Electronic Conspicuity (EC) Consolidated Study Report – An analysis of the potential of Electronic Conspicuity technology to support the Airspace Modernisation Strategy and Future of Flight Programme.

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Contents

Preface

The CAA has been tasked by the Department for Transport (DfT) to develop the policy and specifications that meet the future needs of all aviation users, including Unmanned Aircraft Systems (UAS) and other new airspace users. This is vital for delivering the Airspace Modernisation Strategy (AMS), of which routine beyond visual line-of-sight (BVLOS) for UAS operations is a key objective. Further detail of this can be found in the AMS Part 3 (CAP 1711b). In addition, the CAA, DfT and UK Research and Innovation (UKRI) are working on the UK Future of Flight (FoF) Programme. This programme will enable the safe integration of innovative aircraft into service, with BVLOS UAS flight forming a core part of this strategy.

Surveillance technologies, such as Electronic Conspicuity (EC), will be a key part of delivering the integration of new users, whilst ensuring the continued safety of existing users. EC is an umbrella term for the technology that can help a range of air users be more aware of what is operating in their surrounding airspace through electronic means, building on the traditional methods of conspicuity (for example visually acquiring another aircraft). EC includes the devices that can be fitted to a range of aircraft and ground vehicles, alongside the supporting infrastructure. Secondary Surveillance Radar (SSR) transponders (for example a Mode-S transponder), air traffic data displays and ground-based antennas are all examples of EC. EC solutions increasingly utilise Automatic Dependent Surveillance-Broadcast (ADS-B) – a surveillance technology in which an aircraft determines its position via satellite navigation.

The information generated by EC devices can be presented to pilots and air traffic services visually, audibly or both, to provide them with information on other traffic nearby. This strengthens the principle of ‘see and avoid’, whilst also enabling ‘collision avoidance systems’ (CAS) and ‘detect and avoid’ (DAA) solutions – the latter of which will be integral to delivering BVLOS UAS operations. EC devices, such as SSR Mode S transponders, are currently only mandatory for specified aircraft in certain blocks of airspace. They are currently not universally mandatory in the UK for general aviation aircraft that operate only in class G airspace (aside from transponder mandatory zones, which can be inside class G airspace).

It is worth noting that The European Union Aviation Safety Agency (EASA) has introduced the term "iConspicuity" to encompass the strategies, technologies and frameworks aimed at enhancing conspicuity (of which interoperability is a key part). Meanwhile, the International Civil Aviation Organization (ICAO) has introduced the term "reduced capability equipment" (RCE) for ADS-B devices that do not fully meet the minimum operational performance standards (MOPS) requirements, but still support conspicuity. It can thus be seen that the distinction between ‘what is’ and ‘what is not’ EC can be open to interpretation. For the purpose of this report, a broad view of what constitutes EC is taken, utilising the linked definition (Electronic conspicuity devices | Civil Aviation Authority (caa.co.uk)).

The CAA previously engaged the services of an external contractor (EGIS) which resulted in reports (CAP2498A, 2498B and 2498C) that recommended ‘minimum technical standards for EC and associated surveillance’. This programme of work aims to build on the recommendations produced within that report and enable the development of the technical concept of operations (ConOps) for EC in the UK. This report also aims to ensure that policy does not act as an unintended barrier to innovation in future EC functionality and safeguard a continued level of safety assurance for current operations. Furthermore, this publication will incorporate the societal, technological and policy developments which have taken place since publication of the EGIS report. For example, Global Navigation Satellite System (GNSS) spoofing and jamming has become a much more prevalent issue and the “enhanced EC devices” recommended within Civil Aviation Publication (CAP) 2498 have not been widely adopted.

Additionally, building on the CAA’s existing policy positions and following their direction, it is worth noting that integrated airspace in this report primarily refers to BVLOS UAS operating alongside manned aircraft. Most visual line of sight (VLOS) operations (for example an operator flying a small UAS over a park or model aircraft flying) will remain visually separated from BVLOS UAS and manned aircraft in the immediate future. This is deemed the most effective mitigation to ensure safe operations, however, this position may evolve in the future as technology develops.

This report consists of five interconnected workstreams which have delivered individual reports to the CAA as part of the wider project. This document brings together these reports to form a coherent narrative, with a central set of recommendations for the CAA to consider in relation to the EC ConOps. The key questions that the reports aim to answer are:

- **Workstream 1: Analysis of the Capacity Limits of ADS-B on 1090MHz and 978MHz**
  This report aims to identify the effective point of degradation for both 1090MHz and 978MHz frequencies. This will enable the CAA to predict the sustainability of the frequencies and number of applications that can be allowed to transmit on the frequencies.

- **Workstream 2: Analysis of the Probability of Detection of EC Devices**
  This report aims to determine the optimal options for EC antenna placement, orientation and diversity for detection across several airframes. It will analyse the real-world likelihood of detection and the impact of the Human Body on detection.

- **Workstream 3: UK EC Air Risk study**
  This report aims to outline how the level of unmitigated air risk varies across different UK regions and air volumes. It will then quantify the risk mitigation required to meet future traffic demands.

- **Workstream 4: UK EC Airspace Architecture study**
  This report aims to outline how EC could be used throughout the UK, by creating a future-state UK Airspace Architecture to enable the integration of new entrants.

- **Workstream 5: Human Factors – Integrating EC derived traffic into an existing 'See and avoid' airspace environment**

This report aims to analyse the impact of EC devices on improving safety. This includes how Human Factors influence and are influenced by EC.

To help the CAA build an effective ConOps (the objective of this report), and reflect how the overall project was approached, the ordering of the above workstreams have been adjusted within this report. A full overview of the report flow and the links between workstreams, can be found in chapter 2.

This study has focused on rapidly evolving technological concepts which are subject to frequent change. Therefore, there are some natural limitations to this study (see chapter 9). This report does not reflect the end of the 'EC-story', rather a key foundational block to build on over the coming years.

This report was produced in partnership with the CAA with their supplier partners: Baringa, Murzilli Consulting and QinetiQ.

Executive Summary

Key findings

1. This report aims to support the CAA in defining an EC ConOps. It includes a set of recommendations for the CAA to consider – to support enabling routine integration of BVLOS UAS operations in UK airspace. For the scope of this report, routine integration refers to BVLOS UAS seamlessly operating alongside manned aircraft, but remaining visually separated from most VLOS UAS operations. In future reports, the CAA will outline further information on the specific use cases which constitute the BVLOS/VLOS split and their specific decisions in relation to UK EC policy, alongside its effective and safe use.

1.1 The key outcomes from each chapter are:

Chapter 2: Unmitigated and mitigated airspace risk (workstream 3)

- Conclusion 1: This study developed a quantitative collision risk model that estimates the unmitigated and mitigated probability of a mid-air collision (MAC), given an encounter rate with other air traffic. After establishing a defined target level of safety (TLOS), estimated risk values can then be computed to assess or set performance targets for mitigating technologies such as EC.

- Conclusion 2: The unmitigated airspace risk range for the 2 modelled regions of UK airspace is estimated to be between $1x10^{-2}$ and $1x10^{-8}$ MAC/H (mid-air collision per hour). This estimated risk level and variability is expected, reflecting area-specific airspace structure and traffic. The introduction of additional traffic (including UAS) may increase the risk profiles differently in different sections of airspace.

- Conclusion 3: It is estimated that in certain scenarios (for example some uncontrolled airspace at very low altitudes or some low-level portions of under-utilised controlled airspace), the effective use of EC data as a primary mitigation source may be able to effectively support the safe integration of BVLOS for UAS. However, in other scenarios (for example most controlled airspace and aerodromes), it is estimated that EC (including EC data) may not suffice as a primary mitigation source, in which case 'heavier' mitigations (or a combination of) would likely be required.

- Key Recommendations (detailed version in chapter 8): CAA to use this analysis in their policymaking, explore opportunities to quantify EC's mitigation performance and the possible expansion of the regions modelled.

Note - the air risk analysis should not be used by any air users when making any operational decisions. This study has been completed only to support CAA policymakers develop future EC policy.

Chapter 3: 1090/978 MHz feasibility for EC (workstream 1)

- Conclusion 1: Air traffic numbers are expected to grow in the coming years. Based on the forecasts developed, the continued use of ADS-B on 1090MHz for primarily manned aircraft is recommended. However, beyond the year 2040, 1090MHz will see ever increasing congestion which may start to have an undesirable effect on Secondary Surveillance Radar (SSR) performance, potentially reducing the mitigating effect of EC in relation to air risk.

  Note – the total number of equipped airframes across the UK for 2040 (when there is a significant degradation) is estimated at 2123 units (further detail in Chapter 3).

- Conclusion 2: Therefore, the CAA should continue to carefully monitor the number of airframes on 1090MHz, which should include the expansion of the European monitoring of interrogators and transponders (EMIT) network in the UK and ongoing monitoring of 1030/1090MHz loading.

- Conclusion 3: As traffic (primarily UAS) on 978MHz increases, there will be an inevitable drop in detection performance on that frequency. However, detection appears to hold up well for ranges less than 11 nautical miles (NM) (see chapter 4 findings) even for the heavy traffic loads assumed for the year 2050 and beyond. Based on this, the CAA should immediately direct UAS on to 978MHz, as this will avoid additional loading of 1090MHz and maximise the mitigation benefit of EC.

- Key Recommendations (see chapter 8): Continue 1090MHz monitoring, direct UAS onto 978MHz and model ADS-B reception performance to understand the vulnerabilities of ADS-B specifically to a high load on 1090MHz.

Chapter 4: Probability of detection (workstream 2)

- Conclusion 1: The analysis did not indicate a strong enough preference across all airframes for a specific antenna location, position or orientation mandate. Instead, antenna placement guidelines should be produced and shared with users by the CAA – helping to maximise EC's mitigation effect.

- Conclusion 2: The CAA may wish to conduct a cost/benefit analysis to explore the impact of a mandate on antenna diversity (multiple antenna), for scenarios where there is a strong use case. For example, where aircraft structure and/or the human body have a significant and unavoidable influence on signal reception.

- Conclusion 3: During the unmanned flight trials (which used 20W transmitters), the range at which air-to-air EC detection became unreliable appeared to be between 11NM and 24NM. At 11NM, the detection between the EC devices was not always completely reliable. This distance should generally be suitable for air-to-air EC detection. However, it is important to stress that ‘real-world’ detection cannot be guaranteed at this distance and any decisions in a ‘real-world’ environment should not be based off this figure, with existing CAA guidance followed.

- Key Recommendations (see Chapter 8): The findings from this study should form additional guidance shared with users by the CAA, alongside a further analysis on an antenna diversity mandate in specific scenarios. The findings could also be inputted into any future analysis of the levels of air risk, to validate EC’s effectiveness as a mitigating technology.

Chapter 5: Human Factors (HF) Impacting EC (workstream 5)

- Conclusion 1: There are multiple HF hazards that should be addressed through publishing new user guidance, which should link closely with the guidance recommended in relation to the probability of detection study (chapter 4). The key current HF hazard is that information currently displayed on an EC display can present a compelling and apparently accurate picture, which may be unknowingly incomplete or inaccurate. This could generate a false impression of being clear of traffic threats.

- Conclusion 2: To maximise the effectiveness of EC as a mitigating technology, a combination of structured visual and aural alerts and a display that provided traffic cues in azimuth, elevation and range are deemed most effective. The human machine interface (HMI) assessment also found that a typical smart phone and tablet portable electronic device (PED) do not meet the perceived just noticeable difference (PJND) ‘warning’ alert criteria required for the ‘detect and avoid’ strategy under high ambient illumination conditions.

- Key Recommendations (see chapter 8): The findings from this study should be utilised by the CAA through publishing updated guidance and training materials published, such as the ‘Skyway Code’ and ‘Safety Sense’ leaflets. Additional engagement, particularly with UAS operators, is also recommended.

Chapter 6: EC airspace architecture (workstream 4)

- Conclusion 1: Based on the findings of the previous chapters, a potential EC airspace architecture for the UK was developed. This is a modular, phased and flexible approach to enable the integration of new entrants into the airspace.

- Conclusion 2: The architecture aims to deliver the necessary mitigations (including through EC) to achieve an acceptable TLOS (as discussed within the air risk study in Chapter 2). Five scenarios were developed which outline how EC would operate in a ‘real-world’ setting, utilising the findings of the other chapters of this report.

 Conclusion 3: The most notable updates and additions to the pre-existing direction of travel, if the architecture is implemented, can be summarised as:

- The potential to equip with dual-band ADS-B IN for all aircraft (as required)
- The introduction of a ground-based element such as multilateration (MLAT), to validate EC positions
- The utilisation of UTM service providers to distribute a "recognised air traffic environment" (RATE) and distribute it via mobile connectivity or a Traffic Information Service – Broadcast / Automatic Dependent Surveillance-Rebroadcast (TIS-B/ADS-R) protocol. **Note** - this service may also be provided by air navigation service providers (ANSPs).
- The option to transmit ownship position via mobile connectivity or TIS-B/ADS-R protocol, in the event of an aircraft has lost its own means to determine position (for example GPS jamming). For example, aircraft equipped with cockpit display of traffic information (CDTI) displays could have an additional "option" to revert to TIS-B ownship when onboard derived position information becomes unreliable.

 Key Recommendations (see Chapter 8): finalise the scope of the architecture (in relation to BVLOS/VLOS split), test the architecture in a live environment and begin the policy and operational activities to achieve its timely implementation.

Limitations of the study

1.2 Although considerable quantitative and qualitative analysis has been undertaken to support findings, there are limitations given it focuses on rapidly evolving technology. These limitations must be addressed in an ongoing manner, to ensure an evolving approach to EC.

1.3 A summarised view of the key limitations can be found below (full details in Chapter 9):

- There was less engagement with the UAS community compared to manned aircraft operators, due to them having less experience in using EC. This limited the richness of the findings in relation to Human Factors and UAS users. Further engagement with this community is recommended.
- The SIEM2 model used to analyse the 1090MHz frequency saturation does not fully incorporate ADS-B reception. This limits the long-term robustness of the recommendations in relation to the use of 1090MHz. Expanding the analysis to incorporate ADS-B and Wide Area Multilateration (WAM) reception performance is recommended.
- The air risk modelling covers only 2 regions of the UK, which were selected as proxies to reflect the wider airspace and to ensure the timely provision of data. Further analysis could expand coverage to the whole of the UK.
- In general, the modelling and analysis has utilised figures for the growth of aviation user numbers based on **estimation**. These figures came from engagement with users and available datasets. These numbers may be subject

to unforeseen changes and in certain cases may not reflect reality across the whole country. It is recommended that this analysis is regularly reviewed and updated by the CAA based on real-world outcomes.

- This report does not define on a use-case-by-use-case basis what constitutes BVLOS or VLOS operations. Whilst typical industry definitions apply, there will be specific use cases where it is not easily identifiable whether an operation is BVLOS or VLOS (or where the definition may change throughout an operation). The CAA must address this through future publications.

Chapter 1

Report flow and links between the studies

1.1 Each of the core chapters within this report are standalone studies with individual reports that have been shared with the CAA. To build a comprehensive narrative, different elements of each of the studies have been used to create a cohesive report here.

1.2 The "air risk study" (chapter 2) forms the initial input for the study, providing an overview of the "as-is" situation and the requirements from mitigating technologies such as EC to deliver BVLOS for UAS. We then discuss the frequency saturation of 1090MHz and 978MHz (chapter 3) and the probability of detection (chapter 4) to understand how to maximise the potential of EC from a feasibility and usage perspective. After this, we analyse the Human Factors implications of EC (chapter 5), taking all this information into account to design the new EC airspace architecture (chapter 6), which will aim to meet the required mitigations set out in chapter 2. The flow of this report, can be seen below:

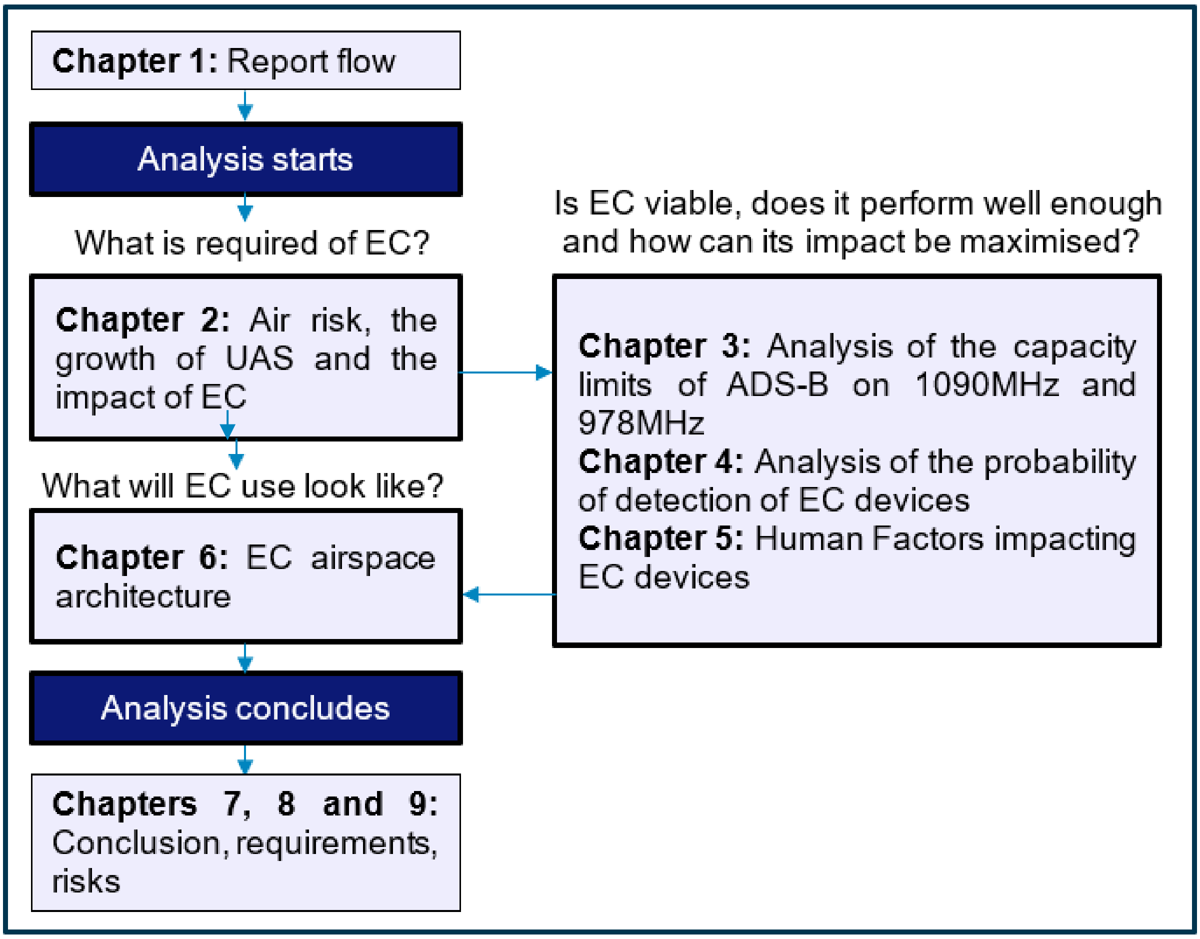

Figure 1.1 – Relationship between the workstreams

1.3 Throughout the analysis and this report, there are multiple links between each of the workstreams which have been used when computing results and making qualitative assessments. An overview of the key links between the chapters can be found below:

Chapter 2: UK EC air risk study

- Link 1 – The outputs highlight the trade-off between decreasing air risk through greater EC adoption and increasing frequency saturation of 1090MHz (chapter 3).
- Link 2 – The outputs were analysed against the findings from the probability of detection study (chapter 4) to understand how the “real-world” detection distances impact risk. Future analysis could utilise this when quantifying EC’s effectiveness.
- Link 3 – The outputs of the air risk study were used extensively when deciding the most appropriate airspace architecture (chapter 6). This included informing the scenarios developed, specifically where EC-alone was likely to be a suitable mitigation and where it would need to be supported by other technologies.

Chapter 3: Analysis of the capacity limits of ADS-B on 1090MHz and 978MHz

- Link 1 – Inputs (projections of growth of air traffic) were used in collaboration with the inputs for the air risk study (chapter 2), to ensure consistency.
- Link 2 – The outputs of this study were considered when computing the probability of detection (chapter 4) and how this would change as traffic increased.
- Link 3 – The findings of this study were utilised extensively when defining the airspace architecture and the most appropriate frequency for different air users.

Chapter 4: Analysis of the probability of detection of EC devices

- Link 1 – The findings from the probability of detection of EC study was used when analysing the Human Factors impact of EC (chapter 5). This included how detection rates (and missed detections) could influence user behaviours.
- Link 2 – the probability of detection informed elements of the 1090/978MHz study and airspace architecture – validating UAS to UAS detection distances.

Chapter 5: Human Factors – integrating EC derived traffic into an existing 'see and avoid' airspace environment

- Link 1 – The Human Factors study utilised findings from the probability of detection study (chapter 4), including the human body measurement campaign, when producing the recommended guidance for airspace users when using EC.
- Link 2 – The outputs of this study and the possibility that EC may be used incorrectly were considered when discussing the findings of the air risk study (chapter 2) and the impact of EC as a mitigation.

Chapter 6: UK EC airspace architecture study

- Link 1 – The airspace architecture drew on the outputs of all the studies when making assumptions about EC’s use and in its final designs. Additionally, the five scenarios were developed closely based on the findings outlined in previous chapters. They were also used as a proxy across wider work, such as for the functional hazard assessment.

Chapter 2

Air risk, the growth of UAS and the impact of EC

Intro

It is important to get a view of the estimated levels of unmitigated air risk in the UK and how this could be impacted by the introduction of BVLOS for UAS. Unmitigated risk means the estimated level of risk without the adoption of new technologies such as EC and unmanned aircraft system traffic management (UTM). For this analysis, mid-air collisions per hour (MAC/H) was used as the notation for capturing risk range. MAC/H means for all the aircraft flying in a region at any given time, how often (on average) would these aircraft crash into each other within one hour of total flying time.

Mitigated risk means the estimated level of risk of mid-air collisions, after taking specific safety measures to reduce risk. For EC, we do not have a specific figure for the level of risk mitigation it will provide, but from this analysis, we can estimate the level of mitigation that technologies such EC would need to provide. This analysis is therefore essential to understanding what EC may need to deliver, where this is likely to be achievable and where EC alone may not be enough.

Note – the air risk analysis is not complemented by any extensive safety testing beyond what is reasonably expected as part of the scope of the project. The estimations should not be used by any air users when making any operational decisions, as real-world risk-levels may be profoundly different to what the modelling estimates. Additionally, any third-party researchers or industry groups utilising this report for academic purposes should engage with the CAA before developing any broader analysis based on this work. The modelling has been developed only for the CAA and there are many additional factors which would need to be considered before any robust analysis could take place by third parties.

Objectives and Study Method

2.1 Regular and safe access to airspace is a key enabler to deliver routine BVLOS UAS operations in the UK. To explore the impact of air risk on this, the advanced air risk analysis software (which employs the Boeing-QUT collision risk model) enables an estimated baselining of the current unmitigated air risk and an evaluation of future mitigated air risk, with additional integrated traffic (including UAS) added.

2.2 These values can be used to evaluate mitigation requirements (for example EC), when compared against a TLOS such as an acceptable risk level. This gap is known as the residual risk. Where the residual air risk (the ratio of TLOS over the MAC risk) is 1 or greater, the mitigations used may be considered acceptable for safe operation in that volume of airspace (the TLOS has been achieved or exceeded by the mitigations). Where the residual air risk is less than 1, further mitigations may be required to achieve TLOS operations. The further less than 1 the figure is, the ‘heavier’ the mitigations required will be. This provides insight on what mitigations (primarily focused on EC), may need to provide to achieve TLOS in an airspace.

2.3 The UK does not currently have a clearly defined TLOS that covers all UK airspace. Joint Authorities for Rulemaking on Unmanned Systems (JARUS) propose 2 distinct TLOS values and the UK CAA is in the process of reviewing them for UK suitability for this type of MAC risk modelling application.

2.4 Two regions of the UK were chosen to be modelled to estimate air risk. The first region was in the south of England (ref: Chatham[1]) and captures major aerodromes in the UK, representing 'busy' airspace. The second region is in the south of Scotland (ref: Scotland) and contains regional aerodromes and would represent "rural" and/or 'regional' airspace. The intention of selecting these two regions (in consultation with the CAA) was to provide results that may be considered representative and insightful (with many different airspace features) without the requirement to model the whole of the UK. An image of the regions can be seen in figure 2.1.

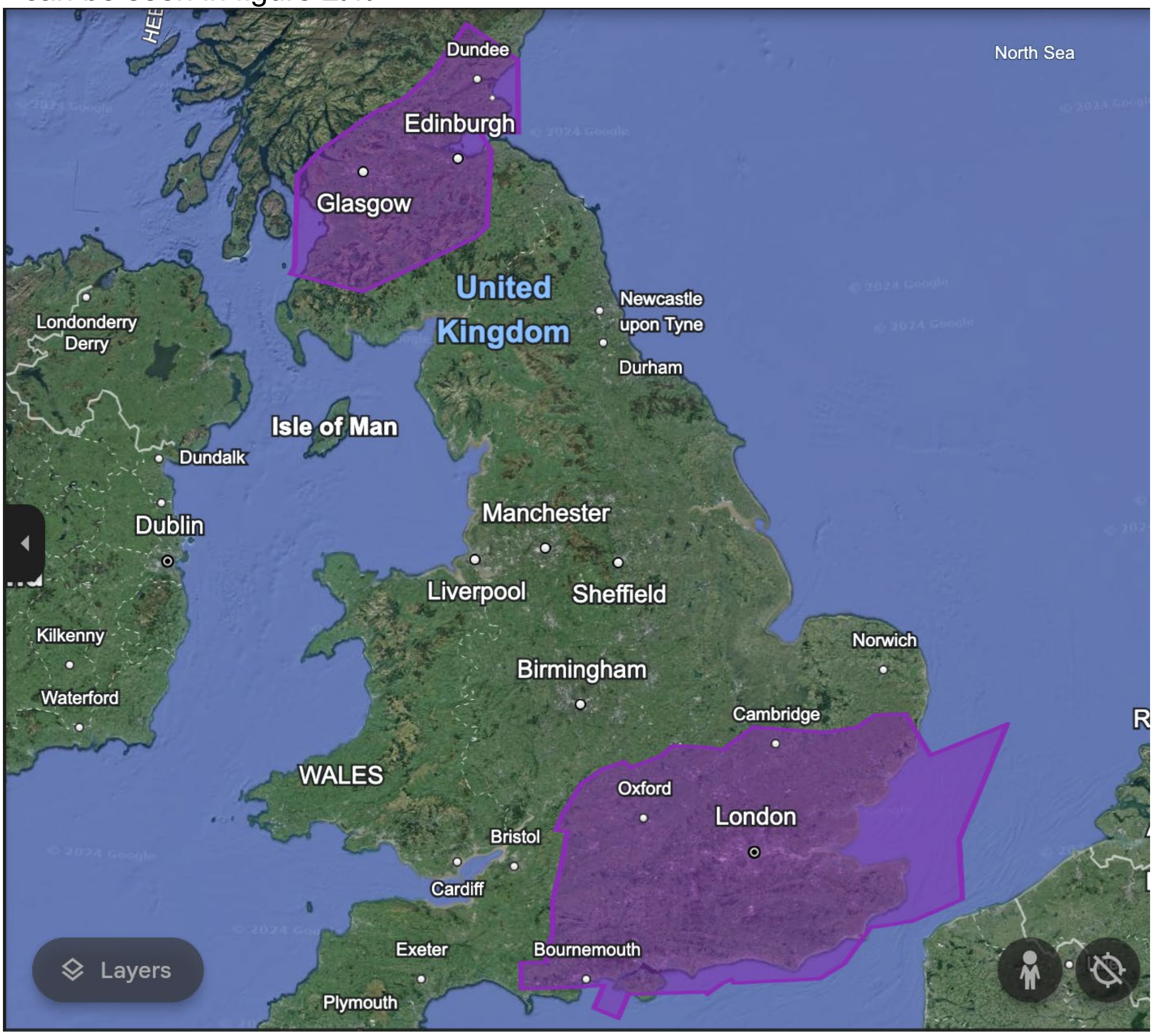

Figure 2.1 – the 2 regions modelled in the UK

[1] The name "Chatham" is based on an area surrounding the Chatham altimeter setting region, but it does not represent the actual dimensions of this altimeter setting region.

2.5 It is important to note that this report does not compute a specific level of risk mitigation that EC will provide. But from the analysis, we can attempt to estimate the level of mitigation that EC (alongside other technologies) would need to provide, and thus where this is or is not likely to be viable. Where possible, the analysis has attempted to link these with the scenarios used within the airspace architecture (chapter 6) for example UAS flying near aerodromes.

Analysis

Unmitigated air risk – current air risk with existing traffic and without new mitigations

2.6 The unmitigated air risk range identified across the two UK regions is estimated to be between $1x10^{-2}$ and $1x10^{-8}$ MAC/H. This means that on average, the estimated unmitigated risk of a collision per hour will be between 1% and 0.000001% when flying. This estimated risk level and variability is consistent with other analyses (other regions that have been modelled globally) and commonly assumed levels. These findings and the specific risk levels within the regions can help to identify where EC may be a more effective mitigation, once we move on to analyse estimated mitigated air risk (chapter 2.11 onwards).

2.7 In general, the unmitigated air risk analysis enables the identification of high-level airspace structures based on the levels of estimate risk they display (see figure 2.2, next page). Higher-risk areas (such as near traffic flows and near approach and departure paths) can often be seen in the darker colours (closer to 0 on Y axis). These reflect busier airspace where operating without mitigation is estimated to bring a higher level of risk (MAC/H). Low-risk areas, such as uncontrolled airspace that is not near approach and departure paths, can be seen in the lighter colours (closer to -10 on the Y axis). These are typically less busy or even sometimes ‘empty’ airspace, so operating in these regions unmitigated is usually lower risk.

2.8 To make an approximation, the estimated unmitigated air risk range for areas near aerodromes is estimated at between $1x10^{-2}$ and $1x10^{-4}$ and for traffic flows is estimated at between $1x10^{-3}$ and $1x10^{-5}$ (scenarios 1, 2 and 4 in chapter 6). Structures such as this can be seen in figure 2.2, such as the darker areas around traffic flight paths near the major London aerodromes. This indicates that the airspace is very close to busy aerodromes and traffic flows has typically higher levels of estimated unmitigated risk, versus those far away from such structures.

2.9 Additionally, some regions contain minimal data due to terrain, equipage, limited ground infrastructure or otherwise. An example of this is over the North Sea, which can be seen as well in figure 2.2. Most of the data in the model for areas with limited coverage (where aircraft may not have been detected) has come from augmented estimations only, rather than ‘real-world’ data.

2.10 In areas with stronger coverage (for example areas with more ground infrastructure where it is easier to detect transmitting aircraft in the real-world, for example around London), it is easier to identify with greater certainty the areas of airspace that could potentially be lower-risk and therefore may have low or no 'tactical mitigation performance requirements' (TMPR). TMPRs are the standards set to ensure that mitigations are effective in maintaining or enhancing safety within a section of airspace. An example would be an airborne collision avoidance system (ACAS), which must issue an alert at a **specific amount of time** before the closest point of approach between transponder equipped aircraft, to allow sufficient time for evasive action.

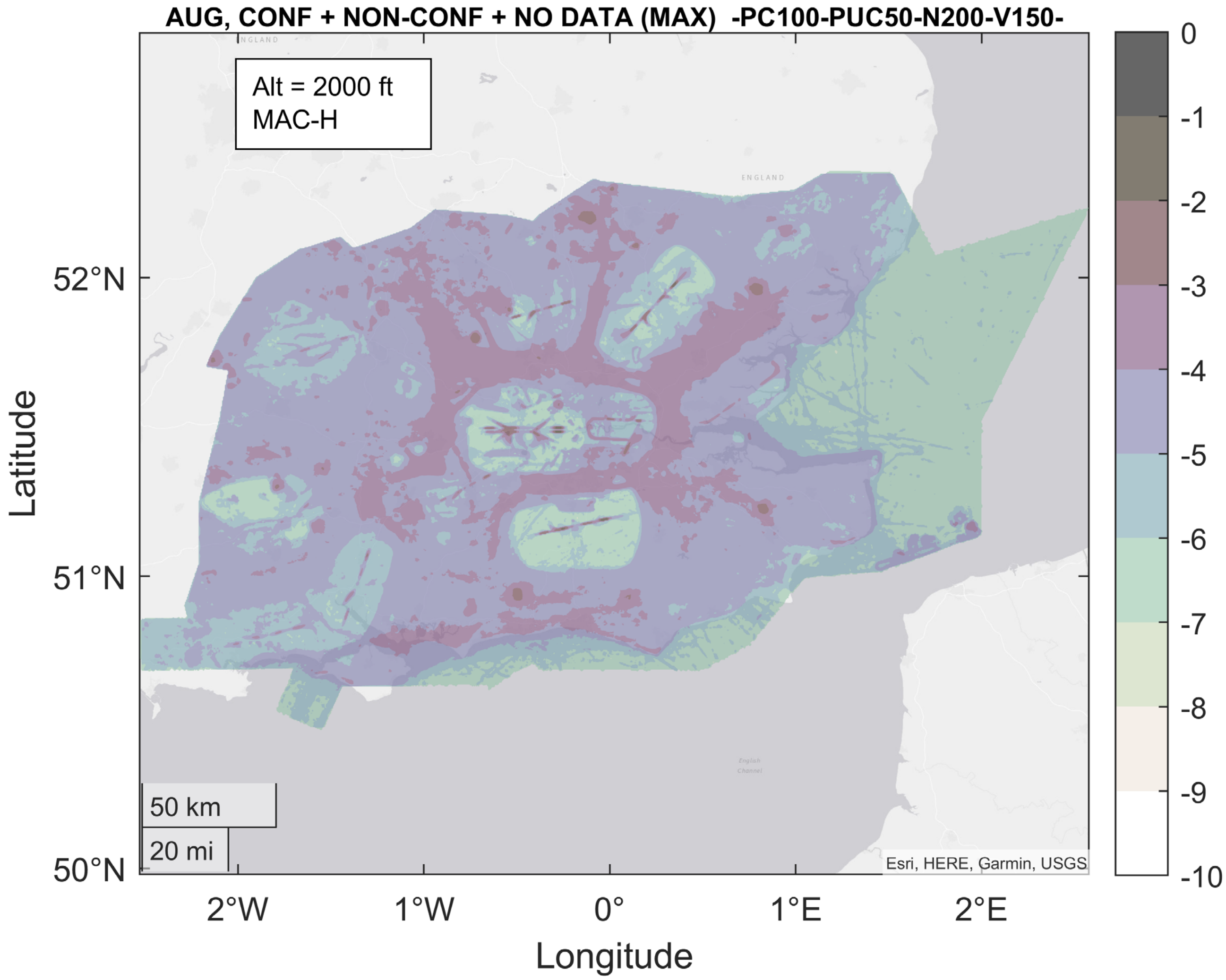

Figure 2.2 – Augmented unmitigated air risk for Chatham

Mitigated air risk – future air risk with increased traffic and mitigations

2.11 Following assessment of the estimated unmitigated air risk, we now assess how risk could change with additional traffic injected. This will allow us to quantify the estimated residual risk (the level of the mitigation that may be required to meet a desired TLOS) and understand where EC may be most effective. As the UK is still defining its TLOS, this assessment has used the TLOS set out in the JARUS Specific Operations Risk Assessment (SORA) framework (TLOS values of 1×10^{-7} MAC/H and 1×10^{-9} MAC/H, for encounter type 1 and 2).

2.12 It is important to briefly explain air risk classes (ARC) and their relation to TMPRs. ARCs (a, b, c or d) are used in the SORA framework to categorise the level of air risk associated with a specific UAS operation. Across ARCs, there is variation in relation to TMPR standards. This ensures that the level of mitigation requirement is appropriate for the specific risks and operational demands of each airspace risk class. An example to bring the concepts of residual risk, TLOS and ARCs together is that the study found that residual risk (the level of the mitigation required to meet a desired TLOS) naturally increases by two orders of magnitude near control boundaries. This is due to the assumed TLOS difference between ARC-d (high air risk) and ARC-a/b/c (low to medium air risk).

2.13 Moving onto the core findings, the estimated residual air risk for very low altitudes (0 to 500ft) suggests the required mitigation to meet the TLOS may be less than $1x10^{-3}$ (for 100% of the areas analysed), less than $1x10^{-2}$ (for ~60 to ~80% of the areas analysed) and less than $1x10^{-1}$ (for ~40 to ~60% areas analysed). It can thus be estimated that many (~40 to ~60% from the areas analysed) very low altitude operations could only require at least $1x10^{-1}$ mitigation effect. This may be achievable through the effective use of EC data and/or ‘detect and avoid’ (subject to further analysis).

2.14 The estimated residual air risk for mid-high altitude (4000ft and between FL100 and FL150) in controlled airspace suggests the required mitigation to meet the TLOS could be between $1x\ 10^{-3}$ and $1x10^{-6}$. Specifically, holding patterns may require between $1x10^{-5}$ and $1x10^{-6}$ combined mitigations in this altitude range. This suggests additional heavier mitigations (such as air traffic services) would likely be required to meet the TLOS, rather than just the use of EC data, as the proposed TMPRs for ARC-d of $1x10^{-1}$ will not suffice (subject to further analysis).

2.15 The estimated residual air risk for mid-high altitude (4000ft and between FL100 and FL150) in uncontrolled airspace suggests the required mitigation to meet the TLOS could be between $1x10^{-1}$ and $1x10^{-3}$. This suggests EC (air to air) alongside the proposed TMPRs for ARC-d could be sufficient in certain cases. Alternatively, ‘light touch’ (temporal, pre-flight de-confliction) mitigations may compensate for no EC (or use of EC data), where applicable (TMPR still required) and subject to further analysis.

2.16 We can now go into more detail to estimate the levels of mitigation that EC would need to provide if it is to be a suitable mitigation (remembering that we do not have a quantified level of the mitigation that EC will always provide). In summary:

- If the effective use of EC data provides at least $1x10^{-6}$ mitigation and TMPR provides at least $1x10^{-1}$, this could be all that is required to meet TLOS in any airspace. However, the emerging thinking around the mitigating impact levels of EC is such that any higher levels of mitigation (for example $1x10^{-3}$ or above) will be very difficult to achieve in a ‘real world’ setting. This scenario can therefore be discounted.
- If the effective use of EC data provides at least $1x10^{-3}$ mitigation and TMPR provides at least $1x10^{-1}$, this could be all that is required to meet TLOS in most

uncontrolled airspace and some special cases (sparser, bespoke regions) of controlled airspace. Again, emerging thinking is that this level of mitigation is very unlikely to be provided by EC alone. It is also important to note that controlled airspace is a broad definition, and the levels of risk within it (and near it) may change over time. For example, very low level (0 to 500ft) controlled airspace at the periphery of a control zone may carry little activity today, but they may be in significant demand by BVLOS operators in the future. This scenario can therefore also be discounted.

- If the effective use of EC data provides at least $1x10^{-1}$ mitigation and TMPR provides at least $1x10^{-1}$, this could be all that is required to meet TLOS in most low altitude (sub 500ft) airspace excluding inner aerodrome regions (such as near approach and departure paths or landing pads). Given emerging thinking on the effectiveness of EC, scenarios within this category could be a feasible solution where the effective use of EC data (TMPR still required) could deliver the mitigation required to meet TLOS (in a hypothetical air environment).

2.17 Based on these findings, we can therefore make some key estimations in relation to the applicability of EC to mitigate air risk. It is important to note that all the cases below assume a higher TMPR of at least $1x10^{-1}$ and should not be used to make any 'real-world' decisions on where is safer to fly in any live environment:

- For most uncontrolled (>90%) very low (0 to 500ft) and low-mid (2000ft to 4000ft) altitude regions, some aerodromes and some controlled airspace regions, the effective use of EC data with at least $1x10^{-2}$ mitigation effect could be acceptable for unmanned aircraft to safely integrate. An example of this can be seen from Scenario 1 (chapter 6), which outlines how EC and its data may be sufficient to deliver integration in a radio mandatory zone (RMZ) designated around an aerodrome in class G airspace.
- For the rest of uncontrolled UK airspace, the use of EC (and EC data) with at least $1x10^{-4}$ mitigation effect would likely be required. This mitigation effect is unlikely to be delivered by EC alone. An example of this based on Scenario 3 (chapter 6), would be how EC would need to be supported by other mitigating technologies, to deliver integration in a small area of class G airspace near a volume of airspace where paragliding, gliding and powered aircraft were all operating – should a BVLOS UAS also attempt to fly through.
- For most controlled (>90%) airspace regions (including traffic flows) and most aerodromes, the use of EC alone will likely not be acceptable. This is because EC (and EC data) would need to provide more than $1x10^{-5}$ mitigation effect, which is much more likely to be achieved through a combination of other mitigations, such as separation services and/or UTM. An example of this based on Scenario 4 (Chapter 6), would be how an urban class D aerodrome operating during its busiest hours, accommodating commercial airline flights and delivery BVLOS UAS, would require mitigation services beyond EC to safely integrate all users.

2.18 It can thus be concluded that in certain scenarios (for example some uncontrolled airspace at very low altitudes or some low-level portions of under-utilised controlled airspace), the effective use of EC data may be able to support the safe integration of BVLOS for UAS. However, in other scenarios (for example most controlled airspace and aerodromes), EC alone will likely not suffice. How feasible this is given technical and human constraints, alongside the wider scenarios which EC could operate within, is explored in the following chapters of this report.

Chapter 3

The feasibility of 1090MHz and 978MHz for EC use

Intro

An understanding of the estimated air risk levels and the levels of mitigation (given a TLOS) that technologies such as EC may need to provide to ensure the safe integration of new entrants has now been provided. But to be assured that EC could be a viable solution, it is vital to identify how EC will work on the 1090MHz (for manned aircraft) and 978MHz (for UAS) frequencies.

This analysis aims to help the CAA validate that the 1090MHz and 978MHz model is viable, establish how long it is viable for (recognising the medium- and long-term challenges due to spectrum loading) and inform any mitigations which may be required to address spectrum issues.

Objectives and study method

3.1 The following is a summary of the methods used to identify frequency degradation and capacity limits in a 1090MHz and 978MHz model.

Objectives and projected traffic growth ahead of modelling

3.2 Frequency saturation of 1090MHz is a known issue, as recognised by the International Civil Aviation Organization (ICAO) in their Global Air Navigation Plan (GANP) and Aeronautical Surveillance Manual (Doc 9924). The volume of both manned and unmanned air traffic is expected to increase between now and the year 2050 and therefore increase the load on the frequencies which these aircraft's EC devices transmit on. The CAA are already working alongside their international partners (such as ICAO) on this issue. To ensure that the frequencies can support the delivery of BVLOS for UAS and an acceptable safety environment for manned aircraft (in line with the air risk levels established in chapter 2), analysis was required to understand the limits of 1090MHz and 978MHz.

3.3 It is assumed that the 1090MHz frequency is to be used for primarily manned aircraft transmission (it may also be used by Instrument Flight Rules (IFR), operating unmanned traffic in controlled airspace in rare circumstances). It is also assumed that 978MHz will primarily be used by low-altitude UAS transmission (therefore aircraft are unlikely to be mixing with high-altitude commercial traffic). This assumption is based on the policy direction provided by the CAA.

3.4 To conduct the modelling, traffic growth scenarios were designed which represented present day and future traffic and surveillance equipage. These used predictions of air traffic growth (from EUROCONTROL forecast, EGIS report and in consultation with “Dynamic Airspace Allocation and Traffic Management”), to 2050 and beyond. These figures were designed to push the frequencies towards the limit of what was deemed likely to cause saturation and do not necessarily resemble what is likely to happen in the ‘real-world’ across all aircraft types.

Type	Present Day	2030	2040	2050	2050+
Commercial aircraft	Based on data records	Present day +13.6%	Present day + 26.3%	Present day + 39.0%	Present day +50%
Powered GA	Based on data records	Stable – No growth	Stable – No growth	Stable – No growth	Stable – No growth
Gliders	Based on data records	Present day +3.5%	Present day +8.5%	Present day +13.5%	Present day +60%
Ultralight aircraft	Based on data records	Present day +3.5%	Present day +8.5%	Present day +13.5%	Present day +60%
Other non-powered GA	Based on data records	Present day +3.5%	Present day +8.5%	Present day +13.5%	Present day +60%
Military aircraft	Based on data records	Increase with MOD expectations	Increase with MOD expectations	Increase with MOD expectations	Increase with MOD expectations
UAS	100 UAS	200 UAS	400 UAS	800 UAS	1600 UAS
eVTOL	None	None	100 eVTOL	200 eVTOL	400 eVTOL

Table 3.1 Scheme for the growth of traffic from present day to 2050 and beyond

3.5 Utilising these scenarios, two software models were then used to see how the capacity of the Radio Frequency (RF) environment may evolve over time; these are referred to as the SIEM2 and Universal Access Transceiver (UAT) Receiver models respectively. SIEM2 covers 1090MHz. The UAT model covers 978MHz.

Modelling the Radio Frequency (RF) environment for 1090MHz

3.6 The SIEM2 model is designed to simulate the RF environment for Identification Friend or Foe (IFF) and SSR signals. A “snapshot” of the operational environment, consisting of defined surface and air IFF/SSR systems is used to calculate metrics that are used to assess the ‘health’ of the RF environment. These metrics are:

i) **Reply efficiency (RE)** – The probability that a transponder replies to a particular interrogation

ii) **Round trip reliability (RTR)** – The probability that an interrogator will decode a reply to a particular interrogation that it has broadcast

3.7 The RF interference effects were measured from the perspective of the following six Interrogators of Interest, placed at strategic locations around the country (Great Fun Fell, Clee Hill, Cromer, Burrington, Heathrow).

Literature Review for ADS-B reception in 1090MHz

3.8 It is important to note that whilst the SIEM2 modelling includes ADS-B, WAM and traffic collision avoidance system (TCAS) transmission on 1090MHz, SIEM2 does not examine the performance of the ADS-B or WAM reception. A literature review was therefore conducted as a supplementary activity to address the ADS-B receiver performance aspect and explore the opportunity for additional modelling.

3.9 Considering the research available, there is some consensus that ADS-B on 1090MHz will (at some point) likely reach a saturation point. The precise 'saturation point' is not known as it depends on many factors. It is therefore recommended that ADS-B reception performance is modelled in the future to better understand the vulnerabilities of ADS-B to a high load on 1090MHz.

Modelling the Radio Frequency (RF) environment – 978MHz

3.10 The UAT (978MHz) model is an RF simulation tool that models the effectiveness of a UAT receiver in a multiple aircraft environment. It can model both ground based (air to ground) and airborne (air to air) performance of the receiver with respect to the reception and successful decode of ADS-B messages on 978MHz.

3.11 The key metric for the UAT Receiver Model is the **message success rate (MSR)** - the probability that an aircraft UAT transmission will be detected and decoded on each UAT (1 second) period.

1090/978 MHz feasibility – Analysis

Degradation of 1090MHz

3.12 As the volume of manned air traffic is expected to increase over the coming years, this will drive an increased load on 1090MHz. It is estimated that for primarily manned aircraft, the current 1090MHz load is sustainable up to around the year 2040, when a total of 2123 active airframes were estimated to be transmitting across the UK. At this point, a drop in RTR of almost 2 percentage points is anticipated. This figure indicates a notable impact on SSR performance.

3.13 Beyond the year 2040 (or 2123 active airframes), there is consensus that the 1090MHz spectrum will reach a saturation point, where some degradation of SSR performance will likely occur. This could reduce the mitigating effect of EC in relation to the air risk study (chapter 2), leading to a greater gap between the TLOS and the real-world mitigation effect.

3.14 It must be stressed that the 2040 timeline is an estimate and the precise 'saturation point' will always remain an estimate – meaning that it could come earlier than 2040. However, the study concludes that based on the modelling and ADS-B receiver literature review, 2040 is a suitable date to plan for. Additional modelling of ADS-B and WAM receivers could, in principle, allow future scenarios to be examined from the perspective of ADS-B reception to give greater validation to this timeline.

3.15 Moving onto Automatic Dependent Surveillance Rebroadcast (ADS-R), the modelling indicates that ADS-R is reasonably well accommodated on the 1090MHz frequency, especially as the added load from 978MHz traffic is expected to be moderate at worst. This outcome would support the use of localised rebroadcast of 978MHz BVLOS traffic, as part of an ADS-R rebroadcast on 1090MHz, without a significant risk to overall 1090MHz performance. This finding is incorporated into the designs for the airspace architecture (chapter 6).

3.16 Throughout the modelling, it is important to note that the key metrics vary more between the locations (interrogators of interest) in the present day than they do between the scenarios modelled. For instance, even when using present day traffic loads, the transponders within the operational range of Heathrow radar are more occupied than those anywhere else in the country over all the future scenarios modelled. It is therefore essential that the CAA continue to monitor usage of the 1030/1090MHz spectrum, and (where possible) expand it right now, regardless of future EC use.

Degradation of 978MHz

3.17 As the primarily UAS traffic on 978MHz increases, there will be an inevitable drop in detection performance. However, linking in with the findings of the probability of detection study (chapter 4), the modelling indicates that detection holds up well for the identified detection ranges (less than 10NM), even for the 2050 timeframe and beyond. Therefore, 978MHz is considered a viable frequency for UAS traffic for the foreseeable future, which should support EC as a mitigating technology in relation to Air Risk.

3.18 The modelling identified that obstruction beacons, covering glider, parachuting and model flying sites are easily accommodated on 978MHz in all future epochs, up to and including the extreme loading scenario. This finding has been utilised in the design of the EC airspace architecture (chapter 6).

3.19 A Traffic Information Service Broadcast (TIS-B) service (when considered as a service to rebroadcast SSR only aircraft, like those not using ADS-B OUT – further detail https://www.faa.gov/air_traffic/technology/equipadsb/capabilities/ins_outs), is easily supported by UAT on 978MHz due to the relatively small number of aircraft with a non-ADS-B OUT transponder. However, the UK's future airspace strategy may encourage wider EC use and, in due course, result in non-ADS-B transponders falling out of use. Hence, any TIS-B service (rebroadcasting SSR only aircraft) may have a relatively short lifecycle, and investment in the infrastructure to support TIS-B alone (without ADS-R or Flight Information System Broadcast, FIS-B) could be difficult to justify. This is why it is not included as a core service, in the airspace architecture in chapter 6.

3.20 ADS-R transmission on 978MHZ (which refers to the rebroadcasting of all 1090MHz traffic on 978MHz) has the potential to significantly impact UAT detection performance. Therefore, any implementation of ADS-R (on 978MHz) must be carefully managed. TIS-B/ADS-R (the use of the UAT TIS-B service to broadcast TIS-B/ADS-R messages on 978MHz) service volumes (ground to air) would need to be highly configurable (for example polygons, with altitude limits), to optimise the overlap in service volumes and mitigate the interference of critical air-to-air messages. Additionally, TIS-B/ADS-R transmitter power must be fully controllable, to allow the power and service volume to be matched. This finding is incorporated in the airspace architecture designs (chapter 6), which allows for TIS-B/ADS-R protocol in specific scenarios as part of a managed process.

3.21 Linking in with the conclusions of previous UAT Receiver modelling undertaken by QinetiQ and the Probability of Detection study (Chapter 4), it can be concluded that, as much as possible, all (UAT/978MHz broadcasting) aircraft should aim to transmit using the same output power. This is to avoid higher power transmitters swamping the lower power transmitters.

Recommendations for 1090/978MHz

3.22 The modelling supports the use of 1090MHz in the short to medium term (up to the year 2040), particularly from the perspective of the SSR system – as utilised in the airspace architecture designs in chapter 6. Beyond 2040, there is consensus that the 1090MHz spectrum will likely reach a saturation point, where some degradation of SSR performance may occur. This may reduce the mitigating effect of EC.

3.23 Therefore, planning for the alleviation of 1090MHz congestion should be an immediate priority for the CAA. The CAA have been using EMIT equipment to identify issues related to RF loading and it is highly recommended that the CAA continues to undertake their monitoring activities using EMIT. They should also seek to expand the EMIT network in the UK to provide a fuller picture of the RF spectrum usage.

3.24 Alongside this, limiting saturation could be supported by limiting the number of unsolicited transmissions on 1090MHz (such as through ADS-B). More importantly however, will be the management of the 1030MHz spectrum, in line with EUROCONTROL guidelines. For radar operators, this would include:

- Using a transmit power which aligns with the operational range.
- Limiting the BDS register extraction rate to that which is operationally necessary.
- Limiting the number of Mode S all call replies by setting the probability of reply to an appropriate value.
- Limiting the maximum number of re-interrogations.
- Increasing data sharing between military and civil sources.
- Reducing the overall number of interrogators.

3.25 The modelling also indicated that for 1090MHz the transponder-equipped aircraft have a significantly larger effect on the key metrics than those aircraft equipped with a non-transponder 1090MHz EC squitter device – something which should be considered within planning, alongside the recommendation above.

3.26 Currently, ADS-B and WAM reception performance are not measured by SIEM2. The development and use of an ADS-B and WAM receiver model could help the CAA to better understand any vulnerabilities of ADS-B to increased 1090MHz loading in a variety of future EC scenarios and predict the specific saturation point. Doing this will increase the robustness of the overall analysis, with respect to ADS-B.

3.27 The CAA should be directing UAS to use 978MHz immediately, to minimise frequency congestion on 1090MHz (whilst noting that some large military drones may still equip with 1090MHz).

3.28 A wide range of scenarios have been developed for this study, providing a good level of confidence in the results. However, if the underlying assumptions around equipage should change (for example an unforeseen change in EC policy), then these may need to be retested using newly developed scenarios. Additionally, whether the CAA adopts the 1090MHz 978MHz split in this paper, traffic on 1090MHz is expected to grow. This means that active monitoring is required regardless of the specific policy decisions which CAA take.

Chapter 4

The probability of detection when using EC

Intro

Following the analysis of the frequencies which EC will utilise and how they are expected to perform, the report now moves on to look at the possible optimal options for antenna placement and use, incorporating the impact of the human body. Doing this will enable an evidence-based decision on how best to use EC, by ensuring the maximum possible chance of detection and thus maximise the potential benefit of EC as a mitigating technology.

Note – this analysis should not be relied upon by any air users in a real-world environment. For example, an air user should not amend the placement of their antennae or expect detection at a certain distance, based on the outputs of this report. Any formal guidance on antenna placement and detection performance will be independently published at a later date by the CAA.

Objectives and study method

4.1 The findings of this study aim to aid the CAA in deciding whether to create either a mandate or guidelines regarding EC antennas and their use. A mandate could be justified if the real world and antenna modelling results showed a significant difference in detection performance from a particular antenna and device configuration, and if that result is held up across several aircraft types.

4.2 The following analysis was completed and split by aircraft type:

- Manned aircraft: antenna modelling – determine the antenna transmission patterns of EC devices when placed in or on several airframes and the development of expected detection performance.
- Manned aircraft: Manned flight trials – examining the differences in detection between an internally and an externally fitted EC device, alongside ground tests to produce real world polar diagrams of the EC antennae.
- Manned aircraft: human body measurement campaign – a campaign to examine the human body attenuation at the radio frequencies of interest.
- UAS: UAT Receiver Model – to predict how reliably a particular UAT signal can be received.
- UAS: UAS flight trials – examining the detection range of small EC devices operating on 978MHz and 1090MHz.

Analysis

Manned aircraft: antenna modelling – to estimate detection performance of manned aircraft

4.3 The antenna modelling aimed to understand the interactions between antennas and manned GA aircraft. It investigated the effects of positioning a particular EC device in various positions inside and outside an airframe. The study used three popular EC devices, identified in this document as Device 1, Device 2 and Device 3. The devices are anonymised to avoid showing favour towards any manufacturer. The antenna placement location by aircraft can be seen in figure 4.1.

Aircraft	Cockpit	Rear window	Under	Above	Nose	Wing	Tail
DG1000	Yes	Yes	Yes	No	No	Yes	Yes
DA42	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PA28	Yes	Yes	Yes	Yes	No	Yes	Yes
R44	Yes	Yes	Yes	No	No	No	Yes

Figure 4.1 outlines which airframes were modelled, with which antenna position.

4.4 For the manned airframes, the antenna modelling results for the rear-window mounted antenna were similar across all aircraft types. The vertical orientation indicated better performance due to radiation being allowed to propagate towards the nose, as well as the port/starboard directions. If placed underneath the aircraft, results were also similar across aircraft type, with lots of radiation being directed below the airframe. Tail mounted antenna radiation was dependent on the placement of the antenna, and the form of the tail. For those airframes that had a top mounted antenna, the results are like those of the underneath-mounted antennas but in the opposite direction.

4.5 Aside from the DA42 result (the only aircraft where the antenna could be safely fitted to the nose), performance for 'in-cockpit' antenna positions was not significantly worse than external positions. Therefore, externally mounting an antenna will not guarantee a better overall detection, as it very much depends on the individual aircraft type and the directions in which the operator is required to be detected from over the largest distances. Based on this, it is difficult to determine a generalised, 'best case' antenna location which will improve detection and maximise the impact of EC as a mitigating technology in relation to air risk (chapter 2). For example, mounting the antenna on the top (bottom) is only useful if you want detection above (below) the airframe, the latter of which is beneficial for ground detection. This links into Scenario 1 (chapter 6) – of which detection from below may be beneficial if manned aircraft traffic is approaching an aerodrome where BVLOS UAS is known to operate near at low altitudes.

Manned aircraft: manned flight trials – to validate the antenna modelling

4.6 The manned flight trial's purpose was to understand the air-to-ground detection performance of aircraft using EC device transmissions, including for different device placements. This would then be used to compare against the previously discussed antenna modelling and validate the findings.

4.7 The trials used a Diamond DA42M-NG Twin Star, carrying an EC device transmitting on 1090MHz. They were conducted utilising QinetiQ's Radio Trials Centre (RADEX) hardware and software facilities, dedicated to surveillance performance evaluations. The trials used multiple EC devices, of varying power outputs, using the data to create polar plots.

4.8 In terms of the power outputs, EC Device 1, which had a higher transmit power, achieved a better range than EC Device 3. Although a higher transmit power indicates a better detection performance, increasing transmit power beyond what is reasonable for the type of aircraft, may lead to a net-negative impact in relation to the overall frequency performance of 1090MHz (linking in with the chapter 3 findings).

4.9 Nose and window (right hand side) positions were tested, with the nose position proving to be distinctly better overall for detection. These broadly reflected what would have been expected – that is, for the nose position, stronger received signal when the aircraft is aligned towards the receiver; for the window position stronger received signal when there was a clear line of transmission out of the right-hand side window. Additionally, the results showed good matching with the antenna modelling results. The results help to give credibility to the antenna modelling and the conclusions that are drawn regarding antenna placement on the various platforms.

4.10 The trials also revealed repeated orbits (at the same range) did not always lead to the same pattern of detections. This is very likely due to each orbit not being exactly repeatable – for example, the roll angle of the aircraft being different on each orbit, due to variations in wind and turbulence. Congestion on 1090MHz is also a possible factor. Therefore, it is important to note that we cannot always predict with full certainty the range at which a threat aircraft will be detected, which must be considered when assessing the range at which detection is likely to occur within.

Manned aircraft: human body measurement campaign

4.11 The human body measurement campaign then went onto investigate the impact of a pilot’s body on the radiated fields from two different EC devices. This would be relevant in relation to Scenario 3 (chapter 6), in an area where paragliding operations co-exist with regular manned aircraft flights (which may contain multiple passengers). The measurements were carried out in the anechoic chamber in Funtington, enclosed to eliminate any outside signals. The walls and floor were covered with radar absorbing material that absorb a portion of the signal and reduce any reflections that could be picked up at the receiver.

4.12 The EC devices were first measured independently at different angles around the horizontal to record a baseline for later comparison with how the signal is attenuated with a human present. Once the unimpeded signal was measured, the EC devices were measured with a human volunteer stood directly in front, behind, to the side and diagonally in front of the device at different distances, to determine how the transmitted signal was affected by being partially or fully obstructed by a human.

4.13 Five volunteers were measured with a variety of body weights and heights to give good variation in the response and to inform the importance of body size on the attenuation. Two different EC devices were used, which were the same devices as used in the manned flight trials. Figure 4.2 shows how the separation of the EC device from the volunteers reduces the detectable range. For example, for Device 1 at a separation of 10cm, the detectable distance reduces to 18% of the unimpeded distance (at the angles when a pilot is positioned between the EC device and the receiver).

Distance (cm)	Device 1 range as a percentage of unimpeded	Device 3 range as a percentage of unimpeded
0	9%	7%
10	18%	14%
25	30%	27%
50	40%	34%

Figure 4.2: Approximate percentage reduction in detectable range for different separations of EC device and volunteer, averaged over the five volunteers.

4.14 We can therefore conclude that when inside the cockpit, the effects of a single human body serve to attenuate the RF transmissions (and thus the detection ranges) of the antenna. The radiation pattern will be affected in a similar way for each body present, but when multiple bodies are present there will be a compounding of attenuation and a larger number of angles where these effects are present. As the number of passengers increases beyond one, the radiation patterns vary significantly, and the levels (and thus the detection ranges) are reduced further. Therefore, having additional passengers in a cockpit will lead to a varying radiation pattern that will likely impact detection range. For operators in the para/hang gliding communities, CAA guidance may wish to consider recommending that operators place antennae in a location that will have a direct line-of-sight towards desired detection (as far as possible). However, this will need to be balanced against practicality in real-world conditions, where direction is often desired in multiple directions at the same time.

UAS: The UAT Receiver Model and UAS flight trials to test UAS detection performance

4.15 Moving onto UAS, the UAT Receiver Model computes received signal power in relation to EC devices. Its output enables a prediction of how reliably a particular signal can be received and therefore the probability of detection for UAS in an air-to-air environment. This could then be validated with the subsequent unmanned flight trials, comparing the performance of the model against a real-world setting. This information would help to validate the proposed approach for EC set out in Scenario 5 (chapter 6) which envisages multiple UAS in proximity over an urban area, requiring stable air-to-air detection.

4.16 The initial modelling using the UAT receiver model suggested that the UAS used in the flight trials should be detected (by each other) over tens of nautical miles.

4.17 Based on this, the UAS trials (which used: Hexsoon EDU-450, multirotor UAS; MFE Believer and fixed-wing UAS) were conducted to compare the UAT receiver prediction of “over tens of nautical miles” against real-world evidence.

4.18 During the flight trials, the range at which detection became unreliable with EC Device 1 and Device 2 appeared to be somewhere between 11NM and 24NM. At 11NM, the detection between the EC devices was not always completely reliable.

4.19 This was a far smaller range than was predicted in the UAT receiver model. It was thus clear that there was a large gap between expectations and outputs. Based on this, the model parameter values used in the UAT receiver model were revisited. The power output of the EC device 2 was measured as 20W, a value that matched the technical specifications provided by the manufacturer. Based on the achievable detection range quoted by the manufacturer, a more appropriate setting of the receiver sensitivity was set. This value was then reused for an updated UAT Receiver Model comparison, against the UAS flight trial results.

4.20 The correction of the receiver sensitivity enabled an accurate prediction to be made, which broadly supported the conclusion that 10NM is the maximum detection range. This is deemed a suitable distance to enable effective air-to-air detection on 978MHz, supporting the architectural designs (chapter 6).

4.21 This process demonstrated that that the configuration of devices (for example autopilot parameter settings, such as maximum range filters) receiving detections from an EC device must be well understood by the pilot and the implications of any such configuration, especially data filtering, should be fully considered for the use-case of the intended operation of the UAS.

4.22 The results also demonstrated that many detections can be received when using a small EC device. For instance, commercial aircraft typically have a transmit power in the range 150W to 250W, so they may be easily detected by low-cost EC equipment. This could give the false impression that these other air users can detect you. Based on this, a suitable detection range filter should be configured for the operation and capabilities of the UAS to reduce clutter and workload of the operator. This concern was raised by extant UAS operators in the Human Factors report (chapter 5).

4.23 As addition, the UAT model was also used to compare the examination of ADS-B on 1090MHz for the purpose of determining the likely detection ranges (for manned aircraft). This is possible because both 978MHz and 1090MHz are subject to the same attenuation considerations (including antenna gains, cable losses, free space path loss and atmospheric losses). The comparisons between the UAT Receiver Model and the manned flight trials were reasonably good matching, giving additional confidence in the UAT Receiver Model and the results presented in chapter 3 (in relation to 1090MHz frequency saturation).

Recommendations for the Probability of Detection

4.24 Taking the full set of platforms into account, the antenna modelling did not indicate a strong enough preference to justify a widely applied mandate for a specific antenna position, location or orientation. This is primarily because the results are not common across all the platforms and because some aircraft models may have constraints with regards to antenna placement. This was supported by human body measurement campaign, which concluded that due to the large number of different scenarios and possible user configurations, it is not recommended to justify a mandate regarding antenna position, location or orientation.

4.25 Rather than a mandate, the study team recommends that the results of this study feed into a set of guidelines, published by the CAA and recommended to airspace users. The guidelines would cover antenna placement, orientation and location aspects as well as the point at which an antenna pattern analysis is recommended. The guidelines could also discuss the RF transparency of aircraft materials. The specific guidelines recommended are outlined in the overall study recommendations (chapter 8).

4.26 There are however two specific situations where the CAA may wish to conduct additional research into whether a mandate is viable, given the potential to improve detection. The first is if there are four or more people in the cockpit. A mandate on antenna placement and/or pattern analysis in this scenario may improve detection. However, because human body size, shape and distribution could change for every flight – it would likely be unjustified to mandate an antenna pattern analysis when passenger configuration could regularly change. From the human body measurement results, the most important element of guidance in relation to this is that an EC device/antenna should be attached as far as possible from any person in the aircraft. Having more people present in the cockpit will lead to a larger number of detection angles where attenuation will occur.

4.27 The second area (where there is arguably a stronger case for investigating a mandate), is in relation to antenna diversity. A mandate for antenna diversity in the specific scenarios where it is deemed particularly beneficial could improve detection likelihood and therefore reduce air risk (linking in with the chapter 2 findings). A specific example of this would be when the aircraft structure and/or the human body(s) has a significant and unavoidable influence on signal reception. However, there are likely to be considerable cost impacts of this to users and in some cases, it may be unnecessarily burdensome to implement. Therefore, this study recommends that the CAA undertake future analysis to understand the specific cost-benefit ratio on this issue, in a use-case by use-case basis.

4.28 If antenna diversity is used, two EC antennas positioned perpendicular to each other would cover the user in the horizontal and vertical planes and if positioned at opposite ends of the aircraft this would help reduce the effect of blind spots due to a pilot being present.

4.29 When considering more generally the best way to improve the electronic conspicuity of an aircraft at range, it may be tempting to look at using a higher power transmitter. Comparing the manned flight trial results (which used an EC device with 20W transmit power) to the pre-flight trials results (where a 7W transmitter was used), there was a significant improvement in detection performance when using a higher power transmitter. However, there should be some caution applied when it comes to increasing the EC device transmit power, especially for devices that may be near the human body. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has published guidelines (ICNIRP Guidelines 2020) with regard to RF exposure, which should be fully taken into account in any guidelines. This is coupled with the fact that increasing transmit power beyond the necessary range will have a detrimental impact on 1090MHz congestion (as described in chapter 3). This is therefore not recommended as a solution to improve conspicuity as it is likely to have an impact on 1090MHz congestion.

4.30 Additionally, previous UAT capacity studies indicated that the use of mixed power levels penalised the lower power transmitting aircraft (in terms of detection range). Therefore, increasing EC transmit power for one group of airspace users may be detrimental to the electronic conspicuity of another set of airspace users, and should be avoided where possible. As set out in Chapter 6, it is recommended that air users consider the different ranges that detection may or may not occur, in relation to the type of EC device which are being used. This is an important Human Factors consideration (chapter 5), minimising the risk that air users negatively assume there are no threats just because they are not immediately visible through the EC device.

4.31 From the UAS trials, there are additional recommendations linking into human factors and the probability of detection (chapter 5). Many detections can be received when using a small EC device, which can give the false impression that these other air users can detect you. This can lead to an inappropriate flightpath management decision. Therefore, a suitable detection range filter should be configured for the operation and capabilities of the UAS to reduce clutter and work overload. Additionally, the configuration of devices receiving detections from an EC device must be well understood by the pilot and the implications of any such configuration. These conclusions should be used when forming a set of guidelines for UAS operators, which is discussed in the upcoming human factors chapter (chapter 5). They could also be considered in any future analysis of the levels of air risk (chapter 2), to quantify EC's effectiveness as a mitigating technology.

4.32 It is also recommended that EC device manufacturers review the in-depth study report in detail to ensure that stated performance and guidance aligns as closely with real-world detections as possible – especially in relation to transmit power, receiver sensitivity power outputs and expected detection ranges between EC devices.

4.33 Finally, the flight trials (both manned and unmanned) also revealed that repeated orbits at the same range did not always lead to the same pattern of detections (for example due to turbulence).

Chapter 5

Human factors in relation to EC

Intro

After establishing that EC is likely to be workable on 1090/978MHz and that the CAA should publish guidance on how to best ensure detection – we now investigate the human factor (HF) impacts of EC on airspace users (both manned and unmanned). This is critical to maximise EC's effectiveness as a mitigation tool (critical to achieving a desired TLOS) and minimise any potential negative impacts of its use.

Note – air users should not use this report to inform any real-world decisions and should wait for formal safety guidance updates from the CAA.

Study objectives and method

5.1 This study aimed to understand the current, and potential future, HF impacts of EC from the perspectives of manned aircraft pilots, UAS operating BVLOS, and Air Traffic Control Officers (ATCO) and Aerodrome Flight Information Service Officers (AFISO) when using (or potentially using) Flight Information Displays (FIDs). The approach can be broken down into several stages, as shown in Figure 5.1 below.

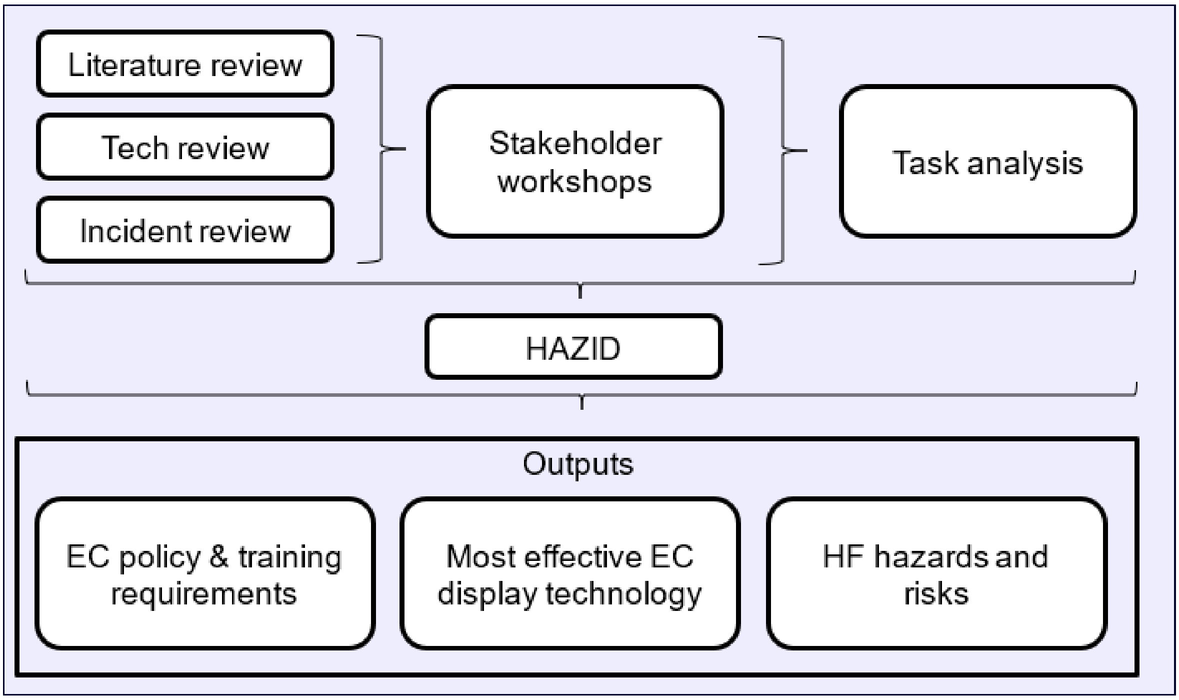

Figure 5.1 approach to the human factors analysis (HAZID refers to Hazard Identification).

5.2 The first step was a literature review to establish the extent of scientific and industry led research on EC use. The information gathered from these reviews was used to inform 10 stakeholder workshop focus groups. These were conducted with 46 Participants from GA and Commercial aircraft, UAS and Air Navigation Service Provider (ANSP) communities. Additionally, a Hazard

Identification Workshop (HAZID) was conducted across the same communities to identify hazards associated with EC and potential mitigations.

5.3 It is important to note that as the manned aircraft user groups are the most experienced operators of EC, the gathered data is unavoidably skewed towards manned aircraft pilot experiences. UAS and ATS (Air Traffic Service) user groups had limited exposure to EC due to lower levels of usage. While some AFISO participants had experience of using FIDs, ATCO participants described using radar surveillance displays.

5.4 From the air traffic control perspective, only FIDs were considered due to the study scope being confined to EC device use. While some AFISO participants had experience of using FIDs, the ATCO participants in this study had only experienced using radar surveillance displays. However, the ATCO participants expressed valuable insight of how the addition of EC emitting aircraft to a radar surveillance display might impact their role. Future work in this area could analyse the broader impact of ATS surveillance systems, beyond that of specifically EC device use.

5.5 This work was supplemented by an HMI review. This considered EC devices in terms of how information is provided to the user within the cockpit in two scenarios:

(1) Use Case A: Tablet computer resting on pilot’s knee
(2) Use Case B: Smartphone mounted to cockpit coaming

Analysis

Literature review

5.6 The literature review highlighted several scientific studies which showed that visually acquiring an airborne aircraft is an unreliable process which requires cognitive effort to perform, when sufficient time to scan, locate and recognise the target is available. This aligns with the findings of the General Aviation Safety Council (GASCo, 2023) report on EC devices and human factors. Alerted searching technology (such as EC) is effective in terms of improving reliability of visual acquisition, particularly by reducing the time taken to locate the target.

5.7 However, EC assisted searches can present an increased risk of airborne conflict if pilots exhibit too much or too little belief in the technology. Additionally, while alerted searching technology can be effective, it is also accompanied by increased information processing for a pilot or operator to cope with. This could be an issue in relation to Scenario 3 (chapter 6), a busy uncontrolled traffic area where multiple types of aircraft interact and many traffic alerts (from EC data) are likely to occur. Furthermore, where an alerted system produces alerts which prove to be spurious, then operator trust reduces which may lead to disregarding genuine collision risks. An example of this could be alerts which falsely indicate a collision risk when a pilot is flying safely in an aerodrome traffic circuit.

Incident review

5.8 The findings from the incident review can be grouped into three categories:

5.9 Disregarded or inaccurate EC traffic alert cue: in three cases, the EC device produced an alert but with no vector or altitude data to direct visual search. In another incident, a Traffic Alert and Collision Avoidance System (TCAS) Traffic Advisory (TA) alert was disregarded because the crew believed the system to be inaccurate, so the aircraft remained on its flight path sufficiently close to the target aircraft to prompt an airprox report (the pilot disregarded a genuine alert as the system was previously known to have errors).

5.10 Visually acquired Traffic Advisory System (TAS) threats: eight cases reported use of EC in the alerted see and avoid task; detecting an EC threat, visually acquiring it then manoeuvring to avoid it based on the threat aircraft visual behaviour. However, in one reported case, an identical process led to an 'airprox' with a third aircraft which was not EC detectable. In two cases, crews visually acquired the EC threat aircraft and chose to monitor it without taking avoiding action, leading to the threat aircraft pilot filing an airprox report.

5.11 Non-visually acquired TAS threats: the most frequently occurring theme described pilots taking avoiding action based purely on their interpretation of EC alerts indicating the location of an EC threat aircraft which had not been visually acquired.

Stakeholder workshops

5.12 The stakeholder workshops led to the identification of several HF impacts. These are outlined below and grouped by user group.

5.13 Manned aircraft: the key emergent HF finding was that information displayed on an EC device can present a compelling, comprehensive and accurate picture which may be unknowingly incomplete or inaccurate. This is particularly relevant in relation to the probability of detection study findings (chapter 4), which indicates that detection is variable and cannot be guaranteed at distances over 10NM. This could generate a false impression of being clear of traffic threats, which risks increasing the likelihood of a MAC.

5.14 Manned aircraft: whilst all manned aircraft participants also emphasised using EC data to direct 'see and avoid', the results indicated that EC data is used strategically at distances beyond visual acquisition range to prevent or reduce exposure to 'pop up' traffic threats.

5.15 Manned aircraft: when pilots make avoidance decisions based upon EC information alone, there is risk of reduced separation from undetected aircraft, or detected aircraft which have not detected them (supporting the findings from the probability of detection study chapter 4). Pilots should regard EC information as a partial representation of traffic density. Conversely, when an EC system produces non-urgent alerts, it may lead to disregarding a genuine collision risk, reducing the EC display from a part of the flight instrument panel that pilots use to navigate, to a device which is purely an aid. Pilots should therefore ensure that their EC display is configured to produce as few non-urgent alerts as possible. This will likely need to be monitored by the regulator and manufacturers as part of any future approaches to alert thresholds and user configuration – in conjunction with DAA technical standards. It will also be important when finalising the mitigating impact of EC, as recommended in Chapter 2.

5.16 Manned aircraft: an additional key HF impact is that large amounts of EC data presented to users may increase their workload to the point of saturation. Manned aircraft participants felt that overload was more likely when EC is integrated into moving map displays because a traffic alert icon may blend into mapping and symbol colours. This can delay the acquisition of a collision threat and reduce the benefit of EC to avoid collisions. Participants described that busy airspace such as aerodrome environments (for example Scenario 4, chapter 6) can generate multiple EC alerts which increase cognitive workload.

5.17 UAS: where multiple systems are used by UAS users, it is suggested that fusion of data from each EC system should be combined into a single display so that there is one unified picture of the airspace around the UAS vehicle. Given the reduced visual cues, it is recommended that this picture should contain a plan view alongside a view of aircraft position/separation as a function of altitude.

5.18 UAS: while UAS EC usage was nascent, several UAS industry led sandbox trials are underway to identify how EC could be used to visually separate UAS from other airborne traffic and, if necessary, prompt a hold or avoidance manoeuvre. Participants in this study stated that UAS are more manoeuvrable and better suited than manned aircraft to perform avoidance manoeuvres (although this is likely to be dependent on the specific type of aircraft). The CAA should remain engaged with industry led sandbox trials to determine these manoeuvres and update future UAS EC guidance.

5.19 AFISO: AFISO descriptions of using ADS-B FID included using EC data to gather accurate information of where pilots are operating within the vicinity of their aerodrome (for example Scenario 2, chapter 6). AFISOs described that this information improves the accuracy of flight information they convey to pilots. AFISOs also described that the compelling nature of the FID presents a risk that AFISO may use EC for control rather than advise, particularly if they are not aware of FID limitations as stipulated in CAP 797 and CAP 493 MATS part 1. This could lead to a pilot being directed to a course of action that brings them into conflict with a collision threat which is not visible on a FID.

5.20 ATCO: ATCO participants asserted that incorporating EC data into surveillance radar displays was dependent on robust accuracy assurance of EC position, type and altitude data. Participants also identified a risk that the addition of EC data could increase display saturation and associated workload. Reducing this risk was described as achievable by applying data filters to declutter the display. However, ATCOs suggested such filtering is not always possible due to the requirements imposed by controlled airspace or ATCO role.

Hazard Identification (HAZID)

5.21 Many of the hazards raised during the HAZID aligned with those raised during the stakeholder workshops. One of note was the pilot reaction to a portable electronic device (PED) failure, EC device malfunction or loss of signal. Participants described experiences where such failures had prompted heads-in time to diagnose and resolve them, reducing available attention to flight path management and external scanning.

5.22 Additional hazards were described in which PEDs and associated internal antennas and cabling running navigation and EC applications presented distractions and potential control restrictions when dislodged during flight, either by turbulence, manoeuvring or failure of the device mount (suction mounts were described as particularly prone to failure). The mounting of PEDs and associated componentry may also present a hazard to safe emergency egress; dislodged devices may strike occupants during manoeuvring or may obstruct escape routes. This should be considered by the CAA when deciding on mandating antenna diversity, as set out in chapter 4.

Human Machine Interface (HMI)

5.23 This review considered EC in terms of how information is provided to the user within the cockpit environment, forming a qualitative and quantitative assessment. The aircraft cockpit provides a challenging operating environment for a display system because the airborne ambient environment can vary due to dynamic orientation of the aircraft (along with aircraft type and configuration) and increased area for sunlight to penetrate. As a result, the illumination, shadow and glare effects can vary in the cockpit.

5.24 In recent years, mobile computing and display devices have developed with more in-built functionality such that they may be used as a cockpit display. The lack of specific aviation design requirements has led to a range of display technologies being available to the GA pilot who may not have the necessary knowledge of HF, display metrology and specification to discriminate between effective and ineffective devices.

5.25 Based on the findings of the quantitative analysis, the key HMI impact is that typical smart phone and tablet PEDs (as assessed) do not meet the PJND ‘Warning’ alert criteria required for the ‘detect and avoid’ strategy, described in literature source 149, under high ambient illumination conditions.

5.26 Additionally, there is also a need to consider the appearance of the symbols used in EC devices and how their saliency can be improved to increase detection when a traffic threat increases. Additionally, the displaying of traffic threats should raise their prominence as a visual cue and can be achieved through a change in the luminance or colour of the traffic threat symbol. If a colour change is combined with a change in luminance it will assist in increasing the saliency of the object and allow the change to be detected by the pilot during their scan pattern.

5.27 The study also found that using combined audio and visual cues can have significant benefits to the user. Audio cues to traffic threats should include a unique alerting attention followed by a verbal message, giving a cue of the type of alert, location and heading of the traffic threat. Visible cues should include redundancy through a combination of luminance, colour, shape, and temporal properties, for example blink rate and changes in luminance.

5.28 In terms of preferences, manned aircraft users did not describe a singular HMI as most effective; users employed their preferred visual and audio alerts based on their previous operating experience or trial and error of using EC. As a result, no ideal single EC usage method was identified, suggesting that configurability of alert types is highly important to effective EC use.

Recommendations

5.29 The CAA currently share comprehensive awareness information to the user community via numerous print, audio and visual sources such as ‘Safety Sense’ leaflets and ‘Skyway code’ updates. It is recommended that future updates to user awareness information sources include:

- Use of recommended EC devices which are appropriately installed, configured and tested for acceptable performance.
- Specific user training for operating EC devices, collision avoidance rules and mitigations such as traffic information provided by an AFISO. Such training should include the HF considerations identified in this report.

5.30 The specific updates recommended are outlined in the recommendations chapter of this report (chapter 8). An example includes, informing pilots that they should ensure their EC device is configured to produce as few non-urgent alerts as possible to reduce risk of dis-regarding EC alerts. Where possible, any guidance should link closely with the recommended guidance in relation to the probability of detection (chapter 4) and antenna placement.

5.31 The CAA may also want to consider developing future bespoke EC training for users. In a ‘detect-and-be-detected’ airspace environment, some level of EC training should be mandated. For manned aircraft operators, this could be provided during student pilot training or during revalidation. The operating scenarios described by UAS operators suggest that a similar level of training as ATCOs undergo to perform radar surveillance tasks could be appropriate. Such training should include the best practise for using EC and mitigating potential use risks, linking in with the findings of the other chapters of this report as much as possible.

5.32 This study also recommends that a stakeholder volunteer working group of manned aircraft, UAS and ATS participants agree a set of standardised features and cues, which can be used by EC HMI original equipment manufacturers (OEMs) when designing EC products for future use. The specific updates are also outlined in the recommendations chapter of this report (chapter 8).

5.33 As mentioned previously, the manned aircraft user groups were the most experienced operators of EC devices, while UAS user groups had very limited exposure to EC. Whilst the manned aircraft operator findings can be inferred to the UAS domain, an unavoidable research gap remains. Identifying the HMI requirements for UAS operators will require further research which places those operators in a simulated airspace environment. Such research will also address the cognitive workload concerns expressed by UAS users.

5.34 While some ATS users were experienced in using FIDs, the ATCO participants in this study reported no EC device use but were highly experienced at controlling traffic using radar surveillance technology. ATCO concerns were focused on being able to differentiate between radar and EC contacts on the same display, given their technological differences. ATS users should therefore agree on a suitable EC icon design which enables identification of EC contacts amongst radar contacts.

Chapter 6

EC airspace architecture

Intro

Up to this point, the report has concluded that EC could help support BVLOS for UAS and that it is viable from a frequency use perspective (assuming monitoring activities are scaled). Its effectiveness can be impacted by antenna configuration and how the human uses the device – areas which the CAA can look to mitigate through regulation, training and guidance.

Building on this, the report now outlines the potential future UK EC airspace architecture. This architecture builds on the previous studies and aims to achieve the risk mitigations required to ensure integrated BVLOS for UAS. However, EC cannot be viewed a “standalone solution”, and its use should be incorporated alongside wider technologies such as UTM – as seen in the architecture designs (Chapter 2).

Study objectives and method

6.1 Based on the objectives outlined in the AMS and FoF strategies, alongside the findings of this report, the use and adoption of EC will support delivering BVLOS UAS operations in the UK. However, specifying ‘how’ this will be done requires thorough investigation.

6.2 To begin this process, an extensive literature review of previous EC reports and publications was performed. This was combined with additional engagement with numerous aviation authorities and industry contacts world-wide. The key findings identified from this literature review, alongside the extensive results from the other studies of this report (for example Chapter 3’s finding to direct UAS operation onto 978MHz), generated a set of ‘airspace assumptions’ which would be used as the foundations for the airspace architecture. After these were developed and tested with a range of stakeholders – a full Airspace Architecture, with use case scenarios, was developed.

6.3 After being developed, the architecture was extensively tested with CAA stakeholders to ensure robustness. An independent functional hazard assessment was also conducted to assess resilience against defined functions.

Analysis

Literature review of EC technology – key findings and trends:

6.4 **Spectrum separation between manned and unmanned aircraft and “enhanced EC”**: There are only two categories of EC devices, 1) Basic EC devices (CAP1391 or equivalent) or 2) Certified devices. The EGIS reports (which the CAA previously commissioned) highlighted a requirement for a new type of EC, the so-called “enhanced EC”. This would be available at lower costs than a certified solution, but with assured data provision. However, the "enhanced EC" solution formulated has not fully materialised, with no widescale adoption of all the recommended functionality. This highlighted an adjustment from the recommendations within the EGIS report may be required.

6.5 **The existing CAA requirements for EC in the UK are not risk-based and have not yet been fully captured:** The literature review did not identify any source that adequately captures the full set of requirements that would be required for EC use in the UK. In the absence of a complete set of validated requirements, the proposed UK EC architecture has been developed around the critical capabilities and functions required to provide a recognised air traffic environment (RATE) to all airspace users.

6.6 **The safety contribution of EC technologies that are not certified (for example those in CAP1391) and any other equivalent technology, is unclear:** The literature review did not identify any source that properly considers the safety contribution of non-certified EC technologies. While such technology cannot be used for safety-critical purposes, it is less clear why its safety contribution to the overall TLOS has not been investigated or considered.

6.7 **UTM has not been adequately considered in early work on EC:** The review highlighted a gap in the consideration of UTM technology with a significant "skew" towards EC technology that might be unjustified. The updated UK EC airspace architecture considers the integration of UTM-like solutions, to mitigate the risk of mandating technology that could be made unnecessary by parallel technological developments in other fields – as the CAA are also currently doing.

6.8 **Insufficient recognition of essential trends in the advancement of UAS technology:** Several reports analysed show a simple understanding of UAS technology. Large UAS operations with a 1:many ratio (between operator and UAS) and urban operations, were only superficially considered throughout. Conversely, many studies depict a pilot using a command unit to steer small drones, failing to capture the complexity, cost and real nature of low-level UAS operations.

6.9 **Risk-based operational volumes:** With the gradual adoption of the JARUS SORA methodology in the UK, a significant emerging trend will be the use of different air risk classes (ARCs) to capture the different nature of the risk within existing airspace classes. This could ultimately result in different EC performance requirements (and equipage requirements) for the same airspace class solely based on ARC. In support of this work described above, the findings from the air risk study (chapter 2) could be used to support quantitatively defining the different ARC for the UK.

Airspace assumptions

6.10 Based on the findings from the literature review, the other chapters in this report and the objectives shared by the CAA – a set of 30 airspace assumptions were developed to guide thinking. These assumptions are integral to ensuring that the architecture delivers the CAA's objectives in a way that is technically feasible and safe. The following list is the top 5 assumptions, part of the wider catalogue that lays the groundwork for the UK EC architecture:

6.11 The EC functions to be deployed in a volume of airspace will depend on the class, risk level and complexity of the airspace in which flight operations are going to take place.

6.12 EC solutions can be broadly categorised as follows:

- Category 1 EC solutions providing information to be used by ATS services (CAP 670 Subsection SUR 02) exclusively on certified 1090MHz.
- Category 2 EC solutions providing information for ICAO FIS services in controlled airspace and detect and avoid applications for UAS, possibly on 1090 MHz and 978 MHz with additional position validation by for example multilateration (MLAT).
- Category 3 EC solutions providing information to aid situational awareness.

6.13 Each aircraft must be equipped according to the requirements applicable to the airspace it operates in, independently from EC (they must follow the equipage rules for where they are flying).

6.14 Any mandate to use EC technology (airborne and/or ground) is in support of the achievement of the TLOS.

6.15 The top-level functions that EC solutions support in UK airspace are:

- Aid to pilot situational awareness
- Provision of Flight Information Service data (in accordance with UK Regulation (EU) No.923/2012 Section 9)
- ACAS hybrid surveillance and future collision avoidance applications
- Detect and Avoid for UAS

Worked example

6.16 Before going into the specifics of the architecture and the supporting scenarios, it is worth providing an example of how the findings from previous chapters were used to formalise the architectural design. The architecture proceeded under the assumption that any EC solution would be developed with 1) the availability of a RATE to all airspace users, 2) adequate guidance on how EC should be utilised (for example where to place an EC device from Chapter 4 and how best to use one from Chapter 5) and 3) the ability to function effectively from a frequency perspective (from Chapter 3). If these conditions are met, it is estimated that EC could provide a reduction in risk of up to two orders of magnitude (for example $1x10^{-2}$).

6.17 Based on this, figure 6.1 (an intersection of the layers of airspace from 100ft to 500ft from the air study in chapter 2) indicates the regions where a reduction of $1x10^{-2}$ could be sufficient to meet the TLOS. In other words, the areas represented in brown provide an initial indication of areas that **could** be candidates for BVLOS UAS operations with only EC (including the use of EC data) as a mitigation. The areas in a lighter colour would likely need heavier mitigations (for example UTM and EC). Findings such as these are incorporated throughout the designs of the architecture that follows.

REQUIRED RISK MITIGATION TO ACHIEVE TLOS FOR BVLOS OPERATION

Combination of airspace layers from 100 ft to 500 ft for South-East England (top) and Scottish region (bottom) resulting in required mitigation order of magnitude to achieve defined TLOS for BLVOS operation.

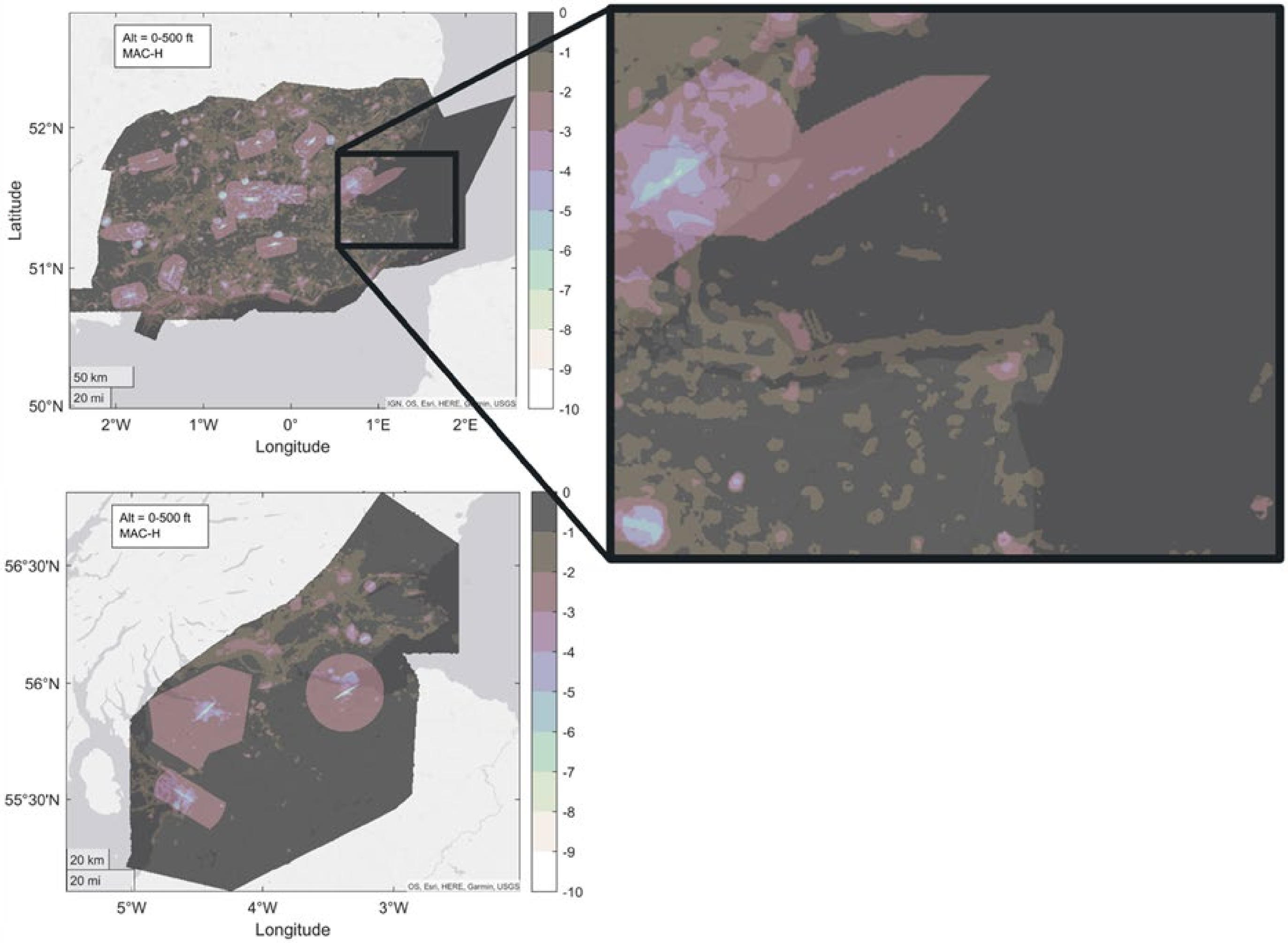

Figure 6.1: required risk mitigation to achieve TLOS for BVLOS operations

Airspace architecture

6.18 Based on the findings discussed throughout this report and the assumptions developed – a potential UK EC airspace architecture was developed. The architecture provides a modular, risk-based and flexible approach to enable the integration of new entrants into the existing UK airspace. The architecture describes a theoretical concept that, at the time of writing, has not been fully verified for its operational feasibility or fully safety assessed.

6.19 The Architecture reflects that most VLOS operations are expected to remain visually separated from BVLOS UAS/manned aircraft operations. How this operates in practise (alongside the specific use cases of what constitutes VLOS or BVLOS) will be addressed by the CAA in their publications.

6.20 It is envisaged that the architecture will be delivered in a phased approach, which will evolve over time. The modular nature of the architecture will allow for different levels of integrity and assurance in different scenarios. It can also be deployed in an 'on-demand' basis, based on the specific airspace requirements. The architecture diagram can be seen below:

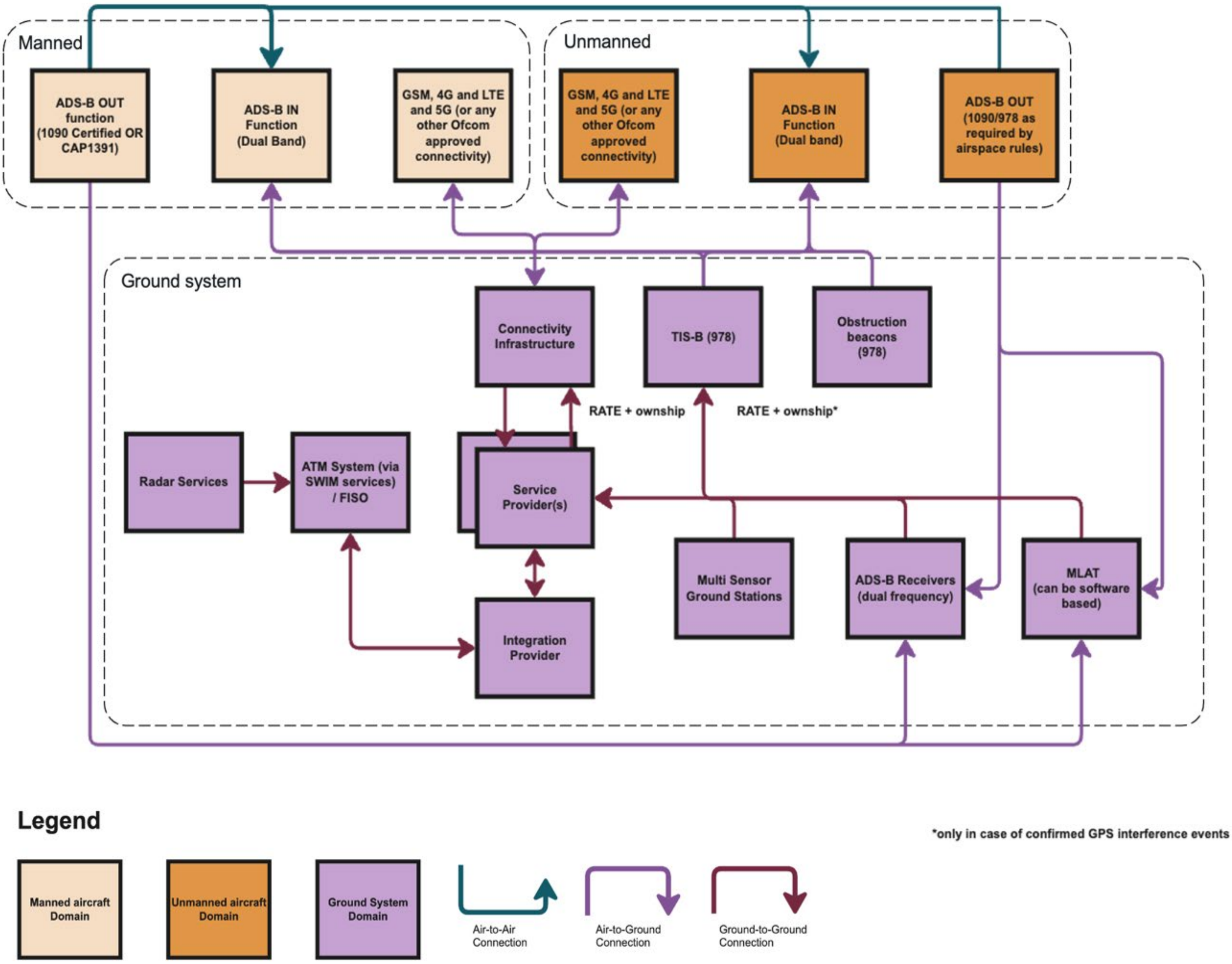

Figure 6.2, UK EC airspace architecture

6.21 In summary, the architecture consists of three element groups:

- manned aircraft systems, shown in light yellow boxes (top-left),
- systems of unmanned aircraft, given in orange boxes (top-right), and
- ground systems, given in purple boxes (centre).

6.22 The connection between the elements is given by:

- air-to-air connections, shown in dark green arrows (top)
- air-to-ground connections, shown in purple arrows (top centre & bottom centre),
- ground-to-ground connections, shown in dark red arrows (centre)

6.23 The architecture is composed of several functional blocks and utilises a variety of systems to fulfil to provide three distinct functions:

- Provide traffic surveillance
- Provide A-PNT. **Note** - A-PNT refers to 'alternative position, navigation, and timing', which are systems that provide backup capabilities for position, navigation, and timing (PNT) services, which are typically reliant on GNSS for example GPS.
- Provide obstruction information

6.24 The most notable updates and additions to the pre-existing direction of travel can be summarised as follows:

- The potential to equip with dual-band ADS-B IN for all aircraft (as required).
- The introduction of a ground-based element (such as MLAT) to validate the EC positions.

6.25 The utilisation of UTM service providers to compute a RATE and distribute it via mobile connectivity or TIS-B/ADS-R protocol. To note, this service may also be completed by ANSPs.

- The option to transmit ownship position via mobile connectivity or TIS-B/ADS-R protocol, in the event of an aircraft having lost its own means to determine position (from GPS jamming). For example, aircraft equipped with cockpit display of traffic information (CDTI) displays could have an additional "option" to revert to TIS-B ownship when onboard derived position information becomes unreliable.

6.26 The EC system described in the architecture covers the functionality required for aircraft (both manned and unmanned) to detect other aircraft and be detected by other aircraft or ground-based stations over a RF band (including, when desired, using cellular communication). The system also includes the functionality required for ground-based stations to compute and distribute a RATE to airspace users and active obstructions. The system also has a provision to provide A-PNT to selected airspace users in specific circumstances.

6.27 The EC system relies on ADS-B OUT system on 1090MHz (for manned aircraft) and Universal Access Transceiver (UAT) OUT on 978MHz (for UAS) to provide the position of each collaborative aircraft. Similarly, an ADS-B IN system on both 1090MHz and 978MHz and associated track processing and display functions allow the detection of every other cooperative aircraft and the display of the relative positions (either onboard or on the unmanned aircraft ground control station). On the ground, the EC system relies on a series of dual-band ADS-B receivers installed at known locations to detect the position of each cooperative aircraft. This is supported by the findings of the 1090/978MHz study (chapter 3).

6.28 The EC system relies on a series of multi-sensor ground stations. These can receive EC devices other than ADS-B and UAT (for example FLARM), if required. These devices can also optionally employ additional technology to detect non-cooperative traffic (for example via sound, radar and so on.) These devices are typically connected to the internet for data processing by supplemental data service providers (SDSP) that can distribute the data either via own UTM-like systems or via application programming interface (API) to other users.

6.29 The MLAT system included calculates the position of the aircraft using the time difference of arrival (TDOA) of the received signals from onboard the aircraft. Local aerodrome installations typically consist of three or more receiving stations located around the runway and aerodrome terminal. The response signal from the aircraft is received by at least three or more receiving stations and is calculated by a hyperbolic curve based on the time difference in arrival times between them to detect the position of the aircraft. In addition to the traditional, purpose-built MLAT systems, software-based MLAT is also available to the EC system, leveraging the ADS-B receivers' installation (and their precise known location). Such software-based systems are typically employed by SDSPs (Surveillance Data Service Providers) to enhance their data provision capabilities.

6.30 The timing and synchronisation between all the ground stations do not depend on GPS timing, independently of the specific MLAT solution employed in the particular use case, making this system resilient to GPS security threats (like jamming or spoofing). In the context of the EC architecture, the MLAT technology is used to validate the EC position independently.

6.31 The EC system employs obstruction beacons operating on UAT 978MHz to warn all airspace users of collision risks associated with overflight of higher-risk areas, such as winch launch gliding sites, when active. These aim to increase pilot awareness and can be turned on/off depending on activity. Their incorporation was supported by the findings of the 1090/978MHz study (chapter 3).

6.32 The EC system leverages TIS-B/ADS-R protocol technology on UAT 978MHz to perform two distinct functions. TIS-B/ADS-R protocol can be defined as the use of the UAT TIS-B service to broadcast TIS-B/ADS-R messages on 978MHz. The functions are: 1) Provide a broadcast of RATE [2] to all airspace users and 2) Provide broadcast of own ship position (derived via MLAT) to GA aircraft. It is

[2] The definition of RATE used in this report differs from that outlined in CA1430. For this report, RATE refers to a validated, assured and secure view of the airspace.

important to note that the TIS-B/ADS-R protocol needs to be done in a way which is configurable and does not overwhelm critical air-to-air messages (linking in with the Chapter 3 findings which outlined a risk of high frequency saturation from using it without configuration).

6.33 The EC system leverages UTM service providers (UTMSP) to compute and distribute a RATE to all connected airspace users as well as to the TIS-B/ADS-R protocol. UTMSP may provide additional services to connected users that are out of scope of the EC system. The UTMSP(s) may, depending on the UTM architecture that will emerge in the UK, be either directly connected or connected via an Integration Provider to the ATM system. Such integration would allow data exchange between the two systems, further reinforcing the RATE. This is supported by the initial Air Risk (chapter 2) findings which stressed the need for multiple mitigations in areas with a significant residual risk.

6.34 The EC system benefits from connectivity infrastructure (via ethernet, mobile connectivity or other solutions such as mobile ad-hoc networks) to provide a RATE to all connected users. In addition to providing a RATE, ownship position, if available, can also be provided to connected users. The aircraft-side element of the connectivity infrastructure can be either wired or wireless depending on whether the connectivity must be achieved in the air (always the case for manned aircraft) or on the ground (such as ground control stations or integrated control centres, in the case of unmanned aircraft).

6.35 The EC system leverages the existing ATM system to provide traffic information to airspace users. FIS provides such information to pilots via VHF radio or, in the future, dedicated SWIM (System Wide Information Management) and/or UTM services.

6.36 Global Navigation Satellite Systems (GNSS) are the primary source for positioning, navigation, and timing (PNT) in aviation. However, their susceptibility to interference and disruption (a key trend since the EGIS report took place) necessitates robust backup systems. Distance measuring equipment (DME), particularly in a DME/DME configuration, offers a possible alternative PNT (A-PNT) solution for manned aviation (DME/DME configuration refers to two DME ground stations which are strategically placed to provide distance measurements to an aircraft). By using the distances from these two stations, the aircraft can determine its position more accurately through triangulation – which could be helpful when GNSS is not available. While DME/DME provides a reliable A-PNT solution for manned aviation, its technological constraints, such as multipath errors and line-of-sight issues, can affect its performance at low altitudes. The unavailability of suitable equipment for UAS therefore limits its use to manned aircraft equipped with radio-navigation equipment.

6.37 It is important to note that not all elements of the EC architecture are required at all times, and each can be deployed on-demand based on the specific airspace requirements.

6.38 Additionally, different pieces of functionality are likely to “go live” in different timeframes – based on factors such as securing funding and deployment lead times. This means that delivering the full architecture in one “big bang” approach is unlikely, and more likely over a phased approach, where new functionality is gradually introduced over time. This may in time also evolve to include new functionality not included in the current architecture, such as novel ‘non-ADS-B’ solutions.

Scenarios in which the architecture will operate within

6.39 To outline how the EC Airspace Architecture could operate in a ‘real-world’ setting, five hypothetical scenarios were developed (see below). These have been referred to throughout this report.

6.40 **Scenario 1**: Departure from a regional aerodrome.

- **Setting**: A regional uncontrolled aerodrome (airspace Class G), designated as a ‘Radio Mandatory Zone’ [3](RMZ), accommodating a diverse mix of aerial traffic including operations of UAVs and manned aircraft, operating under visual flight rules (VFR).
- **Interaction**: The UAS pilot is conducting a flight to monitor the status of the aerodrome’s runway – published in a NOTAM for awareness. The manned aircraft pilot is operating under VFR and is already in the aerodrome traffic circuit, ready to land at the aerodrome.
- **Role of EC in future airspace**: Both aircraft are equipped with EC systems that actively disseminate their respective positions. The UAS is equipped with ADS-B (978MHz Outbound, Dual Band Inbound). The manned aircraft pilot is equipped with ADS-B (1090MHz Outbound, Dual Band Inbound). The EC system of the VFR flight accurately displays the UAS’ altitude, heading and forecasted flight path. This position information allows the VFR pilot to take the appropriate actions for landing, based on EC data, with respect to the UAS.
- **Similarities with Air Risk regions (Chapter 2):** This example could be reflected in specific 0 to 500ft areas for both Chatham and Scotland.

6.41 **Scenario 2**: Control Zone (CTR) operations in Class D airspace.

- **Setting**: An aerodrome with a CTR classified as Class D airspace, with a mix of aerial traffic including: a UAS, a commercial air transporter operating under instrument flight rules (IFR) and a helicopter engaged in a special operation (for example a medical flight) operating under VFR.

6.42 **Interaction**: The commercial air transport is an IFR flight following the standard arrival (STAR) procedure to the destination aerodrome. The helicopter is operating under VFR engaged in a special operation (medical flight), overflying the CTR to reach the destination hospital. The UAS operator is conducting aerial works for the aerodrome within the Specific category.

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[3] Whilst Radio Mandatory Zones are one of the primary mitigation methods used today, this may be evolve in the future to Transponder Mandatory Zones (TMZ).

- **Role of EC in future airspace**: The commercial air transport aircraft is equipped with ADS-B (1090MHz Outbound, Dual Band Inbound). The pilot sets the VHF NAV frequency on the DME on-board interrogator. The helicopter is equipped with ADS-B (1090 MHz Outbound, Dual Band Inbound) and the UAS is equipped with ADS-B (978 MHz Outbound, Dual Band Inbound). Each aircraft actively transmits its position, heading and velocity via EC systems. The IFR traffic keeps following the STAR procedure for landing with no deviation. The helicopter's EC system processes the data and promptly informs the pilot of the IFR traffic and UAV positions. This information allows the helicopter pilot to maintain self-separation and take measures while overflying. Additionally, MLAT would be utilised as part of the country-wide WAM that combines 1090 MHz and 978 MHz
- **Similarities with Air Risk regions (Chapter 2):** This example could be reflected in the 2000 to 4000ft and FL100 to 150 areas for Chatham.

6.43 **Scenario 3**: Mixed activity in Class G airspace

- **Setting**: A countryside region located within Class G airspace where aerial sports are conducted, mixed with recreational manned traffic (operating under VFR).
- **Interaction**: The airspace demands high situational awareness from its users. Within a radius of 10 NM and 2000ft of altitude, there are two paragliding operations co-existing, a gliding operation and a manned powered aircraft, all conducting recreational activities.
- **Role of EC in future airspace**: The region is marked with an ADS-B obstruction beacon. Dual-band ground receivers are installed as part of the countrywide ground systems to receive PNT data from participants. This data is validated using MLAT and other ground-based sensors to enhance the accuracy and reliability of PNT information, enabling UTMSP to generate a RATE for all airspace participants in the area. The paragliding pilots carry with them mobile phones displaying RATE based on 4G/5G and UTM data. The glider is equipped with ADS-B (1090MHz Outbound, Dual Band Inbound). The powered aircraft is also equipped with ADS-B (1090MHz Outbound, Dual Band Inbound). Each participant utilises a portable EC device. The glider pilot receives an alert about the approaching VFR traffic, enabling them to visually confirm its position and adjust their flight path accordingly. Simultaneously, the powered aircraft pilot receives notifications about the presence of the paragliders, which allows the pilot to take effective measures to keep clear of the other aircraft.
- **Similarities with Air Risk regions (Chapter 2):** This example could be reflected in specific 0 to 500ft and 2000 to 4000ft areas for Scotland.

6.44 **Scenario 4**: Landing in mixed UAS and manned aircraft traffic

- **Setting**: An urban aerodrome with a CTR classified as Class D airspace, operating during its busiest hours, with a commercial airline flight operating under IFR and commercial delivery UAS.
- **Interaction**: The IFR flight is following a standard instrument departure (SID) procedure from the aerodrome. The UAS is flying within the Specific category at

the exterior limits of the CTR, but still within it, where the delivery routes are located.

- **Core role of EC in future airspace**: The IFR flight is equipped with ADS-B compliant with Enhanced Mode S (1090MHz Outbound and receiving on Dual Band). The UAS is outfitted with ADS-B (978MHz Outbound, Dual Band Inbound). The aerodrome's ATC unit utilises a centralised EC system that amalgamates data from both manned aircraft and UAS, creating a dynamic live traffic map available with validated position data through MLAT, which is transmitted to all pilots and operators within the vicinity via TIS-B/ASD-R protocol and 4G/5G. In this case, the EC system advises rerouting of the UAS, ensuring that they do not interfere with the IFR traffic's departure trajectory. The system relies on local UTM for managing UAS operations.
- **Similarities with Air Risk regions (Chapter 2):** This example could be reflected in specific 0 to 500ft areas for both Chatham and Scotland.

6.45 **Scenario 5**: UAS delivery in London with an urban helicopter operation

- **Setting**: UAS-enabled deliveries of medical supplies between hospitals and an urban helicopter operation co-exist around Soho. In that part of London there is a Restricted area EGR157 HYDE PARK. To fly within EGR157 HYDE PARK, the operators need to meet the restrictions or have a special authorisation from the ATC unit. UAS flights are also restricted and need a Non-Standard Flight authorisation from NATS prior to operation.
- **Interaction**: The UAS operator is coordinating multiple drone operations for the delivery of medical supplies between hospitals that require crossing the Restricted area "EGR157 HYDE PARK". The UAS operator has a Non-Standard Flight authorisation from NATS. At the same time, the helicopter is operating under VFR and flying Helicopter Route H4 which also crosses EGR157. As published in the remarks section of the relevant aeronautical information publication (AIP) entry, helicopter flights that follow the Helicopter Route H4 are permitted within the Restricted area.
- **Core role of EC in future airspace**: The UAS operator manages a fleet equipped with ADS-B (978MHz Outbound, Dual Band Inbound) and 4G/5G. The helicopter is equipped with ADS-B (1090MHz Outbound, Dual Band Inbound). The helicopter's EC system detects the presence of the delivery drones operating near the route that the pilot is following. The EC system facilitates seamless communication with the control systems of the nearby UAVs, initiating an automated response to temporarily modify their intentions and maintaining a safe distance – utilising local UTM.
- **Similarities with Air Risk regions (Chapter 2):** This example is reflected within the 0-500ft and 2000-4000ft areas for London, within Chatham.

6.46 As can be seen from the scenarios, there will be situations where EC-alone is insufficient to ensure the safe integration of UAS operating BVLOS and additional technologies will be required – this is supported through the mitigated airspace risk analysis (chapter 2). A general example of this is near aerodromes, which are high risk environment with many manned and unmanned participants. For aerodromes, it is estimated that EC might be an acceptable means of compliance for risk mitigation only up to a maximum TLOS of $1x10^{-2}$ MAC/H. Anything beyond this will likely require additional mitigations such as additional tactical and strategical mitigation, for example DAA-based tactical mitigation.

Functional Hazard Assessment

6.47 To get an initial view of the safeness and robustness of the Airspace Architecture, an independent Functional Hazard Assessment (FHA) was undertaken and developed with the CAA Safety team. This analysis maybe used as part of the overall Future ATM/ANS programme of work. (Footnote)

Recommendations

6.48 This report has outlined the potential optimal architecture which could be designed, built and implemented for a robust EC provision in the UK by the CAA. It is recommended that the CAA provisionally adopt this architecture and plan for additional analysis (including “live testing”) to ensure that airspace is robust from a safety and performance perspective. This may include largescale tests and demonstrations. Any wider use of the presented data and concepts without prior verification is strongly discouraged until such testing has been completed.

6.49 It is critical that the airspace architecture reflects value for money for the CAA, UK Government, UK PLC and air users. Due to the architecture's risk-based setup, value for money should be achieved by ensuring that the required technical elements are only installed in the specific region or air-risk environment. In addition, this approach enables the usage of uncertified devices where safety requirements allow, which will also reduce the cost of equipment. An initial cost estimation on a per unit basis has been conducted, however the CAA may wish to conduct this at a national level to further validate the findings. It must also be considered that the cost-burden is minimised as much as possible for existing and new air user. Based on this, the CAA may wish to explore options such as rebate schemes (if required) to minimise any additional expense for users.

6.50 In addition to live tests, the system's end-to-end design needs to be fine-tuned and the process of making it operational on a national scale needs to begin. The recommended steps for the CAA to move forward with this are:

- Develop a fully detailed ConOps and the associated Business Case, including: 1) a full list of high-level requirements, 2) a detailed regulatory assessment to verify how the EC functions could be introduced in the overall system and 3) an economic assessment
- Develop an EC policy paper to describe the intended use of EC in UK airspace
- Plan and execute one or more Test & Evaluation campaigns to verify the technical requirements for which little experience is available
- Pursue the regulatory changes required to fully implement the EC. This could vary from simple Acceptable Means of Compliance or Guidance Material (for

example for the introduction of EC in uncontrolled airspace) to full-fledged regulatory updates (for example for allowing use of EC by ATS in controlled airspace)

6.51 This EC architecture has been designed with other technologies, such as UTM, closely in mind. It is strongly recommended that the CAA utilise this Architecture across their Ground Infrastructure, Detect and Avoid, UTM and C2 Links workstreams – to ensure that the overall architecture for all UK airspace is cost effective. It is also worth noting that the architecture (alongside the conditions it operates within, for example segregation for most VLOS UAS) may change over time as technology evolves. This architecture should therefore be amended to reflect the most viable solutions available at the time.

Chapter 7

Conclusion and potential impact to different users

Conclusion

7.1 The estimated level of risk in UK airspace for the regions analysed is varied and impacted by a range of factors, including traffic density, geography and primary usage. Broadly, the estimated risk level is in-line with what would be expected internationally for these geographies. The introduction of additional traffic (which could include UAS users) increases the risk profile differently in different sections of airspace.

7.2 The following estimations can be made from the modelling (assuming higher tactical mitigation performance requirements of at least $1x10^{-1}$) in relation to future airspace:

- For most uncontrolled airspace regions (>90%) at very low (0 to 500 ft AMSL) and low-mid altitude (2000 to 4000 ft AMSL), the use of EC data with at least $1x10^{-2}$ mitigation effect could be acceptable for unmanned aircraft to safely meet TLOS (and integrate) if certain conditions are met.
- For the rest of uncontrolled UK airspace (including edge cases), the use of EC data with at least $1x10^{-4}$ mitigation effect would likely be required. This effect is unlikely to be delivered by EC alone.
- For most controlled (>90%) air regions and most aerodromes, the use of EC data alone will likely not be acceptable. This is because it would need to provide more than $1x10^{-5}$ mitigation effect, which is more likely to be achieved through a combination of mitigation services.

7.3 We can therefore conclude that in specific scenarios, EC (and its data) may be able to support the safe integration of BVLOS for UAS (noting that most extant VLOS operations are expected to remain visually separated from BVLOS and manned traffic operations). This report therefore recommends the continued use and adoption of EC by the CAA as a key enabler to achieving their objectives, alongside other mitigating ‘Detect and Avoid’ technologies.

7.4 Based on the results of this study, the use of EC on 1090/978MHz is deemed technically feasible in relation to frequency use. The modelling supports the use of 1090MHz in the short to medium term – up to the year 2040 (for primarily manned aviation). This is primarily from the perspective of the SSR system (transponder and secondary radar performance).

7.5 There is however a consensus that 1090MHz will at some point reach a saturation point (estimated at 2123 airborne equipped airframes by the year 2040), and that when this happens another radio frequency may be required to alleviate spectrum issues on 1090MHz. This precise ‘saturation point’ is not known as it depends on many factors, meaning that it could come earlier than 2040.

7.6 Additional modelling of ADS-B reception could help the CAA to better understand any vulnerabilities of ADS-B to increased 1090MHz loading, in a variety of future EC scenarios and predict the specific saturation point.

7.7 Regardless, the CAA should continue to take immediate measures to carefully manage Radio Frequency load on 1030/1090MHz and monitor 1090MHz saturation. This should include the expansion of the EMIT network in the UK, monitoring of 1030/1090MHz loading and directing UAS on 978MHz.

7.8 As the traffic on 978MHz increases, there will be an inevitable drop in detection performance on that frequency. However, detection holds up well for ranges less than 11NM (as found in chapter 4) even for the heavy traffic loads assumed for the 2050 timeframe and beyond. This frequency should be suitable for primarily UAS traffic expected on 978MHz and therefore the CAA should immediately direct UAS traffic on to 978MHz (UAT) to help avoid additional load on 1090MHz.

7.9 It is also important to note that although the detection distance between the EC devices during the flight trials was estimated to be reliable up 10NM, this will not be the case for all 'real-world' operations. In certain scenarios, detection may not occur for distances below 10NM (detection rate generally reduces with distance, even at shorter range).

7.10 To ensure the benefits of EC are maximised, the placement, orientation and location of detection antennas are important. However, the report concludes that a mandate on these categories is not recommended. Rather than a mandate, the study team recommends that the results of this study feed into a set of guidelines, published by the CAA for airspace users. The guidelines would cover multiple elements of antenna use, as well as the RF transparency of aircraft materials.

7.11 The CAA may however wish to consider a mandate for antenna diversity, in specific cases where aircraft structure and/or the human body have a significant and unavoidable influence on signal reception. However, the potential increased detection benefit would need to be carefully analysed against potential impact to the user, to ensure it is not over-burdensome.

7.12 The increased use of EC devices for air users has potential to support the continued safety of air users in what will be a changing airspace environment. However, there are broader human factors implications of EC's use, which could limit its effectiveness. We would therefore recommend that the CAA update their awareness materials such as 'Skyway Code' and 'Safety Sense' leaflets to incorporate the report's findings, as well as incorporating the specific HMI guidance on smart-phone usage, to ensure the safe and effective use of EC by all airspace users. This should look to link in with the guidance on antenna placement as much as possible.

7.13 After concluding that EC is likely viable from a technological perspective, the report then analysed how it could be incorporated within a potential integrated

UK's airspace architecture. Within this airspace architecture, how EC could be used in a 'real-world' setting is mapped out across five scenarios.

7.14 Should the CAA adopt the recommendations within this report, this should help move towards achieving their objectives in relation to routine BVLOS operations. It is important to note that there will likely be scenarios where EC is not a suitable mitigation to ensure routine BVLOS UAS operations (especially as a standalone mitigation) and other technological solutions, for example UTM, may be better placed. It is thus recommended that the CAA continue to develop the EC airspace architecture with other mitigating technologies closely in mind and see this architecture as an evolving piece which will change as technology develops. It is also recommended that the CAA further define the specific use cases which will constitute BVLOS or VLOS in their publications.

7.15 Operationalising these findings will take time and require close partnership between industry and Government. However, the potential impact is significant and will be a real driver to delivering the objectives set out in the AMS and FoF.

Summarised potential impact to User Groups

7.16 Below are the key summarised potential impacts across the impacted critical user groups; should the recommendations of this report be formalised and publicly adopted by the CAA:

Manned aircraft

7.17 The potential requirement to equip ADS-B Out 1090MHz in the future.

7.18 The potential requirement to equip with dual-band ADS-B IN (as required) in the future.

7.19 To be aware of the potential future introduction of a ground-based element (such as MLAT) to validate EC positions, the use of UTM service providers (or ANSPs) to distribute a RATE and the option to transmit ownship position via mobile connectivity or TIS-B/ADS-R protocol in the event of an aircraft has lost its own means to determine position.

7.20 The potential that any future EC system could employ obstruction beacons operating on UAT 978 MHz to warn all airspace users of collision risks, especially associated with overflight of higher-risk areas, such as winch launch gliding sites.

7.21 That future updated guidelines will be published by the CAA in relation to antenna placement, orientation and diversity. This will aim to outline how best to enable a suitable probability of detection on manned aircraft.

7.22 That CAA will publish updated print, audio and visual information through awareness sources such as 'Safety Sense' and 'Skyway code' leaflets to outline Human Factors recommendations for the use of EC in a manned aircraft environment. This may be supported by additional training and additional discussions around the displaying of data on EC devices, which would be discussed at ongoing CAA-led stakeholder working groups.

Unmanned aircraft (for BVLOS UAS)

7.23 The potential requirement to equip ADS-B Out 978MHz in the future.

7.24 The potential requirement to equip with dual-band ADS-B IN (as required) in the future.

7.25 To be aware of the potential future introduction of a ground-based element (such as MLAT) to validate EC positions, the use of UTM Service Providers (or ANSPs) to distribute a RATE and the option to transmit ownship position via mobile connectivity or TIS-B/ADS-R protocol in the event of an aircraft has lost its own means to determine position.

7.26 That future updated guidelines will be published by the CAA in relation to antenna placement, orientation and diversity. This will aim to outline how best to enable a suitable probability of detection on UAS.

7.27 The potential for increased CAA-led engagement between UAS operators and policymakers to ensure effective guidance is published on a regular basis for Human Factors recommendations for the use of EC in an UAS environment.

7.28 That BVLOS/VLOS future use cases in relation to potential EC adoption will be addressed further by the CAA in their publications.

Providers of Air Services (including Air Navigation Service Providers)

7.29 To be aware of the potential future introduction of a ground-based element (such as MLAT) to validate EC positions, the use of UTM Service Providers (or ANSPs) to distribute a RATE and the option to transmit ownship position via mobile connectivity or TIS-B/ADS-R protocol in the event of an aircraft has lost its own means to determine position.

7.30 The potential that the EC system will use the existing ATM system to provide traffic information to airspace users. FIS provides such information to pilots via VHF radio or, in the future, dedicated SWIM/UTM services.

7.31 The potential that the EC system will leverage TIS-B/ADS-R protocol technology on UAT 978MHz.

7.32 To be aware that dual frequency ADS-B reception could be a vital component of the EC system, which could be utilised by ANSPs delivering surveillance systems.

7.33 The potential that surveillance services at currently un-serviced locations may become available following the deployment of the Architecture.

EC device manufacturers

7.34 That the CAA may look to organise additional stakeholder engagement with manufacturers to discuss content from this work. This may include a working group with manned aircraft, UAS and ATS participants to agree a set of standardised features and cues, which could be used by EC HMI Original Equipment Manufacturers (OEMs) when designing EC products for future use.

Chapter 8

Workstream-specific recommendations for the CAA

8.1 To begin delivering this report, we recommend a set of actionable next steps for the CAA to consider implementing. These recommendations are solely for the CAA to consider and come from the findings and outcomes outlined in the chapters above. They are condensed in comparison to the individual workstream reports which were shared with the CAA, to allow for simplicity.

8.2 Recommendations are prioritised as either; “High”, “Medium” or “Low”. Certain recommendations may have an additional categorisation of “Conditional” or “As Necessary” – reflecting their specific considerations. A full description can be found in Appendix C.

8.3 It is important to note that the CAA are not obliged to deliver all the recommendations outlined in this paper. Further work will be undertaken to analyse and prioritise the recommendations and plan their delivery.

Ref	Area	Title	Recommendation for the CAA	Priority
1.1	978MHz / 1090MHz	Undesirable Loading on 1090MHz	Continue to use of ADS-B on 1090MHz is recommended. However, 1090MHz will see ever increasing congestion, and beyond the year 2040 continued 1090MHz loading may start to have an undesirable effect on SSR performance, especially in the absence of mitigating actions.	High
1.2	978MHz / 1090MHz	Expand EMIT network in UK	Continue to undertake monitoring activities using EMIT and seek to expand the EMIT network in the UK to provide a fuller picture of the RF spectrum usage. This will include a deployment strategy and close engagement with Eurocontrol.	High
1.3	978MHz / 1090MHz	The use of ADS-B squitter preferable to transponders	Avoid overloading the 1030/1090MHz spectrum, note that ADS-B squitter devices are preferable to the widespread use of transponders for specific types of aircraft.	High
1.4	978MHz / 1090MHz	ADS-B and WAM Receiver Model	Model ADS-B and WAM reception performance to better understand the vulnerabilities of ADS-B to a high load on 1090MHz.	High
1.5	978MHz / 1090MHz	ADS-R management	ADS-R has the potential to significantly impact the UAT	Medium

Ref	Area	Title	Recommendation for the CAA	Priority
			(978MHz) detection performance. Therefore, it is important to ensure that if it is used, it is configurable so not to overwhelm air-to-air communications. In the event of too high levels of saturation on 978MHz, one option could be to use the ground segment of the UAT frame for all TIS-B/ADS-R transmissions.	
1.6	978MHz / 1090MHz	Ground segment configuration	If the ground segment was used for TIS-B/ADS-R, it is recommended that the UAT ground segment should be completely configurable to allow the appropriate balance between FIS-B and TIS-B/ADS-R services.	Conditional
1.7	978MHz / 1090MHz	Use of UAT ground segment	To ensure ADS-R load is sustainable, it may be sensible to reduce the number of FIS-B channels to ~22 and retain the remainder of the ground segment for a TIS-B/ADS-R capacity for 220 qualifying targets.	Conditional
2.1	Probability of Detection	Antenna Placement Guidelines	Use the results of this study to form a set of guidelines published by the CAA to cover the specific antenna placement, orientation and diversity aspects as well as the circumstances in which an antenna pattern analysis is recommended. The guidelines should also discuss the RF transparency of aircraft materials. It is also noted that CAP1391 places requirements on the EC device operating manual. The operating manual should be reviewed to ensure it contains sufficient information to allow the user to set up the device antenna in such a way that it allows the EC device to operate at its intended, optimal performance level. **Potential guidelines could include**:	High

Ref	Area	Title	Recommendation for the CAA	Priority
			For manned, fixed wing and rotary wing aircraft: • External fitment of the antenna on the nose of the aircraft is preferred, where this is possible; • Internal fitment of the EC device is generally sufficient, but varies by aircraft type; • For internal fitment, on the inside window , behind the pilot is recommended (opposite side to the pilot preferable). • The antenna should be mounted in a vertical orientation; • If there is a passenger in the seat next to the device, then mounting in the cockpit, front window may be considered; • If the antenna is externally fitted, consideration should be given to antenna diversity. For example, a top (or bottom) mounted antenna may not have good coverage below (or above) the aircraft, and therefore, a second antenna placement is recommended; • For external antenna placement, the airspace user should consider undertaking an antenna field strength (far field) analysis to assure good coverage in all directions. For paragliders and hang gliders: • The human body has shown to attenuate radiation significantly, and for the best performance, it is advised that operators in the paragliding and hang-gliding communities should place the antenna in a location that will have a direct line-of-sight in the desired detection directions. • Having the EC device in front of the stomach or on the back leads to a significant amount of attenuation.	

Ref	Area	Title	Recommendation for the CAA	Priority
			• Some manufacturers operating manuals also instruct a minimum distance of a few centimetres between the transmitter and the pilot's body, when the device is in use. This may impose further restrictions on where the user should place the device. • Ultimately, two antennas (antenna diversity) would offer better overall electronic conspicuity, and therefore better protection for paragliders and hang gliders. For UAS multirotor operators: • Orientation of the EC device is not critical for detection. However, for good angular coverage, it is recommended the antenna be aligned vertically (perpendicular to the airframe).	
2.2	Probability of Detection	Configuration of EC devices must be understood and correctly set	Aim to ensure that pilots are aware that the configuration of devices receiving detections from an EC device must be well understood by the pilot and the implications of any such configuration, especially data filtering, should be fully considered for the use-case of the intended operation of the UAS.	Medium
2.3	Probability of Detection	Testing of UAS configuration	Aim to ensure that pilots are aware that the autopilot documentation relating to uncertified UAS should only be used as an initial guide and the configuration should be tested to ensure that it behaves as expected.	Medium
3.1	Airspace Risk	Electronic Conspicuity Statistics	Explore estimating the effectiveness of EC (absolute and/or range) using statistical methods, incorporating the findings of the Probability of Detection study (Chapter 4) on the 'real-world' detection ranges. This could include incorporating additional evidence of "EC-in" to a manned aircraft in providing a mitigation against UAS conflicts.	High

Ref	Area	Title	Recommendation for the CAA	Priority
3.2	Airspace Risk	Unmitigated Parameters	Explore conducting unmitigated air risk analysis using other CAA-specified parameters (uncertainty, encounter dimensions and so on).	High
3.3	Airspace Risk	Mitigated Parameters	Explore conducting mitigated air risk analysis using other CAA-specified parameters (detection probability (RR), target safety levels). This will aim to link with the UK SORA.	High
3.4	Airspace Risk	Qualitative Framework Evaluation	Explore conducting statistical analysis air risk values within and between each ARC at multiple altitude	Medium
3.5	Airspace Risk	Encounter Type Evaluation	Explore conducting air risk analysis assuming appropriate (or alternate) encounter type for each flight at each location instead of fixed encounter per location.	Low
3.6	Airspace Risk	Flight Rule Evaluation	Explore conducting air risk analysis assuming flight rules instead of surveillance source (additional risk matrices).	Low
3.7	Airspace Risk	Temporal Evaluation	Explore conducting air risk analysis for different time (temporal) windows in the data sets and/or for larger duration data sets.	As necessary
3.8	Airspace Risk	Risk Components	Explore providing individual risk component maps for regions and altitudes analysed.	As necessary
3.9	Airspace Risk	Large Scale Analysis	Explore conducting unmitigated air risk analysis (nation-wide) to create a digital repository. **Note** - this will only be commenced after the potential use of such maps within a BVLOS environment have been defined. Any work in this area would also need to include recommendations on augmenting historical surveillance for both non-cooperative traffic and regions with surveillance gaps.	As necessary
3.10	Airspace Risk	Data Mining and Statistics	Explore conducting deeper statistical analysis of data source attributes to sharpen or augment some data pre-processing steps and risk analysis parameters.	As necessary
4.1	Airspace Architecture	Finalise the definition of	Finalise the distinction between BVLOS and VLOS operations,	High

Ref	Area	Title	Recommendation for the CAA	Priority
		BVLOS and VLOS	including for scenarios where the distinction is not clear. The CAA may also wish to include reference in their ConOps to future "non-ADS-B" technologies and how these could be incorporated in longer-term ambitions for UK airspace.	
4.2	Airspace Architecture	Identify relevant airspace regulations	Identify the relevant airspace regulations and policy which will be impacted / impact the airspace architecture and the specific solutions scenarios.	High
4.3	Airspace Architecture	ConOps for Airspace Architecture	Expand on the airspace architecture within the ConOps, to account for any additional operational context, for example outline technical and operational regulatory requirements and procedures that would be required in both controlled and uncontrolled airspace.	High
4.4	Airspace Architecture	Regulatory changes	Identify and propose the necessary changes and adjustments to UK regulations to implement the final EC future solutions.	High
4.5	Airspace Architecture	Air Risk Categories	Finalise Air Risk Categories for the whole UK airspace, based on the input from the Airspace Risk study, linking in very closely with UK SORA.	High
4.6	Airspace Architecture	EC airspace performance requirements	Design & Define performance requirements and architecture for EC Ground Infrastructure, per Airspace Classes and ARCs.	High
4.7	Airspace Architecture	EC technical performance requirements	Based on the outputs of this work, finalise the UK performance requirements and architecture for EC cyber safety - including ground & space, GPS anti spoofing & jamming architecture.	High
4.8	Airspace Architecture	Full set of EC requirements	Design & define the full set of UK EC requirements including for example user, safety and legal transformation requirements.	Medium
4.9	Airspace Architecture	Trial of architecture	Create a test and evaluation trial of the EC architecture in airspaces controlled and uncontrolled and	Medium

Ref	Area	Title	Recommendation for the CAA	Priority
			verified the proposed ConOps. This will include more tests to finalise evidence on the use of MLAT to validate its use as part of a low-cost EC solution.	
4.10	Airspace Architecture	Implementation Strategy	Define an implementation and delivery strategy for the resulting UK EC architecture with precisely associated costs, actions and timelines to establish the outlined functionalities.	High
5.1	Human Factors	Update Safety materials 1/2	Update user safety advice promulgated by print, audio and visual mediums to include the below points: • That EC devices presents a compelling, and comprehensive picture which may be unknowingly incomplete or inaccurate. Pilots should therefore regard EC information as a partial representation of traffic density. • Pilots should ensure their EC device is configured to produce as few non-urgent alerts as possible to reduce risk of dis-regarding EC alerts. • Pilots should adjust the screen brightness of their PED to ensure that they can effectively always see the device, regardless of its position. • Pilots should be aware of potential control restriction, loose article or egress obstruction hazards when mounting EC devices and associated equipment such as antennas and cabling. • Where possible for their aircraft category, pilots should use EC audio and visual alerting EC device functions. Pilots should be aware that distraction caused by EC device faults, loss of signal or PED failure may lead to airspace infringement or loss of control.	High

Ref	Area	Title	Recommendation for the CAA	Priority

5.2	Human Factors	Update Safety materials 2/2	Promulgate user safety advice to ensure that Pilots:
			• Apply most appropriate EC mode for flight phase to reduce workload produced by non-urgent alerts.
			• Are aware that EC symbology on moving map display will take longer to interrogate when:
			  ○ Icon colours are similar to mapping colours
			  ○ When moving map is in 'North Up' mode
			  ○ When heading and track values are different
			• Know they should apply EC device alert range and altitude filtering to reduce workload in flight.
			
			Pilots should ensure automatic deactivation of EC emission when on the ground to reduce high EC traffic threat workload to other pilots, UAS and ATS stakeholders.
				High

5.3	Human Factors	HMI user led icon standards for future airspace	Organise an ATS, UAS and manned aircraft pilot stakeholder working group to produce a standard set of EC device icons to be displayed consistently to reduce risk of error and manage operator workload.	As necessary
5.4	Human Factors	HMI EC device cueing mechanisms for future airspace	Work with EC devices OEMs to seek to ensure that EC devices provide audio and visual alert cues to convey five key pieces of information at regular intervals to allow parameter changes to be identified: • Location. • Azimuth angle relative to current heading. • Elevation angle relative to current heading. • Range. • Direction of travel or heading.	As necessary
5.5	Human Factors	EC device HMI 'radar' display design for future airspace	Work with EC device OEMs to seek to ensure devices provide 'radar' display with range circles for the range for detection and recognition of	As necessary

Ref	Area	Title	Recommendation for the CAA	Priority
			a 1m-by-1m target by a pilot with visual acuity of 6/12 and 6/9.	
5.6	Human Factors	HMI EC device colour discrimination for future airspace	Work with EC device OEMs to seek to ensure user device HMIs have a difference between colour hues of 0.028 units and colour saturation of 0.084 units in CIE1976 colour space.	As necessary
5.7	Human Factors	HMI redundancy of visual cueing mechanisms for future airspace	Work with EC device OEMs to seek to ensure devices provide user HMI displays with redundancy of visual cues to mitigate the effect of CVD by using stimuli comprising: • Luminance. • Chromaticity. • Temporal properties, for example blink rate. • Change in shape. Change in size.	As necessary
5.8	Human Factors	HMI standardisation of EC device aural alerts for future airspace	Work with EC device OEMs to seek to ensure devices provide user HMI with an audible alert comprising a unique attention alert sound and a verbal message comprising of the following information: • Azimuth angular range in clock position. • Elevation angular range. • Range. • Direction of travel or heading. Where possible, audio warnings provided by carry-on EC systems are integrated into the aircraft's audio system to facilitate them being heard above the noise of the aircraft.	As necessary
5.9	Human Factors	HMI assessment of EC display performance for future airspace	Work with EC device OEMs to seek to ensure OEMs assess EC display devices using the PJND methodology.	As necessary

Chapter 9
Key risks to manage and limitations of the study

9.1 There are several key risks which have been identified which it will be crucial for the CAA, working closely with their partners in industry, to manage. These, alongside the proposed management activities, are outlined below:

Risk	**Proposed management activity**
Managing the 978MHz and 1090MHz frequencies is essential to ensuring effective EC use in the short-medium term.	The expansion of the EMIT network in the UK and continued monitoring of 1030/1090MHz load.
Viewing EC in silo of other important technologies such as DAA, UTM, Ground Infrastructure and C2-links risks duplication and solutions not complementing each other.	CAA to continue managing complementary workstreams in a way which encourages sharing and collaboration.
Training and guidance for users on how to use new technologies such as EC needs regularly reviewing and updating, else it risks becoming quickly out of date.	Regular reviews take place of EC training material, utilising EC stakeholder groups to assess effectiveness.
New and evolving technologies such as EC must be always approached through a safety-first mindset. However, this must be done in a way which does not unduly penalise new entrants from industry and stifles innovation.	Additional safety assessments such as Functional Hazard Assessments to take place in good time across EC, to quickly report back ways to resolve issues
EC is a controversial topic with some entrenched views in support and opposition, across user groups. This will need to be carefully managed by the regulator to ensure progress is made in a way which is most beneficial to the sector.	Continue close engagement with all parts of the sector (including representative organisations) to ensure all views are considered, with ongoing support from the Department for Transport.

9.2 Alongside the risks outlined above, there are natural limitations to the long-term robustness of this analysis, given it focuses on rapidly evolving technology which is subject to frequent change. These limitations must be addressed to ensure that this work is not viewed as a “once and done” initiative and instead is the basis for an evolving approach to EC. The key limitations, their impact and the recommendations to address them, are outlined below:

Limitation of the study	**Potential impact**	**Recommendation**
Less engagement with the UAS community compared to manned aircraft operators due to them having less	Views and needs to UAS users are not effectively	CAA to explore the use of existing or creation of new engagement forums with UAS users, whilst ensuring

Limitation of the study	Potential impact	Recommendation
experience in using EC technologies.	considered when making decisions.	that stakeholders from different backgrounds are included at existing industry engagement groups.
The report does not define on a use-case-by-use-case basis what constitutes BVLOS or VLOS operations, in relation to the current scope of integration with BVLOS UAS and VLOS operations.	Whilst the typical industry definitions of each apply, there will be specific use cases where it is not easily identifiable whether an operation is BVLOS or VLOS (or may change throughout).	The CAA have outlined that this will be addressed fully within their publications.
SIEM2 model used to analyse the 1090MHz frequency saturation does not fully incorporate ADS-B Reception.	Full extent of pressures on the frequency cannot be computed.	CAA to explore the building of a model which can conduct this and commission a standalone report to share findings.
Extent of Airspace Risk modelling does not cover the whole of the UK.	Specific features of geographies not modelled may not be incorporated within the analysis.	CAA could explore extending the analysis across the whole UK airspace.
All modelling and analysis of the growth of Aviation user numbers (specifically UAS) is based on estimation. These numbers may be subject to unforeseen changes.	Should the numbers of airspace users be significantly greater than forecast, 1090MHz and 978MHz may come under pressure earlier than expected.	CAA to regularly review the number of airspace users versus the expected growth levels used in this study.

APPENDIX A

Abbreviations & Definitions

Abbreviations	Explanation
ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-R	Automatic Dependent Surveillance - Rebroadcast
AFISO	Aerodrome Flight Information Service Officer
AMS	Airspace Modernisation Strategy
ANSP	Air Navigation Service Provider
API	Application Programming Interface
A-PNT	Alternative Position, Navigation, and Timing’
ARCs	Air risk classes
ATCO	Air Traffic Control Officer
ATS	Air Traffic Service
BVLOS	Beyond Visual Line of Sight
CAA	Civil Aviation Authority
CAP	Civil Aviation Publication
CAS	Collision Avoidance System
ConOps	Concept of Operations
CDTI	Cockpit Display of Traffic Information
CTR	Control Zone
DAA	Detect and Avoid
DfT	Department of Transport
DME	Distance Measuring Equipment
EC	Electronic Conspicuity
EMIT	European Monitoring of Interrogators and Transponders
ES	Extended Squitter
EU	European Union
EASA	European Union Aviation Safety Agency
FHA	Functional Hazard Assessment
FIDs	Flight Information Displays
FIR	Flight Information Region
FIS-B	Flight Information Service - Broadcast
FLARM	Flight Alarm
FL	Flight Level
FRUIT	False Replies Unsynchronised in Time
GNSS	Global Navigation Satellite System
HMI	Human Machine Interface
ICAO	International Civil Aviation Organisation
IFF	Identification Friend or Foe

Abbreviations	Explanation
IFR	Instrument Flight Rules
JARUS SORA	Joint Authorities for Rulemaking on Unmanned Systems Specific Operations Risk Assessment
MAC	Mid Air Collision
MAC/H	Mid Air Collisions Per Hour
MLAT	Multilateration
MOPS	Minimum Operational Performance Standards
MSO	Message Start Opportunity
MSR	Message Success Rate
NM	Nautical Miles
NOTAM	Notice To Aviation
Pd	Probability of Detection
PEDs	Portable Electronic Device
PJND	Perceived Just Noticeable Difference
PNT	Position, Navigation, and Timing
Ppts	Percentage points
Pu	Probability of Update
RADEX	Radio Trials Centre
RATE	Recognised air traffic environment
RCE	Reduced Capability Equipment
RE	Reply Efficiency
RF	Radio Frequency
UAS	Remotely Piloted Air Systems
RTR	Round Trip Reliability
SDSP	Supplemental data service providers
SIEM	SSR IFF Environment Model
SIEM2	SSR IFF Environment Model 2
SID	Standard Instrument Departure
SORA	Specific Operations Risk Assessment
SSR	Secondary Surveillance Radar
STAR	Standard Terminal Arrival Route
SWIM	System Wide Information Management
TAS	Traffic Advisory System
TCAS	Traffic Alert and Collision Avoidance System
TCAS TA	Traffic Alert and Collision Avoidance System, Traffic Advisory alert
TCG	Technical Cooperation Group
TDOA	Time Difference of Arrival
TLOS	Target Level of Safety
TMPR	Tactical Mitigation Performance’ Requirements
TIS-B	Traffic Information Service - Broadcast
UAS	Unmanned Aircraft System
UAT	Universal Access Transceiver
UAV	Unmanned Aircraft Vehicle

Abbreviations	**Explanation**
UKRI	UK Research and Innovation
UTM	Unmanned aircraft system traffic management
UTMSP	UTM Service Providers
VFR	Visual Flight Rules
WAM	Wide Area Multilateration

APPENDIX B

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APPENDIX C

Recommendation priority definitions

Priority	**Potential impact**	**Recommended timeframe**
"Very High" priority	Urgent safety implication which requires immediate action	Aim to begin planning and delivery within 3 months
"High" priority	Significant importance or a key dependency in achieving the objectives set out in AMS/FoF to enable the integration of airspace for all airspace users	Aim to begin planning and delivery within 12 months
"Medium" priority	Important in achieving the objectives set out in AMS/FoF but not a key dependency	Aim to begin planning and delivery within 1-2 years
"Low" priority	Not required to achieving the objectives set out in AMS/FoF but a recommended to enhance the solution	Aim to begin planning and delivery beyond 2+ years
"Conditional"	N/A	Conditional on another recommendation being taken forward
"As necessary"	N/A	Only required if a certain outcome occurs