PHASE 2 REPORT

MINIMUM TECHNICAL STANDARDS FOR ELECTRONIC CONSPICUITY AND ASSOCIATED SURVEILLANCE

10 June 2022

Document information

GENERAL INFORMATION

Author(s)	Philip Church, Andrew Burrage, Ben Stanley, Ludo Gabris, Stewart Wallace
Document volume	Minimum Technical Standards for Electronic Conspicuity and Associated Surveillance
Version	V1.0
Reference	P3205D002
CRM number	AVRK077

HISTORY OF CHANGES

Version	Date	Drafted by	Checked by	Changes
V0.1	25-April-2022	Andrew Burrage, Ludo Gabris	-	Initial draft
V0.8	16-May-2022	Andrew Burrage, Ludo Gabris, Ben Stanley	Philip Church	Draft for distribution to CAA review
V1.0	10-Jun-2022	Andrew Burrage, Ludo Gabris	Ben Stanley	Addition of remaining sections, updates based on comments on previous draft.

RECIPIENTS

Name	Entity
Priyesh Vyas	UK CAA
Colin Chesterton	UK CAA

Executive Summary

The CAA was tasked by DfT to "*develop Surveillance specifications that take into account future requirements for all aviation including drones and not be an unintended barrier to innovation in future electronic conspicuity functionality*"[1].

This is the second of three independent reports (D2) developed by Egis, exploring the potential minimum specifications to support beneficial applications enabling UAS and the wider Airspace Modernisation Strategy. This report sets out a gap analysis of the UK regulatory regime for the chosen option 3a from the first report D1.

Context

There is a desire to accelerate the deployment of BVLOS operations, enabling the beneficial applications (including social and safety benefits) and impact on UK GDP. To do so, the current barriers found in segregated airspace and difficult airspace planning to enable the new users must be overcome. One facilitator for more integrated airspace planning is the provision of a known traffic environment using assured position.

New supported applications (with safety impact) could include:

- ICAO Flight Information Services using surveillance (Class G, E, and VFR traffic in Class D), including traffic information and a course of traffic avoidance advice.
- Supporting UAS detect-and-avoid (DAA).
- Supporting on-board deconfliction and collision avoidance systems (Hybrid ACAS / ACAS X).

The existing aid to situational awareness is intended to remain, and could be enabled by CAP1391 devices or these new enhanced EC devices.

The application or operational service requirements are not defined for these applications at this time. Likewise, the exact role for enhanced Electronic Conspicuity (EC) compared to other sources of position information is not yet agreed – for example, the emerging UAS detect and avoid concept may rely more on computer vision-based systems than electronic conspicuity. The existing environment, including EC in use today, is complex. The international benchmarks, whilst facing common challenges, are not aligned.

This study is therefore developing a ***building block***, based on a ***minimum viable standard,*** that aims to:

- Provide stakeholders with a means to enable the applications (e.g. providing a trusted source for DAA)
- Ensure interoperability with other surveillance systems and safety nets (e.g. Hybrid ACAS) to enable application benefits associated with these systems
- Be deployable in the short term (i.e. not depend on development of novel technology, standards, or assurance approaches with unknown timelines)

Analysis

Use cases for key scenarios under each of the applications have been explored. Analysis of the use cases provides an assumed set of qualitative operational requirements, which are further translated to functional and performance requirements for the enhanced EC devices.

Use cases consistently show that assured position information can be a key enabler for the application, though there are no defined minimum performance requirements defined today. To deliver an assured position, data quality indicators need to be provided by the enhanced EC device alongside the position report. ADS-B Standards today utilise the following data quality indicators:

---

[1] Quoted text uses drones, however UAS is used for the rest of the document.

- Navigation Accuracy Category – position (NACp) – reports the expected accuracy of the position report, giving a boundary the aircraft has a 95% probability of being positioned within, e.g. NACp = 5 means the actual position of the aircraft is expected to be within 0.5NM of the measured position 95% of the time.
- Navigation Integrity Category (NIC) – specifies the containment radius associated with horizontal position data, this is provided in conjunction with the SIL (see next bullet), e.g. NIC = 5 means the radius is less than 1NM.
- Source Integrity Level (SIL) – complements the NIC and gives the probability that the actual position is outside the reported containment radius, e.g. NIC 6 and SIL =1 means there is a 0.1% probability that the actual position of the aircraft is more than 0.5 NM from the measured position. This is important for safety purposes, ensuring appropriate control over the risk of nuisance, false or risk-bearing erroneous position reports from the ADS-B OUT device.

If enhanced EC devices can deliver sufficient performance including providing these quality indicators to a required level, receiving systems will be able to use the information for identified applications with safety impact.

The study notes that the performance requirements for the applications in Class E and G (primarily) are distinct from those required from commercial air traffic; for example, aircraft speeds tend to be slower (meaning NACp is a bigger determinant of received position accuracy than data age, for example), and the tolerable risk may be different, meaning a containment radius error could be accepted more of the time.

Reviewing the applications elicits some assumed high-level requirements for assured performance, with driving requirements (across all applications) identified. Whilst there are no agreed standards for the applications, upper and lower bounds can be found on a benchmarked basis, building on the assumed requirements such as the need for assured position data. For the upper bound, existing ADS-B OUT standards (ED-126) can give some values. The Traffic Awareness Beacon Systems (TABS) standard provided a lower-bound benchmark standard for providing assured position.

Other key requirements identified include:

- The need for a range comparable to airport Declared Operational Coverage volumes (as a driving case), which infers performance in terms of probability of detection.
- Data quality sufficient to allow the ATSO to provide beneficial collision avoidance information and avoid nuisance information.
- The need for UAS to detect all airspace users, whilst manned aircraft can optionally detect UAS.
- Interoperability with emerging ACAS X standards to enable application benefits.
- Ensuring that receiving systems are given sufficient information to disassociate non-assured position information and assured information to enable appropriate usage.

Conclusions

The bounded requirements give some viable minimum specifications which could act as a building block for the supported applications. We recommend that a more formal analysis is conducted to ensure that the safety and performance of the enhanced EC data will be sufficient.

A regulatory approach similar to CAP1391 gives flexibility in specifying an appropriate standard for enhanced EC devices, leveraging existing regulatory and standards work from around the world. Use of ADS-B OUT over 978MHz (UAT) allows new airspace users to leverage protections provide for aviation spectrum, without risking frequency occupancy issues.

Using ADS-B standards greatly simplifies the required regulatory/standards framework changes (compared to a novel standard) and enables hybrid ACAS and wider interoperability. The changes that would be required in the UK regulatory framework extend well beyond simply MASPS or MOPS for EC devices, however there are global standards that could be referenced in most cases, and changes to overarching CAPs (such as CAP 670) would be very minor. The adoption of 978MHz for EC and analysis to derive appropriate standards to balance performance needs against cost will be the most challenging aspects, but again can leverage standards develop elsewhere.

In terms of costs, both avionics, and ground-based receivers are available on the market (potentially through assembly of existing components in the case of avionics), to support the rapid adoption of the proposed enhanced EC solution.

It will be necessary to tackle specific issues around achieving the required probability of detection performance whilst balancing costs for airspace users. Probability of detection depends upon both the ground and airborne elements of the system, although the ground elements are mature and their performance is not constraining. The airborne contribution is more complex:

- Basic EC devices (CAP1391) are not subject to any requirements in terms of installation and antenna capabilities, which means the performance cannot be assured.
- Certified devices have strict installation requirements, which would meet performance needs, but drive costs outside the desirable range.

This results in the need for novel installation guidance, sensitive to the constraints of different airspace users, developed through activities to be identified within the roadmap.

Government subsidies may also be required to encourage initial enhanced EC devices to achieve a desirable cost for airspace users to adopt and trigger a positive cycle that sees manufacturers invest in developing the devices.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

1 - INTRODUCTION

1.1 - General

This document has been produced by EGIS as part of the project working on behalf of the UK Civil Aviation Authority (CAA) to Develop Minimum Technical Standards for enhanced Electronic Conspicuity (EC[2]) and associated Surveillance.

1.2 - Background and objectives

The CAA wish to develop minimum technical standards for EC and associated surveillance in order to:

1. Realise the full benefits outlined in the Airspace Modernisation Strategy (AMS) CAP 1711,
2. Respond to the request from the Department for Transport (DfT) to develop specifications which take into account future requirements for all aviation and thus take account of a wider set of use cases, and
3. Enable innovation in future EC capability.

The objective of the AMS is to deliver quicker, quieter and cleaner journeys, and more capacity for the benefit of those who use and are affected by UK airspace. Importantly, one of the parameters within which this must be achieved is ensuring a shared and integrated airspace that facilitates safe and ready access to airspace for all classes of airspace users, including Commercial Air Transport (CAT), General Aviation (GA), military, and new entrants such as Unmanned Aircraft Systems (UAS) and spacecraft. To achieve the objective while delivering airspace for all airspace users, the AMS outlines the UK's communications, navigation and surveillance infrastructure and air traffic management as specific enablers that will help deliver the expected benefits. Specifically, the enablers identified within the AMS are:

1. Review of Flight Information Services (FIS) provision in the UK.
2. Airspace classification review.
3. Electronic surveillance solutions.

The CAA's requirements listed above are directly relevant to this third point, i.e. the deployment of electronic surveillance solutions to aircraft and at airports (and other airspace) to aid integration of traffic. This includes the development of new airspace structures such as transponder mandatory zones, new procedures for air traffic services, and the deployment of EC devices and electronic surveillance information displays. The deployment of electronic surveillance solutions (depending upon solutions selected, may depend upon:

1. The widespread introduction of interoperable EC devices.
2. The further development of airborne and ground-based equipment.
3. The development of national standards for the core requirements the devices and equipment should meet.

The CAA established an Electronic Conspicuity Deployment Programme (ECDP) to manage the elements highlighted above and was tasked by the Department for Transport to develop surveillance specifications that consider the future requirements for all airspace users including new entrants such as UAS operators and spacecraft. This would serve as an evolution of the current limited use of EC to mitigate the risk of collisions for the wider GA community in controlled airspace to a scenario whereby all aircraft will need to be electronically conspicuous to each other and to air traffic services on the ground to enable the concept of future airspace described in the AMS.

This project is to develop a suitable minimum technical standard for EC and associated surveillance that will evolve the current limited use of EC in support of the objective of the AMS.

---

[2] *EC refers to Electronic Conspicuity; European Commission is spelt in full.*

1.3 - Scope of the report

The project is has broken down the services required into three phases:

1. Phase 1: Assessment of the current environment and existing standards concluding in a high-level recommendation for a future approach.
2. Phase 2: Assessment of the recommended approach from Phase 1 with industry stakeholders to define the future environment.
3. Phase 3: Definition of the regulatory standards and regulatory framework required to proceed with the implementation of the minimum technical standards for EC and associated surveillance in the UK to cover both Air to Air, Ground to Air and Air to Ground.

This report is **Phase 2** (as described above) which develops a more detailed view of the recommended approach from Phase 1 and its applicability in the UK. This includes the development of supporting use cases as part of a CONOPS to ensure a common understanding of the future airspace operational concept and how EC could be deployed in this environment. This report develops high level performance specifications needed to support the use cases, assigns responsibilities for between ground and air and for the recommended approach identifies what needs to be updated in policy or regulation to enable this deployment. This will form the basis for the updates this proposed in Phase 3.

1.4 - Intended readership

The primary intended readership of this report is the UK CAA and DFT.

The report may be distributed to UK aviation stakeholders such as ATS providers, Avionics manufacturers and airspace user group representatives.

1.5 - Document structure

The document follows a structure as presented in Figure 1.

Section 1: - Introduction

- This chapter, which presents the context in which this document is presented and the scope of the content.

Section 2: - Concept of Operations

- Chapter 2 develops a Concept of Operations (ConOps) which enhanced EC devices could support. This includes elaboration of key use cases to elicit operational requirements from which detailed specifications can be derived. The ConOps includes a description of the environment, use case analysis, details of supporting infrastructure and roles and responsibilities of stakeholders. Finally, a collation of the identified requirements and assumptions provides a reference.

Section 3: - Detailed surveillance specifications

- Chapter 3 provides a derivation of EC functional and performance requirements derived from the ConOps and uses available standards and analysis to provide benchmarking.

Section 4: - Gap analysis

- Chapter 4 provides a systematic assessment of the applicable regulatory and standards framework in the UK to identify gaps where requirements identified within the ConOps are not fulfilled. The chapter includes identification of appropriate global standards that offer requirements which could potentially be adopted into the UK framework.

Section 5: Cost assessment for manufacturers

- Chapter 5 provides an assessment of costs to manufacturers under the potential deployment scenarios, and costs for stakeholders to adopt the proposed solution under a variety of representative scenarios.

FIGURE 1: DOCUMENT STRUCTURE

2 - CONCEPT OF OPERATIONS (CONOPS)

2.1 - Purpose of the CONOPS

The CONOPS together with the results of the regulatory gap analysis will be used to identify:

- The potential operational requirements from the applications supported by the selected option (in particular, those potential operational requirements which relate to enhanced EC need are identified, based on the best available understanding of the emerging applications today);
- The minimum functional requirements for the enhanced EC devices to enable the expected benefits and deliver the expected functionality; and
- The missing regulatory requirements and guidance in the UK regulatory framework to enable implementation of the selected option.

The identified gaps in the regulatory framework include ground components, airborne components, and their interoperability and interfaces.

The CONOPS is be written as an airspace user and service provider oriented document and describes concept characteristics and provides an overall picture on an operations as expected under 3A option. As part of the CONOPS we have described:

- How the 3A solution[3] will support the operational scenarios including ground and airborne elements and their interfaces;
- Stakeholders and their roles;
- Operational environment in detail to provide an understanding of how the option should work, what assumptions have been taken, what are the constraints, what is the capacity and the limits of the option, etc.;
- High level architecture estimated for the option considering all ground and airborne components and stakeholders, their relations and interactions;
- Spectrum needed to support information flows;
- Information and message exchange flows between all relevant air and ground elements and stakeholders will be described considering technologies and frequencies proposed in the particular option;
- Potential impact on the airspace users and service providers.

It is noted that the "concept" (focus of this study) is a minimum standard for enhanced EC devices. This is effectively a technical enabler to a set of operational services that will be utilised in future, whereas a ConOps typically describes a proposed new or altered type of operation. The operational services which the enhanced EC devices will support are not all finalised, and furthermore, other system elements that will enable the operational services are not yet defined. Therefore, **this ConOps necessarily makes assumptions about the requirements of the operational services, and the demand that will be allocated to the enhanced EC devices to derive a set of requirements on the enhanced EC devices**.

As there are many uncertainties, this ConOps aims to deliver a high-level description, and through capturing associated requirements for the most stringent needs, will identify the minimum standards for the enhanced EC devices. This ConOps does not aim to be exhaustive in describing the operational environment, or potential scenarios, instead focusses on the most pertinent to determining the performance required of the enhanced EC devices.

[3] *Option 3A was defined in the Phase 1 report of this study, an overview is provided below for readers' convenience*

2.2 - Overview of the selected option (3A)

This section provides a summary of the selected option from Phase 1 of the study. This is the context within which enhanced EC devices would function.

2.2.1 - Overview of the option selected for evaluation

In the Phase 1 report, the top five options were assessed, and a recommendation made from which the CAA and DfT selected Option 3A for further evaluation as the potential for provision of a UK wide EC solution. This option aims to adopt, as far as possible, existing global standards for EC, and principally mandates the equipage of *enhanced EC devices* within specified airspace volumes supported by Transponder Mandatory Zones (TMZ). Any uptake outside the specified airspace volumes would be voluntary. The option addresses spectrum occupancy by separating the frequency used for EC with manned aircraft using 1090MHz and unmanned on 978MHz.

Enhanced EC devices, within this document, are defined as devices providing assured position information that conforms to a minimum standard. In this context assured is a quality measure, indicating that the signal should have data properties with a defined probability of being valid upon reception by the user.

The diagram below shows the logical architecture of the operational environment under consideration. It shows the enhanced EC equipped aircraft domain (top left - green), other manned receiving aircraft (top centre - green), UAS (in orange, with airborne domain top-right and the remote pilot bottom-right), and the ground ATS domain in blue. Note that voice communications links are excluded as the diagram focusses on depicting EC architecture and information flows of the related surveillance data.

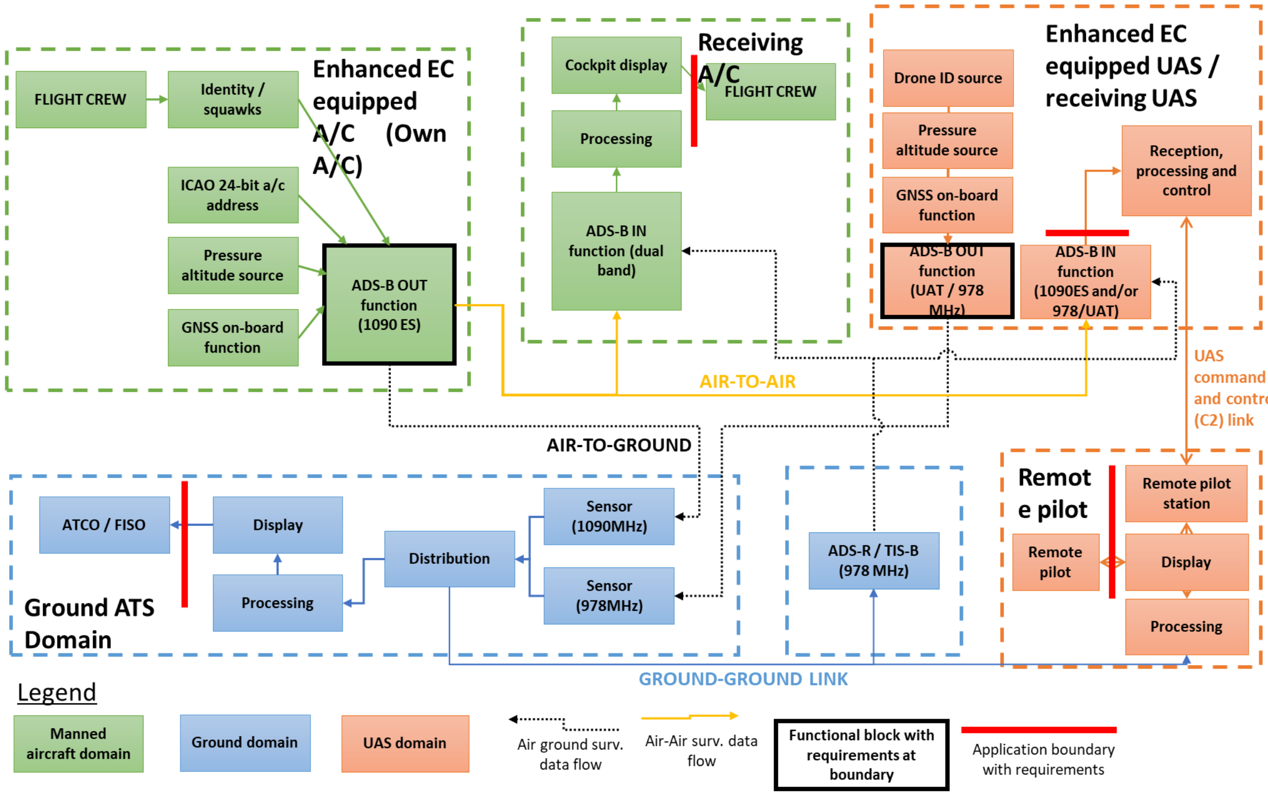


FIGURE 2: Logical Architecture of the Proposed Option

The key requirements for and enhanced EC device is set at the ADS-B OUT function in the manned aircraft and UAS functional blocks shown with a bold black border on the diagram above.

To set these requirements, a top-down process would consider application requirements and translate them into emitting device requirements based on assumptions on the surveillance data chain. These application-level requirements would be placed at the boundaries indicated by the solid red bars – for example, surveillance requirements for ICAO FIS would be seen at the display of surveillance information to the ATSO in the ground domain.

As this CONOPS makes clear above, an issue in setting requirements for enhanced EC is the existing lack of clear operational requirements the application level, which would help answer the question "how good is good enough?". ICAO FIS has no surveillance requirements, and although UK FIS has traditionally used deconfliction minima, this is being retired as a concept and will no longer be applicable.

An alternative approach to applying a top-down process (deriving specifications from assumed operational requirements as identified at the red bars in the above diagram) is to benchmark against other environments (e.g. US), recognising that if surveillance information is beneficial and safe in that context, it could be in the future UK airspace.

Option 3A assumes that:

- Manned aircraft will operate a device working on 1090 MHz, and ADS-B Out functionality is considered as a minimum (transmitting ADS-B messages, aircraft identification and category, airborne position, airborne velocity, barometric altitude, and aircraft operational status). This approach will ensure that all surveillance operations will be conducted within the protected aviation spectrum bands and the equipment would retain interoperability with the international standards to which certified devices comply.
- The use of enhanced EC devices on 1090 MHz (ADS-B), or ED102-B compliant ADS-B device, would be mandated for all manned aircraft requiring access to the specified airspace volume.
- The risk of 1090 MHz frequency saturation will be minimised, and new digital services (TIS-B, FIS-B) would therefore be enabled on another frequency, most likely 978 MHz.
- Aircraft not requiring controlled airspace access or equipped for access to CAS IFR services may maintain current avionic fit. Users operating with 978 MHz equipment could be provided with a re-broadcast of traffic information via a ground architecture enabling TIS-B, FIS-B. Users broadcasting on 1090 MHz will be electronically visible and can choose whether to receive 978 MHz data or digital services for situation awareness.
- Building upon current equipment fits, existing user types maintain 1090 MHz (ADS-B Out is considered as a minimum) devices, while new unmanned user groups equip with 978 MHz and all will adopt existing global standards for EC devices where possible.
- Additional regulation may be required to enable entry of new user operations (i.e. BVLOS or UAS segregated airspace) and use of 978 MHz UAT within UK.
- Other airspace users will be encouraged to adopt regulated EC devices through safety arguments & enabling access to more airspace blocks.
- Class G avionics requirements remain unchanged. Electronic conspicuity is therefore voluntary and mixed equipage can be expected outside of TMZs, with potentially more users being equipped. There will remain some portion of airspace users who will be restricted in access to segregated airspace if not equipped with an enhanced EC device.
- ANSPs and airports with TMZs may need to commission ADS-B (if not already) including 978MHz reception. Ideally this could be built into planned equipment upgrades. The ultimate source of funding is beyond the scope of this report, but it is noted that there may be a LAS service provider funded by government, and unmanned aircraft operators may have economic incentive and means to support retrofit of 978MHz ground surveillance if it enables BVLOS operations.

2.2.2 - Regulatory consideration

From the regulatory perspective, ADS-B on 1090Mhz technology and standards are well known and established. This therefore offers a simple route to a set of minimum standards compared to developing novel means of assurance. Conversely, regulatory actions will be required to implement and initiate use of 978MHz in UK and interoperability with core Europe remains a risk.

The new regulatory framework will therefore change the current airborne or ground-based equipage[4] and encourage the voluntary uptake of EC devices. To create specified airspace volumes and allow enhanced EC devices to support the expected operational services, it will be necessary for:

- Manned aircraft and BVLOS UAS to equip with ADS-B (if not already) and
- Ground-based equipment to receive ADS-B on 1090Mhz ES and 978MHz.

2.2.3 - Expected benefits from enhanced EC

Considering the outcomes from the Phase 1 report, the new enhanced EC is expected to bring the following benefits which will need to be considered by the CONOPS:

- Ability to drive safety improvements;
- Enabling safety applications such as:
  - ICAO FIS using surveillance – in Class G and Class E, and for VFR flights in class D
  - Crossing service (Danger Area, ATZ etc)
  - A source of information supporting UAS detect-and-avoid
  - Input into Hybrid ACAS (ACAS X) and future collision avoidance applications;
- Ability to safely integrate new users (BVLOS, VLOS) in a known traffic environment;
- Enabling access to airspace with TMZ, facilitates[5] access to Class D dynamic airspace proposed by the AMS;
- Improved interoperability between aircraft in Class G;
- Enabling the market to innovate and invest, giving a clear path forward to a standard that enables benefits;
- Enabling the future digitalised airspace services (e.g. digital FIS, dynamic airspace);
- Increasing sustainability through reduced managed airspace volumes, and possible reduced ground infrastructure footprint;

2.3 - Environment assumptions

This section captures the key assumptions for the environment into which the enhanced EC devices are intended to be introduced. It considers UK airspace from 2024 onwards.

The key reference for this section is the Airspace Modernisation Strategy which was a critical input to Phase 1 of this project. Phase 1 of this project identified 4 key applications which enhanced EC devices will support, which are considered the operational services.

The UK mix of airspace classes, airspace users, ATSPs and ground equipment and rules of the air form the pertinent operational environment for the purpose of this CONOPS. They are themselves outside the scope of this document to define, but set out the underlying environment which the enhanced EC devices operate in and the services they must support.

OPERATIONAL SERVICE	AIRSPACE CLASS(ES)	USER GROUP(S)	ALTERNATIVES TO ENHANCED EC	REQUIRES TMZ[6]?
SITUATIONAL AWARENESS	G (and E)	GA	Existing EC	No
ACCESS TO CONTROLLED AIRSPACE	D	GA	Mode S	Yes

[4] *Space-based reception of ADS-B is excluded for reasons identified in use case analysis in 2.4.3.1.*

[5] *Provides ATSOs an assured data source for the VFR flight, through which they can gain comfort in giving VFR clearance in Class D airspace (or future dynamic airspace). Potentially reduce workload, helping the ATSO accept more VFR flights into Class D (at present, if they feel they cannot handle the VFR flight and provide IFR separation against it, they won't allow it to enter).*

[6] *For enhanced EC to enable the operational service*

OPERATIONAL SERVICE	AIRSPACE CLASS(ES)	USER GROUP(S)	ALTERNATIVES TO ENHANCED EC	REQUIRES TMZ[6]?
DETECT AND AVOID	All	Unmanned	None mature	Yes[7]
ICAO FIS WITH SURVEILLANCE	G and E	All	Primary radar[8]	Yes
HYBRID ACAS[9]	All	GA	TCAS (etc)	Yes

2.3.1 - Airspace classes

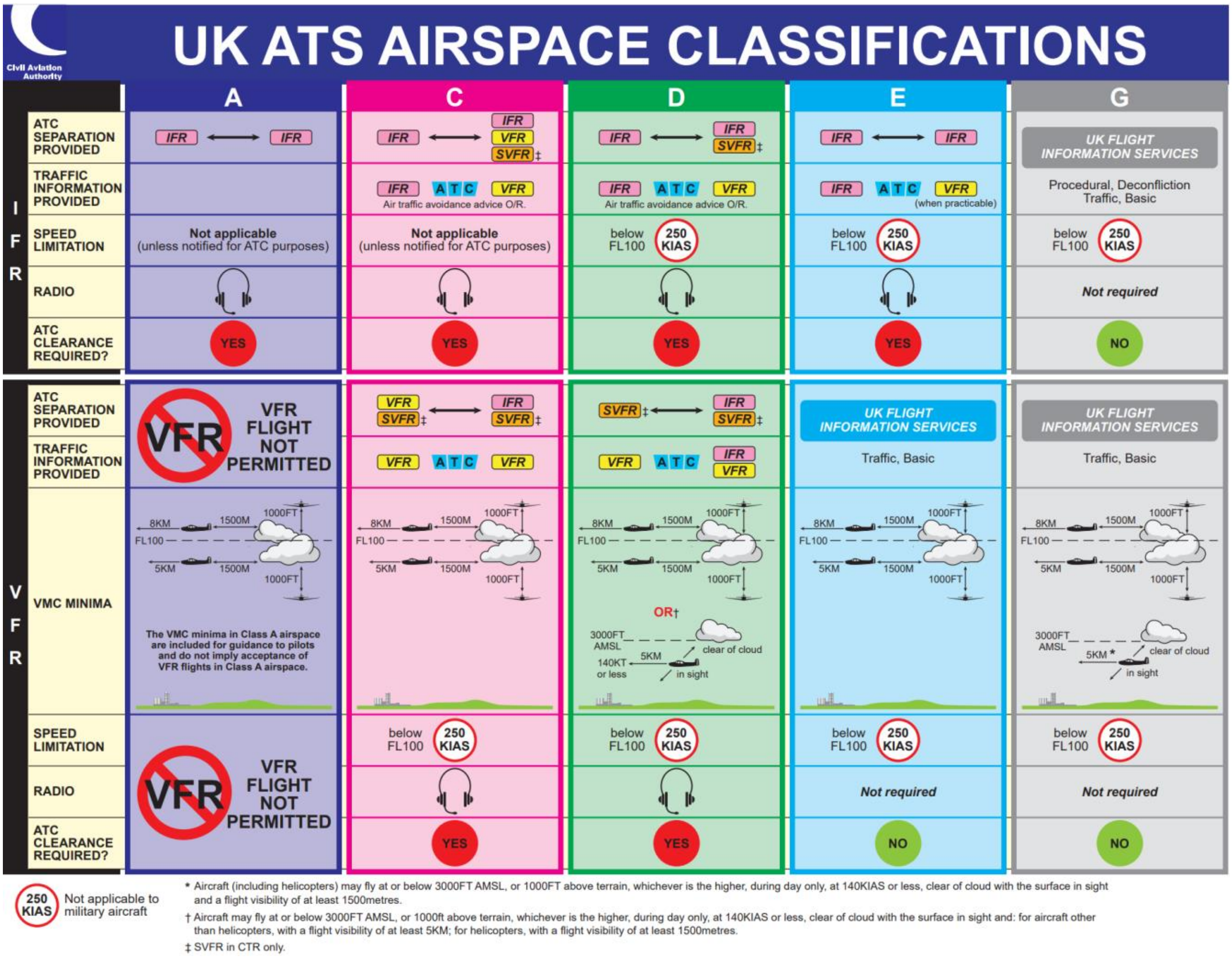


FIGURE 3: UK Airspace Classifications

Figure 3 above provides a pictorial overview of existing UK airspace classes, including the changes introduced by the Airspace Modernisation Strategy (AMS) and proposed within the selected option.

The AMS introduces the concept of dynamic use of airspace, whereby airspace could change between Class G and Class D, depending upon user need. This study uses the term a specified airspace volume to indicate any airspace in which the carriage of an enhanced EC device would be required to gain access. This could be an area of controlled airspace (e.g. Class D) or a TMZ which could be established inside or outside of controlled airspace.

---

[7] *Future systems may not rely solely on enhanced EC and therefore could operate without a TMZ*

[8] *Assuming operational use does not require altitude, and safety argument can be made to account for aircraft with low RCS*

[9] *Including other ACAS standards under development*

2.3.2 - Airspace users

UK airspace is utilised by a broad range of users. Commercial air traffic is not expected to be affected by this concept (except increased effectiveness of ACAS through compatibility in enhanced EC devices), but other airspace users are. They are summarised below:

- Fixed Wing General Aviation. Approximately 4000 aircraft registered in UK. Operate in a wide range of airspace, but most abundant within Class G Wide variety of EC equipment fits depending upon airspace entry requirements.
- Rotary Wing General Aviation. Approximately 1200 registered aircraft. Operate in a variety of airspace classifications but again mostly operate within Class G at lower levels. A wide variety of EC types fitted including Protected Aviation Band and ISM Band Systems, depending upon airspace requirements.
- Gliders. Approximately 2200 aircraft within UK. Mostly operate in Class G. Wide variety of EC types fitted including Protected Aviation Band and ISM Band Systems, depending upon airspace requirements.
- Non-Powered GA (excluding Gliders), including c.8500 flying pilots, 6400 skydivers. Normally within Class G airspace. Limited use of EC.
- Large Model Aircraft (Up to 150kg). 800 Model Flying Clubs, normally within Class G airspace. Limited use of EC.
- Military Aircraft. Approximately 800 using all classifications of airspace. Most are transponder equipped, transport aircraft ADS-B equipped.
- UAS. Mostly in Class G airspace – in visual line of sight. BVLOS currently in temporary segregated airspace. 5800 registered operators. Very limited use of EC.

Within the timeframe of this concept the airspace user mix is expected to evolve. Of particular relevance is the introduction of space launch vehicles and the growth of unmanned services and potential Advanced Air Mobility (AAM) operators. This concept aims to support the integration of said users into UK airspace.

2.3.3 - Current EC equipage

As described above there is a mix of Electronic Conspicuity devices within the UK environment. Current Electronic Conspicuity falls into two categories: situational awareness, and certified ADS-B.

Presently the only EC devices which can support applications with a safety impact are certified ADS-B avionics operating on 1090MHz. Situational awareness EC devices include proprietary models (with closed standards) and CAP1391 devices, which provide 1090MHz ADS-B against open specifications, but without assured performance. Situational awareness devices are equipped by a considerable proportion of the UK General Aviation fleet supported by the CAA EC device rebate scheme.

The analysis from the Phase 1 report showed that the penetration of ADS-B 1090MHz ES within the General Aviation fleet has been increasing. It is noted in the analysis that the observed sample had approximately 40% equipped with ADS-B out. Adding in the success of the CAA EC rebate scheme and this could be expected to increase further.

2.4 - Use cases for the selected scenario

2.4.1 - Overview of use cases

This section provides a description of key use cases identified where enhanced EC devices meeting a minimum standard could be used to support the operational services. As there are many possible use case scenarios, and many of the services supported are still under development, it was not feasible to fully elaborate use case scenarios in this document (for example recording every step, all alternative flows, every individual information flow and state change). Instead, key scenarios are explored with a focus on the interactions which result in *driving* requirements; those which will dictate the minimum requirements for enhanced EC devices in order to achieve the intended operational benefits.

Phase 1 of this study identified the following applications that would be supported by enhanced EC devices:

- Access to airspace
- ICAO FIS using surveillance
- Crossing service (e.g. Danger Area, ATZ etc)
- A source of information supporting UAS detect-and-avoid
- Input into Hybrid ACAS (ACAS X) and future collision avoidance applications

In addition, it is recognised the introduction of enhanced EC devices could allow increased access to airspace (a key driver for the study), and that the selected option should not prevent the continued benefits of situational awareness.

The following table shows the use cases and scenarios that have been elaborated here, together with justification for their selection.

TABLE 1: OVERVIEW OF SCENARIOS

Use Case	Scenario	Justification
Access to airspace	Class D access	This scenario covers the potential for enhanced EC devices to improve access to air space for equipped users, which was a key driver identified for this study.
	Class G ATZ with IFPs	This scenario was identified as a potential driving constraint full the range required by enhanced EC devices.
ICAO FIS with surveillance	manned- manned interaction	ICAO FIS with surveillance represents one of the key applications (operational services) identified in phase one. Interactions between manned aircraft represent a core use case for enhanced EC devices, particularly in class G or E airspace. this used case was expected to identify driving requirements related to ATSP needs.
	manned-unmanned interaction	This scenario was explored to assess any additional requirements arising from the introduction of new airspace users into the previous scenario.
Detect And Avoid (in specified airspace volumes)	Conflict avoidance of manned aircraft	Support to detect and avoid capabilities was expected to elicit driving requirements for enhanced EC devices. Whilst DAA is expected to operate in all airspaces this analysis focused on its function within the specified airspace volumes identified in this study as operation of DAA outside of these cases would rely on other technology than enhanced EC devices. The conflict avoidance function within detect and avoid was expected to require the most stringent performance as it provides the final mitigation (other than Providence) against mid-air collision risk.
	Remain well clear of manned aircraft	the remain world clear function of DAA has the potential to introduce additional ground elements compared to the conflict avoidance function. It was explored to assess any additional requirements compared to the previous scenario.
	Coordinated remain well clear between unmanned aircraft	This scenario was included to assess if any additional driving requirements arise when interactions are exclusively between unmanned aircraft and two consider the potential impact of a ground based deconfliction service search as UTM.
Hybrid ACAS	manned- manned collision avoidance	Hybrid ACAS is an operational service with specific requirements on airborne equipment. it was explored to identify any driving requirements given its use as a safety net.
	manned-unmanned	This scenario was explored to assess if the introduction of unmanned enhanced EC devices (operating on 978 MHz) resulted in any additional driving requirements.

Use Case	Scenario	Justification
	collision avoidance	
situational awareness	-	A key driver for the study is to ensure that the introduction of enhanced EC devices does not result in the loss of capabilities already provided by EC devices already available and operating. This scenario was explored to ensure that any constraints (for example interfering with existing EC devices) were not overlooked.

Other user groups, such as space launch, are also under consideration. It is noted that space launch is not expected to be in operation within the 2024 timeframe, and the most applicable use case is monitoring of down-range airspace. This use case would not yield any driving requirements for performance requirements as the objective is simply to know if the airspace is clear or not.

Many danger areas (even temporary ones) may be subject to existing ground surveillance, and whilst enhanced EC can contribute to the provision of a Danger Area Crossing Service (DACS) or Danger Area Activity Information Service (DAAIS), the enhanced EC will not be the sole provider of surveillance data, and therefore will not elicit any driving requirements on the performance on enhanced EC devices over those already covered under the provision of ICAO FIS.

Danger areas may also be managed procedurally, particularly Temporary Danger Areas enacted for the enabling of BVLOS operations. In future, TDAs may be combined with TMZs requiring enhanced EC devices for entry and supporting DAAIS and DACS utilising the derived surveillance information.

Note that these use cases are treated separately and have overlapping requirements. This is intentional, and allows the identification of *driving requirements* (those which place the highest demand on enhanced EC device performance) in order to identify the minimum performance needed.

2.4.2 - Access to airspace

A key driver of enhanced EC is to maintain and improve access to airspace, including avoidance of additional barriers as new platforms become operational. This could include enabling increased access of VFR traffic to Class D, through better situational awareness of the aircraft's position and ongoing flight path delivered through the enhanced EC device.

The AMS also introduces the possibility of dynamic use of airspace, whereby airspace could change between class G and class D, depending upon user need. Again, enhanced EC could enable this solution, providing increased access to GA.

For this dynamic airspace solution, there is a need to ensure that the end states and transition state are acceptably safe. Two end states exist: a Class G airspace environment (ICAO FIS with surveillance), and a Class D airspace environment with controlled separation services (between IFR and SVFR[10]) and the potential for VFR clearances with traffic information provided (ICAO FIS with surveillance). The transition state will be the ATSO (ATC or FIS) deciding how to assure safety as the airspace classification is changed, which will at least involve having a full picture of the traffic within the airspace. This would enable the ATSO to understand and inform flight crew of potential collision hazards, and provide traffic information as relevant, in line with ICAO Annex 11 Section 4.1.

Merely replicating controlled airspace surveillance regulations (and accepted standards) will not enable the innovation being sought in this CONOPS for enhanced EC. Instead, the concept seeks to enable more aircraft to benefit from being electronically conspicuous, including those who struggle to justify the costs associated with fitting the fully certified solutions.

[10] *Within a CTR*

Access to airspace is therefore assumed to require sufficient surveillance performance to enable situational awareness (as with today's procedural VFR clearances), delivered through a suitably performant EC device.

R1. Enhanced EC devices should enable access to class D, and the AMS "dynamic" airspace.

Furthermore, airports with busy ATZs may operate IFPs or Points IN Space (PINS) approaches, even within class G without the CTR/CTA. In such cases it is likely that they would operate with surveillance sensors within the aerodrome boundary, as the service provider/aerodrome operator would need to make a safety case and could show surveillance coverage as a mitigation for mid-air collision risk between the aircraft arriving on the IFR approach (IFP or PINS) and transiting other traffic. The enhanced EC devices should support these types of operations as a means to improving safety in uncontrolled airspace with a relatively high density or converging operations.

R2. Enhanced EC devices should support the monitoring of traffic for airport ATZs with IFPs or PINS approaches.

This infers a minimum range requirement, such that the information can be provided early enough to optimise cockpit workload (e.g. during instrument approaches).

R2a. Enhanced EC devices should have a range comparable to the size of airport DOCs.

2.4.3 - ICAO FIS with surveillance

In specified airspace volumes, manned aircraft could be required to equip 1090MHz EC devices and UAS equip 978MHz EC devices. These would support the delivery of ICAO FIS with surveillance, particularly the provision of traffic information to assist the pilot in collision avoidance, within Class G and E airspace, and for VFR traffic in Class D. As is captured in the Phase 1 report.

If enhanced EC is the only source of surveillance information for the provision of ICAO FIS, the ICAO documents – for example ICAO Doc 4444 section 8.11 (and analogies with the existing CAP774 UK FIS 4th edition – even though it will retired shortly) would suggest:

- It must enable the positive identification of an aircraft.
- It must be able to provide pressure-altitude derived level information.
- It must be able to support traffic information for collision avoidance with sufficient surveillance information and data quality (even though the pilot-in-command remains responsible, the ATSO may have a duty-of-care, and if provided with surveillance, should be assured that it will (at least) not degrade the situation). The equivalent language in Doc 4444 8.11 suggests the information must enable the FISO to provide "suggestions or advice regarding avoiding action" - or in other words, provide traffic information and a course of traffic avoidance advice.

From which the following requirements are derived:

R3. Enhanced EC devices shall provide the required data to support ICAO FIS surveillance.

R3a. Enhanced EC devices shall provide positive identification of the aircraft.
R3b. Enhanced EC shall provide assured position.
R3c. Enhanced EC devices shall provide barometric altitude derived level information.
R3d. Enhanced EC devices shall provide sufficient data performance and quality for an ATSO to provide beneficial collision avoidance information and avoid nuisance information.

ICAO FIS with surveillance (as described in ICAO Annex 11, Doc 9426 and Doc 4444) does not prescribe advisory minima (i.e. a minimum distance the ATSO should assure to provide avoidance of a collision). No surveillance safety case for ICAO FIS exists, which might set surveillance integrity requirements, for example. Any traffic information is provided to assist pilots in collision avoidance purposes from another aircraft.

In uncontrolled airspace, this surveillance information is noted in ICAO Doc 9426 and Annex 11 as being potentially incomplete (i.e. not everyone may be equipped) and unreliable (i.e. performance parameters may not be met, which Doc 9426 describes as of "doubtful accuracy").

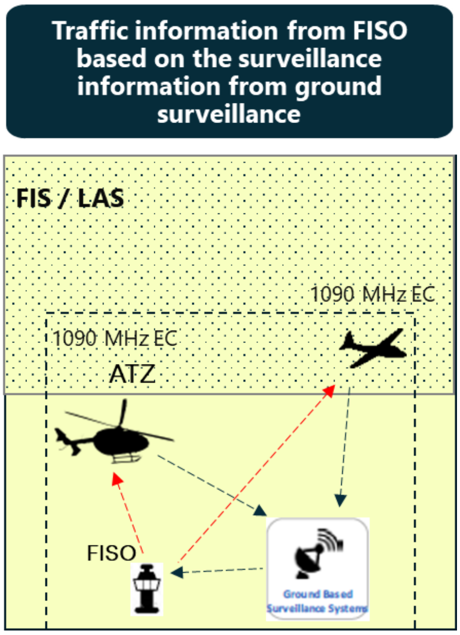
An IFATCA paper noted in 2019 that "The standards prescribed (for FIS) are ambiguous and not sufficient to define the limits of obligation and information to aircraft. Only basic criteria can be found in ICAO DOC 9426, not doing justice to the service level that is provided by- and expected of ATCOs and FISOs" and "Both on ICAO and European level, there are no standards and technical requirements for the use of ATS Surveillance for provision of FIS in class G airspace."

In terms a form of precedent, UK Regulatory Article 3228[11] states that, in Class G airspace when providing a Deconfliction Service, controllers should provide information and advice aimed at achieving the lateral and vertical separation standards defined in CAP 774 (i.e. UK FIS). These are 5NM laterally and/or 3000ft vertically (against uncoordinated traffic) or 3NM laterally and 1000ft vertically against traffic benefiting from the same ATS. Whilst stressing that these are UK FIS (and not ICAO FIS), it nevertheless gives a benchmark in understanding potential surveillance performance needs according to the operational norms that have been used in the UK.

Asm1. 3NM/1000ft separation standards are assumed to be an upper bound to the required surveillance performance for ICAO FIS with surveillance.

In exploring this use case, there are two sub-scenarios depending on the involvement of unmanned aircraft, which are illustrated in the figures below.

2.4.3.1 - Manned-Manned interaction



[11] *It is noted that 3228 is from military regulation, but it provides a benchmark of upper bound performance requirements.*

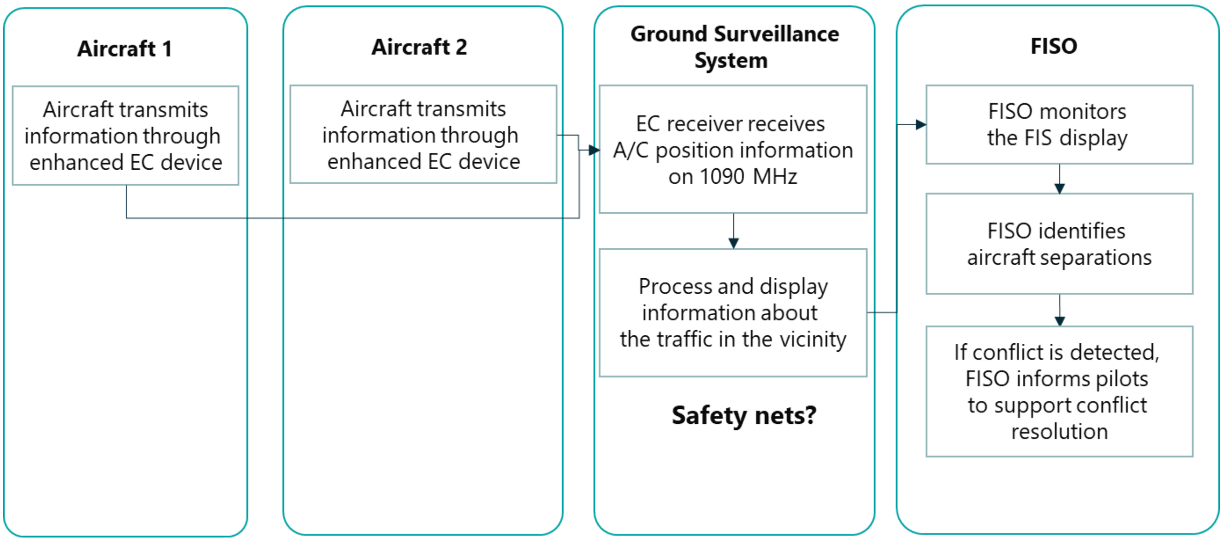


FIGURE 4: MANNED-MANNED INTERACTION WITH ICAO FIS

Within this scenario two manned aircraft are interacting within a specified airspace volume in Class G/E. As they are both equipped with 1090MHz EC devices meeting the minimum standard, they are detected by the surveillance systems available to the local ATSP (who are assumed to have deployed ADS-B sensors). This infers the following operational requirement:

R4. The ATS provider shall have sufficient surveillance coverage for the specified airspace volume.

R4a. Enhanced EC devices shall have range sufficient to be detectable by typical ADS-B ground stations with a reasonable network density over the specified airspace volume.

This information is displayed to a FISO, who can identify a potential conflict and provide information to the aircraft to advise a suitable avoiding action. The FISO can monitor the resolution and advise the aircraft further if they deem necessary. Ultimately the pilot in command remains responsible for separating themselves from other aircraft.

Given the density of traffic within the UK, in general, and the lower power output being proposed for this application specifically, it is assumed that space-based surveillance would not be able to provide suitable performance to support the enhanced ICAO FIS with surveillance service, particularly as providers currently have no known plans for 978MHz reception. It might also place additional demands on the enhanced EC device to support probability of detection requirements.

Asm2. Spaced-based EC reception is not suitable for providing coverage of the enhanced EC devices in this study.

As noted in the access to airspace use case, the air to ground range to support enhanced ICAO FIS with surveillance with enhanced EC devices is likely to be considerably lower than that required by existing certified ADS-B or other secondary surveillance avionics.

Where a specific airspace volume exists, for example with a TMZ applied, enhanced EC devices could help support ATSPs comply with their Safety Management Systems (SMS), through a risk-based analysis and deliver safety benefits. To deliver these benefits they will want to be certain that:

- They can detect all aircraft within the airspace they are monitoring, inferring:
  - Either all aircraft are cooperative, or the FISO has access to non-cooperative surveillance which is able to provide required information.
  - The ATSP has access to sufficient surveillance systems to provide coverage needed at the performance levels (e.g. availability) required.
- The information they are provided can be trusted, inferring either:

- The performance and quality of the information provided by the EC device meets standards used today for comparable applications, or
- The EC device includes data quality information within its broadcast information *and* a suitable approach to utilising quality of position reports (e.g. from ED-106B, or an enhanced EC device) is established including operational procedures and FISO HMI design (e.g. in line with FID requirements in CAP 670 Appendix F).

Whilst the development of appropriate operational procedures for managing varying data quality, together with suitable HMI design is possible and even likely in the future, it cannot be assumed to be available within the 2024 timeframe this study targets. This need would be served via **R3**.

2.4.3.2 - Manned – Unmanned interaction

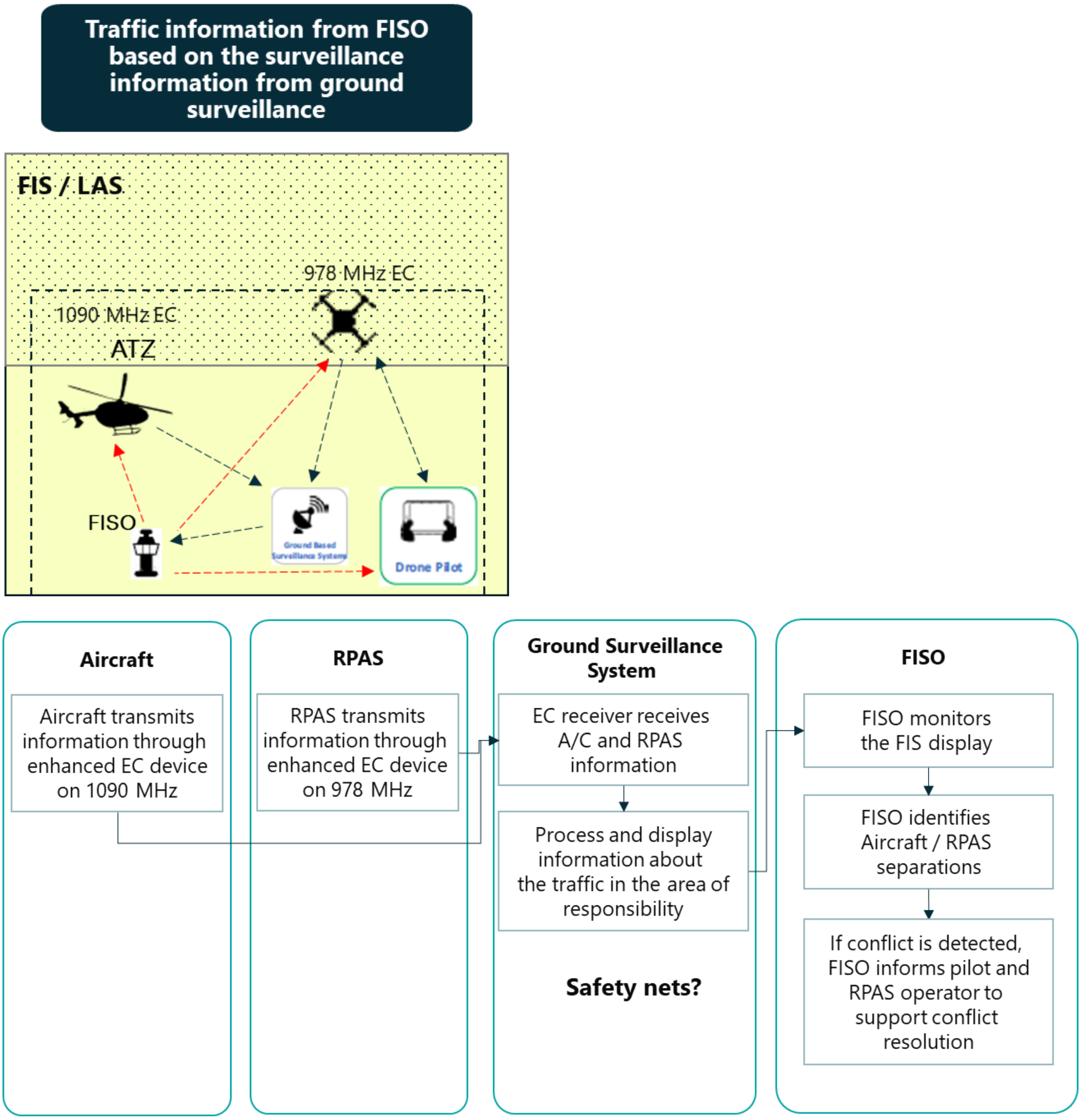


FIGURE 5: MANNED-UNMANNED INTERACTION WITH ICAO FIS

This scenarios shares much in common with the first enhanced ICAO FIS with surveillance scenario, and indeed all the statements around FISO duty of care remain equally valid. In addition, this scenario introduces additional considerations:

- The surveillance system may receive position data from unmanned, by either:
  - Reception of 978MHz EC directly, or
  - In future, integration with unmanned system operator to provide position data downlinked through C2 in accordance with the data quality requirements (although the performance of such a solution is not yet understood).
  - This further justifies the assumption that space-based surveillance would not be suitable, as there are no known plans to incorporate 978MHz reception into space-based surveillance systems at the time of writing.
- The remote pilot (or potentially operator depending on the nature of operations) would need to be contactable to the FISO.

The scenario also highlights challenges in relation to the provision of barometric altitude. Whilst this is standard practice in manned aircraft, and particularly with certified equipment, it is less commonly available in UAS and on more basic EC devices. Furthermore, there are potential training issues around the setting of QNH which would need to be ensured where applied to unmanned aircraft. It is noted however, that standard pressure (1013) is the basis for vertical separation of traffic, while QNH adjustments are relevant where a defined vertical distance to the ground has to be maintained.

There are SESAR workstreams underway and position papers that are seeking to either enable the conversion of geometric height to barometric altitude or push the adoption of geometric height in general. These are not yet mature and cannot be expected to be available in the short term this study seeks to address, but may be relevant for longer term.

2.4.4 - Detect and Avoid

The Detect And Avoid (DAA) concept is still in development, but aims to provide a function equivalent to see and avoid, for UAS flying BVLOS. Within Europe it is expected to work in all airspaces, and with non-cooperative aircraft. Where EC is used by the DAA function, known performance will be required.

R5. When using EC input, DAA systems shall only use data from enhanced EC devices with known performance.

Whilst future systems may be developed which can detect and locate non-cooperative aircraft, there are no proven systems today. It is therefore logical to assume that in the shorter term such operations will first be enabled through specified airspace where all aircraft are cooperating with suitably performant EC. No requirements are set for EC performance as a contributor to DAA, although precedents are emerging which suggest assurance or a containment bound will be required in the eventual standards.

R5a. The position and velocity data provided by enhanced EC devices shall be assured
R5b. Enhanced EC devices shall provide sufficient data for the receiver to calculate a containment bound on the reported position

Under the selected option this project is exploring, specified airspace volumes will require unmanned aircraft to equip with performant EC transmitting on 978MHz and manned aircraft with performant EC transmitting on 1090MHz. Furthermore, unmanned aircraft would equip with 1090MHz receivers to support detection of manned aircraft. This would be the case in specified airspace volumes in class G and E airspace only, as in controlled airspace other equipage requirements apply and are therefore out of scope of this project. It is noted that in cases where manned aircraft are able to access controlled airspace through equipping a performant EC device on 1090MHz the solution could contribute to DAA.

As unmanned aircraft operating BVLOS operations are expected to be smaller than typical manned aircraft it is assumed that the ability of pilots to see and avoid unmanned aircraft will be lower compared to manned aircraft.

Asm3. The ability of pilots to see and avoid unmanned aircraft will be lower compared to manned aircraft.

This implies that the risk mitigation will rely to a greater extent on a single actor (the UAS), and to achieve equivalent safety performance overall, the performance of DAA would need to be greater than see and avoid on a probability basis across the airspace:

Asm4. ***There will be a greater reliance on the capability of DAA to enable unmanned aircraft to take avoiding action compared to see and avoid.***

Asm5. ***DAA introduces no change in the rules of the air – a pilot should still take appropriate action if they see an unmanned aircraft.***

In exploring this use-case, there are three key scenarios elaborated below.

2.4.4.1 - DAA conflict avoidance (CA) of manned aircraft

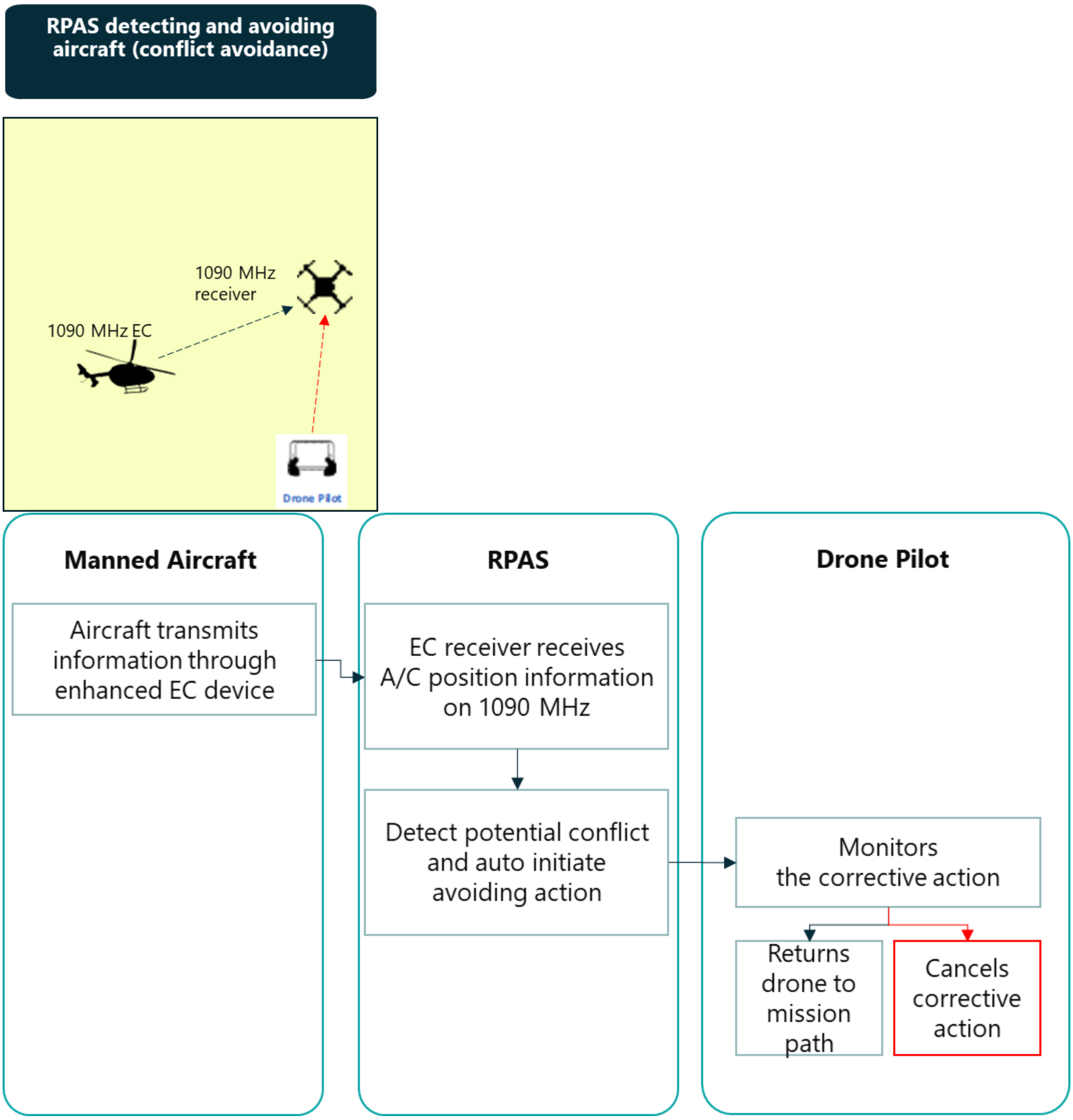


FIGURE 6: MANNED UNMANNED DAA CONFLICT AVOIDANCE

In this scenario the unmanned aircraft requires a 1090MHz receiver to receive assured position data from the manned aircraft and take suitable avoiding action. A pre-condition of this scenario is that prior avoidance actions (i.e. the RPAS alerting the RP and the RP taking avoiding action, covered in the next scenario) have not been possible or successful for a conflict avoidance action to be necessary. Initial DAA systems are likely to still require manual intervention by the RP, but this scenario considers possible future automated systems.

To support DAA CA function within the specified airspace volumes, unmanned aircraft will need to equip a 1090MHz receiver. This function is intended to operate even in the event of C2 link failure (i.e. through automated functions on-board the UAS), which implies that a ground-based relay function would not provide a suitable solution.

R6. Unmanned aircraft shall detect and avoid manned aircraft.

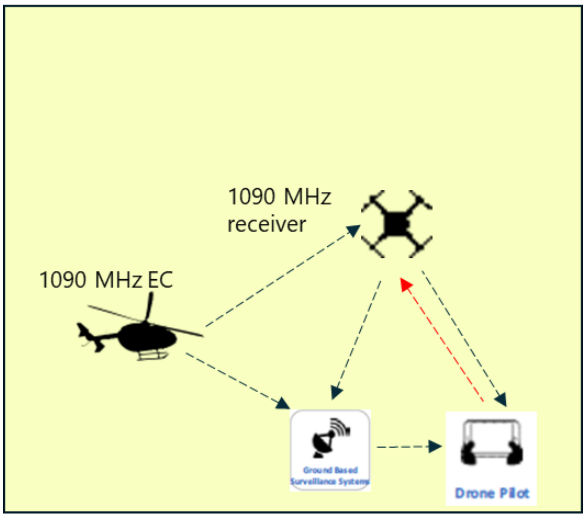
> ***R6a. Enhanced EC devices used by unmanned aircraft shall include 1090MHz ADS-B reception.***

R7. Unmanned aircraft shall perform detect and avoid CA function even in the absence of C2 link with no degradation in assurance.

> ***R7a. Enhanced EC devices used by unmanned aircraft shall not rely upon ground based reception of 1090 MHz ADS-B and relay***

2.4.4.2 - DAA remain well clear action to manned aircraft

RPAS operator detecting aircraft and performing avoiding maneuver (remain well clear)



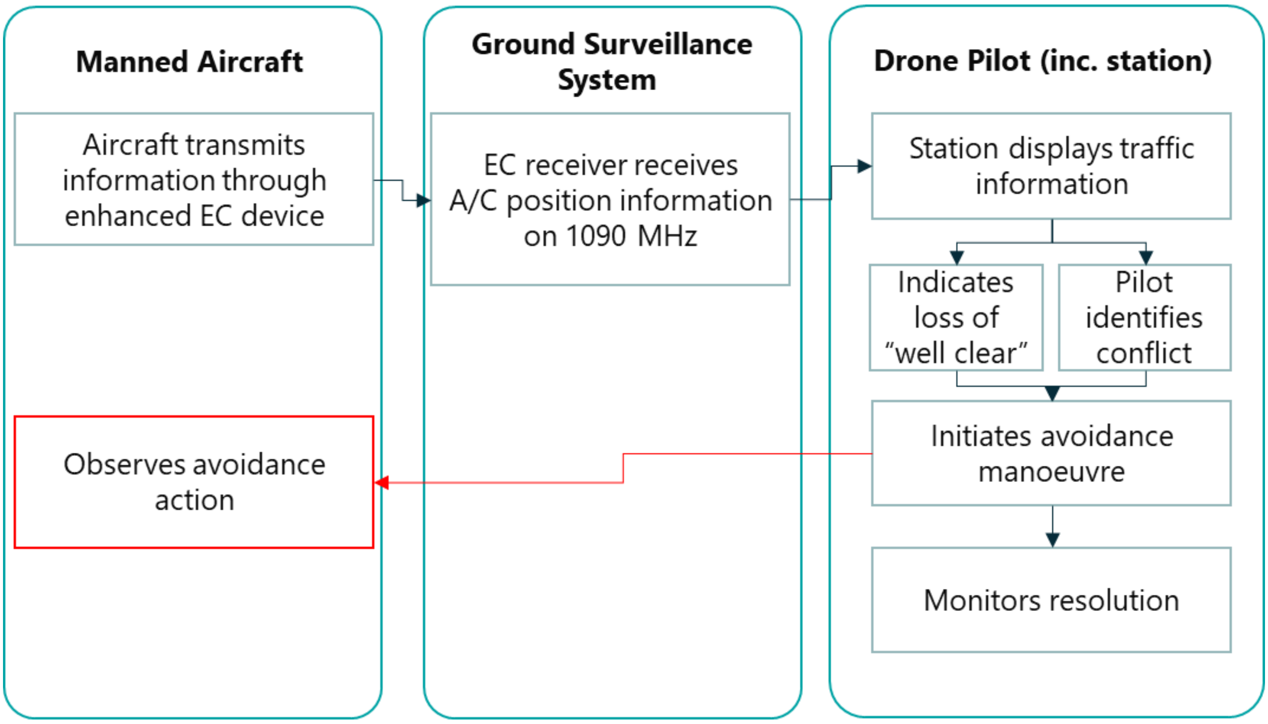
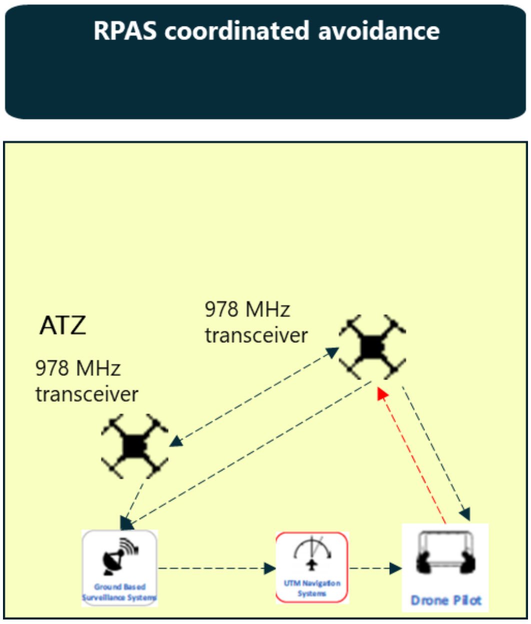


FIGURE 7: MANNED - UNMANNED REMAIN WELL CLEAR INTERACTION

This scenario addresses the Remain Well Clear (RWC) function of DAA. The enhanced EC devices support the function in a similar way to the conflict avoidance scenario, by providing assured position information from the manned aircraft to the unmanned aircraft. The scenario elicits the following additional observations:

- The route of information flow (for RWC at least) may be airborne and then through the UAS C2 link *or* via ground based surveillance systems relayed to the remote pilot's operation station via other communications means.

2.4.4.3 - DAA coordinated remain well clear action between unmanned aircraft



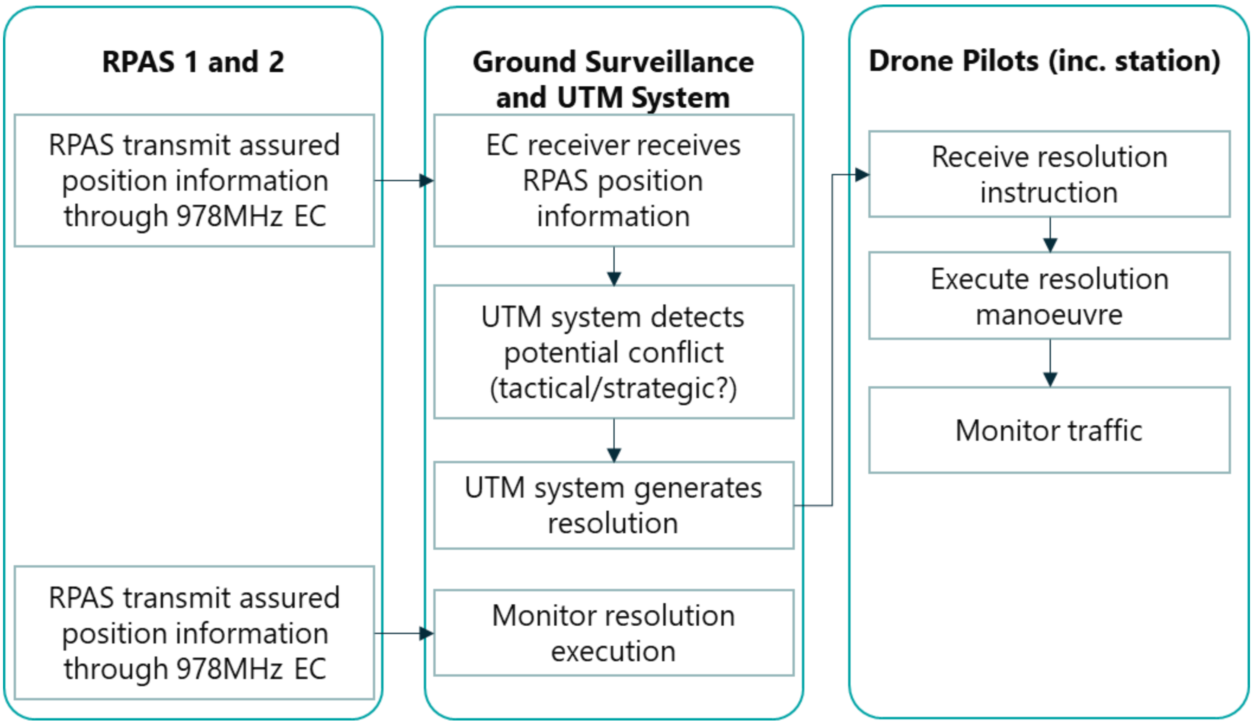


FIGURE 8: UNMANNED AIRCRAFT COORDINATED AVOIDANCE ACTION

This scenario considers DAA avoidance actions between unmanned aircraft. These could include both RWC and CA functions. Compared to the previous scenarios, it elicits the following considerations:

- The use of 978MHz for airborne coordination.
- The possibility for a Unmanned Traffic Management system to provide deconflictions services based on ground surveillance data.

2.4.5 - Hybrid ACAS

There are several technologies available to provide collision avoidance capabilities between aircraft as a safety net. Of interest are the applications which provide collision avoidance resolutions, and thus require assured data on which to base that resolution.

The minimum requirements for an aircraft-based surveillance system to support air-to-air surveillance for airborne collision detection, for GA aircraft not equipped with TCAS, have been standardised in "Traffic Situation Awareness with Alerts" (TSAA) in ED-232 / DO-348 [12] and MOPS ED-194A/DO-317A [16]). This could therefore be used as a basis for enhanced EC to support such an application – although recognising this standard was developed for particular contexts that may not replicate the UK airspace precisely in terms of assumptions used.

Hybrid ACAS uses surveillance means such as ADS-B and Electronic Conspicuity to track potential intruders and does not rely solely on active interrogation as with traditional ACAS. Versions of ACAS X are being defined for UAS (ACAS X_O in EUROCAE ED-256) and GA aircraft (ACAS X_R yet to be standardised and published).

In each case, it would seem beneficial to use a surveillance source which gave assured traffic information, reducing the possibility of nuisance advisories and alerts, and the potential to take an inappropriate action based on false position information delivered electronically. This is particularly the case if used in IMC.

In exploring this use case two key scenarios are explored below:

2.4.5.1 - Manned – Manned collision avoidance

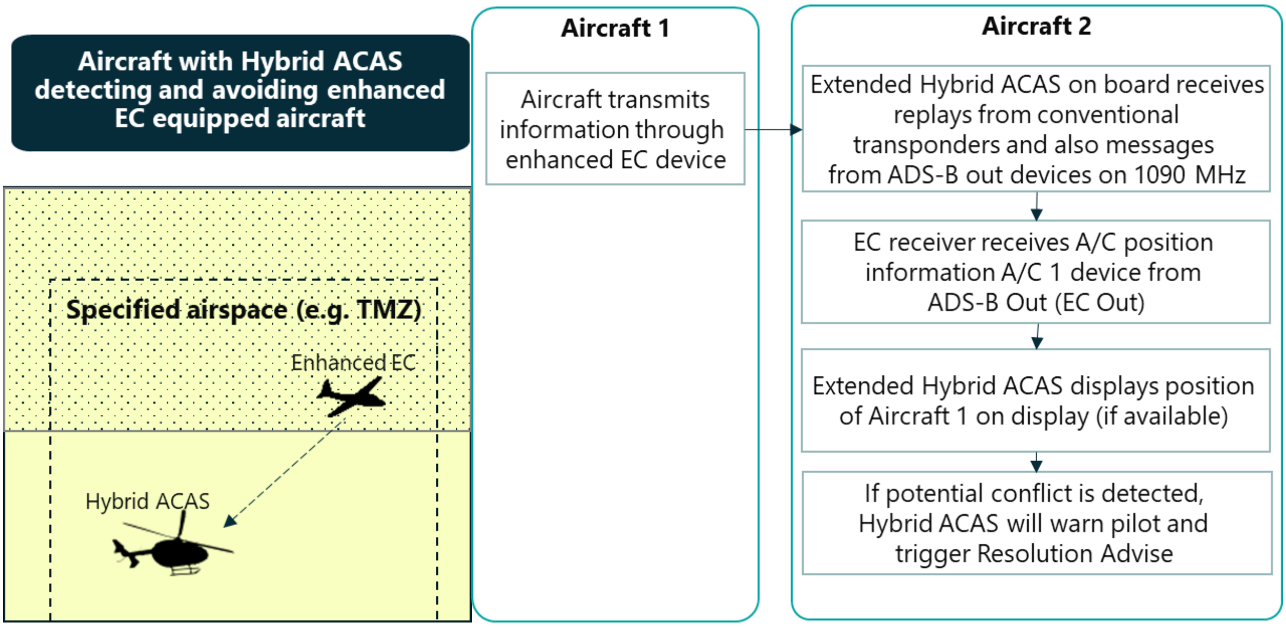


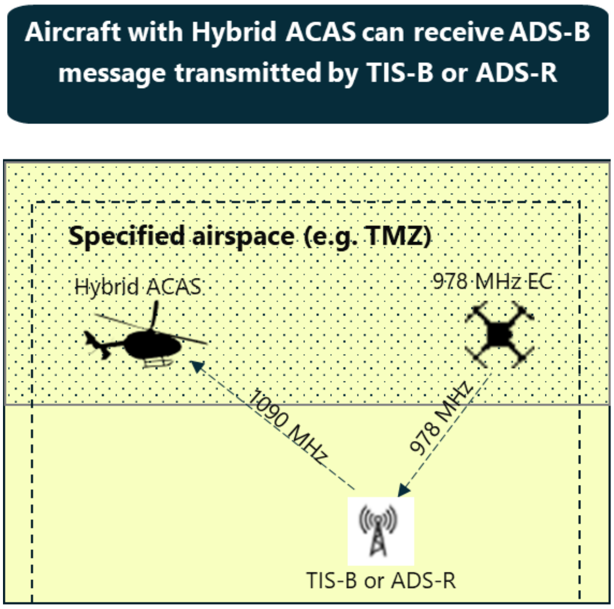
FIGURE 9: MANNED - MANNED COLLISION AVOIDANCE

In this scenario an aircraft equipped with hybrid ACAS is able to receive and utilise data from the enhanced EC device equipped aircraft, including position information, to assess the possibility of conflict trigger resolution advise if required.

R8. Enhanced EC devices shall support ACAS X.

R8a. Enhanced EC devices shall be interoperable with emerging ACAS X standards.

2.4.5.2 - Manned – Unmanned collision avoidance



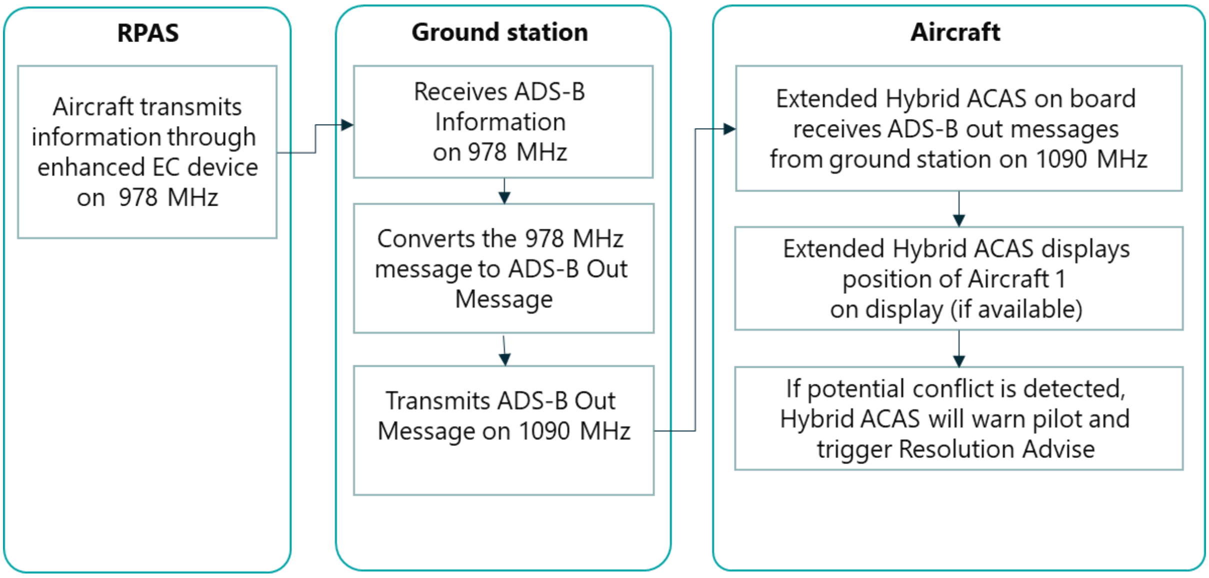


FIGURE 10: MANNED - UNMANNED COLLISION AVOIDANCE

As the Hybrid ACAS is working on 1090 MHz and not on 978 MHz, it would not support air-to-air collision avoidance from an enhanced EC equipped UAS without some additional capabilities:

- The manned aircraft could equip with 978MHz IN capability. This could be a recommendation for enhanced EC devices, and would be logical if services such as FIS-B are deployed on 978MHz. However, manned aircraft outside the TMZ, in controlled airspace, may not be expected to equip with 978MHz IN, but may still want their ACAS to be aware of nearby UAS.
- Therefore a 'middle element' ground re-broadcast function could be used– TIS-B (on 1090 MHz) or ADS-R (converting 978MHz messages to 1090 MHz).

For such an architecture, there would be an impact on application performance requirements, in particular data age (latency). However, given the airspeed of aircraft in question and the nature of the application, it may not be a driving requirement toward the enhanced EC device performance requirements.

This application is considered **out of scope** of the Option 3A approach, as it would negate the spectrum benefits of separating UAS onto 978MHz. Consideration should be given to the potential for manned aircraft to receive 978MHz directly to enable ACAS. Future work, to be considered in the Phase 3 roadmap of this study, could investigate the impact of using 1090MHz ADS-R.

2.4.6 - Situational awareness

Beyond the specified airspace volumes, EC devices should continue to contribute to aviation through supporting situational awareness. There are, furthermore, scenarios where a stakeholder may wish to receive situational awareness data as well as utilising enhanced EC device data. Wherever this is possible, it is important the that the stakeholder is able to identify the source of data to avoid using non-assured information in support of safety services.

R9. Non-assured inputs shall not be conflated with enhanced EC or certified surveillance inputs

R9a. Enhanced EC devices shall not utilise input from non-assured EC devices.
R9b. Enhanced EC or certified inputs shall be identifiable to ATSP systems

2.5 - Supporting infrastructure

2.5.1 - Ground segment

2.5.1.1 - ADS-B reception (including 978MHz)

Controlled airspace will continue to be supported by the extensive network of ATM Surveillance infrastructure operated in the UK. A considerable proportion of this network will be able to receive ADS-B messages transmitted by manned aviation today from either certified or the proposed enhanced EC device in the future, at least those broadcasting 1090MHz. Where reception of unmanned traffic is required (for example to provide ICAO FIS with surveillance in a BVLOS airspace), upgrades to existing stations or deployment of new receivers operating on both frequencies (1090MHz and 978MHz) will be required.

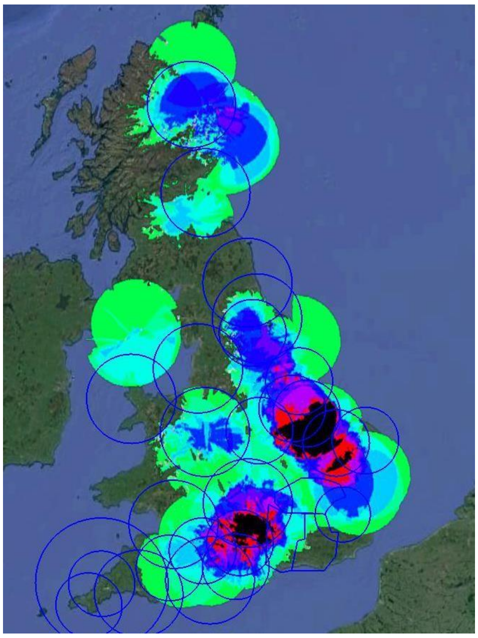


FIGURE 11: ADS-B COVERAGE PROVIDED BY WAM RECEIVERS AT 1000 FT AGL FOR LOW POWER TRANSPONDERS

As is shown in Figure 11, there are significant areas of coverage provided by Wide Area Mulitlateration (WAM)[12] today that would be capable of receiving ADS-B transmissions on 1090MHz but which may not be capable at the same network density of supporting lower-level coverage (I.e., <1000ft) that would meet the needs of the UAS community. Therefore, where this coverage is needed to be provided at a lower level, it will be the ATSP's responsibility to deploy the ground infrastructure to assure coverage and availability. Note the figure is based on 20W transponders, however the coverage limitation at low altitude is driven by terrain rather than transponder range, even considering the lower power for enhanced EC devices proposed in this study.

At the local level, this might mean that an assessment is needed of the horizontal and vertical extents in which a surveillance picture is needed, and the number of ground station receivers specified accordingly.

Asm6. It is assumed that where ATSPs wish to provide a surveillance based ICAO FIS they will include 978MHz coverage.

Where specified airspace volumes are implemented to support BVLOS operations, it is expected that ICAO FIS would be provided. It may be in some deployment cases that the BVLOS UAS operator will be responsible for implementing suitable 978MHz coverage to support their operations. They will likely include 1090MHz coverage to ensure visibility of manned aircraft on their ground systems. In some cases, coverage may be procured as a service from an ATSP rather than implemented supporting ground infrastructure.

In terms of coverage for ground surveillance, line of sight is expected to be the main constraint for an ATSP. Assuming a 10W[13] transmission, with typical antenna value of 3dB gain and a ground-based receiver with 90% Pd at -93dBm, with a 5.5dB antenna gain, and cable losses of 4dBm, the range of an enhanced EC device would be approaching 60NM. These values are not intended to provide a definitive answer to all possible cases, but simply illustrate that transmission power does not need to be aligned with certified ADS-B standards to achieve ranges required by this ConOps. Given the requirement of 20W for CAP1391 devices, and the existence of

---

[12] Coverage of WAM systems is shown because these are in use in the UK and can receive ADS-B for ATS provision.

[13] 10W has been considered as a minimum proposed during consultations. Given CAP1391 20W maybe adopted in practice.

lightweight certified ADS-B transponders designed for UAS, and consultation with STF members, the 10W transmission power is considered to be pragmatic and achievable.

Assuming an antenna height on the ground station of 50ft and aircraft at 1000ft the total radar line of sight is 50NM. This assumes no terrain. The ATSP would also require a level of redundancy within their surveillance network. Overall, for air-to-ground applications line of sight would be the key constraint in designing a network to provide coverage of a specified airspace volume.

2.5.1.2 - Flight information displays

Flight Information Displays (FIDs) provide a level of surveillance display that can be used by FISOs at aerodromes. They are currently solely used as an aid to situational awareness (basic functionality), and do not require any integrity for the data they display. This may change over time as the role and deployment of FIDs matures.

In future, it may be possible to enable a FID to take inputs from enhanced EC devices. These could be shown with unique symbols on the display (based on data decoded from the ADS-B message protocol), to show the FISO that higher quality data was being received. This could still be used as an aid to situational awareness, but would also support provision of ICAO FIS with surveillance (traffic information for avoiding action of conflicts) if used in conjunction with a specified airspace volume TMZ and suitable ground surveillance coverage. Depending on the nature of operations within the airspace, the FISO may filter out the unmanned aircraft.

2.5.1.3 - TIS-B and ADS-B re-broadcast

TIS-B and ADS-R are to be used to provide situational awareness. Typically, this would provide information on airspace users who are not equipped with ADS-B devices, or are equipped with devices on another frequency, as in the case of unmanned aircraft with enhanced EC on 978MHz.

Within the selected option, it is proposed that TIS-B/FIS-B services would be delivered via 978MHz to reduce 1090MHz spectrum occupancy. This would mean manned aircraft could equip with ADS-B IN over 978MHz to benefit from these services, and air-to-air reception of unmanned aircraft EC. The use of 1090 MHz ADS-R is not considered within this proposed solution, but could be studied separately to assess the impact on spectrum if deployed on a local basis for specific use case scenarios.

At the local level, coverage may be needed to support operations within the declared operational coverage of an aerodrome. This would facilitate provision of ICAO FIS within the local area outside of an aerodrome ATZ.

2.5.1.4 - Unmanned Traffic Management systems

In future Unmanned Traffic Management systems may be implemented, and even integrated with ATSP systems. There are a variety of architectures which may ultimately be developed, including the delivery of assured position data exclusively through the C2 link and ground links between stakeholders.

Some DAA concepts even include the possibility of a ground-based element of the conflict avoidance function. In such a scenario it is possible that unmanned aircraft would have little use for devices operating on 978MHz. Such solutions are, however, not based on existing standards, protected aviation spectrum (i.e. they may use mobile frequencies via the C2 link), and, sometimes, air data quality processes. They would therefore require considerable work to achieve safety approval. In contrast, the use of 978MHz for unmanned aircraft relies primarily on existing standards with relatively minor modifications and can make use of existing equipment available in the market, or relatively minor modifications to existing equipment.

2.5.2 - Airborne segment

2.5.2.1 - Overview

This concept of operations proposes no changes to requirements for fitment of avionics outside the equipage of enhanced EC devices to access specified airspace volumes. Furthermore, it does not propose any changes to standards that would alter the requirements for other airborne equipment. Any other equipage would be on a benefits-driven basis.

2.5.2.2 - Certified transponders

Within controlled airspace, users will continue to be required to fit certified transponders (as mandated for given airspace class and type of flight).

Ultimately adoption of ADS-B out/in transponders would have benefits under this concept of operations, as it would improve interoperability between airspace users.

Commercial aircraft are not expected to equip 978MHz IN, and airspace design is expected to remain the main barrier between commercial aircraft and other airspace users. In any case, a UAS would be required to meet standard fitment requirements to enter such controlled airspace. An enhanced EC device, whilst potentially providing incidental benefits in such a scenario, would not be an enabler to access such airspace.

2.5.2.3 - Low powered transponders

Lower power mode-S/ADS-B transponders are available and are proposed for access to controlled airspace on 1090MHz. These are not approved today, as they do not comply with ADS-B standards in regard to transmission power. They do represent a plausible way to enable access to controlled airspace (for example for UAS) whilst limiting the impact on frequency saturation.

These devices serve different applications to those targeted by enhanced EC devices but should remain interoperable due to the use of ADS-B protocol.

2.5.2.4 - ADS-B out

The adoption of ADS-B out amongst airspace users is expected to continue growing. This will be composed of both certified and uncertified (CAP1391) devices.

For most systems (outside of situational awareness) to utilise received ADS-B it is necessary for the device to provide a Source Integrity Level (SIL) >=1. There are a number of ways to achieve this, including ABAS and SBAS. Within the UK, EGNOS Safety Of Life function is not available at present, but the Open Service remains available. Delivery of SIL >=1 is there expected to continue to be practicable. Furthermore, the UKSBAS testbed project is underway, and full SBAS service may become available in future.

ADS-B IN through 978MHz in, would become an option for such devices to receive FIS-B services.

2.5.3 - Transition from the current to future architecture

Detailed timelines will be evaluated in the Phase 3 report of this study. However, there are some important considerations in terms of key transitions for this concept of operations.

Evolution of BVLOS integration

TDAs = segregated airspace

→

TDAs with TMZ benefiting from ICAO FIS with surveillance and entry via DAAIS or DACS

→

BVLOS in a known environment (TMZ with enhanced EC) benefitting from ICAO FIS with surveillance

→

BVLOS carrying out Detect And Avoid

FIGURE 12: EVOLUTION OF SERVICES

The figure above provides a broad overview of the main steps towards enabling BVLOS operations. Presently TDAs are used to segregate airspace and ensure safety of operations.

When enhanced EC devices are available, an intermediate step could be utilising a TDA with a TMZ benefiting from ICAO FIS with surveillance, with published guidance on entering the area. Whilst TDAs are advisory, the TMZ would help ensure a known traffic environment and encourage use of the DACS or DAAIS, creating an effective safety barrier when integrating new BVLOS operations.

Later, TMZs could be used to enable specified airspace volumes to allow BVLOS operations in a known traffic environment without the need for a TDA. This might particularly be the case when BVLOS operations become more commonplace, meaning there is not a unique risk when they operate (as today).

The timing for EC devices to become available will depend upon the necessary regulatory updates (particularly including the introduction of 978MHz EC into UK environment), and the changes required by avionics manufacturers. This could be achievable within the early part of the AMS timeframe. TMZs would allow other airspace users to continue to access the airspace, subject to equipping an enhanced EC device, and benefit from ICAO FIS with surveillance. Such TMZs and TDAs would need to be deployed in accordance with airspace change regulations (e.g. CAP1616) and would potentially take time and effort to implement.

Over time the equipage rate of enhanced EC devices should increase, and the DAA function of UAS (and other associated technology) should mature, allowing for broader deployment of BVLOS with DAA.

2.6 - Roles and responsibilities of stakeholders

2.6.1 - Overview

In general, the introduction of enhanced EC devices should not change the roles and responsibilities of stakeholders within the UK airspace. There are no proposed changes to the responsibilities of either airspace users, or ATSOs. The introduction of enhanced EC devices does provide additional information (together with quality indicators related to that information) that stakeholders can utilise in carrying out their duties.

2.6.2 - Airborne segment

2.6.2.1 - Manned airspace users

There are no proposed changes to the responsibilities of manned airspace users within this concept of operations. Manned aircraft still have a responsibility to identify and avoid other aircraft, enhanced EC devices may provide a situational awareness input to support this, but manned aircraft will not be required to equip with 978MHz IN devices.

This consideration is captured in Asm5.

2.6.2.2 - UAS

UAS will have a responsibility to detect and avoid other airspace users. As noted above the capability of manned aircraft to see and avoid UAS is expected to be lower than compared to other manned aircraft. This infers a degradation in the performance of see and avoid as a barrier to mid-air collision risk. This, in turn, infers a need for detect and avoid to perform better than see and avoid, in order to maintain the overall safety performance of the system.

This consideration is captured in Asm4.

2.6.3 - Ground segment

2.6.3.1 - ATC Officer

Air traffic control remains unaffected by the introduction of enhanced EC devices under this concept. There are some cases where the enhanced EC devices could be visible to ATCOs depending on the configuration of their surveillance systems. However, enhanced EC inputs are not expected to be a input to ACTO operations.

2.6.3.2 - FISO

Enhanced EC devices should provide assured position information into the surveillance chain used by FISOs. The expected use remains situational awareness sufficient to provide beneficial collision avoidance information and avoid nuisance information as described in 2.4.3 -

2.6.3.3 - UAS operators / Remote pilot

UAS operations Beyond Visual Line of Sight are of particular interest to this study, as enhanced EC devices can be an enabler. In such operations the UAS operator (typically assumed to be a remote pilot, but noting that in the longer term there may be some level of automation) will be responsible for detecting and avoiding other airspace users. The safety performance of this detect and avoid function has not yet been identified, and indeed may vary depending upon the specific operation. However:

Asm7. Safety performance of detect and avoid will be at least equivalent to GA safety performance, and likely require better performance.

2.6.3.4 - UTM operators

UTM systems, and their specific role in the future ATM system is not defined and agreed. At present some UTM systems are deployed to coordinate UAS flight plans in the vicinity of airports. In future, enhanced EC could provide an assured input to surveillance driven functions of UTM systems. These functions could range from simply monitoring that a UAS is conforming to its flight plan, through to provision of an automated separation service for UAS. In either extreme, the UTM system would require assured surveillance data to provide the function, and the enhanced EC devices should support this in order to be "future proof".

2.7 - Summary of requirements

Table , below, provides a consolidated list of the Requirements captured from the use case analysis above. It should be noted that these requirements are not exclusively operational requirements. Requirements include operational, identified directly from the use case, and inferred or derived requirements, which identify the demand placed on the enhanced EC devices by the parent operational requirement. The latter are captured as functional or performance requirements.

TABLE 2: COLLATED OPERATIONAL REQUIREMENTS

ID	Requirement	Service	Req. Type
R1	Enhanced EC devices should enable access to class D, and the AMS "dynamic" airspace.	Access to airspace	Operational

ID	Requirement	Service	Req. Type
R2	Enhanced EC devices should support the monitoring of traffic for airport ATZs with IFPs or PINS approaches.	Access to airspace	Operational
R2a	Enhanced EC devices should have a range comparable to the size of airport DOCs.	Access to airspace	Performance
R3	Enhanced EC devices shall provide the required data to support ICAO FIS surveillance.	Enhanced ICAO FIS	Operational
R3a	Enhanced EC devices shall provide positive identification of the aircraft.	Enhanced ICAO FIS	Functional
R3b	Enhanced EC shall provide assured position.	Enhanced ICAO FIS	Functional
R3c	Enhanced EC devices shall provide barometric altitude derived level information.	Enhanced ICAO FIS	Functional
R3d	Enhanced EC devices shall provide sufficient data performance and quality for an ATSO to provide beneficial collision avoidance information and avoid nuisance information.	Enhanced ICAO FIS	Performance
R4	The ATS provider shall have sufficient surveillance coverage for the specified airspace volume.	Enhanced ICAO FIS	Operational
R4a	Enhanced EC devices shall have range sufficient to be detectable by typical ADS-B ground stations with a reasonable network density over the specified airspace volume.	Enhanced ICAO FIS	Performance
R5	When using EC input, DAA systems shall only use data from enhanced EC devices with known performance.	DAA	Operational
Error! Reference source not found.	The position and velocity data provided by enhanced EC devices shall be assured	DAA	Functional
R5b	Enhanced EC devices shall provide sufficient data for the receiver to calculate a containment bound on the reported position	DAA	Functional
R6	Unmanned aircraft shall detect and avoid manned aircraft.	DAA	Operational
R6a	Enhanced EC devices used by unmanned aircraft shall include 1090MHz ADS-B reception.	DAA	Functional
R7	Unmanned aircraft shall perform detect and avoid CA function even in the absence of C2 link with no degradation in assurance.	DAA	Operational
R7a	Enhanced EC devices used by unmanned aircraft shall not rely upon ground based reception of 1090 MHz ADS-B and relay	DAA	Functional
R8	Enhanced EC devices shall support ACAS X.	Hybrid ACAS	Operational

ID	Requirement	Service	Req. Type
R8a	Enhanced EC devices shall be interoperable with emerging ACAS X standards.	Hybrid ACAS	Functional
R9	Non-assured inputs shall not be conflated with enhanced EC or certified surveillance inputs	Situational awareness	Operational
R9a	Enhanced EC devices shall not utilise input from non-assured EC devices.	Situational awareness	Functional
R9b	Enhanced EC or certified inputs shall be identifiable to ATSP systems	Situational awareness	Functional

2.8 - Assumptions

Table , below, provides a consolidated list of the assumptions captured from the use case analysis above.

TABLE 3: CONSOLIDATED ASSUMPTIONS

ID	Requirement	Service
Asm1	3NM/1000ft separation standards are assumed to be an upper bound to the required surveillance performance for ICAO FIS with surveillance.	Enhanced ICAO FIS
Asm2	Spaced-based EC reception is not suitable for providing coverage of the enhanced EC devices in this study.	Enhanced ICAO FIS
Asm3	The ability of pilots to see and avoid unmanned aircraft will be lower compared to manned aircraft.	DAA
Asm4	There will be a greater reliance on the capability of DAA to enable unmanned aircraft to take avoiding action compared to see and avoid.	DAA
Asm5	DAA introduces no change in the rules of the air – a pilot should still take appropriate action if they see an unmanned aircraft.	DAA
Asm6	It is assumed that where ATSPs wish to provide a surveillance based ICAO FIS they will include 978MHz coverage.	Ground surveillance
Asm7	Safety performance of detect and avoid will be at least equivalent to GA safety performance, and likely require better performance.	UAS operations

3 - DETAILED SUR SPECIFICATIONS

3.1 - Considerations for performance requirements

The use case analysis above derives a set of high-level requirements that apply to enhanced EC devices to support the applications (operational services) under Option 3A. Although they are qualitative requirements, they provide a basis for a simplified, first principles analysis of the required performance of enhanced EC devices.

It is beyond the scope of this study to develop the full collision risk model and operational performance assessment (and related safety analysis) to be able to show top-down derived functional and performance requirements. Instead, in combination with identified upper and lower bound benchmark standards, this high-level analysis provides a level of confidence in the performance requirements identified in section 4.2.

In all use cases, the safety driver for enhanced EC device performance is ultimately supporting mitigating Mid-Air Collision (MAC) risk. Enhanced EC devices are not claimed to be a sole solution for mitigating MAC risk, and instead merely contribute to part of the overall system of air traffic management which comprises everything from airspace design and flight planning, training, procedures, communication and rules of the air, to safety nets.

3.2 - First principles analysis

In all use cases, there is some form of *interaction* between two aircraft. The expected future 4D position of the two aircraft is within some boundary to trigger the consideration of mitigating action. Expanding on the previous statement: the volume of uncertainty (or the probability distribution) of the expected future position of one aircraft intersects a pre-defined protection boundary distance (which may vary by dimension) around the volume of uncertainty of the predicted future position of another aircraft. It is noted that currently in class G, under see and avoid, this boundary may in fact be entirely dependent on the perception of risk for a given pilot.

Figure 13 below visualises this situation, showing the predicted tracks of a green aircraft and an orange aircraft. One aircraft is depicted in green with its pre-defined boundary in yellow, the other aircraft is depicted in orange with a dashed line representing a potential mitigating action it could take (noting that other mitigating actions such as changing altitude could be taken).

The uncertainty grows the further ahead in time a prediction is made (hence the cone shapes), and there is a circular area can be identified within which the aircraft has a certain probability of being located. In practice this will be some form of probability distribution within the area and there would be a probability distribution associated with the vertical position. The performance of the positioning system affects the size of this probability distribution.

This scenario considers the interaction of a manned aircraft (green) and UAS (orange). The UAS is assumed to have detected the manned aircraft through enhanced EC data, while the manned aircraft is assumed to be unaware of the UAS.

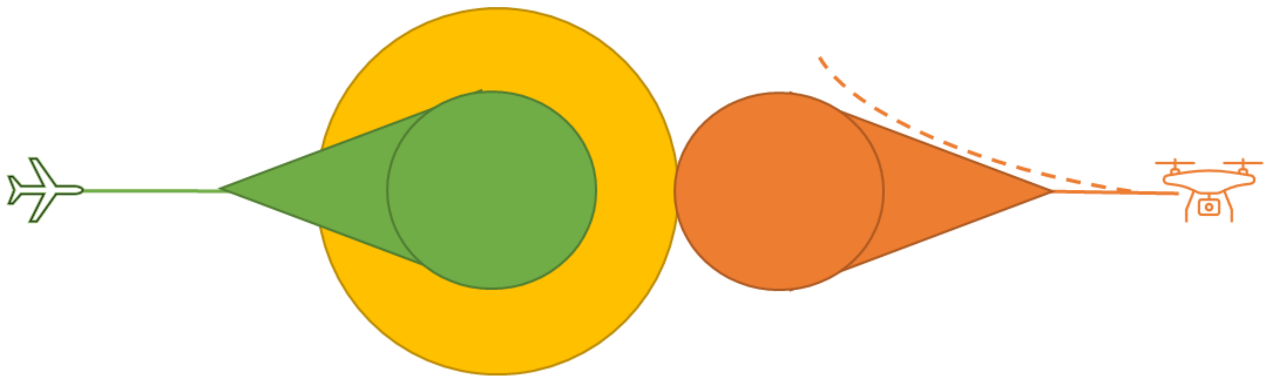


FIGURE 13: SIMPLIFIED INTERACTION DIAGRAM

There are a great many factors which influence the size of the protection boundary, including the uncertainty surrounding the aircraft's predicted future position (including position accuracy errors). Considering the two extremes for this uncertainty:

1) The uncertainty is unbounded (as is presently the case for situational awareness EC devices). In this case, no services can be provided until the uncertainty has been resolved (e.g. by visual detection and observation of the aircraft).
2) The information is perfect (which may be theoretically possible with some future technology but is by no-means practical). In such a case the boundary could be set by, for example, wake vortex minima.

Clearly in practice, both in terms of delivering services with a reasonable safety margin, and in terms of achievability, the boundary would need to be somewhere between the two extremes. A practical example can serve to help quantify a reasonable uncertainty performance.

Many UK airprox reports in class G over recent years involve an interaction (proximities sub-100m) between a manned aircraft (such as PA28, paragliders and Learjets) and an UAS resulting in an ICAO risk classification of C (examples airprox reports include: 2022037, 2022034, 2021252, 2022006). These cases include UAS operating outside the airspace they are authorised to enter, and users of enhanced EC are expected to be flying in accordance with the rules of the air. Nonetheless they provide for a benchmark:

- Proximity < 100m/300ft considered worthy of reporting.
- Manned VFR aircraft travelling below 150kts.
- UAS effectively stationary (in practice a UAS velocity of 50kts is assumed as this represents a realistic case when a UAS is flying a commercial BVLOS mission).

A Eurocontrol assessment as part of the ACAS Guide[14] highlights that for TCAS II the caution area represents 20-48 seconds of flight, and a warning area (with resolution advisory) relates to 15-35 seconds of flight depending upon the altitude. Although not directly comparable, it provides a benchmark to populate elements of Figure 13.

When considering the applications enhanced EC devices will support, the more tactical (less strategic) will have the most demanding requirement for the size of the uncertainty. This represents a scenario whereby, for whatever reason, more strategic actions have failed to result in adequate separation of the aircraft, and a DAA conflict avoidance action is activated.

It is therefore logical to consider the DAA conflict avoidance functions to be comparable to the TCAS II warning area, i.e. assuming 15 seconds of flight in the most demanding case. Assuming a manned aircraft flying at 90kts and a UAS flying at 50kts in a head-on geometry, this would translate 1080m (0.6NM) + 2rU (the uncertainty around both aircraft's position) + 100m (the proximity buffer) since the predicted interaction would be detected when the leading edge of the uncertainty intersects protection boundary, not when the aircraft are exactly 15 seconds ahead of an interaction.

[14] https://skybrary.aero/sites/default/files/bookshelf/1783_0.pdf

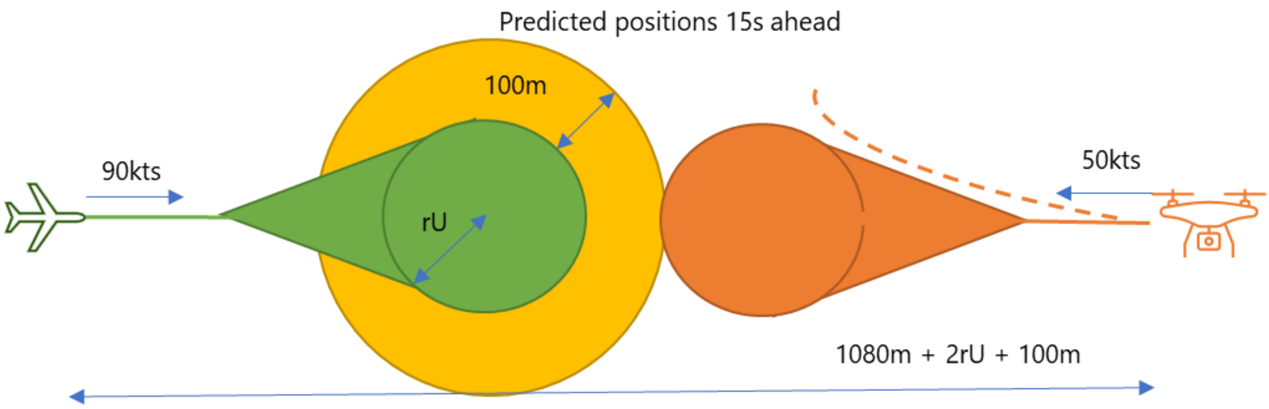


FIGURE 14: SIMPLIFIED INTERATION WITH EXAMPLE DIMENSIONS

With the values input, a value for the radius of Uncertainty (rU) can be established, noting that the smaller the rU is, the fewer nuisance alerts will be generated.

The following parameters influence the boundary of uncertainty over a future position:

- Navigation System Error, of which there are primary contributing factors:
  - Position accuracy (horizontal and vertical) – can be qualified by Navigation Accuracy Category (Position)
  - Position integrity – can be qualified by Navigation Integrity Category (NIC)
  - Data age/latency (influenced by update rate and probability of detection)
- Intent – beyond providing velocity, a surveillance system cannot provide information on intent.
- Flight Technical Error – a surveillance system cannot provide information on flight technical error.

NIC (in combination with SIL) and NACp provide a set of relevant performance parameters and a selected set are shown below:

TABLE 4: NIC AND NCAP VALUES AND CORRESPONDING PERFORMANCE

NACp	Estimated position uncertainty	NIC	Containment Radius
8	<0.05 NM (93 m)	9	<75m
7	<0.1 NM (185 m)	8	<0.1 NM (185 m)
6	<0.3 NM (556 m)	7	<0.2 NM (370 m)
5	<0.5 NM (926 m)	6	<0.5 NM (926 m)
4	<1.0 NM (1852 m)	5	<1.0 NM (1852 m)
3	<2 NM (3704 m)	4	<2 NM (3704 m)

- Navigation Accuracy Category – position (NACp) – reports the estimated position uncertainty, giving a boundary the aircraft has a 95% probability of being positioned within, e.g. NACp = 5 means the actual position of the aircraft is expected to be within 0.5NM of the measured position 95% of the time.
- Navigation Integrity Category (NIC) – specifies the containment radius associated with horizontal position data, this is provided in conjunction with the SIL (see next bullet), e.g. NIC = 5 means the radius is less than 1NM.
- Source Integrity Level (SIL) – complements the NIC and gives the probability that the actual position is outside the reported containment radius, e.g. NIC 5 and SIL =1 means there is a 0.1% probability that the actual position of the aircraft is more than 1NM from the measured position.

Compared to Figure 14, these values can drive a known[15] value for rU that can be specified, subject to flight technical error or change in intent, and assuming suitable performance regarding data age and latency. It can be intuitively identified from the dimensions on the diagram, that a NACp≤6 or NIC≤6 (SIL=1 is assumed to be the maximum feasible performance given the intended low cost nature of the enhanced EC devices) would be problematic, as the uncertainty would entirely dominate the activation of the CA function, and could result in many nuisance alerts. Taking NIC=6 as an example, would make rU a minimum of 926m, meaning the measured (based on reported positions) distance between the aircraft would be at least 3000m (corresponding to 42 seconds of flight time), whilst still predicting a proximity bust within 15 seconds.

A 2015 study by NATS on ADS-B performance in general aviation[16] assessed a horizontal performance error of ~44m (mean) and a standard deviation of ~45m for GA ADS-B devices when excluding a very small set of outliers. This indicates that a NACp of 7 (corresponding to 185m 95%) is realistically achievable.

Conversely, existing standards for devices typically only specify a requirement for NIC/NACp≥6. It is recognised that requiring NIC significantly greater than 6 would be difficult to justify. Therefore, a NACp = 7 would seem to provide a realistic requirement for minimum enhanced EC device performance, to meet the most demanding applications assessed in this study and be achievable.

It is noted with the environment and use cases considered for the enhanced EC performance that a wide range of conflict geometries are possible, particularly considering the speed of approach between own-ship and conflicting aircraft. Whilst UAS may be almost stationary, military aircraft or jets may be travelling at 250kts+. The design parameters of the future system (for DAA and potentially manned aircraft collision avoidance tools) will need to make decisions on the envelopes of conflicts they are designed to deal with.

Clearly, this analysis only outlines the possible calculations. A proper operational performance assessment should be carried out, with a collision risk model developed to help understand the likely impacting factors. EUROCONTROL's Specification for ATM Surveillance System Performance (using benchmarking to existing radar surveillance norms supporting 3 and 5NM separation services) and the GEN-SUR SPR (Surveillance Safety and Performance Requirements, using more top-down analyses) help show approaches to achieve this.

3.3 - Functional and performance requirements derivation

Based on the collated operational requirements derived from the use case analysis, this section derives high level functional and performance requirements applicable to the enhanced EC devices. At this stage, requirements are identified at qualitative or order of magnitude detail.

This allows the identification of deltas between the required function and performance of enhanced EC devices and the existing specifications within standards in the UK framework. A roadmap to fully quantify these requirements and update the standards as necessary will be developed in Phase 3.

Function/Performance area	Driving requirement	Inferred EC device requirement
Data elements		
Identity and Category	R3a Enhanced EC devices shall provide positive identification of the aircraft.	ICAO 24bit address, or UAS identity
Position	R3b Enhanced EC shall provide assured position.	Geometric horizontal position in line with ED-102B
Altitude	R3c Enhanced EC devices shall provide barometric altitude derived level information.	Barometric, In line with ICAO Annex 10, Vol. IV, ED-102B
Containment bound	R5b Enhanced EC devices shall provide sufficient data for the receiver to	Quality indicators (NIC/SIL)

[15] In the sense that the probability of exceeding that value through navigation system error will be below a certain associated value.

[16] https://nats.aero/blog/wp-content/uploads/2016/03/GA-ADS-B-GPS-Trial-report.pdf

Function/Performance area	Driving requirement	Inferred EC device requirement
	calculate a containment bound on the reported position.	
Velocity	R5b Enhanced EC devices shall provide sufficient data for the receiver to calculate a containment bound on the reported position.	Airborne velocity in line with ED-102B
Aircraft operational status	R3d Enhanced EC devices shall provide sufficient data performance and quality for an ATSO to provide beneficial collision avoidance information and avoid nuisance information.	Aircraft operational status in line with ED-102B
Data Quality		
ATSPs must satisfy their SMS processes. At present there are no agreed standards for enhanced ICAO FIS with surveillance and IFACTA have raised concerns about this. In the absence of a top-down analysis of requirements, we have used the following assumption to derive a driving requirement set. Using existing standards will provide the fastest way for ATSPs to implement the services. **Asm1** 3NM/1000ft separation standards are assumed to be an upper bound to the required surveillance performance for ICAO FIS with **surveillance.** ED126 provides airborne requirements for 3NM/1000ft separation. These are based on a body of analysis which cannot be replicated in this study, and are therefore taken as a baseline, representing the most stringent possible performance requirements in the case where the enhanced EC device provides the sole source of surveillance data. This provides an upper bound on the performance requirements. The most lenient requirements would be those representing the lowest performance device that still provides assured position data (which is required for delivery of enhanced ICAO FIS with surveillance, and by DAA systems). In terms of global precedent, the TABS device specification provides a suitable benchmark for this lower bound on the performance requirements.		
Horizontal Position Accuracy	R3d Enhanced EC devices shall provide sufficient data performance and quality for an ATSO to provide beneficial collision avoidance information and avoid nuisance information.	<0.3NM 95% (NACp ≥ 6) Can be derived from HDOP First principles requirement: NACp = 7 NIC = 6 SIL = 1
Vertical Position Accuracy	R3d Enhanced EC devices shall provide sufficient data performance and quality for an ATSO to provide beneficial collision avoidance information and avoid nuisance information.	Aligned with ICAO annex 10 (125ft) Pressure altitude required for ATS
Horizontal Velocity Uncertainty	**Error! Reference source not found. Error! Reference source not found.**	<10 m/s 95% (NACV ≥ 1) NACV = 1
Update rate	R3d Enhanced EC devices shall provide sufficient data performance and quality for an ATSO to provide beneficial collision avoidance information and avoid nuisance information.	Up to 2Hz (0.5s)

Function/Performance area	Driving requirement	Inferred EC device requirement
	ADS-B allows for 0.2 – 2Hz depending on the message type and phase of flight. The optimal transmission rate depends upon the probability of detection, density of ground network and number of simultaneous airspace users. At this stage there is no obvious justification for deviating from ADS-B standards.	
Data age/latency	R3d Enhanced EC devices shall provide sufficient data performance and quality for an ATSO to provide beneficial collision avoidance information and avoid nuisance information.	< 1.5s 95% (airborne transmit domain of horizontal position and quality indicators) No requirement
Range	R2a Enhanced EC devices should have a range comparable to the size of airport DOCs.	Power ~= 10W Suitable antenna guidance needed to ensure probability of reception, whilst balancing cost implications compared to a fixed antenna installation.
	Typical DOC = assumed to be 15-20NM.	
Integrity	R3d Enhanced EC devices shall provide sufficient data performance and quality for an ATSO to provide beneficial collision avoidance information and avoid nuisance information.	1e-5 of >1.0 NM per flight hour (NIC ≥ 5 & SIL ≥ 2) 1e-03 of being >0.5NM per flt hr (NIC=6 & SIL=1)[17] Time To Alert of <2s (for non-0 qual. indicator)
Continuity	R3d Enhanced EC devices shall provide sufficient data performance and quality for an ATSO to provide beneficial collision avoidance information and avoid nuisance information.	2e-04 per flight hour unavailability during an operation No requirement
System Design Assurance	R3d Enhanced EC devices shall provide sufficient data performance and quality for an ATSO to provide beneficial collision avoidance information and avoid nuisance information.	SDA ≥ 2 SDA = 1

[17] *Whilst this figure is important to the results, the ultimate value needs to be driven by a safety analysis for the supported applications, but this study didn't have access to the analysis for TABS to be able to compare effectively. The roadmap will therefore include an activity to address this.*

4 - GAP ANALYSIS

The operational requirements gathered in Section 2 were translated into the performance and interoperability requirements for the enhanced EC device. The requirements were compared with the existing UK regulatory framework, and if the existing national regulatory framework or mandated standards are not sufficient to cover the requirements, globally recognised standards or recommendations have been identified which could be transposed into UK standards and thus fill the regulatory gaps.

4.1 - Frequency management

The UK Frequency Allocation Table, managed by Ofcom, assigns the frequency range 960-1164 MHz to Aeronautical Mobile and Aeronautical Radio navigation Services and the 978 MHz frequency could be made available for use by enhanced EC devices.

To avoid any future interference issues, the 978 MHz band should be specifically assigned to UAT services covering UAT ADS-B, TIS-B and FIS-B. This would require consideration of the Programme Making and Special Events frequency sharing agreement and review of existing guard bands that that agreement put in place. Similarly, an impact assessment on DME and JTIDS provision will be required. In future, if LDACS is considered for adoption, an impact assessment may need to be considered.

As an example, FAA Order 6050.32B Spectrum Management and Procedure Manual could be used to ensure that the necessary UAT bandwidth is reserved for the planned services to be applied in a safe and effective manner.

4.2 - EC Devices

The current CAP1391 considers only use of 1090 MHz ADS-B and does not cover frequency on which the UAT protocol is applied (978 MHz). A new standard would need to be defined to enable enhanced EC devices, and the usage of the new 978 MHz frequency will need to be incorporated, or a new CAP defined.

CAP1391 EC defines minimum requirements on EC devices derived from existing standards. As the EC devices are not certified, there are only general installation requirements and specifications in the CAP. To achieve some of the Enhanced EC device goals, certain system elements may need to be certified and therefore additional certification standards may need to be introduced, as well as installation guidance and requirements.

Depending on the final decision regarding certification of the Enhanced EC device or its components, new installation and certification standards may need to be developed and mandated. The following installation and certification standards could be mandated or transposed into UK standards:

- CS-STAN Certification Specifications for Standard Changes and Standard Repairs, Issue 3
- CS-SC002c - Installation of Mode S elementary surveillance equipment
- CS-SC004a - Installation of antennas
- CS-SC005a - Installation of an ADS-B OUT system combined with a transponder system
- CS-SC058a - Installation of traffic awareness beacon system (TABS) equipment
- FAA AC 20-164A Designing and Demonstrating Aircraft Tolerance to Portable Electronic Devices FAA
- FAA AC 20-165B Airworthiness Approval of Automatic Dependent Surveillance - Broadcast OUT Systems
- FAA AC 20-172B Airworthiness Approval for ADS-B In Systems and Applications
- FAA AFS-360_2016-03-02 Installation Approval for ADS-B Out Systems
- FAA AFS-360-2017-1 Installation of ADS-B OUT Equipment
- DO-307A Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance
- DO-294C Guidance on Allowing Transmitting Portable Electronic Devices (T-PEDs) on Aircraft.

4.3 - Enhanced EC GNSS sensor

CAP 1391 defines three categories of EC devices – basic, intermediate and full. While basic and intermediate category devices are allowed to utilise the non-qualified GPS/GNSS sensors and 'full' category assumes that GNSS sensor is fully compliant with SPI IR.

To meet the drivers for Enhanced EC device definition, the GNSS sensor within the EC device should be capable to provide minimum data elements and containment bound. This would be necessary for instance to support:

- Aircraft visibility to ATCO / FISO providing services in Class D airspace or ICAO FIS with surveillance support
- Aircraft visibility to other aircraft equipped with hybrid ACAS.

CAP 1391 in Section 6.15 and 6.16 defines the minimum features for EC device as required for Class A0 transponders in EUROCAE ED-102A. However, the existing minimum requirements may not be sufficient for separation services in Class D terminal areas and should provide additional data items and additional features.

Therefore, the new minimum data element, performance and interoperability requirements on GNSS sensors for enhanced EC device should be determined considering the surveillance requirements for Airspace Class D and interoperability with hybrid ACAS.

For this purpose, ED-102B MOPS for 1090 MHz Extended Squitter ADS-B and TIS-B and DO-242 MASPS for ADS-B could be used considering ED-232 - Safety and Performance and Interoperability Requirements document for Traffic Situation Awareness with Alerts (TSAA) and ED-194B - Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications (ASA) System

SC-159, Navigation Equipment Using the Global Navigation Satellite System (GNSS) SC-159 has produced and maintained a suite of minimum operational performance standards (MOPS) and minimum aviation system performance standards (MASPS) for aviation equipment using the Global Positioning System (GPS) as augmented by aircraft-based, ground-based, and satellite-based augmentation systems (ABAS, GBAS, and SBAS, respectively) as defined by the International Civil Aviation Organization (ICAO).

4.4 - Aircraft operations

Currently, aircraft operations are regulated by UK reg (EU) No 965/2012 Air Operations Regulation. The introduction of enhanced EC on UAT 978 MHz frequency and new TIS-B and FIS-B services may induce a need for complementary rules.

As the use of UAT for manned operations already been introduced in USA, the inspiration for the aircraft operation regulations could be taken from FAA AC 90-114B Automatic Dependent Surveillance-Broadcast Operations.

4.5 - UAT

UAT for UAS operations, TIS-B and FIS-B services will become new elements in UK aviation environment. As the UAT based services have not been used, there is a clear gap in national regulatory framework. The only existing material which could be used in UK are ICAO Annex 10, Vol. 3 SARPS which provide minimum set of requirements for UAT and additional requirements will be needed to ensure successful implementation of the UAT into operations for instance:

- Missing European MOPS for Universal Access Transceiver (UAT) ADS-B
- UAT avionics requirements
- UAT performance requirements and.
- UAT certification specifications

To fill the gaps, the following standards could be mandated or used for the development of national standards:

- ICAO Doc 9861 – Manual on the Universal Access Transceiver (UAT)
- TSO-C154c - UAT ADS-B equipment operating on frequency of 978 MHz and

- RTCA DO-282B, Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance — Broadcast.

4.6 - ADS-B Out devices

The valid CAP 670 Air Traffic Services Safety Requirements specifies operational and interoperability requirements on ADS-B Out devices. However, the CAP defines only general installation requirements and certification specifications requirements which are related to 1090 MHz only devices.

With introduction of EC devices working on UAT frequency of 978 MHz, the CAP will need to be amended considering the new devices working on 978 MHz, their interoperability and interactions with 1090MHz devices. Additionally, UAT ADS-B equipment certification standards will need to introduce complementary requirements for ADS-B Systems with 978 MHz frequency

To achieve that, TSO-C154c - UAT ADS-B equipment operating on frequency of 978 MHz can be mandated and FAA AC 90-114B Automatic Dependent Surveillance-Broadcast Operations could be transposed into UK regulatory framework.

4.7 - ADS-B IN receivers (TIS-B, FIS-B)

EUROCAE ED-102A defines MOPS for TIS-B and which is mandated in UK, but the latest version of the document is ED-102B. However, there are no UK specific standards for FIS-B avionics besides ICAO Annex 10 SARPS. Therefore, the missing FIS-B requirements will need to be developed and published to allow utilisation the new FIS-B digital services by airspace users.

The missing FIS-B avionics operational and performance requirements can be derived from the RTCA DO-267A, MASPS for Flight Information Services Broadcast (FIS-B) Data Link as this service has been in operation in US for several years.

4.8 - UAS

CAP722 Unmanned Aircraft System Operations in UK Airspace does not consider use of the 978 MHz devices for UAS operations. Therefore, before the EC device on UAT frequency is introduced, the CAP722 should be updated considering the usage of EC devices and also potential TIS-B and FIS-B services provided on 978 MHz.

4.9 - ICAO FIS surveillance requirements

Currently, the main CAP dealing with Flight Information Services is CAP 774, which defines the UK FIS. Additionally, CAP 670 Air Traffic Services Safety Requirements which provides the specifications for ATS surveillance systems and, as with ICAO, it draws no distinction between the requirements of a system used to support the establishment of ATC separation and a system used only to support the provision of FIS. CAP 797 Flight Information Service Manual provides operating procedures for FISOs. These CAPS do not define minimum data elements requirements or minimum quality / performance requirements on data items for FIS. Minimum requirements would be useful to determine the performance and interoperability requirements on the enhanced EC device which should support provision of the full ICAO FIS.

Unfortunately, presently there are no globally available standards, which could be used for ICAO FIS with surveillance support. Therefore, the minimum standards still need to be determined.

To define the minimum performance requirements for FIS service, separate safety analysis would be required, and the following documents could be considered to support the development of a minimum FIS surveillance quality and performance requirements:

- GUID-147 EUROCONTROL Specification for ATM Surveillance System Performance
- ED 126/DO-303 Safety, performance and interoperability requirements for ADS-B NRA application
- EUROCAE ED-161 Safety Performance and Interoperability Requirements for ADS-B in Radar Airspace

- ICAO Circular 326 - Assessment of ADS-B and Multilateration Surveillance to Support Air Traffic Services and Guidelines for Implementation (Cir 326 AN/188) – noting that this circular will be withdrawn soon and relevant information will be included in new documents under development.
- CS-ACNS Certification Specifications and Acceptable Means of Compliance for Airborne Communications, Navigation and Surveillance,

The following tables summarise the airborne and ground domain requirements for 3NM terminal separations as defined by ED126.

TABLE 5: ED 126 AIRBORNE DOMAIN REQUIREMENTS (3NM TERMINAL SEPARATIONS)

Parameter	Requirement
Horizontal Position Accuracy	For 3NM separation, the 95% accuracy of the horizontal position measured at D shall be less than 0.3 NM (i.e. NACP ≥ 6)
Altitude Accuracy	Altimeter accuracy - including accuracy of measurement and accuracy of reported value through use of encoding - shall be at least as good as Mode C provisions in ICAO Annex 10 which specifies 38.1m (125ft). Note: These are minimum accuracy requirements for altimeters, and are dependent on the type of airspace. Many airspace regions, such as RVSM, will require better altimeter performance than specified in this table.6
Position Integrity	For 3NM separation, the likelihood that a position error exceeds the maximum 1.0 NM containment radius without detection shall be less than 1e-5 per flight hour. (i.e. NIC ≥ 5 & SIL ≥ 2)
Position Integrity	The time to alert regarding a change of the position quality indicator value shall be no more than 10s when the new value is 0, and no more than 2s in other cases Note: For equipment and circumstances where the values above cannot be met, a more detailed safety analysis will be required for considering the simultaneous loss of integrity together with a transmitted erroneous position.
Continuity	The probability that the Aircraft Domain is unavailable during an operation, given that it was available at the start of the operation, shall be no more than 2e-04 per flight hour. *Note: This value for continuity corresponds to a Mean Time to Failure of 5,000 flight hours. It is intended to be commensurate with typical values for single thread transponders.*
Integrity	The likelihood that the Aircraft Transmit Domain corrupts ADS-B information shall be no more than 1e-05 per flight-hour *Note: This integrity requirement represents the probability that the avionics introduce errors into the data to be transmitted. The integrity of the position information itself (i.e. containment radius) is specified in Tables 1 and 2 above.*
Latency	The Airborne Transmit Domain shall have a 95% latency of 1.5s or less for horizontal position and quality indicators
Latency	For barometric altitude, aircraft identification, mode A code, SPI and Emergency indicators, the Airborne Transmit Domain shall have a latency no greater than specified in current implementations for SSR

TABLE 6: ED 126 GROUND DOMAIN REQUIREMENTS (3NM TERMINAL SEPARATIONS)

Parameter	Requirement
Data Integrity	The likelihood that the ADS-B receive subsystem corrupts ADS-B information through the reception, processing or delivery of data (E2) shall be no more than 5e-6 per ATSU hour *Note 1: This integrity requirement represents the probability that the ADS-B Receive subsystem introduces systematic errors into the data transmitted via ADS-B Messages to the extent that the errors become operationally relevant to the Controller.* *Note 2: Since this document assumes that the functions of the ATC automation system remains largely unchanged from the radar environment, this requirement focuses on the delivery of incorrect data that would produce undetected errors on the ATC display.*
System Reliability	The likelihood that ADS-B Receive subsystem does not provide updated ADS-B surveillance reports for more than one aircraft from which ADS-B messages are being received shall be no more than 5e-6 per ATSU hour.
	The likelihood that the ADS-B receive subsystem does not provide updated ADS-B surveillance reports for one aircraft from which ADS-B messages are being received shall be no more than 1e-04 per ATSU-hour.
Latency	The 95% latency for ADS-B Surveillance Reports (measured between points D- Transmission from the aircraft and E2- reception of ADS-B Surv Report by ground system) shall be no greater than 0.5s
Time of Applicability Accuracy	The time of applicability conveyed in the ADS-B Surveillance Report shall have a absolute accuracy relative to UTC of +/- 0.2 seconds or less.
	Each type of ADS-B Surveillance Report (i.e. containing position, identity and/or Emergency/SPI data) shall contain a time of applicability (Interface E2).
Update Interval	The update interval (as defined in section 3.2) for Surveillance Reports containing any new ADS-B Position data associated with any single aircraft shall be less than 5s with a probability of 95%
	The update interval (as defined in section 3.2) for Surveillance Reports containing only ADS-B Identity data associated with any single aircraft shall be less than 100s with a probability of 95%
Time to alert	The time to alert for a change in surveillance Emergency/SPI reports measured at point E2 shall be no longer than 5s for TMA.

4.10 - Ground surveillance sensors

The existing CAP670 Air Traffic Services Safety Requirements considers cooperative surveillance systems working on 1090MHz. With introduction of the 978 MHz devices used by UAS, the ANSPs or Surveillance Service Providers where UAS operations will be integrated into manned aircraft operation will gradually need to install surveillance sensors capable to detect UAS utilising UAT ADS-B.

To do so, CAP670 will need to be amended to allow installation and usage of surveillance sensors working on 978 MHz. It will also need to consider minimum requirements for UAS surveillance to ensure safety and efficiency of provided services.

To define the UAS surveillance requirements RTCA DO-381 MOPS for Ground-based Surveillance System (GBSS) for Traffic Surveillance implemented with UAS could considered as a baseline and tailored to UK specific environment.

4.11 - Flight Information Display

Currently there are two CAPS defining requirements on Flight Information Display - CAP 670 Air Traffic Services Safety Requirements and CAP 797 Flight Information Service Manual.

The existing display requirements allow for the display of non-certified EC device information with symbols representing data quality, owing to the December 2021 amendment. A further amendment would be required to accommodate the display of enhanced EC device data supporting ICAO FIS with surveillance.

To develop requirements on Flight Information Display, DO-381 standards on MOPS for Ground-based Surveillance System (GBSS) for Traffic Surveillance implemented with UAS, could be considered.

4.12 - FIS-B

The existing UK regulatory framework does not cover provision of FIS-B services. The only regulatory provisions are provided in ICAO Annex 10, Vol. IV, Chapter 7, which only specifies minimum requirements. To successfully utilise the potential of FIS-B services, additional national operational performance standards would be needed.

As a base line, RTCA DO-358A Minimum Operational Performance Standards (MOPS) for Flight Information Services - Broadcast (FIS-B) with Universal Access Transceiver (UAT), could be used to develop UK specific requirements considering the specifications of the selected option 3A

5 - COST ASSESSMENT FOR MANUFACTURERS

5.1 - Overview

This section provides a high-level costs assessment of introducing enhanced EC devices into the UK market for both the ground and airborne segment. Whilst quantified costs are targeted, in many cases they are not feasible and qualitative cost and market considerations have been identified.

This analysis is based on a combination of inputs from STF members, and avionics experts in the study team, as well extensive past experience in supporting development and deployment of ATM systems and avionics across the aviation industry from research and development to decommissioning and end of life management.

The aim of the section is to capture the key economic factors that will influence the deployment on enhanced EC (as defined by Option 3A) in the UK environment and to provide an input to the roadmap exercise.

5.2 - Ground segment costs

Currently, ADS-B data are mostly gathered through Enhanced Mode-S transponders (DF17 Extended Squitters) on 1090 MHz, WAM systems or airport multilateration systems. However, only limited number of ground surveillance sensors process broadcasted DF18 messages even though most of the multilateration receivers are capable.

Therefore, the exiting multilateration would need to be reconfigured to be able to receive DF18 messages. However, such a reconfiguration would not be sufficient to achieve the full air traffic overview because the selected option 3A requires UAS to be equipped with devices working on 978 MHz. Therefore, provision of ICAO FIS with surveillance utilising option 3A and TMZs would need to consider augmentation of existing surveillance systems with dual frequency ADS-B receivers. It is understood that systems with planned replacement programmes could specify dual frequency reception with relatively low incremental costs.

The cost for the ground segment to adopt changes to their surveillance systems extends far beyond the simple cost of procuring the relevant hardware. Figure 15, below, provides an illustration of the set of activities that are typically involved for an ATSP to complete and approve changes to their surveillance systems. Whilst many of these activities are outside the scope of this study, some are influenced by the design of the enhanced EC solution, and are further explored below against key elements of the enhanced EC architecture (5.2.1 - to 5.2.3 - and two implementation scenarios (5.2.4 - to **Error! Reference source not found.**5.2.5 -).

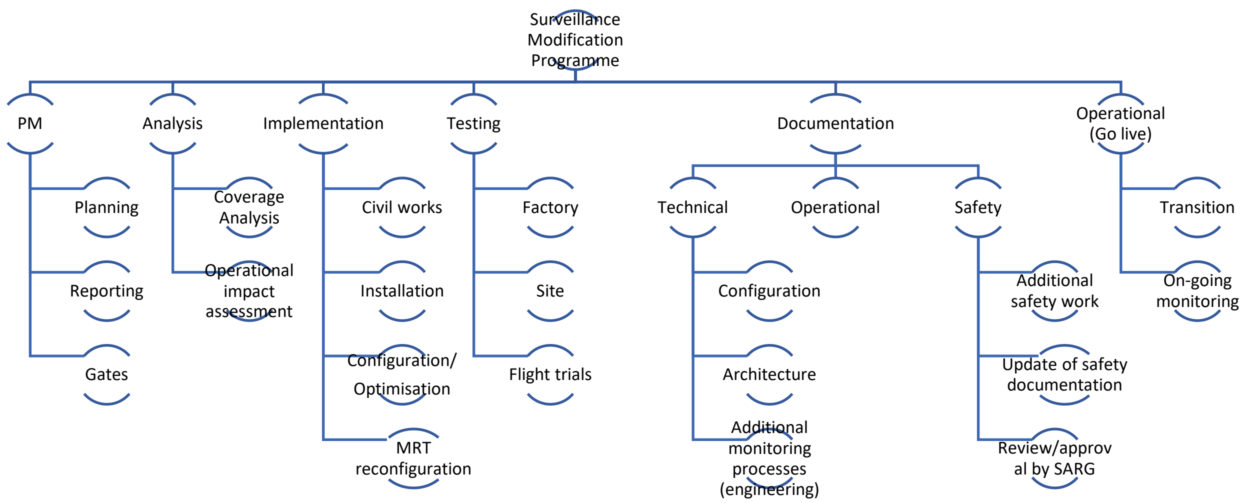


FIGURE 15: ILLUSTRATION OF SURVEILLANCE MODIFICATION ACTIVITIES

5.2.1 - Sensors for ATC

The use of enhanced EC devices for ATC is outside of the scope of this project, but aspects related to implementation costs for ATS providers are strongly related. ANSPs are likely to utilise sensors for both ATC and FIS services, since an ADS-B receiver can contribute to both. Changes would need to be made to the surveillance systems to accept and route the data correctly, and as mentioned above, to accommodate use of 978MHz for UAS.

It is proposed that the enhanced EC device will broadcast ADS-B information as specified in the Section 3 - The existing ground surveillance infrastructure used for ATC service is partially able to decode 1090 MHz ADS-B as the multilateration systems are already installed in some parts UK are capable to receive DF18 messages from aircraft. This potential has not been used fully used as there were no operational needs to fully utilise DF18 ADS-B messages in the airspace with multilateration coverage.

Option 3A assumes that UAS will utilise 978 MHz which means that the most of the existing multilateration receivers will not be suitable for reception of information from enhanced EC devices operating on 978MHz. While some of them might be upgradable (e.g. SAAB Sensis receivers), others may not because the manufacturers have not developed receivers for 978 MHz as there was no demand in the market of their interest (for example ERA and Frequentis).

Some of the multilateration system manufacturers have the UAT technology available (Thales) or are capable to integrate third party UAT receivers into their system (ERA) so most of the existing systems installed currently in UK should be upgradable to be able to process ADS-B messages on both 1090 and 978 MHz frequencies. It should be noted that not all multilateration receivers would need to be dual frequency as the sensitivity of the receivers is very high and can provide long distance coverage. However, as mentioned in the previous chapters, the driver for the number of sensors would be low altitude coverage requirements and terrain constraints.

ANSPs using secondary or primary radars only which would require surveillance information about EC devices in their area of responsibility would need to install ADS-B dual frequency receivers to receive ADS-B DF18 messages from all enhanced EC devices.

The implementation of the new dual frequency receivers into existing surveillance systems would infer the following costs:

- Replacement of the 1090 MHz receivers by dual band receivers (existing multilateration systems)
- Reconfiguration or upgrade of the Central Processing Systems of the existing multilateration system not capable to process ADS-B messages (Asterix CAT021)
- Reconfiguration or upgrade of the Surveillance Data Processing (SDPS) or Surveillance Display System to integrate ADS-B information
- Upgrade of the ATM system might be needed if changes in HMI would be required
  - New symbols for unmanned aircraft or new symbols for the targets for which the quality of the surveillance information is not suitable for the separation services
  - Display of ADS-B version V0 and V1 on the CWP of ATCO if enhanced EC device is not meeting V2 requirements
  - Utilisation of the geometric heights
  - Safety assessment of the changes in the ATS system

5.2.1.1 - Cost of the receivers

Considering the information about the receivers available on the market, the price of dual band multilateration receiver is between 30,000 and 55,000 GBP. Currently, there are approximately 70 multilateration receivers in 10 WAM systems so the replacement of all multilateration receivers would cost between 2,1 – 3.85 mil GBP.

The cost of the dual band ADS-B receivers which could complement radar sites can vary between 2,500 and 8,500 GBP. As there are about 60 secondary surveillance radars in UK, the total cost of the ADS-B receivers complementing the secondary radar coverage would be 150k – 510k GBP.

Siting costs in this case (including power, communications, access and security) are not considered, as receivers would be assumed to be installed at existing sites. Installation costs would be in addition, but are site dependent and have not been estimated.

5.2.1.2 - ADS-B implementation costs

Reconfiguration or upgrade of the Central Processing Systems (CPS) of the existing multilateration system not capable to process ADS-B messages (Asterix CAT021).

The following estimates are based on the experience from our previous works for ANSPs in recent years and vary significantly from manufacturer to manufacturer:

- Reconfiguration of the CPS 20-30 % of the CPS price which is 20,000 – 90,000 GBP
- Upgrade of the CPS - 40-60 % of the CPS price – 40,000 – 180,000 GBP
- New CPS 100,000 – 300,000 GBP.

5.2.1.3 - ADS-B integration into existing Surveillance Data Processing System (SDPS)

Integration of ADS-B information into SDPS also significantly varies between SDPS manufacturers and heavily depends on SDPS readiness for ADS-B implementation (Asterix 021). The estimated cost can be between 8,500 and 42,500 GBP.

Additional costs would need to be expected if other than ADS-B Version 2 messages would be processed and displayed to ATCOs.

5.2.1.4 - Utilisation of geometric heights

Presently, all certified avionics provide pressure-derived altitude and therefore the existing SDPS systems process and display the pressure altitudes. However, geometric heights may be processed as well and be used for low flying aircraft/equipment where the pressure altitude does not have an impact aircraft performance and where more precise vertical separation between aircraft would be required.

The existing Asterix 021 message format includes an optional field I021/140 dedicated to Geometric Height and also I021/157 dedicated to Geometric Vertical Rate.

The future SDPS systems may process the information and to be directly used for vertical separations or may be converted to pressure altitude. The tools are now under development and the cost of such tools is not known yet.

5.2.1.5 - Safety assessment of the changes in the ATS system

Any functional change in the ATS system should be subject to safety assessment. Usage of the new surveillance means does not bring a functional change, but the change may have an impact in safety of the service provision and safety shall be assessed. Note that the cost of introducing a new type of operation (e.g. ICAO FIS with surveillance) is outside of scope of this study, which focuses on the impact of implementing enhanced EC to support these services. Therefore, in practice costs related to safety assessment are expected to be absorbed by the overall introduction of new services.

The cost of the assessment would depend on the scope of the assessment and the scale of the system. Based on experience of supporting safety assessments the costs are estimated to be between 15,000 to 150,000 GBP.

5.2.2 - Sensors for FIS service

Information for ICAO FIS with surveillance could be provided from different sources with sufficient coverage of the FIS area:

- Neighbouring ANSP if equipped with dual/ multi-channel receivers
- SDP provider with dual/multi-channel receivers (in the future)

- Own surveillance dual/multi-channel sensors and SDP (if other sources are not available, insufficient, or economically ineffective).

Considering the surveillance data quality and data integrity, surveillance data from ANSP or SDP provider, as certified service providers, could be a suitable solution if the cost of the surveillance data would be bearable by the FIS provider.

However, considering the existing costs of surveillance data feeds from the ANSPs including costs of all security and cyber security measures, own installation and operation of the surveillance dual channel sensors might, despite initial installation cost, be more beneficial option in the long term.

As there are no Surveillance Data Providers (SDP) available (noting as in Asm2 that space based ADS-B would not cover 978MHz), we cannot estimate the cost of surveillance information from such source. However, in the near future, the SDP may provide competitive price for surveillance data to FIS provides.

Regardless of the surveillance data source, use of the surveillance information for FIS should go through the safety assessment process to prove suitability of the surveillance information for the intended services.

5.2.2.1 - Cost of the receivers

Besides the systems certified for ATC service (Saab Sensis, Thales, etc.), there are currently several different surveillance systems designed for FIS or general situational awareness of aircraft operators based on ADS-B which are capable to process ADS-B information on 1090 MHz as well as 978 MHz. Some systems can also receive and process also information from non-assured devices and thus enhance the situational awareness of the system user.

Systems supporting 1090 MHz and 978 MHz on the European market are:

- uAvionix pingstation 3 which costs 2,600 Eur (which is approximately 2,220 GBP)
- uAvionix Pingstation 2 Weatherproof 978/1090 Networkable ADS-B Receiver (1,415 GBP)
- Involi 5 G-1090 Air traffic Receiver which costs 10,000 Eur (which is approximately 8,500 GBP).

The provided prices are for the hardware and software and do not include installation nor Flight Information Display integration costs which would need to be considered. The price may differ depending on the coverage requirements (size of the area, minimum altitude, surveillance data quality) as more sensors might be needed.

As a benchmark, the receiver installation cost of typical ADS-B receivers can range between 6,000 GBP and 12,800 GBP depending on installation site and the distance between the receivers and the processing unit and display.

5.2.2.2 - UK market for FIS surveillance systems

Additionally, there are other manufacturers of ADS-B receivers designed for 1090 MHz, which might be modified to receive also ADS-B messages on 978MHz. As the size of the UK market is limited and the ultimate European Union direction is unknown, surveillance systems manufacturers may be hesitant to invest into development of the new dual band surveillance systems. The situation may limit the market offer to very few manufacturers. This may potentially be alleviated through government subsidy schemes.

5.2.2.3 - Safety assessment of the changes in the ATS system

As FIS and AFIS are regulated services, change in their provision related to introduction of the surveillance information would require a functional assessment and safety assessment. Usage of the new surveillance means and introduction of new FIS with surveillance information will bring the functional change

The cost of the safety assessment would depend on the scope of the assessment. Previous experience suggests the cost of the assessment for single FIS unit would be between 10,000 to 80,000 GBP. It is noted that ANSPs will need to undertake assessments to introduce ICAO FIS with surveillance in any case (even if not utilising enhanced EC input), so these costs may already be factored into ANSP plans.

5.2.3 - Flight Information Display for FIS

Whilst not strictly a direct cost factor for the use of enhanced EC devices, it is important to consider the overall costs for ATSPs, as it may influence uptake. FISOs could use the display system which has been designed for ATC services, but they are cost-prohibitive to smaller airports. Therefore, the CAA has initiated development of the new standards on Flight Information Display (CAP670 Air Traffic Services Safety Requirements, Part C, Section 5: Flight Information Display) which define minimum FID requirements. FIDs compliant with the minimum standards should be significantly cheaper than those designed for ATC surveillance services.

However, there is currently no CAP compliant FID available on the market, so the cost of such system can only be derived from the simplified ATM systems which available on the market. The cost of such system for a single airport with approach surveillance services is between 100,000 and 180,000 GBP.

Considering the significant reduction in FID functionalities and simplified testing, verification and assurance requirements of FIDs comparing to a system designed for surveillance ATC service it is assumed that the FID price will eventually be significantly lower.

The proposed enhanced EC devices would operate based on existing standards and protocols, meaning that they would not introduce any additional cost factors for ATSPs, as they would not introduce novel data or protocols to requiring testing and approval.

5.2.4 - Airport airspace access

Considering low flying aircraft or UAS at 500 ft equipped with an enhanced EC device transmitting ADS-B information with 10W, the theoretical ground-to-air coverage of an ADS-B receiver would be at least 40 NM, which approximates to typical Line of Sight (LoS) coverage distance (depending on receiver height). This theoretical coverage would be valid under ideally flat terrain so the real operational coverage of the ground EC receivers will depend on the terrain profile under the FIS airspace and will be shorter.

5.2.4.1 - Class D CTR

Assuming the typical Class D CTR has a radius of 25 NM, with flat terrain, a single receiver would be sufficient to cover whole CTR with the surveillance coverage from 500 ft above the airport level. To achieve the redundancy of surveillance information in Non Radar Airspace, two independent receivers might be required.

In case of real terrain or if the lower altitude coverage requirements, more receivers would be needed. It can be assumed that 3 receivers on average might be needed to cover the Class D CTR.

The following cases are considered:

- Case 1: ATS Unit with existing multilateration system which would require installation of the new dual band sensors and upgrade and reconfiguration of the existing multilateration CPS
- Case 2: ATS unit with existing multilateration system but installing additional dual frequency receivers including their integration into the SDPS
- Case 3: ATS unit with existing radar installing additional dual frequency receivers and integration into the SDPS

The following table indicates case 1 costs relating directly to the enhance EC solution:

TABLE 7: CASE 1 - EXISTING MULTILATERATION SYSTEM REPLACING THREE RECEIVERS BY THE NEW DUAL BAND SENSORS, UPGRADE AND RECONFIGULATION OF THE EXISTING MULTILATERATION CPS

Type of device	Number of devices	Device cost range (GBP)	Total cost range (GBP)
Dual band multilateration receivers	3	30,000 - 55,000	90,000 - 165,000
Reconfiguration of the existing CPS	1	-	20,000 - 90,000
Safety assessment	1	-	15,000 - 50,000
Total			125,000 - 305,000

The following table indicates case 2 costs relating directly to the enhance EC solution:

TABLE 8: CASE 2 – EXISTING MULTILATERATION COMPLEMENTED BY ADDITIONAL DUAL FREQUENCY RECEIVERS INCLUDING THEIR INTEGRATION INTO THE SDPS

Type of device	Number of devices	Device cost range (GBP)	Total cost range (GBP)
Ground dual band only ADS-B receivers	3	2,500 - 8,500	7,500 - 25,500
Integration of the receivers into the existing SDPS	3	8,500 - 42,500	24,500 - 127,500
Safety assessment	1	-	15,000 - 50,000
Total			47,000 - 203,000

The following table indicates case 3 costs relating directly to the enhance EC solution:

TABLE 9: CASE 3 - EXISTING RADAR INSTALLING ADDITIONAL DUAL FREQUENCY RECEIVERS AND INTEGRATION INTO THE SDPS

Type of device	Number of devices	Device cost range (GBP)	Total cost range(GBP)
Ground dual band only ADS-B receivers	3	2,500 - 8,500	7,500 - 25,500
Integration of the receivers into the existing SDPS	1	8,500 - 42,500	24,500 - 127,500
Safety assessment	1	-	15,000 - 50,000
Total			47,000 - 203,000

5.2.4.2 - Class G AFIS airport

It is assuming that the typical Class G AFIS would implement a single receiver based on the aerodrome. If redundancy is required two receivers will be needed. However, it is assumed that a single receiver will be installed without any redundancy. It is also assumed that the safety assessment work in such a case would come at a lower cost, as the operational services supported are reduced compared to the previous examples.

In this case the cost of the ground surveillance system directly related to the enhanced EC solution would include:

TABLE 10: COSTS ASSOCIATED WITH IMPLEMENTATION AT CLASS G AFIS AIRPORT

Type of device	Number of devices	Device cost range (GBP)	Total cost range (GBP)
Ground receivers	1	2,500 - 8,500	2,500 - 8,500
FID	1	15,000 - 54,000	15,000 - 54,000
Safety assessment	1	-	5,000 - 20,000
Total			22,500 - 82,500

5.2.5 - Linear BVLOS mission

This scenario considers that BVLOS will be equipped with an enhanced EC device with 10 W ADS-B transmitter and may fly at 400 ft AGL.

Under ideal conditions with the flat terrain the surveillance along the route could be achieved with the receivers with not more than 80 NM spacing. However, the surface of the UK is not flat and therefore the spacing between the surveillance receivers will be shorter and will need to be determined by the terrain along the routes and by siting of the receivers.

As an example, a BVLOS flight from Culdrose Airport to Brize Norton Airport has been selected. As in broader scenario we will use the following option for demonstration of the surveillance coverage:

- Coverage provided by the new dual band ADS-B sensors on the existing sites (radars and WAM sites). This case indicates the potential coverage along the route if the existing WAM receivers are replaced by dual band ADS-B receivers and if the existing radars sites are complemented by dual band ADS-B receivers.

New dual band ADS-B receivers installed at existing surveillance sites could provide good coverage even at very low altitudes. The following figures indicate the estimated coverage at 400 ft AGL along the route from Culdrose Airport to Brize Norton Airport if the existing surveillance sites would be utilised and complemented by the new dual band ADS-B receivers.

Figure 16 shows estimated coverage at 400 ft which could be provided if the new dual band ADS-B receivers would be collocated with the existing radars.

FIGURE 16 SURVEILLANCE COVERAGE AT 400 FT – DUAL BAND ADS-B RECEIVERS COLLOCATED WITH THE EXISTING RADARS

Figure 17 shows estimated coverage at 400 ft which could be provided if the existing WAM receivers would be replaced or complemented by the dual band ADS-B receivers.

The green colour indicates the coverage and the blue and violet shades indicate that the coverage at those locations would be include redundant layers of coverage.

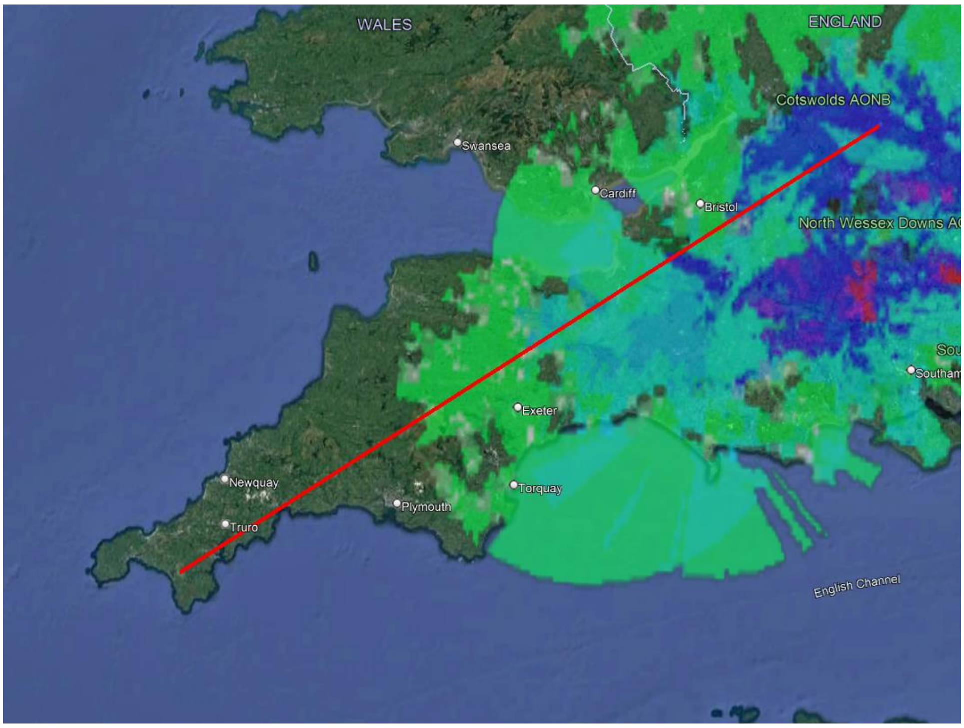


FIGURE 17 SURVEILLANCE COVERAGE AT 400 FT – EXISTING WAM RECEIVERS REPLACED OR COMPLEMENTED BY THE DUAL BAND ADS-B RECEIVERS

Figure 18 indicates the estimated coverage at 400 ft which could be provided if the existing WAM receivers would be replaced or complemented by the dual band ADS-B receivers and the existing radar sites would be complemented by the dual band ADS-B receivers.

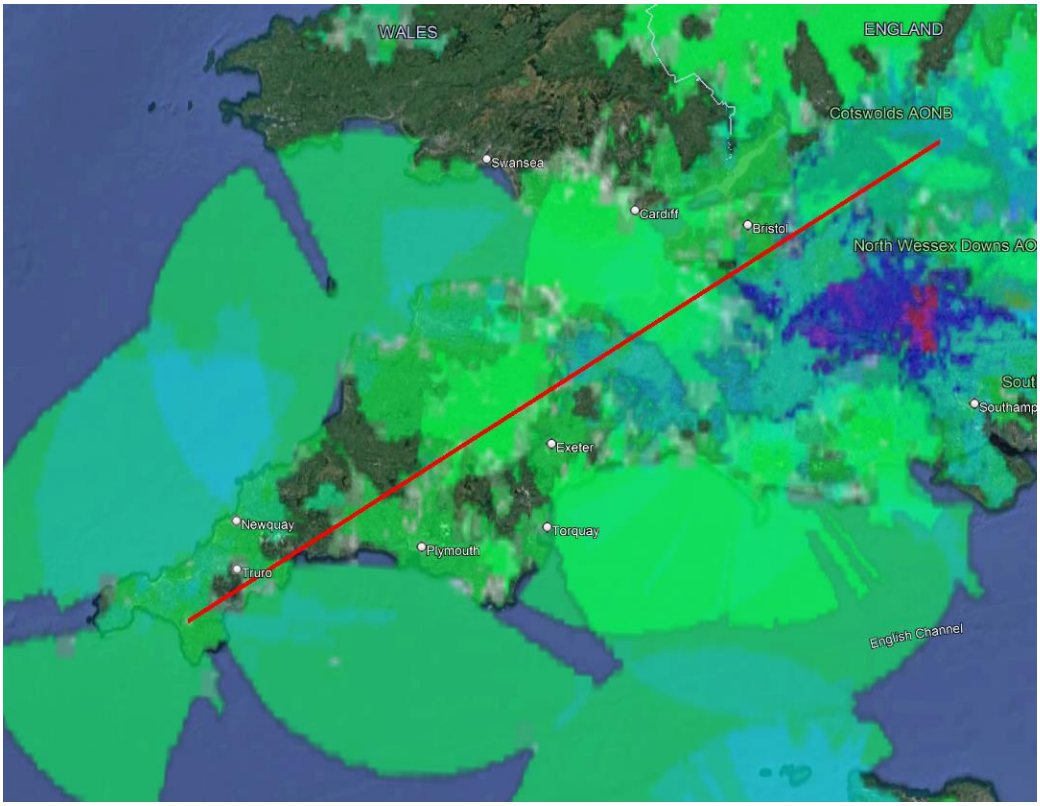


FIGURE 18 SURVEILLANCE COVERAGE AT 400 FT PROVIDED BY BOTH, DUAL BAND ADS-B RECEIVERS COLLOCATED WITH THE EXISTING RADARS AND REPLACED WAM RECEIVERS BY THE DUAL BAND ADS-B RECEIVERS

As seen in Figure 18, the existing surveillance sites could provide a good baseline for a future surveillance network which could support operation of both aircraft and UAS. The gaps in the coverage could be covered based on the operational needs by the additional surveillance sensors or system to support future operations.

5.3 - Avionics costs

The recommendation for the minimum functional and performance requirements on the new Enhanced EC devices define that Enhanced EC device for:

- Manned aircraft will include ADS-B Out transceiver working on 1090 MHz and to detect all other aircraft it would be recommended that it could also include ADS-B IN on both 978 MHz and 1090 MHz
- UAS will include ADS-B Out transceiver working on 978 MHz and to detect all other aircraft it would be required to include ADS-B IN functionality on both 978 MHz and 1090 MHz.

The minimum requirements as specified in Section 3 - require the aircraft to transmits the following information:

- Identity and Category,
- Position and Horizontal Position Accuracy
- Altitude and Vertical Position Accuracy
- Containment bound
- Velocity and Horizontal Velocity Uncertainty
- Aircraft operational status
- Source / Surveillance Integrity Level and

- System Design Assurance level.

This can be achieved through ADS-B messages sent either through Transponder-based systems (ADS-B Extended Squitters) or through Non-transponder-based systems. While the ADS-B Extended Squitters sent from a Mode S transponder using Downlink Format 17 (DF=17) and Non-transponder-based ADS-B transmitters using DF=18.

Therefore, there are two options how the minimum requirements could be met:

- Mode S ES like equipment using DF=17 message format or
- ADS-B like transmitter using DF=18.

As the minimum Enhanced EC Device requirements are derived from the standard avionics' requirements, the existing certified ADS-B transmitters and Mode-S ES transponders meet the requirements. However, the aim of the Enhanced EC device is to provide equipment which could be affordable to a wider set of GA and UAS airspace users and support the defined applications.

5.3.1 - Enhanced EC device cost acceptability by airspace users

As highlighted by airspace users and by avionics manufacturers, to achieve the wider implementation of the Enhanced EC and thus support the intended applications, the cost of the Enhanced EC device will have to be attractive to airspace users. Enhanced EC devices outside a desirable price range may result in airspace users choosing to simply avoid the specified airspace volumes (TMZs) instead of equipping, and thus a failure to meet the objectives of Enhanced EC device deployment.

To determine the desirable range for the Enhanced EC device, the following previous programs for General Aviation to equip new devices were considered:

- Replacement of the 25kHz channel spacing VHF radios by new radios with the 8.33 kHz and
- Introduction of the CAP1391 EC devices.

In both cases GA was offered a rebate to achieve wider acceptance of the prosed changes.

The low-end of the desirable range is assumed to be close to the current cost of the basic EC device. According to CAP 1391 stakeholders assessed, an acceptable cost for a basic EC device would be approximately £250.00 including VAT. As the UK offered rebate of £250 for each device, the actual acceptable price of the device was around **£500**.

Price of a new 8.33 kHz channel spacing VHF radio for GA aircraft provides a benchmark for the upper limit of the desirable price. The cost of the cheapest fixed radio is on average about **£1,250.**

To address the market, the enhanced EC device must also be cheaper than fully certified ADS-B transceivers. The Garmin GDL 82 Built-In GPS ADS-B Kit provides a benchmark for the minimum price end of the market, and costs **£1,680** and therefore it is assumed that the Enhanced EC device could related to a similar price.

Considering those identified benchmarks and the rebate for the EC device, the desirable price for the device should be in the order of **£1,000** for the GA airspace user.

5.3.2 - Requirements vs Enhance EC device cost

As indicated below in the section 5.3.4 - , there are existing solutions which could support implementation of Option 3A on certified airframes. However, the cost of such systems, its airframe installation and its approval will be significantly higher than the expected desirable range. Additionally, most existing avionics require electric power supply from the airframe and are not suitable for airframes without internal power supply (gliders, balloons, etc).

To achieve the desirable cost of the enhanced EC device, there must be a balance between the operational requirements and the detailed surveillance and technical requirements. For instance:

- Operational range of the device vs transmission power
- Probability of detection vs installation requirements

- Data quality requirements vs certification requirements
- Power supply requirements vs universality of the device.

To achieve the balance and keep the price within the acceptable range, proposed Enhanced EC device implementation roadmap will need ensure suitable activities and trials account for these aspects.

5.3.2.1 - Operational range of the device vs transmission power

The operational range of the Enhanced EC device has in impact on capability of the ground surveillance systems and other airframes to detect the EC device. However, too high output power requirements would increase the weight of the device or shorten the operational time of the device. CAP1391 summarised the user requirements which would accept the device without internal power could be in service for 12 hours. Required battery life-time and the output power determine the battery capacity. A higher output power would increase the battery capacity requirements and enhanced transmitter components. Both will increase the price. Heavier and larger device will also complicate the device installation within the airframe.

Therefore, the minimum transmission power requirements shall take into account the duration of Enhance EC device operation expected by the airframe users, the operational range and eventually the weight and price of the components.

5.3.2.2 - Probability of detection vs installation requirements

Availability (driven by probability of detection) will be an application requirement, and the application have not yet quantified the requirement. As the applications have a safety impact it can be assumed that an assured level of performance will be needed from the enhanced EC device to support the applications.

Portable EC devices installed or attached inside of the airframe usually face unpredictable signal attenuation. This may cause that the device could be invisible to ground surveillance systems or to other aircraft even though it would be within the estimated operational range of the device, and would directly interfere with the ability of the enhanced EC device to provided assured position information.

To maximise the quality of the position information and probability of detection, it would be desirable that the device antenna would be installed outside of the airframe in a position with an unobscured omnidirectional radiation pattern. However, the installation of the antenna on the outer part of the airframe will require certification and additional installation and administration costs which would likely exceed the upper limit of the desirable price range.

The minimum Enhanced EC device installation requirements should avoid requirements which would cause a need for additional certification or installation approaval process. Whilst also ensuring the device installation enables the desired probability of detection performance. The installation requirements will vary by airspace user, for example open cockpit or no cockpit aircraft would not suffer obscuration issues. This problem is likely to require development of novel guidance for airspace users, in order to achieve the balance between performance and cost that is needed.

5.3.2.3 - Data quality requirements vs certification requirements

To enable the Enhanced EC device to be visible by ground surveillance systems and also by the airborne collision avoidance systems, the information broadcasted shall be of required quality and the quality of the information needs to be known.

Therefore, it would be desirable if the GNSS position component and the transmitter meet the latest version ED102 (MOPS for 1090 MHz Extended Squitter ADS-B and TIS-B) requirements or at least ETSO-C199 requirements on TABS Class B devices.

However, fully certified devices normally exceed the desirable cost range, therefore the Enhanced EC device requirements will include only the minimum requirements which would enable desired applications.

There are available certified GNSS receivers which meet the requirements, and which could be used for either for integration with ADS-B transmitter/transceiver or as a GNSS circuit integrated into the Enhanced EC device as they meet the existing ADS-B standards (ED-102B - ARINC 743A) or TABS standards (TSO-C199). However, their price is relatively high and their usage might increase the price of the device above the desirable range.

There are several other GNSS sensors with high quality of provided PNT information available from recognised manufacturers like Trimble, NovAtel, Septentrio or U-blox which could provide PNT information with comparable or even better quality for competitive prices. However, if such sensors were used, the enhanced EC device manufacturer would need to assess the sensors against the requirements and ensure also provision of the data quality (accuracy, integrity, timeliness, etc.) information in an interoperable format. Use of non-certified sensors could decrease the production costs as the receiver circuits might be cheaper compared to certified sensors, but will increase the costs of enhanced EC device development to prove capabilities.

The device certification process should follow the existing CAP1391 EC device procedures to minimise the administration burden.

5.3.2.4 - Power supply requirements vs universality of the device.

As there will be different enhanced EC device users, the requirements should also include flexibility to enable different system architecture based on the user requirements:

- Portable device with internal power supply or external power supply from airframe
- Device with internal antenna and/or possibility to connect external antenna
- Device with ADS-B In (978 MHz or 1090 MHz or both) or without ADS-B In functionality
- Connectivity to other avionics or portable devices.

The flexibility in requirements should allow airspace users to scale their Enhanced EC device based on their needs and evolving operations especially UAS operations).

5.3.3 - Potential impact of the requirements on the avionics market

The selected approach, with manned aircraft on 1090 MHz and UAS on 978 MHz frequency moves the UK towards the US and deviates slightly from the current EU[18] path (978MHz is not envisaged in the EU and the integration of UAS is expected to focus more on LTE/5G). This may result in US manufacturers having a first mover advantage, but conversely gives an opportunity for EU manufacturers to develop devices that may address both the UK and US markets.

The size of the UK market may not be sufficient for other manufacturers to invest into the avionics development on 978 MHz as the cost of development diluted into the cost of the avionics may cause that the price of new enhanced EC device to be uncompetitive with US manufacturers or undesirable for airspace users.

From the airspace user perspective, it is a positive situation because the enhanced EC device could be on the market very soon after the new regulation is published as existing products may be leveraged to provide enhanced EC devices compliant with the new UK standards.

5.3.4 - Avionics for the manned aircraft

Considering the minimum requirements on Enhanced EC device as specified in Section 3 - , there are currently several avionics devices available on the market which meet the requirements or could be modified to meet the minimum requirements.

Reviewing known GA and UAS avionics market offers, there are already devices on the market which meet the proposed requirements and thus would enable the implementation of Option 3A. However, the current market offer is limited to US manufacturers due to 978 MHz requirements.

As mentioned in the beginning of this section, manned aircraft may use either Mode-S transponders or ADS-B Out transceivers working on 1090 MHz. To enable detection of all other aircraft it would be recommended

[18] At the time of writing, it is unclear when the approach under consideration within the EU will reach fruition, and believe that the Option 3A proposed in this study will allow for more rapid adoption of the supported applications.

that they could include ADS-B IN functionality working on both 978 MHz and 1090 MHz to provide traffic information about all airspace users equipped with either enhanced EC devices, Mode-S transponders, or ADS-B transmitters on both 1090 MHz and 978 MHz frequencies.

This section provides a non-exhaustive overview of existing avionics and its cost on the market, which could support either implementation of option 3A by manned aircraft either through the direct installation in the airframe, or as components that could be integrated into an enhanced EC device, or could be modified into an enhanced EC device (e.g. change of the ADS-B Out from 1090 MHz to 978 MHz or vice-versa).

5.3.4.1 - GNSS receiver

To provide the PNT data with required and known quality (accuracy, integrity, timeliness, etc.) the enhanced EC device will need to be equipped with the GNSS receiver meeting the requirements defined in Section 3 -

There are several GNSS receivers designed for the ADS-B systems available on the market, which could be used for either for integration with an ADS-B transmitter/transceiver or as a GNSS circuit integrated into an enhanced EC device, as they meet the existing ADS-B standards (ED-102B - ARINC 743A) or TABS standards (TSO-C199).

The costs of certified GNSS receivers for GA vary from £340 up to £1.500. They could be used for complementary installation to the existing airframe which might be already equipped with Mode A/C or Mode-S transponders and thus enable ADS-B message transmission utilising the existing avionics.

The following certified GNSS receivers were identified through market research:

- MGL Avionics SP-12 (£448)
- TQ Systems NexNav 21.000 (£1280)
- NexNav Micro-i (£640 for OEM circuit card and £1285 for the kit)
- Trig TN72 - GPS receiver (£340)
- Garmin GPS 20A (£720)
- Garmin GDL 82 Built-In GPS ADS-B Kit Including WAAS Antenna for certified aircraft (£1525)
- uAvionix SkyFYX GPS receiver with WAAS (can be connected to EchoUAT transceiver) (£445)
- uAvionix SkyFYX-EXT GPS antenna and receiver (£ 405)
- FreeFlight Systems RANGR TX Lite (Transmitter includes internal WAAS/GPS sensor, Ball and Stick Antenna and WAAS/GPS antenna) (£1500)

Use of non-certified GNSS receivers for an enhanced EC device may meet or even exceed the performance requirements. Their price can be significantly lower than the certified GNSS receivers although some can even be higher depending on their capabilities. However, their performance would need to be approved and the receiver be capable of supporting the required data quality parameters for required data elements.

- U-blox NEO-7N GNSS module (£38)
- U-blox NEO-M8P RTK GNSS receiver (£130)
- Septentrio AsteRx-i D/S UAS – (£970)
- Novatel OEM7720 (£2050)

5.3.4.2 - Transponder based devices

Implementation of Option 3A can be also supported by transponder based devices which could either fully Mode S ES certified or TABS Class A transponders (FAA TSO-C199 / EASA ETSO-C199) which meets the proposed requirements.

The owners of the GA aircraft may consider investment into the standard avionics and thus unlock the services which will require enhanced EC device as a minimum, as well as additional services. The price for the equipment only would be between £1,540 and £4,130. The following list indicates the approximate cost of the Mode S ES transponder with ADS-B which could be expected by the GA aircraft owners:

- Trig TT22 Xpdr And Tn70 UAT ADS-B Out Transponder Combo (£3,530)
- Trig TT22 compact transponder, TN72 X GPS (TSO-C199) and TA70 GPS antenna (£2,565)
- Trig TT26 Transponder – Mode-S 1090 MHz originally developed for UAVs (£1,540)
- Garmin GTX335 UAT ADS-B Transponder With GPS + GAE 12 Encoder (£2,820)
- Garmin GDL 82 & GTX 327 Package (£1,940)
- Garmin GDL 82 w/GPS + ADS-B "In" Bundle (£2,125)
- uAvionix tailBeacon TSO Nav Light UAT ADS-B Out For Certified Aircraft (£,1610)
- uAvionix tailBeaconX Mode S ADS-B Transponder for experimental aircraft (£2,020)
- uAvionics ping200Sr (Class 1 Mode S Extended Squitter (ES) ADS-B OUT transponder) (£3,250)
- uAvionics Ping200Xr –Mode S ADS-B Transponder 1090 MHz with Integrated Aviation GPS (£4,130)
- uAvionix Ping20Si Mode S transponder, ADS-B 1090ES DF17 transmitter, Integrated WAAS GPS, Integrated static pressure sensor (£2,430)
- uAvionix Ping200Si - Mode S transponder, ADS-B 1090ES DF17 transmitter, Integrated WAAS GPS, Integrated static pressure sensor (TSOC166b) (£3,250)
- Appareo Stratus ESGi Transponder And Stratus 3I 1090 MHz ADS-B Receiver (£3,310)
- Dynon Skyview Xpdr Transponder (£1,800).

Additional installation and administration costs need to be considered.

5.3.4.3 - ADS-B transmitter based devices

Potentially, more affordable options for Option 3A are through ADS-B transmitter based devices, which can be either installed on the aircraft or could be designed as portable devices. The devices can be fully compliant ADS-B transmitters or TABS Class B (FAA TSO-C199 / EASA ETSO-C199) compliant devices.

The price of for such equipment would be between £605 and £2,100. The following list indicates the approximate costs of the ADS-B transmitters which could be expected by the GA aircraft owners if they decide for such installation:

- uAvionix Skysensor Integrated Wingtip ADS-B In System for experimental aircraft (£605)
- uAvionix Echouat ADS-B Out / In Transceiver (Receives 978MHz and 1090MHz, no GNSS receiver) (£810)
- uAvionix skyBeacon + skySensor ADS-B In / Out Bundle (£1,940)
- uAvionix tailBeacon-TSO (ADS-B Out | WAAS GPS | Encoder) (£1,625)
- uAvionix Bundle Echouat With Skyfyx Remote Mount Receiver (Class B1S ADS-B UAT transmitter coupled with a dual-link 1090MHZ / UAT receiver) (£1,170)
- uAvionix Ping1090i - full range, dual-link ADS-B transceiver. ADS-B-In on both 1090ES and 978UAT. ADS-B-Out on 1090MHz at 20W nominal output (£2,100)
- Garmin GDL 82 Built-In GPS ADS-B Kit Including WAAS Antenna For Experimental Aircraft (broadcasts on the 978 MHz frequency) (£1575).

Additional installation and administration costs will need to be added to the cost of the equipment.

Other option would be use of the portable device such as CAP 1391 successor uAvionics SkyEcho 2 which is a portable ADS-B IN/OUT transceiver, 1090ES transmitter (1090 MHz) which can receive on both 1090MHz and 978MHz frequencies, the cost of the device is £540.

5.3.4.4 - ADS-B Receivers

Aircraft which are already equipped with ADS-B transmitters or Mode-S ES transponders may enhance their situational awareness by installing an ADS-B IN receiver. Besides the improved overview of the surrounding operations the devices can be used in the future for reception of the digital services like FIS-B. The benefits of the ADS-B IN installations will increase with spreading of UAS operations and deployment of the digital services through 978MHz.

The price of the ADS-B In equipment could be between £405 and £1,900 but most of the receivers are between £405 and £650. The following list indicates the approximate costs of the ADS-B IN receivers which could be expected by the GA aircraft owners if they decide for such installation:

- Avidyne SkyTrax200 Dual-Band ADS-B IN Receiver (£1,900)
- Dual XGPS190 GPS / AHRS / ADS-B Weather & Traffic Receiver (£565)
- uAvionix Skyfyx-Ext GPS All-In-One Receiver And Antenna (£405)
- Dynon Avionics SV-ADSB-472 dual band via 978 MHz (UAT) and 1090 MHz (£625)
- Dynon Skyview Sv-GPS-2020 GPS / ADS-B Receiver (£510)
- Garmin GDL 50R Remote-mount ADS-B Receiver (£650).

Other option would be use of the portable ADS-B receivers such as:

- Garmin GDL 50 Portable ADS-B / GPS Receiver (1090 Out and 978 UAT and 1090 ES In) (£610) and
- Stratus 3 Portable dual band ADS-B In / GPS / AHRS Receiver (£610).

5.3.5 - Avionics for UAS

Selection of Option 3A requires 978MHz to be introduced. Even though the 978MHz EC would be new in UK aviation environment, the technology and its usage for the manned and UAS operations in the lower part of the airspace has been in place in US for several years.

Studying the UAS avionics market has identified that 978MHz based devices developed for UAS operations which meet the proposed Enhanced EC device requirements. Their availability would expedite deployment of the Options 3A. However, the offer is limited to US manufacturers today.

To support DAA functionalities, UAS may utilise ADS-B IN information from both, 978 MHz and 1090 MHz, for detection of other airframes in its vicinity.

Further in this section provides a non-exhaustive overview of existing UAS avionics and its cost on the market, which could support either implementation of option 3A by UAS operators either through the direct installation in the airframe, or as components that could be integrated into an enhanced EC device, or which could be modified to an enhanced EC device.

5.3.5.1 - Transponder based devices

Currently, there is a requirement that UAS flying BVLOS shall be equipped with a standard transponder when passing through the controlled airspace. Such devices are currently available on the market, but their price is higher than the estimated price range for the enhanced EC device.

The price of the UAS transponders is currently between £1540 and £2,550. The following list indicates the approximate costs of the UAS transponders which could be expected by the UAS operator if there is a need to fly in the airspace where the transponder is required:

- Trig TT26 Transponder working on 1090 MHz (£1540)
- Ping20s Mode S ADS-B transponder transmitting ADS-B on 1090MHz ES 20W nominal (£1710)
- Ping20Si (with FYXnav – GPS and SBAS receiver and antenna), Mode S ADS-B transponder, integrated barometer, transmits ADS-B on 1090MHz ES 20W nominal (£2550).[19]

Some of these devices are equipped with ADS-B transmitters. However, according to Option 3A, UAS will need to be equipped with ADS-B Out working on 978MHz and therefore the usage of UAS transponders may not be allowed.

[19] *Note that at 20W this device does not meet existing ADS-B standards and would need to be approved for use in controlled airspace.*

5.3.5.2 - ADS-B transmitter based devices

Compared to transponder based devices, ADS-B transmitters could be a more affordable option to comply with Option 3A and be visible to ground surveillance and to other airframes.

The price of for ADS-B transceivers for UAS can be expected between £855 and £4,100. The following list indicates the approximate costs of the ADS-B transmitters which could be adopted by UAS:

- echoUAT - Class B1S ADS-B UAT transmitter coupled with a dual-link 1090MHZ / UAT receiver for Experimental and Light Sport Aircraft. Modifications for UAS would be needed (£855)
- uAvionix Ping2020 with FYXnav-B GPS (Transmits on 978MHz, receives 1090MHz and 978MHz) (£1280)
- uAvionix Ping2020i is integrated all-in-one ADS-B out solution (ADS-B, GPS, and baro). ADS-B In on 1090MHz and 978MHz, ADS-B out is on 978MHz with 20W) (£1710)
- uAvionix ping200XR is the FAA TSO Certified Mode S ADS-B OUT transponder for UAS with ADS-B In receivers 1030/ 1090 MHz – would require upgrade of ADS-B Out on 978 MHz - (£3,670)
- uAvionix ping200X is the FAA TSO Certified Mode S ADS-B OUT transponder for UAS with ADS-B In receivers, SIL 3, 1030/ 1090 MHz – would require upgrade of ADS-B Out to 978 MHz - (£4,100)
- uAvionix Skybeacon TSO UAT ADS-B Out For Certified Aircraft which could be modified for UAS (£1500).

5.4 - Conclusions of the cost analyses

In summary, the implementation of option 3A is supported by available devices on the market, although in some cases the devices exceed the desired cost range for an enhanced EC device to encourage adoption and support the applications:

- As devices (or components that can be assembled into a device) meeting the requirements are available on the market, implementation of Option 3A could be very rapidly enabled.
- Costs of existing devices, particularly considering equipping on closed cockpit aircraft, may be outside the desirable price range. It is therefore necessary, to identify ways to set up a positive reinforcement cycle whereby:
  - Enhanced EC device costs are attractive to airspace users;
  - Airspace users therefore adopt the devices in significant numbers;
  - Requirements are sufficiently harmonised with the US market to allow manufacturers to address both markets within a single product line;
  - Manufacturers are therefore incentivised to invest in developing enhanced EC devices increasing competition in the market and further reducing costs to airspace users;

If enhanced EC device deployment successfully enables the applications in a relatively short timescale, this could also influence Europe towards a compatibility, which would further reinforce this cycle. It may be necessary for government subsidy to spur initial adoption, by bringing initial devices into the desirable range.

The main challenge, which will have to be addressed through activities identified in the roadmap, will be to enable probability of detection performance in a cost-effective way, which may require novel guidance based on trials.

Regarding the ground segment, devices are again available on the market which could support the implementation of ICAO FIS with surveillance using enhanced EC devices as defined in this study. ATSPs will have considerable work to conduct in any case, to transition to provision of ICAO FIS with surveillance, and Option 3A provides a possible route to meeting the surveillance needs for such a service.