UK Research and Innovation

Future Flight Initial Aviation Safety Framework

Report for UKRI
July 2021

In partnership with

egis

University of York

Executive summary

This report analyses and documents the potential developments in future flight that will influence safety and identifies the activities required to address the safety impacts especially those that will have a significant impact on the development of the future aviation system. It has been produced by Egris and the University of York under contract to UK Research and Innovation (UKRI).

The analysis was structured into a set of future scenarios using actor diagrams as pictorial elements. These represent the evolution of the (future) aviation system over different time horizons (short-/medium-/long-term). Within the scenarios, use cases have been defined. The use cases describe the primary applications of new flight technology which are relevant to the scope of the Future Flight Challenge (FFC). In addition, a set of transversal themes were also defined which are relevant across all scenarios and use-cases. The transversal themes are topics which are considered to have a significant impact on future aviation safety.

The use cases selected for the project were:

- Use case 1 - Drones, which comprises three sub-use cases: drones for delivery, drones for inspection/monitoring/broadcast and drones that perform robotic functions (e.g. repair, crop spraying)
- Use case 2 - Urban Air Mobility (UAM)
- Use case 3 - Regional Air Mobility (RAM)

Four transversal themes were also identified for the project:

- Safety management of complex systems
- Integrated risk and safety management
- Role of the human and autonomy
- Supporting infrastructure

The analysis addressed safety impacts across the governance, organisational and technical layers. This was performed through application of the safer complex systems framework developed by Engineering X at the strategic level and complemented by use of bowtie analysis to analyse hazards and controls at a more detailed level. These complementary approaches led to a set of recommendations placed on different stakeholder groups and supplemented by requirements placed orthogonally on functions and capabilities of the key elements of the future aviation system. A detailed analysis of the key safety management challenges associated with the four transversal themes added further recommendations at the strategic level.

The output of this project comprises an initial safety framework, with a particular focus on the top layers of the argument and constructed in the goal structuring notation (GSN) language that is familiar to many safety professionals. The framework is defined at the strategic level and this report provides the key contextual elements of the framework as well as setting out the claims and evidence required to be produced as part of future work.

The analysis concludes with a presentation of the highest priority recommendations to address as the first steps in setting out a programme of safety work for future flight operations:

Recommendation 9.1 – Development of a concept of operations for the future aviation system which includes transitional states.

Recommendation 9.2 – Establishment of Target Levels of Safety for aircraft operations, including specific future flight use cases.

Recommendation 9.3 – Establishment of an aviation system risk baseline made up of both the current risk profile and the future expected risk profile, based upon future concepts of operations.

Recommendation 9.4 – Prioritisation of the issues and recommendations in the report and the establishment of a safety work program in support of the FFC. This should include, amongst other things, a plan for managing the impacts of complex systems at the Governance, Management and Task/Technical layers. This should also include consideration of the many more detailed recommendations in this report. Consideration should be given to placing the responsibility for developing and delivering this plan on a pan-industry body or, establishing one specifically for this purpose.

Contents

List of figures

List of tables

Introduction

1

Introduction

1

1.1 Context

Developments in future flight (FF) are leading to potential fundamental changes in the aviation safety risk landscape. It is necessary to understand these potential changes and to respond to them in the design of the future aviation system including the regulatory environment, safety management processes and mitigating actions.

This report analyses and documents the potential developments in FF that will influence safety and identifies the activities required to address the safety impacts especially those that will have a significant impact on the development of the future aviation system. It has been produced by Egris and the University of York under contract to UK Research and Innovation (UKRI).

1.2 Background

The Future Flight Challenge (FFC) is a UKRI initiative that will support the development, in the UK, of new aviation technologies such as freight-carrying drones, urban air passenger vehicles and hybrid-electric regional aircraft that will transform the way that people and goods fly. The challenge will also support the development of the necessary ground infrastructure, regulation and control systems required to use these new aircraft safely.

The FFC programme identified that, as new aircraft and systems are introduced, the aviation safety risk landscape would potentially change fundamentally. Autonomous aircraft will mix with electrically powered vertical take-off and landing (eVTOL) air taxis and drones in a myriad of applications. Not only will the types of risk change but the way they are assessed and managed may have to change to maintain or enhance the required level of safety. The FFC therefore contracted a study to investigate this issue and to determine what actions need to be taken to ensure that safety can be appropriately assured in the future environment.

1.3 Structure of Report

The report is structured into the following sections:

Section 2 presents the approach to the project including the definition of different scenarios, the project scope and use of the project working group.

Section 3 presents the current aviation system including relevant aspects of both international and national governance and regulation.

Section 4 presents the future aviation system including more detail on the scenarios and use-cases considered as part of the project scope.

Section 5 identifies some of the safety management challenges associated with FF and is structured into discussions around each of the transversal themes.

Section 6 presents safety analysis of specific aspects of the future aviation system using the bowtie notation.

Section 7 presents an analysis of the key safety management challenges associated with FF including the use of the safer complex systems framework.

Section 8 presents the initial safety framework drawing together the analysis and provided in a Goal Structuring Notation (GSN) format.

Section 9 provides a series of conclusions and high priority recommendations for further work based on the analysis conducted in the previous sections.

Appendix A provides a glossary of terms used throughout the report in an attempt to standardise the language and terminology attached to each of the concepts.

Appendix B provides the bowtie diagrams for all of the assessed hazards and the detailed analysis of each of the long-term bowtie diagrams.

Appendix C provides the detailed analysis from the application of the safer complex systems framework. This analysis supports the recommendations contained in Section 7.2.

Appendix D provides a list of all the recommendations and requirements made in this study.

Project Approach

2

Project Approach

2

2.1 Introduction

The nature of the FFC is such that an extremely broad range of topics could potentially be included within the scope of this work. It was therefore necessary to focus the effort on a set of areas considered to be most relevant to future aviation safety. In particular, the focus has been placed on areas that match the objectives of the FFC programme in promoting the UK's role in building, using and exporting greener and more efficient modes of air transport through advances in electric and autonomous flight technology.

To structure the analysis, a set of future scenarios was defined representing the evolution of the (future) aviation system over different time horizons. These scenarios represent a realistic progression of the technological, operational and regulatory aspects of the aviation system as it seeks to address the transport needs of society into the future in a cost-effective manner. However, the uncertainty associated with the definition of the future scenarios increases proportionately with the distance from the present time.

Within the future scenarios, use cases have been defined. The use cases describe the primary applications of new flight technology which are relevant to the scope of the FFC. In addition, a set of transversal themes were also defined which are relevant across all scenarios and use-cases. The transversal themes are topics which are considered to have a significant impact on future aviation safety. These themes may also be relevant to innovations in the 'traditional' aviation space of large air transport vehicles although this is beyond the scope of the FFC and this report.

This approach allows for different categories of use-cases to be represented whilst also recognising that certain core themes related to technology development and risk management will also evolve across those horizons.

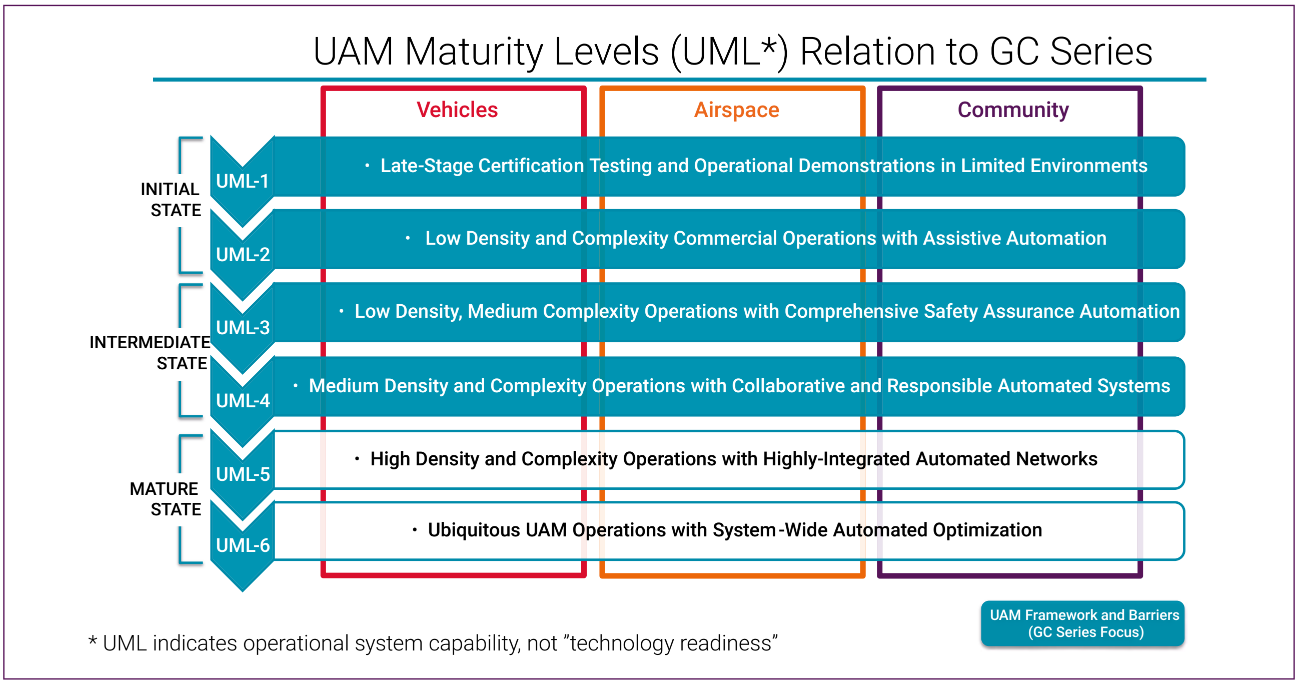


Figure 1: NASA UAM Maturity Levels

1. NASA Advanced Air Mobility (AAM) Urban Air Mobility (UAM) and Grand Challenge AIAA

2.2 Scenarios, Use Cases and Transversal Themes

Three future scenarios are defined:

- Short-term horizon (approximately year 2025)
- Medium-term horizon (approximately year 2030)
- Long-term horizon (approximately year 2035)

These are consistent with NASA's AAM/UAM (Advanced Air Mobility / Urban Air Mobility) Maturity Level (UML)[1] as shown in Figure 1. For this study, the NASA UMLs have been grouped into pairs.

While indicative dates are provided above, the more important factors are the maturity of the technology and the scale of operations.

The use cases selected for the project were:

- **Use case 1 –** Drones, which comprises three sub-use cases: drones for delivery, drones for inspection/monitoring/broadcast and drones that perform robotic functions (e.g. repair, crop spraying)
- **Use case 2 –** Urban Air Mobility (UAM)
- **Use case 3 –** Regional Air Mobility (RAM)

To ensure key safety challenges are identified and addressed early in the evolution of UK aviation, transversal themes were identified which are likely to have the greatest impact on safety across all use cases. Four transversal themes were identified for the project:

- Safety management of complex systems
- Integrated risk and safety management
- Role of the human and autonomy
- Supporting infrastructure

The future scenarios, use-cases and transversal themes are described in detail in Sections 4 and 5.

2.3 Project Scope

The scope of the project focusses on operations that are within the purview of the FFC programme, i.e. drones, UAM and RAM. The following operations are out of scope:

- High Altitude Platforms (HAPS) and associated operations
- Space vehicles and associated operations
- Activities covered by other programs such as Jet Zero[2] and FlyZero[3], including future developments of supersonic, transatlantic and larger passenger carrying aircraft.

Note that while these operations are out of scope, many of the concepts discussed in this report will relate to, and can be applied to, these operations.

2.4 Output of Project

The output of this project comprises an initial safety framework, with a particular focus on the top layers of the argument and constructed in the goal structuring notation (GSN) language that is familiar to many safety professionals. This framework will identify a set of goals relating to the required safety outcomes of the future aviation system. These goals are based on and informed by the context of current aviation safety performance and FF activities. The framework also comprises a set of arguments and evidence that have the potential to satisfy those goals. A limited amount of evidence will be provided as specific outputs of this study; other evidence will result from activities or tasks to be progressed as part of future work.

This framework is not intended to be definitive or represent a framework that industry or the regulator is committed to, but a means to identify principal activities and tasks required to demonstrate that the future aviation system can meet defined target level(s) of safety. These activities and tasks can then be used to build a roadmap of activities/tasks that should be progressed to develop the safety framework in a collaborative and practical manner.

The framework will also be supplemented by a set of written conclusions and recommendations that provide more detail to the safety argument structure.

2. Jet Zero Council: Government unveils new collaborative initiative to decarbonise aviation
3. ATI Launches FlyZero Initiative

2.5 Working group

A working group of industry experts was established to support the project and provide validation of the study outputs. This validation aimed to ensure that no significant aspects have been overlooked and that the outputs of the study are relevant and useful for the different aviation stakeholders. The composition of the working group was chosen to be as broad as practical whilst representing those domains related to the FFC objectives.

The working group participants comprised the following individuals:

- Graham Braithwaite (Cranfield University) – Director of Aviation
- Graham Brown (ARPAS-UK) – Chief Executive Officer
- Gary Cutts (UKRI) – Director of Future Flight Challenge
- Hannah Tew (UKRI) – Innovation Lead and Future Flight Challenge
- Isabel del-Pozo (Airbus) – Head of Unmanned Traffic Management (UTM)
- David Morgan (EasyJet) – Director of Flight Operations
- Andy Sage (UK NATS) – Head of Unmanned Traffic Management (UTM)
- Andy Sinclair (Gatwick Airport) – Head of Noise Management Group
- Darrell Swanson (Swanson Aviation) – Director of Swanson Aviation
- Kim Tuddenham (UK CAA) – Innovation Business Lead
- Alan Peters (Connected Places Catapult) – Principal Technologist
- David Wilson (Queens University Belfast) – Director of Engineering
- Sam Golden (Flock Insurance) – Head of Sales and Marketing
- Tim Williams (Vertical Aerospace) – Chief Engineer

The Current Aviation System

3

The Current Aviation System

3

3.1 Introduction

To facilitate a common understanding, this section describes the current aviation system, with an emphasis on topics relevant to the study.

The following topics are discussed:

- International Governance and Regulation (Section 3.2)
- UK Governance and Regulation (Section 3.3)
- Key Aviation Stakeholders and their Interactions (Section 3.4)

3.2 International Governance and Regulation

3.2.1 ICAO

The International Civil Aviation Organisation (ICAO) was established to manage the administration and governance of the Convention on International Civil Aviation (Chicago Convention). ICAO works with the Convention's 193 Member States and industry groups to reach consensus on international civil aviation Standards and Recommended Practices (SARPs) and policies in support of a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector.

ICAO's rules are global, but the standard setting process is often slow compared to the rapid rate of technology innovation.

3.2.2 ICAO's Activities relevant to Future Flight

ICAO has several initiatives relevant to the topic of FF. Ranging from the development of several guidance documents, to running the DRONE ENABLE symposium in early 2021. The initiatives include:

- Guidance
  - Model UAS (Unmanned Aerial Systems) Regulations[4]
  - U-Aid Guidance[5]
  - UTM (UAS Traffic Management) Guidance, Edition 2[6]
  - UAS Toolkit[7]
  - RPAS (Remotely Piloted Aerial System) CONOPS (CONcept of OPerations)[8]
- Expert Groups
  - Remotely Piloted Aircraft Systems Panel (RPASP)
  - Task Force on Unmanned Aircraft Systems for Humanitarian Aid and Development (TF-UHAD)
  - Unmanned Aircraft Systems Advisory Group (UAS-AG)
  - Unmanned Aviation Bulletin
  - RPAS Workshops

3.2.3 ICAO Annex 19

Annex 19 to the Chicago Convention is particularly relevant to this study as it addresses the management of safety.

ICAO requires all States to develop a State Safety Programme (SSP). According to ICAO Annex 19, an SSP is "an integrated set of regulations and activities aimed at improving safety". The SSP should set out the specific safety activities a State will carry out to ensure the safe and efficient performance of aviation activities. These activities are set out in the four components of the SSP:

- State safety policy and objectives
- State safety risk management
- State safety assurance
- State safety promotion

4. ICAOs Model UAS Regulations
5. ICAO U-Aid Guidance Document
6. ICAO UTM Guidance, Version 2
7. ICA UAS Toolkit
8. ICAO RPAS CONOPS for International IFR Operations

These components can be directly mapped to a standard Safety Management System (SMS), however the SSP was a major shift for State Regulators from a pure compliance-based oversight to a Risk and Performance based oversight and will become more relevant still in the future aviation system. This is a significant culture change and challenges established organisational structures and staff competencies. To aid States, ICAO, in conjunction with International Air Transport Association (IATA), has provided a Global Aviation Safety Plan (GASP) which shows a Safety Roadmap for States to follow.

3.2.4 EASA

The European Aviation Safety Agency (EASA) has published drone regulations[9] that act as a starting point for the UK as it defines its future regulations.

These regulations include technical as well as operational requirements for drones. They define:

- the capabilities a drone must have to be flown safely
- the laws on registration of drones
- the rules covering each operation type, from those not requiring prior authorisation, to those involving certified aircraft and operators
- the minimum remote pilot training requirements

The new rules will replace existing national rules in EU Member States and are applicable from 31 December 2020.

EASA has also published a Special Condition for VTOL and Means of Compliance[10] which address the unique characteristics of VTOL aircraft.

EASA has also created Opinion 01/2020[11] which aims to create and harmonise the necessary conditions for manned and unmanned aircraft to operate safety in the U-Space airspace. The intent is to create a regulatory framework for the U-space which permits safe aircraft operations in all areas and for all types of unmanned operations.

3.3 UK Governance and Regulation

3.3.1 Introduction

The role of the UK Civil Aviation Authority (UK CAA) as the UK's single aviation regulator and competent authority is set out in primary and secondary legislation. Its main statutory functions include regulating civil aviation safety, advising the Secretary of State on all civil aviation matters (including policy for the use of UK airspace), the licensing of airlines, and regulation of aviation security functions. The CAA is required to ensure that a high standard of safety is maintained across the aviation industry and its duties such as 'secure the most efficient use of airspace consistent with the safe operation of aircraft and the expeditious flow of air traffic' and 'satisfy the requirements of operators and owners of all classes of aircraft' also contain some elements that will influence FF topics.

3.3.2 State Safety Plan

The UK CAA, in its capacity as competent authority, is responsible for implementing the UK's performance-based safety regulation. This performance-based regulation is based on building a comprehensive risk picture using proactive safety performance indicators. The indicators inform the decision-making on where regulation should be best targeted for improving safety performance across the total aviation system. Safety performance in this context is the achievement of a state in which risks associated with the operation of aircraft are reduced and controlled to a tolerable level. The performance indicators are outlined in the UK's SSP and are as follows:

- Loss of control occurrences due to weather; human performance; or technical failure
- Fire occurrences
- Smoke and fumes occurrences
- Ground handling occurrences: resulting in aircraft damage; relating to loading errors; or, because of other ground services (de-icing, fuelling, etc)
- Occurrences relating to airborne conflict
- Traffic Collision Avoidance System Resolution Advisories (where systems onboard the aircraft alert the crew to take action to avoid another aircraft)

9. Commission Delegated Regulation (EU) 2019/945 and (EU) 2019/947
10. Special Condition for Small-Category VTOL Aircraft
11. High-level regulatory framework for the U-space

- Occurrences of 'level bust' where an aircraft descends below or climbs above their cleared level by a defined amount (usually 200ft (in Reduced Vertical Separation Minima (RVSM) airspace) or 300ft)
- 'Airprox' events
- Airspace infringement events
- Occurrences relating to controlled flight into terrain
- Runway incursions by vehicles, aircraft or people
- Occurrences that could have resulted in a runway excursion due to weather, human performance, or technical failure

These performance-based indicators allow the UK CAA to objectively demonstrate that the Acceptable Level of Safety Performance (ALoSP) has been reached. In the UK SSP, the ALoSP is established through the following safety objectives:

- No fatal accidents in commercial air transport aeroplanes where the UK has State oversight responsibility
- No fatal accidents in commercial air transport rotorcraft where the UK has State oversight responsibility
- No fatal accidents involving people on the ground in the UK as a result of an aviation accident

3.3.3 The 'Significant Seven'

To help in understanding the key safety considerations within UK aviation, the CAA developed the "Significant Seven"[12]. These are seven groups of Bowtie models[13] that analyse the following safety hazards all of which can lead to consequences resulting in direct harm to humans:

- Loss of Control in Flight
- Runway Excursion
- Controlled Flight into Terrain (CFIT)
- Runway Incursion
- Airborne Conflict
- Ground Handling (Outside Mass/ Balance Envelope)
- Fire

It should be noted that these hazards only relate to operation of fixed wing CAT (Commercial Air Transport) aircraft (passenger and cargo) operating in UK airspace. The scope of these hazards does not therefore cover rotary wing aircraft operations, general aviation, business aviation and are therefore only a part of the overall risk picture for UK aviation. Correspondingly, there is no overarching safety case for aviation in the UK (as is also true for other states) which presents an argument and evidence that all aviation operations are tolerably safe.

In developing these models, the CAA investigated the precursors to the hazards above and the safety barriers and controls which are most heavily relied on. The accuracy of the models was confirmed with the use of actual safety data and the input of several subject matter experts during workshops. This led to the development of leading indicators in safety performance which in turn aid the demonstration and discussion of the four main components required in the SSP.

The Significant Seven help to understand the key safety impacts associated with the FF scenarios because they can be used to determine how controls and threats could change as the aircraft, systems and operations change.

3.3.4 Activities Related to Future Flight

At the time of writing, there are a number of activities underway related to FF. These include activities related to:

- Beyond Visual Line of sight (BVLOS) in non-segregated airspace including publishing a fundamentals paper (CAP1861[14]) and a sandbox challenge (a scheme where the CAA support trials of innovative aviation solutions)
- Drone topics including collecting evidence for 'detect and avoid' solutions and developing a target level of safety (TLOS) for UAS
- Future air mobility (FAM) including a sandbox challenge and gathering industry insights on risk management to increase understanding of FAM business concepts. This activity also includes a consultation activity with industry on hazards associated with FAM

12. CAA Significant Seven
13. Bowtie is a barrier risk model notation available to assist the identification and management of risk
14. CAP1861 - Beyond Visual Line of Sight in Non-Segregated Airspace

- UAS traffic management including published guidance (CAP1868[15]) on the CAA's position on UTM and developing a report on economic regulation
- Autonomy and automation, including work to investigate autonomous and automated systems and develop the CAA's view on a regulatory approach
- Social licence, including a paper (CAP1900[16]) on how innovators can build social engagement as part of their development strategy
- Aerodrome operations, including investigating new and multiple fuel types and ways to ensure safety standards at unlicensed aerodromes
- Connected Places Catapult UTM CONOPS[17] - describes the steps the UK has already taken and forthcoming steps that need to be taken to assure the UK's position at the forefront of commercial drone development
- ICAO RPAS CONOPS[18] - the concept of operations for remotely piloted aircraft systems aims to describe the operational environment of manned and unmanned aircraft to highlight the challenges of effectively integrating them into a single airspace environment
- SESAR U-Space work[19] - a programme of work tasked with defining a vision of how to make the U-Space operationally feasible
- FAA (Federal Aviation Authority) UAM CONOPS[20] - the concept of operations is designed to provide a common frame of reference to support the FAA, NASA, industry, and other stakeholder discussions and decision-making with a shared understanding of the challenges, technologies, their potential, and examples of areas of applicability to the National Airspace System
- ICAO UTM CONOPS - intended to provide a framework and core capabilities of a "typical" UTM system to States that are considering the implementation of a UTM system. A common framework is needed to facilitate harmonization between UTM systems globally and to enable industry, including manufacturers, service providers and end users, to grow safely and efficiently without disrupting the existing manned aviation system.

3.4 Stakeholders and interactions

The stakeholders in the current aviation system are numerous, with interactions occurring between many of them. These stakeholders and their main interactions are shown in the actor diagram depicted in Figure 2 on the following page.

The diagram is structured into a central portion (enclosed by the dotted line) which shows the main elements and interactions. Some of the main elements are expanded into groups which sit outside the dotted line to provide additional detail.

Each scenario within the future aviation system is presented using an actor diagram. Changes from one scenario to the next are highlighted in red both for elements and for interfaces. The changes are described below each diagram in summary form.

The image below is a diagrammatic representation of the current aviation system and the key interfaces between actors within the system. A summary of the key interfaces is presented on the following page.

The current system is characterised by airspace users using portions of the airspace in a controlled and regulated manner. Air navigation services (ANS) for airspace users in controlled airspace are provided by a combination of enroute and aerodrome service providers depending on the part of the airspace the airspace users occupy.

15. CAP1868 - A Unified Approach to the Introduction of UAS Traffic Management
16. CAP1900 - Social Licence to Operate
17. Enabling Unmanned Aircraft Traffic Management in the UK Report
18. RPAS CONOPS for International IFR Operations
19. SESAR U-space documentation
20. FAA U-Space Concept of Operations

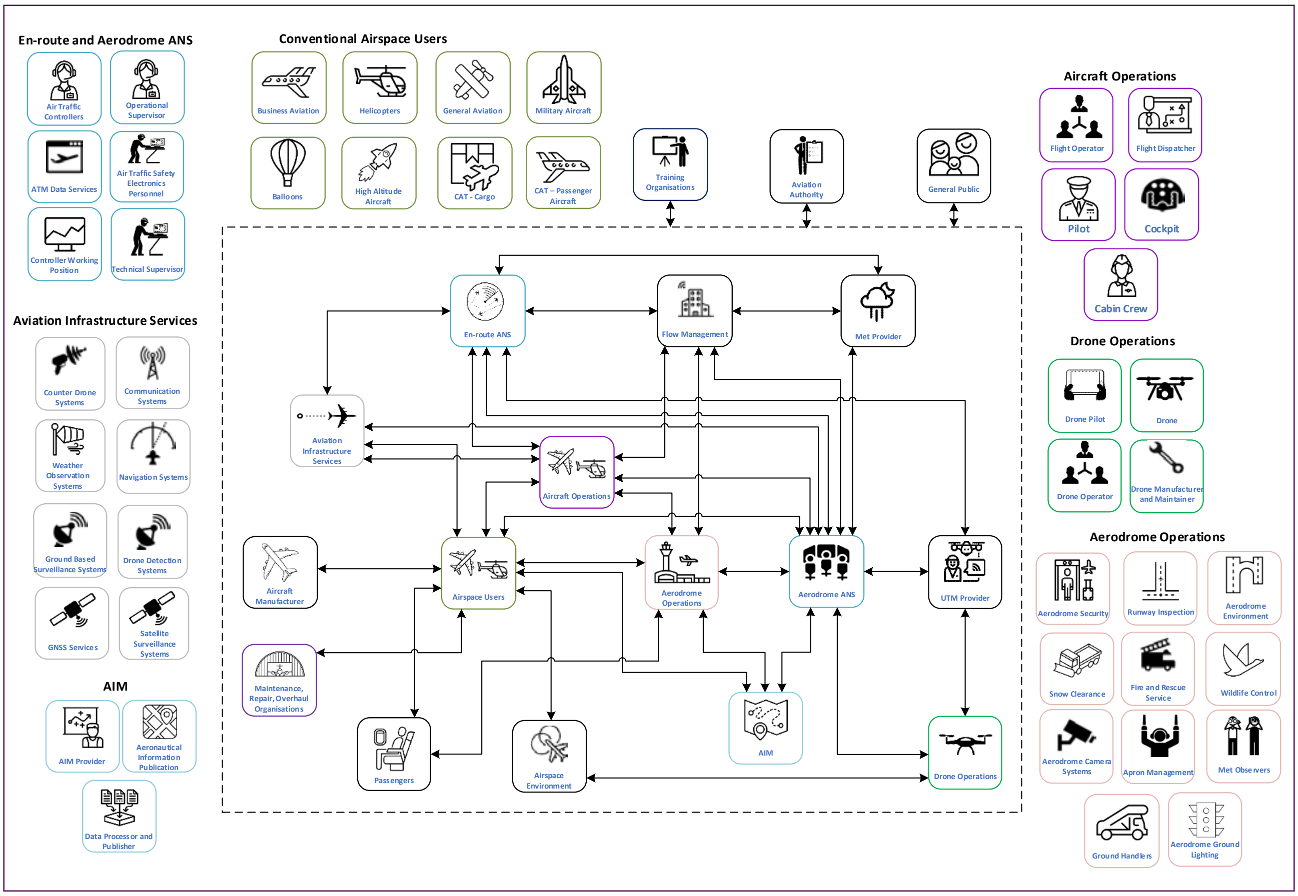


Figure 2: Current system actor diagram

The ANS relies upon a combination of support and infrastructure information services to operate effectively. Airspace users are supported by a range of support services such as maintenance, repair, overhaul (MRO) and by the aircraft manufacturers. Airspace users are usually supported by aircraft operating organisations, e.g. airlines. Aerodromes are also supported by aerodrome operating organisations providing the necessary functions to support operation of the aerodrome. Conventional airspace users comprise fixed-wing and rotary wing aircraft operating on a commercial and leisure basis.

This group also includes military aircraft. In the current aviation system, conventional aircraft and drones are operated in a segregated fashion with separate operating organisations and separate traffic management providers. Drones do however use the aerodromes as a base for operations and there are specific capabilities for drones within both aerodrome operations and infrastructure services to support their operation and the safe interaction between drones and conventional airspace users.

The Future Aviation System

4

The Future Aviation System

4

4.1 Introduction

This section describes the Future Aviation System in the context of this study.

Three future scenarios are first described in Section 4.2 including, in diagrammatic form, the actor diagram for each scenario. The actor diagrams are useful to aid discussion on the changes to aviation, but they are not intended as a comprehensive description of all actors and roles.

The three use cases (drones, UAM and RAM) are then described in Sections 4.3, 4.4 and 4.5 respectively, and each is described in the context of the three different scenarios.

4.2 Scenarios

4.2.1 Introduction

Three future scenarios are described based below on short, medium and long-term aviation system horizons. They adapt the current system, shown in Figure 2, with the addition of new concepts of operation, service providers, vehicles or infrastructure based on our knowledge of upcoming technology or regulation.

The scenarios are not meant to be fixed points of development but rather they are tools to show the evolution of systems and operations. Some of the changes from one scenario could happen before or after the others in that scenario and the illustrative timescales shown are only to anchor the study.

4.2.2 Short-term

This scenario is characterised by early adopters of drone and UAM aircraft operating on a limited volume basis within the current regulatory and airspace structure. Requirements for certification and aircraft approval will be similar to today's environment. New aircraft will generally operate below 2,000ft Above Ground Level (AGL) (and 400ft AGL for drones), in Class G airspace (under current procedures) or portions of controlled airspace that are either segregated from other airspace users or where positive separation is assured through existing procedures (e.g. for UAM aircraft flying under Visual Flight Rules (VFR) in controlled airspace).

It is anticipated that any form of new technology will be limited in terms of functionality (range / capacity etc.) and automation will be limited to operating in an assistive capacity similar to current autopilot and automatic landing functions.

The existing aviation infrastructure will remain, at this stage, largely unchanged. Drones and UAM aircraft will operate in a limited capacity within the existing infrastructure with a pilot in command (PiC) either in a remote or on-board capacity. Drones will increase in number and variety of operations more quickly compared to UAM aircraft.

This diagram on the following page shows the expected changes to the aviation system within the short-term (approximately five years). The changes from the previous actor diagram are shown in red.

The key changes between now and the short-term future are the introduction of:

- ATM Data Service Providers (ADSPs), including different types of service provider
- UAM Operations
- Vertiports[21]
- UTM services as a more generic term to replace UTM provider

The introduction of ADSPs is currently being investigated under European initiatives such as the Airspace Architecture Study[22] and the Wise Persons Group report[23]. The scope of these providers has not yet been fully established, but it is expected that a number of services could be provided.

21. The area of land, water, or structure used, or intended to be used, for the landing and take-off of VTOL aircraft together with associated buildings and facilities
22. SESAR Airspace Architecture Study
23. Report of the Wise Persons Group on the Future of the Single European Sky

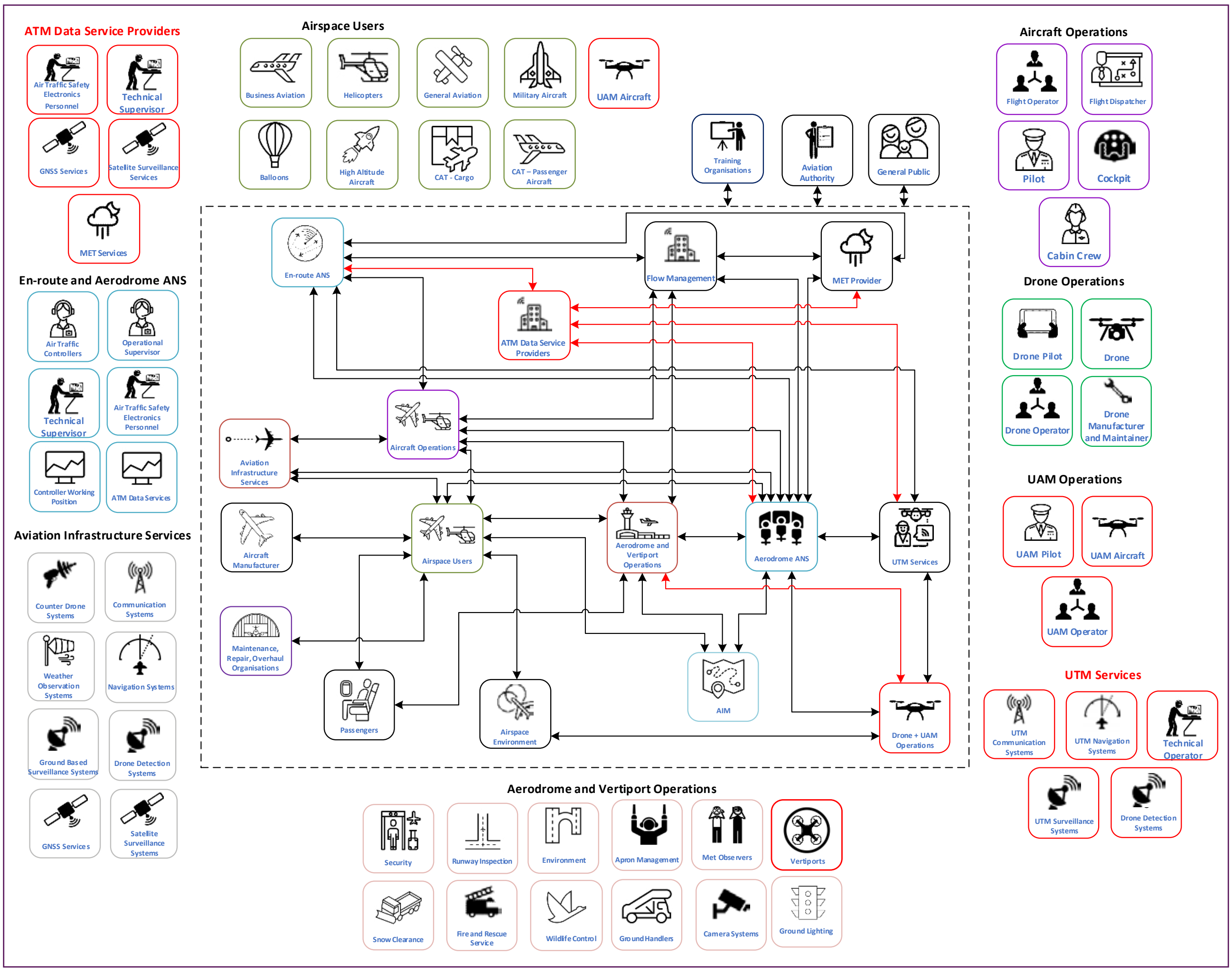


Figure 3: Short-term actor diagram

This could include, but not be limited to Meteorological (MET) services, satellite-based surveillance (such as Automatic Dependent Surveillance - Broadcast (ADS-B)), or other flight data information.

The introduction of UAM aircraft is expected to occur in the short-term, for example with introduction of at least one planned in 2024[24]. Initially they may operate from existing aerodromes, however new UAM ground-based infrastructure known as vertiports will also start to be established to support an expanded range of operating locations. The growth of UAM will need to be matched by deployment of the supporting infrastructure (e.g. vertiports and dedicated traffic management services). UAM services may be scheduled or on-demand.

BVLOS operation for drones will be common and some operations will rely on autonomous, rather than remote pilot, control.

Supporting industries will also change and evolve in this timeframe. This could include, for example, changes in the insurance industry, weather forecasting and obstacle survey services.

4.2.3 Medium-term

This scenario is characterised by more widespread and higher density use of drones and UAM aircraft operating with increased use of autonomous functions. The regulatory and airspace structures will evolve to meet the demands of higher volumes of drones operating in very low level (VLL) airspace (i.e. <400ft AGL) concentrated in urban areas as well as UAM aircraft operating up to 1,500 or 2,000ft AGL.

This scenario is also expected to include a limited volume of aircraft for inter-city journeys (over 100 miles). These journeys will involve larger aircraft operating with electric or hybrid propulsion with or without Vertical Take Off and Landing (VTOL) capability at altitudes above 2,000ft AGL. Given the longer distance nature of this use case, the aircraft are expected to operate predominantly on a scheduled basis with less use of on-demand services.

24. Vertical Aerospace Reveals 'VA-1X' Air Taxi, Targets 2024 for Commercial Operations

The physical and digital infrastructure will develop to accommodate the needs of these new types of vehicle with construction of multiple vertiports in urban environments where demand is expected to be greatest. It is likely that smaller airfields (e.g. today's GA-only airfields) will also become more widely used for operations of new aircraft types alongside existing uses. Supporting infrastructure, including traffic management systems, will need to have the ability to cope with on-demand as well as planned services.

The infrastructure supporting 5G mobile communications link and more widespread satellite-based communications links will be present albeit some of these will be in an immature state. It is expected that electronic conspicuity (EC) for all aircraft types, including GA, will become more important and potentially mandatory as a mechanism for enabling detect and avoid solutions to be effective, as well as more strategic forms of separation (e.g. traffic/flow management).

This scenario will also lead to the formal designation and segregation of airspace at VLL and the introduction of UAS and UAM service suppliers[25], e.g. UAS traffic management service providers, operating in a unified fashion with existing ATM service providers (although not yet in a Unified Traffic Management Service (UnTMS)). This concept is shown in Figure 4. These service providers will share information bilaterally as necessary to improve the efficiency of the ATM service and permit entry on an exceptional basis of UAS aircraft into airspace normally occupied by manned aircraft. UAM aircraft will be subject to the same ATM service as other aircraft operating in controlled airspace due to the nature and location of operations.

The airspace and regulatory structures will evolve to meet the needs of the emerging UAM and drone sectors although these factors may hinder a faster pace of adoption of these technologies into the aviation sector. Some challenges are expected to emerge related to the provision of safety assurance for the new platforms and service providers to meet the necessary safety requirements. For example, in this timeframe, there may be more composite aircraft that do not provide a primary radar return entering high-density airspace where primary radar has an important safety role. Also, autonomous vehicles may start to be deployed and mix with traditional manned aircraft. The new entrants may be high-technology start-ups that do not have a corporate knowledge of traditional aviation procedures or culture.

There will be limited integration of airspace structures between manned and unmanned aircraft, although the UAS traffic management function will develop rapidly to support this transition.

This diagram on the following page shows the expected changes to the aviation system for the medium term, i.e. up to approximately 10 years. The changes from the previous actor diagram (short-term) are shown in red, with the main changes being the introduction of RAM operations and the evolution of more services in ADSPs and ANS.

In the medium-term, drones, UAM and RAM aircraft will develop further, with increased levels of infrastructure and service provision made available. This will include more physical infrastructure for UAM aircraft such as "Vertiports" and adaptation of existing infrastructure (e.g. providing hydrogen storage at conventional aerodromes). Some aerodromes may become 'service centres' for UAM aircraft where they can be parked safely overnight, hangered and maintained by qualified personnel.

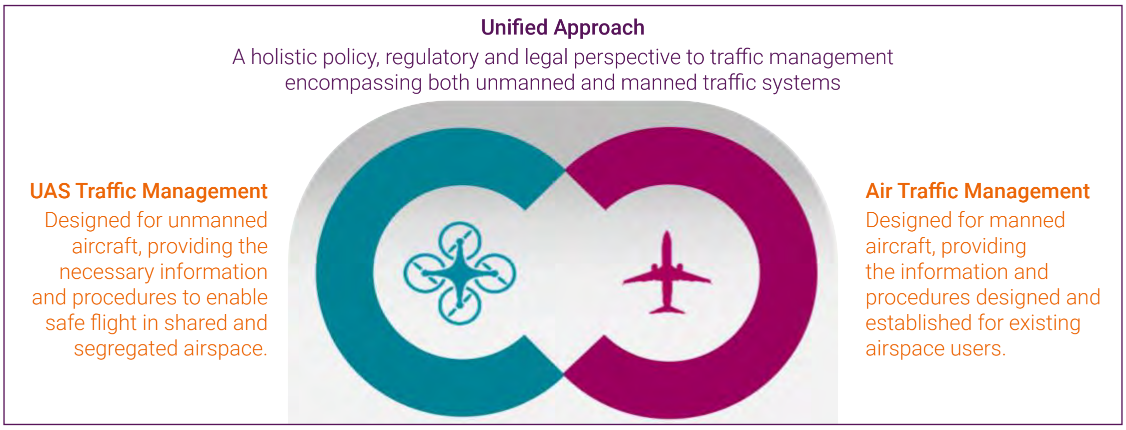


Figure 4: A Unified Approach to Traffic Management of UAS and Manned Aircraft[26]

25. The FAA is also promoting the concept of a Provider of Services for UAM (PSU).
26. CAP1868 - A Unified Approach to the Introduction of UAS Traffic Management

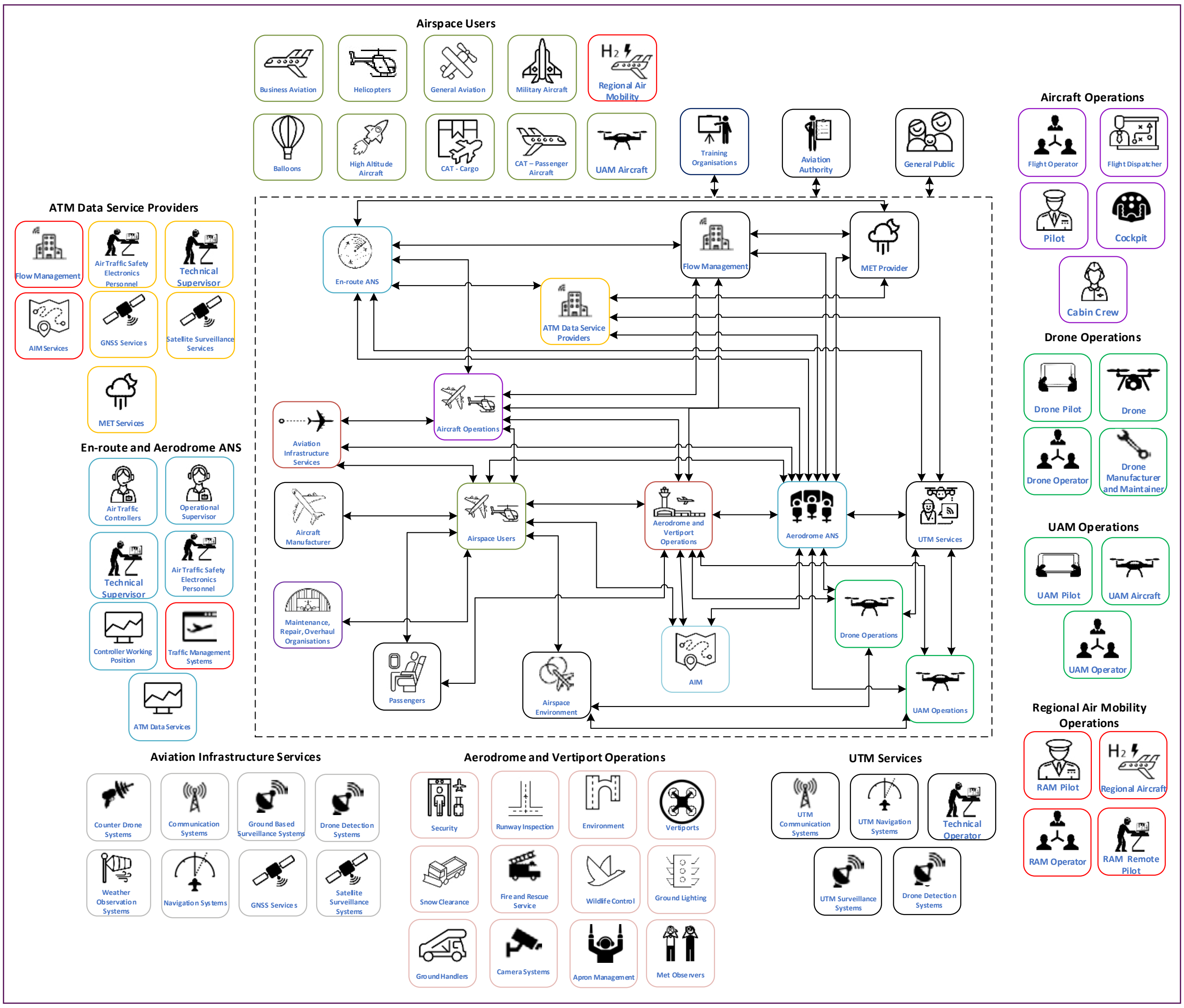


Figure 5: Medium-term actor diagram

ATM and UTM service provision will evolve to provide a greater range of services to the new vehicles. This will include Communications, Navigation and Surveillance (CNS) infrastructure specifically for UAM and drones alongside the necessary technical staff required to operate these systems.

Another change in the medium-term is the addition of more advanced Traffic Management Systems. It is predicted that in future the role of Air Traffic Controllers (ATCOs) will evolve to a supervisory role, where they will be required to act in the event of emergencies, rather than providing continuous active control. Increased dependability in ATM systems will be needed to address integrity, resilience and cybersecurity challenges posed by greater automation. These systems will become more active in the medium-term; however, the evolution of the ATCO will not yet be complete and so they will still remain as important stakeholders in the aviation system.

4.2.4 Long-term

This scenario is characterised by widespread use of drones operating in an increasing variety of use-cases from provision of delivery services, inspection and monitoring, surveillance and broadcast, and robotic functions. The operational capabilities such as range, payload and complexity of function of these aircraft will increase over time increasing their potential deployment options. For example, there are drones in development today that will have a payload of 800kg and this is expected to increase over time well beyond 1,000kg. The principal impact of increases in drone mass relate to the expected increase in severity of the consequences should a drone impact the ground or another airborne object. This will lead to a requirement to revisit the safety case for drone operations given the expected increase in potential risk. The expansion in freight aircraft is expected to include large, wide-body aircraft that are autonomously or remotely piloted as an option for reducing the crew costs of cargo flights. Numerous regionalised drone freight-hubs could emerge in industrially dense locations as well as adjacent to population centres.

UAM and RAM aircraft will be well-established and operate across a range of intra and inter-city use-cases serving the aerial transport needs of significant portions of society on a cost-effective, low carbon basis.

Advanced technology across both aircraft propulsion, guidance and control domains will be mature and some aircraft will operate in a fully autonomous mode on both a scheduled and on-demand basis. Traffic management and other service providers will be fully integrated across both unmanned and manned aircraft domains forming a unified traffic management function.

The regulatory and safety management framework will evolve to meet the demands of the new vehicles and operators with an integrated airspace structure, an integrated safety and other risk management framework and established safety assurance standards and processes for manufacturers, operators and service providers.

This diagram shows the expected changes to the aviation system in the long-term, i.e. up to approximately 15 years. The changes from the previous actor diagram (medium-term) are shown in red.

In the long-term, the main transition will be a move to a UnTMS that includes both ATM and UTM.

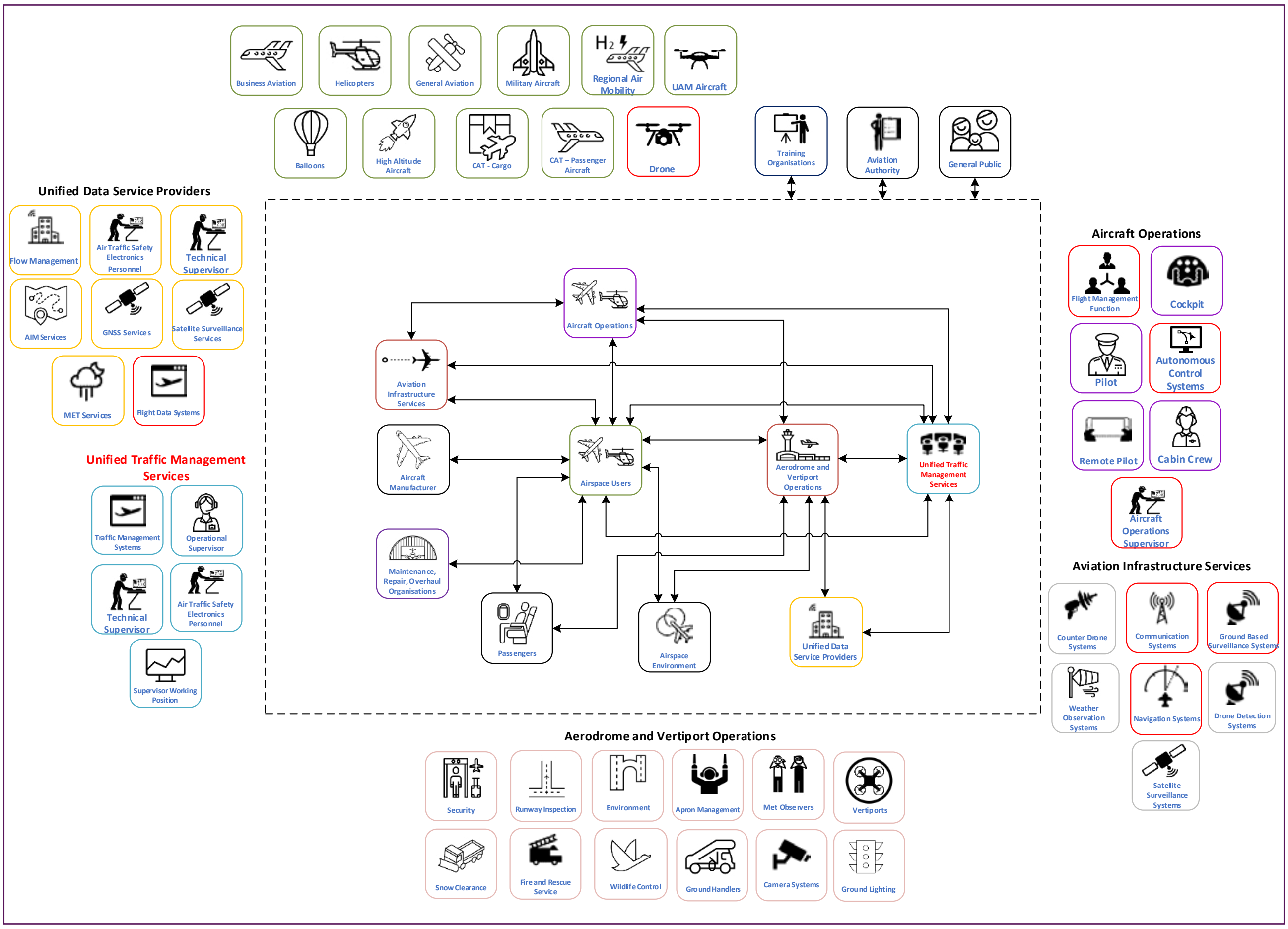


Figure 6: Long-term actor diagram

This will represent the merging of service provision from the medium-term position to leave a less fragmented system. This change will include the continued evolution of the ATCO to a supervisor role, with the UnTMS providing separation and flow information to all airspace users. This change could also include the expansion of the Data Provision Services, with all flight data now being provided by Unified Data Service Providers (UnDSPs).

It is also noted that in this long-term vision, density of operations and variety of locations will significantly increase, with UAM aircraft being more commonplace in many large cities and other locations where the transport mode is value adding (e.g. remote locations with poor transport links). This will be reflected in an increase to the levels of infrastructure such as vertiports and maintenance facilities required in major cities as well as remote locations.

Drone services will become more extensive, with long range and/or long duration operations and higher weight category operations occurring. In addition, multi-drone operations (e.g. swarm operations) may become more common. Operations will occur across urban and remote environments.

For both drones and UAM, there could be a step change in the number of active air-operators/airspace users with many smaller new entrants with limited corporate history of aviation.

In this timeframe, climate change could become a significant factor in UK society. There could potentially be more extreme weather events causing higher temperature extremes and weather variability. Aircraft and supporting infrastructure will need to be qualified to operate in these extreme conditions to assure continued operations. Further, the importance of timely and accurate MET information will also increase under these conditions. Equally, resource usage constraints and maximising efficiency will increase in significance.

4.3 Use Case 1 – Drones

4.3.1 Introduction

The rapid expansion of drones in recent years has been enabled by technological developments (e.g. battery evolution) and new manufacturing processes (e.g. to reduce costs).

We consider three sub-cases of drone operation in this section:

- Drone delivery - e.g. for parcel or part delivery. There are also safety critical examples here such as blood or organ transfer between hospitals
- Drones for monitoring, surveying, inspection, surveillance and broadcast - e.g. for construction site surveys, filming, Wi-Fi broadcast
- Drones that perform a robotic function - e.g. for crop spraying, painting or repair of inaccessible items such as wind turbines. These drones will carry robotic systems to perform their function

4.3.2 Short-term

Initially, many drones can be expected to be less than 20kg and operating at VLL with a mission distance of a few miles, perhaps up to tens of miles. However, in remote locations early applications may include larger drones providing cargo delivery (e.g. to oil rigs[27] and islands[28]). The operating characteristic parameters will expand over time with larger and longer-range drones becoming more widespread and operating at higher altitudes. Some novel, larger eVTOL cargo drones are under development[29] that are due for entry into service in this scenario. In addition, drones with robotic functions will provide specialist services such as wind turbine cleaning and de-icing[30].

Some applications will have controlled take-off and landing areas (e.g. at hospitals), while others will be expected to have reasonably uncontrolled take-off and landing zones (e.g. parcel delivery). The use of uncontrolled take-off and landing zones may be limited in number in the short-term especially in densely populated urban environments.

Most of the drone services will be on-demand although some will operate on a regular or scheduled basis.

In the short-term, the generalised use of drones for BVLOS will still be in development. Initially BVLOS operations will be under controlled conditions (e.g. hospital to hospital or for infrastructure (e.g. railway) inspection purposes) where the take-off and landing points can be controlled and the route is pre-defined with low-risk exposure. BVLOS trials[31] to carry hospital supplies have already taken place in 2020 during the Covid-19 crisis and also for deliveries to oil rigs[32].

27. Camcopter S-100 helicopter drone makes world-first oil rig delivery
28. Flylogix to trial UAV freight delivery for Isles of Scilly
29. Pipistrel begins to accept orders for Nuuva series of cargo eVTOL aircraft
30. Aerones develops de-icing and cleaning drone for wind turbines
31. NHS Drone Delivery Trial
32. Camcopter S-100 helicopter drone makes world-first oil rig delivery

As the use of drones in urban areas expands, there will be a corresponding increase in awareness of non-safety issues such as noise impacts and social acceptability, although they may be raised in combination with safety concerns.

Drones operating at VLL away from aerodromes and other restricted areas are out of range of most aviation infrastructure (e.g. radio, radar) and may be too small to carry transponders. They will operate on current Global Navigation Satellite Systems (GNSS) navigation services (multi-constellation) and, where they operate BVLOS, they will most likely use mobile telephony infrastructure for communication.

4.3.3 Medium-term

The main difference in the medium-term will likely be the expansion of BVLOS services into more generalised operations involving wider use of 'uncontrolled' take-off and landing zones.
The increased use of 'uncontrolled' take-off and landing zones will be important for supporting an expansion of drone use-cases including emergency medical evacuation but will need to be supported by increased capabilities to ensure an uncontrolled zone is safe for use.

These operations may be enabled by improved vision systems on drones that can recognise and avoid obstacles in take-off and landing zones. These will be enabled by Artificial Intelligence (AI) vision systems. They may also assist conflict detection and resolution.

Drones may be deployed to repair and recover other drones. Drones may be used for extremely long missions both in time and distance. Equally, micro drones may be more widely used, individually and in swarms.

From a technology perspective, there will be a continued evolution of inertial navigation systems to allow continued navigation in the case of loss of GNSS or a degraded GNSS signal due to the "urban canyon" effect. Satellite communications may become enabled on relatively small drones (e.g. via the Starlink system).

Whilst the short-term use of drones may be identified from current Research and Development (R&D) activities, by the medium term there could be whole new classes of drones in a new range of activities that we cannot foresee at this stage.

4.3.4 Long-term

In the long-term there will be an expansion in intelligent drones that will operate with little or no tactical input from the ground. This may include the ability to self-charge at charging points and plan and undertake autonomous missions with no direct human engagement.

Drones will increasingly interact with other aircraft as UAM aircraft, which will also operate at low altitudes and in urban centres and increase in number. Drones will also develop additional applications which require access to airspace at all levels for potentially extended periods of time.

4.4 Use Case 2 – Urban Air Mobility

4.4.1 Introduction

UAM exists today in the form of helicopter transport and there are already a substantial number of helicopter movements. For example, between 2016 and 2019 annual helicopter movements in London ranged between 18,500 and 25,000[33]. Significant investment is being made in the UK and internationally in future UAM aircraft with VTOL capability. Current research and development are focused on eVTOL and Hybrid Electric VTOL aircraft.

Current UAM aircraft R&D is focussed on propeller or ducted fan for vertical lift with some designs also utilising wings for cruise flight. The flight phases of UAM aircraft will be:

- Take-off
- Transition (climb)
- Cruise
- Transition (descent)
- Landing

A key objective of many UAM aircraft currently in research and development is a significantly reduced noise footprint compared with current helicopter operations. The expected cost reductions in manufacturing and operation of eVTOL and hybrid aircraft and the expected reduced noise profile is the basis for predicted UAM industry growth.

A number of potential business cases for these aircraft have been identified including:

- Short intra-city air taxi
- Airport commute

33. Data for helicopter operations within the London (Heathrow) and London City Control Zones (CTRs)

- Longer distance taxi (up to 200 miles on a regional basis)
- Emergency services, including air ambulance, fire monitoring and fire fighting in high rise buildings, search and rescue operations

UAM services may be delivered through scheduled services or on an on-demand basis. UAM services may carry passengers or cargo or a combination of both. Most current research and development are focussed on aircraft which will carry between two and five passengers.

Ground based infrastructure for UAM operations will be required. Vertiports will provide take-off and landing facilities as well as parking facilities dedicated for UAM operations. Around aerodromes, vertiports may be integrated with other ground-based aviation infrastructure (for example airside facilities) or located close by but not integrated. Vertiports will have charging facilities for the aircraft; the patterns of aircraft movements and charging times will ensure sufficient energy for operations. Energy usage and recharging profiles will likely vary between UAM aircraft designs,

A trip may involve multiple UAM aircraft movements to re-position the vehicle before and/or after an intended flight.

Operation could be via large fleet operators similar to today's airlines or networks of private operators.

4.4.2 Short-term

In the short-term it is expected that trials of UAM aircraft, carrying passengers, will occur with the intention of providing assurance for commercial services. Following trials, initial services would commence and at least one manufacturer has targeted 2024 to start operational UAM services that will be operated with a pilot and four passengers[34].

Initial services are expected to have a PiC on board with the UAM aircraft operating under VFR in Visual Meteorological Conditions (VMC) and complying with current airspace and ATM requirements in a manner similar to other airspace users. Current conventional technology (e.g. ADS-B transponders, Very High Frequency (VHF) radio) applicable to other airspace users will be used.

Current helicopter routes may be used as well as other airspace in a manner similar to VFR operations by other airspace users. Existing aerodrome and heliport ground infrastructure may be used, but it is expected that vertiports, with some situated in dense urban environments, would be established and enter operation in the short-term to support early UAM services.

4.4.3 Medium-term

In the medium-term following initial services, an increase in the density of operations is expected, with more service providers operating numerous aircraft in the same airspace. To provide reliable services, flights will need to occur in Instrument Meteorological Conditions (IMC) which may require new regulations and procedures if current Instrument Flight Procedures (IFP) cannot be applied in a dense urban environment.

As well as requiring new flight rules, the current ATM procedures and airspace designs are likely to be insufficient to manage higher density operations.

New technology will likely be available in the medium-term including increased automation (e.g. sense and avoid), improved CNS (e.g. improved Navigational Performance). New technologies may lead to a change in role of various components of the aviation system including a move away from reliance on voice communications as the principal communication mechanism.

In the medium-term new technology may allow the trialling of remote pilot capability and the introduction of UnTM airspace concepts such as managed and unmanaged airspace with differing requirements on levels of aircraft equipage to operate in those airspace environments. The concept of simplified pilot skills may emerge whereby many current pilot functions are fully automated. This may reduce operating costs and enable pilot labour shortages to be overcome.

In the medium-term, it is likely that the peak in the range and variety of vehicle types will occur before potential consolidation.

The number of vertiport locations in cities will increase to support a greater volume and diversity of operations.

34. Vertical Aerospace Reveals 'VA-1X' Air Taxi, Targets 2024 for Commercial Operations

4.4.4 Long-term

In the long-term, there will likely be a further increase in the density of operations. A greater use of autonomy may see services provided with no PiC on board. However, some UAM services and other airspace users will still have a PiC on board. As such, a mix of autonomous, ground controlled and PiC on board operations will occur in the same airspace. Greater levels of integration of UAM operations with other airspace users will occur. Improvements in technology (e.g. CNS technology) will lead to higher navigation performance precision in flights and reductions in separation standards. Some airspace may become free-route with other airspace maintaining fixed routes. It is expected that overarching airspace system design and procedure specification will need oversight by an authority responsible for systems integration.

4.5 Use Case 3 – Regional Air Mobility

4.5.1 Introduction

Regional Air Mobility (RAM) will likely be the next class of size up from UAM aircraft. Passenger numbers up to 100 will take city-city journeys to cover the distances between major population centres. Cargo will also use this mode. Similar to UAM, these aircraft will make use of new technologies to reduce the carbon footprint of the vehicle. These technologies may include pure/hybrid electric and hydrogen fuel cell forms of propulsion. The Airbus ZEROe[35] aircraft are powered by turbofan or turboprop engines using hydrogen as a fuel and are intended to be climate neutral zero-emission commercial aircraft.

4.5.2 Short-term

The first aircraft will be evolutions of current regional aircraft with similar characteristics. They will be treated in a similar way to conventional aircraft. The piloting of these aircraft will continue with the same trends as conventional aircraft, i.e. piloted but with increasing automation to support the pilot.

These aircraft will be treated as conventional aircraft, operating from airports and under conventional air traffic control rules. Initially, cargo aircraft may be more widely deployed than passenger ones.

Hybrid aircraft will be able to achieve a longer range than all-electric aircraft and will be the first to emerge[36].

Hydrogen-powered aircraft may also emerge powered by hydrogen fuel cells with airports developing new fuel storage and loading systems.

4.5.3 Medium-term

In this time frame, all electric-powered aircraft will start to be introduced. As eVTOL aircraft increase in size and range, urban take-off and landing zones will also emerge for this class of aircraft in a similar manner to vertiports for UAM aircraft.

Hydrogen-powered aircraft may also become more widespread.

Autonomous aircraft will start to emerge for passenger travel. Several control combinations are possible:

- Single pilot in aircraft with autonomous fallback
- Single pilot in aircraft with remotely piloted fallback
- Remotely piloted aircraft with autonomous fallback
- Entirely autonomous aircraft

These autonomous and semi-autonomous aircraft will pose challenges as they are integrated with traditionally piloted aircraft. For example, the ATM system will need to treat autonomous aircraft as if they are manned and will communicate by voice and datalink. Even in abnormal or emergency situations such as responding to rapidly changing weather conditions or emergency avoiding instructions from the ATCO. The autonomous systems will need to be able to safely cope with the inconsistent sensor inputs and/or incorrect actions by external actors (e.g. an unsafe clearance given by mistake by an ATCO).

4.5.4 Long-term

In the long-term, flight performance of RAM aircraft may diverge significantly from conventional ones. For example, a blended wing aircraft[37] could have a different operating envelope to current aircraft.

The complexity of traffic management will increase as these aircraft mix on a broader basis with conventional aircraft - for example, when eVTOL aircraft rise vertically into complex airspace which is occupied by traditional jets travelling at high speed.

35. Airbus ZEROe Range of Hydrogen Powered Aircraft
36. Electric Aviation Group Unveils World's First Hybrid Electric 70+ Seater Aircraft
37. Airbus reveals its blended wing aircraft demonstrator

Safety Management Challenges of Future Flight

5

5

Safety Management Challenges of Future Flight

5.1 Introduction

It is important to ensure key safety challenges are identified and work commences to address them early in the evolution of UK aviation. These challenges must be considered in parallel with the advancement of technology for FF operations. If this does not occur it will be difficult to integrate and assure the new operations identified by the FF use cases. This will be particularly true through the medium- and long-term as operations scale and complexity increases. This section discusses the primary safety management challenges of FF using four transversal themes as the basis:

- Safety management of complex systems (Section 5.2)
- Integrated risk and safety management (Section 5.3)
- Role of the human and autonomy (Section 5.4)
- Supporting infrastructure (Section 5.5)

Further safety management challenges may be identified and explored in the future in a similar manner. However, initially, these four areas are considered the most significant given they require long-term consideration and planning to achieve effective outcomes in their management.

5.2 Complex Systems in the Aviation System

Aviation systems are becoming more complex[38] (both technically and organisationally). Complex systems have emergent behaviours based upon the interaction of the components of the system. Emergent behaviour cannot be reliably predicted simply from knowledge of the system components and their interactions. In addition, it can also be difficult to draw a boundary around a complex system and there are often interactions between systems and their environment which can lead to unexpected behaviour. This emergent behaviour can include safety-significant behaviours and outcomes. While it may be possible to determine the causes of these outcomes after a safety occurrence, predicting these outcomes becomes extremely challenging as system complexity increases. These issues are already apparent in the current aviation system and will become more prevalent as complexity increases.

Complex systems can lead to a variety of challenges for safety management including:

- Predicting and Managing Tipping Points, where the system changes from one state to another potentially unsafe state from which it can be difficult to recover
- Achieving Resilience, where due to the potential for emergent behaviour, system operators and other stakeholders must have recovery mechanisms in place to manage failures, and other safety occurrences and reduce the likelihood and consequence of accidents

Unless this is done, it will be hard to achieve trust, as the unexpected, emergent behaviour makes it more difficult for the system operators, users or regulators to have confidence or assurance of a system's ongoing safety performance.

38. Safer Complex Systems: An Initial Framework, S Burton, J A McDermid OBE FREng, P Garnett, R Weaver, University of York, July 8, 2020 (available here in January 2021)

Understanding the impact of complexity on the aviation system must be considered at all layers including:

- Governance - specifically regulatory and policy roles
- Management - organisational activities and processes that contribute to the safety performance of systems (e.g. safety culture and contracting)
- Task and Technical - the operation and use of systems

Within aviation, the complexity of systems is increasing rapidly. The number of organisations involved in FF, the pace of change and the technical complexity of the aviation system components are all increasing. A recent example is the impact of drones on ATM, as seen at Gatwick Airport in December 2018[39].

5.3 Integrated Risk and Safety Management

As documented in ICAO Annex 19, a key element of safety management is the consideration of risk. All safety management activities, but especially risk management, should be undertaken in an integrated manner. Integration ensures that activities are not undertaken in isolation (say within a single organisation) but in the context of other safety and risk management activities which may influence the outcome. These activities will often be in other organisations within the aviation system but may also extend beyond the aviation system, e.g. to infrastructure providers.

For the UK, (as is true for other States) there is no overarching safety case for aviation which presents an argument and evidence that all aviation operations are acceptably safe.

Within the current aviation system there is an implicit acceptance of different levels of safety for different operations. For example, for 2002-2011, the FAA estimated global airline accident rates of 0.4 fatal accidents per million hours flown. In the same period, for General Aviation (GA), the annual figure did not drop below 12. In the UK there is no data on the relative accident rate of different sectors, but we can expect that a similar distribution exists - GA may fly more in airspace without an ATC service to monitor their proximity to other traffic. Larger aircraft tend to have more systems such as TCAS (the traffic collision avoidance system) to provide a safety net.

Different ALoSP are therefore applicable to different types of operation, and they may also be applicable to different phases of flight, although these are not necessarily documented and set as targets.

Given the lack of an overarching UK Aviation Safety Case, it is likely that the current safety management regime relies on a number of assumptions which may not be documented. The extent to which these assumptions impact the way safety is achieved is unknown. For FF, new types of aircraft and operations may break existing, implicit, assumptions which impact how an acceptable safety performance might be achieved. For example, the turn or acceleration performance of new types of aircraft may mean that they cannot be treated like existing aircraft from a collision risk perspective.

Managing safety across multiple stakeholders has potential benefits but is likely to be challenging. Currently, safety assessments are completed separately by ANSPs, airports and other aviation stakeholders. Instead, if an innovative, harmonised and integrated national framework was developed, as planned for within the UK Drone Strategy, the safety of the aviation system as a whole could be analysed and improved. This will become more important as more stakeholders enter the aviation system. The aim of this report is to take a first step towards overcoming the challenges of producing a safety case for FF that should realise some of these benefits.

Risk Integration

As documented in Section 3, there are many participants in the aviation system that together contribute toward safety outcomes. From a safety perspective, individual actors have significant ability to impact actors in other organisations which can either increase or reduce risk (i.e. provide external mitigation) beyond organisational boundaries. If not well managed, safety objectives within an organisation can be in contradiction with safety objectives in another organisation. For example, ATC instructions to an aircraft on approach may help maintain separation standards but could also be a contributing factor to an unstable approach for a pilot.

Approaches to consider risk across the aviation system, beyond organisational boundaries, are already an important element of effective risk management in aviation.

39. Gatwick Airport: Drones ground flights

For example, the EUROCONTROL Risk Analysis Tool[40] is a tool which aims to integrate consideration of risk beyond organisational boundaries. Further evidence of integrated risk management approaches is available from integrated Safety Management Systems (iSMS) such as the one in operation to manage risk at Schiphol airport[41]. The tool looks at the contribution of both the ATM and Airborne component to risk.

A key role for all aviation system participants is to understand how their services and operations impact, and are impacted by, other actors' aviation safety risk management. As new FF service providers join the aviation system it will be important for all participants to understand how their operations might impact aviation safety risks.

Risk management standardisation

A key element of achieving safety in aviation is the standardisation of practices which contribute to achieving safety outcomes. While standardisation can be beneficial it is inherently slow and can lead to slow change in what is required or allowed. A property which is common to drone and UAM development is the speed with which innovation occurs. A key challenge for FF will be to reconcile innovation speed with slow rate of change in standardisation and regulation.

Measurement and quantification of risk

New operations may need different ways of considering overarching level of risk acceptability - movements vs hours vs distance travelled. For example, UAM will have much higher number of movements over shorter distances.

The complexity of systems and the role of humans and organisations means that accurate predictive quantitative safety analysis is challenging and will become more challenging in the future[42].

Trade-offs with other Key Performance Areas

ICAO identifies 11 Key Performance Areas (KPAs) within aviation (reference ICAO Doc 9854[43]). They are safety, security, environmental impact, cost effectiveness, capacity, flight efficiency, flexibility, predictability, access and equity, participation and collaboration, interoperability. While safety will always remain the highest priority in aviation, achieving an effective operation requires the need to balance or trade-off different KPAs. It is increasingly important to understand and manage other risks such as environmental impact, security and community/social impact. How the management of these risks impact safety risk management and mechanisms to understand the relationship between these risks to allow explicit consideration of trade-offs will become progressively more important.

5.4 Role of the Human and Autonomy

Increasing autonomy and use of AI/pattern matching algorithms will change the role of the human in operations. Humans will oversee autonomous systems in their own organisation and also interact with external autonomous systems.

As a system becomes more autonomous and complex it is harder for humans to maintain an understanding of all the actions in the system. Current flight-deck automatic systems return control to the pilot if an event occurs that the system cannot cope with, for example turbulence can cause the autopilot to disengage. It will not be possible to hand back control to a human in a complex, fast moving situation and expect that human to resolve it. Therefore, autonomous systems will need to be capable of maintaining control and safely resolving the situation under all failure modes - a major technical challenge.

Although all roles (e.g. pilot, ATCO) will benefit from increasing automation, it is important to note that a mixed equipage scenario will always exist, i.e. there are (manned) aircraft being delivered today that will be flying in 20+ years, operating in airspace with newly delivered unmanned/autonomous aircraft. Highly autonomous aircraft will still have to operate in parts of the world with a traditional traffic management system.

One solution is for autonomous aircraft to "fit around" the manned aircraft - i.e. they take account of them and avoid them. However, this will not result in an optimum airspace utilisation or traffic patterns and may even contribute to less safe operating environments - an example of the trade-offs mentioned above.

40. Eurocontrol Risk Analysis Tool (RAT)
41. Safety in the Dutch Aviation Sector
42. A J Rae, R Alexander, J A McDermid, Fixing the cracks in the crystal ball: A maturity model for quantitative risk assessment. Reliability Engineering and System Safety, 2013, pp. 67-81. ISSN 0951-8320, http://dx.doi.org/10.1016/j.ress.2013.09.008i.
43. Global Air Traffic Management Operational Concept, ICAO Doc 9854, First Edition 2005

5.5 Supporting Infrastructure

Physical and digital infrastructure will need to evolve to meet the FF operations. However, as described above, there will always be heterogeneous equipage situation with new aircraft using, 5G and satellite communications and older ones using radar and VHF datalink. One of the challenges (as it is today) is to allow all aircraft with significantly different technical capabilities to operate in the same airspace.

One solution applied today is airspace segregation (e.g. aircraft require a radio and transponder to enter controlled airspace) and this principle may also be applied in the future. However, a segregated airspace model will lead to sub-optimal solutions and as demand increases it may not remain practical. Access and equity obligations to ensure all aviation stakeholders can make use of airspace resources are expected to become more significant.

Detect and avoid systems will be key to enabling the co-existence of UAS and manned aircraft. This is an existing CAA programme of work.

One challenging area is air-to-air data interchange. Today, collision avoidance uses a standard air-air datalink but it is expensive and not suitable for very small aircraft. It may be necessary to assume that air-air direct communications are not always possible meaning that collision avoidance may need to be resolved by air-to-ground communications.

Cybersecurity will become increasingly important, especially when the system is entirely interconnected and controlled without manual intervention. As data provision services become more prevalent in the future ATM service architecture, the security of the data must be maintained.

In the UK, the CAA is developing the "Cybersecurity oversight process for aviation" (CAP1753[44]) with the aim of creating a "proportionate and effective approach to cyber security oversight that enables aviation to manage their cyber security risks without compromising aviation safety, security or resilience."

Current technology assumptions will be challenged, e.g. current primary radar cannot always 'see' composite aircraft. So, the concept of primary radar as a backup in case Secondary Surveillance Radar (SSR) fails (which is its main use today) may not be possible. This would require existing safety cases in controlled airspace to be revisited.

A similar problem is that current standards are often written around particular technologies or specific operations. A simple example is airport control towers, where the procedures assume the controller is looking out of the window - this assumption was broken when remote towers were introduced and there was no window for the controller. Again, existing safety cases need to be revisited and new ones need to be developed that try to avoid locking procedures into specific technology solutions.

New technology will be introduced on shorter timescales than it was historically. Airworthiness standards will need to evolve rapidly, and aircraft certification may need to become more agile.

In general, FF will require safety management and regulation to become more agile whilst increasing effectiveness. The safety case approach proposed here, and the three "epochs" for FF introduced in Section 4, are intended to provide a framework which enables agility whilst also promoting the coherence necessary to achieve integrated safety and risk management.

44. The Cyber Security Oversight Process for Aviation, CAP1753, UK Civil Aviation Authority, Issue 2 August 2020

Safety Analysis of the Future Aviation System

6

Safety Analysis of the Future Aviation System

6

6.1 Introduction

This section introduces the detailed safety analysis of the future aviation system across the three scenarios and use-cases described in Section 4.2. The approach uses the bowtie modelling concept[45], a method adopted across many safety-critical industries to convey risk information to a variety of stakeholders. It is a flexible approach that can be applied at different levels of detail and does not require a detailed system or concept knowledge to bring value and insight. It is therefore ideal as a tool for understanding risk at a conceptual level for programmes early in the development lifecycle hence is well suited to the FF programme.

The bowtie approach hinges on a central hazard/top-event combination where the top event represents a loss of control event arising from the hazard. In an aviation context, a hazard may simply be the operation of an aircraft with the top event representing some deviation from normal in-flight parameters, e.g. failure to follow a cleared path through the airspace. The approach also recognises that there are causal chains linking causes (known as threats) to each top event and that the occurrence of each top event can lead to a range of different consequences. Controls that act to reduce the frequency of either the top event (preventative) or the frequency of a consequence (recovery) can also be represented in the diagram. In a safety context, consequences must lead directly or indirectly to a harmful effect (e.g. injuries or fatalities). The risk associated with each consequence is then a function of the severity and frequency and can be plotted on a risk classification scheme to determine acceptability.

45. CAA Introduction to Bowtie

6.2 Application to Future Flight

The bowtie approach has been applied to FF to achieve the following objectives:

- Understand the impact of FF on the risk of existing UK aviation operations
- Understand the new hazards and risks associated with FF

The analysis to support the achievement of these two objectives is covered in Sections 6.3 and 6.4 respectively. The scope of the bowtie analysis is focused on safety consequences although other concerns (e.g. environmental) are important and should be considered in a broader FF context. Furthermore, the bowtie concept can be applied at varying levels of detail from analysing a single hazard within a system or component to a much higher level, where the objective is to understand, at an overall system level, the key hazards, the key threats and key controls. In the FF context, the approach has been applied at a strategic level to understand any new potential hazards and controls that may be needed to reduce the associated risk to acceptable levels.

The expected output of this analysis is a greater understanding of the risks, and causes of risks, associated with FF operations across all scenarios and use-cases with a particular focus on the new and modified controls that will be needed to manage those risks. The refinement, specification and implementation of these controls into the future aviation system will then be a key objective moving forward for the programme.

6.3 Impact of Future Flight on Existing UK Aviation Operations

6.3.1 Introduction

It is clear that both the introduction of new aircraft and expansion in use of existing forms of aircraft (drones) covered under the use-cases has the potential to affect the risk associated with existing UK aviation operations. The extent of this impact will depend on the rate of expansion (i.e. volume of new aircraft) and the diversity of missions and therefore airspace types that they occupy. The approach to regulation and certification of these new aircraft types together with changes to airspace structures and other supporting infrastructure will also influence the risk impact but, even with these uncertainties, it is still possible to make informed judgements about the potential risk impact when compared to an existing risk baseline.

For existing UK aviation operations, this risk baseline is provided partially by the Significant Seven series of bowtie models described in Section 3.3.3. Although the scope of these models is limited to CAT aircraft, it provides a useful baseline from which to draw some initial conclusions about the risk impact from introduction of new aircraft and expansion in the use of drones. The analysis of the impact is limited to the short-term scenarios as the long-term scenario assumes fully integrated operations and therefore the distinction between existing operations and new operations will no longer be present. This means that there will be a "future" equivalent of the significant seven that aims to address all aircraft operations in the long-term vision of the future aviation system.

6.3.2 Summary of Analysis Results

6.3.2.1 Impact on Existing Hazards

From a short-term perspective, the impact of FF on existing UK aviation operations is related to the anticipated increase in drone-related operations which has impacts on the following existing Significant Seven hazards:

- Hazard 1.2 - Loss of Control of Large CAT Fixed Wing Aircraft (adverse environmental conditions)
  - New threat line and associated controls related to encounter with small drone resulting in thrust or other critical system loss
- Hazard 4.1 - Runway Incursion - Large CAT Fixed Wing Aircraft operating on the ground or in close proximity in the protected area of an active runway
  - New threat line and associated controls related to drone pilot/operator not having adequate situational awareness whilst approaching a protected area
  - New threat line and associated controls related to drone pilot/operator mistakenly believing they have access to protected area
  - Additional recovery controls relating to drone pilot or flight crew taking avoiding action and responding to ATC alerts of impending collision and taking avoiding action
- Hazard 4.3 - Runway Incursion - Large CAT Fixed Wing Aircraft - Takeoff and Landing Operations
  - Same changes as for Hazard 4.1
- Hazard 5.1 - Airborne Conflict - Large CAT Fixed Wing Aircraft whilst airborne in Class A airspace
  - New threat line and associated controls related to unauthorised penetration of UK Class A airspace by drone
  - New recovery control related to drone pilot recognising conflict and taking avoiding action
- Hazard 5.2 - Airborne Conflict - Large CAT Fixed Wing Aircraft whilst airborne in Class G airspace
  - Same as for Hazard 5.1
- Hazard 8.3 - Environmental Factors
  - New threat line relating to excessive small drone aerial activity

The bowtie diagrams for these hazards showing the new FF related elements (coloured in turquoise) are presented in Appendix B.1.

From the discussion above and the more detailed information in the diagrams, the changes to the risk associated with existing hazards relate to the increased volume of drones operating in the airspace particularly at lower altitudes and around aerodromes. This could manifest itself in an increased frequency of interference or disturbance to existing aviation (CAT aircraft) which could result in an increased frequency of occurrence to the hazards[46] listed above. Increases in hazard frequency would then result in increases in consequence frequency although there are a number of hazards which feature additional recovery controls which would mitigate that increase in consequence frequency.

It is clear that existing procedures and approvals related to drone operations must account for increased drone activity particularly around aerodromes where CAT aircraft are more vulnerable to drone strikes and have fewer opportunities to take avoiding action. Drone pilots/operators and flight crew must maintain situational awareness (SA) to ensure separation particularly as the ability of ATC to detect small drones and inform flight crew will be limited with current surveillance technology.

46. In bowtie notation the threat lines are connected to the top events rather than the hazards, so it is top event frequency that is affected by changes in threat frequency rather than hazard frequency. However, the term hazard is more familiar than top event and, in this context, there is a one-to-one relationship between hazard and top event, so the term hazard will be used.

There may be some additional controls relating to aircraft design that may make them more resistant to drone-strikes but this is expected to be less effective as drones become larger and heavier in the future. Deployment of counter-drone systems may also reduce risk but there is some uncertainty over the effectiveness of these systems particularly as drones that have been disabled in flight may lead to other safety consequences particularly to individuals on the ground.

It will be important to further validate the impact of drones on existing CAT aircraft operations and attempt to understand, from operational experience, the risk impact. This is a key input to the decision-making process to determine whether the existing controls are sufficient and whether new controls, or improvements to the effectiveness of existing control are required.

6.3.2.2 New Hazards

The potential for new hazards associated with drone operations has also been considered given the potential for safety consequences associated with drone-drone collisions and collision with the ground. These are not addressed in the current Significant Seven hazards.

A limited set of new hazards has been proposed using the Significant Seven as a basis. These are presented in Appendix B.2. However, these have been adapted for drone operations and recognise that some of the traditional strategic defences (e.g. ATM based flow management or separation management) may not be effective or as effective in a drone context.

The new hazards are:

- Hazard 1.4 - Loss of Control - Drone operations (Human Performance)
- Hazard 1.5 - Loss of Control - Drone operations (Adverse Environmental Conditions)
- Hazard 1.6 - Loss of Control - Drone experiencing technical or loading failures
- Hazard 3.4 - CFIT - Drone operation in uncontrolled airspace
- Hazard 3.5 - CFIT - Drone operation in controlled airspace

The risks associated with these new hazards are uncertain at this stage, but the profile will be significantly different from the risk profile associated with CAT aircraft. This is due to many factors, but the severity of drone based mid-air collisions and ground collisions, and the frequency of those consequences, will be very different to CAT aircraft. The threats and controls for the loss of control hazards (1.1 to 1.3) are similar to CAT aircraft but there are some significant changes related to the expected effectiveness of controls. These include the following key areas:

- Drone Pilot/Operator - the ability to detect and correct deviations from planned flight paths based on SA will be dependent on the level of information available to the remote pilot and the training/competency of the pilot to react to that information. The level of SA will be dependent on whether the operation is visual or beyond visual and the drone's capability to sense obstacles, adverse weather and other aircraft. The status of the drone's systems and its ability to communicate that reliably to the pilot/operator is also important in allowing the pilot/operator to take an appropriate course of action
- Drone Platform - the performance characteristics of the drone will be key in determining its ability to withstand adverse weather and respond in a timely manner to control inputs whether in normal or emergency situations. Integrity of drone systems and the level of redundancy/diversity in propulsion, energy storage and control systems will also be critical
- ATM / ATC Input - the reduced role of air traffic management/control will require drone pilot/operators to take greater responsibility for self-separation from other drones and obstacles. Although restrictions on drone use particularly around aerodromes will be enforced, unauthorised entry into controlled airspace and the ability of ATC to detect and resolve those occurrences will be limited based on current communications and surveillance technology.

As with the changes to the existing Significant Seven bowties, it will be important to validate the new hazards associated with drone operations and confirm that the key risks are understood and controls are sufficient to manage the risk. The emergence of BVLOS operations will be fundamental to validating the understanding of risks and sufficiency of controls given this mode of operation is likely to present significant safety and operational issues that challenge traditional forms of mitigation associated with visual operations.

6.4 Impact of Future Flight on Future UK Aviation Operations

6.4.1 Introduction

This section focuses on the long-term scenario for the UK aviation system as described in Section 4.2.4 and seeks to identify the key hazards that are most relevant to the use-cases for future operations including those that do not exist in the current aviation system.

The approach is focused at a strategic level and, for each hazard, identifies the key controls from a preventive and mitigative perspective that can reduce the risk associated with the consequences of each hazard. It is not intended to be an exhaustive or detailed exercise that identifies all potential controls but focuses on identifying the controls that comprise the following strategic defences against aviation risk:

- Design (airspace, aircraft, system) features providing inherent protection against the hazard and/or consequences
- Strategic controls such as flow management as provided by Air Traffic Management
- Tactical controls such as separation provided by Air Traffic Control
- Pilot see-and-avoid (more generically known as detect and avoid in the future)
- ACAS (an automated collision avoidance system)
- Emergency response planning

The bowtie diagrams have been colour-coded in a way that allows these strategic defences to be identified and a high-level review has been conducted to ensure that a suitable number of strategic defences are employed against each threat and consequence. Where gaps were identified, controls were identified to provide additional mitigation against the risk. In the vast majority of cases, the existing controls (or a modified version of them) provided sufficient coverage of the hazards and/or consequences. The diagrams have also been developed with recognition of the uncertainty in how key functions will be delivered. For example, the control of an aircraft may consist of a human pilot on board the aircraft or a remote human pilot or an autonomous system. The objective was not to focus on one particular solution or technology but to identify the key capabilities of that control system irrespective of whether it is delivered by a human or an autonomous system.

For this reason, the bowties use the following nomenclature to describe key functions:

- DAA - Detect and Avoid
- FCS - Flight Control System
- TMS - Traffic Management System

Although the diagrams are extremely useful for communication of the key features of the key hazards relevant to FF, they do feature some known limitations that need to be addressed through additional analysis. They do not define the functional or capability requirements for each control to be able to adequately mitigate the threat in the future aviation system.

Each hazard is therefore subject to an analysis that reviews each control against several key characteristics predicted to change significantly with FF including:

- Traffic Density
- Pilot Autonomy
- Aircraft Mix
- ATM Autonomy
- CNS Technology
- Aircraft Performance
- Operating Environment

From this analysis, a number of requirements were derived that relate to the technical capabilities of the systems and elements needed to deliver the functions associated with each control. These requirements are presented in Section 6.4.3. These requirements are one of the key outputs from the bowtie analysis as they provide detail on the capabilities that will need to be developed and implemented in the future aviation system. The requirements are structured into categories relating to the systems (e.g. traffic management system) that help to deliver the strategic defences.

6.4.2 Hazards and Risks Associated with Future Flight Operations

This section provides an overview of the hazards that have been identified as significant in the context of the long-term scenario.

The bowtie diagrams and associated detailed threat/control/mitigation analyses can be found in Appendix B.3.

6.4.2.1 Hazard 1.1 – Loss of Control – Aircraft Operations (Aircraft Upset)

This hazard is based on an existing Significant Seven hazard and relates to a loss of aircraft control due to either internal control system issues or external factors affecting the control of the aircraft. Internal control system issues include flight control system errors or aircraft systems issues whereas external factors include turbulence, ice formation, bird/drone strike or ash cloud encounters all of which can lead to aircraft control issues. The potential safety consequences include mid-air collision, CFIT and passenger/crew injuries/fatalities resulting from violent aircraft movements. There is a robust mix of controls for each threat and consequence line from the different strategic defences which should provide confidence that the risk is adequately mitigated.

6.4.2.2 Hazard 1.2 – Loss of Control – Aircraft Operations (FCS Malicious Takeover)

This is a new hazard and addresses the possibility that control of the aircraft may be compromised due to an attack on the flight control system either from an internal or external source (e.g. cyber attack). The potential consequences are more numerous than other hazards given the aircraft could be flown maliciously into other airborne objects or into terrain or other ground-based objects. The analysis shows comparatively few controls exist to mitigate this hazard compared to more traditional hazards and should therefore be a focus for analysis as part of a wider review into the security of aircraft and traffic management systems.

Recommendation 6.1 – It is recommended that a more detailed review is conducted into the risks attached to cyber related attacks on aircraft flight control systems to understand the potential risks and inform system design activities.

6.4.2.3 Hazard 2.4 – Landing Area Excursion – VTOL Aircraft Operations – Landing Operations

This hazard is a derivative of an existing Significant Seven hazard associated with landing excursions but has been modified to account for VTOL operations. VTOL operations may be at a traditional aerodrome or at a vertiport. The threats relate to flight control system error, inaccurate traffic management system clearances, technical failures of the aircraft and unsuitable landing conditions due to environmental issues or due to conflict with another aircraft/vehicle/person on the landing area itself. The only consequence is related to an excursion leading to fatalities against which there are a number of design and tactical based controls.

6.4.2.4 Hazard 2.5 – Takeoff Area Excursion – VTOL Aircraft Operations – Takeoff Operations

Similar to 2.4, this hazard is a derivative of an existing Significant Seven hazard but has been modified to account for VTOL operations. The threats and consequences are similar to hazard 2.4 and also demonstrate a robust mix of controls against each threat and consequence. Aircraft loading issues which are commonplace in current aviation operations are an additional threat to this hazard and smaller/lighter aircraft may be more susceptible to such issues in the future.

Recommendation 6.2 – It is recommended that vulnerability of new aircraft types to loading errors is investigated further and appropriate automated and procedure-based mitigation developed as necessary.

6.4.2.5 Hazard 3.1 – CFIT – Aircraft Operations – Arrival or Departure (General)

This is an existing Significant Seven hazard adapted for FF operations. There are a range of threats leading to the hazard including flight control system errors, traffic management errors as well as navigation errors. Each threat line contains multiple controls although a number of threat lines do not feature diverse strategic defences which would be preferable. CFIT is the only projected consequence and features multiple controls from a number of strategic defences. In the long-term scenario featuring aircraft flying at lower altitudes, terrain/obstacle avoidance will be a key issue leading to a greater reliance on situational awareness, navigation performance and terrain avoidance systems to mitigate the increased risk.

Recommendation 6.3 – It is recommended that terrain avoidance systems are specified to operate safely and effectively in an (urban) obstacle-rich environment.

6.4.2.6 Hazard 5.1 – Airborne Conflict – Aircraft Operations whilst airborne in UK managed airspace

This is an existing Significant Seven hazard adapted for FF operations. There are a range of threats leading to the hazard including flight control system errors, traffic management errors as well as navigation errors. There is also the potential for unknown aircraft to enter the airspace and lead to a potential conflict. Each threat line contains multiple controls although a number of threat lines do not feature diverse strategic defences which would be preferable. There are a range of consequences including mid-air collision, uncontrolled collision with terrain and abrupt avoidance manoeuvres. Each consequence features multiple controls from a number of strategic defences providing confidence in adequate risk mitigation.

6.4.3 Requirements for Future Aviation Systems

This section provides a summary of the functional requirements derived from the bowtie analysis to be considered in the design, implementation and operation of the key technical elements of the future aviation system. The detailed analysis behind these requirements is contained in Appendix B.3.

The requirements are not intended to be exhaustive and are not described in a traditional requirement specification format (e.g. with integrity levels) but are intended to highlight the key functions that each element should provide. Table 1 presents the requirements for each of the key elements in turn.

6.4.4 Recommendations for Further Work

The bowtie approach represents individual controls in a simplistic, linear manner and does not reflect dependencies between controls or common cause failures that can undermine multiple controls. Experience shows that in many high-reliability, high-integrity systems, common cause failures are the largest contributors to system failure. This leads to the following recommendation for further work:

Recommendation 6.4 – It is recommended that the threat lines associated with a sample of bowtie diagrams are analysed in more detail to understand the dependencies between controls whether those are human or machine based. The reliance on shared systems (e.g. electrical power from the same source) should also be investigated as part of this activity.

Element	Requirement
Airspace Design	Must account for: - Increases in traffic density (greater resolution) - Aircraft autonomy mix - Improvements in CNS technology and associated separation s standards - Changes in operating environment (e.g. increased use of vertiports and drone takeoff and landing sites)
	Airspace design must enable all airspace users to operate safely whilst ensuring access and equity and other performance attributes
	Airspace design must make use of more dynamic airspace structures to improve airspace safety performance or maintain safety performance and enable other performance attributes
Traffic Management System	Must ensure detection and conflict resolution: - In higher traffic density - With a greater traffic mix - With a greater range of aircraft performances
	Avoiding action instructions must consider the impact of: - Greater traffic density - Variability in aircraft performance
	Autonomy in traffic management systems must: - Have the ability to detect, recognise and correct potential conflicts via monitoring - Have a mechanism to identify aircraft intent to deviate from a clearance prior to the clearance being executed - Achieve an appropriate level of integrity with instructions - Be able to consider the aircraft performance and weather when issuing traffic management instructions - Be able to consider a query from the FCS - Be able to consider an inability to comply with communication from FCS - Be able to recognise and manage unusual / emergency events - Have the ability to issue avoiding action instructions
	ATM Autonomy Conflict detection may require an additional independent TMS system from that used for separation

Element	Requirement
Flight Control System	FCS must have situational awareness maintained as traffic increases to be able to clarify clearance
	FCS must be able to continually adapt and develop its knowledge and decision-making ability through information inputs such as PIREPs or other information sources
	SA tools must consider the impact of greater traffic density
	Aircraft must have appropriate SA tools: - To allow DAA (Detect and Avoid) - Which are compatible with each other
	DAA procedures must consider the variability in aircraft performance
	FCS autonomy must: - Be able to accurately interpret traffic management clearance - Have the ability to query a traffic management clearance based upon its own SA - Be able to implement avoiding action instructions and ACAS RA procedures - Feature diversity in the provision of an independent second protective function that identifies errors in its own actions and perform corrective action. - Have the ability to conduct automated weight and balance measurement to ensure appropriate aircraft configuration
	DAA tools and avoiding action procedures must consider the impact of greater traffic density
	Aircraft must have appropriate DAA tools to allow conflict detection
	Aircraft must have DAA tools and avoiding action procedures which are compatible
	ACAS RA (Resolution Advisory) procedures must consider the impact of greater traffic and obstacle densities
	All aircraft types must have compatible approaches to avoiding action and ACAS RA
CNS Technology	Accuracy and coverage of Communications Navigation and Surveillance (CNS) infrastructure across all operating environments
	Accuracy and coverage of CNS infrastructure to support pilot/FCS situational awareness
Aircraft Design	New aircraft types must achieve: - Appropriate cabin design to secure passengers, crew and other objects - Appropriate protection of aircraft structural integrity during attempted avoidance manoeuvres - Crash protection systems to mitigate the consequences of crash landings - Features to allow controlled landings in the event of system(s) failures - Appropriate protection against icing, bird strike and other external impacts either through active protection or passive design features - No single points of failure in design, provision of diversity and redundancy in safety-critical functions
	Aircraft Autonomy systems must fulfil the role played by pilot and cabin crew in adherence to secure cabin SOPs or appropriate revisions to SOPs should be made
	Aircraft designs must feature greater (than current) levels of controllability and faster responses to control inputs for manoeuvring and avoidance actions especially in urban environments
Aircraft Collision and Avoidance Systems	Future ACAS should have the ability to: - Operate effectively in a range of different operating environments including urban environments - Detect potential wake turbulence issues and issue appropriate resolution advisories - Respond to multiple simultaneous or near simultaneous conflicts and provide appropriate resolution advisories

Table 1: Future Aviation System High-Level Requirements

Analysis of Key Safety Management Challenges

7

Analysis of Key Safety Management Challenges

7

7.1 Introduction

The previous section described how the bowtie approach has been used to undertake a safety risk analysis to understand the impact of the FF use cases on UK aviation. To assist in developing a more comprehensive safety analysis of FF, in this section we present additional analysis of the safety management challenges associated with FF which were introduced in Section 5, namely:

- Safety management of complex systems
- Integrated risk and safety management
- Role of the human and autonomy
- Supporting infrastructure

These four transversal themes reflect what we consider the most critical considerations for safety as FF concepts are implemented. Their significance is related to both their impact on the safety of the aviation system and the length of time and level of co-ordinated effort required to address them. The safety challenges are considered below, with recommendations, actions and requirements identified where possible to help inform future safety planning for FF and UK aviation in combination with the bowtie safety risk analysis.

A detailed analysis has been conducted of the impact of complex systems, as this particular challenge encompasses the greatest breadth of future issues, including integrated risk and safety management and autonomy. Following the description of this complex systems analysis, further analysis of the other transversal themes is provided, and additional areas of consideration are addressed which are not covered within the complex systems analysis. Importantly, in the supporting infrastructure analysis, the roles of airspace, traffic management and separation are addressed.

7.2 Complex Systems in the Aviation System

In this section we present the results of an analysis of the impact of complex systems in the future aviation system and the associated additional controls that may be needed to mitigate negative impacts. Issues regarding integrated risk and safety analysis and autonomy are integrated into this analysis.

7.2.1 Introduction to Safer Complex Systems Framework

Engineering X, an international collaboration founded by the Royal Academy of Engineering and Lloyd's Register Foundation (LRF), has launched a £5 million, 5-year programme, Safer Complex Systems, to enhance safety and resilience of complex infrastructure systems globally[47]. The objectives of the programme are:

- Enhanced understanding and capacity of key stakeholders to deal with complexity and to safely design, manage and regulate complex systems globally
- To build and convene a diverse, global complex systems community to improve collaboration and increase knowledge sharing across sectors, disciplines and international boundaries
- Improved pathways for application of theory into practice to practically address issues that make complex systems unsafe

Engineering X commissioned the University of York to undertake an initial review of safety in the design, management and governance of complex systems. The aim of the review was to develop conceptual clarity; identify methods for the design, management and governance of complex systems; and outline emerging challenges and opportunities with regard to the safety of complex systems. The study included findings from stakeholder workshops (including a large technical advisory group),

47. www.raeng.org.uk/global/international-partnerships/engineering-x/safer-complex-systems

informal meetings, and an online questionnaire. A framework was developed for the design, management and governance of complex systems. A final report and recommendations for future work will be published in early 2021[48].

The purpose of the Safer Complex Systems Framework FF analysis was to apply the Safer Complex Systems Framework to the FFC to gain insight into the potential considerations for the use of complex systems in FF. The analysis supports the development of a Future Flight Aviation Safety Framework.

7.2.2 Description of Safer Complex Systems Framework

As stated in the study report, "Ensuring the safety of increasingly complex systems is challenging. In particular, unacceptable levels of risk will occur if the complexity of the systems and their operating environments outpace our ability to engineer, operate and govern such systems." The study considers the impact of complex systems across three layers:

- Governance – This layer consists of incentives and requirements for organisations to adhere to best practice through direct regulation, so-called soft law approaches or a consensus in the form of national and international standards. In formulating these standards and regulations, governments and authorities represent societal expectations on the acceptable level of residual risk that is to be associated with the systems
- Management – This layer coordinates tasks involved in the design, operation and maintenance of the systems, enabling risk management and informed design trade- offs across corporate boundaries, control over intellectual property and liability, management of supply chain dynamics and sustaining long-term institutional knowledge for long-lived and evolving systems
- Task and technical – This layer covers the technical design and safety analysis process that allows systems to be deployed at an acceptable level of risk, then actively monitored to ensure deviations between what was predicted and what is actually happening so that these gaps can be identified and rectified. This layer includes not only the technological components but also the tasks performed by the users, operators and stakeholders within a sociotechnical context. In some cases, users may be unwilling or unknowing participants in the system who are nevertheless impacted by risk.

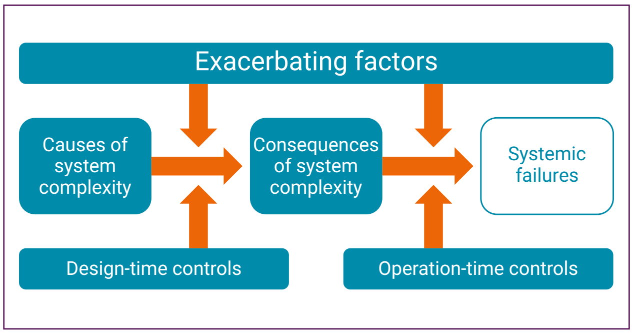


Figure 7: Safer Complex Systems Framework Elements

The framework has six major elements, as identified in Figure 7. The framework elements are defined as follows, starting with the middle causal flow and ending with the exacerbating factors:

- Causes of systems complexity – factors at the governance, management and task and technical levels that engender complexity in systems, building on the concepts from complex systems theory, for example rapid technological change
- Consequences of systems complexity – manifestations of complexity at the governance, management and task and technical levels, which can lead to unsafe behaviour if not properly managed, such as unintentional and unrecognised risk transference between stakeholders
- Systemic failures – failures relating to the whole system, rather than a particular part, that impact the safety of some or all of the stakeholders in a system, for example inadequate regulatory control
- Design-time controls – approaches that can be applied at the governance, management and task and technical levels to reduce the causes of complexity and/or to reduce the likelihood that the consequences will occur, such as inclusive design
- Operation-time controls – approaches that can be applied at the governance, management and task and technical levels to reduce the likelihood of the consequences of complexity giving rise to systemic failures or reducing the risk associated with such failures, for example contingency planning
- Exacerbating factors — things that make the management of complexity more difficult perhaps inhibiting both design time and operational management strategies. This might be conflicting legislative requirements on the system as a whole or between system elements.

The individual elements are described in greater detail within the Safer Complex Systems Framework Report, including the constituent factors which make up each of the elements.

48. Framework to be published at: www.raeng.org.uk/safer-complex-systems-initial-framework

7.2.3 Application to Future Flight

The Safer Complex Systems Framework FF analysis identified the key constituent factors within each element of the framework that are relevant to the FFC. Priority was placed on design-time controls and operation-time controls as these can be used as a basis to identify the key recommendations and activities which FFC stakeholders should consider in order to manage the safety challenges of complex systems. Recommendations and activities are focussed on actions that could commence in the short-term. As future horizons are reached, other recommendations and activities are expected to be identified following further analysis.

The analysis included:

- A description based upon that within the Safer Complex System Framework Report with minor edits to improve comprehensibility in the aviation context
- An analysis of the relevance to FF
- Identification as to whether the controls are a priority consideration for FF
- The key FF stakeholders to which the control is relevant
- Key recommendations and activities that should be implemented to assist in ensuring the effectiveness of the control for FF

7.2.4 Summary of Analysis Results

The following results have been drawn from the analysis which is detailed in Appendix C. Recommendations have been developed for a range of FF Stakeholder Groups. These groups are:

- Governance Organisations (Policy and Regulation)
- Standards/Professional Bodies, Industry Organisations (current aviation and other industries on which aviation depends – e.g. communications industry organisations)
- Supporting Infrastructure Providers
- New Entrants
- New Technology and FF Operators
- Current Aviation Industry

In addition, a research agenda has been identified where further work is needed to determine the applicability of certain Safer Complex Systems Controls to FF.

The recommendations and activities may be relevant to other stakeholder groups including:

- Urban Infrastructure Providers and Operators
- Aviation Financing and Insurances organisations
- Adjacent service providers

Addressing the scale of work required

It should be noted that the recommendations below present a significant and challenging work programme if they are to be addressed. The FF use cases in this project have been described across the time horizons described in the short-, medium- and long-term scenarios. The challenges of complex systems described in the analysis are expanded to extend out to the long-term time horizon. As such, it is expected that addressing the impacts of complexity of safety in aviation will be a continual activity into the future. Some impacts of complex systems are likely to occur in the short term and it will be important to commence action to address these quickly. To aid this process, initial activities which are identified as the first step towards achieving the recommendations have also been identified. These activities were developed in collaboration with the FF Safety Working Group and are documented in the full analysis in Appendix C.

7.2.5 Governance Organisations (Policy and Regulation) Recommendations

Recommendations and activities for Governance Organisations are broken down across three areas:

- Standards/Regulation/Law
- Engagement
- Safety Performance

Standards/Regulation/Law

- Determine the extent to which current standards can be applied or adapted to new FF operations using the principles of outcome-based standards supported by Acceptable Means of Compliance (AMCs).
- Develop appropriate standards for FF operations where current standards cannot be adapted using the principles of outcome-based standards supported by AMCs. For example, aircraft certification processes will need to potentially support a higher volume of certification resulting from a large number of new entrants and the likely shorter service lifecycle of novel air vehicles, including major through-life upgrades.

- Review how tort/common law are impacting other industries adopting autonomous systems and assess the implications to FF.

Engagement

- Ensure appropriate diversity and inclusion in Policy, Regulation and FF concept and system development
- Ensure regulators have a practical means to engage with FF industry development during advancement of technology and services
- Ensure that a mechanism exists for the active management of negative consequences of regulatory engagement in development

Safety Performance

- Ensure early proactive incident and accident analysis of FF operations to ensure lessons can be learnt across the FF industry
- Ensure appropriate Target Levels of Safety are defined, achieved and reviewed for Drones, UAM and RAM
- Ensure an enhanced operational monitoring approach is in place for FF operation
- Ensure active alerting practices are enhanced to manage the high tempo and reduced human control use cases of FF operations

7.2.6 Standards/Professional Bodies, Industry Organisation Recommendations

- Identify key areas where industry community guidelines would support safety assurance of FF and produce a roadmap for their development
- Establish means for industry-wide learning from FF complex systems incidents and accidents, with a particular focus on smaller FF participants
- In light of global events in aviation and other safety critical industries, review the effectiveness of learning from experience at Governance and Management Layers in UK Aviation

7.2.7 Supporting Infrastructure Providers Recommendations

- Ensure supporting infrastructure providers publish Concepts of Operation (CONOPS) to enable FF technology development
- Ensure supporting infrastructure has a roadmap for Publicly Available Specification (PAS) development which aligns with FF technology development and associated PASs
- Ensure future traffic management provider roles are defined and their role in system integration is strategically planned

7.2.8 New Entrants Recommendation

- Ensure FF new entrants understand and adopt the mature aviation industry safety management practice in: principles of High Reliability Organisations[49], Safety Management Systems, risk and hazard analysis, active risk management, monitoring and analysis, incident and accident analysis, learning from experience as part of an effective safety culture (including Accident investigations), change management, CONOPS development, safety/assurance cases (design and operational risk management), independent assessment, competency management (for operations, development and safety), organisational resilience, contingency planning and contingency rehearsals.

7.2.9 New Technology Developer and Future Flight Operator Recommendations

Organisations developing new technology and/or operating FF systems and services should:

- Ensure new FF technology development has strong engagement with aviation and urban industry stakeholders and is cognisant of the future landscape
- Ensure appropriate stakeholder diversity and inclusion in FF concept and system development
- Ensure incremental delivery roadmaps are used to strategically work towards radical change in FF operations[50]
- Ensure new technology and systems apply design for assurance principles

49. 5 Principles of High Reliability Organisations

50. FF includes some radical changes in how aviation operates. Thus it is important to provide system and software capability progressively (in small increments) allowing for early stakeholder validation and thus helping to derisk the change and reduce any emerging 'semantic gap'. It is envisaged that this approach would be possible on certain products and services. Examples include autonomy and traffic management systems, which may see incremental changes which eventually lead (over many years) to more radical shifts in operational practices from today. Such incremental changes should be strategically planned over the long term.

- Ensure new technology and systems provide effective diversity and redundancy in delivery of products/services compared to the current aviation system
- Ensure the impact of autonomy is reflected in safety assurance requirements across the supply chain/network
- Ensure competency management practices evolve as the role of Autonomy increases
- Ensure FF participants adapt their SMS to incorporate FF challenges including new concepts, new stakeholders, integrated risk management and complex systems
- Ensure aviation safety change management practices are adapted to manage the dynamic and complex nature of FF change
- Ensure practices are in place to manage safety across the supply chain/network
- Ensure all FF participants have mature processes for cyber resilience (design & operation)

7.2.10 Current Aviation Industry Recommendations

- Ensure that all aviation system participants consider the changing aviation system landscape and how FF operations will impact the safety of their operations
- Ensure aviation safety change management practices are adapted to manage the dynamic and complex nature of FF change
- Assess how existing diversity and redundancy in systems is impacted by new FF systems and operations, including the potential for cyber threats to introduce common mode safety-relevant failures

7.2.11 Research Agenda

In addition to the recommendations and activities identified above, certain controls from the Safer Complex Systems Framework require further research to understand their applicability and relevance to FF. A research agenda has been identified for these areas with the following areas highlighted as most relevant:

- The application of risk and hazard analysis techniques for complex systems and their adoption in aviation
- The role of the following controls in safety assurance for autonomous FF operations
  - Simulation and modelling
  - Digital twins
  - Dynamic risk management
  - Self-monitoring
  - Scenario Based testing
- The impact of Autonomy on:
  - Maintaining appropriate levels of human competency in FF operations
  - System adaptation processes
  - Human oversight
- The role of future traffic management systems in providing run-time assurance (similar to current ATC services)
- The importance of task analysis in supporting the transition of FF to greater use of autonomy

Recommendation 7.1 – A joint academic and industry research program should be established to advance understanding in these areas.

7.3 Integrated Risk and Safety Management

Many of the future challenges for risk and safety management in FF and UK aviation have been introduced above in the analysis of complex systems. However, certain topics which are of relevance to FF are described and expanded upon below.

7.3.1 Risk Trade-off and Target levels of Safety

As the range of operations and participants in aviation increases, the challenge of effective risk management across the aviation system (beyond safety risk management) will grow.

As an example, societal acceptance of FF (or the social license for aviation operations) will become more complex as low-level operations expand beyond areas close to airports, increasing noise impacts. This will occur even where new technology has a much smaller noise profile, due to operations being new and at a much higher scale. The management of safety risk will need to be undertaken in coordination with other risk management activities and trade-offs explicitly analysed and considered. These risk management considerations will extend to activities outside the aviation environment as aircraft operations become more tightly integrated with the urban environment. As a simple example, it may be preferable for environmental and community reasons to concentrate aircraft operations over non-noise sensitive areas, such as roads. However, this may increase airborne conflict risk by bringing aircraft operations closer together, as well as creating distraction risks for road users.

There is a feedback loop here - gaining societal acceptance could require higher risk operations which could lead to lower societal acceptance - and thus iteration might be needed to find socially acceptable risk management strategies.

Risks affecting service availability will be critical for FF operators. The ability to operate in all weather conditions (including IMC) and manage disruptions due to airspace or other infrastructure unavailability will need to be planned and managed. Risks associated with predictability of service availability, flight efficiency, airspace access will all require management. Where service availability is reduced due to these factors, it could affect societal acceptance. The role of security risk management, in particular cyber security, will continue to grow and have a strong relationship with safety risk management.

It will be important to develop mechanisms for considering and "trading off" these risks at the operational, organisational and aviation system level. The risk integration challenges will exist beyond consideration of aircraft operations. They will extend into all areas of governance and management relating to aviation. As an example, a slow and cautious approach to safety regulation and technology development and acceptance, may lead to other global entities progressing technology and operational practices more quickly, which may become "de facto" standards and acceptable operational and technical approaches. It might also mean that economic benefits from FF delivered in other countries would not be available in the UK until later. Balancing regulatory development and cautious adoption of new technology against the benefits of such technology for society and UK industry will need to be carefully considered.

7.3.2 Aviation System-wide approach to Safety Management

To enable consideration of complex risk decisions, it will be important to have a defined target level of safety for aircraft operations, including FF operations. To achieve a target level of safety and allow trade-off considerations with other risks it will be important to maintain an overarching risk analysis approach for the UK aviation system. At an aviation system level, various safety performances are achieved for different types of aircraft operations, such as commercial air transport, general aviation and charter flights. Achieving the safety performance of commercial air transport, involves a significant commitment to safety management practices and associated costs. Ensuring societal expectations are built into appropriate target levels of safety for FF operations will be important, and it will be equally important for FF developers and operators to understand the costs associated with achieving such a safety performance. New mechanisms may be needed to maintain industry-wide safety management practices.

Risk management practices across organisations in the aviation system will also need to be more closely integrated and an aviation system risk baseline will provide a mechanism for this to occur. This will be important as it is expected that individual small scale FF developers and operators may have less internal safety performance information and potentially less safety management capability. A whole-of-system approach to safety risk management and other safety management practices will support the achievement of a target level of safety for the aviation system.

The bowtie notation and the work in this report, combined with the Significant Seven, provide a good basis for establishing an aviation system risk baseline. The bowtie notation provides a mechanism to enable a wide range of stakeholders to engage in discussions about risk and bring together a variety of types of threats and controls. The technique can be applied in varying levels of detail, including up to the aviation system level. A UK aviation system risk baseline provides a means of identifying safety performance monitoring measures and can also be used as an input for safety occurrence management and investigations.

The risk baseline should also be extended to facilitate more quantitative risk assessments at greater levels of integration both horizontally (i.e. an end-to-end assessment of accidents from initiator through to consequence) and vertically (to enable multiple hazards to be assessed in a single model). This approach will be complementary to, and based on, the qualitative models (i.e. those in bowtie format) but extend to address the issue of dependency between controls, common cause failure of controls, and reliance on shared systems, e.g. electrical supplies. This will provide valuable insights into the safety performance of the aviation system at a more realistic level, enable more accurate comparison with the target levels of safety and highlight vulnerabilities in design and/or operation to be addressed. This approach has been used successfully in other complex, safety-critical industries (e.g. rail and nuclear energy) to provide risk insights for both operators and for the regulator.

Recommendation 7.2 – An aviation system risk baseline should be established to provide all stakeholders with a common reference for safety risk management and assessment and is especially relevant for multi-stakeholder risks. This should be encoded in a format that facilitates discussions at varying levels within organisations such as risk owner level (i.e. senior management) to safety practitioner level (for assessment and update).

Recommendation 7.3 – The aviation system risk baseline should be extended to facilitate quantitative risk assessment where feasible and practical to do so. This should provide valuable risk insights that are complementary to the qualitative baseline but allow more direct comparison against numerical target levels of safety and address issues such as dependency and common cause failure.

7.3.3 Incorporating new approaches to Safety Risk Management

Safety engineering and safety management practices will need to evolve over the time horizons of FF. New and higher integrity controls will be identified and implemented to manage existing and future threats. It will be important to consider the potential for new or enhanced controls to create new hazards or threats in the operating environment especially with the advent of new technology and procedures. This consideration will be needed at both the aviation system and operations level and will be part of the ongoing safety processes.

As well as new controls, new hazard or risk analysis and assurance techniques will be developed over the time horizons of FF. It is unlikely that new techniques will completely replace existing approaches and these new methodologies, including Safety II[51] and other safety analysis techniques that feature a more holistic, systems-based view (e.g. Systems Theoretic Process Analysis (STPA[52])) of the behaviour of complex systems rather than the reductionist approach of traditional techniques. However, there will still be a place for traditional safety analysis techniques alongside the newer approaches - both in the engineering domain and other 'soft' safety processes.

Without doubt, the role of safety culture will remain central to the effective safety performance of the aviation system. It will be important for all future aviation stakeholders to maintain the priority of safety culture as part of best practice safety management.

7.4 Role of the Human and Autonomy

Traditionally, aviation has been and continues to be a human-centric system. The role of the human has always been key to the safety performance of aviation, with both the Pilot and ATCO playing critical roles. Based upon this, many human-based controls have been developed which contribute to delivering an acceptable safety performance in aviation. A significant example of this are the roles of voice communications and impact of radar performance, and their criticality in human decision-making around provision of effective separation for aircraft.

The changes that will occur through FF operations will challenge the effectiveness of current human-based controls. For example, the level of traffic density in the urban environment will impact the effectiveness of voice communications as a key control and sufficient radar coverage will not be possible in urban areas. Attempting to replicate current safety management approaches for high density FF operations would require significantly higher levels of humans in the system and may not be possible. The cost of qualified human resources, the unavailability of qualified humans (in particular projected pilot shortages) and the prevalence of human error is likely to drive a concerted effort to increase automation and eventually move to greater use of autonomy.

Automation is increasing across all aviation operations and significant autopilot and flight control capabilities are now certified or in development for all types of aircraft. For example, avionics safety nets which previously required human intervention (e.g. TCAS and Enhanced GPWS (EGPWS)) are being integrated with automatic flight systems. FF developers are actively developing their systems to be autonomous or autonomous ready.

There are specific challenges with automation and autonomy in aviation, in particular the following:

- The ability for humans to intervene and take control is difficult particularly in unsafe states where the operation is close to an accident consequence. There are many recent high profile aviation accidents where late intervention or an inability to intervene effectively by the human contributed to catastrophic consequences. This is caused partly by the difficulty of quickly assimilating a complex systems state (that may include erroneous and inconsistent information) to decide on the right course of action

51. Safety-I and Safety-II
52. STPA Handbook, March 2018, Nancy G. Leveson, John P. Thomas

The 'decoupling' of avionics systems when an error occurs (e.g. autopilot drops out when system parameters are outside of certain bounds) will no longer be possible, meaning that automatic systems will need to manage the aircraft through the emergency

- It is difficult to bring an aircraft to a safe state when threats or failures occur. In other uses of autonomy (e.g. driving), it can be more straightforward to bring the operation to a safe state, however this is not so easily achieved with airborne aircraft

As the use of autonomy develops, there are many characteristics of the human within the aviation system which can help inform the effectiveness of future autonomy. These include:

- Both Pilots and ATCOs are trained, autonomous human operators in the system, who are fallible and make mistakes. The aviation system recognises this fallibility and has developed many controls to manage these potential human autonomy failures. The approaches used in aviation for training, familiarisation, standardisation, conformance monitoring, occurrence reporting, performance checking and redundancy (e.g. co-pilot), provide a structured approach for assuring autonomy where individual humans have unique failure modes that cannot always be accurately predicted. These approaches could be translated into the use of computer-based autonomy to achieve integrity where individual autonomy assurance cannot be guaranteed. Highest levels of assurance are most likely to be achieved at a system level rather than the individual level as currently occurs for humans
- Humans in the aviation system employ learning from experience at an individual, team, organisational and industry level. These approaches could be translated into computer-based autonomy. Mechanisms for learning between autonomous systems will be important
- Communications between humans in the aviation system are often critical to identify and resolve human errors. This includes the use of Crew Resource Management in the cockpit and readbacks between pilots and ATCOs. Computer-based autonomy will at times fail and the ability for redundancy or interfacing systems to be able to communicate and challenge autonomy will be important
- Autonomy will be able to utilise a much broader and deeper view of situational awareness than a human is able to process. The challenge will then become about information management (including integrity and data consistency between users) and mechanisms to provide the most accurate and useful picture to allow safe and effective autonomous decision making. This is discussed further in Section 7.5.1

The effectiveness of autonomy in the aviation system will be most important in the management of off-nominal or emergency situations. As described above, it is unlikely that human control will be effective in managing these situations if autonomy fails. Addressing this issue will most likely be one of the greatest barriers to entry for autonomy in aviation.

It will be important for certification that autonomous system developers can produce not only high integrity autonomous systems, but ones for which assurance can be provided and a safety case developed. It is highly likely that other industries, e.g. automotive, rail and possibly healthcare, will progress this challenge more quickly and aviation will need to learn from other successful applications to achieve sufficient levels of both integrity and assurance.

Recommendation 7.4 – Develop guidance for autonomous system developers to identify and explain the level of assurance and supporting evidence that will be required, including for operations in emergency situations. This will help industry calibrate its expectations early in the product lifecycle development process.

7.5 Supporting Infrastructure

Supporting infrastructure for aviation is critical to the success of FF use cases, particularly if FF operations are to be able to scale. Supporting infrastructure covers both legacy aviation infrastructure as well as new infrastructure that will be adapted or developed for use in by FF operations and other aviation participants. This section explores the following key infrastructure elements which are critical to the introduction and scaling of FF operations:

- Airspace, Traffic Management and Separations Systems
- CNS and other Supporting Traffic Management Technology
- Vertiports

7.5.1 Airspace, Traffic Management and Separation Systems

As can be seen from the use case descriptions and the bowtie analysis it is expected that airspace structures and traffic management systems will continue to play an important role in assuring the safety of UK aviation. As discussed in Section 6.4.1, there are several strategic defences against aviation accidents within the current aviation system including those identified below from an airspace, traffic management and collision avoidance perspective:

- Airspace design providing segregation between different airspace users
- Flow management provided by Air Traffic Management
- Separation provided by Air Traffic Control
- DAA
- ACAS

Traffic management is a critical component of maintaining tolerable levels of safety as traffic levels increase. Currently, Air Traffic Services (ATS), which incorporate Air Traffic Management and Air traffic Control, are provided in controlled airspace where the density of traffic means that the other strategic defences are insufficient to maintain safety.

The role of ATS systems is to provide safe separation (for expeditious traffic flows) based on pre-flight and in-flight management. An extra layer of safety is provided from safety nets such as ACAS and ground proximity warning systems. In the future we envisage a similar concept with the primary UnTM systems providing a planned safe traffic flow and other safety nets available when it fails.

It is envisaged that traffic management will evolve in two ways:

- Enhancement of current ATM and UTM practices
- Development of a new approach to Unified Traffic Management

These approaches are described below and a mechanism to move between the concepts is also described. Recommendations are made to ensure that traffic management infrastructure is developed to achieve the required performance outcomes of airspace.

Enhancement of current ATM and UTM practices

In the existing ATM environment, there will be a transition towards new technologies, e.g. to support the introduction of UTM. For example, the requirements for aircraft to be equipped with Electronic Conspicuity (EC) capabilities are increasing as part of the UK's Airspace Modernisation Strategy[53], and it is reasonable to expect an environment with total equipage of EC in the near/medium-term. This will support the introduction of other technologies such as DAA. There will also be wider deployment of Required Navigation Performance (RNP) and advanced navigation functions such as Require Time of Arrival and Radius-to-Fix (RF)-Legs (i.e. constant radius turns) on aircraft. On the ground there will be greater tool support for ATC. These changes will happen irrespective of FF but they will also support the introduction of drones, UAM and RAM aircraft.

When new aircraft enter the traditional airspace, they will need to comply with the associated requirements therein. For example, an unmanned drone will need something functionally equivalent to a see and avoid capability. The principle that aircraft comply with the requirements of the airspace they enter will remain, although new aircraft may comply with those requirements in a different way (e.g. unmanned drones using DAA instead of see-and-avoid).

However, some existing airspace volumes will reach limits where they cannot support the numbers of new aircraft entering the airspace. In this case, the airspace will need to change to the new types of UnTM airspace described below.

Recommendation 7.5 – A roadmap should be developed for the enhancement of ATM and UTM which objectively determines the limits to which the current practices can be extended

Development of a new approach to Unified Traffic Management

It is unlikely that current ATM concepts can be enhanced to achieve the required level of performance from CNS systems to reduce separation standards and instrument procedures to a level that can be adopted for high density autonomous operations. Much higher levels of precision will be required, and minimum standards of performance will be required by all airspace users in this type of operating environment.

Equally, it is expected that the continued reliance on a human at the centre of the ATC system and the use

53. UK Airspace Modernisation Strategy, CAP1711, UK Civil Aviation Authority, December 2018

of voice communications will become impractical as aircraft density increases and autonomy becomes more widely used.

It is important to understand the role that ATM currently plays in maintaining the safety of the aviation system. This role relates to the strategic, pre-tactical and tactical separation of aircraft, but also independent conformance monitoring of the safety performance of airspace users and the management of dynamic airspace issues relating to threats (such as weather, non-compliant airspace users) and prioritisation and management of unplanned airspace usage requirements.

As FF operations grow in density and complexity (including autonomous operations) it is expected that, for certain airspace to maximise the performance of aircraft operations, traffic management will be required in addition to airspace design, DAA and ACAS.

It is proposed that a new concept of unmanaged and managed airspace is adopted which, similar to Class G and other airspace classes, allows for different traffic management approaches depending upon the density of the aircraft operations. Where there are fewer operations, such as in rural locations, enroute and high altitude airspace, it is envisaged that airspace design, DAA and self-separation practices will be sufficient to allow aircraft operations. However, in busier airspace, such as the urban environment, managed airspace shall be used with some centralised management authority to ensure the performance of the airspace is maintained. Note that the concept is centralised, although methods of implementation may be decentralised, however a centralised traffic management authority is the most practical method of implementing such a concept.

Both types of airspace will make use of new technologies and be suited for low-level urban operations and new class(es) of aircraft. For example, they will not use primary radar as a surveillance system (some modern composite aircraft are not readily visible with primary radar) or traditional forms of ACAS as their collision avoidance system (traditional forms of ACAS requires high power which is not suitable for small drones).

The two types of UnTM airspace are summarised below.

Low density UnTM airspace	High density UnTM airspace
Suitable for low density operations in low-density obstacle environments, e.g. HAPS	Suitable for high density operations in a high-density obstacle environment, ego inner-city UAM
Unmanaged traffic with autonomous control	Managed traffic with a traffic management system to co-ordinate and control all aircraft
Traffic density below a pre-defined threshold	Traffic density above a pre-defined threshold

Table 2: Characteristics of UnTM airspace

Both airspace types share some characteristics:

- They employ new technologies unencumbered by existing airspace technology requirements, e.g. they may use a different air/ground communication system(s) not compatible with current air/ground VHF aviation systems. (Note the use of unprotected frequency bands for traffic management is a known issue being addressed by the international community.)

Any aircraft that need to transition across 'traditional' airspace will need the capability to do so. Some aircraft will therefore carry dual technology systems to allow themselves to operate in both types of airspace.

In establishing UnTM, it may be possible to use many of the concepts and technologies developed for UTM, however this airspace would need to be designed for use by all airspace users, not just drones. The threats and hazards managed by ATM in nominal and off-nominal scenarios (e.g. mass diversion) will need to be addressed in UnTM in addition to any new hazards and threats introduced by the change in operations (e.g. removal of human control).

It must be recognised that UnTM airspace will itself evolve with new technologies and procedures introduced over the different time horizons. Nevertheless, it is a chance to define a new type of airspace that safely meets the requirements of FF in the short-term.

Realistically, some existing air traffic will not be able to enter UnTM airspace. Existing aircraft will not or cannot be suitably equipped and may never be upgraded, although some cost-effective technology may be able to be retrofitted to legacy aircraft to meet requirements. Where aircraft cannot meet requirements, it may be necessary for traditional non-UnTM compliant operators to have means of access (e.g. through airspace reservation) in a similar conceptual manner that drones currently use to gain access to controlled airspace. It is however expected that these "edge" cases will reduce over time as older, less well-equipped aircraft, transition out of service and the traffic management systems evolve to meet the needs of all airspace users.

Recommendation 7.6 – A concept of operations is developed for Unified Traffic Management (UnTM) airspace which supports new airspace users. UnTM airspace should enable UK operations to maximise performance of UK airspace for all airspace users and be based on best practice technologies and safety principles. Two types of UnTM airspace are envisaged: unmanaged and managed airspace.

Recommendation 7.7 – Establish CNS technology expectations and minimum performance standards for airspace users to operate in unmanaged and managed UnTM airspace

Transition to Unified Traffic Management

It is unlikely that current ATM can be enhanced to achieve the objectives of UnTM. As such it is expected that airspace should be dedicated to the new UnTM concepts of managed and unmanaged, with development of these concepts occurring in parallel with enhancement of the current system. Participants in UnTM airspace (both managed and unmanaged) would be expected to meet the performance requirements for the new airspace, which will likely be different from traditional airspace.

Unmanaged UnTM airspace would most likely be used first and the concepts implemented for this type of airspace, whilst managed airspace concepts are still in development. However, it will be important to establish a concept for managed airspace to ensure that demand for airspace usage can be met.

It is expected that new UnTM airspace trials will commence in the short-term, with initial operations in the medium-term before much wider operations in the long-term. In the long-term the amount of traditional controlled and uncontrolled airspace would reduce.

A new approach to information management

The need for the right information at the right time in the right place has been recognised for several years within manned aviation. It enables better levels of coordination between each actor and provides a better customer experience to passengers. Information can be a mix of operational and safety driven - tactical and strategic - which in turn places requirements on the quality (integrity, accuracy and timeliness) of the data. The volume of operational data being delivered today affecting manned aviation on a day-to-day basis is only expected to increase as the level of automation and data driven decision making is rolled out. The importance of data integrity and its recognition as a source of safety risk in aviation context are described in publications from the Safety Critical Systems Club, Data Safety Initiative Working Group (DWISG)[54]. Accordingly, as integration of UAM and drones mix with manned aviation, the sharing and updating of data that supports safe operations becomes critical.

This level of automation affecting both manned and unmanned aviation includes the concepts being proposed by the FF programme. The introduction of drones and UAM introduces the need to share the data already available to manned aviation but also new requirements that might be needed to support specific types of missions. Within an urban environment, for example, it is expected that the existing manned aviation requirement for a 28-day update cycle for published data will not provide sufficient timeliness and deployment will require more dynamic updates of data with notifications that impact operations covering:

- Airspace, aerodrome and vertiport access
- Meteorological information
- Regulation updates and advisories of a safety nature
- Restrictions on operations
- Limitations of supporting infrastructure – in particular, affecting communications, navigation and surveillance

Analogous from a manned aviation perspective is the concept of System Wide Information Management (SWIM) with data owners/publishers and data subscribers supporting a network view in which all actors have access to the latest data available. In this ecosystem, the security protocols, data formats and data quality can be critical to supporting the safety of the operations. Add-on capabilities support the ability for service providers to offer data subscribers business specific views. Interoperability of the systems and the data is essential within the concept

54. Data Safety Guidance, Version 3.2, produced by the Data Safety Initiative Working Group, February 2020

of SWIM and modelling the data interactions and system bandwidth and latency requirements to support timely information exchanges will be needed to ensure that the underlying communications infrastructure is sized appropriately.

Extending this concept of SWIM to the FF programme, the information exchange data requirements could be significant. It is still not identified what data, what refresh rate and what level of assurance is required to support operations. Neither is it fully determined the mechanisms through which interoperability or information exchanges will necessarily take place. For example, could a 4G link be used for C2, reporting of position to support a surveillance capability and as an alternate to GNSS for navigation through localised positioning? Will this information be shared through a centralised function or will it be shared into a more distributed network that relies on authentication and authenticity of the message set through application of technologies such as blockchain? What data must be exchanged and with what frequency to support tactical manoeuvring within an automated environment. And how will information on airspace access and restrictions be seamlessly shared with manned aviation?

There is no single solution posed by answering these questions. Without overarching direction and leadership, a risk exists of several distinct solutions being developed that are not entirely interoperable or do not have sufficient capability to support the perceived end state demand therefore delaying readiness or limiting capacity.

Recommendation 7.8 – It is recommended, that given the criticality of information management to support the operations of the future, that further investigation is undertaken to identify the data requirements and information flows needed to enable the FF vision. This should determine the extent to which manned aviation standards could be adopted in full or where alteration could be beneficial. Alternatively, to support the specific requirements of the FF vision, a new data exchange specification and communications infrastructure may be needed.

7.5.2 CNS and other Supporting Traffic Management Technology

The range of potential technologies that will be available for information exchange/management and decision-making to support FF will be significantly larger than historically used in aviation. It is expected that the underlying concepts of CNS will continue to exist and be important for the safety of aircraft operations in both airspace/procedures design and separation standards. One of the significant challenges for FF new technology usage will be in understanding and then meeting the safety integrity and assurance requirements that will be needed to achieve target levels of safety performance for the aviation system. These requirements will need to be architected and determined for the system as a whole based upon tolerable levels of safety for different airspace and aircraft operations. This challenge will extend to:

- communications technology
- navigation systems
- detection systems (e.g. LIDAR)
- geospatial and topographical information
- and autonomous decision making

Redundancy in supporting technology has been a critical part of the aviation industry achieving its current safety performance. It will be important to ensure architectural solutions are developed so that new technology maintains an appropriate level of redundancy similar to that which currently exists in the aviation system.

FF aircraft system developers and operators will need early insight into how these technological systems will be architected. In addition, architectural decisions will need to be harmonized with other international approaches. Within each particular technology area there are significant challenges to be overcome (e.g. Radio Frequency Spectrum availability and protection) and these challenges must be considered in light of the planned aviation system architectural approach.

The challenge is to enable new CNS technology to be used to maintain or improve safety performance, while recognising that there will always be a mixed range of equipage across different aircraft.

Recommendation 7.9 – Develop a methodology to understand the safety integrity and assurance requirements for future flight CNS and other supporting technologies.

Recommendation 7.10 – Determine the challenges and safety integrity and assurance impact for specific FF technology areas, including communications technology, geospatial and topographical information and autonomous decision making

Recommendation 7.11 – Develop an aviation system architecture which considers the challenges and capability to achieve safety integrity and assurance requirements.

7.5.3 Vertiports

Airspace around some vertiports will potentially become some of the most complex in the future aviation system. Vertiports in the urban environment, where the greatest use of UAM is likely to occur, will commonly be located at locations that may also see great demand for the use of drone capabilities. The approach and departure phases of UAM flights must be integrated with other airspace users around vertiports. Access and equity of access, prioritisation, capacity and predictability will need to be considered alongside safety in these locations. A particular issue facing vertiports will be their location close to or in urban centres meaning that traditional safeguarding procedures will be insufficient. Many of these challenges need to be addressed prior to the establishment of infrastructure, which may have long-term implications.

Decisions regarding whether single or multiple vertiports service a local community will also have impact on airspace design and traffic management. In addition, the evolution of FF operations will see new vertiports opening which may impact existing airspace structures and aviation operations. Safety change management practices will need to consider both the transition risks as well as the long-term impact of establishing new infrastructure.

Recommendation 7.12 – Determine the safety challenges for implementing Vertiports, particularly in the urban environment with the likely complexity of airspace usage.

Recommendation 7.13 – Establish a safety change management framework for the establishment of Vertiports.

An Initial Safety Framework for Future Flight

8

8 An Initial Safety Framework for Future Flight

8.1 Introduction

This report has described the key contextual components for an initial safety framework for FF, which are:

- A description of the current UK Aviation System focussed on elements relevant to FF
- A description of the future UK Aviation System which shows how the roles of different stakeholders will change over time as new FF operations are implemented
- A description of the use cases for FF operations described over different time horizons
- A description of the key safety management challenges of FF

Based upon this contextual description an analysis has been undertaken to consider the safety impact of FF. This analysis has focussed on:

- The impact on hazards, threats and controls of FF use cases in the current and future aviation system using the bowtie notation
- Key safety challenges relating to FF

In this section we describe how these elements can be brought together to develop an initial safety framework for FF. This framework is particularly focussed on the top layers of a safety case which sets out the safety argument strategy for demonstrating the overarching goal has been met with respect to FF. The framework is outlined below using GSN. Given this is the first iteration of this framework, many of the goals outlined are not yet satisfied with appropriate evidence. The aim of presenting the framework at this stage is to indicate what activities are required to achieve the intent of the overarching safety case. This is similar in nature to the development of an initial safety argument during a safety change management activity, which then can be used to inform safety planning.

The framework below is not intended to be definitive or represent something that industry or the regulator is committed to, but a means to identify principal activities and tasks required to demonstrate that the future aviation system is tolerably safe. These activities and tasks can then be used to build a roadmap of activities/tasks that should be progressed to develop the FF industry safety case in a collaborative and practical manner.

As the UK aviation industry evolves, this safety framework will need to evolve and be developed with evidence produced to satisfy the claims made.

8.2 Top-level argument

The overarching goal of the framework is to assure that:

UK Aviation will achieve an acceptable safety performance during and after the implementation of Future Flight (FF) operations.

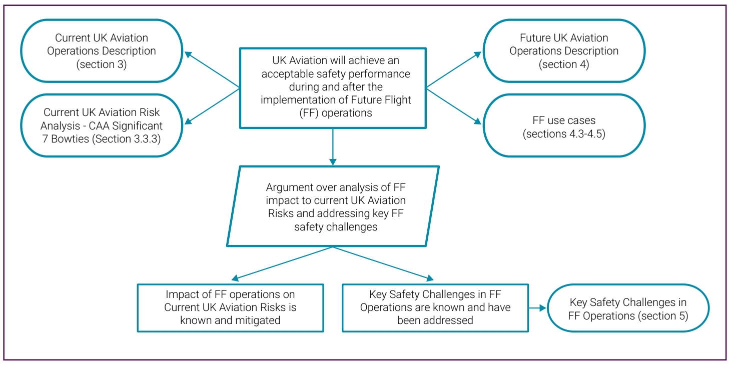


Figure 8: Top-level argument for the FF Aviation Safety Framework

The top-level argument to achieve this claim is described below. Following the approach taken in this project, the argument is divided over the mitigation of the impact of FF on current UK aviation safety risks and the management of key safety challenges related to FF.

The lower-level claims in the argument above are broken down further in the following sections in line with the approach taken in this project.

8.3 Impact of Future Flight on UK Aviation Safety Risks

Understanding the impact of FF operations and mitigating that impact is key to ensuring acceptably safe outcomes with respect to FF integration with UK aviation operations. The argument below presents the impact of FF on current UK Aviation Safety Risks (see figure 9). Note, not all goals are fully developed in the argument structure below. Those which have not been expanded are shown with a diamond underneath the goal.

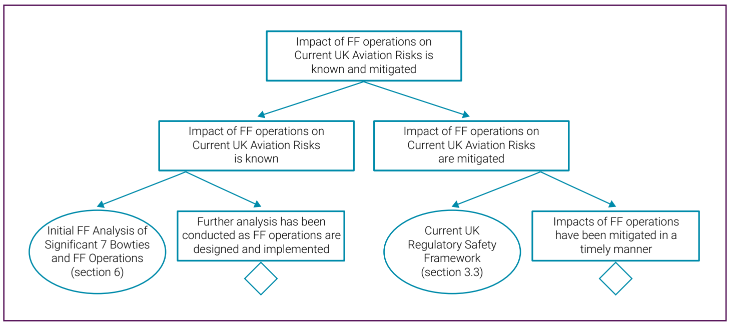


Figure 9: Argument regarding the impact of FF on current UK Aviation Safety Risks

This project has conducted an initial analysis of the impact of FF operations across both the short-term current UK aviation safety risk profile and the long-term future UK aviation safety risk profile, based upon the expected changes to the aviation system. The analysis will require further development as knowledge increases, especially as FF operations are designed and implemented.

It will be critical to mitigate the known impacts of FF on hazards, threats and controls at a whole-of-aviation-system level and this goal will need to be developed further as FF operations are designed and implemented. Mitigations should be considered across the governance, management and task/technical layers of the UK aviation system as discussed in the complex systems analysis. It is unlikely that any individual layer or stakeholder group (e.g. regulators or FF systems developers) will be able to fully mitigate UK system-wide aviation safety risks that are likely to occur over the long-term. Holistic and coordinated consideration by UK aviation system stakeholders is needed to achieve effective mitigation.

Mitigation will need to address both transitional risks as well as longer term steady-state operational risks. At an aviation system-wide level, transitional risks may be more challenging, for example where there is a mix of operational performance capabilities and levels of autonomy. Determining the exposure length of these transitional risks as the aviation system moves from the short-term concepts to the long-term concepts should be explicitly considered and determined. The challenges of a quicker transition to new operating concepts must be weighed up against the transitional risks of a more complex operating environment.

To be able to conduct further analysis throughout the short-, medium- and long-term, it is recommended that a UK Aviation Risk Baseline is maintained using an appropriate methodology such as the bowtie notation. The benefit of using the bowtie notation is that it enables a wide range of stakeholders to engage in discussions about risk and bring together a variety of types of threats and controls. The technique can be applied in varying levels of detail, including up to the aviation system level, as has been done in this project. As shown by this project, maintaining a risk baseline made up of both current risks and the future risk landscape will help inform understanding of the risk impact of strategic changes to the UK aviation system. These strategic changes should be considered holistically in addition to individual, specific changes that will occur through the implementation of specific FF operations.

In addition, a UK aviation system risk baseline in this format provides a means of identifying safety performance monitoring measures and can also be used as an input for safety occurrence management and investigations.

8.4 Mitigation of Known FF Safety Challenges

It is not expected that all safety issues can be identified through traditional risk analysis. To provide increased assurance it is beneficial to use a range of methodologies to identify and mitigate safety impacts. In addition to the bowtie risk analysis discussed above, the second pillar of the safety argument within this framework is based upon the identification and management of key safety challenges. At a whole-of-aviation-system level this approach allows for the most significant issues to be identified quickly and approaches for their management determined and implemented in a planned, expeditious manner.

Understanding the key safety challenges in FF and assuring that they have been addressed is key to ensuring acceptably safe outcomes with respect to FF integration with other UK aviation operations. The argument below presents an initial argument structure to achieve this goal.

This project has conducted an initial analysis of the safety challenges associated with the implementation and growth of FF operations. The analysis will require further development as knowledge increases when FF operations are designed and implemented. This may include more detailed analysis of the transversal themes described in this project and the identification and analysis of additional challenges.

The safety challenges identified in this project for the integration of FF operations into the UK aviation system over the long-term are significant. The level of effort and co-ordination required to address certain recommendations in this document must be considered and consulted with key stakeholders to ensure effective resolution. To achieve this, it is recommended to develop a prioritised plan for addressing the recommendations and ensure the participation of appropriate stakeholders and to establish a forum for continual interaction with key stakeholders.

Progress on the safety challenges identified in this project will be best achieved through wide engagement and consultation across FF and UK aviation stakeholders. Ensuring diversity in the stakeholders involved in developing solutions and transparency in decisions to resolve these challenges will be important for the industry, given the complexity of the future aviation landscape and the number of participants. Many of the recommendations to address the safety challenges are focussed on industry-wide strategy and planning with explicit decision making (e.g. publication of concepts of operation). It will be important to consider this across the governance, management and task/technical layers of the UK aviation system (as discussed in the complex systems analysis).

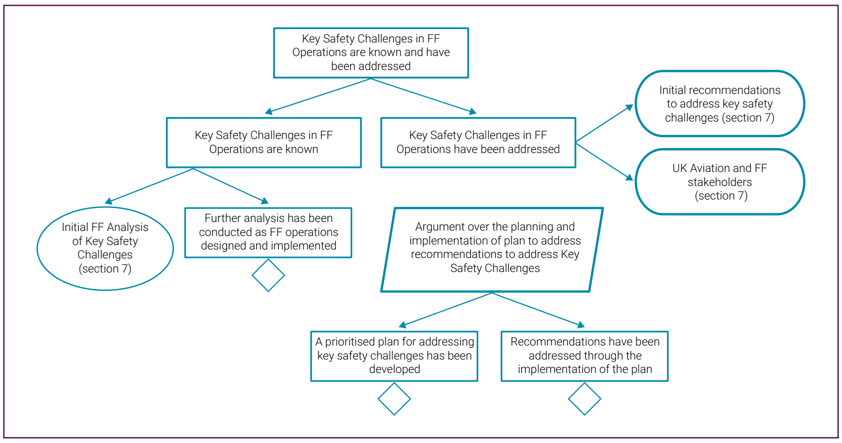


Figure 10: Argument regarding the management of specific safety challenges associated with FF

Conclusions and Recommendations

9

Conclusions and Recommendations

9

9.1 Conclusions

UK aviation will change dramatically in the long-term, in large part driven by innovations in FF. In this report an initial framework has been articulated to support the future safety assurance of FF operations, and hence the ongoing safety of UK aviation. This framework is made up of four key parts:

- The identification of new FF use cases and scenarios, and an understanding of how the integration of the aviation system evolves over time in the context of these use cases (Section 4)
- An analysis of the impact of new use cases on the hazards, threats and controls of the overarching aviation system (Section 6)
- An analysis of key safety challenges which will have a significant impact on aviation safety into the future (Section 7)
- An initial safety framework that describes the role each component of the framework plays towards providing future assurance regarding the safety of FF operations and the aviation system (Section 8)

9.1.1 Use Cases and Aviation System Stakeholders

This framework has considered the use cases for FF over the short-, medium- and long-term as a basis to determine the potential changes in these three time frames. These use cases do not necessarily reflect all future changes to UK aviation, but are focussed on the evolutionary parts of the industry that are relevant to the FFC. In the framework a description of how the roles of key actors will evolve over the short-, medium- and long-term has been presented. With the increasing number and changing nature of stakeholders in the aviation system, it will be important to maintain this viewpoint to ensure a common understanding of the aviation system into the future.

9.1.2 Risk Impact

The impacts of FF use cases have been considered from a risk perspective using the bowtie methodology. An analysis of both current UK safety risks and the future risk profile of operations involving drones, UAM and RAM has been undertaken to understand key considerations which will be important to the safety of future operations. This has led to a set of high-level requirements relating to necessary functions and capabilities of key system elements such as flight control and traffic management to support risk mitigation in the long-term.

9.1.3 Key Safety Challenges

Key areas of safety focus across the short-, medium- and long-term operation of FF use cases have been identified as transversal themes. Critical themes for future safety have been identified as:

- Complex Systems (and their impact on safety)
- Integrated Safety and Risk Management
- The role of human and autonomy
- Supporting Infrastructure

The significance of these themes is related to both their impact on the safety of the aviation system and the length of time and level of coordinated effort required to address them.

9.2 Recommendations

This project has identified many recommendations which will contribute to assuring the acceptably safe integration of FF operations into the future aviation system. They relate to all aspects of the system and the stakeholders within it and act as a starting point for further development.

The highest priority recommendations are listed below, and the final recommendation provides the means to address the many detailed recommendations in this report.

Recommendation 9.1 – Development of a concept of operations for the future aviation system which includes transitional states

Recommendation 9.2 – Establishment of Target Levels of Safety for aircraft operations, including specific FF use cases

Recommendation 9.3 – Establishment of an aviation system risk baseline made up of both the current risk profile and the future expected risk profile, based upon future concepts of operations.

Recommendation 9.4 – Prioritisation of the issues and recommendations in the report and the establishment of a safety work program in support of the FFC. This should include, amongst other things, a plan for managing the impacts of complex systems at the Governance, Management and Task/Technical layers. This should also include consideration of the many more detailed recommendations in this report. Consideration should be given to placing the responsibility for developing and delivering this plan on a pan-industry body or, establishing one specifically for this purpose.

To ensure effective development of the work within this report, it will be important to undertake wide engagement and consultation across the aviation industry.

9.3 Evolution of the Safety Framework

It should be noted that this is an initial framework, and the evolution of FF is expected to occur over a significant period of time. Thus, the range of issues identified in this report is large and work to address them will occur over a long period to time. At this early stage of FF, it is not possible to be complete in the identification of issues and it is expected that this work will require continual enhancement as knowledge grows about the implications of FF. However, the framework approach used in this report will remain valid and can be expanded as a way of identifying and prioritising areas of focus for safety work.

To progress this work, the following recommendations are made:

Recommendation 9.5 – Presentation of the analysis and recommendations to FFC participants and the wider UK aviation community to:

- **Seek feedback on the completeness of the analysis and prioritisation of issues; and**
- **Inform planning of future work across all aviation stakeholders.**

Recommendation 9.6 – Expansion of the concepts to the full UK aviation system (including other new aviation concepts such as HAPS and autonomous CAT).

Recommendation 9.7 – Identification of other additional key safety challenges that can have a critical impact on the success of future UK aviation, both within the scope of FF and other aviation innovation activities.

Recommendation 9.8 – Establishment of an international engagement strategy and plan to ensure that the UK remains central to developing and influencing globally harmonised approaches and standards.

Glossary

A

Glossary

A

Abbreviation	Definition
AAM	Advanced Air Mobility
ACAS	Automated Collision Avoidance System Umbrella term for various air/ground collision avoidance systems including TCAS, GPWS, eGPWS etc.
ADS-B	Automatic Dependent Surveillance - Broadcast
ADSPs	ATM Data Service Providers
AGL	Above Ground Level
AI	Artificial Intelligence
ALoSP	Acceptable Level of Safety Performance The minimum level of safety performance of civil aviation in a State, expressed in terms of both safety targets and safety performance indicators. [ICAO]
ANS	Air Navigation Service
ATCO	Air Traffic Controller
ATM	Air Traffic Management The dynamic, integrated management of air traffic and airspace including air traffic services, airspace management and air traffic flow management — safely, economically and efficiently — through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground-based functions. [ICAO]
ATS	Air Traffic Service An umbrella term that includes four principal forms of air traffic service: Air Traffic Control Air Traffic Advisory Flight Information Service Alerting service
BVLOS	Beyond Visual Line of Sight An operation in which the remote pilot or observer does not use visual reference to the remotely piloted aircraft in the conduct of flight. [ICAO]
CAT	Commercial Air Transport
CFIT	Controlled Flight into Terrain
CNS	Communications, Navigation, Surveillance
CONOPS	Concept of Operations Describes the characteristics of the organisation, system, operations and the objectives of the user. [UK CAA]
CPS	Cyber-Physical Systems
DAA	Detect and Avoid
EASA	European Union Aviation Safety Agency

Abbreviation	Definition
EC	Electronic Conspicuity Electronic Conspicuity (EC) is an umbrella term for a range of technologies that, in their most basic form, transmit the position of the host aircraft to other airspace users operating compatible equipment.
(e)VTOL	(Electric) Vertical Take-off and Landing (aircraft)
FAM	Future Air Mobility
FCS	Flight Control System
FF	Future Flight
FFC	Future Flight Challenge
FMS	Flight Management System
FRA	Free Route Airspace A specified volume of airspace in which users can freely plan a route between defined entry and exit points. Subject to airspace availability, routing is possible via intermediate waypoints, without reference to the air traffic service route network. [Eurocontrol]
GASP	Global Aviation Safety Plan
GNSS	Global Navigation Satellite System The ICAO definition for all satellite navigation systems, such as GPS and Galileo.
GSN	Goal Structuring Notation
HAPS	High Altitude Platforms
HRO	High Reliability Organisations
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IMC	Instrument Meteorological Conditions Conditions (e.g. cloud or fog) that require pilots to fly primarily by reference to instruments rather than by outside visual references. Defined by ICAO as: Meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling, less than the minima specified for visual meteorological conditions (VMC).
IRS	Inertial Reference System
MRO	Maintenance, Repair, Overhaul
NOTAM	Notice to Airmen
PAS	Publicly Available Specification
PIC	Pilot in Command
PIREPs	Pilot REPortS A report of actual weather conditions encountered by an aircraft in flight traditionally relayed by radio to an appropriate ground station for dissemination.
QNH	Quadrant Nautical Height
R&D	Research and Development
RAIM	Receiver Autonomous Integrity Monitoring
RAM	Regional Air Mobility
RF	Radius-to-Fix (in an aircraft navigation context)
RNP	Required Navigation Performance

Abbreviation	Definition
RPAS	Remotely Piloted Aircraft System A set of configurable elements consisting of a remotely piloted aircraft, its associated remote pilot station(s), the required command and control links and any other system elements as may be required, at any point during flight operation. [ICAO]
RPASP	Remotely Piloted Aircraft Systems Panel
RVSM	Reduced Vertical Separation Minima A section of airspace where approved aircraft can be vertically separated by a minimum of 1,000ft between flight level (FL) 290 and 410. This is to enable more efficient use of the airspace. [ICAO]
Safety Performance	Achievement of a level of safety where the risks associated with aviation activities related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level [ICAO].
SARPs	Standards and Recommended Practices
SESAR	Single European Sky ATM Research
SESAR JU	Single European Sky ATM Research Joint Undertaking
SMS	Safety Management System
SSP	State Safety Programme This is an integrated set of regulations and activities aimed at improving safety. It is a management system for the administration of safety by the State. [ICAO]
SWIM	System Wide Information Management The System Wide Information Management (SWIM) concept consists of standards, infrastructure and governance enabling the management of ATM related information and its exchange between qualified parties via interoperable services [ICAO Doc.10039].
TAWS	TAWS (Terrain Avoidance Warning System)
TF-UHAD	Task Force on Unmanned Aircraft Systems for Humanitarian Aid and Development [ICAO]
TLOS	Target Level of Safety A generic term representing the level of risk which is considered acceptable in particular circumstances. [Eurocontrol]
TMS	Traffic Management System
TMSP	Traffic Management System Provider
U-space	U-space is a set of new services and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones. [SESAR JU]
UAM	Urban Air Mobility A system for air passenger and cargo transportation within an urban area, inclusive of small package delivery and other urban unmanned aircraft systems services. [NASA]
UAS	Unmanned Aircraft Systems An aircraft and its associated elements which are operated with no pilot on board. [ICAO]
UAS-AG	Unmanned Aircraft System Advisory Group
UAV (Drone)	Unmanned Aerial Vehicle This is an aircraft without a human pilot on board. A UAV is commonly referred to as a "Drone". (The term "UAV" is considered obsolete by ICAO)
UKRI	UK Research and Innovation
UML	UAM Maturity Level

Abbreviation	Definition
UnDSPs	Unified Data Service Providers
Urban Canyon	Poor GNSS positioning accuracy is common in urban canyons where tall buildings block the direct line-of-sight signals from many, sometimes most, of the satellites, effectively casting GNSS shadows over the adjacent terrain. Without direct signals from four or more satellites, an accurate position solution cannot be determined. [GPSWorld]
USS	UAS Service Supplier USS help enable the safe, secure, and efficient use of our airspace. They act as a communication bridge between authorities and drone operators, and often provide tools to monitor the airspace, execute safe missions, and store operational data. [FAA]
UTM	UAS Traffic Management UTM is how airspace will be managed to enable multiple drone operations conducted beyond visual line-of-sight, where air traffic services are not provided. [FAA]
UnTM	Unified Traffic Management A concept that includes the provision of both Air Traffic Management and UAS Traffic Management services within the same function. [Project definition]
VFR	Visual Flight Rules
VHF	Very High Frequency
VLL	Very Low Level (airspace) Airspace below 500ft AGL. [ICAO]
VLOS	Visual Line of Sight An operation in which the remote pilot or observer maintains direct unaided visual contact with the remotely piloted aircraft. [ICAO]
VMC	Visual Meteorological Conditions Conditions that allow pilots to fly primarily by outside visual references. Defined by ICAO as: The meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling equal to or better than specified minima.

Bowtie Analysis

B

Bowtie Analysis

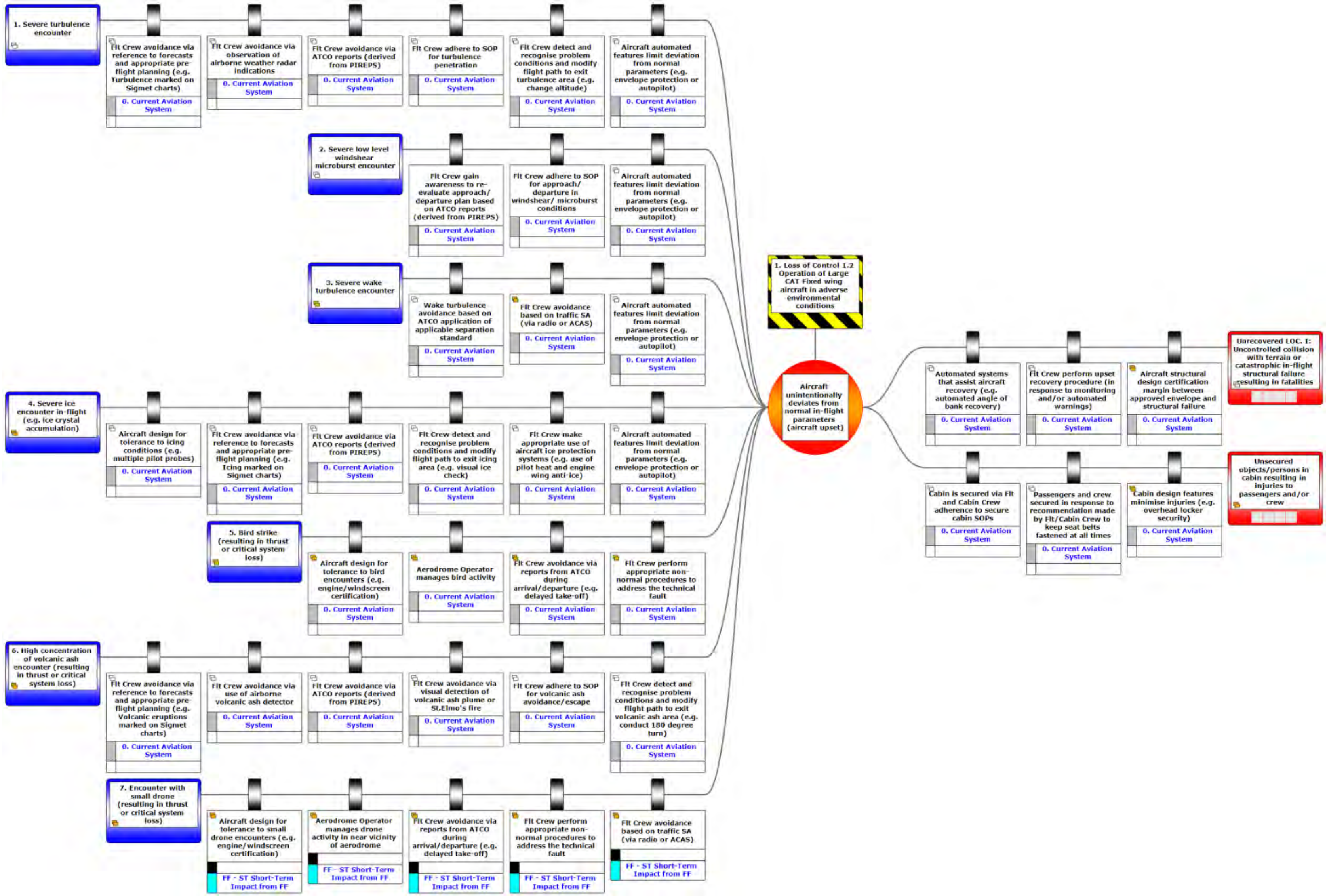
B

This section contains the bowtie diagrams for each of the hazards affected by FF operations across the different scenarios. It is structured into the following three subsections:

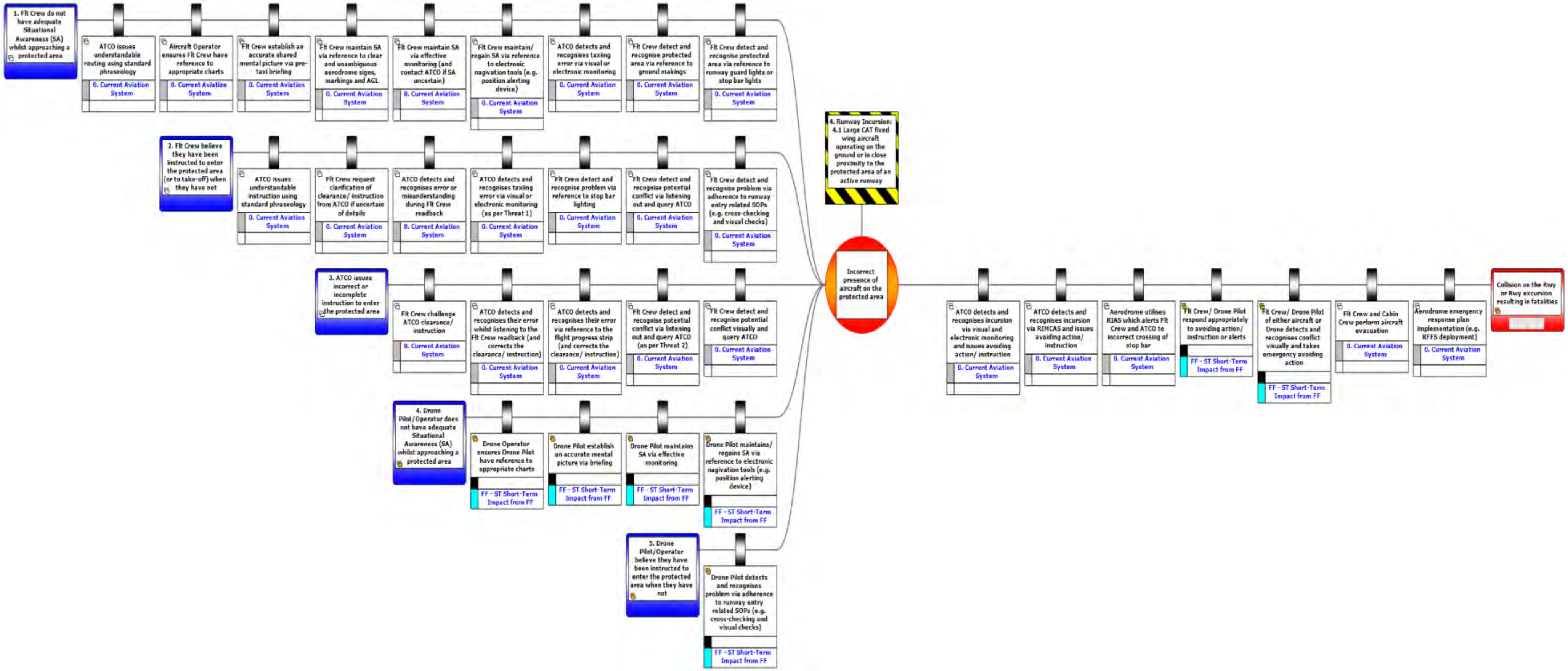
- Impacts to the existing Significant Seven bowties for the short- and medium-term
- New hazards related to operations in the short- and medium-term
- New hazards related to operations in the medium- and long-term

B.1 Updates to Existing Significant Seven Bowties for Short- and Medium-Term

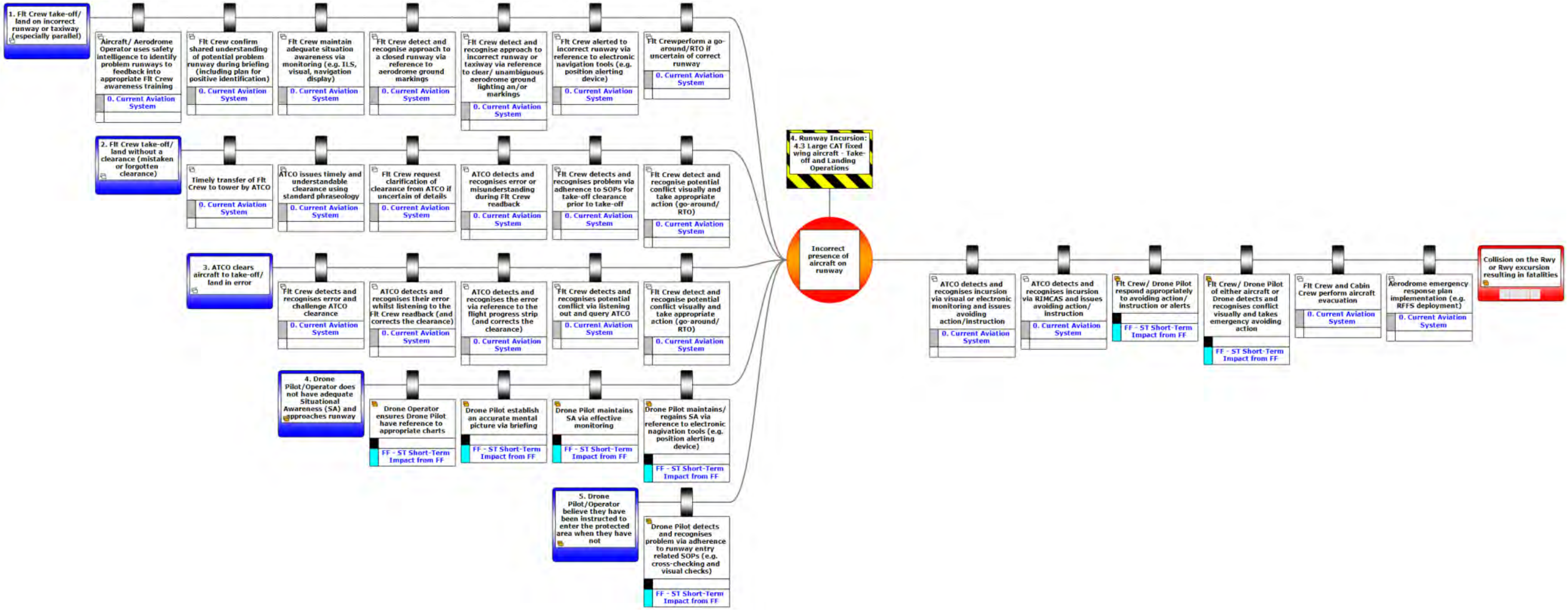
B.1.1 Hazard 1.2 – Loss of Control of Large CAT fixed wing aircraft in adverse environmental conditions



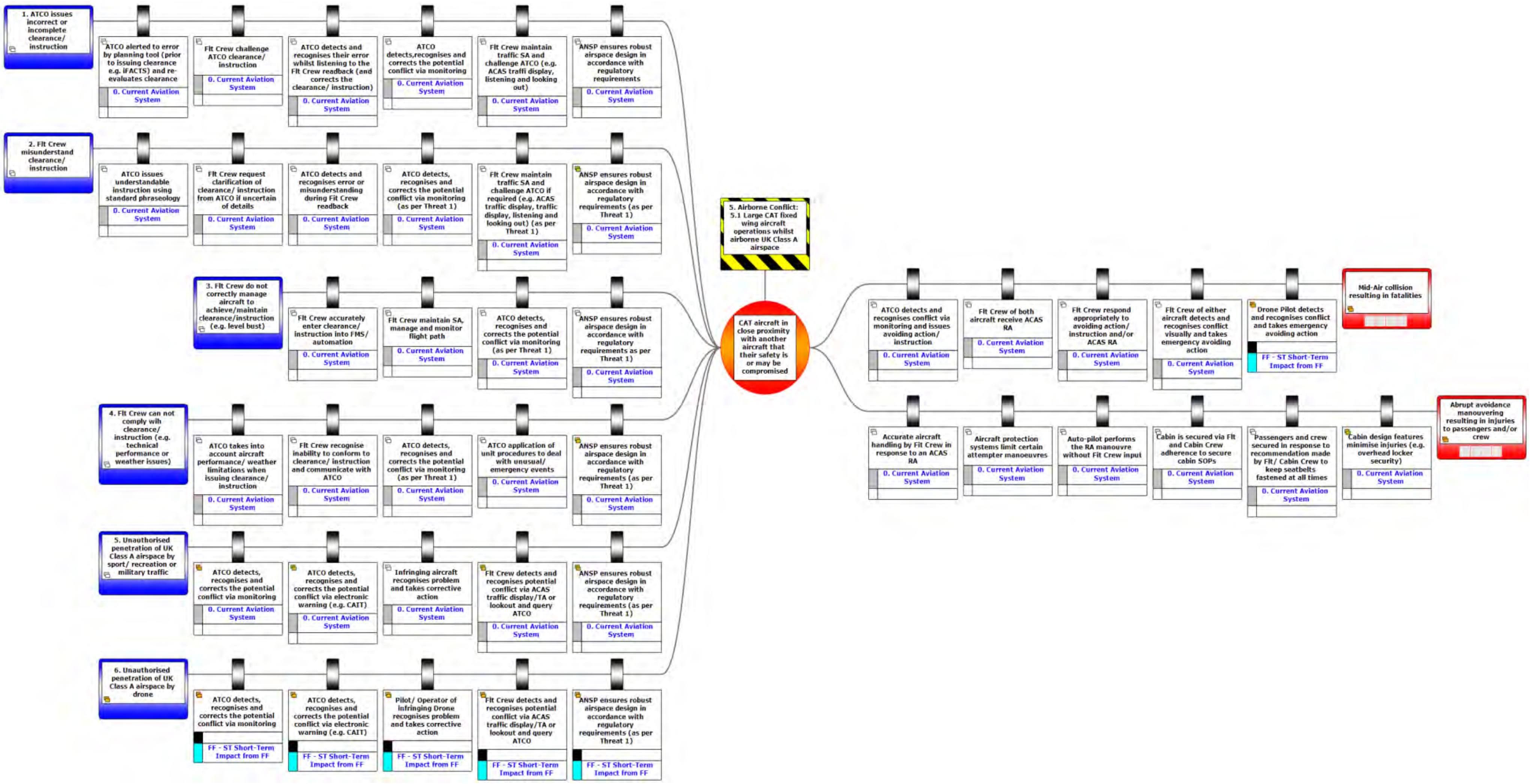
B.1.2 Hazard 4.1 – Runway Incursion – Large CAT fixed wing aircraft operating on the ground or in close proximity to the protected area of an active runway



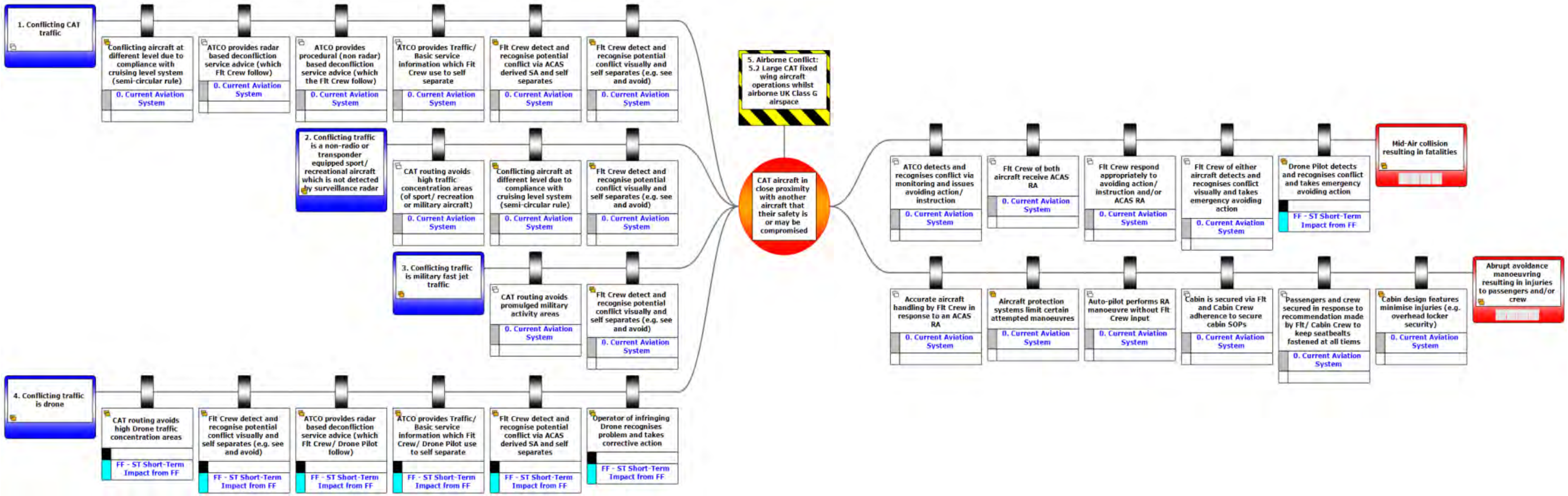
B.1.3 Hazard 4.3– Runway Incursion – Large CAT fixed wing aircraft – Take-off and Landing Operations



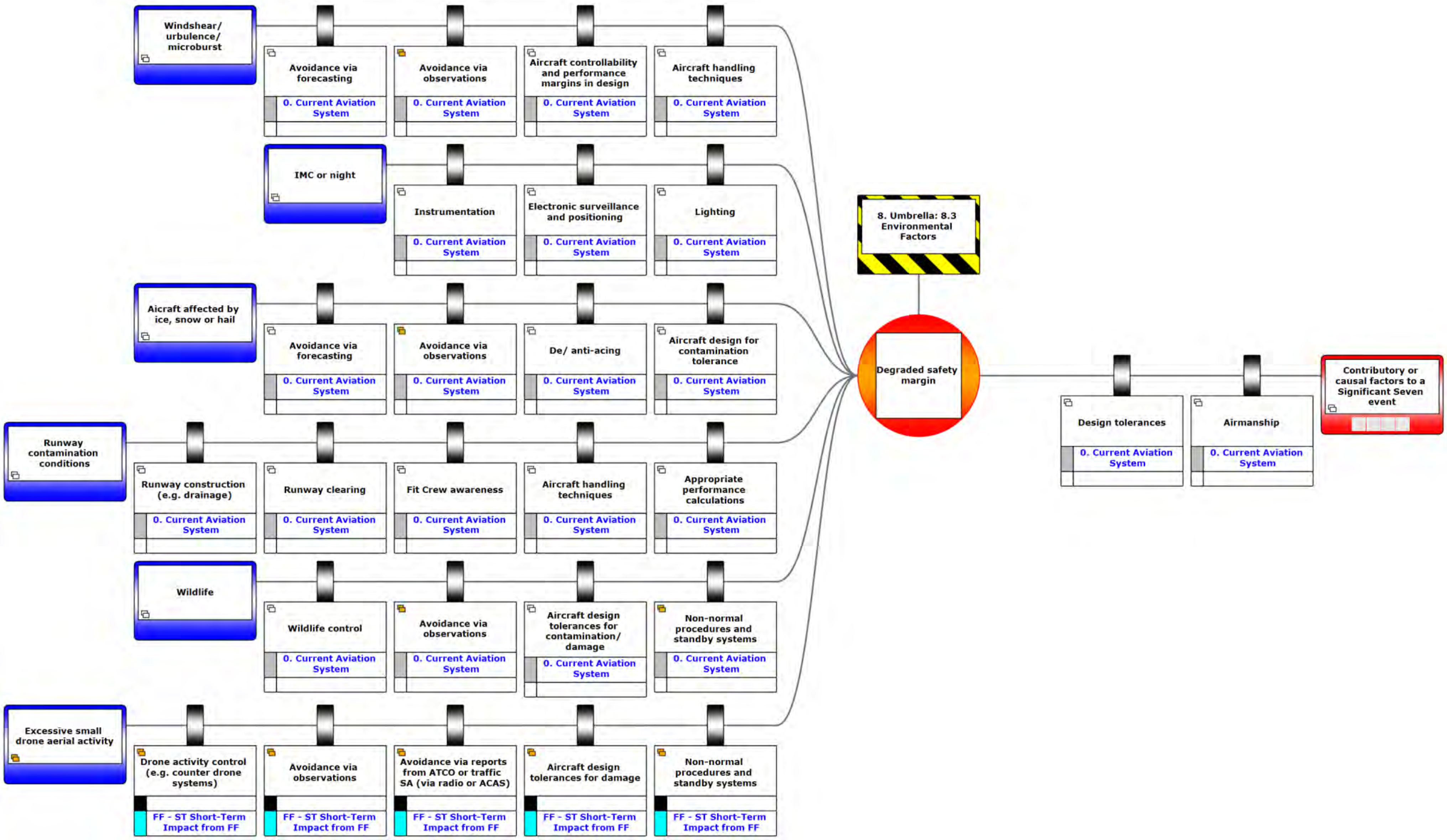
B.1.4 Hazard 5.1 – Airborne Conflict – Large CAT fixed wing aircraft operations whilst airborne UK Class A airspace



B.1.5 Hazard 5.2 – Airborne Conflict – Large CAT fixed wing aircraft operations whilst airborne UK Class G airspace

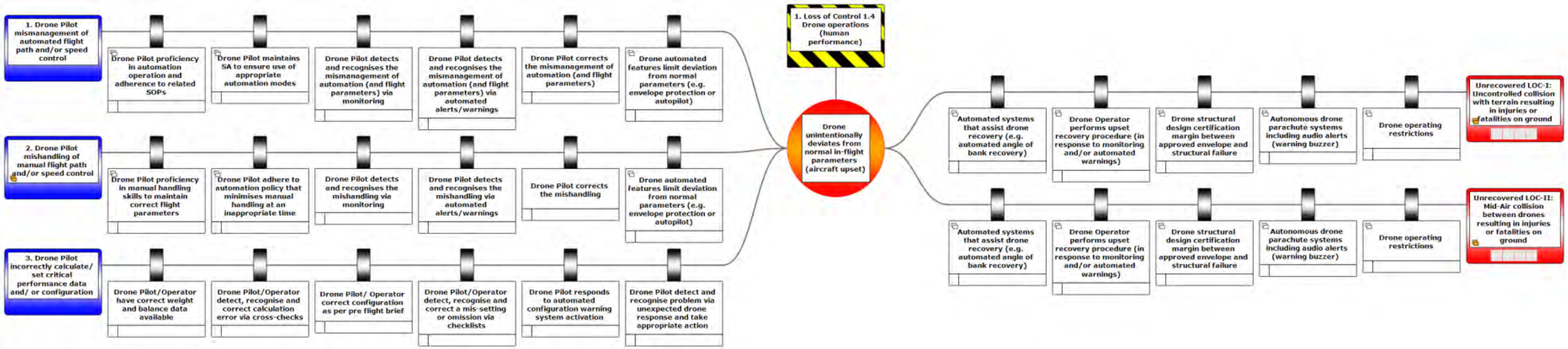


B.1.6 Hazard 8.3 – Environmental Factors

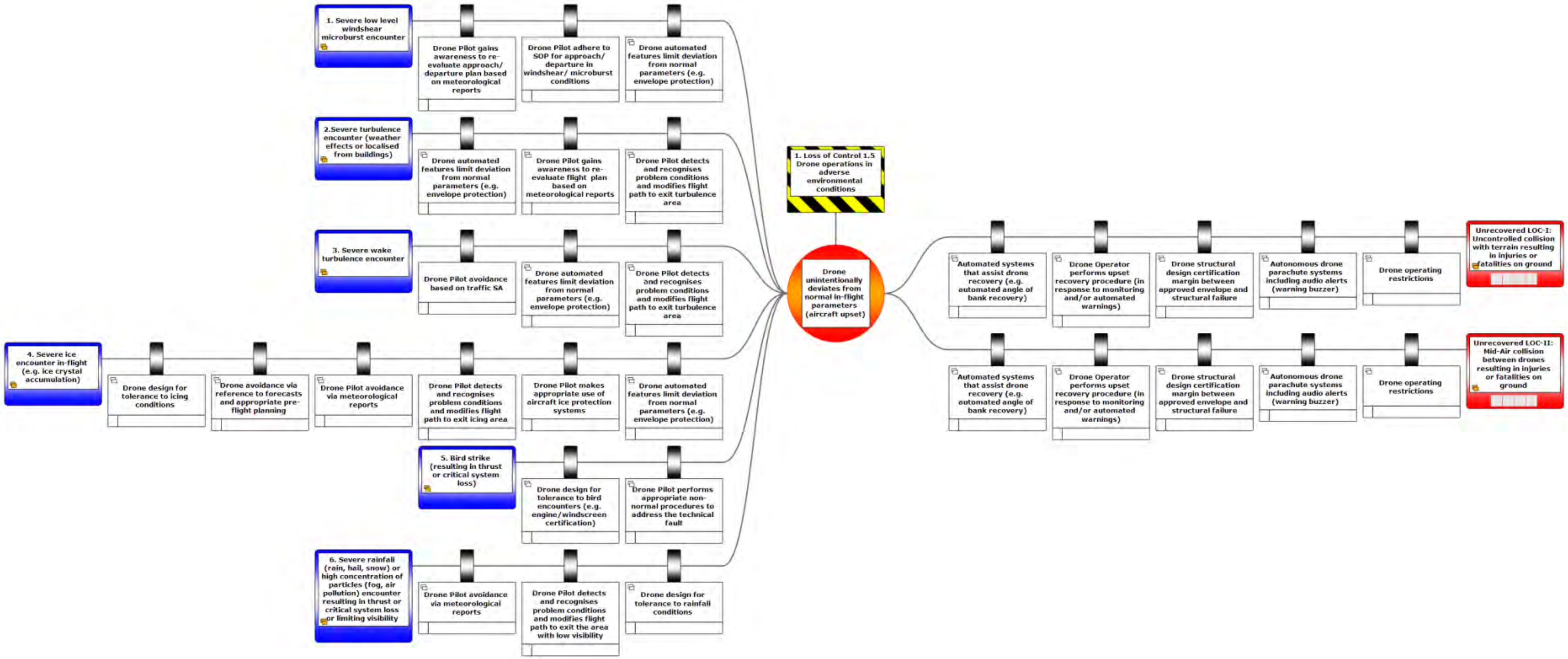


B.2 New Hazards related to operations in the Short- and Medium-Term

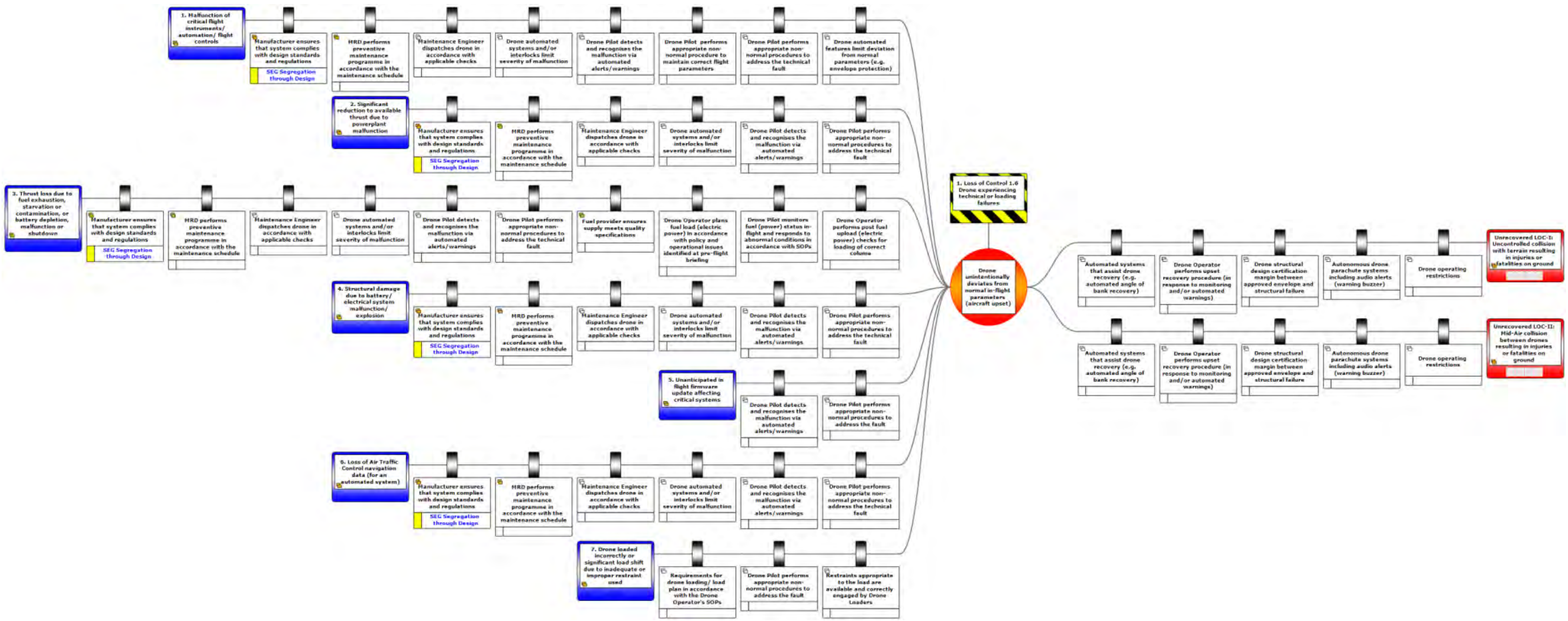
B.2.1 Hazard 1.4 – Loss of Control – Drone Operations (Human Performance)



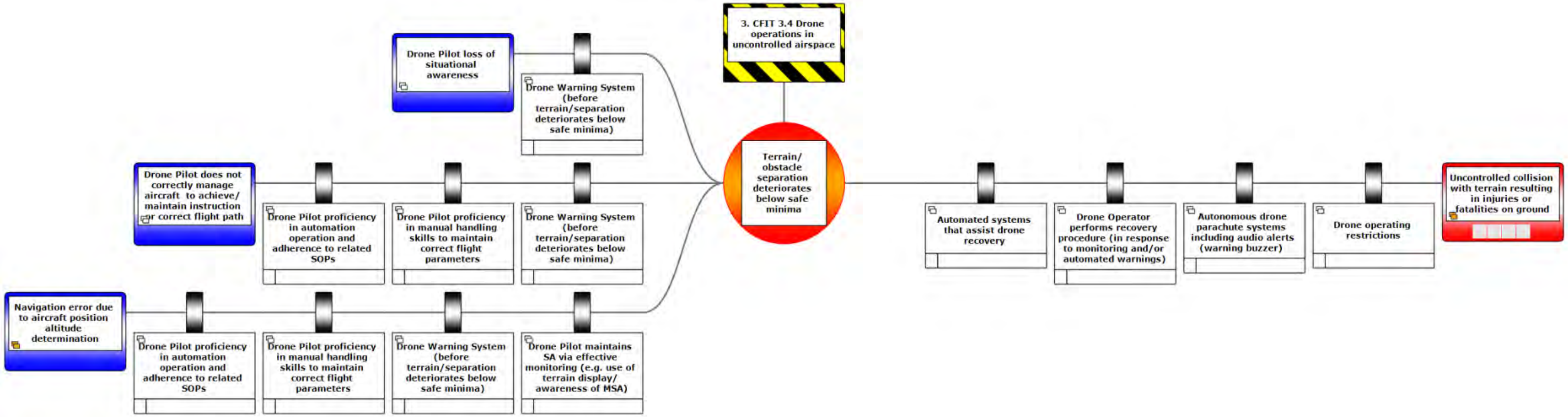
B.2.2 Hazard 1.5 – Loss of Control – Drone Operations (Adverse Environmental Conditions)



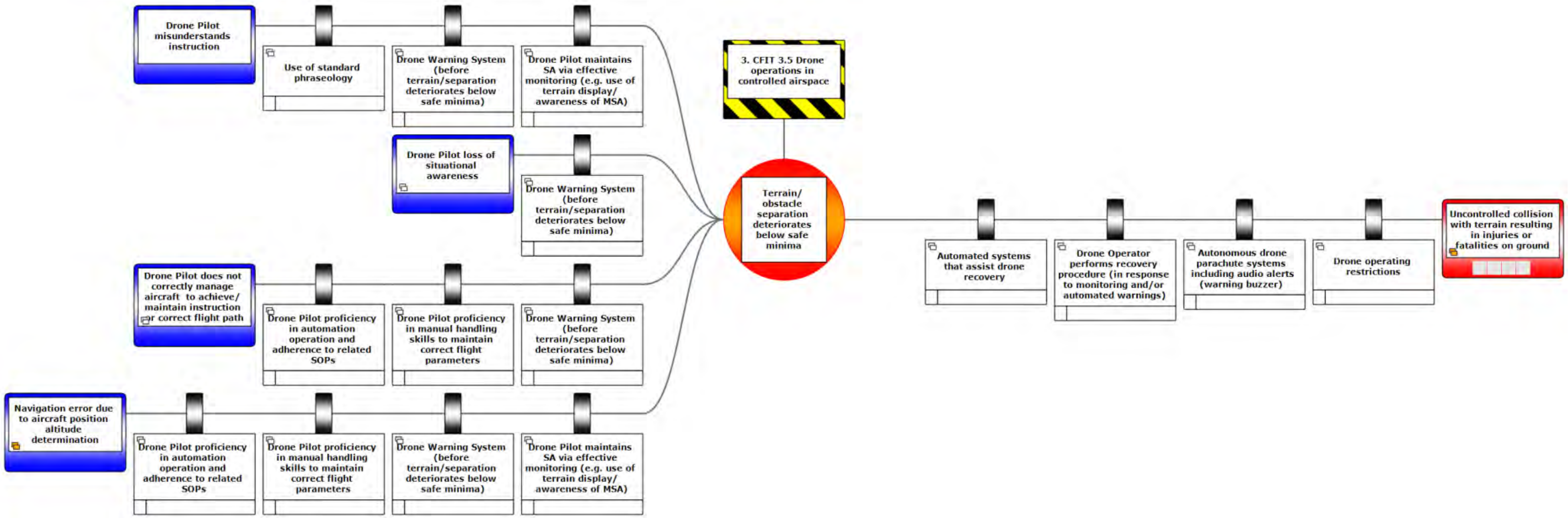
B.2.3 Hazard 1.6 – Loss of Control – Drone experiencing technical or loading failures



B.2.4 Hazard 3.4 – CFIT – Drone operations in uncontrolled airspace

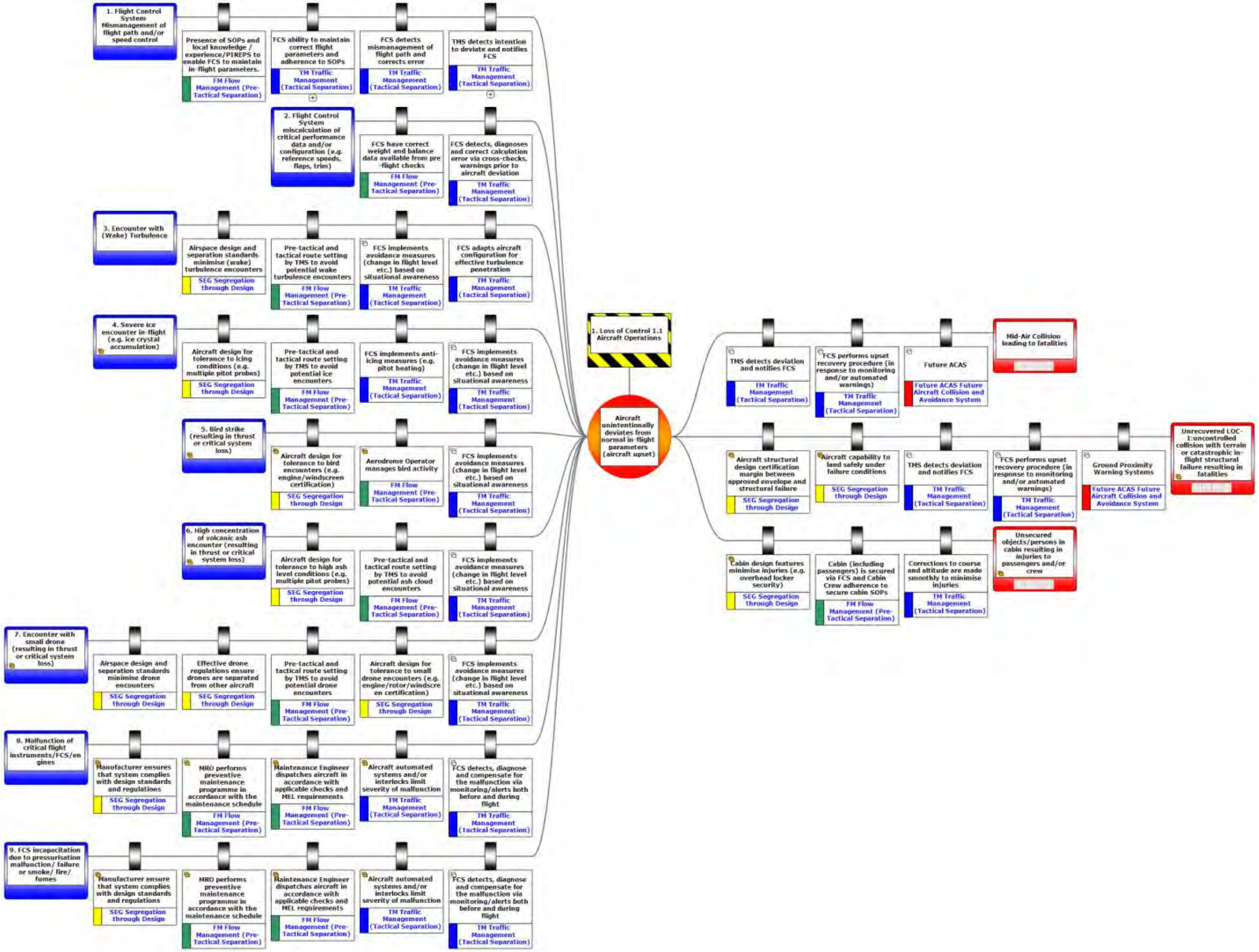


B.2.5 Hazard 3.5 – CFIT – Drone operations in controlled airspace



B.3 New Hazards related to operations in the Medium- and Long-Term

B.3.1 Hazard 1.1 – Loss of Control – Aircraft Operations (Aircraft Upset)



Threats and Control Analysis

THREAT: 1. Flight Control System Mismanagement of flight path and/or speed control			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Presence of SOPs and local knowledge/PIREPS to enable FCS to maintain in-flight parameters	Traffic Density	Reduction in effectiveness due to higher traffic densities impacting SOP effectiveness	SOPs will need to account for increases in traffic density (become more flexible) and the FCS will need to accommodate a larger volume of PIREPs
	Pilot Autonomy	Increase in effectiveness due to better performance of autonomous system vs human pilot at rule-based adherence to procedures	Autonomy must be able to adapt and learn from experience and to process information from PIREPs and other information sources
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS ability to maintain correct flight parameters and adherence to SOPs	Traffic Density	Reduction in effectiveness due to increased demands on FCS due to increased traffic densities	FCS will need to process larger volumes of SA related information to maintain flight parameters and adherence to SOPs
	Pilot Autonomy	Increase in effectiveness due to better performance of autonomous system vs human pilot	Performance requirement on operation of autonomous system
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Increase in effectiveness due to more accurate CNS performance	Accuracy and coverage of CNS infrastructure to within Xm across all operating environments
	Aircraft Performance	Increase in effectiveness due to expected improved aircraft response and controllability	Requirement on aircraft response to control inputs and manoeuvrability of aircraft especially when operating in dense/urban environments
	Operating Environment	Reduction in effectiveness due to greater demands on FCS to maintain flight path within tighter constraints due to urban environment	FCS must be able to maintain flight parameters when operating in a dense, obstacle-rich urban environment

THREAT: 1. Flight Control System Mismanagement of flight path and/or speed control			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS detects mismanagement of flight path and correct error	Traffic Density	Reduction in effectiveness due to increased traffic densities increasing FCS workload	FCS performance must be able to account for increased traffic density resulting in higher workload
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error if system is able to detect errors – see design requirement	Diverse functions within FCS to be able to self-identify errors and correct
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	Reduction in effectiveness due to complex nature of environment impacting FCS ability to detect mismanagement	FCS performance must be able to demonstrate self-checking performance under high workload situations.
TMS detects intention to deviate and notifies FCS	Traffic Density	Reduction in effectiveness due to higher traffic densities leading to higher demands on TMS	TMS must be able to maintain performance levels against a backdrop of high traffic densities and complex operating environments
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	TMS/FCS functions must be implemented that allow the TMS to understand FCS intention before execution, similar to pilot readback
	Aircraft Mix	No impact	
	ATM Autonomy	Improved control effectiveness due to autonomous nature of TMS and reduction in human error	TMS/FCS functions must be implemented that allow the TMS to understand FCS intention before execution, similar to pilot readback
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	No impact	TMS must be able to maintain performance levels against a backdrop of high traffic densities and complex operating environments
THREAT SUMMARY: Overall the threat frequency is expected to be reduced due to improved control effectiveness due principally to introduction of autonomous capabilities in flight control and traffic management.			

THREAT: 2. Flight Control System miscalculation of critical performance data and/or configuration (e.g. reference speeds, flaps, trim etc.)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS has correct weight and balance data available from pre-flight checks	Traffic Density	Reduction in effectiveness due to increased traffic densities increasing FCS workload	FCS performance must be able to account for increased traffic density resulting in higher workload
	Pilot Autonomy	Increase in control effectiveness due to autonomous nature of FCS and reduction in human error	Automated weight and aircraft balance measurement capability to be implemented
	Aircraft Mix	Decrease in control effectiveness due to wide variation in aircraft types and configuration types leading to greater potential for errors	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS detects, diagnoses and corrects calculation error via cross-checks, warnings prior to aircraft deviation	Pilot Autonomy	Increase in effectiveness due to autonomous nature of FCS and reduction in human error	Diverse functions within FCS to be able to self-identify errors and correct
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	Reduction in control effectiveness as it is expected that smaller aircraft will be more sensitive to weight and balance misalignments in terms of flight performance	
	Operating Environment	Reduction in effectiveness due to complex nature of environment impacting FCS ability to detect issues	FCS must be able to demonstrate it can maintain integrity of performance under high workload situations
THREAT SUMMARY: No change in threat frequency has improvements in control effectiveness from introduction of autonomous capabilities are balanced out by greater sensitivity of smaller aircraft (e.g. drones/UAM) to misalignments in balance and weight distribution.			

THREAT: 3. Encounter with (Wake Turbulence)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Airspace design and separation standards minimise wake turbulence encounters	Traffic Density	Neutral impact as airspace design for low altitude environments should exclude larger aircraft even though there is a greater density of aircraft in the airspace	Airspace design and separation standards should account for wake turbulence e.g. separate smaller aircraft from larger ones in urban environments
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	Reduction in effectiveness due to wider variety of operating environments (e.g. urban, rural, low/high altitude) all under formal airspace classification	Airspace design should account for turbulence (including wind shear effects from tall buildings) in setting airspace structures and routes for different aircraft types, e.g. separate smaller aircraft from larger ones in urban environments
Pre-tactical and tactical route setting by TMS to avoid wake turbulence encounters	Traffic Density	Reduced control effectiveness due to impact of higher traffic densities resulting in flow conflicts that the TMS cannot adequately resolve	TMS must have algorithms to manage flow using aircraft type/weight/ prevailing weather conditions to minimise wake related and other turbulence issues
	Pilot Autonomy	Less effective with human control but more effective with autonomous control, aircraft performance (e.g. manoeuvrability may help this)	The future ACAS should also be able to help detect potential (wake) turbulence issues and notify the FCS with a potential resolution
	Aircraft Mix	Reduced effectiveness as smaller aircraft less able to penetrate turbulence	New aircraft designs should consider what potential turbulence protection measures they can employ
	ATM Autonomy	Improved control effectiveness due to enhanced TMS capability to manage flow using wake turbulence and building turbulence algorithms	TMS must have algorithms to manage flow using aircraft type/weight/ prevailing weather conditions to minimise wake related and other turbulence issues.
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments

THREAT: 3. Encounter with (Wake Turbulence)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS implements avoidance measures (change in flight level etc.) based on situational awareness	Traffic Density	More dense traffic will reduce the effectiveness of this control due to the greater likelihood of infringing another aircraft	FCS will need to perform and account for high density environments
	Pilot Autonomy	Increase in effectiveness due to autonomous nature of FCS and reduction in human error	FCS will need to be able to receive and process a wide variety of SA related information in a timely manner to enable effective avoidance measures to be taken
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	Increase in effectiveness due to improved aircraft response to control inputs (i.e. greater manoeuvrability)	Aircraft requirements should include response to control inputs, important in densely populated and urban environments
	Operating Environment	Reduction in effectiveness due to more congested nature of environment and proximity of obstacles (e.g. buildings)	
FCS adapts aircraft configuration for effective turbulence penetration	Traffic Density	No impact	
	Pilot Autonomy	Increase in effectiveness due to autonomous nature of FCS and reduction in human error	
	Aircraft Mix	Reduction in effectiveness as smaller aircraft are less likely to be configurable for turbulence penetration	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
THREAT SUMMARY: Overall, the threat frequency is increased due to higher prevalence of aircraft suffering from and being susceptible to turbulence conditions caused by other aircraft and proximity of structures, e.g. wind shear effect / crosswinds.			

THREAT: 4. Severe ice encounter in-flight (e.g. ice crystal accumulation)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Aircraft design for tolerance to icing conditions (e.g. ice crystal accumulation)	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	Reduction in effectiveness due to more limited opportunity to incorporate icing tolerance into small aircraft designs	New aircraft designs should employ anti-icing systems and design the control surfaces to be less prone to icing
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	Aircraft design should allow for a certain degree of icing to occur before aircraft performance is affected
	Operating Environment	No impact	
Pre-tactical and tactical route setting by TMS to avoid potential ice encounters	Traffic Density	Reduced control effectiveness due to impact of higher traffic densities resulting in flow conflicts that the TMS cannot adequately resolve.	TMS must have algorithms to manage flow using aircraft type/weight/ prevailing weather conditions to minimise icing related issues
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	Improved control effectiveness due to enhanced TMS capability to manage flow in response to external factors (e.g. weather patterns, ice conditions)	TMS must have algorithms to manage flow using aircraft type/weight/ prevailing weather conditions to minimise icing related issues
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	Increase in effectiveness as it is assumed that more aircraft will be operating at lower altitudes where ice formation is less likely	

THREAT: 4. Severe ice encounter in-flight (e.g. ice crystal accumulation)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS implements anti-icing measures (e.g. pitot heating)	Traffic Density	No impact	
	Pilot Autonomy	Increase in effectiveness due to autonomous nature of FCS and reduction in human error	
	Aircraft Mix	Reduction in effectiveness as smaller aircraft are less likely to feature anti-icing technology	New aircraft designs should employ anti-icing systems and design the control surfaces to be less prone to icing
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	Aircraft design should allow for a certain degree of icing to occur before aircraft performance is affected
	Operating Environment	No impact	
FCS implements avoidance measures based on SA	See equivalent control for Threat 3		
THREAT SUMMARY: Overall, it is expected that the frequency of this threat will reduce given the more favourable operating environment (lower altitudes) from an ice formation perspective. It is noted that aircraft are less likely to be equipped with anti-icing technology however and therefore any icing incidents may result in more significant consequences.			

THREAT: 5. Bird strike (resulting in thrust or critical system loss)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Aircraft design for tolerance to bird encounters (e.g. engine / rotor / windscreen certification)	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	Reduction in effectiveness due to more limited opportunity to incorporate bird strike tolerance into small aircraft designs	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	Aircraft design should allow for a certain degree of bird strike to occur before aircraft performance is affected
	Operating Environment	No impact	
Aerodrome Operator manages bird activity	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments including detection of bird activity
	Aircraft Performance	No impact	
	Operating Environment	Reduction in effectiveness due to increased prevalence of birds in urban locations where new aerodromes are located	
FCS implements avoidance measures based on SA	See equivalent control for Threat 3		

THREAT SUMMARY: Overall, it is expected that the frequency of this threat will increase given both the greater likelihood of experiencing bird strikes from operating in urban environments and the increased effects of damage from bird strike incidents on smaller aircraft.

THREAT: 6. High concentration of volcanic ash encounter (resulting in thrust or critical system loss)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Aircraft design for tolerance to high ash conditions (e.g. multiple pitot probes)	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	Reduction in effectiveness due to more limited opportunity to incorporate ash cloud tolerance into small aircraft designs	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
Pre-tactical and tactical route setting by TMS to avoid potential ash cloud encounters	Traffic Density	Reduced control effectiveness due to impact of higher traffic densities resulting in flow conflicts that the TMS cannot adequately resolve	TMS must have algorithms to manage flow using aircraft type/weight/ prevailing weather conditions to minimise ash cloud encounters
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	Improved control effectiveness due to enhanced TMS capability to manage flow in response to external factors (e.g. weather patterns, ash cloud conditions)	TMS must have algorithms to manage flow using aircraft type/weight/ prevailing weather conditions to minimise icing related issues
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	Increased control effectiveness due to lower likelihood of encountering ash clouds in urban environments / low altitudes	
FCS implements avoidance measures based on SA	See equivalent control for Threat 3		
THREAT SUMMARY: Overall, it is expected that the frequency of this threat will decrease given the reduced likelihood of experiencing ash cloud encounters from operating in urban environments and the improvements in effectiveness of avoidance measures from autonomous control.			

THREAT: 7. Encounter with small drone (resulting in thrust or critical system loss)

Control	FF Characteristic	Impact (Control Effectiveness)	Requirement
Airspace design and separation standards minimise drone encounters	Traffic Density	Neutral impact as airspace design for low altitude environments should exclude larger aircraft even though there is a greater density of aircraft in the airspace	Airspace design should account for drone encounters in setting airspace structures and routes for different aircraft types, e.g. separate smaller aircraft from larger ones in urban environments
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	Reduction in effectiveness due to wider variety of operating environments (e.g. urban, rural, low/high altitude) all under formal airspace classification	Airspace design should account for drone encounters in setting airspace structures and routes for different aircraft types, e.g. separate smaller aircraft from larger ones in urban environments
Effective drone regulation ensure drones are separated from other aircraft	Traffic Density	Reduction in control effectiveness given expected increases in traffic density are principally based on higher volumes of drones	Drone regulations must account for expected increases in traffic density especially in urban areas
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
Pre-tactical and tactical route setting by TMS to avoid potential drone encounters	Traffic Density	Reduced control effectiveness due to impact of higher traffic densities resulting in flow conflicts that the TMS cannot adequately resolve	TMS must have algorithms to manage flow using aircraft type/weight/ prevailing weather conditions to minimise ash cloud encounters
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	Improved control effectiveness due to enhanced TMS capability to manage flow in response to external factors (e.g. weather patterns, ash cloud conditions)	TMS must have algorithms to manage flow using aircraft type/weight/ prevailing weather conditions to minimise icing related issues

THREAT: 7. Encounter with small drone (resulting in thrust or critical system loss)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	Increased control effectiveness due to lower likelihood of encountering ash clouds in urban environments / low altitudes	
Aircraft design for tolerance to small drone encounters (e.g. engine / windscreen certification)	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	Reduction in effectiveness due to more limited opportunity to incorporate drone tolerance into small aircraft designs	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	Reduction in effectiveness as it is assumed that more aircraft will be operating in locations where drones are more likely and volume of drones will also increase	
FCS implements avoidance measures based on SA	See equivalent control for Threat 3		
THREAT SUMMARY: Overall, it is expected that the frequency of this threat will increase given the increased likelihood of experiencing drone encounters from operating in urban environments and the increase in volume of drones. The increase should be tempered by the ability of the TMS to pre-tactically separate aircraft and the FCS to take avoiding action due to autonomous control capabilities.			

THREAT: 8. Malfunction of critical flight instruments/FCS/engines			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Manufacturer ensures that system complies with design standards and regulations	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
MRO performs preventive maintenance programme in accordance with the maintenance schedule	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to capacity to perform "Over The Air" updates to aircraft in operation	Implementation of OTA capability in aircraft systems for emergency or other urgent updates
	Aircraft Performance	No impact	
	Operating Environment	No impact	
Maintenance Engineer dispatches aircraft in accordance with applicable checks and MEL requirements	Traffic Density	No impact	
	Pilot Autonomy	No impact	Consider incorporation of automatic checks on equipment operability to identify cases where aircraft does not MEL requirements
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
Aircraft automated systems and/or interlocks limit severity of malfunction	Traffic Density	No impact	
	Pilot Autonomy	Increase in effectiveness due to autonomous nature of FCS and reduction in human error in dealing with abnormal situations	Autonomy must demonstrate it can operate under failure conditions within the FCS system itself or when other aircraft systems have failed
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	

THREAT: 8. Malfunction of critical flight instruments/FCS/engines			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
	Aircraft Performance	Increase in effectiveness due to increased redundancy in critical items, e.g. ducted fan design vs 1 or 2 conventional propulsion units	Aircraft design must conform to existing requirements namely no single point of failure, provision of diversity and redundancy around critical systems/functions
	Operating Environment	No impact	
FCS detects, diagnoses and compensates for the malfunction via monitoring/alerts both before and during flight	Traffic Density	No impact	
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error if system is able to detect errors – see design requirement	Diverse functions within FCS to be able to self-identify errors and correct
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
THREAT SUMMARY: Overall, it is expected that the frequency of this threat will reduce due to enhanced reliability of aircraft from increasing levels of automation in terms of response to failures, improvements in maintenance capabilities through OTA updates and designs that include enhanced levels of redundancy and reduced complexity.			

THREAT: 9. FCS incapacitation due to pressurisation malfunction/failure or smoke/fire fumes			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Manufacturer ensures that system complies with design standards and regulations	See analysis from equivalent control for Threat 8		
MRO performs preventive maintenance programme in accordance with the maintenance schedule	See analysis from equivalent control for Threat 8		
Maintenance Engineer dispatches aircraft in accordance with applicable checks and MEL requirements	See analysis from equivalent control for Threat 8		
Aircraft automated systems and/or interlocks limit severity of malfunction	See analysis from equivalent control for Threat 8		
FCS detects, diagnoses and compensates for the malfunction via monitoring/alerts both before and during flight	See analysis from equivalent control for Threat 8		
THREAT SUMMARY: Overall, it is expected that the frequency of this threat will reduce due to enhanced reliability of aircraft from increasing levels of automation in terms of response to failures, improvements in maintenance capabilities through OTA updates and the reduced susceptibility of autonomous control systems to incapacitation issues.			

Mitigation Analysis

MITIGATION THREAD Leading to Mid-Air Collision			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMS detects deviation and notifies FCS	Traffic Density	Reduction in effectiveness expected due to higher traffic densities making it more challenging to detect individual deviations	TMS must be specified to accommodate significant traffic densities with suitable margin above the maximum expected values
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	Improved control effectiveness due to autonomous nature of TMS and reduction in human error	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS performs upset recovery procedure (in response to monitoring and/ or automated warnings)	Traffic Density	More dense traffic will reduce the effectiveness of this control due to the greater likelihood of infringing another aircraft	
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	Improved control effectiveness due to greater manoeuvrability of aircraft in response to control inputs	
	Operating Environment	Reduced control effectiveness due to congested nature of environment and presence of obstacles (e.g. buildings etc.)	

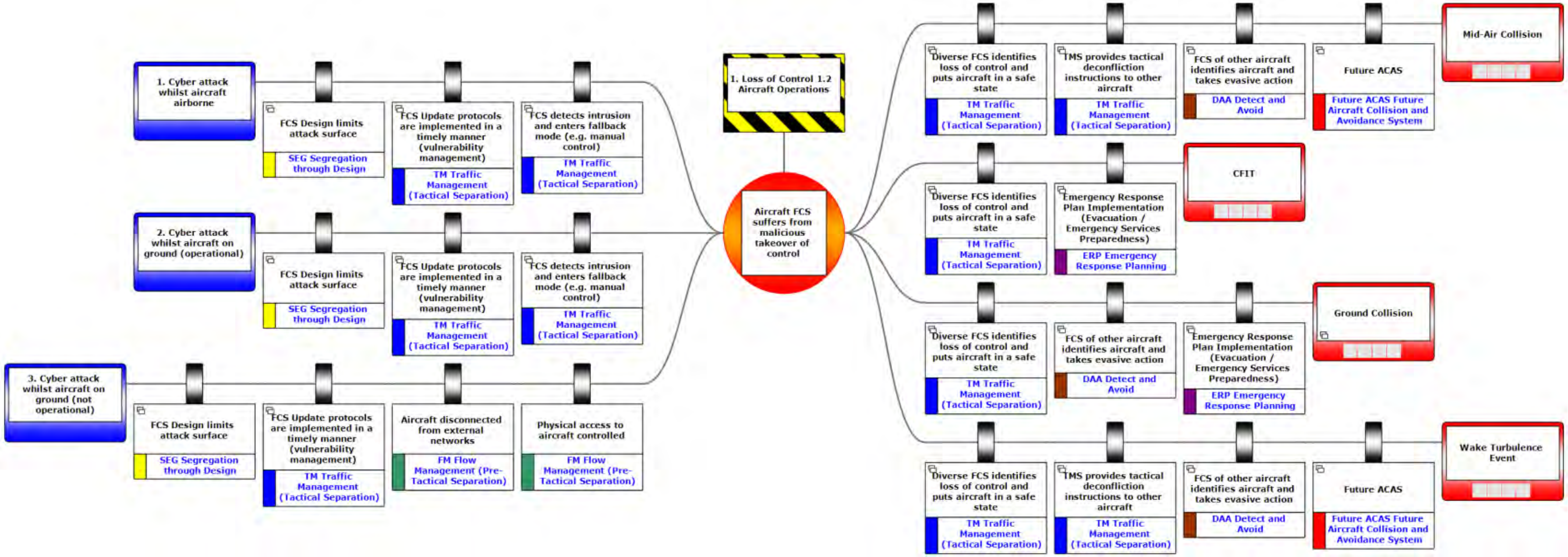
MITIGATION THREAD Leading to Mid-Air Collision			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Future ACAS	Traffic Density	Reduced control effectiveness due to higher traffic densities resulting in fewer possible avoidance strategies	Requirement for ACAS to be capable of responding to multiple simultaneous conflicts and providing appropriate resolution advisories
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error.	
	Aircraft Mix	Reduced control effectiveness as not all aircraft may be equipped with ACAS or appropriate electronic conspicuity	Requirement for aircraft to be equipped with ACAS if operating in certain airspace volumes
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness if ACAS is linked to improved CNS infrastructure either for communications or surveillance purposes	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	Improved control effectiveness as aircraft may be more manoeuvrable and responsive to control inputs	
	Operating Environment	Reduced control effectiveness due to congested nature of environment and presence of obstacles, e.g. buildings	

MITIGATION THREAD Leading to Uncontrolled Collision with Terrain			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Aircraft structural design certification margin between approved envelope and structural failure	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	Increased control effectiveness due to use of advanced materials in aircraft design leading to improved structural performance	
	Operating Environment	No impact	
Aircraft capability to land safely under failure conditions	Traffic Density	Higher traffic densities will make this control more challenging due to the need to avoid other aircraft in landing safely	
	Pilot Autonomy	Autonomy is expected to improve the effectiveness of this control due to the reduction in human error	Autonomy must be designed to control aircraft under failure conditions with loss of a single or multiple systems
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	Increased control effectiveness due to use of advanced materials in aircraft design leading to improved structural performance	Aircraft design must take account of systems failure and still permit a level of controllability to enable aircraft to land safely
	Operating Environment	Reduced control effectiveness due to urban nature of environment and higher densities of obstacles etc	
TMS detects deviation and notifies FCS	See equivalent control in MAC consequence		
FCS performs upset recovery procedure (in response to monitoring and/or automated warnings)	See equivalent control in MAC consequence		

MITIGATION THREAD Leading to Uncontrolled Collision with Terrain			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Ground Proximity Warning Systems	Traffic Density	No impact	
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	
	Aircraft Mix	Reduced control effectiveness as not all aircraft may be equipped with GPWS	Requirement for aircraft to be equipped with GPWS if operating in certain airspace volumes
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness if GPWS is linked to improved CNS infrastructure either for communications or surveillance purposes	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	Improved control effectiveness as aircraft may be more manoeuvrable and responsive to control inputs	
	Operating Environment	Reduced control effectiveness due to congested nature of environment and presence of obstacles, e.g. buildings	

MITIGATION THREAD Leading to Unsecured objects/persons in cabin			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Cabin design features minimise injuries (e.g. overhead locker security)	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
Cabin (including passengers) is secured via FCS and Cabin Crew adherence to secure cabin SOPs	Traffic Density	No impact	
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
Corrections in course and altitude are made smoothly to minimise injuries	Traffic Density	More dense traffic will reduce the effectiveness of this control due to the greater likelihood of infringing another aircraft	
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	Improved control effectiveness due to greater manoeuvrability of aircraft in response to control inputs	
	Operating Environment	Reduced control effectiveness due to congested nature of environment and presence of obstacles (e.g. buildings etc.)	

B.3.2 Hazard 1.2 – Loss of Control – Aircraft Operations (Aircraft FCS Malicious Takeover)



Threats and Control Analysis

THREAT: 1. Cyber attack whilst aircraft airborne			
Control	**FF Characteristic**	**Impact (Threat Likelihood or Control Effectiveness)**	**Requirement**
FCS design limited attack surface	Traffic Density	No impact	
	Pilot Autonomy	Increase in likelihood due to greater role of autonomous technology	Requirements on cyber resilience for autonomous systems
	Aircraft Mix	No impact	
	ATM Autonomy	Increase in likelihood due to greater role of autonomous technology	Requirements on cyber resilience for autonomous systems
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS Update protocols are implemented in a timely manner (vulnerability management)	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS detects intrusion and enters fallback mode (e.g. manual control)	Traffic Density	No impact	
	Pilot Autonomy	Reduction in likelihood due to challenges of making effective fallback modes in highly autonomous systems	Requirements on credible fallback modes in autonomous systems
	Aircraft Mix	No impact	
	ATM Autonomy	Reduction in likelihood due to challenges of making effective fallback modes in highly autonomous systems	Requirements on credible fallback modes in autonomous systems
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	

THREAT: 2. Cyber attack whilst aircraft on ground (operational)			
Control	**FF Characteristic**	**Impact (Threat Likelihood or Control Effectiveness)**	**Requirement**
FCS design limited attack surface	See equivalent control in Threat 1		
FCS Update protocols are implemented in a timely manner (vulnerability management)	See equivalent control in Threat 1		
FCS detects intrusion and enters fallback mode (e.g. manual control)	See equivalent control in Threat 1		

THREAT: 3. Cyber attack whilst aircraft on ground (not operational)			
Control	**FF Characteristic**	**Impact (Threat Likelihood or Control Effectiveness)**	**Requirement**
FCS design limited attack surface	See equivalent control in Threat 1		
FCS Update protocols are implemented in a timely manner (vulnerability management)	See equivalent control in Threat 1		
Aircraft disconnected from external networks	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Disconnection from network may be harder to assure (e.g. systems normally remain online for software online updates/backups)	Requirements on network access controls for non-operational systems and to prevent background software updates
	Aircraft Performance	No impact	
	Operating Environment	No impact	
	Other	No impact	
Physical access to aircraft controlled	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
	Other	No impact	

Mitigation Analysis

MITIGATION THREAD Leading to Mid-Air Collision			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Diverse FCS identifies loss of control and puts aircraft in a safe state	Traffic Density	More dense traffic will reduce the effectiveness of this control due to the greater likelihood of infringing another aircraft	
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	Improved control effectiveness due to greater manoeuvrability of aircraft in response to control inputs	
	Operating Environment	Reduced control effectiveness due to congested nature of environment and presence of obstacles (e.g. buildings etc.)	
TMS provides tactical deconfliction instructions to other aircraft	Traffic Density	More dense traffic will reduce the effectiveness of this control due to the greater likelihood of infringing another aircraft	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	
	CNS Technology	No impact	
	Aircraft Performance	Improved control effectiveness due to greater manoeuvrability of aircraft in response to control inputs	
	Operating Environment	Reduced control effectiveness due to congested nature of environment and presence of obstacles (e.g. buildings etc.)	

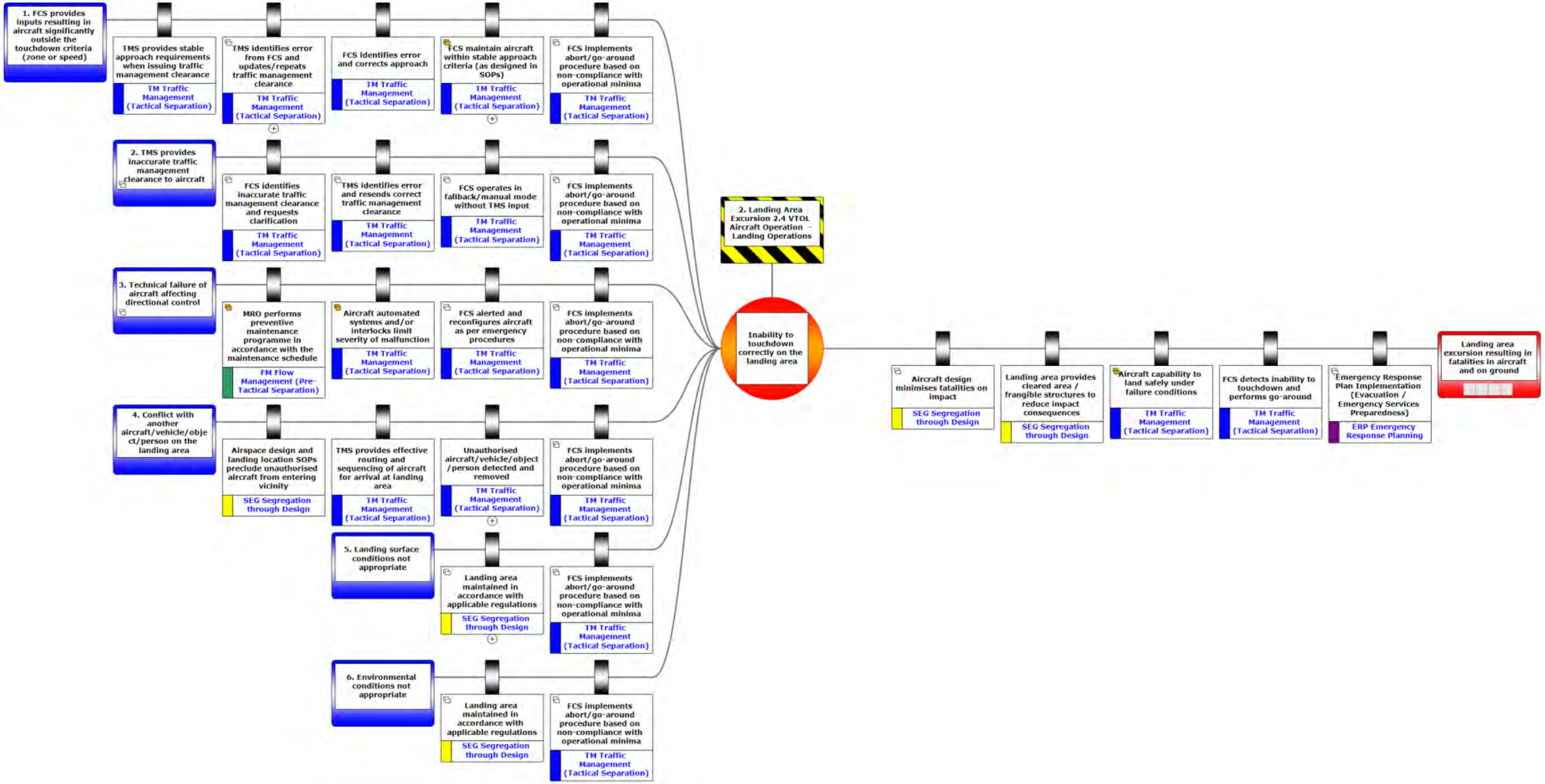
MITIGATION THREAD Leading to Mid-Air Collision			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS of other aircraft identifies aircraft and takes evasive action	Traffic Density	Reduced control effectiveness due to higher traffic densities resulting in fewer possible avoidance strategies	
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness if CNS technology is able to provide more precise location for conflicting aircraft	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	Improved control effectiveness as aircraft may be more manoeuvrable and responsive to control inputs	
	Operating Environment	Reduced control effectiveness due to congested nature of environment and presence of obstacles, e.g. buildings	
Future ACAS	Traffic Density	Reduced control effectiveness due to higher traffic densities resulting in fewer possible avoidance strategies	Requirement for ACAS to be capable of responding to multiple simultaneous conflicts and providing appropriate resolution advisories
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	
	Aircraft Mix	Reduced control effectiveness as not all aircraft may be equipped with ACAS or appropriate electronic conspicuity	Requirement for aircraft to be equipped with ACAS if operating in certain airspace volumes
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness if ACAS is linked to improved CNS infrastructure either for communications or surveillance purposes	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	Improved control effectiveness as aircraft may be more manoeuvrable and responsive to control inputs	
	Operating Environment	Reduced control effectiveness due to congested nature of environment and presence of obstacles, e.g. buildings	

MITIGATION THREAD Leading to Controlled Flight into Terrain			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Diverse FCS identifies loss of control and puts aircraft in a safe state	See equivalent control in MAC consequence		
Emergency Response Plan Implementation (Evacuation / Emergency Services Preparedness)	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness as emergency services should be able to track precise location of aircraft through improved CNS infrastructure	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	Reduced control effectiveness due to congested nature of environment, potentially densely populated area and presence of obstacles, e.g. buildings	Emergency response plans must account for operations in urban environments, and evacuation of large numbers of people from nearby buildings

MITIGATION THREAD Leading to Ground Collision			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Diverse FCS identifies loss of control and puts aircraft in a safe state	See equivalent control from MAC consequence		
FCS of other aircraft identifies aircraft and takes evasive action	See equivalent control from MAC consequence		
Emergency Response Plan Implementation (Evacuation / Emergency Services Preparedness)	See equivalent control from MAC consequence		

MITIGATION THREAD Leading to Wake Turbulence Event			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Diverse FCS identifies loss of control and puts aircraft in a safe state	See equivalent control from MAC consequence		
TMS provides tactical deconfliction instructions to other aircraft	See equivalent control from MAC consequence		
FCS of other aircraft identifies aircraft and takes evasive action	See equivalent control from MAC consequence		
Future ACAS	See equivalent control from MAC consequence		

B.3.3 Hazard 2.4 – Landing Area Excursion – VTOL Aircraft Operations – Landing Operations



Threats and Control Analysis

THREAT 1: FCS provides inputs resulting in aircraft significantly outside the touchdown criteria (zone or speed)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMS provides stable approach requirements when issuing traffic management clearance	Traffic Density	Traffic density will increase which may reduce the effectiveness of this control due to greater demands on the TMS	The TMS must be designed to accommodate greater traffic densities in providing the same level of integrity for this function
	Pilot Autonomy	No impact	TMS must be designed to accommodate differing levels of pilot autonomy in the provision of robust clearances
	Aircraft Mix	A greater range of aircraft types operating within the airspace with differing approach requirements may reduce the effectiveness of this control	TMS must be designed to accommodate different aircraft types in the provision of robust clearances
	ATM Autonomy	ATM autonomy should result in improved effectiveness due to the corresponding reduction in human error from operation of an autonomous system	
	CNS Technology	Improved CNS technology will lead to a reduction in the separation required between aircraft	TMS design must take account of improvements in CNS technology and the ability to provide more refined clearances
	Aircraft Performance	No impact	
	Operating Environment	Increased number of vertiports and drone take-off and landing sites will increase the complexity of route structures and airspace and may impact control effectiveness	TMS must be able to accommodate the approach routes and associated requirements for many more vertiports and takeoff/landing sites
TMS identifies error from FCS and updates/repeats traffic management clearance	Traffic Density	Increased traffic density will require this control to have higher integrity to achieve the same effectiveness	TMS must ensure detection and resolution in higher traffic density
	Pilot Autonomy	No impact	
	Aircraft Mix	Increased traffic mix will require this control to consider a greater range of scenarios to achieve the same effectiveness	TMS must ensure detection with a greater traffic mix
	ATM Autonomy	Improved control effectiveness due to autonomous nature of TMS and reduction in human error	ATM Autonomy must have the ability to detect, recognise and correct the potential conflict via monitoring
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments

THREAT 1: FCS provides inputs resulting in aircraft significantly outside the touchdown criteria (zone or speed)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS identifies error and corrects approach	Traffic Density	FCS situational awareness will be degraded as traffic density increases resulting in a reduction in control effectiveness	FCS must have situational awareness maintained as traffic increases to be able to identify error and correct approach
	Pilot Autonomy	Improved control effectiveness due to autonomous pilot ability to compare aircraft position with own situational awareness	Pilot Autonomy must have the ability to identify errors in aircraft position and correct based upon its own situational awareness
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage for FCS situational awareness	Accuracy and coverage of CNS infrastructure for pilot situational awareness
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS maintain aircraft with stable approach criteria (as designed in the SOPs)	Traffic Density	FCS situational awareness will be degraded as traffic density increases resulting in a reduction in control effectiveness	FCS must have situational awareness maintained as traffic increases to be able to identify error and correct approach
	Pilot Autonomy	Improved control effectiveness due to autonomous pilot ability to maintain aircraft within approach criteria	Pilot Autonomy must have the ability to identify errors in aircraft position and correct based upon its own situational awareness
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage for FCS situational awareness	Accuracy and coverage of CNS infrastructure for pilot situational awareness
	Aircraft Performance	Improved aircraft performance and manoeuvrability should increase the effectiveness of this control	Aircraft designs should ensure high levels of controllability and manoeuvrability especially for those operating in densely populated obstacle-rich environments
	Operating Environment	Operation in urban and obstacle-rich environments may reduce the effectiveness of this control	FCS must have the ability to control the aircraft in line with stable approach criteria along a complex approach route

THREAT 1: FCS provides inputs resulting in aircraft significantly outside the touchdown criteria (zone or speed)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS implements abort/ go-around procedure based on non-compliance with operational minima	Traffic Density	FCS situational awareness will be degraded as traffic density increases resulting in a reduction in control effectiveness	FCS must have situational awareness maintained as traffic increases to be able to identify error and correct approach
	Pilot Autonomy	Improved control effectiveness due to autonomous pilot ability to maintain aircraft within operational minima and detect the need for an abort procedure	Pilot Autonomy must have the ability to identify errors in aircraft position and determine whether an abort procedure is required
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage for FCS situational awareness	Accuracy and coverage of CNS infrastructure for pilot situational awareness
	Aircraft Performance	Improved aircraft performance and manoeuvrability should increase the effectiveness of this control	Aircraft designs should ensure high levels of controllability and manoeuvrability especially for those operating in densely populated obstacle-rich environments.
	Operating Environment	Operation in urban and obstacle-rich environments may reduce the effectiveness of this control	FCS must have the ability to control the aircraft in line with stable approach criteria along a complex approach route
THREAT SUMMARY: Autonomy in the FCS is likely to reduce the level of human error in the occurrence of this threat. Greater traffic density will increase the potential for this threat to occur as more clearances will be provided.			

THREAT 2: TMS provides inaccurate traffic management clearance to aircraft			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS identifies inaccurate traffic management clearance and requests clarification	Traffic Density	Pilot situational awareness will be degraded as traffic density increases	Pilot must have situational awareness maintained as traffic increases to be able to clarify clearance
	Pilot Autonomy	Improved control effectiveness due to autonomous pilot ability to compare clearance with own situational awareness	Pilot Autonomy must have the ability to query a traffic management clearance based upon its own situational awareness
	Aircraft Mix	No impact	
	ATM Autonomy	ATM Autonomy may not be able to undertake self-checking of a previously issued clearance	ATM Autonomy must be able to consider a query from FCS
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage for Pilot situational awareness	Accuracy and coverage of CNS infrastructure for pilot situational awareness
	Aircraft Performance	No impact	
	Operating Environment	Increased number of vertiports and drone take-off and landing sites will increase the complexity of airspace and may impact control effectiveness	Airspace design must take account of changes in the operating environment (e.g. increase number of vertiports and drone take-off and landing sites)
TMS identifies error and resends correct traffic management clearance	Traffic Density	Increased traffic density will require this control to have higher integrity to achieve the same effectiveness	TMS must ensure detection and resolution in higher traffic density
	Pilot Autonomy	No impact	
	Aircraft Mix	Increased traffic mix will require this control to consider a greater range of scenarios to achieve the same effectiveness	TMS must ensure detection and resolution with a greater traffic mix
	ATM Autonomy	Improved control effectiveness due to autonomous nature of TMS and reduction in human error	ATM Autonomy must have the ability to detect, recognise and correct the potential conflict via monitoring
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	Increased range of aircraft performances will require this control to consider a greater range of scenarios to achieve the same effectiveness	TMS must ensure detection and resolution with a greater range of aircraft performances
	Operating Environment	Increased number of vertiports and drone take-off and landing sites will increase the complexity of airspace and may impact control effectiveness	Airspace design must take account of changes in the operating environment (e.g. increase number of vertiports and drone take-off and landing sites)

THREAT 2: TMS provides inaccurate traffic management clearance to aircraft			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS operates in fallback/ manual mode without TMS input	Traffic Density	FCS situational awareness and ability to control manually will be degraded as traffic density increases. This will likely reduce the effectiveness of this control	FCS must have situational awareness maintained as traffic increases to be able to clarify clearance
	Pilot Autonomy	Improved control effectiveness due to autonomous FCS' ability to control aircraft in manual mode compared to human pilot	Pilot Autonomy must have the ability to operate aircraft safely without TMS input and in range of complex environments and scenarios
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS implements abort/ go-around procedure based on non-compliance with operational minima	See equivalent control from Threat 1		
THREAT SUMMARY: Autonomy in the TMS is likely to reduce the level of human error in the occurrence of this threat. Greater traffic density will increase the potential for this threat to occur as more clearances will be provided.			

THREAT 3: Technical failure of aircraft affecting directional control			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
MRO performs preventive maintenance programme in accordance with the maintenance schedule	See equivalent control from Threat 8 of Hazard 1.1 – Loss of Control		
Aircraft automated systems and/or interlocks limit severity of malfunction	See equivalent control from Threat 8 of Hazard 1.1 – Loss of Control		
FCS operates in fallback/ manual mode without TMS input	Traffic Density	No impact	
	Pilot Autonomy	Improved control effectiveness due to autonomous FCS' ability to reconfigure aircraft according to procedures compared to human pilot	Autonomous FCS must have the ability to follow emergency procedures and deviate intelligently from procedures if procedures are not effective in establishing control
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	Aircraft design will impact this control especially if aircraft requires constant control inputs to maintain controlled flight	Aircraft design should be failure-tolerant especially from a controllability perspective
	Operating Environment	No impact	
FCS implements abort/ go-around procedure based on non-compliance with operational minima	See equivalent control from Threat 1		
THREAT SUMMARY: Autonomy in the FCS limiting the impact of human effort should reduce the threat frequency although this does depend on FCS design and aircraft design for new aircraft ensuring failure-tolerance is embedded in the design.			

THREAT 4: Conflict with another aircraft/vehicle/object/person on the landing area			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Airspace design and landing location SOPs preclude unauthorised aircraft from entering vicinity	Traffic Density	Neutral impact as airspace design for low altitude environments should ensure separation of aircraft on approach to and on landing sites	Airspace design and landing
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	Reduction in effectiveness due to wider variety of operating environments (e.g. urban, rural, low/high altitude) all under formal airspace classification	Airspace design should account for turbulence (including wind shear effects from tall buildings) in setting airspace structures and routes for different aircraft types, e.g. separate smaller aircraft from larger ones in urban environments
TMS provides effective routing and sequencing of aircraft for arrival at landing area	Traffic Density	Increased traffic density will require this control to have higher integrity to achieve the same effectiveness	The TMS must be designed to accommodate greater traffic densities in providing the same level of integrity for this function
	Pilot Autonomy	No impact	TMS must be designed to accommodate differing levels of pilot autonomy in the provision of robust clearances
	Aircraft Mix	A greater variety of aircraft may reduce this control's effectiveness as the TMS will need to provide routing and sequencing for a greater range of scenarios	TMS must be designed to accommodate different aircraft types in the provision of robust clearances
	ATM Autonomy	ATM autonomy is expected to improve control effectiveness due to a reduction in human error.	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	Increased number of vertiports and drone take-off and landing sites will increase the complexity of route structures and airspace and may impact control effectiveness	TMS must be able to accommodate the approach routes and associated requirements for many more vertiports and takeoff/landing sites

THREAT 4: Conflict with another aircraft/vehicle/object/person on the landing area			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Unauthorised aircraft/vehicle/object/person detected and removed	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage identifying unauthorised aircraft	Accuracy and coverage of CNS infrastructure across all operating environments including on the ground
	Aircraft Performance	No impact	
	Operating Environment	The presence of a greater number of vertiports/landing sites with a less formal level of control is expected to make this control more challenging to achieve the same effectiveness as a traditional aerodrome environment	An operating authority for vertiports/landing sites
	CNS Technology	No impact	
FCS implements abort/go-around procedure based on non-compliance with operational minima	See equivalent control from Threat 1		
THREAT SUMMARY: Autonomy in the TMS is likely to reduce the level of human error in the occurrence of this threat. Greater traffic density will increase the potential for this threat to occur as more clearances will be provided.			

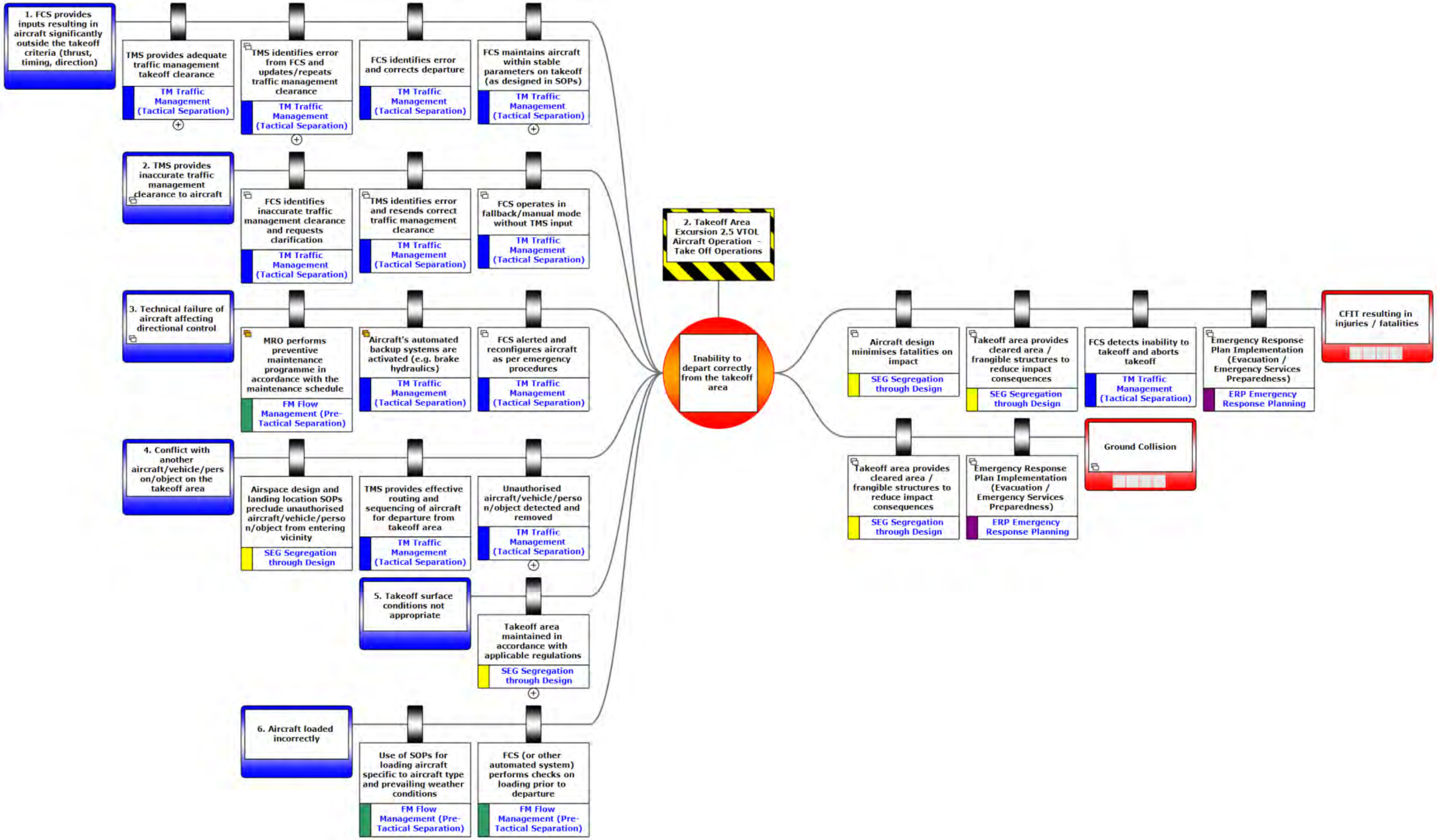
THREAT 5: Landing surface conditions not appropriate			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Landing area maintained in accordance with applicable regulations	Traffic Density	Higher traffic densities may result in difficulties in maintenance of landing area due to increased use and greater risk of contamination with debris etc.	Relevant operating authorities must be able to maintain landing surfaces in accordance with applicable regulations during periods of extreme weather and heavy use
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
	CNS Technology	No impact	
FCS implements abort/ go-around procedure based on non-compliance with operational minima	See equivalent control from Threat 1		
THREAT SUMMARY: Traffic density and the consequent increase in likelihood of wear and tear and presence of debris / foreign objects is expected to increase the frequency of this threat.			

Mitigation Analysis

MITIGATION THREAD Landing area excursion resulting in fatalities in aircraft and on ground			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Aircraft design minimises fatalities on impact	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	Increased control effectiveness due to use of advanced materials in aircraft design leading to improved structural performance	
	Operating Environment	No impact	
Landing area provides cleared area / frangible structures to reduce impact consequences	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	Reduced control effectiveness due to congested nature of environment making it more challenging to provide an appropriate cleared area	Vertiport and landing area design must accommodate additional cleared areas to accommodate different aircraft types when making a partially controlled or uncontrolled landing
Aircraft capability to land safely under failure conditions	See equivalent control in Uncontrolled Collision with terrain consequence from Hazard 1.1 – Loss of Control		
FCS detects inability to touchdown and performs go-around	Traffic Density	FCS situational awareness will be degraded as traffic density increases resulting in a reduction in control effectiveness	FCS must have situational awareness maintained as traffic increases to be able to identify error and perform go-around
	Pilot Autonomy	Improved control effectiveness due to autonomous pilot ability to detect inability to touchdown and detect the need for an abort procedure	Pilot Autonomy must have the ability to identify errors in aircraft position and determine whether an abort procedure is required
	Aircraft Mix	No impact	

MITIGATION THREAD Landing area excursion resulting in fatalities in aircraft and on ground			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage for FCS situational awareness	Accuracy and coverage of CNS infrastructure for pilot situational awareness
	Aircraft Performance	Improved aircraft performance and manoeuvrability should increase the effectiveness of this control	Aircraft designs should ensure high levels of controllability and manoeuvrability especially for those operating in densely populated obstacle-rich environments
	Operating Environment	Operation in urban and obstacle-rich environments may reduce the effectiveness of this control	FCS must have the ability to control the aircraft in line with stable approach criteria along a complex approach route
Emergency Response Plan Implementation (Evacuation / Emergency Services Preparedness)	See equivalent control from MAC consequence of Hazard 1.2 – Loss of Control – Malicious Takeover		

B.3.4 Hazard 2.5 – Takeoff Area Excursion – VTOL Aircraft Operations – Takeoff Operations



Threats and Control Analysis

THREAT 1: FCS provides inputs resulting in aircraft significantly outside the takeoff criteria (thrust, timing, direction)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMS provides adequate traffic management takeoff clearance	Traffic Density	Traffic density will increase which may reduce the effectiveness of this control due to greater demands on the TMS	The TMS must be designed to accommodate greater traffic densities in providing the same level of integrity for this function
	Pilot Autonomy	No impact	TMS must be designed to accommodate differing levels of pilot autonomy in the provision of robust clearances
	Aircraft Mix	A greater range of aircraft types operating within the airspace with differing takeoff requirements may reduce the effectiveness of this control	TMS must be designed to accommodate different aircraft types in the provision of robust clearances
	ATM Autonomy	ATM autonomy should result in improved effectiveness due to the corresponding reduction in human error from operation of an autonomous system	
	CNS Technology	Improved CNS technology will lead to a reduction in the separation required between aircraft	TMS design must take account of improvements in CNS technology and the ability to provide more refined clearances
	Aircraft Performance	No impact	
	Operating Environment	Increased number of vertiports and drone take-off and landing sites will increase the complexity of route structures and airspace and may impact control effectiveness	TMS must be able to accommodate the approach routes and associated requirements for many more vertiports and takeoff/ landing sites
TMS identifies error from FCS and updates/repeats traffic management clearance	See equivalent control from Threat 1 of Hazard 2.4 – Landing Area Excursion		
FCS identifies error and corrects departure	Traffic Density	FCS situational awareness will be degraded as traffic density increases resulting in a reduction in control effectiveness	FCS must have situational awareness maintained as traffic increases to be able to identify error and correct takeoff
	Pilot Autonomy	Improved control effectiveness due to autonomous pilot ability to compare aircraft position with own situational awareness	Pilot Autonomy must have the ability to identify errors in aircraft position and correct based upon its own situational awareness
	Aircraft Mix	No impact	

THREAT 1: FCS provides inputs resulting in aircraft significantly outside the takeoff criteria (thrust, timing, direction)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage for FCS situational awareness	Accuracy and coverage of CNS infrastructure for pilot situational awareness
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS maintain aircraft with stable parameters on takeoff (as designed in the SOPs)	Traffic Density	FCS situational awareness will be degraded as traffic density increases resulting in a reduction in control effectiveness	FCS must have situational awareness maintained as traffic increases to be able to identify error and correct takeoff
	Pilot Autonomy	Improved control effectiveness due to autonomous pilot ability to maintain aircraft within takeoff criteria	Pilot Autonomy must have the ability to identify errors in aircraft parameters and correct based upon its own situational awareness
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage for FCS situational awareness	Accuracy and coverage of CNS infrastructure for pilot situational awareness
	Aircraft Performance	Improved aircraft performance and manoeuvrability should increase the effectiveness of this control	Aircraft designs should ensure high levels of controllability and manoeuvrability especially for those operating in densely populated obstacle-rich environments.
	Operating Environment	Operation in urban and obstacle-rich environments may reduce the effectiveness of this control	FCS must have the ability to control the aircraft in line with stable approach criteria along a complex approach route
THREAT SUMMARY: Autonomy in the FCS is likely to reduce the level of human error in the occurrence of this threat. Greater traffic density will increase the potential for this threat to occur as more clearances will be provided.			

THREAT 2: TMS provides inaccurate traffic management clearance to aircraft			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS identifies inaccurate traffic management clearance and requests clarification	See equivalent control in Threat 2 – Hazard 2.4 – VTOL Landing Operations		
TMS identifies error and resends correct traffic management clearance	See equivalent control in Threat 2 – Hazard 2.4 – VTOL Landing Operations		
FCS operates in fallback/ manual mode without TMS input	See equivalent control in Threat 2 – Hazard 2.4 – VTOL Landing Operations		
THREAT SUMMARY: Autonomy in the TMS is likely to reduce the level of human error in the occurrence of this threat. Greater traffic density will increase the potential for this threat to occur as more clearances will be provided.			

THREAT 3: Technical failure of aircraft affecting directional control			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
MRO performs preventive maintenance programme in accordance with the maintenance schedule	See equivalent control from Threat 8 of Hazard 1.1 – Loss of Control		
Aircraft automated systems and/or interlocks limit severity of malfunction	See equivalent control from Threat 8 of Hazard 1.1 – Loss of Control		
FCS alerted and reconfigures aircraft as per emergency procedures	See equivalent control from Threat 3 in Hazard 2.4 – VTOL Landing Operations		
THREAT SUMMARY: Autonomy in the FCS limiting the impact of human effort should reduce the threat frequency although this does depend on FCS design and aircraft design for new aircraft ensuring failure-tolerance is embedded in the design.			

THREAT 4: Conflict with another aircraft/vehicle/object/person on the takeoff area			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Airspace design and landing location SOPs preclude unauthorised aircraft from entering vicinity	See equivalent control in Threat 4 – Hazard 2.4 – VTOL Landing Operations		
TMS provides effective routing and sequencing of aircraft for departure from takeoff area	Traffic Density	Increased traffic density will require this control to have higher integrity to achieve the same effectiveness	The TMS must be designed to accommodate greater traffic densities in providing the same level of integrity for this function
	Pilot Autonomy	No impact	TMS must be designed to accommodate differing levels of pilot autonomy in the provision of robust clearances
	Aircraft Mix	A greater variety of aircraft may reduce this control's effectiveness as the TMS will need to provide routing and sequencing for a greater range of scenarios	TMS must be designed to accommodate different aircraft types in the provision of robust clearances
	ATM Autonomy	ATM autonomy is expected to improve control effectiveness due to a reduction in human error	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	Increased number of vertiports and drone take-off and landing sites will increase the complexity of route structures and airspace and may impact control effectiveness	TMS must be able to accommodate the approach routes and associated requirements for many more vertiports and takeoff/landing sites
Unauthorised aircraft/vehicle/object/person detected and removed	See equivalent control from Threat 4 – Hazard 2.4 – VTOL Landing Operations		
THREAT SUMMARY: Autonomy in the TMS is likely to reduce the level of human error in the context of this threat. Greater traffic density will increase the potential for this threat to occur as more clearances will be provided.			

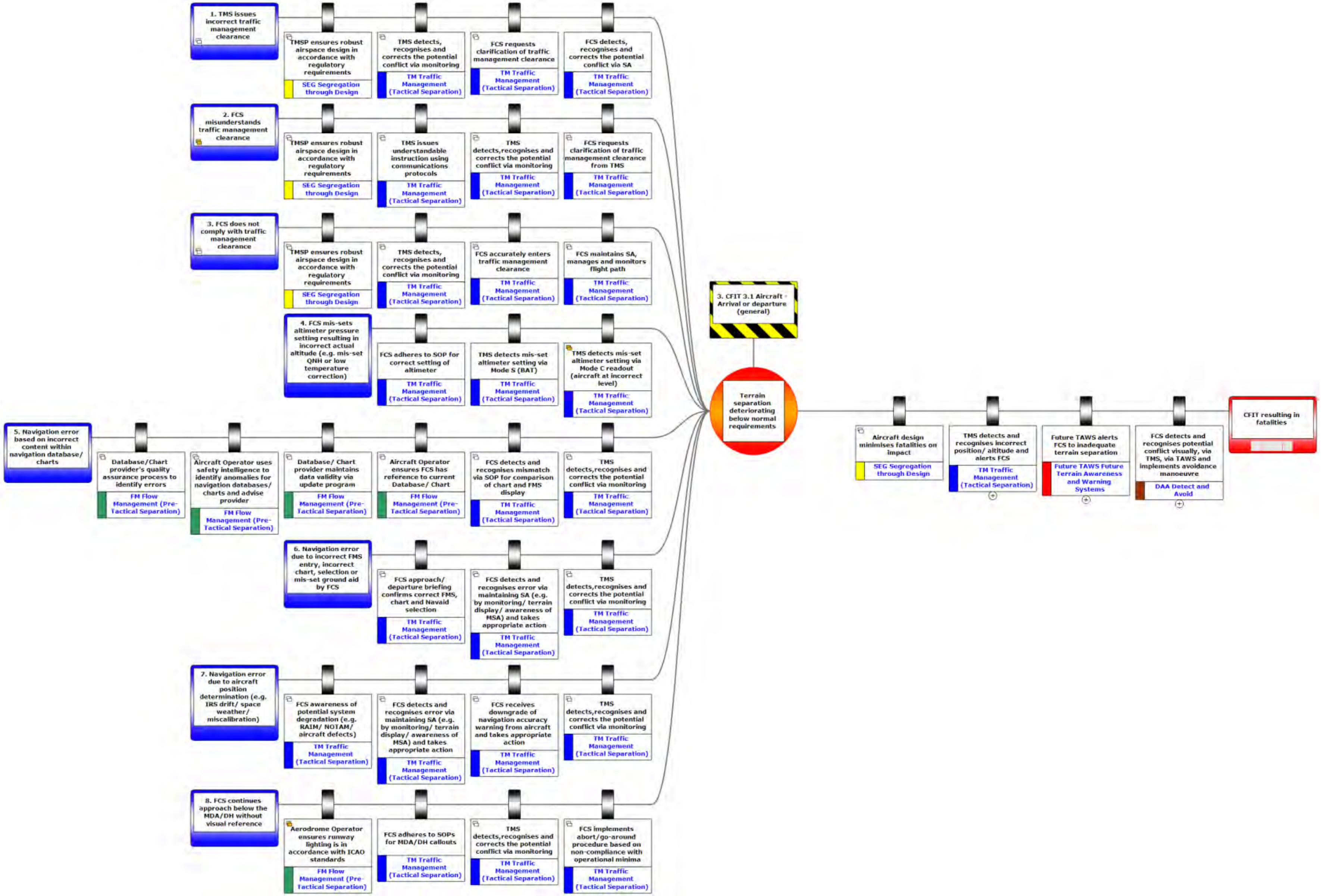
THREAT 5: Takeoff surface conditions not appropriate			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMS provides effective routing and sequencing of aircraft for departure from takeoff area	Traffic Density	Higher traffic densities may result in difficulties in maintenance of landing area due to increased use and greater risk of contamination with debris etc.	Relevant operating authorities must be able to maintain landing surfaces in accordance with applicable regulations during periods of extreme weather and heavy use
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
THREAT SUMMARY: Traffic density and the consequent increase in likelihood of wear and tear and presence of debris / foreign objects is expected to increase the frequency of this threat.			

Mitigation Analysis

MITIGATION THREAD CFIT resulting in injuries/fatalities			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Aircraft design minimises fatalities on impact	See equivalent control in Landing area excursion consequence from Hazard 2.4 – VTOL Landing Operations		
Takeoff area provides cleared area / frangible structures to reduce impact consequences	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	Reduced control effectiveness due to congested nature of environment making it more challenging to provide an appropriate cleared area	Vertiport and landing area design must accommodate additional cleared areas to accommodate different aircraft types when making a partially controlled or uncontrolled landing
FCS detects inability to takeoff and aborts takeoff	Traffic Density	FCS situational awareness will be degraded as traffic density increases resulting in a reduction in control effectiveness	FCS must have situational awareness maintained as traffic increases to be able to identify error and perform go-around
	Pilot Autonomy	Improved control effectiveness due to autonomous pilot ability to detect inability to takeoff and the need for an abort procedure	Pilot Autonomy must have the ability to identify errors in aircraft position and determine whether an abort procedure is required
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage for FCS situational awareness	Accuracy and coverage of CNS infrastructure for pilot situational awareness
	Aircraft Performance	Improved aircraft performance and manoeuvrability should increase the effectiveness of this control	Aircraft designs should ensure high levels of controllability and manoeuvrability especially for those operating in densely populated obstacle-rich environments
	Operating Environment	Operation in urban and obstacle-rich environments may reduce the effectiveness of this control	FCS must have the ability to control the aircraft in line with stable approach criteria along a complex approach route
Emergency Response Plan Implementation (Evacuation / Emergency Services Preparedness)	See equivalent control from Landing Area Excursion consequence from Hazard 2.4 – VTOL Landing Operations		

MITIGATION THREAD Ground Collision			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Takeoff area provides cleared area / frangible structures to reduce impact consequences	See equivalent control from CFIT consequence		
Emergency Response Plan Implementation (Evacuation / Emergency Services Preparedness)	See equivalent control from CFIT consequence		

B.3.5 Hazard 3.1 – CFIT – Aircraft Operations – Arrival or departure (general)



Threat and Control Analysis

THREAT 1: TMS issues incorrect traffic management clearance			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMSP ensures robust airspace design in accordance with regulatory requirements	See equivalent control from Threat 1 in Hazard 5.1 – Airborne Conflict		
TMS detects, recognises and corrects the potential conflict via monitoring	See equivalent control from Threat 1 in Hazard 5.1 – Airborne Conflict		
FCS requests clarification of traffic management clearance	See equivalent control from Threat 1 in Hazard 5.1 – Airborne Conflict		
FCS detects, recognises and corrects the potential conflict via SA	Traffic Density	Increased traffic density will require this control to have higher integrity to achieve the same effectiveness	TMS must ensure detection and resolution in higher traffic density
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	FCS Autonomy must have the ability to detect, recognise and correct the potential conflict via monitoring
	Aircraft Mix	Increased traffic mix will require this control to consider a greater range of scenarios to achieve the same effectiveness	TMS must ensure detection and resolution with a greater traffic mix
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	Increased range of aircraft performances will require this control to consider a greater range of scenarios to achieve the same effectiveness	TMS must ensure detection and resolution with a greater range of aircraft performances
	Operating Environment	No impact	
THREAT SUMMARY: Autonomy in the TMS is likely to reduce the level of human error in the context of this threat. Greater traffic density will increase the potential for this threat to occur as more clearances will be provided.			

THREAT 2: FCS misunderstands traffic management clearance			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMSP ensures robust airspace design in accordance with regulatory requirements	See equivalent control from Threat 1		
TMS issues understandable instruction using communication protocols	See equivalent control from Threat 2 in Hazard 5.1 – Airborne Conflict		
TMS detects, recognises and corrects the potential conflict via monitoring	See equivalent control from Threat 2 in Hazard 5.1 – Airborne Conflict		
FCS requests clarification of traffic management clearance from TMS	See equivalent control from Threat 2 in Hazard 5.1 – Airborne Conflict		
FCS maintains SA, manages and monitors flight path	See equivalent control from Threat 2 in Hazard 5.1 – Airborne Conflict		
THREAT SUMMARY: The likelihood of the threat due to pilot human error may be reduced with an autonomous Pilot and/or an autonomous TMS.			

THREAT 3: FCS does not comply with traffic management clearance			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMSP ensures robust airspace design in accordance with regulatory requirements	See equivalent control from Threat 1		
TMS detects, recognises and corrects the potential conflict via monitoring	See equivalent control from Threat 3 in Hazard 5.1 – Airborne Conflict		
FCS accurately enters traffic management clearance	See equivalent control from Threat 3 in Hazard 5.1 – Airborne Conflict		
FCS maintains SA, manages and monitors flight path	See equivalent control from Threat 3 in Hazard 5.1 – Airborne Conflict		
THREAT SUMMARY: The likelihood of the threat due to pilot human error may be reduced with an autonomous Pilot and/or an autonomous TMS.			

THREAT 4: FCS mis-sets altimeter pressure setting resulting in incorrect actual altitude (e.g., mis-set Quadrant Nautical Height (QNH) or low temperature correction)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS adheres to SOP for correct setting of altimeter	Traffic Density	No impact	
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	FCS Autonomy must have the ability to follow SOPs with a high degree of integrity
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage providing more accurate and alternative methods for height determination, e.g. GNSS, radio etc.	Accuracy and coverage of CNS infrastructure across all operating environments including determination of aircraft height
	Aircraft Performance	No impact	
	Operating Environment	Potential improvement in control effectiveness if aircraft operate at lower altitudes than other aviation where pressure differences are less of an issue for barometric altimeters	
TMS detects mis-set altimeter setting via Mode S (BAT)	Traffic Density	Increased traffic density will require this control to have higher integrity to achieve the same effectiveness	TMS must ensure detection and resolution in higher traffic density
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	Improved control effectiveness due to autonomous nature of TMS and reduction in human error	ATM Autonomy must have the ability to detect, recognise and inform the mis-setting via monitoring
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage including height determination	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	No impact	

THREAT 4: FCS mis-sets altimeter pressure setting resulting in incorrect actual altitude (e.g., mis-set QNH or low temperature correction)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMS detects mis-set altimeter setting via Mode C readout (aircraft at incorrect level)	Traffic Density	Increased traffic density will require this control to have higher integrity to achieve the same effectiveness	TMS must ensure detection and resolution in higher traffic density
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	Improved control effectiveness due to autonomous nature of TMS and reduction in human error	ATM Autonomy must have the ability to detect, recognise and inform the mis-setting via monitoring
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage including height determination	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	No impact	
THREAT SUMMARY: The likelihood of the threat due to pilot human error may be reduced with an autonomous Pilot and/or an autonomous TMS.			

THREAT 5: Navigation error based on incorrect content within navigation database/charts			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Database/Chart Providers' quality assurance process to identify errors	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	Potential reduction in control effectiveness due to the more complex nature of urban airspace and the more onerous requirements on map quality and resolution of detail	Chart/map providers must be able to account for frequent changes in the urban landscape and incorporate those into a high-integrity update process for end-users
Aircraft Operator uses safety intelligence to identify anomalies for navigation databases/charts and advise provider	Traffic Density	No impact	
	Pilot Autonomy	Potential improvement in control effectiveness due to more reliable reporting of anomalies in databases/charts through autonomy	Autonomy must demonstrate the capability to determine differences between map/chart information and information gained from situational awareness
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	

THREAT 5: Navigation error based on incorrect content within navigation database/charts			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage including comparison with issues in map quality	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	No impact	
Database/Chart provider maintains data validity via update programme	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
Aircraft Operator ensures FCS has reference to current database/chart	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS detects and recognises mismatch via SOP for comparison of chart and FMS display	Traffic Density	No impact	
	Pilot Autonomy	Potential improvement in control effectiveness due to FCS autonomously comparing current map/chart information against the reference data	FCS autonomy must include validity checks on use of map/chart data against the current version of such information
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
TMS detects, recognises and corrects the potential conflict via monitoring	See equivalent control from Threat 2 in Hazard 5.1 – Airborne Conflict		
THREAT SUMMARY: The likelihood of the threat due to pilot human error may be reduced with an autonomous Pilot and/or an autonomous TMS.			

THREAT 6: Navigation error due to incorrect FMS entry, incorrect chart, selection or mis-set ground aid by FCS			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS approach/departure briefing confirms correct FMS, chart and Navaid selection	Traffic Density	No impact	
	Pilot Autonomy	Potential improvement in control effectiveness due to FCS autonomously comparing FMS, chart and Navaid selection against correct data	FCS autonomy must include validity checks on use of FMS, chart and Navaid selection against the appropriate version of such information
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	Potential reduction in control effectiveness due to the more complex nature of the airspace and more complex FMS, chart and/or Navaid selections that may be required	Briefings must be able to account for the more complex airspace and corresponding requirements on the integrity of the briefing, chart and Navaid selection
FCS detects and recognises error via maintaining SA (e.g. by monitoring/terrain display/awareness of MSA) and takes appropriate action	Traffic Density	Increased traffic density will require this control to have higher integrity to achieve the same effectiveness	FCS must ensure detection and resolution in higher traffic density
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	FCS Autonomy must have the ability to detect, recognise and correct the potential conflict via monitoring
	Aircraft Mix	Increased traffic mix will require this control to consider a greater range of scenarios to achieve the same effectiveness	FCS must ensure detection and resolution with a greater traffic mix
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	Increased range of aircraft performances will require this control to consider a greater range of scenarios to achieve the same effectiveness	FCS must ensure detection and resolution with a greater range of aircraft performances
	Operating Environment	No impact	
TMS detects, recognises and corrects the potential conflict via monitoring	See equivalent control from Threat 2 in Hazard 5.1 – Airborne Conflict		
THREAT SUMMARY: The likelihood of the threat due to pilot human error may be reduced with an autonomous Pilot and/or an autonomous TMS although higher traffic densities and more complex airspace will complicate the process of ensuring the correct navigation information is entered correctly.			

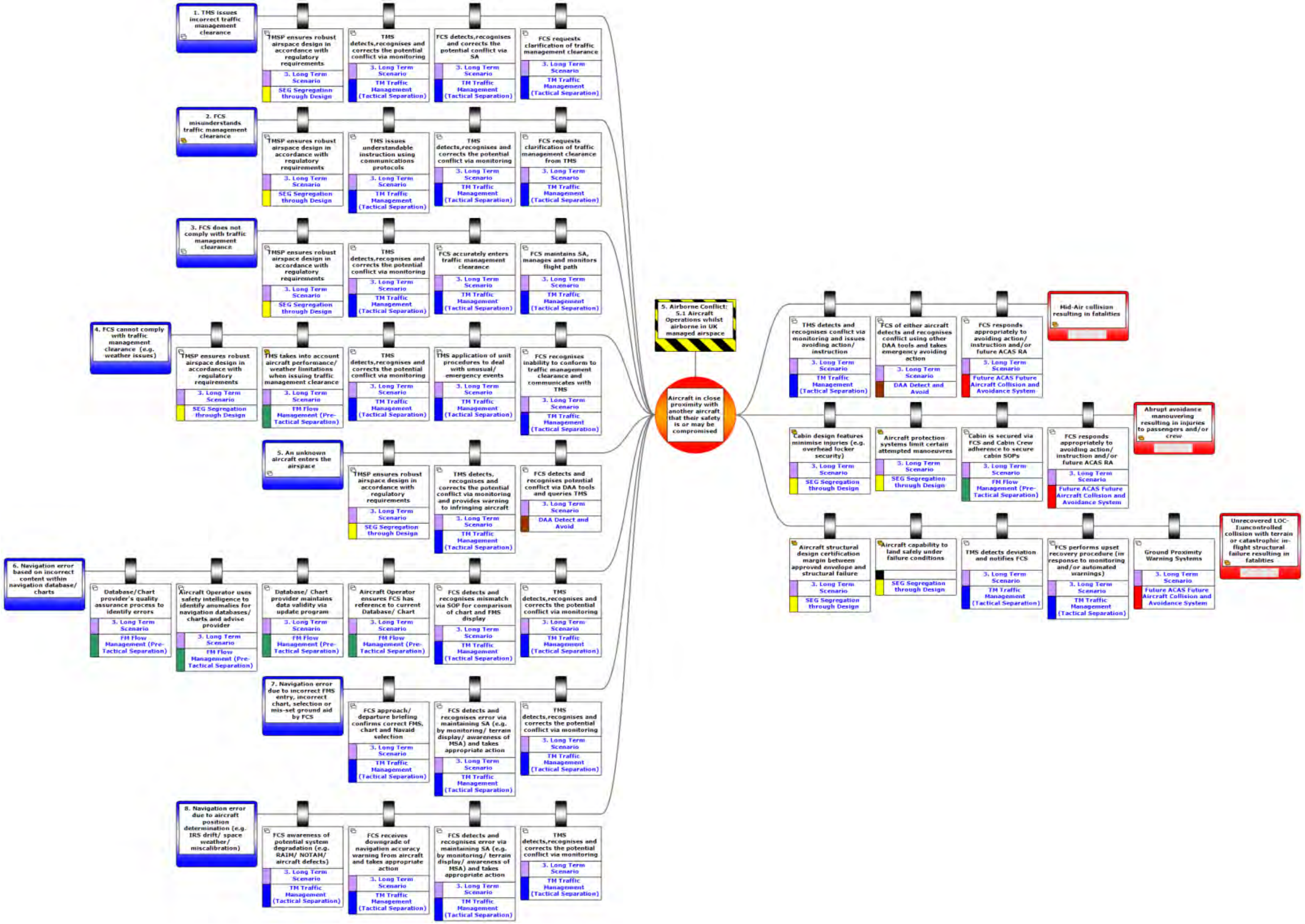
THREAT 7: Navigation error due to aircraft position determination (e.g. IRS drift/space weather/miscalibration)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS awareness of potential system degradation e.g. Receiver Autonomous Integrity Monitoring / Notice to Airmen (RAIM / NOTAM)	Traffic Density	Increased traffic density will require this control to have higher integrity to achieve the same effectiveness	FCS must ensure detection and resolution in higher traffic density
	Pilot Autonomy	Potential improvement in control effectiveness due to FCS autonomously comparing monitoring information on system health	FCS autonomy must include validity checks on use of RAIM/NOTAM and system defect information
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS receives downgrade of navigation accuracy warning from aircraft and takes appropriate action	Traffic Density	Increased traffic density will require this control to have higher integrity to achieve the same effectiveness	TMS must ensure detection and resolution in higher traffic density
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	FCS Autonomy must have the ability to respond to navigation accuracy warnings and take appropriate action
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	Potential reduction in control effectiveness due to the more complex nature of urban airspace and the more onerous requirements on navigation accuracy and consequences of poor accuracy	Aircraft and navigation systems must be designed with multiple, diverse systems for providing accurate navigation information especially when operating in urban obstacle-rich environments
FCS detects and recognises error via maintaining SA (e.g. by monitoring/terrain display/awareness of MSA) and takes appropriate action	See equivalent control from Threat 6		
TMS detects, recognises and corrects the potential conflict via monitoring	See equivalent control from Threat 2 in Hazard 5.1 – Airborne Conflict		
THREAT SUMMARY: The likelihood of the threat due to pilot human error may be reduced with an autonomous Pilot and/or an autonomous TMS although higher traffic densities and more complex airspace will complicate the process of ensuring the correct navigation information is entered correctly.			

THREAT 8: FCS continues approach below the MDA/DH without visual reference			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Aerodrome operator ensures runway lighting is in accordance with applicable ICAO standards	Traffic Density	No impact	
	Pilot Autonomy	Autonomous pilots may require additional, diverse sources of runway identification compared to current lighting methods to maintain effectiveness of this control	Aerodrome operators must take account of how autonomous FCS can visually detect the position of the runway/landing surface relative to aircraft position
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	Potential reduction in control effectiveness due to the more complex nature of urban airspace and impacts of buildings and other obstacles from obscuring view of runway/landing surface	Operators must ensure that runway/landing surface lighting is visible from all relevant approach directions and distances
FCS adheres to SOPs for MDA/DH callouts	Traffic Density	Increased traffic density will require this control to have higher integrity to achieve the same effectiveness	FCS must ensure detection and resolution in higher traffic density
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	FCS Autonomy must have the ability to follow SOPs for MDA/DH determination
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	Potential reduction in control effectiveness due to the more complex nature of urban airspace and the more onerous requirements on navigation accuracy and consequences of poor accuracy	Aircraft and navigation systems must be designed with multiple, diverse systems for providing accurate navigation information especially when operating in urban obstacle-rich environments
TMS detects, recognises and corrects the potential conflict via monitoring	See equivalent control from Threat 2 in Hazard 5.1 – Airborne Conflict		
FCS implements abort/go-around procedure based on non-compliance with operational minima	See equivalent control from Threat 1 in Hazard 2.4 – VTOL Landing Operations		
THREAT SUMMARY: The likelihood of the threat due to pilot human error may be reduced with an autonomous FCS.			

Mitigation Analysis

MITIGATION THREAD CFIT resulting in injuries/fatalities			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Aircraft design minimises fatalities on impact	See equivalent control in CFIT resulting in fatalities consequence from Hazard 2.5 – VTOL Takeoff Operations		
TMS detects and recognises incorrect position/altitude and alerts FCS	See equivalent control in MAC consequence from Hazard 1.1 – Loss of Control		
Future Terrain Avoidance Warning System (TAWS) alerts FCS to inadequate terrain separation	Traffic Density	No impact	
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	
	Aircraft Mix	Reduced control effectiveness as not all aircraft may be equipped with TAWS	Requirement for aircraft to be equipped with TAWS if operating in certain airspace volumes
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness if TAWS is linked to improved CNS infrastructure either for communications or surveillance purposes	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	Improved control effectiveness as aircraft may be more manoeuvrable and responsive to control inputs	
	Operating Environment	Reduced control effectiveness due to congested nature of environment and presence of obstacles, e.g. buildings	
FCS performs upset recovery procedure (in response to monitoring and/or automated warnings)	Traffic Density	More dense traffic will reduce the effectiveness of this control due to the greater likelihood of infringing another aircraft	
	Pilot Autonomy	Improved control effectiveness due to autonomous nature of FCS and reduction in human error	
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	Improved control effectiveness due to greater manoeuvrability of aircraft in response to control inputs	
	Operating Environment	Reduced control effectiveness due to congested nature of environment and presence of obstacles (e.g. buildings etc.)	

B.3.6 Hazard 5.1 – Airborne Conflict – Aircraft Operations whilst airborne in UK managed airspace



Threats and Controls Analysis

THREAT 1: TMS issues incorrect traffic management clearance			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMSP ensures robust airspace design in accordance with regulatory requirements	Traffic Density	Traffic density will increase which will impact the effectiveness of airspace structures	Airspace design must take account of increases in traffic density
	Pilot Autonomy	Airspace will operate with mixed levels of autonomy or be required to segregate autonomy from piloted aircraft if control effectiveness cannot be achieved	Airspace design must take account of aircraft autonomy mix
	Aircraft Mix	A greater range of aircraft types operating within the airspace could impact control effectiveness	Airspace design must enable all airspace users to operate safely whilst ensuring access and equity and other performance attributes
	ATM Autonomy	ATM autonomy will allow a more dynamic set of airspace structures to be used	Airspace design must make use of more dynamic airspace structures to improve airspace safety performance or maintain safety performance and enable other performance attributes
	CNS Technology	Improved CNS technology will lead to a reduction in the separation required between aircraft	Airspace design must take account of improvements in CNS technology and the associated required separation standards
	Aircraft Performance	Aircraft with a greater range of performance capabilities will operate within the airspace	
	Operating Environment	Increased number of vertiports and drone take-off and landing sites will increase the complexity of airspace and may impact control effectiveness	Airspace design must take account of changes in the operating environment (e.g. increase number of vertiports and drone take-off and landing sites)
TMS detects, recognises and corrects the potential conflict via monitoring	Traffic Density	Increased traffic density will require this control to have higher integrity to achieve the same effectiveness	TMS must ensure detection and resolution in higher traffic density
	Pilot Autonomy	No impact	
	Aircraft Mix	Increased traffic mix will require this control to consider a greater range of scenarios to achieve the same effectiveness	TMS must ensure detection and resolution with a greater traffic mix
	ATM Autonomy	Improved control effectiveness due to autonomous nature of TMS and reduction in human error	ATM Autonomy must have the ability to detect, recognise and correct the potential conflict via monitoring

THREAT 1: TMS issues incorrect traffic management clearance			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	Increased range of aircraft performances will require this control to consider a greater range of scenarios to achieve the same effectiveness	TMS must ensure detection and resolution with a greater range of aircraft performances
	Operating Environment	No impact	
FCS detects, recognises and corrects the potential conflict via SA	Traffic Density	Pilot situational awareness will be degraded as traffic density increases	Pilot must have situational awareness maintained as traffic increases to be able to clarify clearance
	Pilot Autonomy	Improved control effectiveness due to autonomous pilot ability to compare clearance with own situational awareness	Pilot Autonomy must have the ability to query a traffic management clearance based upon its own situational awareness
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage for Pilot situational awareness	Accuracy and coverage of CNS infrastructure for pilot situational awareness
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS requests clarification of traffic management clearance	Traffic Density	Pilot situational awareness will be degraded as traffic density increases	Pilot must have situational awareness maintained as traffic increases to be able to clarify clearance
	Pilot Autonomy	Improved control effectiveness due to autonomous pilot ability to compare clearance with own situational awareness	Pilot Autonomy must have the ability to query a traffic management clearance based upon its own situational awareness
	Aircraft Mix	No impact	
	ATM Autonomy	ATM Autonomy may not be able to undertake self-checking of a previously issued clearance	ATM Autonomy must be able to consider a query from FCS
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage for Pilot situational awareness	Accuracy and coverage of CNS infrastructure for pilot situational awareness
	Aircraft Performance	No impact	
	Operating Environment	No impact	
THREAT SUMMARY: Autonomy in the TMS is likely to reduce the level of human error in the occurrence of this threat. Greater traffic density will increase the potential for this threat to occur as more clearances will be provided.			

THREAT 2: FCS misunderstands traffic management clearance			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMSP ensures robust airspace design in accordance with regulatory requirements	See Threat 1 Analysis		
TMS issues understandable instruction using communication protocols	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	Potential improved control effectiveness with autonomous TMS and reduction in human error	ATM Autonomy must achieve an appropriate level of integrity with instructions
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	No impact	
	Operating Environment	No impact	
TMS detects, recognises and corrects the potential conflict via monitoring	See Threat 1 Analysis		
FCS requests clarification of traffic management clearance from TMS	See Threat 1 Analysis		
THREAT SUMMARY: The likelihood of the threat due to pilot human error may be reduced with an autonomous Pilot and/or an autonomous TMS.			

THREAT 3: FCS does not comply with traffic management clearance			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMSP ensures robust airspace design in accordance with regulatory requirements	See Threat 1 Analysis		
TMS detects, recognises and corrects the potential conflict via monitoring	See Threat 1 Analysis		
TMS issues understandable instruction using communication protocols	Traffic Density	No impact	
	Pilot Autonomy	Reduced human error likelihood leading to a more effective control	Pilot autonomy must be able to accurately interpret traffic management clearance
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	

THREAT 3: FCS does not comply with traffic management clearance			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS maintains SA, manages and monitors flight path	Traffic Density	Increased traffic density may impact the effectiveness of this control	SA tools must consider the impact of greater traffic density
	Pilot Autonomy	Reduced likelihood for human error in maintaining SA increasing control effectiveness	Aircraft must have appropriate SA tools to allow DAA
	Aircraft Mix	Control effectiveness only maintained if all aircraft types have compatible SA approaches	Aircraft must have SA tools which are compatible
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage for FCS situational awareness	Accuracy and coverage of CNS infrastructure for FCS situational awareness
	Aircraft Performance	Variability in aircraft performance may impact the effectiveness of this control	DAA procedures must consider the variability in aircraft performance
	Operating Environment	No impact	
THREAT SUMMARY: The likelihood of the threat due to pilot human error may be reduced with an Autonomous Pilot. An increased range of aircraft performance will increase the likelihood of the threat occurring.			

THREAT 4: FCS cannot comply with traffic management clearance (e.g. weather issues)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMSP ensures robust airspace design in accordance with regulatory requirements	See Threat 1 Analysis		
TMS takes into account aircraft performance / weather limitations when issuing traffic management clearances	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	Potential improved control effectiveness with autonomous TMS and reduction in human error	ATM Autonomy must be able to consider the aircraft performance and weather when issuing traffic management instructions
	CNS Technology	No impact	
	Aircraft Performance	Increased range of aircraft performances will require this control to consider a greater range of scenarios to achieve the same effectiveness	TMS must ensure detection and resolution with a greater range of aircraft performances
	Operating Environment	No impact	

THREAT 4: FCS cannot comply with traffic management clearance (e.g. weather issues)

Control	FF Characteristic	Impact (Control Effectiveness)	Requirement
TMS detects, recognises and corrects the potential conflict via monitoring	See Threat 1 Analysis		
TMS Application of unit procedures to deal with unusual / emergency events	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	To maintain the effectiveness of this control the ATM system must be able to recognise and manage unusual / emergency events	The ATM system must be able to recognise and manage unusual / emergency events
	CNS Technology	No impact	
	Aircraft Performance	Increased range of aircraft performances will require this control to consider a greater range of scenarios to achieve the same effectiveness	TMS must ensure detection and resolution with a greater range of aircraft performances
	Operating Environment	No impact	
FCS recognises inability to conform to traffic management clearance and communicates with TMS	Traffic Density	No impact	
	Pilot Autonomy	Reduced likelihood for human error in recognising inability to conform to traffic management clearance	Aircraft must have appropriate SA tools to allow DAA
	Aircraft Mix	No impact	
	ATM Autonomy	ATM Autonomy must be responsive to Pilot's inability to comply to maintain control effectiveness	ATM Autonomy must be able to consider an inability to comply with communication from pilot
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	

THREAT SUMMARY: With improved autonomy in TMS and FCS, the likelihood of this threat could potentially reduce.

THREAT 5: An unknown aircraft enters the airspace			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMSP ensures robust airspace design in accordance with regulatory requirements	See Threat 1 Analysis		
TMS detects, recognises and corrects the potential conflict via monitoring and provides warning to infringing aircraft	Traffic Density	Increased traffic density will require this control to have higher integrity to achieve the same effectiveness	TMS must ensure detection and resolution in higher traffic density
	Pilot Autonomy	No impact	
	Aircraft Mix	Increased traffic mix will require this control to consider a greater range of scenarios to achieve the same effectiveness	TMS must ensure detection and resolution with a greater traffic mix
	ATM Autonomy	Improved control effectiveness due to autonomous nature of TMS and reduction in human error	ATM Autonomy must have the ability to detect, recognise and correct the potential conflict via monitoring
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	Increased range of aircraft performances will require this control to consider a greater range of scenarios to achieve the same effectiveness	TMS must ensure detection and resolution with a greater range of aircraft performances
	Operating Environment	No impact	
FCS detects and recognises potential conflict via DAA tools and queries TMS	Traffic Density	Increased traffic density may impact the effectiveness of this control	DAA tools must consider the impact of greater traffic density
	Pilot Autonomy	Reduced likelihood for human error in detecting and recognising conflict potentially increasing control effectiveness	Aircraft must have appropriate DAA tools to allow conflict detection
	Aircraft Mix	Control effectiveness only maintained if all aircraft types have compatible approaches	Aircraft must have DAA tools which are compatible
	ATM Autonomy	ATM autonomy must be able to respond to FCS detection to maintain control effectiveness	ATM Autonomy must be able to consider a query from Pilot
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage for FCS situational awareness	Accuracy and coverage of CNS infrastructure for FCS situational awareness
	Aircraft Performance	Variability in aircraft performance may impact the effectiveness of this control	DAA tools must consider the variability in aircraft performance
	Operating Environment	No impact	
THREAT SUMMARY: With increased traffic density the likelihood of this threat occurring is potentially increased. With greater levels of pilot autonomy the likelihood of this threat occurring is potentially reduced.			

THREAT 6: Navigation error based on incorrect content within navigation database/charts			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Database/Chart Providers' quality assurance process to identify errors	See equivalent control in Threat 5 of Hazard 3.1 - CFIT		
Aircraft Operator uses safety intelligence to identify anomalies for navigation databases/charts and advise provider	See equivalent control in Threat 5 of Hazard 3.1 - CFIT		
Database/Chart Provider maintains data validity via update programme	See equivalent control in Threat 5 of Hazard 3.1 - CFIT		
Aircraft Operator ensures FCS has reference to current database/chart	See equivalent control in Threat 5 of Hazard 3.1 - CFIT		
FCS detects and recognises mismatch via SOP for comparison of chart and FMS display	See equivalent control in Threat 5 of Hazard 3.1 - CFIT		
TMS detects, recognises and corrects the potential conflict via monitoring	See equivalent control from Threat 2		
THREAT SUMMARY: The likelihood of the threat due to pilot human error may be reduced with an autonomous Pilot and/or an autonomous TMS.			

THREAT 7: Navigation error due to incorrect FMS entry, incorrect chart, selection or mis-set ground aid by FCS			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS approach/departure briefing confirms correct FMS, chart and Navaid selection	See equivalent control in Threat 6 of Hazard 3.1 - CFIT		
FCS detects and recognises error via maintaining SA (e.g. by monitoring/terrain display/awareness of MSA) and takes appropriate action	See equivalent control in Threat 6 of Hazard 3.1 - CFIT		
TMS detects, recognises and corrects the potential conflict via monitoring	See equivalent control from Threat 2		
THREAT SUMMARY: The likelihood of the threat due to pilot human error may be reduced with an autonomous Pilot and/or an autonomous TMS.			

THREAT 8: Navigation error due to aircraft position determination (e.g. Inertial Reference System (IRS) drift/space/weather/miscalibration)			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS awareness of potential system degradation (e.g. RAIM/NOTAM/aircraft defects)	See equivalent control in Threat 7 of Hazard 3.1 - CFIT		
FCS receives downgrade of navigation accuracy warning from aircraft and takes appropriate action	See equivalent control in Threat 7 of Hazard 3.1 - CFIT		
FCS detects and recognises error via maintaining SA (e.g. by monitoring/terrain display/awareness of MSA) and takes appropriate action	See equivalent control in Threat 7 of Hazard 3.1 - CFIT		
TMS detects, recognises and corrects the potential conflict via monitoring	See equivalent control from Threat 2		
THREAT SUMMARY: The likelihood of the threat due to pilot human error may be reduced with an autonomous Pilot and/or an autonomous TMS.			

Mitigation Analysis

MITIGATION THREAD Leading to Mid-Air Collision resulting in fatalities			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
TMS detects and recognises conflict via monitoring and issues avoiding action/ instruction	Traffic Density	Increased traffic density may impact the effectiveness of this control	Avoiding action instructions must consider the impact of greater traffic density
	Pilot Autonomy	No impact	
	Aircraft Mix	No impact	
	ATM Autonomy	Reduced likelihood for human error in detecting and recognising conflict potentially increasing control effectiveness	Conflict detection may require an additional independent TMS system from that used for separation
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	Variability in aircraft performance may impact the effectiveness of this control	Avoiding action instructions must consider the variability in aircraft performance
	Operating Environment	No impact	
FCS of either aircraft detects and recognises conflict using other DAA tools and takes emergency avoiding action	Traffic Density	Increased traffic density may impact the effectiveness of this control	DAA tools and avoiding action procedures must consider the impact of greater traffic density
	Pilot Autonomy	Reduced likelihood for human error in detecting and recognising conflict potentially increasing control effectiveness	Aircraft must have appropriate DAA tools to allow conflict detection
	Aircraft Mix	Control effectiveness only maintained if all aircraft types have compatible approaches	Aircraft must have DAA tools and avoiding action procedures which are compatible
	ATM Autonomy	No impact	
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage for FCS situational awareness	Accuracy and coverage of CNS infrastructure for FCS situational awareness
	Aircraft Performance	Variability in aircraft performance may impact the effectiveness of this control	Avoiding action procedures must consider the variability in aircraft performance
	Operating Environment	No impact	

MITIGATION THREAD Leading to Mid-Air Collision resulting in fatalities			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
FCS responds appropriately to avoiding action/ instruction and/or ACAS RA	Traffic Density	Increased traffic density may impact the effectiveness of this control	Avoiding action instructions and ACAS RA procedures must consider the impact of greater traffic density
	Pilot Autonomy	Reduced human error likelihood leading to a more effective control	Pilot autonomy must be able to implement avoiding action instructions and ACAS RA procedures
	Aircraft Mix	Control effectiveness only maintained if all aircraft types have compatible approaches	All aircraft types must have compatible approaches to avoiding action and ACAS RA
	ATM Autonomy	ATM autonomy reduces the likelihood of human error in issuing of avoiding action instructions	ATM autonomy must have the ability to issue avoiding action instructions
	CNS Technology	Improved control effectiveness due to expected improvement in CNS performance and coverage	Accuracy and coverage of CNS infrastructure across all operating environments
	Aircraft Performance	Variability in aircraft performance may impact the effectiveness of this control	Avoiding action procedures and ACAS RA procedures must consider the variability in aircraft performance
	Operating Environment	No impact	

MITIGATION THREAD Leading to abrupt avoidance manoeuvring resulting in injuries to passengers and/or crew			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Cabin design features minimise injuries (e.g. overhead locker security)	Traffic Density	No impact	
	Pilot Autonomy	No impact	
	Aircraft Mix	New aircraft types should achieve the same level of control effectiveness	New aircraft types must achieve appropriate cabin design
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
Aircraft protection systems limit certain attempted manoeuvres	Traffic Density	No impact	
	Pilot Autonomy	New aircraft types should achieve the same level of control through aircraft protection systems	New aircraft types must achieve appropriate aircraft protection of attempted manoeuvres
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	

MITIGATION THREAD Leading to abrupt avoidance manoeuvring resulting in injuries to passengers and/or crew			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
Cabin is secured via FCS and Cabin Crew adherence to secure cabin SOPs	Traffic Density	No impact	
	Pilot Autonomy	Autonomy systems will need to achieve the same level of control that human pilot and cabin crew achieve	Autonomy systems must fulfil the role played by pilot and cabin crew in adherence to secure cabin SOPs
	Aircraft Mix	No impact	
	ATM Autonomy	No impact	
	CNS Technology	No impact	
	Aircraft Performance	No impact	
	Operating Environment	No impact	
FCS responds appropriately to avoiding action/ instruction and/or ACAS RA	See Mitigation 1 Analysis		
CONSEQUENCE SUMMARY: Contingent on impact of top event frequency change and performance of mitigation thread – unknown at this stage.			

MITIGATION THREAD Leading to Unrecovered LOC-I: Uncontrolled collision with terrain or catastrophic in-flight structural failure resulting in fatalities			
Control	**FF Characteristic**	**Impact (Control Effectiveness)**	**Requirement**
Aircraft structural design certification margin between approved envelope and structural failure	See equivalent control from Uncontrolled Collision with Terrain consequence from Hazard 1.1 – Loss of Control		
Aircraft capability to land safely under failure conditions	See equivalent control from Uncontrolled Collision with Terrain consequence from Hazard 1.1 – Loss of Control		
TMS detects deviation and notifies FCS	See equivalent control from MAC consequence from Hazard 1.1 – Loss of Control		
FCS performs upset recovery procedure (in response to monitoring and/ or automated warnings)	See equivalent control from MAC consequence from Hazard 1.1 – Loss of Control		
Ground Proximity Warning Systems	See equivalent control from MAC consequence from Hazard 1.1 – Loss of Control		

Safer Complex Systems Analysis

C

Safer Complex Systems Analysis

C

This appendix provides the detailed analysis that supports the conclusions drawn from the Safer Complex Systems Analysis. Activities which are regarded as most relevant to commence actions to implement the recommendations have been identified and are presented below. Following this the full analysis of the application of the design-time controls and operation-time controls from the framework to FF is presented.

C.1 Summary of Recommendations and Activities

C.1.1 Recommendations & Activities - Governance Organisations (Policy and Regulation)

Recommendations for Governance Organisations are broken down across three areas:

- Standards/Regulation/Law
- Engagement
- Safety Performance

Standards/Regulation/Law - Recommendations

- Determine the extent to which current standards can be applied or adapted to new FF operations using the principles of outcome-based standards supported by Acceptable Means of Compliance (AMCs)
- Develop appropriate standards for FF operations where current standards cannot be adapted using the principles of outcome-based standards supported by AMCs
- Review how tort/common law are impacting other industries adopting autonomous systems and assess the implications to FF

Standards/Regulation/Law – Initial Activities

- Investigate regulatory and legal impacts of FF operations, including:
  - How does authority, responsibility and liability change with autonomy and other gaps and overlaps
  - Consideration of ethical impacts in law (especially for autonomy)
  - Review existing laws/regulation which inhibit FF use cases
  - Review assumptions in current regulations about aviation operations which may impact FF operations
  - Review ability to use generic or outcome-based regulation which can apply to different types of services (e.g. Vertiports/Heliports and see-and-avoid/detect-and-avoid)
  - The ability for investigation authorities to investigate FF-related occurrences
- Review level of regulatory expertise in complex systems, including technical disciplines such as Artificial Intelligence, Machine Learning.
- Review the relationship between safety regulatory outcomes and other key factors including:
  - Cost of regulation (including a variety of approaches to cost apportionment)
  - Environmental impact
  - Privacy
  - Nuisance
  - Noise impact
  - Long-term health impacts
  - Security
- Review the regulatory process for safety change management and recertification.

Engagement – Recommendations

- Ensure appropriate diversity and inclusion in Policy, Regulation and FF concept and system development
- Ensure regulators have a practical means to engage with FF industry development during advancement of technology and services
- Ensure that a mechanism exists for the active management of negative consequences of regulatory engagement in development

Engagement – Initial Activities

- Review who the CAA is engaging with to ensure appropriate future industry representation
- Review mechanisms of engagement
- Review how other industries are approaching challenges of Complex Systems (e.g. Automotive)

Safety Performance – Recommendations

- Ensure early proactive incident and accident analysis of FF operations to ensure lessons can be learnt across the FF industry
- Ensure appropriate Target Levels of Safety are defined, achieved and reviewed for Drones, UAM and RAM
- Ensure an enhanced operational monitoring approach is in place for FF operations
- Ensure active alerting practices are enhanced to manage the high tempo and reduced human control use cases of FF operations

Safety Performance – Initial Activities

- Establish an incident, accident and occurrence reporting system tailored for FF, including voluntary safety reporting which includes lead indicators
- Establish appropriate Target Levels of Safety for FF operations, which takes into consideration the potential volume of operations
- Establish objective methods for measuring system safety performance (e.g. Flight data monitoring)
- Review the potential impact of a larger number of smaller operators and the ability for individual organisations to undertake meaningful trend analysis
- Establish industry-wide safety information management system, particularly for smaller-sized FF participants
- Review the relationship between security and safety performance management

C.1.2 Recommendations & Activities – Standards/ Professional Bodies, Industry Organisation

Recommendations

- Identify key areas where industry community guidelines would support safety assurance of FF and produce a roadmap for their development
- Establish means for industry-wide learning from FF complex systems incidents and accidents, with a particular focus on smaller FF participants
- In light of global events in aviation and other safety critical industries, review the effectiveness of learning from experience at Governance and Management Layers in UK Aviation

Initial Activities

- Establish a regulatory mechanism for recognising industry community guidelines
- Industry groups to identify necessary community guidelines and champion their development
- Establish FF safety information sharing mechanism
- Review effectiveness of learning at governance and management in UK aviation
- Review industry competency and skill sets for new types of complex systems used in aviation (e.g. Artificial Intelligence and Machine Learning)

C.1.3 Recommendations & Activities – Supporting Infrastructure Providers

Recommendations

- Ensure supporting infrastructure publish Concepts of Operation (CONOPS) to enable FF technology development
- Ensure supporting infrastructure has a roadmap for Publicly Available Specification (PAS) development which aligns with FF technology development
- Ensure future traffic management provider roles are defined and their role in system integration is strategically planned

Initial Activities

- Develop UK roadmap for traffic management and CNS that:
  - Addresses both organisational and technological considerations
  - Includes a specific stream regarding communications that includes the adoption of non-traditional aviation communications approaches and aligns with other industry roadmaps
  - Addresses flow management approaches for drones and UAM

- Ensure UK representation in relevant international standards for both traffic management and ground infrastructure
- Determine a framework for cost apportionment for traffic management infrastructure to enable investment
- Review the requirements for and approaches to integration of air safety requirements (e.g. protection of airspace) with land and infrastructure planning mechanisms
- Explore the benefits of outsourced or co-ordinated safety management support to share costs amongst industry participants
- Ensure new entrants have a mechanism to easily gain important safety knowledge about the industry (terminology, organisations/stakeholders, regulations, Safety Management practices etc)
- Develop industry awareness about the important of safety culture, which promotes an open learning culture

C.1.4 Recommendations & Activities – New Entrants

Recommendations

- Ensure FF new entrants understand and adopt the mature aviation industry safety management practice in:
  - Principles of High Reliability Organisations
  - Safety Management Systems
  - Risk and hazard analysis
  - Active risk management
  - Monitoring and analysis
  - Incident and accident analysis
  - Learning from experience as part of an effective safety culture. (including accident investigations)
  - Change management
  - CONOPS development
  - Safety/assurance cases (design and operational risk management)
  - Independent assessment
  - Competency management (Operations, Development and Safety)
  - Organisational resilience, contingency planning, contingency rehearsals

Initial Activities

- Develop methodology to assess the safety management maturity of an organisation that considers both culture and technical safety competencies
- Establish a mechanism for new entrants from other industries to share their safety management experience and practices
- Review approaches to ensure that safety management practices are efficient, effective and value adding without being over burdening

C.1.5 Recommendations & Activities – New Technology Developers and Future Flight Operators

Recommendations

- Ensure new FF technology development has strong engagement with aviation and urban industry stakeholders and is cognisant of the future landscape
- Ensure appropriate stakeholder diversity and inclusion in FF concept and system development
- Ensure incremental delivery roadmaps are used to strategically work towards radical change in FF operations
- Ensure new technology and systems apply design for assurance principles
- Ensure new technology and systems has effective diversity and redundancy to the current aviation system
- Ensure the impact of autonomy is reflected in safety assurance requirements across the supply chain/network
- Ensure competency management practices evolve as the role of Autonomy increases
- Ensure FF participants adapt their SMS to incorporate FF challenges including new concepts, new stakeholders, integrated risk management and complex systems
- Ensure aviation safety change management practices are adapted to manage the dynamic and complex nature of FF change
- Ensure practices are in place to manage safety across the supply chain/network
- Ensure all FF participants have mature processes for cyber resilience (design & operation)

Initial Activities

- Explore collaborate-to-compete approaches to develop an environment where participants can share information which will enhance safety
- Understand where incremental delivery is beneficial and where greater change is required (especially for autonomy)
- Share approaches used in Commercial Air Transport where data and information are shared to benefit safety improvement
- Establish a safety panel with drone operators (similar to NATS airline safety panel)
- Develop legal framework for managing safety assurance with autonomy across organisational boundaries
- Develop industry guidance on new competency management best practise as autonomy advances
- Develop an assessment framework or process for assurance of autonomous operations and vehicles
- Develop best practice guidance in safety and security management for FF complex systems
- Establish guidance on managing trade-offs between safety & security (and other risks)

C.1.6 Recommendations & Activities – Current Aviation Industry

Recommendations

- Ensure that all aviation system participants consider the changing aviation system landscape and how FF operations will impact the safety of their operations
- Ensure aviation safety change management practices are adapted to manage the dynamic and complex nature of FF change
- Assess how existing diversity and redundancy in systems is impacted by new FF systems and operations

Initial Activities

- Develop awareness programme for current aviation actors to inform them of likely future changes in aviation and the impact on safety management

C.1.7 Research Agenda

In addition to the recommendations and activities identified above, certain controls from the Safer Complex Systems Framework require further research to understand their applicability and relevance to FF. A research agenda has been identified for these areas with the following areas highlighted as most relevant:

- The application of risk and hazard analysis techniques for complex systems and their adoption in aviation
- The role of the following controls in safety assurance for autonomous FF operations
  - Simulation and modelling
  - Digital twins
  - Dynamic risk management
  - Self-monitoring
  - Scenario Based testing
- The impact of Autonomy on:
  - Maintaining appropriate levels of human competency in FF operations
  - System adaptation processes
  - Human oversight
- The role of future traffic management systems in providing run-time assurance (similar to current ATC services)
- The importance of task analysis in supporting the transition of FF to greater use of autonomy

A joint academic and industry research program should be established to advance understanding in these areas.

C.2 Design-time controls – detailed analysis

The following table provides:

- Identification as to whether the control is a priority consideration for FF (non-priority controls are grey)
- A general description based upon the description from the Safety Complex System Framework Report with minor edits to improve comprehension
- The key FF stakeholders to which the control is relevant
- An analysis of the relevance to FF
- Key recommendations that should be implemented to assist in ensuring the effectiveness of the control for FF

Control (Priority)	General Description	Relevant Stakeholders	Relevance to FF and recommendations
Governance Layer			
Normative/outcome-based standards (FF Priority Control)	Where technology (or other relevant factors) changes fast, then outcome-based, or goal setting, standards can be effective. They go out of date less quickly since they define targets to achieve not specific tasks to be undertaken, although they require more skill to interpret than prescriptive (rule-based) standards.	CAA New Entrants New FF Technology Developers	FF will be a period of change in aviation with rapid innovation in technology available to be applied across all use cases. Use of this control will enable standards to be applied across legacy and future technology and services at the same time. The CAA is already well versed in performance-based regulation and therefore can apply these principles to new FF operations. Standards with higher level objectives will allow application to be broadened where necessary. Examples might include moving from Helicopter Landing Sites regulation to Vertical Take Off and Landing Sites to incorporate UAM operations and moving from 'see-and-avoid' to 'detect-and-avoid' to include non-piloted operations. New entrants to the market may need help to interpret outcome-based standards and therefore it may be necessary to provide guidance through Acceptable Means of Compliance (AMC). AMCs could be developed from Community Guidelines discussed further below. For new concepts and innovation in certain circumstances it may be necessary to have greater levels of prescription where risks are not so well understood or where prescription is a key means of mitigating risks. In these situations, outcome-based regulation may not be appropriate. Determining how standards can be adapted and where new standards are required is a key activity to enable FF operations. Recommendation: Determine the extent to which current standards can be applied or adapted to new FF operations using the principles of outcome-based standards supported by AMCs. Recommendation: Develop appropriate standards for FF operations where current standards cannot be adapted using the principles of outcome-based standards supported by AMCs.
Legislation	Formal legislation can both provide incentives for compliance and guard against (prohibit) system designs where there is a high level of uncertainty in the task to be performed by the system and a low confidence in understanding the system's behaviour.	CAA	As with historical practice in aviation an appropriate legislative framework will be a key component to ensure the ongoing safety of the UK aviation system as FF operations commence. International influences on legislation will potentially change from historic practices if other parts of the world progress with technology developments in FF at a rate faster than historically leading states. Consideration will need to be given to what legislation changes would be required for FF operations.

Tort/common law and soft law (FF Priority Control)	Tort or common law provides a basis for prosecutions where rights have been infringed, and this may apply regardless of system or technology. Further, so-called 'soft law' – rules adopted voluntarily by an industry or sector – may enable fast, industry-wide treatment of issues not addressed through formal regulation.	CAA New FF Technology developers New FF operators	A particular challenge for aviation is the application of just culture and how it may interact with the tort or common law and the prosecution of individuals following errors for which punitive actions can be taken. The importance that aviation places on a learning culture as part of safety management, which requires a just culture to be in place, means that these issues will remain significant into the future. In FF operations the roles of the humans and the autonomous systems must be defined clearly especially where human actions taken to override the autonomous system result in some form of harm. Another important consideration will be the understanding of the role and responsibility of design versus operating organisations, especially in scenarios where there is no pilot in command. These issues will also be seen in other industries (e.g. automotive) and there will be opportunities to learn from their experience as autonomy increases. Recommendation: Review how tort/common law are impacting other industries adopting autonomous systems and assess the implications to FF.
Diversity and inclusion in policy and regulation (FF Priority Control)	There is evidence that diversity improves decision-making and diversity in formulating policy and regulations should help avoid unconscious bias and produce outcomes that are fairer and do not result in unequal risk distributions.	Policy Makers CAA Professional bodies and industry communities ANSP	The new aviation industry that will develop from the FF Challenge will include a range of participants with expertise from aviation as well as many other industries. New aviation participating industries will include car manufacturing, telecommunications, digital and online enterprises. In addition, the integration of drones, UAM and RAM with current aviation operations means that airspace will be used by a much wider range of operators wishing to achieve a greater variety of objectives. Challenges of access and equity will become stronger in key parts of airspace, particularly the low-level urban environment. Ensuring appropriate representation from current and future industry participants will be an important part of policy and regulatory development. In addition, FF will impact other aviation stakeholders in ways beyond the impacts of current aviation. Examples of this include privacy concerns regarding low-level overflying of property and tighter transportation network integration. These challenges will be significant for organisations that play a role in system integration. Ensuring new aviation industry participants and new aviation impacts are considered and views represented in policy, regulatory and system development will be important. Recommendation: Ensure appropriate diversity and inclusion in Policy, Regulation and FF concept and system development.
Engagement in Development (FF Priority Control)	It is difficult to assess complex systems as a 'product' and regulatory engagement in development is a way of gaining system understanding, which would not be available to an end-of-development assessment; note that this is standard practice in aerospace but, as the 737 MAX accidents show, such practices can also 'fail', and are not practical for ad-hoc systems.	CAA New FF Technology Developers	Initiatives such as the CAA's Innovation Sandboxes may become more common place if the rate of innovation increases. They may need to be expanded to allow the rapid assurance and deployment of new technologies into the system. There are issues and challenges in regulatory engagement in development that need to be carefully managed. 737 MAX regulatory oversight provides a potential example of this. Continual assessment of how negative consequences of regulatory engagement during development are being actively managed will be important. Recommendation: Ensure regulators have a practical means to engage with FF industry development during advancement of technology and services. Recommendation: Ensure that a mechanism exists for the active management of negative consequences of regulatory engagement in development.

Publicly available specifications (FF Priority Control)	Standards bodies are developing Publicly Available Specifications (PAS), typically over about one year, enabling a rapid response to new issues enroute to standardisation, for example the British Standards Institution (BSI) is producing PAS for autonomous vehicles.	Standards Bodies Professional bodies and industry communities ANSP UTM Developers UnTM Developers Vertiport Developers New FF Technology Developers	PAS will be an important factor in FF for the supporting infrastructure, including Vertiports and traffic management systems. Standardisation in supporting infrastructure will be critical to ensure FF technology developers are able to design appropriate interfaces for the wider aviation system. Recommendation: Ensure supporting infrastructure has a roadmap for PAS development which aligns with FF technology development.
Community guidelines (FF Priority Control)	Professional communities can develop industry guidelines for dealing with emerging technology, for example the Global Mining Guidelines Group has developed guidance for autonomous systems in mining and quarrying, and this enables the industry to move rapidly on a consensual basis where formal regulation moves slowly.	CAA Professional bodies and industry communities New FF Technology Developers	Due to the new entrants and rapidly changing environment in FF there will be a need for guidelines. Community guidelines support the application of normative standards and can be produced quickly and flexibly. The CAA, new technology developers and industry bodies will have a role in producing these. Recommendation: Identify key areas where industry community guidelines would support safety assurance of FF and produce a roadmap for their development.
Learning from experience (FF Priority Control)	While the (systemic) failures of complex systems can be unprecedented, often there are similarities with previous events and individual causal factors will often have been seen previously, so learning from experience allows steps to be taken to avoid recurrence of similar events – good practice would suggest learning before, during and after events.	CAA AAIB Professional bodies and industry communities New Entrants	As part of a strong Safety Culture, aviation has a good history of learning from incidents and accidents although this may be more effective at a technical level than at an organisational or governance level. This historical practice will need to be maintained and strengthened in the FF environment particularly around organisational development and maturity for new entrants. Recommendation: Establish means for industry-wide learning from FF complex systems incidents and accidents, with a particular focus on smaller FF participants. Recommendation: In light of global events in aviation and other safety critical industries, review the effectiveness of learning from experience at Governance and Management Layers in UK Aviation. Recommendation: Ensure FF new entrants understand and adopt the mature aviation industry practice in learning from experience as part of an effective safety culture.

Management Layer			
Stakeholder engagement (FF Priority Control)	Involvement of all classes of stakeholder in development, particularly in requirements elicitation and in establishing acceptability of risk, increases the chance of achieving system safety and that it will be acceptably safe for all.	New Entrants New Technology Developers FF Operators ANSP	Beyond regulatory engagement in development, it is important for FF technology developers and operators to engage other actors where applicable, in the development and introduction of new products or services. This will contribute to ensuring effective integration into the wider aviation system and urban environment. This is especially necessary where there are established design standards or an agreed approach for interfacing elements, e.g. communications protocols, battery charging. Drone, UAM and traffic management systems will need to understand the dynamic future landscape of aviation and the urban environment and this is best achieved through engagement in development. Having consistent and positive stakeholder engagement in managing risk across multi-stakeholder complex systems is key in ensuring a high level of safety and low level or risk can be achieved and maintained. Recommendation: Ensure new FF technology development has strong engagement with aviation and urban industry stakeholders and is cognisant of the future landscape.
Safety management system (FF Priority Control)	A safety management system (SMS) is a systematic approach to managing safety, including the necessary organisational structures, accountabilities, policies, and procedures. An SMS provides a systematic way to identify and control risks, as well as providing assurance that risk controls remain effective and legislative requirement are met. Effective SMS implementation includes an element of continuous improvement where the organisation monitors and assesses the effectiveness of their SMS to enable enhancement of safety management practices.	Professional bodies and industry communities New Entrants New FF Technology Developers	Aviation has a strong track record with respect to the application of SMSs. An effective SMS will be required in all FF organisations, including innovative ones that do not have a background in aviation or are new start-ups. This could include, for example new elements of the supply chain to UAM aircraft and drones, or urban infrastructure converted to vertiports. SMS development may also be needed for mature industry actors to accommodate the concepts of true integrated risk management across new concepts (e.g. autonomy), stakeholders and risks areas (e.g. cyber security, resilience, environment). Recommendation: Ensure new entrants have the ability to develop mature SMS practices similar to current aviation system stakeholders. Recommendation: Ensure FF participants adapt their SMS to incorporate FF challenges including new concepts, new stakeholders, integrated risk management and complex systems.
Voluntary codes of practice	Voluntary codes of practice influence organisations and set benchmarks for acceptable practices. They embody agreed good practice and provide a means of self- regulation for organisations.	Professional bodies and industry communities New FF operators	Codes of practice will help industry to self-co-ordinate in diverse areas. Industry bodies could co-ordinate these codes of practice for FF operations (e.g. drone and UAM developers and operators). However, it is expected that voluntary codes of practice will be used more commonly for other risk areas such as privacy and noise. With respect to safety, community guidelines will likely be more applicable in aviation.

Principles of high reliability organisations (FF Priority Control)	The following principles are ideally embedded in high reliability organisations (HRO): preoccupation with failure, reluctance to simplify, sensitivity to operations, commitment to resiliency, and deference to expertise.	Professional bodies and industry communities New Entrants	Similar to SMS application, the principles of HROs are already embodied in many aviation organisations and something that new entrants will need to adopt. Recommendation: Ensure new entrants have the ability to develop mature HRO practices similar to current aviation system stakeholders.
Active risk management (FF Priority Control)	Risk management is not a static exercise conducted once. Risk assessments should be updated as new information becomes available and in response to change in the system design or the operating environment. Conduct of risk assessments should be a participative activity involving key stakeholders actively engaging with the process.	Current industry participants New Entrants New FF Technology Developers ANSP Professional bodies and industry communities	Similar to SMS application, active risk management is already embodied in many aviation organisations and something that new entrants will need to adopt. In addition, current industry participants will need to consider the impact of the rapidly evolving environment where causal factors, mitigations and even hazards may change gradually or quickly. Professional bodies and industry communities will need to play a role to bring together aviation system actors to facilitate whole of aviation system consideration. Recommendation: Ensure new entrants have the ability to develop mature active risk management practices similar to current aviation system stakeholders. Recommendation: Ensure that all aviation system participants consider the changing aviation system landscape and how FF operations will impact the safety of their operations.
Change management (FF Priority Control)	Safety change management defines a process to identify changes that may affect the level of safety risk of a system and to identify and manage the safety risks that may arise from those changes. It should be integrated with other change management activities to ensure it is conducted at the most effective point in the process.	New Entrants New Technology Developers FF Operators ANSP	Similar to SMS application, effective change management is already embodied in many aviation organisations and something that new entrants will need to adopt. However, in aviation the rate of change is historically slow. FF aviation will see more rapid change in a more complex environment with increasingly competing risk issues. Those accountable for safety change management practices will need to consider how faster change and more complex interactions between actors and risks can be managed without impacting the aviation system's safety performance. Recommendation: Ensure new entrants have the ability to develop effective change management practices similar to current aviation system stakeholders. Recommendation: Ensure aviation safety change management practices are adapted to manage the dynamic and complex nature of FF change.

Agile development	An approach to producing systems and software so as to be responsive and adaptive to a rapidly changing environment. There are many different approaches but they are usually based on 12 principles from the Agile Manifesto such as "welcoming changing requirements even late in the development process" with some also embracing safety within the agile framework.	New FF Technology Developers	While relevant to modern systems development practices, this control is not considered specifically relevant to FF and the aviation system. Those using agile development processes should consider how safety change management is assured as part of safety management activities.
Incremental delivery (FF Priority Control)	Provide system and software capability progressively (in small increments) allowing for early stakeholder validation and thus helping to derisk the change and reduce any emerging 'semantic gap'; this is strongly related to the ideas of agile development, and the principle of 'delivering working software frequently'.	New FF Technology Developers ANSP	FF includes some radical changes in how aviation operates. It is envisaged that this approach would be possible on certain products and services. Examples include autonomy and traffic management systems, which may see incremental changes which eventually lead (over many years) to more radical shifts in operational practices from today. Such incremental changes should be strategically planned over the long term. Recommendation: Ensure incremental delivery roadmaps are used to strategically work towards radical change in FF operations.
Decision rationale	Providing reasons for key design decisions so that their significance can be properly understood when responding to requirements for change (noting that many faults and failures arise from incompletely understood change).	New Entrants New FF Technology Developers	As part of effective change management and regulatory approval, new entrants and new FF technology developers will need to adopt such practices as used by mature aviation industry participants.
Diversity and inclusion in decision-making (FF Priority Control)	See the governance layer definition.	Current industry participants New Entrants New FF Technology Developers FF Operators ANSP	Similar to Policy and Regulator organisations, industry participants will need to engage with a wider range of actors than historically required. New entrants and technology developers will also need to engage with a wider set of stakeholders in the urban environment. Recommendation: Ensure appropriate stakeholder diversity and inclusion in FF concept and system development.

Supply chain/network management (FF Priority Control)	Overseeing the supply network to ensure that safety-related elements are identified, traced and managed, for example provenance of critical components, bi-directional flow of safety-relevant information and, where appropriate, risk-informed decision-making to maximise the ability of the supply chain to deliver a safe system as a collective.	New Entrants New FF Technology Developers FF operators	Supply chain/network management will be key especially in the longer term as the trend is away from a vertically integrated supply/value chain approach to more of a service provider approach, e.g. ADSPs, Traffic Management Providers, MRO providers. The ability to define and articulate the safety requirements from the top-level safety objective down through the supply chain (and obtain the necessary assurance) is fundamental to achieving and maintaining strong safety performance in the future aviation system. For autonomy, the historical safety accountabilities may vary with greater assurance required from developers where previously there was an ability to rely on operators/pilot assurance. Recommendation: Ensure practices are in place to manage safety across the supply chain/network. Recommendation: Ensure the impact of autonomy is reflected in safety assurance requirements across the supply chain/network.
Competency management (FF Priority Control)	A 'formal' process for defining and achieving the mix of competencies needed in an organisation to ensure that the (safety) skills required are developed and maintained.	New Entrants New FF Technology Developers	A key issue for competency in FF aviation will be the need to consider how well competency can be maintained as autonomy increases. New entrants will also need to ensure appropriate technical and safety competency to fulfil safety management obligations. Recommendation: Ensure competency management practices evolve as the role of Autonomy increases. Recommendation: Ensure new entrants have appropriate competency management practices in place as part of safety management.
Learning from experience (FF Priority Control)	See the governance layer definition.	New Entrants New FF Technology Developers	No further analysis beyond that in governance layer section.
Safety/assurance cases (FF Priority Control)	The decision to enter a system into operation requires management (and regulators) to be assured that the system is acceptably safe to operate. A safety or assurance case is a structured argument and evidence that can provide sufficient assurance to decision-makers that this objective can be achieved.	New Entrants New FF Technology Developers FF Operators	Similar to SMS application, effective safety/assurance cases are already embodied in many aviation organisations and something that new entrants will need to adopt. Recommendation: Ensure new entrants have the ability to develop effective safety/assurance cases similar to current aviation system stakeholders.

CONOPS (FF Priority Control)	The Concept of Operations (CONOPS) describes the (proposed) system in terms of the user needs it will fulfil, its relationship to existing systems or procedures, and the ways it will be used to foster consensus among stakeholders.	New Entrants New FF Technology Developers FF Operators ANSP	Similar to SMS application, use of CONOPS is already embodied in many aviation organisations and something that new entrants will need to adopt. CONOPS will be an important factor in FF for the supporting infrastructure, including Vertiports and traffic management systems. Understanding the role of supporting infrastructure will be critical to ensure FF technology developers are able to design appropriate interfaces for the wider aviation system. Recommendation: Ensure new entrants have the ability to develop effective CONOPS similar to current aviation system stakeholders. Recommendation: Ensure supporting infrastructure publish CONOPS to enable FF technology development.
System integrator (FF Priority Control)	An authority tasked with drawing together the different parts of a system and making them work together effectively, including overseeing all aspects of safety so that individual parts are safe in themselves and the whole system meets safety requirements.	ANSP New FF Technology Developers	The aviation system has no single overarching system integrator, however the ANSP does play a key role in ensuring that parts of the system work together and overseeing aspects of safety. Going forward ATM, UTM and UnTM service providers will play an important role in system integration. Recommendation: Ensure future traffic management provider roles are defined and their role in system integration is strategically planned.
Task and Technical Layer			
Diversity and redundancy (FF Priority Control)	Redundant architectures, such as command-monitor, duplex and triplex, are well-established and still applicable to elements of complex systems. Diversity, in the technical sense, of providing system parts with different functional or physical implementations to meet the same goals, can help to address sources of emergent properties and thus systemic failures; however, achieving diversity in systems using machine learning currently seems to be beyond the state-of-art.	New FF Technology Developers FF Operators ANSP CAA	Similar to SMS application, use of diversity and redundancy is already embodied in many aviation systems and something that new FF technology will need to adopt. It will be important to analyse how current diversity and redundancy in aviation systems is impacted by new FF technology. Recommendation: Ensure new technology and systems has effective diversity and redundancy to the current aviation system. Recommendation: Assess how existing diversity and redundancy in systems is impacted by new FF systems and operations.

Risk and hazard analysis (FF Priority Control)	Apply 'classical' risk and hazard analysis methods to systems early and continuously through their life, particularly assessing proposed changes before they are implemented, recognising that these will need to be enhanced to deal with the failure modes of complex systems.	New Entrants New FF Technology Developers CAA	Traditional safety techniques will continue to be applied in FF but they will need to be enhanced as the environment becomes more complex and diverse. Ongoing guidance may be required in this area to support the industry particularly for new entrants. Recommendation: Research the application of risk and hazard analysis techniques for complex systems and their adoption in aviation. Recommendation: Ensure new entrants have the ability to undertake risk and hazard analysis techniques similar to current aviation system stakeholders.
Design for assurance (FF Priority Control)	Design systems so that their functions and, in particular, structure make them easy to analyse and assure. For example, using modularity, contract-based design where the interface contracts include safety properties such as failure-signalling and programmed response to failures. To be effective the focus on assurance has to be a critical factor used in design reviews.	New Entrants New FF Technology Developers CAA	Mature design processes are used for critical system components in the current aviation system. Ensuring these practices are considered and applied where required for new technology to enable safety assurance will remain important. Recommendation: Ensure new technology and systems apply design for assurance principles.
Independent assessment (FF Priority Area)	Employ a third-party, independent from the main design time, to assess the design (and other development artefacts) from a safety perspective, to provide independent assurance of safety and/or to expose weaknesses in the design that have been overlooked by the developers. This is established good practice in some domains, such as the rail sector.	New Entrants New FF Technology Developers CAA	Similar to SMS application, independent assessment is already embodied in many aviation organisations and something that new entrants will need to adopt where beneficial. Challenges in its effectiveness have been witness in aviation (e.g. 737 MAX) and these will need to be addressed by the wider aviation industry. Recommendation: Ensure new entrants have the ability to undertaken effective independent assessment similar to current aviation system stakeholders.
Design for cyber resilience (FF Priority Control)	Design systems so that they are resilient to cyber attacks and can provide continued service, recognising that the connectedness of Cyber-Physical Systems (CPS)/the Internet of Things (IoT) provides a significant attack surface and noting that there is also a need to consider the impact of security on safety.	New Entrants New FF Technology Developers FF Operators CAA	This is a critical area of FF. Cyber requirements will need to be built into all interfaces and protocols. There are significant efforts underway across the major aviation standards bodies and governing organisations such as ICAO, EASA and CANSO to address this topic for aviation. The drone and UAM community will feature significant autonomy and remote operation capability which leads to a significant attack surface for cyber threats. These communities may be at the forefront of cyber-resilience techniques for aviation systems. Recommendation: Ensure all FF participants have mature processes to design for cyber resilience.

Inclusive design	To make the system usable by, and safe for, all. Systems must be designed for all users, not just the 'average. Systems should be designed for extremes, such as the elderly or infirm, ensuring that the diversity of users is considered.	New FF Technology Developers	Inclusive design is not known to be a significant issue for safety in FF technology development. However, it should be explicitly considered and addressed where it is required.
Standards compliance	Complying with applicable standards can assist in ensuring safety of systems and system parts. For example, for guarding hazardous machinery there are now conflicts between standards and complex systems, such as requiring physical separation, which can limit the utility of collaborative robotics (cobots). There is a need for intelligent interpretation and application of standards.	New FF Technology Developers	Standards compliance is not known to be a significant issue for safety in FF technology development. However, it should be explicitly considered and addressed where it is required.
Simulation and modelling (FF Priority Control)	Simulation, sometimes known as synthetic environments, and other forms of modelling are useful in obtaining understanding of system and environmental properties early in the development process and hence guiding the design to ensure safety. Simulations can also be 'driven' to explore safety properties to ensure designs are robust, for example assessing air vehicle sense-and-avoid algorithms. The use of digital twins can enable such capabilities to be extended through life, see operation- time controls.	New Entrants New FF Technology Developers FF Operators ANSP CAA	Simulation will be critical for FF. Historically simulation is a key part of aircraft design but going forward it is likely to be an important part of assuring autonomous system behaviour. For example, autonomous aircraft control systems can be tested in virtual airspace with other actors. Going further, it may be one of the only realistic ways of obtaining the necessary level of system/sub-system assurance given the complexities of the system operating environment and the associated potential parameters. Simulation and modelling are expected to support product development, system assurance and operations assurance. Recommendation: Research how simulation and modelling can assist in supporting safety assurance for FF with a particular focus on assurance of autonomy.

C.3 Operation-time controls – detailed analysis

The following table provides:

- Identification as to whether the control is a priority consideration for FF (non-priority controls are grey)
- A general description based upon the description from the Safety Complex System Framework Report with minor edits to improve comprehension
- The key FF stakeholders to which the control is relevant
- An analysis of the relevance to FF
- Key recommendations that should be implemented to assist in ensuring the effectiveness of the control for FF

Control (Priority)	General Description	Relevant Stakeholders	Relevance to FF and recommendations
Governance Layer			
Incident and accident analysis (FF Priority Control)	To prevent future safety occurrences, investigation and analysis of incidents and accidents is a key component of good safety governance activities. A structured approach for individual event investigations or more systemic analysis activities will ensure a more robust result to facilitate the learning of lessons. Trend analysis of events across multiple organisations or within a single organisation may provide additional insight into safety performance, which may indicate the possibility of future safety issues.	CAA AAIB	Incident and data reporting for analysis will be key for FF. With many actors in the system, including new entrants such as UAS, UAM and vertiport operators, the recording and analysis of incidents will be critical. It will be essential to look across multiple organisations in a comprehensive manner to look for trends or common themes. This should include incident and accident precursors. This analysis will provide a valuable source of data for both learning from experience (retrospective use) and using predictive techniques as a planning tool (prospective use). Recommendation: Ensure early proactive incident and accident analysis of FF operations to ensure lessons can be learnt across the FF industry.
Legislation	See the design-time definition		Operational impacts discussed in combination with design-time analysis. No further analysis beyond that in design-time section.
Tort/common law and soft law (FF Priority Control)	See the design-time definition	CAA New FF Technology developers New FF operators	Operational impacts discussed in combination with design-time analysis. No further analysis beyond that in design-time section.
Diversity and inclusion in public engagement (FF Priority Control)	The role of the governance layer in representing societal values means that it is necessary to ensure diversity in public engagement and inclusion of as broad a range of stakeholder viewpoints as is practical when conducting governance layer activities. This is particularly important in legislation and guidance development and must be undertaken in a proactive manner to ensure all societal contexts are considered.	CAA Policy Makers	As FF operations progress in maturity, density and complexity it will be important for both policy makers and regulators to ensure continual representation of societal values. In particular, ensuring that appropriate target levels of safety are defined and achieved for the operation of new FF operations and that they reflect societies expectations is important. It will need to be determined whether these should vary for different types of operation (e.g. drones and UAM). Establishment and continual review of these levels will be important as societal expectations may change through the horizons of FF. Recommendation: Ensure appropriate Target Levels of Safety are defined, achieved and reviewed for Drones, UAM and RAM.

Operational monitoring (FF Priority Control)	Regulators should conduct operational monitoring of organisations to ensure compliance with legislation and that compliance is delivering the intended safety results. Operational monitoring at the governance layers is key to knowing whether intended legislative safety outcomes are being achieved by industry.	CAA ANSP	There is strong value to be gained in real-time monitoring of all aspects of the system with aircraft and operators reporting to the CAA and/or other monitoring agencies. It is expected that a number of the existing top-line safety performance indicators will be valid (accident rates etc.) but new ones will need to be defined to reflect the specifics of the new use cases, new mission types. Enhanced levels of operational monitoring should be in place for new types of operation where there is potential for greater uncertainty of service outcomes. Recommendation: Ensure an enhanced operational monitoring approach is in place for FF operations.
Active alerting (FF Priority Control)	Mechanisms to provide immediate notification of unsafe systems or services to the regulator or safety incidents to relevant governance organisations (such as search and rescue or investigatory authorities) allows timely intervention by relevant authorities in the management of safety occurrences or potential future accidents. Similarly, mechanisms to provide timely safety-relevant information from regulators to organisations (for example, faulty equipment alerts) provides mechanisms for safety knowledge to be shared among stakeholders quickly and effectively.	CAA ANSP	The ATM/UTM/UnTM service providers will have a key role in real-time notifications of safety-relevant information. The CAA and other actors will also need real-time alerting mechanisms. For example, a more modern approach than the current NOTAM systems may be required. The higher tempo nature of FF operations combined with a reduced involvement of human-in-the-loop will increase the significance of effective active alerting systems. There will be less capacity to accommodate latencies between equipment failures and notification to operators or service providers. Recommendation: Ensure active alerting practices are enhanced to manage the high tempo and reduced human control use cases of FF operations.

Management Layer			
Incident and accident analysis (FF Priority Control)	To prevent future safety occurrences, investigation and analysis of incidents and accidents is a key component of good operational safety management practices. Organisations should conduct their own investigation and analysis activities at a more granular level than governance organisations. Organisations should expect to investigate and analyse safety occurrences that governance organisations do not have capacity to review. Events analysed do not have to involve actual negative safety outcomes (such as injury or loss of life) - as much can be learned from minor safety occurrences or near misses.	New Entrants FF Operators ANSP	Similar to SMS application, incident and accident analysis is already embodied in many aviation organisations and something that new entrants will need to adopt where beneficial. Recommendation: Ensure new entrants and FF operators have the ability to undertaken effective incident and accident analysis similar to current aviation system stakeholders.
Safety management system (FF Priority Control)	See the design-time definition. Safety management activities continue through the life of the system to ensure acceptable risk levels are maintained during operation and decommissioning.	New Entrants	No further analysis beyond that in design-time section.
Monitoring and analysis (FF Priority Control)	Safety performance monitoring allows an organisation to verify the safety performance of a system and validate the effectiveness of risk controls. Through-life monitoring and safety analysis allows organisations to track leading and lagging indicators that provide insight into the achieved level of safety and risk.	New Entrants FF Operators New FF Technology Developers	Similar to SMS application, monitoring and analysis is already embodied in many aviation organisations and something that new entrants will need to adopt where beneficial. FF participants will need to understand precursor events and develop indicators that monitor these. This allows a more proactive approach to managing safety and a better understanding of what the key contributors to more severe incidents and accidents are. Recommendation: Ensure FF participants have the ability to undertaken effective monitoring and analysis similar to current aviation system stakeholders.

Organisational resilience (FF Priority Control)	Resilience is the ability of a system to absorb the unforeseeable. At an organisational layer, emergency (or crisis) response plans and business contingency (or continuity) planning frameworks provide mechanisms to ensure that system management and organisational management actions are appropriate in response to foreseen or unforeseen events. Plans should exist at many layers within an organisation to address individual system issues as well as larger organisation events. Resilience planning should be closely linked with risk management activities to ensure that hazards and hazard categories identified can be managed through resilience plans should other controls be ineffective.	New Entrants FF Operators	FF operators should expect things to go wrong in the FF complex aviation system. New entrants may struggle to have mature organisation resilience to cope with failure events. It can be difficult for new organisations to proactively develop the necessary processes and layers to provide good resilience. Organisational structure and processes will need to be carefully checked of these new entrants to ensure their resilience. Recommendation: Ensure FF operators have the ability to develop a mature level of organisational resilience reflective of the current aviation industry.
Contingency planning (FF Priority Control)	A key element of resilience is organisational planning for contingency (or continuity arrangements) where systems or services are disrupted. Contingency planning is focused on return to system operation, prioritising essential systems and services. These may be restored in alternative forms initially.	New Entrants FF Operators	No further analysis beyond that in organisational resilience section.
Change management (FF Priority Control)	See the design-time definition. Any changes that occur during operation should be assessed for their safety impact and the associated safety risks should be identified and managed as part of change management.	New Entrants New FF Technology Developers New FF Operators ANSP	No further analysis beyond that in the design-time section.

Dynamic risk management (FF Priority Control)	The risk of systems in operation varies due to changes in the system and the operating environment. Risk levels are unlikely to stay constant and a dynamic approach to risk management is needed in response. Changes in the system that are not captured by change management activities should be considered on a regular basis along with changes in the operating environment. The effectiveness of controls should be regularly reassessed, as well as the threats that are posed during the systems operation. In-service safety performance monitoring should form a strong part of dynamic risk management alongside knowledge and experience of system stakeholders.	New Entrants New FF Technology Developers New FF Operators ANSP	In FF, a more dynamic view of risk will be necessary than today. The rapidly developing, autonomous and very diverse environment will need new risk identification and management tools. Risk decisions will become more proportional and refined than a broad-brush approach based upon available predictive information. Recommendation: Research how dynamic risk management can assist in supporting operational safety assurance for FF with a particular focus on assurance of autonomy.
Digital twins (FF Priority Control)	A digital twin is a digital replica of a physical system. The ability to simulate real-world activities and integrate this analysis with data from actual experience provides a sophisticated approach to understanding impacts in operation before or even after occurrences.	New FF Technology Developers New FF Operators ANSP	As with simulation, digital twins will be critical for FF operations and will be an important part of understanding autonomous system behaviour. Use of digital twins, particularly by ATM/UTM/UnTM service providers, will enable analysis and predictions to be undertaken. This will allow real-time forecasting/what-if analysis of future operations. Recommendation: Research how digital twins can assist in supporting safety assurance for FF with a particular focus on assurance of autonomy.
Competency management/staff training (FF Priority Control)	Procedures to ensure competency is maintained during system operation are a fundamental component to maintaining an assured operation. Competency must be maintained through management practices and training to ensure that changes in the system or operating environment are responded to, as well as the potential for degradation in human capability.	New Entrants New Technology Developers FF Operators ANSP	The impact of autonomy will include how well humans can maintain required levels of competency when autonomy plays an increasing role in operations. Equally important is how new entrants can maintain appropriate levels of competency in all areas of development and operations in comparison to current aviation organisations. Recommendation: Research how competency can be maintained in FF operations with a particular focus on the impact of assurance. Recommendation: Ensure new entrants have the ability to maintain development and operational competencies similar to current aviation system stakeholders.

Diversity and inclusion in management (FF Priority Control)	As part of a strong safety culture, during operations it is important to embed diverse thinking into operations management, safety performance analysis and resilience functions.	Current industry participants New Entrants FF Operators ANSP	No further analysis beyond that in design-time section.
Supply chain management (FF Priority Control)	Ensuring a good understanding of supply chain dependencies during operations and appropriate controls to mitigate issues in supply is a critical part of maintaining an organisations safety performance in normal conditions and abnormal scenarios.	New Entrants New FF Technology Developers FF operators	No further analysis beyond that in design-time section.
Safety/assurance cases (FF Priority Control)	During operations, the logical safety or assurance case for operations must be maintained to ensure current management have confidence that the operation is acceptably safe to continue. The in-service safety or assurance case may vary in form from that used to introduce a system or change, as it will focus heavily on operational risk management and safety performance monitoring, as opposed to safety analysis and testing.	New Entrants FF Operators New FF Technology Developers	Similar to SMS application, safety/assurance cases for ongoing operations are already embodied in many aviation organisations and something that new entrants will need to adopt where beneficial. FF participants will need to understand precursor events and develop indicators that monitor these. This allows a more proactive approach to managing safety and a better understanding of what the key contributors to more severe incidents and accidents are. Recommendation: Ensure FF participants have the ability to maintain a safety/assurance case for ongoing operations similar to current aviation system stakeholders.
Task and Technical Layer			
Self-monitoring (FF Priority Control)	The ability for systems to self-monitor their performance is an early way to gain insight into operational situations that may indicate failure and/or safety issues now or in the future.	FF Operators New FF Technology Developers	This will be an important feature of the design of autonomous systems. Recommendation: Research how self-monitoring can be used with autonomy for FF operations.

Adaptation (optimisation) (FF Priority Control)	Adaptation allows a system to change in response to changes in the operating environment or the system itself. Adaptation can contribute to maintaining an acceptable operational safety performance.	FF Operators New FF Technology Developers	Current aviation adaptation approaches are relatively simple and have change management practices associated with them. FF systems incorporating autonomy are likely to use much more complex adaptation principles. It will be important to understand how these types of adaptation can be assured. Recommendation: Research how safety assurance can be achieved which allows adaptation to be used within FF operations.
Self-repair	In combination with self-monitoring, self-repair allows systems to ensure an acceptable operational safety performance to be maintained or reintroduced following failure.	New FF Technology Developers	Self-repair operational controls are not known to be a significant focus area for safety in FF technology development. However, it should be explicitly considered where applicable.
Run-time assurance (FF Priority Control)	Run-time assurance provides confidence that a system is operating as expected during operations. Real-time system monitoring in combination with a plan to be executed when failure occurs enhances the robustness of a system.	ANSP	Within aviation, the ANSP provides a critical role in run-time assurance independent of aviation operations. How such a run-time assurance role for aviation can be played by future UTM and UnTM traffic management systems for Drones, UAM and RAM will be an important consideration for overarching aviation system safety. Recommendation: Research how future traffic management systems can continue to provide a run-time assurance function similar to current ATC services.
Human oversight (FF Priority Control)	The abilities of humans to interpret and act on information means that in some situations human oversight can play a critical role in managing system failures or operating environment changes. However, human oversight is not effective in all scenarios.	FF Operators New FF Technology Developers	Human oversight will be an important role in FF but at the moment this is not well defined. Work is required to define optimum roles in humans working to oversee autonomous aircraft operations. Recommendation: Research the role of human oversight in FF autonomous systems.
Cyber-security management (FF Priority Control)	Cyber threats pose significant risks in modern complex systems and a mature cyber-security risk management approach is a critical element of preparing for such scenarios.	New Entrants New FF Technology Developers FF operators	No further analysis beyond that in design-time section.

Task analysis (FF Priority Control)	Task analysis enables an understanding of how humans conduct activities as part of the system. This understanding is important as actions can vary between people, over time or in different environments. It is important to understand variance in task performance to maintain system performance.	New FF Technology Developers FF operators	As the role of the human changes with the introduction of more autonomy it will become important to understand in more detail the role that the human has played historically in aviation. Task Analysis will form part of the human performance management activity and influence the design of the human/autonomous system interface. It will also define how the autonomous system is designed to provide informative feedback to the human both during operation and during failure so that the human can intervene in a safe manner. Recommendation: Research how task analysis can support the transition of FF to greater use of autonomy.
Contingency rehearsals (FF Priority Control)	Practising contingency arrangements for system failure is key to ensure that arrangements are appropriate and that the capability exists to implement the arrangements on demand.	New Entrants FF Operators	No further analysis beyond that in organisational resilience section.

Recommendations and Requirements

D

Recommendations and Requirements D

The following tables provide a list of all recommendations and requirements from the analyses conducted as part of this study. The requirement numbering scheme uses the following approach: X.Y - where X is the Level 1 section number containing the recommendation and Y is a sequential number, e.g. 9.1 is the first recommendation from Section 9. The sequential number restarts from 1 each time the section number changes.

D.1 Priority Recommendations

Recommendation Reference	Recommendation
9.1	Development of a concept of operations for the future aviation system which includes transitionary states.
9.2	Establishment of Target Levels of Safety for aircraft operations, including specific FF use cases.
9.3	Establishment of an aviation system risk baseline made up of both the current risk profile and the future expected risk profile, based upon future concepts of operations.
9.4	Prioritisation of the issues and recommendations in the report and the establishment of a safety work program in support of the FF challenge. This should include, amongst other things, a plan for managing the impacts of complex systems at the Governance, Management and Task/Technical layers. This should also include consideration of the many more detailed recommendations in this report. Consideration should be given to placing the responsibility for developing and delivering this plan on a pan-industry body or, establishing one specifically for this purpose.

D.2 Evolution of Safety Framework Recommendations

Recommendation Reference	Recommendation
9.5	Presentation of the analysis and recommendations to FF participants and the wider UK aviation community to: - Seek feedback on the completeness of the analysis and prioritisation of issues; and - Inform planning of future work across all aviation stakeholders.
9.6	Expansion of the concepts to the full UK aviation system (including other new aviation concepts such as HAPS and autonomous CAT).
9.7	Identification of other additional key safety challenges that can have a critical impact on the success of future UK aviation, both within the scope of FF and other aviation innovation activities.
9.8	Establishment of an international engagement strategy and plan to ensure that the UK remains central to developing and influencing globally harmonised approaches and standards.

D.3 Future Flight Safety Recommendations

Recommendation Reference	Recommendation
6.1	It is recommended that a more detailed review is conducted into the risks attached to cyber related attacks on aircraft flight control systems to understand the potential risks and inform system design activities.
6.2	It is recommended that vulnerability of new aircraft types to loading errors is investigated further and appropriate automated and procedure-based mitigation developed as necessary.
6.3	It is recommended that terrain avoidance systems are specified to operate safely and effectively in an (urban) obstacle-rich environment.
6.4	It is recommended that the threat lines associated with a sample of bowtie diagrams are analysed in more detail to understand the dependencies between controls whether those are human or machine based. The reliance on shared systems (e.g. electrical power from the same source) should also be investigated as part of this activity.
7.1	A joint academic and industry research program should be established to advance understanding in the following areas: - Application of risk and hazard analysis techniques for complex systems and their adoption in aviation - Role of controls in safety assurance of autonomous FF operations - Impact of autonomy - Role of future traffic management systems in providing run-time assurance - Importance of task analysis in supporting the transition of FF to greater use of autonomy.
7.2	An aviation system risk baseline should be established to provide all stakeholders with a common reference for safety risk management and assessment and is especially relevant for multi-stakeholder risks. This should be encoded in a format that facilitates discussions at varying levels within organisations such as risk owner level (i.e. senior management) to safety practitioner level (for assessment and update).
7.3	The aviation system risk baseline should be extended to facilitate quantitative risk assessment where feasible and practical to do so. This should provide valuable risk insights that are complementary to the qualitative baseline but allow more direct comparison against numerical target levels of safety and address issues such as dependency and common cause failure.
7.4	Develop guidance for autonomous system developers to identify and explain the level of assurance and supporting evidence that will be required, including for operations in emergency situations. This will help industry calibrate its expectations early in the product lifecycle development process.
7.5	A roadmap should be developed for the enhancement of ATM and UTM which objectively determines the limits to which the current practices can be extended.
7.6	A concept of operations is developed for Unified Traffic Management (UnTM) airspace which supports new airspace users. UnTM airspace should enable UK operations to maximise performance of UK airspace for all airspace users and be based on current best practice technologies and safety principles. Two types of UnTM airspace are envisaged: unmanaged and managed airspace.
7.7	Establish CNS technology expectations and minimum performance standards for airspace users to operate in unmanaged and managed UnTM airspace.
7.8	It is recommended, that given the criticality of information management to support the operations of the future, that further investigation is undertaken to identify the data requirements and information flows needed to enable the FF vision. This should determine the extent to which manned aviation standards could be adopted in full or where alteration could be beneficial. Alternatively, to support the specific requirements of the FF vision, a new data exchange specification and communications infrastructure may be needed.
7.9	Develop a methodology to understand the safety integrity and assurance requirements for future flight CNS and other supporting technologies.
7.10	Determine the challenges and safety integrity and assurance impact for specific FF technology areas, including communications technology, geospatial and topographical information and autonomous decision making.

7.11	Develop an aviation system architecture which considers the challenges and capability to achieve safety integrity and assurance requirements
7.12	Determine the safety challenges for implementing Vertiports, particularly in the urban environment with the likely complexity of airspace usage.
7.13	Establish a safety change management framework for the establishment of Vertiports.

D.4 Stakeholder Specific Recommendations

Stakeholder	Sub-topic	Recommendation
Governance Organisations	Standards/ Regulation/Law	Determine the extent to which current standards can be applied or adapted to new FF operations using the principles of outcome-based standards supported by Acceptable Means of Compliance (AMCs).
		Develop appropriate standards for FF operations where current standards cannot be adapted using the principles of outcome-based standards supported by AMCs.
		Review how tort/common law are impacting other industries adopting autonomous systems and assess the implications to FF.
	Engagement	Ensure appropriate diversity and inclusion in Policy, Regulation and FF concept and system development.
		Ensure regulators have a practical means to engage with FF industry development during advancement of technology and services.
		Ensure that a mechanism exists for the active management of negative consequences of regulatory engagement in development.
	Safety Performance	Ensure early proactive incident and accident analysis of FF operations to ensure lessons can be learnt across the FF industry.
		Ensure appropriate Target Levels of Safety are defined, achieved and reviewed for Drones, UAM and RAM.
		Ensure an enhanced operational monitoring approach is in place for FF operations.
		Ensure active alerting practices are enhanced to manage the high tempo and reduced human control use cases of FF operations.
Standards/ Professional Bodies, Industry Organisation		Identify key areas where industry community guidelines would support safety assurance of FF and produce a roadmap for their development.
		Establish means for industry-wide learning from FF complex systems incidents and accidents, with a particular focus on smaller FF participants.
		In light of global events in aviation and other safety critical industries, review the effectiveness of learning from experience at Governance and Management Layers in UK Aviation.
Supporting Infrastructure Providers		Ensure supporting infrastructure providers publish Concepts of Operation (CONOPS) to enable FF technology development.
		Ensure supporting infrastructure has a roadmap for Publicly Available Specification (PAS) development which aligns with FF technology development and associated PASs.
		Ensure future traffic management provider roles are defined and their role in system integration is strategically planned.

New Entrants		Ensure FF new entrants understand and adopt the mature aviation industry safety management practice in: principles of High Reliability Organisations, Safety Management Systems, risk and hazard analysis, active risk management, monitoring and analysis, incident and accident analysis, learning from experience as part of an effective safety culture (including Accident investigations), change management, CONOPS development, safety/assurance cases (design and operational risk management), independent assessment, competency management (for operations, development and safety), organisational resilience, contingency planning and contingency rehearsals.
New Technology Developer and FF Operator		Ensure new FF technology development has strong engagement with aviation and urban industry stakeholders and is cognisant of the future landscape.
		Ensure appropriate stakeholder diversity and inclusion in FF concept and system development.
		Ensure incremental delivery roadmaps are used to strategically work towards radical change in FF operations.
		Ensure new technology and systems apply design for assurance principles.
		Ensure new technology and systems provide effective diversity and redundancy in delivery of products/services compared to the current aviation system
		Ensure the impact of autonomy is reflected in safety assurance requirements across the supply chain/network.
		Ensure competency management practices evolve as the role of Autonomy increases.
		Ensure FF participants adapt their SMS to incorporate FF challenges including new concepts, new stakeholders, integrated risk management and complex systems.
		Ensure aviation safety change management practices are adapted to manage the dynamic and complex nature of FF change.
		Ensure practices are in place to manage safety across the supply chain/network.
		Ensure all FF participants have mature processes for cyber resilience (design & operation).
Current Aviation Industry		Ensure that all aviation system participants consider the changing aviation system landscape and how FF operations will impact the safety of their operations.
		Ensure aviation safety change management practices are adapted to manage the dynamic and complex nature of FF change.
		Assess how existing diversity and redundancy in systems is impacted by new FF systems and operations, including the potential for cyber threats to introduce common mode safety-relevant failures.

D.5 Requirements for Future Aviation System Key Elements

Element	Requirement
Airspace Design	Must account for: - Increases in traffic density (greater resolution) - Aircraft autonomy mix - Improvements in CNS technology and associated separation standards - Changes in operating environment (e.g. increased use of vertiports and drone takeoff and landing sites).
	Airspace design must enable all airspace users to operate safely whilst ensuring access and equity and other performance attributes.
	Airspace design must make use of more dynamic airspace structures to improve airspace safety performance or maintain safety performance and enable other performance attributes.
Traffic Management System	Must ensure detection and conflict resolution: - in higher traffic density - with a greater traffic mix - with a greater range of aircraft performances.
	Avoiding action instructions must consider the impact of: - greater traffic density - variability in aircraft performance.
	Autonomy in traffic management systems must: - have the ability to detect, recognise and correct potential conflicts via monitoring - have a mechanism to identify aircraft intent to deviate from a clearance prior to the clearance being executed - achieve an appropriate level of integrity with instructions - be able to consider the aircraft performance and weather when issuing traffic management instructions - be able to consider a query from the FCS - be able to consider an inability to comply with communication from FCS - be able to recognise and manage unusual / emergency events - have the ability to issue avoiding action instructions.
	ATM Autonomy Conflict detection may require an additional independent TMS system from that used for separation.
Flight Control System	FCS must have situational awareness maintained as traffic increases to be able to clarify clearance.
	FCS must be able to continually adapt and develop its knowledge and decision-making ability through information inputs such as PIREPs or other information sources.
	SA tools must consider the impact of greater traffic density.
	Aircraft must have appropriate SA tools: - to allow DAA (Detect and Avoid) - which are compatible with each other.
	DAA procedures must consider the variability in aircraft performance
	FCS autonomy must: - be able to accurately interpret traffic management clearance - have the ability to query a traffic management clearance based upon its own SA - be able to implement avoiding action instructions and ACAS RA procedures - feature diversity in the provision of an independent second protective function that identifies errors in its own actions and perform corrective action. - have the ability to conduct automated weight and balance measurement to ensure appropriate aircraft configuration.

Flight Control System (cont.)	DAA tools and avoiding action procedures must consider the impact of greater traffic density.
	Aircraft must have appropriate DAA tools to allow conflict detection.
	Aircraft must have DAA tools and avoiding action procedures which are compatible.
	ACAS RA (Resolution Advisory) procedures must consider the impact of greater traffic and obstacle densities.
	All aircraft types must have compatible approaches to avoiding action and ACAS RA.
CNS Technology	Accuracy and coverage of Communications Navigation and Surveillance (CNS) infrastructure across all operating environments.
	Accuracy and coverage of CNS infrastructure to support pilot/FCS situational awareness.
Aircraft Design	New aircraft types must achieve: - appropriate cabin design to secure passengers, crew and other objects - appropriate protection of aircraft structural integrity during attempted avoidance manoeuvres - crash protection systems to mitigate the consequences of crash landings - features to allow controlled landings in the event of system(s) failures - appropriate protection against icing, bird strike and other external impacts either through active protection or passive design features - no single points of failure in design, provision of diversity and redundancy in safety-critical functions.
	Aircraft Autonomy systems must fulfil the role played by pilot and cabin crew in adherence to secure cabin SOPs or appropriate revisions to SOPs should be made.
	Aircraft designs must feature greater (than current) levels of controllability and faster responses to control inputs for manoeuvring and avoidance actions especially in urban environments.
Aircraft Collision and Avoidance Systems	Future ACAS should have the ability to: - operate effectively in a range of different operating environments including urban environments - detect potential wake turbulence issues and issue appropriate resolution advisories - respond to multiple simultaneous or near simultaneous conflicts and provide appropriate resolution advisories.

UK Research and Innovation