2 link to be re-established. After a determined time period, if the C2 link is not re-established the RPA has to flies the termination flight procedure direct to the termination point.

6.3 Advantages, Disadvantages, and Gaps

As readable from the state-of-the-art [1] and the MASPS for RPAS ATOL [11], developed by EUROCAE in collaboration with the project “Enhanced RPAS Automation (ERA)” and main reference for the ATOL concept in the INVIRCAT project, ATOL capability is considered as essential for safe integration of RPAS into non-segregated areas considering non-normal situations such as the loss of the C2 link.

Moreover, considering that C2 link latency is an intrinsic characteristic of all the RPAS architectures and specifically affect the interaction between RPIL and RPA ATOL automatic operations couldn’t be considered that beneficial allowing to minimize the need for manual flight and enhance the safety level during such critical phases as take-off and landing. Indeed, for the RPIL involved in the RTS ATOL represented an important help-system to perform landing and departure even when high latency occurs.

From the beginning of the INVIRCAT project the increase in time of response to ATCO request of RPASs respect to manned aviation was under the lens. For RPASs, apart from effects due to C2 and communication link latency already discussed in previous chapter, the use of ATOL shouldn’t affect this time of response and to this regard the main factor to considered is the interaction between RPIL and RPA. To avoid this eventuality the assumption for the RPIL to be adequately trained for the ATOL operations was defined in [2]. Moreover, despite performances connected to RPS interface are not under investigation in the INVIRCAT project the RPILs involved in the RTS confirmed to receive the information in time and clear through the HMI used during the experiment.

Both ATCOs and pilots reported to consider the RPAS ATOL procedures defined in INVIRCAT, and reported in [10], as totally corresponding to ATOL procedures executed by manned aircraft in both nominal and contingency conditions, respecting the assumption for the RPAS under ATOL control to ensure compliance with the same rules and procedures as the other airspace users recalled above. The only exception was represented by the C2 link loss procedure regarding which born an interesting round table with the ATCOs and pilots taking part in the simulations. The two main topics that arose are whether consider C2 link loss as a contingency or an emergency, allowing therefore the continuation of the other operations or not, and the possibility to allow an RPAS to land autonomously through ATOL under pre-determined circumstances in case of a failure of the C2 link.

Further feedback from controllers and pilots on the RPAS ATOL operations proposed in INVIRCAT and the effect of C2 link and communication latency on them will be contained in the upcoming D3.4 document, the INVIRCAT Exploratory Research Validation Report.

Table 6-1: Advantages, disadvantages, and gaps of the ATOL technological concept

ATOL technological concept	
Advantages	+ Mitigate the effect of latency on RPAS operations + Overcome loss of RPA control during failure of C2 link
Disadvantages	- May require dedicated and expensive ground equipment in the runway area
Gaps	* New certified low complexity and cost equipment for precise navigation

Table 6-2: Advantages, disadvantages, and gaps of ATOL related procedures

ATOL related procedures	
Advantages	+ New procedures for RPAS using ATOL can lead an increase of automation and a reduction of pilot workload also for manned aviation
Disadvantages	No disadvantages identified
Gaps	* Specifically defined procedures for C2 link failure * Specifically defined set of messages exchanged by the RPIL with ATCO

7 Taxi Systems

Following the motivation from [12], as also mentioned in D2.3 [2], the integration of RPAS in the airport environment should not have a significant impact on other users of the airport and the predominant infrastructure. However, due to the RPIL not being on-board the RPA, some measures have to be taken to enable efficient taxi operations. Different stages of automation are thinkable, which are presented below and investigated regarding the advantages, disadvantages, and gaps.

The INVIRCAT project's scope is complete operations in the TMA and at airports, which includes taxiing to and from the gate. However, due to limited resources, taxiing has not been included in the simulation activities as described and justified in D3.3 *Use Cases Simulation Plan* [5]. All described advantages, disadvantages, and gaps regarding taxi systems are thus based on literature research in D2.1 *Current state-of-the-art and regulatory basis* [1], early conclusions in D2.3 Initial CONOPS "RPAS in the TMA" [2], and additional research towards this deliverable. They are not confirmed or supplemented by validation exercise findings in the course of the INVIRCAT project.

7.1 Traditional Taxi System

In this concept, the RPIL performs a manual taxi in such a way that existing RPAS are controlled by the RPIL from an RPS on its own propulsion and travel the runway as a manned aircraft would do. The RPIL controls the RPAS on the taxiway using a forward view from the RPAS camera displayed on the piloting screen. The RPIL is usually located close to the landing and take-off airfield of the RPAS, and is familiar with the aerodrome configuration. The RPIL could also follow the RPA, in that case using a mobile RPS and is responsible for collision avoidance as well as for listening to ATC or Common Traffic Advisory Frequency. Following EUROCAE [13], RPAS are usually allowed to taxi on airfields shared with manned aircraft if at least one of these points is applied:

- RPAS and manned aircrafts are parked on different and well defined parking area, and RPAS and manned aircrafts never use simultaneously same taxiways and runways;
- The ATC provides separation between RPAS and manned aircrafts;
- The ATC temporary stops all manned aircraft operations when an RPAS is taxiing.

With the introduction of the AutoTaxi [13] capability, RPAS will be able to operate through the runway in a similar manner as manned aircraft, taxiing along planned and authorised trajectories and reacting to obstacles. Two modes are proposed for this purpose:

- Automatic: the RPA will automatically perform the planned taxi phase and react to any collision risk. In this case, the RPIL remains in the loop, provided with situation awareness from RPA AutoTaxi sensors and data, and informed of the RPA intentions, able to react and override the RPA as required;
- Improved Manual: the RPIL controls directly the RPA on the planned taxi phase and remains at all times in the loop, provided with situation awareness from RPA AutoTaxi sensors and data, able to react to any collision avoidance alert.

In contingency situations, as it happens in the case of loss of the communication link between the ATC and the RPIL, the RPA must either stop or leave the runway and stop, manually or automatically with the AutoTaxi capability.

7.2 Segmented Taxiways

As described in [2], and stemming from the project PJ.03a-09 SUMO [12], the segmentation of taxiways for RPAS traffic is an easy way of integrating RPAS at an airport without the requirement for infrastructural modification. The principles of this new SESAR operating method are shown in [2].

This concept allows an easy integration of RPAS into manned aerodrome traffic and the procedure is very simple and very definite and minimizes the risk in nominal and non-nominal conditions. In case of a loss of communication or a loss of C2 link, the aircraft would stop at the next mandatory holding point in any case, which guarantees that safety is maintained.

As only one RPA per route segment is allowed and the ATC has to ensure that before giving the 'go command' the cleared segment is free of other traffic, RPAS do not need a Detect-and-Avoid capability for ground movements.

The procedure provides a high transparency of the unmanned traffic to other pilots, air traffic controllers or ground personnel and ATC is able to manage the traffic because all aerodrome traffic is under control and at least basic means are available to influence the RPAS movements.

Nevertheless, this system has some shortcomings and it may need a higher level of attention on ATC side as traffic de-conflicting with RPAS is done by the controllers only. Also, traffic efficiency will be lower compared to pure manned traffic as there are only restricted options to guide unmanned traffic.

7.3 External and On-board Taxiing Systems

From a technology perspective, taxiing can be supported by either external systems or on-board additions to the airframe of the RPA. In this context, external systems are understood as vehicles or other mechanisms to tow the RPA [14], while on-board systems are located on or in the RPA and remain installed for the entirety of the flight. Research and development towards these systems seems to be motivated mostly by the aim of reducing environmental impact and associated costs (e.g. fuel savings compared to taxiing via aircraft engine power) [14]. As these systems are also used in manned aviation, application in RPAS operations has two advantages: Future developments are more likely to happen due to the broader customer base, and RPAS can follow introduction of potential new airport surface movement concepts relying on such systems.

As an example for an external taxiing system and associated advantages and disadvantages, the TaxiBot system can be mentioned. TaxiBot is a hybrid-electric semi-robotic towbarless aircraft tractor system developed by the company Israel Aerospace Industries (IAI) for taxiing aircraft and the operation on national and international airports [15]. The TaxiBot tractor is able to lift the nose gear of the aircraft and taxi the aircraft via its tail landing gear. The system was first approved by EASA for airport operations in November 2014 [16] and is currently used on various international airports as e.g. Frankfurt airport (EDDF) [15]. One key advantage of this system is the ability to be controlled from the pilots' position using a unique nose landing gear (NLG), which steers all wheels of the tow tractor [14]. In an RPA the NLG would be steered by the RPIL facilitating the independence from ground personnel or other system. Fuel consumption for the taxi process can be significantly reduced by up to 85% for some representative passenger aircraft [16].

On-board taxi systems, opposed to the external taxi systems, are electrical systems that can be installed directly on the RPAS, allowing more flexible and efficient usage. The WheelTug is such an on-board taxi system, which has been introduced in 2005 [17]. This system introduces an additional electrical engine in the front gear of an aircraft, which can be directly steered by the RPIL. The WheelTug is permanently installed and thus adds to the total weight of the RPAS, therefore increasing fuel consumption. Advantages are the ability to closely follow a given speed profile along the taxiways, if required. Installation of such a system can be foreseen during the development of integrated RPAS, thus keeping cost and additional effort at a minimum. Further advantages of on-board systems, facilitating the integration of RPAS, are the independence of ground personnel and equipment. However, currently only selected aircraft manufacturers opted for an installation of the system, which shows that the cost and effort might be high, and/or the modification required per different airframe is complex.

While the assumptions in chapter 3 state that the RPAS must be able to perform taxi operations on its own power, the application of external or on-board taxiing systems is not contradictory. These systems can be regarded as supplementary options for reduction of the environmental impact, the improvement of taxi operations performance, and/or the integration at the airport similar to conventional aircraft, if facilitated by the airport.

7.4 Autonomous Taxiing

In this concept, as also described in [12], the mission profile along the taxiways is uploaded and then executed automatically with autonomous support features, such as detection of stop-bars/obstacles/hazards. The RPIL does not have to interact with the RPA.

Main advantage of such concept is the significantly reduced workload for the RPIL and the ground ATCO, as the RPA proceeds autonomously. However, if integrated into conventional taxi systems, this autonomous RPA poses an unknown factor to the ground ATCO. Further, the safety while taxiing relies on sensors and machine based decision-making on-board, with little to no possibility for timely human intervention, if required. The missing possibility to prevent critical situations by anticipation of the RPIL and/or the ATCO may also lower acceptability. Last, the presumed high cost and the demand for technological novelties pose a significant challenge for implementation of this concept. In the future, sophisticated artificial intelligence might be available to replace the human decisions to be made, but at present, autonomous taxing without human intervention does not seem to be capable of maintaining the required and desired level of safety.

The concept is not followed in the INVIRCAT CONOPS due to the assumption that the RPAS is not autonomous as described in chapter 3.

7.5 Advantages, Disadvantages, and Gaps

This section elaborates on the advantages, disadvantages, and gaps that were identified for the presented systems and procedures for taxi systems. As indicated before, these are based on the research results and related work and were not assessed in the simulations carried out in the INVIRCAT project.

Traditional taxi systems require the least modifications to existing systems and procedures. All additional equipment is located on the RPA and thus independent from the existing infrastructure. Compared to other more sophisticated systems, the environmental impact remains high, with taxiing enabled through own propulsion. Additionally, performance will be degraded if no AutoTaxi feature is applied, and workload for the RPIL in manual modes, and/or ATC when separation to other aircraft has to be provided, will increase.

The concept of segmented taxiways comes with high predictability and safety. The step-wise process along the taxiways with a mandatory holding point allows safe traverse of a free taxiway and makes detect-and-avoid capabilities unnecessary. However, as each segment has to be approved by ATC and cannot be used by other traffic, this method implies a negative impact on traffic efficiency during taxi operations.

Taxiing systems, external or on-board, apply support systems to the taxiing process. If such a system removes the necessity to start up the engines on an RPA, the advantages are manifold, from noise to pollution. However, there might be additional personnel needed in some cases, and on-board modifications both add weight to the RPA and require particular modification.

Finally, autonomous taxiing – although not in INVIRCAT’s scope – would solve RPIL- and ATCO-related challenges in the taxiing process. The high technological nature of this concept also presents its biggest disadvantage so far: the loss of anticipation from a human actor in the loop, and the safety that is purely linked to sensors, either on board the RPA or external. Associated costs might become affordable with time, but artificial intelligence to fully replace the involved humans and their decisions is a considerable gap to cover.

Table 7-1: Advantages, disadvantages, and gaps of the traditional taxi system

Traditional Taxi System	
Advantages	+ Little modifications
Disadvantages	- Pollution/environmental impact - Limitations when operating with manned aircrafts - Higher workload for the RPIL (mostly in manual mode) and ATC
Gaps	No gaps identified

Table 7-2: Advantages, disadvantages, and gaps of segmented taxiways

Segmented taxiways	
Advantages	+ No need for infrastructural modification + Safety maintained + Fast and easy implementation + Transparent

	+ Predictable + No need for a Detect and Avoid capability for ground movements
Disadvantages	- Limitation of existing taxiways for conventional traffic - Lower traffic efficiency - Higher level of attention on ATC side
Gaps	No gaps identified

Table 7-3: Advantages, disadvantages, and gaps of external and on-board taxiing systems

External and on-board taxiing systems	
Advantages	+ (Hybric)-electric power instead of RPAS engines during taxi possible + Reduction of emissions + Reduction of acoustic noise + Reduction of fuel consumption/costs + Shorter pushback time + Parallel parking enabled with on-board taxiing systems
Disadvantages	- Personnel still required for pushback on some external taxiing systems - Increased take-off weight for on-board taxiing systems
Gaps	* Modifications required per airframe (and thus per RPA model), hindering global “off-the-shelf” usage

Table 7-4: Advantages, disadvantages, and gaps of autonomous taxiing

Autonomous taxiing	
Advantages	+ Little workload for RPIL and ATCO
Disadvantages	- High technological demand and associated costs - Sensor-dependent safety - Lack of anticipation
Gaps	* Artificial intelligence for full replacement of human decisions

8 Implementation Recommendation

8.1 Order of Implementation

In the course of the project, crucial thematic topics for RPAS integration into to the TMA were identified. These different thematic topics were explained above and their possible advantages, disadvantages or gaps were identified. In this section, the objective is to establish a recommendation in the order of implementation of these thematic topics or technologies according to the level of technological maturity they present. In order to measure and assess the maturity level of a particular technology the European Commission [18] uses the Technology Readiness Levels (TRLs). Each technology project is evaluated against the parameters for each technology level and is then assigned a TRL rating based on the projects progress. There are nine technology readiness levels. TRL 1 is the lowest, where just basic principles are observed and identified, and TRL 9 is the highest, where the actual system has been proven a valid basis for operational environment. TRLs concept has a relation with the E-OCVM Concept Lifecycle Model (CLM) phases. TRL 5 has relation with V3 (Build, consolidate and test) phase of CLM. In order to establish an order of implementation depending on the maturity level of the technologies mentioned, two different steps have been defined:

- Step 1: where the technologies with the highest level of maturity are implemented. Technologies with a TRL greater than or equal to 5 (achieved once there is component/breadboard validation in a relevant environment) would be in this implementation phase.
- Step 2: where the technologies with the lowest level of maturity are implemented. In this step, technologies with a TRL of less than 5 will be located.

These two implementation steps will be carried out at different points in time. In order to establish these time periods, reference [7], outlines which RPAS-related research and development (R&D) activities should be prioritised in order to support the expansion of the drone market and achieve the smooth, safe and fair integration of these new aircraft systems into the European airspace. In the Figure 3-1, in order to achieve integration with manned aviation, three different integration phases are shown.

The step 1 defined in this document would correspond to the interval from 2022 to 2030 which allows the accommodation of IFR RPAS in classes A-G. As it is explained in reference [7], in this phase, RPAS flying under IFR will have a DAA capability, enabling them to integrate with IFR and VFR traffic, both cooperative and non-cooperative, in airspace classes A-G. Communications with ATC will use an appropriate architecture, addressing integrity and security requirements.

The step 2 would correspond to the interval implemented from 2030 onwards, which would include also VFR flights, which are not part of the scope of INVIRCAT. This step will allow the integration of RPAS in classes A-G (IFR and VFR). RPAS will be able to operate in controlled/uncontrolled airspace, both under IFR or VFR, and safely integrate with cooperative and non-cooperative traffic. Increased use of datalink for ATC communications is likely. Work on broadening the range of RPAS types and mission continues, and the ATM environment starts to evolve as routine operations diversify.

In order to carry out this development, first of all, a table has been defined consisting of the technologies mentioned above, as well as all the flight phases. In the following table, architectures and technologies are placed according to the step and the phase of flight to which they apply. Features are marked by a cross if no distinction in technology is made. Features introduced in step 1 remain available in step 2.

Please note that, while the potential advantages, disadvantages, and gaps of taxi systems have been identified in chapter 7, taxi systems have not been part of the INVIRCAT simulation campaign as explained in D3.3 [5]. As the implementation recommendation is limited to actually validated technologies and architectures, taxi systems are not included.

Table 8-1: Phase of implementation (step 1 or step 2) of each technology per flight phases

	Flight phases	Introduction in step 1	Introduction in step 2
C2 link	Taxi Take-off Departure via SID Arrival via STAR Holding Approach Landing	RLOS	RLOS via gateway[2]
	En-route	SATCOM	
Communication link	Taxi Take-off Departure via SID Arrival via STAR Holding Approach Landing	RLOS	Ground-ground
	En-route	SATCOM	
ATOL	Take-off Holding Approach Landing	Available for airports with ILS CAT III or GLS GAST c/d	Available for minor airports

8.2 Step 1

As it is explained above, on a first step (2022-2030) IFR flights in all airspace classes will be allowed and technologies with a higher level of maturity will be implemented. In this step 1 of implementation, C2 link is available, which is essential to progress from occasional missions requiring specific authorization to routine access to the airspace supporting large numbers of RPAS operating whenever and wherever needed. The Command and Control (C2) link must be highly reliable and robust, and both RLOS links

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[2] RLOS should be used when possible. RLOS via gateway, if available, should be preferred over SATCOM.

using terrestrial-based communications and BRLOS links using satellite communications are present in this phase. Allocations are already available for RPAS use in the frequency band 5030 – 5091 MHz. These allocations are shared between the aeronautical mobile (route) and the aeronautical mobile satellite (route) services, and shared with the aeronautical radio-navigation service as well.

As it happened with communications, in the case of C2 link using VHF radio-communication, the main problem which could affect the INVIRCAT concept, is that the radio range may be small and this can be solved with the handover procedure. The same happens when the curvature of the earth or obstacles prevents the use of VHF.

From an operational perspective, the main difference between an RLOS operation and a BRLOS operation will be the delays associated with control and display information and the design features selected to accommodate the available C2 link capacity. When using a SATCOM link, the latency associated will be higher.

As a summary, communications would be carried out in the following manner:

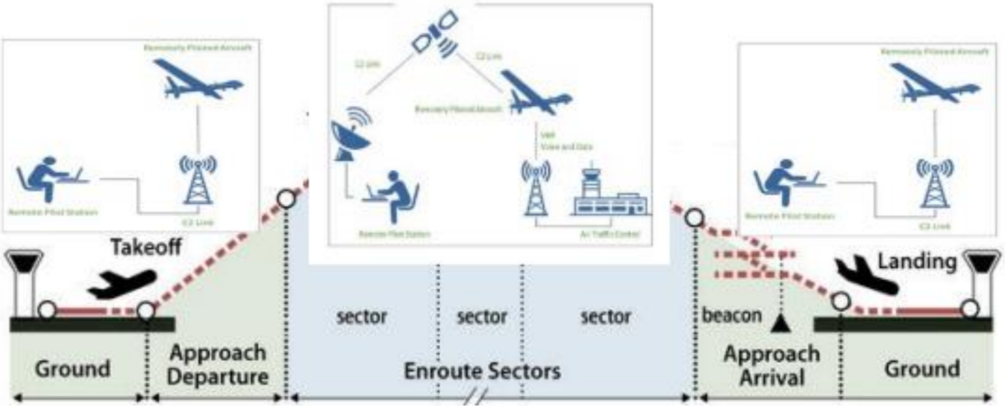

Figure 8-1: C2 link architectures implemented in step 1 depending on the phase of flight

During the taxi, take-off, departure via SID, arrival via STAR, approach and landing phases, C2 link via RLOS will be used and in the en-route sectors, C2 link via satellite will be preferable. C2 link should be available and the pilot will be able to actively manage the flight. Coordination between the respective RPILs and with ATC will be necessary.

During this period, the communications between the RPIL and ATC are planned to be carried out mainly through the two architectures mentioned below. This step would include the case of RLOS communications. In this case, no major changes are needed and standard VHF ATC equipment is used in RPS, so there is no need to change the ATC structure or procedures. VHF radio communication is a good option when flying over areas where there are regular radio towers to send and receive signals, and due to the low latency, is a good option in critical phases of the flight. However, when flying over the oceans and in situations where the curvature of the earth or obstacles prevents the use of VHF, VHF communications are not really an option. In the concept of INVIRCAT, this architecture is useful for all the corresponding phases of flight in the TMA (taxi, take-off, departure via SID, arrival via STAR, approach and landing), and will allow communications between the RPIL and ATC.

This first phase of implementation would also include satellite communications. Satellite communications (SATCOM) are already today an important component of aeronautical communications for manned aviation, in particular for the oceanic airspace where it is not possible to use VHF communications. There are SATCOM systems already operational and compliant with the current SATCOM SARPs, such as INMARSAT Classic Aero and SB Safety, and Iridium [19]. According to the INVIRCAT concept, this kind of communications are primarily used for providing communications in a BVLOS operation, RPAS can utilise a variety of different services, such as the before mentioned satellites, INMARSAT and Iridium, which have different global coverages, uptime percentages and bandwidth capabilities. As it was explained in [2], SATCOM voice communications still require standard radio discipline procedures, as avoiding garbling, and it is important to note that a so called “party line” is not automatically available during SATCOM communications. However, it is possible for the controller to initiate a conference between one more aircraft as and when necessary. In this step 1, satellite communications are planned to be mostly used for en-route phase of flight, due to the higher latency associated with it, which is not a phase of flight that occur within the TMA and is not part of INVIRCAT's main focus. This architecture can be used for all the phases of flight if necessary, but not preferable due to its higher latency and the problems associated with it.

As already reported in chapter 6, ATOL is deemed essential for safe integration of RPAS into non-segregated areas e.g. considering non-normal situations such as the loss of the C2-link. ATOL systems are already used in manned aviation and different precision approach systems exists based on radio or GNSS navigation systems. According to the INVIRCAT concept, RPASs’ ATOL system shall allow the RPIL to land with “No Decision Height”. This can be achieved by mean of different technologies involving the RPA alone or together with the airport in some cases. Precision approach systems that allow this, i.e. ILS CAT III and GLS GAST c and d, are already available also if may require dedicated and expensive ground equipment in the runway area and, therefore, might not be so commonly available especially in minor airports. In this first phase of implementation the ATOL concept will be applicable only in these airports. ATOL systems shall automatically perform operations during take-off, approach and landing, in nominal and some contingency situations. In the concept of INVIRCAT, when considering the IFR take-off, once the RPIL acknowledges clearance from TWR ATCO, the automatic take-off will be initiated. When arriving to the approach phase, as soon as the RPA is established on the xLS, the RPIL will activate the ATOL system and the ATOL system will land the RPA on runway and reduce the speed automatically.

8.2.1 Effects on Safety and Efficiency

This section shows the effects that C2 link and communication architectures and ATOL system have on safety, feasibility and efficiency during step 1, taking into account the advantages, disadvantages and gaps identified in the previous paragraphs (for the C2 link architecture refer to section 4.4, for communication architecture to section 5.4 and for the ATOL system to section 6.3).

The ICAO defines safety as “the state in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level” [20]. In the INVIRCAT scope, feasibility addresses the “workability” of the assessed aspect (concept, procedures, methods, tools, etc.). Feasibility is key pre-requisites for acceptance, effective and efficient usage of any new system, concept, procedures or methods. The RPAS operational acceptance was investigated using controller feedback from questionnaires, debriefings and interviews addressing the feasibility of the tasks in the different conditions. The efficiency aspects are related to the assessment of the C2 and R/T voice latencies and the information provision for the ATCO and RPIL.

According to the Table 8-1, in the Step 1, the RLOS will be implemented for both the C2 link and communication architectures, while the ATOL system will be used for the airport where the ILS CAT III or GLS GAST c/d are available.

Table 8-2: Step 1 implementation

	C2 link architectures	Communication link architectures	ATOL systems
STEP1	RLOS	RLOS	Available for airports with ILS CAT III or GLS GAST c/d

Hence, each Step 1 architecture/technology is evaluated from Safety, Feasibility and Efficiency point of view as follows:

Table 8-3: Safety, feasibility and efficiency assessment for Step 1

	C2 link architecture: RLOS	Communication link architecture: RLOS	ATOL systems
Safety	As shown in section 4.4, the RLOS architecture works with low latency (1 second) but in a short range. The INVIRCAT scope looks the operations in TMA and airport where the lowest latency is needed. This because, especially in such critical phases (e.g. landing and take-off), the time of response of the RPIL to the ATCO clearances/instructions have to be very short. For these reasons, the RLOS architecture in the Step 1, under the safety point of view, represents the best option to be implemented.	As shown in section 5.4, the RLOS architecture works with Low latencies (290ms one way). Even if is not the best architecture, the safety level is acceptable since the INVIRCAT scope looks at TMA and airport operations where the VHF antennas are always available. For these reasons, the RLOS architecture is considered reliable and safe.	As shown in section 6.3, ATOL system has the most important advantage to mitigate the effects of the latency related to the most critical flight phases (e.g. landing and departure). In fact, even the lowest level of C2 latency could lead into a catastrophic event. This because the RPIL has to immediately react to any sudden event that could occur and even any delay might have a safety implication.
Feasibility	The RLOS architecture allows the RPIL to work with an acceptable level of situational awareness and workload since the latency is the lowest. In addition, the ATCO, thanks to the low latency, can manage the RPAS as a conventionally-manned aircraft. For these reasons,	The RLOS architecture, due to the low latency level (290ms one way) allows the RPIL to quickly receive instructions/clearances from the ATCO. Thus, the RPIL can have a good level of situational awareness without increase the level of workload. In addition, the ATCO can quickly	Under the feasibility point of view, in the step 1, the ATOL system is available only where the airport is equipped with ILS CAT III or GLS GAST c/ d. These kind of landing systems require dedicated and expensive ground stations in the runway area and, therefore, they are not so

	the RLOS architecture allows the safe execution of the operations in TMA and airport.	receive information on the status of the RPAS (e.g. nominal situation, C2 link lost, contingency situations).	commonly available especially at minor airports.
Efficiency	The RLOS architecture, thanks to the low latency related to the C2 link (1 second), allows to the RPIL to perform his/her desired manoeuvres. In fact, the RPIL is able to comply with ATCO instructions/clearances in 1 second. In addition, the RLOS architecture related to the C2 link allows the RPIL to quickly receive information on the status of the RPAS.	As stated in section 5.4, no additional ground network connection is required for the RLOS architecture. In addition, if there is a connection to a ground network of VHF antennas, RLOS connections are possible beyond LOS (ground relay). However, thanks to the low latency, the information provision is acceptable.	As already stated, the ATOL system, in the step 1, will only be available for a little percentage of airports. Nonetheless, the ATOL system automatically performs landing and take-off procedure and, in this perspective, the ATOL system allows a safe and efficient integration of RPAS systems into TMA and airports.

8.2.2 Mitigation of Negative Effects

Based on what is stated in the previous paragraph and related to the disadvantages and gaps identified in sections 4.4, 5.4 and 6.3, this section takes into account possible mitigation means that could help the introduction of RPAS into TMAs and airports.

In the Step 1, the only disadvantage identified for the RLOS architecture in the C2 link is the short range, however the INVIRCAT scope takes into account operations that are always covered by RLOS since they are performed in TMA and airports. However, a C2 link lost link can occur, and the mitigation of this negative effect is to define dedicated procedures for the RPAS. In particular, the RPAS have to be separated from the manned traffic. In this way, the RPAS shall perform a dedicated holding pattern well separated from the conventionally-manned holding pattern. In addition, ATCO have to be trained on these contingency situations, since it represents the substantial difference between the RPAS and manned aircraft. In fact, the ATCO can only act on manned traffic to separate them. For this reason, a training on the C2 link loss shall be required to increase the situational awareness and to reduce the level of workload of the ATCOs regarding this specific event.

In the Step 1, the only disadvantages identified for the RLOS architecture in the communication link is the medium risk of weak signal or signal loss. Actually, this issue is also related to manned traffic, for this reason it is not specific for the RPAS. However, in the INVIRCAT scope, a basic assumption is that the RPIL is able to establish two-way communication with ATC. When a communication link loss occurs, a mitigation mean can be a back-up telephone. The back-up telephone is a conventional telephone line between the ATCOs and the RPIL in order to continue the operations without arise any emergency situations.

In the Step 1, the only disadvantages identified for the ATOL system is that this system may require dedicated and expensive ground equipment in the runway area. Of course, as already stated, in the step 1, only a few percentages of airports allow the introduction of RPAS system (since they are equipped with currently available CAT III like systems). The gaps identified are three:

1. New certified low complexity and cost equipment for precise navigation.
2. Specifically defined procedures for C2 link failure.
3. Specifically defined set of messages exchanged by the remote crew with ATCO.

8.3 Step 2

In a second step, from 2030 onwards, technologies with a lower level of maturity nowadays will be implemented allowing IFR and VFR flights in all airspace classes.

In addition to the C2 link architectures mentioned in step 1, RLOS via Gateway will be implemented too. Considering this new architecture, an extensive network of RLOS ground radios can be used to support the C2 link and the ground relay would lead to a smaller increase in delay times when compared to SATCOM. RLOS will be used when possible, and in the case of a BRLOS situation between the RPIL and the RPS, not only C2 link via SATCOM will be available. This architecture will cover the TMA operations in such a way that transmitters and receivers could be placed as a gateway at airports that are BRLOS for the RPS and allow for coverage of the terminal airspace in RLOS.

In addition to the communication architectures between the RPIL and ATC presented in step 1 (VHF and SATCOM), this step would include the case of ground-ground communications. This architecture requires a new network to be created between the RPS and ATC and these connections are part of the plans of future communication infrastructure. In Europe and the USA standards have already been defined, but they have not been realized yet. As it is explained on reference [21], current ground-ground Air Traffic Management voice communication systems are based on a hybrid analogue or digital technology, using point-to-point circuits, radios and disparate service infrastructures. ETHERNET and VoIP bring a revolutionary change to provide reliable, cost effective, and scalable communications capacity to meet future ATM demands. In the concept of INVIRCAT, this technology will allow for coverage of the terminal airspace in RLOS, including all the corresponding phases of flight in the TMA: taxi, take-off, departure via SID, arrival via STAR, holding, approach and landing, and once developed, it can be a substitute or support for the aforementioned architectures, with the advantage of low latency. Another option is that the backup phone line could become a dedicated voice communication ground link, and other less reliable methods will become the backup solution, in this way there would still be a redundant means of communication.

Regarding the application of ATOL systems, in the second step of implementation, technologies as Dual Frequency Multi Constellation GNSS systems might have reduced the complexity and costs of the on-ground equipment and increased the number of supported runways. Moreover, as reported in [1], manned and unmanned building company already announced systems able to perform take-off and landing operations down to the ground with no need for ground equipment. These enablers could ease the requirements and allow the ATOL system to be also available for minor airports.

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8.3.1 Effects on Safety and Efficiency

This section shows the effects that integration of C2 link and communication architectures and ATOL system have on safety, feasibility and efficiency during step 2, taking into account the advantages, disadvantages and gaps identified in the previous paragraphs (for the C2 link architecture refer to section 4.4, for communication architecture to section 5.4 and for the ATOL system to section 6.3).

According to the Table 8-1, in the Step 2, the RLOS via gateway will be implemented for the C2 link, while a ground-ground communication architecture will be available (even if the phone line may become the principal communication mean). The ATOL system will be used also available for minor airports.

Table 8-4: Step 2 implementation

	C2 link architectures	Communication link architectures	ATOL systems
STEP2	RLOS via gateway	Ground-ground connection / Phone line	Available for minor airports

Hence, each Step 2 architecture/technology is evaluated from Safety, Feasibility and Efficiency point of view as follows:

Table 8-5: Safety, feasibility and efficiency assessment for Step 2

	C2 link architecture: RLOS via gateway	Communication link architecture: Ground-ground / Phone line	ATOL systems
Safety	As shown in section 4.4, the RLOS via gateway architecture works with a lowest latency (1.5 seconds) compared to SATCOM architecture but in a short range. The RLOS via Gateway operation describes a situation where the RPS and the RPA are effectively beyond RLOS. However, data communication via the C2-link is achieved through ground relay stations that allow the connection of the RPS to transmitters and receivers that are positioned at a location	As shown in section 5.4, the ground-ground architecture works with the lowest latency (150ms one way). It represents the best architecture. However, due to the high reliability, these wired connections are recommended as a backup means for voice communication between RPILs and ATC when the radio equipment at the RPS or in the RPA fails. The phone line may become a dedicated voice communication ground link and other less reliable	Under the safety point of view there are no differences with the previous table. For this reason, please refer to the safety assessment conducted in Table 8-3:.

	where RLOS operations with the RPA are possible. Under the safety point of view, it will be better to use RLOS architectures, where possible.	methods will become the backup solution. Turning that concept around, and making the (integrated) backup phone connection the primary means of communication, would not change that attitude, as there would still be a redundant means of communication.	
Feasibility	The RLOS via gateway architecture allows the RPIL to work with an acceptable level of situational awareness and workload since the latency is lowest compared to SATCOM. In addition, it allows to work BRLOS and hence to increase the range of VHF communications thanks to ground relay stations.	The RLOS architecture, due to the lowest latency level (150ms one way) allows the RPIL to quickly receive instructions/clearances from the ATCO. Thus, the RPIL can have a good level of situational awareness without increase the level of workload. In addition, the ATCO can quickly receive information on the status of the RPAS (e.g. C2 link loss, contingency situations). The phone line imposes only low latency levels and may become the principal communication mean. Indeed, making the (integrated) backup phone connection the primary means of communication, would not change the ATCOs attitude.	Under the feasibility point of view, in the step 1, the ATOL system will be available also for minor airports. In this second step of implementation, technologies as Dual Frequency Multi Constellation GNSS systems might have reduced the complexity and costs of the on-ground equipment and increased the number of supported runways.
Efficiency	The RLOS via gateway architecture, thanks to the latency related to the C2 link (1.5 seconds), allows to the RPIL to perform his/her desired manoeuvres in TMA and airport. In fact, the RPIL can comply with ATCO instructions/clearances within a few moments. In addition, the RLOS via	As stated in section 5.4, there is a low risk of weak signal or signal loss. In addition, the ground-ground connection is very reliable and for this reason, is preferable to use it as backup communication means when a VHF communication fails, while the phone line may become the principal	The ATOL system, in the step 2, will also be available in minor airports. The ATOL system automatically performs landing and take-off procedure and, in this perspective, the ATOL system will allow a safe and efficient integration of RPAS systems into all TMAs and airports.

	gateway architecture allows the RPIL to receive information on the status of the RPAS even in a medium range where ground stations are available.	communication link between the ATCO and the RPILs.	

8.3.2 Mitigation of Negative Effects

Based on what is stated in the previous paragraph and related to the disadvantages and gaps identified in sections 4.4, 5.4 and 6.3, this section takes into account possible mitigation means that could help the introduction of RPAS system into TMAs and airports.

In the Step 2, there are no disadvantages identified for the RLOS via gateway architecture. Of course, it will be possible to use the RLOS via gateway where the RPS and RPA are effectively beyond RLOS increasing the range of link. However, RLOS architecture (where possible) will be preferred, as the RLOS via gateway increases the latency by 0.5 seconds compared to RLOS architecture. In addition, the only gap identified is that the RLOS via gateway requires ad-hoc infrastructure that should be available after step 2.

In the Step 2, the ground-ground connection for voice will be the one with the lowest level of latency (150ms one way). Of course, the improvement of this system may require new ground infrastructure. In addition, the phone line may become the dedicated communication link between the ATCOs and RPILs since there is only a small effect on latency. However, two gaps are identified for the ground-ground connection in the step 2:

1. Reliability leads to use as backup communication option, as current VHF radio communication is very reliable. Thus, the use of ground-ground wired connections is recommended as a backup means for voice communication between RPILs and ATC when the radio equipment at the RPS or in the RPA fails.
2. Ground-ground communication link may have to be integrated into frequency for party-line effect (not necessary if already used for regular communication on the frequency).

In the Step 2, for the ATOL system there are no differences identified in terms of technology compared to the step 1. The only gap identified is that technologies as Dual Frequency Multi Constellation GNSS systems shall be available in the step 2 to allows the safe introduction of RPAS systems also in minor airports.

9 Conclusions

This document summarised key findings on alternatives and effects of the thematic topics C2 link, communication link, ATOL systems, and taxi systems. For each thematic topics, architectures and approaches with the consequent advantages, disadvantages, and gaps are identified. The findings build the basis, aligned with the SESAR Joint Undertaking ATM European Master Plan, for an implementation recommendation in two steps. Effects on safety and efficiency per step have been assessed, and potential mitigations have been identified.

For C2-link alternatives, most advantages and disadvantages are physics-based and depend on the available implemented architecture. If possible, the use of RLOS connection is deemed to be preferable over other solutions, with other available connection as alternatives. To be kept in mind is the fact that an increasing number of RPAS also increases the load on the RLOS spectrum. The introduction of an RLOS via Gateway connections reduced the necessity to locate the RPS in the vicinity of the airport for stable, low-latency TMA operations. SATCOM can only be seen as a medium to transfer to and from a TMA, and as a backup strategy, and it is not the preferred option even in earlier stages of implementation.

Architecture options for voice communication comprise RLOS, SATCOM and ground-ground connection with certain advantages and disadvantages. RLOS will be the primary choice in earlier stages of implementation due to availability. As wired connections can be considered more reliable than radio connections (with respect to interference), this reliability could be the main factor as choice for the primary communication line, with the radio connection (i.e. VHF, if available, and SATCOM otherwise) as backup after the second step of implementation. The security on the wired connection, with only authenticated users and genuine sources, is considered important. Another aspect in this regard is the seamless integration of wired connections on the frequency for manned traffic to achieve a party-line effect for increased situational awareness of all airspace users and air traffic control.

As stated above, ATOL is considered essential for safe integration of RPAS in TMA but to enable it both procedural and technological development needs to be done. Even if most of current procedures and phraseology apply well also to RPAS ATOL operations, a further effort will be needed in their refinement and in the definition of appropriate procedures and phraseology to cover RPAS peculiar contingencies as failure in C2 link. For broad diffusion of IFR RPAS ATOL operations, the further development of technologies that allow RPAS achieving the required precision navigation performances with a lower cost in required airfields ground equipment (e.g. Dual Frequency Multi Constellation GNSS) is needed.

The spectrum of taxi systems and what can be regarded as such is broad, and can range from mere assistance systems to real enablers for efficient RPAS integration at airports. Some already existing systems, mainly developed for conventional manned aviation (e.g. the TaxiBot system), have comparable benefits as for their original use, regardless of the fact that an RPAS is remotely piloted, but do not close a gap for integration of RPAS due to the assumptions set in the project. Other techniques, such as the segmented taxiway, can be regarded as a potential enabler for early integration without costly modifications on the infrastructure of the airport. Autonomous taxiing, although out of scope of the INVIRCAT project, may be the real future enabler with very limited impact and disadvantages if implemented correctly and efficiently.

The INVIRCAT project has addressed a wide variety of systems and technologies with different maturity levels. To help establishing a sequenced level of implementation for those technologies, the project has identified two different steps to state the maturity needed, according to Technology Readiness Levels (TRLs).

Step 1 (2022-2030) includes the technologies with the highest level of maturity (TRL > 5), which will allow the accommodation of IFR RPAS in airspace classes A-G. In this step, the Command and Control (C2) link and communication link architectures will be available including RLOS communication. The INVIRCAT concept has identified the availability of these architectures as paramount for the safe operation within the TMA flight phases, while for the en-route phase, C2 link and communication link via satellite will be a better option. Regarding the application of ATOL systems, they will be expected to be used only in a minority of airports, equipped with ILS CAT III or GLS GAST c/d.

Step 2 (2030 onwards) includes the technologies with the lowest level of maturity (TRL < 5), which will allow the full integration of RPAS in airspace classes A-G (IFR and VFR). However, these classes are out of the scope of INVIRCAT. In addition to the C2 link and the communication architectures between the RPIL and ATC mentioned in Step 1, RLOS via Gateway and ground-ground communication will be implemented, respectively. The ATOL system will be also available for minor airports.

Based on the findings presented in this document and the upcoming deliverable D3.4 *Exploratory Research Validation Report*, the INVIRCAT project will create a refined version of the initial CONOPS in D2.4 *Final CONOPS 'RPAS in the TMA'* and the deliverable D4.3 *Final Report: Impacts and Recommendations* later this year.

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Appendix A Acronyms

Term	Definition
A-FUA	Advanced – Flexible Use of Airspace
ACAS	Airborne Collison Avoidance System
ACC	Area Control Centre
ACL	ATC Clearances Service
ACM	ATC Communications Management Service
ADS-B	Automatic Dependent Surveillance - Broadcast
ADS-C	Automatic dependent surveillance - Contract
AES	Aeronautical Earth Station
AH	Alert Height
AHRS	Attitude and Heading Reference System
AIP	Aeronautical Information Publication
AMC	Acceptable Means of Compliance
ANSP	Air Navigation Service Provider
AoR	Area of Responsibility
APP Exe. ATCO	Approach Executive Air Traffic Controller
APR	Approach
ASBU	Aviation System Block Upgrade
ASR	Air Surveillance Radar
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATCS	Air Traffic Control Service
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management

ATOL	Automatic Take-Off and Landing
ATS	Air Traffic Service
ATSU	Air Traffic Services Unit
AU	Airspace User
BADA	Base of Aircraft Data
BLOS	Beyond Line-of-Sight
BRLOS	Beyond Radio Line-of-Sight
BVLOS	Beyond Visual Line-of-Sight
C2	Command and Control
CA	Collision Avoidance
CAA	Civil Aviation Authority
CDM	Collaborative Decision Making
CDTI	Cockpit Display of Traffic Information
CIRA	Centro Italiano Ricerche Aerospaziali (Italian Aerospace Research Centre)
CFIT	Controlled Flight Into Terrain
CLM	Concept Lifecycle Model
CLS	Calculated Level of Safety
CNS	Communication, Navigation and Surveillance
CNPC	Control and Non-Payload Communication
CPDLC	Controller Pilot Data Link Communications
CONOPS	Concept of Operations
CWP	Controller Working Position
DA	Decision Altitude
DAA	Detect and Avoid
DCL	Departure Clearance
DGPS	Differential Global Positioning System

DH	Decision Height
DLIC	Data Link Initiation Capability
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DLS	Data Link Services
DMA	Dynamic mobile area
DME	Distance Measuring Equipment
DMZ	De-Militarized Zone
DOF	Degrees of Freedom
DSC	Downstream Clearance Service
DTA	DAA Terminal Area
DWC	DAA Well Clear
EASA	European Aviation Safety Agency
EAT	Estimated Approach Time
ECAC	European Civil Aviation Conference
ECAM	Electronic Centralized Aircraft Monitoring
EGNOS	European Geostationary Navigation Overlay Service
EMI	Electromagnetic Interference
ESC	Electronic Speed Controller
EVLOS	Extended Visual Line of Sight
FCC	Flight Control Computer
FDPS	Flight Data Processing system
FIS	Flight information service
FIS-B	Flight information service broadcast
FLARE	Flight Laboratory for Aeronautical REsearch
FMS	Flight management system
FPV	First-Person View

FSS	Fixed Satellite Service
FSTD	Flight Simulation Training Device
FTP	Flight Termination Points
GA	General Aviation
GAST	GBAS Approach Service Type
GAT	General Air Traffic
GBAS	Ground Based Augmentation System
GCS	Ground Control Station
GDPR	General Data Protection Regulation
GES	Ground Earth Station
GLS	GBAS Landing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HD	High Definition
HIL	Human-in-the-Loop
HMI	Human Machine Interface
HP	Holding Pattern
HW	Hardware
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organization
ICL	Initial Climb
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IFF	Identification Friend or Foe
IFR	Instrument Flight Rules
ILS	Instrument Landing System

INVIRCAT	Investigation of IFR RPAS Control at Airports and in the TMA
I/O	Input/Output
ISF	Integrated Simulation Facility
LIDAR	Light Detection and Ranging
LPV	Localizer Performance with Vertical guidance
MA	Missed Approach
MALE	Medium altitude long endurance
MAS	Managed Airspace
MCM	Maintenance Control Manual
METAR	METeorological Aerodrome Report
MFD	Multi-Function Display
MLS	Microwave Landing System
MOPS	Minimum Operational Performance Specifications
MTOW	Maximum Take-Off Weight
MUST	Multi UAV Simulated Testbed
NAA	National Aviation Authority
NARSIM	NLR ATC Research SIMulator
NDB	Non-Directional Beacon
NLR	Nederlands Lucht- en Ruimtevaartcentrum (Netherlands Aerospace Centre)
NM	Network Manager
NOP	Network Operations Plan
NOTAM	Notice to Airmen
NPA	Notice of Proposed Amendment
OAT	Operational Air Traffic
OCD	Operational Concept Document
OSED	Operational Services and Environment Definitions

OTW	Out-the-Window
PA	Precision Approach
PAR	Precision Approach Radar
PBN	Performance Based Navigation
PFD	Primary Flight Display
PIC	Pilot in Command
PIO	Pilot-induced oscillation
PPS	Packets Per Second
PPS	Precise Positioning Service
PSR	Primary Surveillance Radar
R/T	Radio/Telephony
RAIM	Receiver Autonomous Integrity Monitoring
RCP	Required Communication Performance
RF	Radio Frequency
RLOS	Radio Line of Sight
RNAV	Area navigation
RNP	Required Navigation Performance
ROC	RPAS Operator Certificate
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft System
RPIL	Remote Pilot
RPS	Remote Pilot Station
RTB	Return to Base
RTO	Rejected take-off
RTS	Real Time Simulation
RWC	Remain Well Clear

SAA	Sense And Avoid
SARP	Standard And Recommended Practice
SATCOM	Satellite Communication
SBAS	Satellite Based Augmentation System
SCB	Stakeholder Consultation Body
SERA	Standardised European Rules of the Air
SESAR	Single European Sky ATM Research Programme
ShMem	Shared Memory
SID	Standard Instrument Departure
SIP	Structural Integrity Program
SiS	Signal in Space
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SMR	Surface Movement Radars
SMS	Safety Management System
SPR	Safety Performance Requirements
SPS	Standard Positioning Service
SSR	Secondary Surveillance Radar
STAR	Standard Terminal Arrival Route
SVS	Synthetic Vision System
SW	Software
SWaP	Size, Weight, and Power
SWIM	System Wide Information Management
TAR	Terminal Approach Radar
TCAS	Traffic Alert and Collision Avoidance System
TCP	Transmission Control Protocol
TIS	Traffic Information System

TLS	Target Level of Safety
TMA	Terminal Manoeuvring Area
TRL	Technology Readiness Level
TSA	(Static) temporary restricted area
TWR	Tower
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UHF	Ultra High Frequency
USP	U-Space/UTM Service Provider
UTC	Universal Time Coordinated
UTM	Unmanned Traffic Management
V&V	Verification & Validation
V1	Take-off Decision Speed for Multi Engine Aircraft
VFR	Visual Flight Rules
VHF	Very high frequency
VLD	Very Large Demonstration
VLL/VHL	Very Low Level/Very High Level
VLOS	Visual Line-of-Sight
VOIP	Voice Over Internet Protocol
VOR	VHF Omnidirectional Range
VR	Rotation Speed
VTOL	Vertical Take-Off and Landing
WAGE	Wide Area GPS Enhancements
WP	Work Package
WRC-15	World Radiocommunication Conference 2015
XPDR	Transponder

Appendix B Glossary of Terms

Term	Definition	Source of the Definition
ADS-B	Automatic dependent surveillance — broadcast (ADS-B): A means by which aircraft, aerodrome vehicles and other objects can automatically transmit and/or receive data such as identification, position and additional data, as appropriate, in a broadcast mode via a data link.	ICAO Doc 4444 PANS-ATM
AH	The alert height (AH) is a specified radio height for CAT III operations, based on the characteristics of the aeroplane and its fail-operational landing system. In operational use, if a failure occurred above the alert height in one of the redundant operational parts of the landing system in the aeroplane or relevant ground equipment, the approach would be discontinued and a go-around executed unless reversion to a higher decision height is possible. If a failure in one of the required redundant operational systems occurred below the alert height, it would be ignored and the approach continued	N/A
AoR	Area of Responsibility: An airspace of defined dimensions within which an ATC unit provides air traffic services.	EUROCONTROL ATM Lexicon
ATS surveillance system	A generic term meaning variously, ADS-B, PSR, SSR or any comparable ground-based system that enables the identification of aircraft.	ICAO RPAS CONOPS for international IFR Operations
BVLOS operation	Beyond visual line-of-sight (BVLOS) operation. An operation in which the remote pilot or RPA observer does not use visual reference to the remotely piloted aircraft in the conduct of flight	ICAO RPAS CONOPS for international IFR Operations
C2 Link	Command and Control Link: The datalink used for the purpose of command and control (C2) functions in an RPAS.	JARUS: RPAS Required C2 Performance (RLP) Concept

DAA	Detect and avoid (DAA): The capability to see, sense, or detect conflicting traffic or other hazards and take appropriate action.	ICAO RPAS CONOPS for international IFR Operations
Drone	Synonym for UAS. Any aircraft and related systems without a pilot on board, either remotely piloted or autonomous.	N/A
GCS	Ground Control Station: RPS are sometimes named Ground Control Stations (GCS)	JARUS: RPAS Required C2 Performance (RLP) Concept
Handover	The act of passing the control of an operation from a human operator to another. The handover could be executed between Air Traffic Control Officers (e.g. in the control transfer from one sector to another, or from ACC to APP controllers). Namely for RPAS operations, the handover refers to passing piloting control from one remote pilot station to another.	N/A
PA	A precision approach (PA) is an instrument approach and landing using precision lateral and vertical guidance with minima as determined by the category of operation, namely CAT I, CAT II, CAT III operations, each related to progressively reducing decision minima.	ICAO Annex 6: Operation of Aircraft, extended
RPA	Remotely Piloted Aircraft: An unmanned aircraft which is piloted from a remote pilot station.	ICAO Annex 2: Rules of the Air ICAO Doc 10019: Manual on Remotely Piloted Aircraft Systems (RPAS)
RPAS	Remotely Piloted Aircraft System: A set of configurable elements consisting of a remotely-piloted aircraft, its associated remote pilot station(s), the required command and control links and any other system elements as may be required, at any point during flight operation.	ICAO Cir 328
RPIL	Remote Pilot: A person charged by the operator with duties essential to the operation of a remotely piloted aircraft and who manipulates the flight controls, as appropriate, during flight time.	ICAO Doc 10019: Manual on Remotely Piloted Aircraft Systems (RPAS) JARUS: RPAS Required C2 Performance (RLP) Concept

RPS	Remote Pilot Station: The component of the remotely piloted aircraft system containing the equipment used to pilot the remotely piloted aircraft.	ICAO Doc 10019: Manual on Remotely Piloted Aircraft Systems (RPAS)
Segregated airspace	Airspace of specified dimensions allocated for exclusive use to a specific user(s).	ICAO RPAS CONOPS for international IFR Operations
TMA	Terminal Manoeuvring Area (TMA): Controlled airspace around an airport.	N/A
TWR ATCO	Tower Air Traffic Controller	N/A
UAS	Unmanned Aircraft System (UAS): Any aircraft and related systems without a pilot on board, either remotely piloted or autonomous.	N/A