EXPLORATORY RESEARCH

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FACT

FUTURE ALL AVIATION CNS TECHNOLOGY

This Final Concept of Operations is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 894616 under European Union's Horizon 2020 research and innovation programme.

Abstract

The primary goal of the project FACT is to evaluate the feasibility of a Performance-Based Integrated CNS (iCNS) concept, in order to support today's and tomorrow's air traffic challenges in the most cost-effective way without negatively affecting the overall operational safety. In particular, the project focuses on selected elements of iCNS concept exploring primarily a potential use of cellular networks (4G and 5G) as a complement to the existing CNS technologies within ATM and U space environment, with a particular focus on GA and drones operations.

This Final Concept of Operations represents an update of the Initial Concept of Operations (D2.1) based on the results of the first validation cycle and progress in preparation of the final operational demo. It further refines a description of the targeted operational scenarios, the list of relevant stakeholders and their roles, as well as overall operational and technical context.

The purpose of this document is to provide an operational framework for technical and validation tasks and interpretation of their results.

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1 FACT Project's Objectives

The primary goal of the project FACT is to evaluate the feasibility of a **Performance-Based Integrated CNS** (iCNS) concept, in order to support today's and tomorrow's air traffic challenges in the most **cost effective way without negatively affecting the overall operational safety.**

The main **design objectives for the iCNS concept** include:

- Enable advanced services, extensive operational data collection, and efficient information sharing among different service providers and airspace users (with special focus on drones and general aviation).
- Rationalization and optimization of frequency spectrum usage.
- Improve access of General Aviation (GA) to the airports and airspace.
- Enable access to airports for new users such as UAM and enable evolution of autonomous operations for drones and UAM in the airspace.
- Improve resilience of CNS functions and quicker migration to new technologies.

From technical perspective, the project focuses on selected elements of iCNS concept exploring primarily a potential use of cellular networks (4G and 5G) as a complement to the existing CNS technologies within ATM and U space environment, with a particular focus on GA and drones operations. Associated performance evaluations in real environment will be supplemented with demonstration of tangible benefits for selected stakeholders, namely GA pilots, drones' remote pilots, and controllers.

This Final Concept of Operations represents an update of the Initial Concept of Operations (D2.1) based on the results of the first validation cycle and progress in preparation of the final operationa demo. It further refines a description of the targeted operational scenarios, the list of relevant stakeholders and their roles, as well as overall operational and technical context.

The selected elements of iCNS concept will be validated in different operational environments and the main project achievements will be demonstrated during the flight demo in Eskisehir airport area (Turkey).

The structure of this document is as follows:

- High-level overview of the ConOps is provided in Chapter 2
- Chapter 3 covers description of individual stakeholders
- Characteristics of operational environments is provided in Chapter 4
- Operational scenarios addressed by the project are described in Chapter 5
- Chapter 6 provides detailed description of testing environment to be used for the project's demo

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- Annexes provide more detailed description of current situation from technological (Annex A) and operational (Annex B and C) perspectives.

1.1 Definitions

Aerodrome Flight Information Service (AFIS) is the provision of information useful for the safe and efficient conduct of aerodrome traffic at those aerodromes designated for use by international general aviation where the appropriate air traffic services authority determines that the provision of aerodrome control service is not justified, or is not justified on a 24-hour basis [18].

Common Information Service (CIS) is entity enabling real time sharing of information between ATM and U-space as well as among individual U-space services providers. According EASA Opinion [20], it will be certified and unambiguously assigned by an authority defining the specific U-space (typically State). It consolidates actual traffic data and other airspace related information (such as geofencing zone, restricted airspace, etc.) from all USSPs and ATC / AFIS, and provides access to this information to the relevant stakeholders [20]

Controller Pilot Data Link Communications (CPDLC) is a two-way data-link system by which controllers can transmit non urgent 'strategic messages to an aircraft as an alternative to voice communications. The message is displayed on a flight deck visual display. The CPDLC application provides air-ground data communication for the ATC service. It enables a number of data link services (DLS) that provide for the exchange of communication management and clearance/information/request messages which correspond to voice phraseology employed by air traffic control procedures. [22]

Flight Information Service (FIS) is a service provided for the purpose of giving advice and information useful for the safe and efficient conduct of flights [17]. It is available to any aircraft within a 'Flight Information Region'. The details of FIS may vary throughout Europe due to different national regulations. The core tasks are published in ICAO-documentation (e.g. Annex 11 & Doc 4444) and include the provision of pertinent information in regard to the following elements: weather conditions. Availability of radio navigation services, changes in condition of aerodromes, etc. [21].

Traffic Information Service (TIS) is a service providing provides traffic advisory information to aircraft. within a specified service volume. It is realized in the USA as part of the FAA's Next Generation Air Transportation System (NextGen).

U-Space is a set of new services relying on a high level of digitalisation and automation of functions and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones [19].

U-Space Service Provider supports the safe and efficient movement of drones in the U-space airspace and ensure coordination with manned aircraft. These organizations must be certified to provide U-space services in one or more European member states. To become certified, organizations are required to provide four mandatory U-space services: network identification, geo-awareness, traffic information, and UAS flight authorization.

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1.2 List of Acronyms

ABAS	Airborne Based Augmentation System
ACARS	Aircraft Communication and Reporting System
ACAS	Aircraft Collision Avoidance System
ADS-B	Automatic Dependent Surveillance-Broadcast
AFIS	Aerodrome Flight Information Service
ANSP	Air Navigation Service Provider
AOC	Aeronautical Operational Communications
A-PNT	Alternative position, navigation and timing
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATFM	Air Traffic Flow Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Services
ATSU	Air Traffic Services Unit
BVLOS	Beyond Visual Line of Sight
CE	Computation Element
CIS	Common Information Sharing
CMU	Communications Management Unit
CNS	Communication, Navigation and Surveillance
COTS	Commercial Off-the-Shelf
CPDLC	Controller Pilot Data Link Communications
CTR	Controlled Traffic Region
D8PSK	Differential 8-Phase-Shift-Keying
DCDU	Datalink control and display unit
DME	Distance Measuring Equipment
DSR	Drone Surveillance Radar

EASA	European Union Aviation Safety Agency
eID	Electronic Identification
FAA	Federal Aviation Administration
FIS	Flight Information Service
FLARM	Flight Alarm
FMS	Flight Management System
GA	General Aviation
GAMA	General Aviation Manufacturers Association
GBAS	Ground Based Augmentation System
GCS	Ground Control Station
GES	Ground Earth Stationatsu
GNSS	Global Navigation Satellite System
GSM	Groupe Spécial Mobile
HF	High Frequency
HSS	Home Subscriber Server
ICAO	International Civil Aviation Organisation
IETF	Internet Engineering Task Force
IFD	Instrument Flight Deck
IFR	Instrument Flight Rules
ILS	Instrument Landing System
INS	Inertial Navigation System
IPS	Internet Protocol Suite
IRS	Inertial Reference Systems
MCDU	Multi-function control and display unit
MEL	Minimum Equipment List
MIMO	Multiple-input multiple-output
MLAT	Multilateration

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MME	Mobility Management Entity
MTOW	Maximum Take-off Weight
NAV	Navigation
OSI	Open System Interconnection
PBN	Performance Based Navigation
PCRF	Policy and Changing Rules Function
POC	Proof-Of-Concept
PSR	Primary Surveillance Radar
P2P	Peer-to-peer
P-GW	Packet Data Network Gateway
QNH	Mean Sea Level Pressure
RAIM	Receiver autonomous integrity monitoring
RNAV	Area Navigation
RNP	Required Navigational Performance
SBAS	Space Based Augmentation System
SSR	Secondary Surveillance Radar
SVFR	Special visual flight rules
SWaP	Size, Weight and Power Consumption
SWIM	System Wide Information Management
S-GW	Serving Gateway
TIS-B	Traffic Information Service – Broadcast
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UAT	Universal Access Transceiver
USSP	U-Space Service Provider
UTM	Unmanned Traffic Management
VDL	VHF Data Link

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VFR	Visual Flight Rules
VHF	Very High Frequency
VLOS	Visual Line of Sight
VoIP	Voice Over Internet Protocol
VOR	VHF omnidirectional range
WAAS	Wide Area Augmentation System

2 Concept Outlines

As stated in introduction, the project FACT focuses on selected elements of iCNS concept exploring primarily a potential use of cellular networks (4G and 5G) as a complement to the existing CNS technologies in ATM and U space environment. The main goal is:

- Technical evaluation of 4G/5G performance in the context of individual CNS functions.
- Assessment and demonstration of benefits resulting from the explored CNS enhancements for operational safety and individual stakeholders: GA pilots, remote pilots of drones, and ATC.

This Concept of Operations aims to describe broader context of the addressed CNS enhancement and therefore it includes elements which won't be fully evaluated in the project validation activities (further specified themselves in the validation plan D5.1). It is and will be complemented with the additional technical deliverables providing more detailed description of the architecture (D2.2 and its update D2.4) and systems (D3.1 and its update D3.3) used within the project.

2.1 Core CNS Functions and CNS Applications

This concept distinguishes two terms:

- **Core CNS functions** are technological elements addressed within the technical validations and/or analysis of technology's limitations.
- **CNS applications** respond to some specific operational needs and are built from one or more of the core CNS functions. CNS applications will be used to define performance requirements for technical validation of the individual CNS core functions. In addition, selected CNS application will be implemented at proof-of-concept level to demonstrate operational benefits associated with the explored CNS enhancements.

At this stage, the following core CNS functions are planned to be explored within the project:

- Air → Ground data-link (e.g., for aircraft's broadcast)
- Ground → Air data-link (e.g., for ground information provision services)
- Air ↔ Ground data-link (for both direction air-ground digital communication)
- Ground-based positioning (for purpose of ground surveillance)
- Airborne positioning (e.g., for NAV and position reporting)
- VoIP (e.g., for communication between remote pilot and ATCo)

The set of considered CNS applications includes:

- Ground surveillance service (using vehicle's report such as ADS-B, eID (U-space) or similar, and/or ground-based positioning (if complexity allows to include it)): Proof-of-Concept (POC) implementation is planned for position reporting using cellular network.

- Information Sharing service (uplink of operational information from ATM/U-space to vehicle, FIS/TIS like services): POC implementation planned for traffic information service and geofence information sharing.

- Situation awareness applications for GA, drone's remote pilot and ATCo benefiting from the above two services: POC implementation planned using dedicated displays.

- CPDLC or similar type of communication between vehicle/pilot and ATC/U-space service provider: requirements analysis planned.

- CNS applications supporting 4D trajectory management (ground conformance monitoring, airborne capability to adhere to agreed 4D trajectory, etc.): requirements analysis planned. POC implementation of conformance monitoring and associated alerting planned as well.

2.2 Operational and Performance Requirements

The CNS applications described above aims to answer the functional requirements of the given operational environment. Corresponding performance requirements are driven by the way how the outputs of these CNS applications will be used within ATM/U-space services. In this context, it is proposed to consider four conceptual levels of performance requirements for assessment of explored technologies. These levels are based on typical layers of conflict management used in ATM and also envisioned for U-space and they are therefore sufficiently generic to be used for both of them:

- Level 1 – **Advisory Services**: the CNS information is used only to support situation awareness and the users cannot rely only on them. AIS/FIS/TIS services are a typical example of this performance level. Results of the SESAR project 14.2.5 represents a nice baseline for GA users and this category.

- Level 2: the CNS information/application are used for **strategic deconfliction** (4D/3D/2D trajectory based). This level requires that a vehicle is able to fly the agreed trajectory within the pre-defined limits (rates of potential deviations/failures being on the acceptable level), and that CNS functions support efficient conformance monitoring.

- Level 3: the CNS information is used for **tactical deconfliction (separation management)**.

- Level 4: **Collision avoidance** as the last layer addressing the situations when the previous conflict management layers fail.

In the operational demo, only Level 1 is expected to be implemented, however, complemented with conformance monitoring and associated alerting (Level 2). In addition, the project is going to measure CNS performance in support to Level 2 and 3. Collision avoidance systems (Level 4) are not included in determining the calculated level of safety required for separation provision as they are considered as safety nets. Although these systems can and will benefit from the addressed CNS enhancements, they are not primary focus of the project and only limited and high-level performance considerations will be included.

2.3 FACT Project's Approach

The main goal of this concept of operations is to specify the operational scope (represented by a set of operational scenarios) addressed by the project's operational demo. The same scope is also used as reference for complementary technical validations focused on selected CNS performance characteristics of 5G networks.

The operational analysis of the above scenarios was used to draft CNS performance requirements related to targeted ATM/U-space services. Performance requirements were proposed based on earlier research (e.g., SESAR 14.2.5, CORUS) and/or similarities with existing ATM services. It is expected that investigated technology will allow to build a solution for targeted set of services but the limitations and gaps will be of course analysed and documented when identified.

As described in PMP, the project FACT includes two steps validation approach driven by the above operational scope. The first set of validations (performed mostly in 2021) was focused on technical validations of core CNS functions.

Results of this first validation step was used to refine design/implementation of CNS applications and overall setup for second validation step (operational demo) which is under preparation for summer 2022. This final ConOps document represents an update of the initial ConOps using these results and is used as a reference for preparation of that final operational demo.

It should be emphasized, that the purpose of the project is to explore CNS enablers of ATM/U-space services, not the services themselves. In this context, the focus of the validation activities is on demonstrating that CNS functions/technologies can support the ATM/U space services described in the operational analysis, not on evaluating maturity and performance of some particular implementation of these ATM/U-space services.

3 Stakeholders

3.1 Air Traffic Management: Air Traffic Service Providers

The objective of ATM, as a complex net with both air and ground based systems, is to perform safe, fast, economical and orderly air traffic flow in all phases of flight. Performed communication, navigation and surveillance operations with this objective are dynamic and integrated with ATM manpower interactions.

Air traffic management comprises of three main services:

- **Air traffic services (ATS),** with the general purposes of ensuring safe and orderly traffic flow (facilitated by the air traffic control (ATC) service) as well as providing the necessary information to flight crews (flight information service, FIS) and, in case of an emergency, to the appropriate (e.g. SAR) bodies (alerting service). ATS is mostly performed by air traffic controllers. Their main functions are to prevent collisions by applying appropriate separation standards and issue timely clearances and instructions that create orderly flow of air traffic (e.g. accommodate crew requests for desired levels and flight paths, ensure continuous climb and descent operations, reduce holding times in the air and on the ground). ATS relies on tactical interventions by the controllers and direct communication with the flight crews usually during the entire flight.

- **Air traffic flow management (ATFM),** the primary objective of which is to regulate the flow of aircraft as efficiently as possible in order to avoid the congestion of certain control sectors. ATFM measures can be seen as pre-tactical, as they do not affect the current situation but rather the near future.

- **Airspace management (ASM),** the purpose of which is to manage airspace - a scarce resource - as efficiently as possible in order to satisfy the needs of its many users, both civil and military. This service concerns both the way airspace is allocated to its various users (by means of routes, zones, flight levels, etc.) and the way in which it is structured in order to provide air traffic services.

The diagram below shows the structure of ATM and explains the relations between ATM, ATS and ATC.

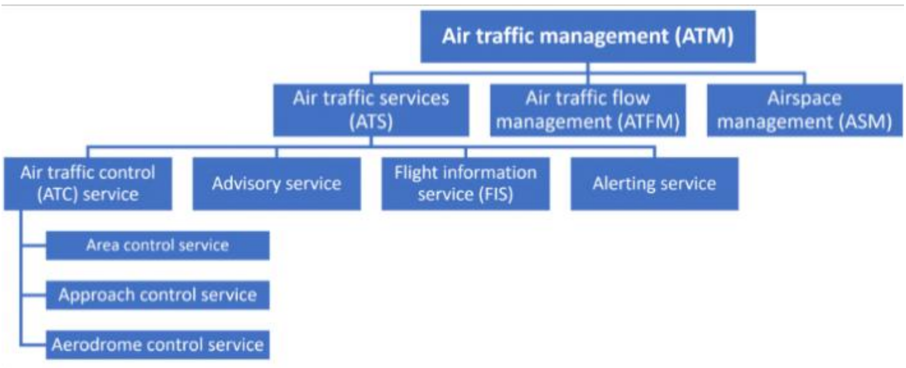

Figure 1 Structure of the ATM (Source: Skybrary)

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Within the FACT project, the focus is given on ATS part of ATM, and more specifically on ATC and FIS. From CNS perspective, traffic surveillance providing ATC with necessary situation awareness and communications ensuring proper interaction of ATC with aircraft/flight crew are key enablers of ATS. Dynamic airspace allocation by ATC between manned and unmanned airspace is planned to be considered.

3.1.1 Current CNS Systems Used by ATC: Surveillance

Main technologies used by ATC for purpose of surveillance are Secondary Surveillance Radar (SSR), Wide Area Multilateration (WAM) and the Automatic Dependent Surveillance – Broadcast (ADS-B)[1]. All three of them are relying on aircraft avionics, in particular a transponder and in case of ADS-B also on airborne navigation using GNSS. Only a short summary of technologies is provided here, more details being included in the Annex.

PSR/SSR

SSR is a radar system used in ATC which regularly interrogates aircraft in its range. Aircraft equipped with transponders replies to the transmission with encoded message containing requested data. Transmitted data depend on communication mode. More details are provided in the Annex. SSR is often collocated with PSR, its predecessor which is able to detect non-cooperative aircraft based on reflecting radio signals.

WAM

Wide Area Multilateration is a method used for en-route surveillance. It consists of system of beacons receiving the transponder signals. The position is calculated by the Time Difference of Arrival (TDOA) principle (triangularization). Performance of WAM system is similar to SSR and the system is able to work only in passive mode (no interrogation).

ADS-B

Automatic dependent surveillance broadcast (ADS–B) is a surveillance technology in which an aircraft broadcasts periodically its position and other information. No external stimulus is required (that's why it is automatic), but it relies on on-board navigation sources (GNSS) and on-board broadcast transmitting subsystems (that's why it is dependent) in order to provide surveillance information to other users. There are several frequencies which can be used to transmit ADS-B messages but only 1090 MHz Extended Squitter is standardized in European airspace.

ADS-C

Automatic Depended Surveillance – Contract differs from ADS-B in a fact that data are provided based on specific contract between aircraft and ANSP.

3.1.2 Current CNS Systems Used by ATC: Communications

VHF Radio

Communication through Very High Frequency is still the most common communication mean between aircraft and ATC. It provides capability for both voice and data communication. Limitation of VHF is the need of line-of-sight. The range can theoretically reach 250 NM, but practically is lower.

Capacity of VHF link is limited. The assigned frequency range is 118 to 137 MHz. Original channel spacing was set to 200 kHz and the value was sequentially reduced up to current 8.33 kHz required in Europe.

CPDLC

The Controller–pilot data link communication (CPDLC) provides air to ground data for the ATC. Controller is able to issue a message to the pilot. Messages can contain flight level assignment, route changes, clearances, speed assignments, radio frequencies change and request for information. Pilot can respond, request clearance and provide required information. Benefits for ATC are possibility to simultaneous dealing pilot's requests, increasing capacity and reduced risk of miscommunication. Data link technologies used for implementation of CPDLC are discussed in the Appendix A.1.

3.2 U-space Service Providers and Common Information Service Providers

New EASA regulation package ([20]) defines two types of services providers for the U-space:

- U-space services providers (USSPs) providing a set of U-space services to UAS operators; and
- Common Information Service (CIS) provider responsible for managing information sharing service among individual USSPs and also with ANSPs (ATC).

According the EASA definition there is always only one CIS provider for a given U-space airspace but there may be multiple USSPs providing services at the same time in this airspace.

Most of the services defined in CORUS ConOps as well as in EASA package are not directly coupled with any specific technology and the particular technological solution is left on USSPs. However, based on the results of U-space demo projects, cellular network is the most often explored non-aerospace communication technology for U-space so far – both for communications and position reporting.

There are two main sources of the definition of potential U-space services: CORUS ConOps [5] and EASA U-space regulation package [20], however they are not fully compatible. While CORUS ConOps aims to provide longer term vision considering 4 gradual deployment steps of U-space services as shown in Figure 2, the current EASA regulation framework focuses on the first deployment steps.

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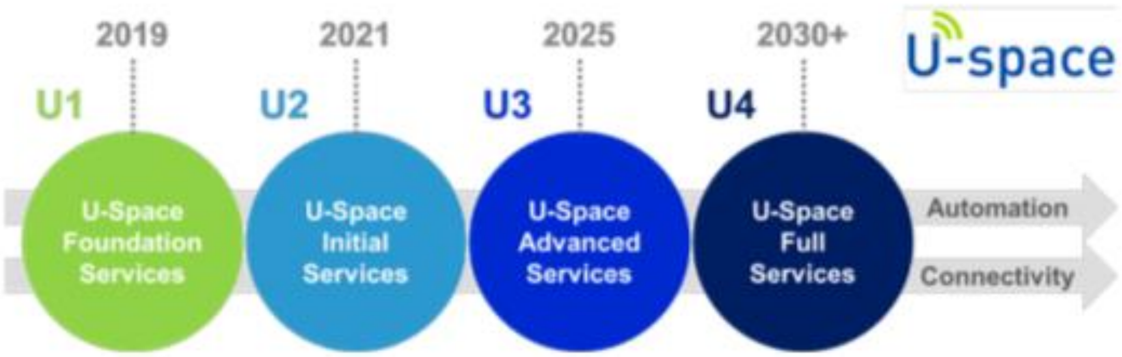

Figure 2: U-space implementation road map. Source: Eurocontrol (2020). U-space services implementation monitoring report (November 2020).

Phase		Service	
U1	Foundation Services	U1.1	e-Registration
		U1.2	e-Identification
		U1.3	Pre-tactical Geo-fencing
U2	Initial Services	U2.1	Tactical Geo-fencing
		U2.2	Flight Planning Management
		U2.3	Weather Information
		U2.4	Tracking
		U2.5	Monitoring
		U2.6	Drone Aeronautical Information Management
		U2.7	Procedural Interface with ATC
		U2.8	Emergency Management
		U2.9	Strategic De-confliction
U3	Advanced Services	U3.1	Dynamic Geo-fencing
		U3.2	Collaborative Interface with ATC
		U3.3	Tactical De-confliction
		U3.4	Dynamic Capacity Management
U4	Full Services	-	TBD

Figure 3: U-space services framework. Source: Eurocontrol (2020). U-space services implementation monitoring report (November 2020).

EASA defines for the first U space deployment a set of mandatory services:

- Network identification service (covering from CNS perspective position and state reporting in line with EU regulation 2019/945)
- Geo-awareness service (requiring upload of geo-awareness information)
- Flight authorization service

- Traffic information service (potentially supported by tracking service and conformance monitoring service).

Beyond this basic set which is required for all U spaces there may be additional services (e.g., by Weather service), implemented and even required by regulator for specific airspaces.

3.3 Airspace Users: Commercial Aviation

Generally, it can be said that commercial aviation exploits mostly (although not exclusively) controlled airspace typically through IFR flights with separation management provided by ATC. This description conforms to airspace class A, B, C and D (as discussed in Section 4.1).

Airspace for cruise exploited by the commercial aviation is usually the highest airspace class in given country. Airspace in CTR of controlled airport is usually class C or D.

3.3.1 Current CNS Equipment Relevant Notes

Communication and surveillance equipment are mostly mentioned already within ATC description above. Beyond transponder potentially with ADS-B Out capability supporting ground surveillance, an aircraft has typically own systems to survey traffic in surrounding. TCAS II (or ACAS X in future) interrogates transponders of nearby aircraft and there may be also ADS-B In function processing ADS-B reports from neighbour traffic.

GNSS+INS is the cornerstone of nowadays area navigation with undoubtable benefits. Some limitations exist, especially in performance in difficult environments, rate of availability and security issues. Difficult environment can represent for instance area of airport where multipath interference is caused by the satellite signal reflection through airport buildings.

Common technology trends include multi-constellation receivers which will become valuable with the recent completion of the BeiDou and Galileo constellations; there are therefore four global GNSS systems (GPS, GLONASS, BeiDou, Galileo) envisioned in the future.

Multiple sources navigational solution including A-PNT aiding provides protection measure against GNSS security threats. Next, price of all types sensors continue to drop which enables integration with GNSS into "kind of 'metasystem', combining various technologies where each subsystem contributes to the performance of the others and where the seamless integration of space and ground components is key to achieving truly global ubiquity" [1]. It makes sense to use positioning in 5G where this capability is integral part of the system contrary to previous generations of networks.

In addition, opportunities to use 5G for aeronautical communications (including safety critical) of commercial aviation (such as CPDLC) should be further explored. Nevertheless, this type of cellular network applications won't be demonstrated in this project.

3.4 Airspace Users: General Aviation

SESAR's Masterplan defines General Aviation (GA) as follows:

- Civil Business Aviation - Fixed Wing

- Civil Business Aviation - Rotorcraft
- Civil Flight Operations Centre
- Civil General Aviation
- Civil Scheduled Aviation
- Civil Unmanned Aircraft System

The scope of FACT, however, is future technical improvement of communication, navigation and surveillance (CNS). A wide range of operating profiles of various airspace users, as defined by air speeds, altitude, airspace classes used, CNS equipment available, and flight rules to be followed, has to be considered. A future ATM environment should enable a safe, high capacity and cost effective seamless operations for all airspace users, regardless whether they fly autonomous or under positive control, on fast or slow, at high or low altitude, under AOC or private operation, just mentioning only a few modes.

Table 1 below summarises some typical characteristics

Airspace User Domains	Aircraft Type	Flight Rules	Operating in AirSpace Classes…	Operating from/to…, Take-off / Landings sites
Business Aviation (BA)	Fixed wing aircraft / from Long range Jets to single engine piston, single + multi engines , but also rotorcraft	Mostly IFR, with changes to VFR, day and night	All	Ops. concept very similar to Commercial Aviation + optionally operations to uncon-trolled aerodromes
Private Aviation	Mostly fixed wing single engine piston, rotorcraft, twins, turbine, experimental a/c, includes most ultra light a/c.	Mixed VFR / IFR, day and night, special regulations, e.g. for training, air work, and test flights exist	All	All types of aero-dromes, off aero-dromes only in cases of emergency
Rotorcraft	*Mixture of Business Aviation and Private Aviation, special operating profiles are described in section 2.2*	Mixed VFR / IFR, day and night, special regulations, e.g. for training, air work, and test flights exist	All, but typically in low and medium altitudes	All types of aero-dromes, off aero-dromes routinely
Air Sports / Aerobatics	Gliders, hang gliders (with/without engine), gyrocopters, balloons, airships / zeppelin / blimps	VFR only, day only	Classes D,E,G, others with special clearance	Public and special use aerodromes, off-aerodrome landing routine for gliders, any obstacle free area for others
Air Taxis	Air Taxis (piloted or autonomous)	*TBD, currently under special regulations.*	Classes D,E,G, others with special clearance	Any aerodrome and off-aerodrome ops. special use landing sites

Drones	Drones (piloted or autonomous)	*TBD, very low altitudes only, minimal distance to aerodromes, other special regulations*	Classes D,E,G, others with special clearance	Any aerodrome and off-aerodrome ops.

Table 1: GA Domains

3.4.1 Current CNS Equipment

The GA fleet in Europe is very inhomogeneous with regard to age and technology of avionics. As there never had been a plan for a future common CNS structure in Europe, in lieu thereof ad-hoc solutions for immediate needs were mandated. Examples are Transponder Mode-S without ES1090 squitter and ADS-B, and analogue VHF communications with 8,33 kHz channel spacing for central Europe only. As a result, a part of AUs had limited benefit in exchange for a costly investment, and are reluctant now to invest into anything else without a clear way into the future. The usages and the deficiencies described below should become a basis for discussions of a future technical concept.

Figure 4: Change of cockpit equipment over time:

(1) 2015: G500 Digital Glass cockpit, IFR, PBN with Autopilot

(2) 2005: Analog Instruments augmented by G430W, IFR, limited PBN, Autopilot

(3) 1995: Analog Instruments only, VFR only, augmented by FLARM / ADS-B-in Traffic information display, no Autopilot

Considering the fact, that today nearly all routine voice communications consist out of keywords and numbers (QNH, waypoints, headings, frequencies, …), whereby most of them have to be repeated by the listening party to correct frequent misunderstandings, the effective data transfer rate of information in voice calls is less than 10 bit/s. This compares to some kilobit/s even in slow digital data communications. It is obvious that the scarce resource of spectrum could be used more wisely. Voice

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communications, however, will always be required for the non-routine communications between air and ground, either in broadcasts or point-to-point connections.

All the GA representatives could profit from broader information sharing like the Flight Information Service (FIS) and the Traffic Information Service (TIS). FIS-B and TIS-B broadcasted in USA as one of the motivations to ADS-B equipment can serve as an example.

3.5 Airspace Users: Urban Air Mobility

Urban air mobility (UAM) in principle covers mobility services in an urban environment using air vehicles. This can potentially include many different types of vehicles such as helicopters, various types of drones or flying taxis. Nevertheless, the term is the most often used having in mind exclusively flying taxis with alternative (electrical) propulsion (typically so-called eVTOL aircraft) operating at low and very low altitudes of suburban and urban areas.

Regarding the navigation, all said in Commercial Aviation section is also valid - It makes sense to use positioning in 5G where this capability is integral part of the system contrary to previous generations of networks.

3.5.1 Envisioned CNS Equipment for initial deployment

CNS equipment for Urban Air Mobility (UAM) early deployment must take into account some specifics of these vehicles and its operation. First specific means that UAM will very probably be all electric vehicles. This means that avionics will be based on batteries and this fact strongly affect the Size, Weight and Power Consumption (SWaP) requirements on equipment. Weight of the vehicle will be a very important factor for performance in terms of range and payload. The higher weight then means the bigger and heavier batteries – and probably very limited space in the vehicle for avionics with its batteries. Use of ground infrastructure to the maximum possible extent seems to be sensible in minimalizing amount of onboard equipment.

Navigation task has also some specifics in case of UAM operation. Per NASA study [Patterson, M. A Proposed Approach to Studying Urban Air Mobility Missions Including an Initial Exploration of Mission Requirements, 2018] it is assumed that majority of UAM traffic will be above cities in altitudes between 500 and 5000 feet. Lower altitudes in city environment brings higher risk of GNSS degradation (for example, landing at rooftop of building in other very high buildings surrounding). This means even higher need of alternate positioning source for backup navigation data or for data fusion. Required navigation performance for these operations still must be defined and it will drive the design of UAM navigational equipment.

Communication requirements for UAM operation need to be discussed and specified for both air-to-ground (vehicle to UTM service provider) and air-to-air (vehicle to vehicle). Datalink for safety critical information will without doubts need to contain some backup solution. Datalink can be based both on commercial and preserved aviation spectrum.

Conventional surveillance means can be used for UAM operation with consideration to low altitude and city environment specifics. Low altitudes can represent issue for detection by secondary radar. ADS-B Out equipment seems to be a reasonable option, but risk of 1090 MHz saturation must be considered. There is motivation to use ground surveillance infrastructure as much as possible. At the same time, interoperability with standard ATM systems is necessary as these vehicles aims to operate also in conventional ATM airspace, for instance, during approach to airport.

3.6 Airspace Users: Drones

The demand for drone operations and their enabling technology is firmly growing, with the potential to generate significant economic growth and societal benefits. Drone's use is spreading from military purposes as historically first ones to wide spectrum of human activities as photography, filming, police, fire fighting, environment monitoring, weather forecast, advertising, small cargo transport and so many other activity areas.

There is wide scale of drones from the ones intended only for recreational use to the most advanced vehicles for governmental and industrial use. Categorization can be done per weight, purpose, construction etc.

Basic construction categories are fixed wing drones and rotor drones (often multirotor). Differences between fixed-wing drones and multirotor drones drives their suitability for different applications consumers want to use the drone for. For example, multirotor drones do not need a landing strip and can hover in the air. Fixed-wing drones can fly faster and are more suitable for long distances use cases than their multirotor counterparts. Hybrid drone uses multiple rotors to take-off and land vertically but usually has also wings so it can fly longer distances.

Next possible division is based on the level of autonomy. The autonomous aircraft are currently used mainly for military purposes, but high rise e.g. in area of transport small packages is expected. The autonomy can vary from full autonomous operation to drone fully controlled by a remote pilot.

3.6.1 Current CNS Equipment

High level approach to the avionics systems used for drones is generally adapted from the manned aviation, but there are some important differences resulting from unmanned vehicles specific requirements (communication datalink - telemetry, actuation for flight control and autopilot, often all electric operation).

Avionics used in drones is often not developed per aerospace standards and it is made from COTS components. Especially for smaller drones and simple operations, it is significantly lighter, simpler and made with stronger focus on affordability than avionics for manned aviation. The description below will be focused to this type of drones because they demonstrate bigger difference from standard manned avionics.

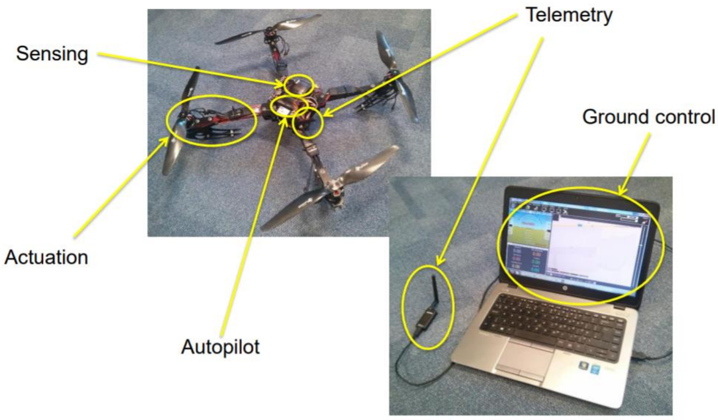

Figure 5: Drone System Components [2]

Technologies used for drone[2] avionics are typically six axis accelerometers, 32-bit microprocessors, GPS and barometers, potentially open source SW and enabling advance in sensors, displays and batteries. DJI or Pixhawk can be considered as representative hardware platforms and the telemetry links are typically realized by Bluetooth, Wi-fi or proprietary links. There are also available flight stacks (airborne software applications) as PX4, Ardupilot or proprietary flight stacks (e.g., from DJI). Specific protocols for data transmission as MAVlink increase systems interoperability.

Navigation is generally solved by IMU on one chip combined with GPS chip. Surveillance (within the meaning of other aircraft detection) is most effectively realized by non-cooperative sensor installation, such as radar or electro-optical or infra-red camera. Within the meaning of “to be seen”, there is an upcoming mandate of the electronic remote identification for most types of drones. This requires direct periodic broadcast of drone identification and position data of drone and remote pilot. Remote identification represents important step in drone’s integration into airspace.

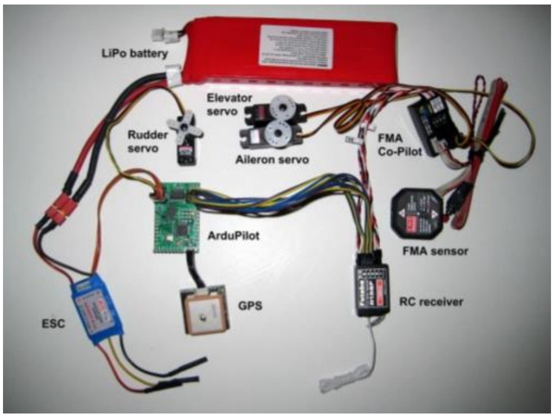

Figure 6: Example of Drone Avionics [2]

3.7 Non-ATM/CNS Communication Service Providers: Terrestrial Cellular Network

This section describes the benefits of a terrestrial cellular network approach based on 4G /5G technology. This network will utilize ground stations connecting with vehicles (aircrafts, drones, helicopter, …) flying overhead, providing a broadband backhaul infrastructure for deploying high-bandwidth, in-flight connectivity. 4G/5G based solutions use an all-IP architecture that, combined with geographic redundancy, reduces potential points of failure and provides the high availability. This also allows operators to build a complete, highly cost-effective, end-to-end network, including core,

[2] This description is related to majority of commercially available drones except the cheapest ones like toys.

backhaul, Radio Access Network (RAN) and modem or end-user devices. Its end-to-end QoS, from the core down to the terminal or user, allows mission-critical services and passenger connectivity on the same infrastructure depending on the requirements. The usage in aviation needs more investigation to define the requirements and the resulting solutions. It provides high throughput for both uploads and downloads and also very low latencies. An additional aspect of the system is the very short time to install this solution on aircraft. 4G/5G networks are based on fully standardized, future-proof technology. A schematic E2E architecture for a 4G network is shown in Figure 7.

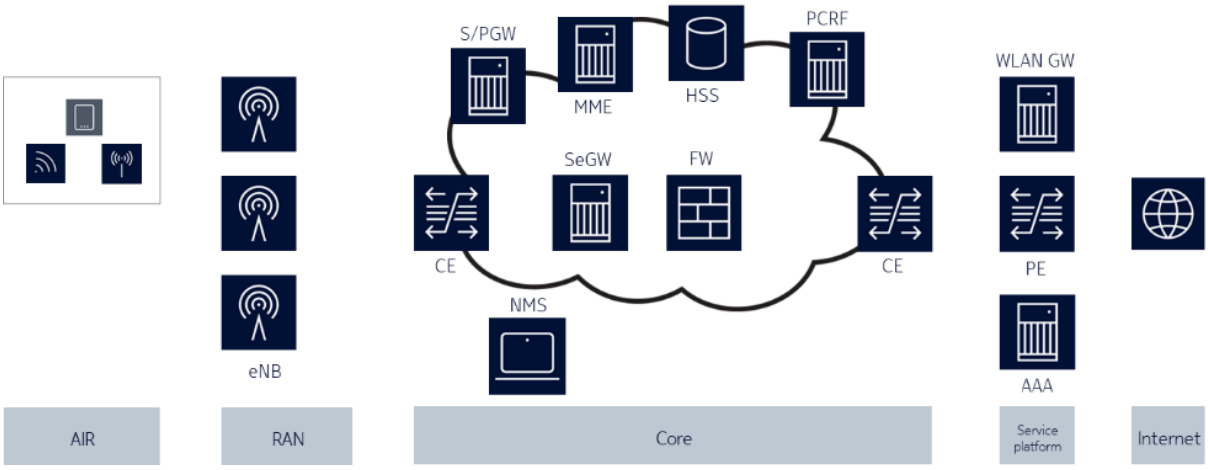

Figure 7: Terrestrial Cellular Network

Cellular systems also offer extensive self-optimizing capabilities for simplified network operations, maintenance and self-healing. They are secure by default, with integrated encryption, access control and authentication.

As illustrated in Figure 8 cellular networks have the capabilities to serve different user groups in a broad altitude range depending on the requirements. Also, densification in areas with higher demands are easy to realize.

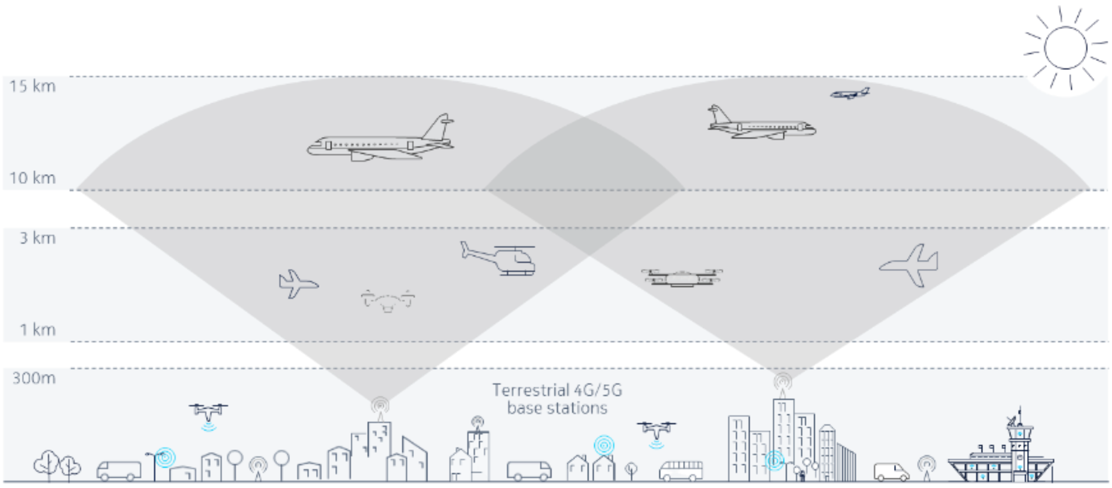

Figure 8: Terrestrial Cellular Network

With vehicle flying below 100m, we can expect terrestrial coverage to fully take care of any needs with regards to quality of service. However, altitudes up to 500 meters or even higher ones in Upper controlled space and other control zones, need to have special layer of coverage that is designed and optimized for such services. In these cases, up-tilting of antennas and deployment of separate frequency layers are among few examples of such technical solutions.

3.7.1 Spectrum Usage

To provide connectivity from the flying vehicles to the ground two potential approaches should be discussed. One of the most important aspect is the available spectrum. Therefore, one potential approach would be the usage of existing public networks with the already assigned spectrum. Technically, some issues must be analysed. The deployment of terrestrial public networks is based on radio network planning for the ground (up to hills and high buildings) but have not considered coverage in areas in several 100 meters above the ground. Due to reflections and antenna patterns the assumption and some initial test from other companies implies in areas up to 500m above ground coverage in many cases. But the quality and/ or interference needs more analyses and maybe tests Also, the interference from the flying vehicle could lead especially in urban areas to high interference of the user on the ground.

From the frequency standpoint we can expect urban areas to be covered with 5G faster, thus expecting usage of C band and consequently mmWave coverage mainly in cities as those are more frequently points of business interest. Rural areas will be covered with basic sub GHz 5G layer and unlike in urban areas, the available bandwidth would be quite limited for some time. So It is expected that all applications (data link, navigation etc..), that would have greater demand for bandwidth, will have under typical commercial set up smoother performance in urban areas, at least until further 5G rollout stages.

Potential improvements could be achieved by using devices in the vehicles, which selects (best signal strength) or combines (collect all available signals) different available public networks. This could improve the coverage but also the quality of the signal and therefore the availability of the services and the data throughput. The devices on board need to operate in the 3GPP bands which are used from the major service provider in Europe. Also, the antenna design should take this requirement into consideration.

One very important point needs also a clarification. What is the requirement on the network availability and service quality which need to be discussed and agreed with the service provider in each country?

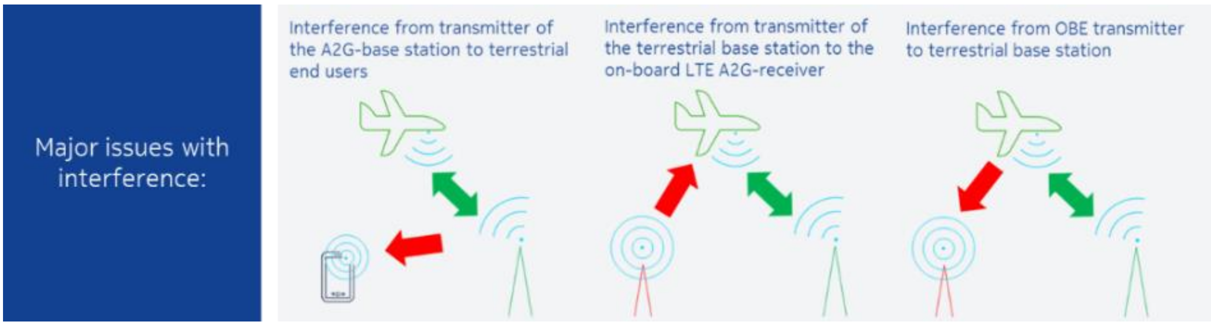

Figure 9: Major Issues with Interference.

In case the requirement is an unique European network to enable a mission critical connection, the A2G network requires a dedicated infrastructure decoupled from established cellular networks designed for “normal” terrestrial mobile broadband applications. In case existing cellular networks shall support flying vehicles interference is the major issue which would be difficult to solve as discussed in Figure 9.

Therefore, it is a clear recommendation that a A2G network operates in a dedicated frequency band on a dedicated cellular network. Additionally, a harmonized frequency band is an important element for ensuring A2G LTE's viability when the network is spread out over different countries and national administrations. Also the design and the radio network planning take as a coverage and capacity requirement in specific altitudes (3D radio network planning is needed).

In the context of the FACT project, a non-aviation technology will be used and therefore:

- For non-aviation spectrum: operator shall obtain a license to operate from each state;

- For aviation Spectrum: idem, but coordination may be performed by authorities, such as ICAO regional offices, and/or EUROCONTROL.

Within the FACT preparation, the aviation C-Band, the so-called MLS (Microwave Landing System) extension band as this band was initially foreseen for MLS systems, was identified as a very promising candidate for possible future industrial solution. However, further development and later potential deployment of such technology/concept will be strongly dependent on support of the National Frequency Managers and guidance/recommendations to the project consortium concerning the appropriate next steps.

Conclusion on the best approach will include many parameters like availability of spectrum, costs, requirements, altitude and many others, but also a combination from dedicated and public networks could be discussed.

4 Operational Environment

Both ATM and U-space uses a classification of the airspace based on the provided services. The key factor for both classifications is how the conflict management is handled in different types of airspace. In this section first a short summary of ATM classification and drafted U space classification (based on CORUS project) are provided as references and then the scope of the FACT project is described.

4.1 ATM Classification of Airspaces

ATM classification of an airspace depends on whether the separation management (tactical conflict management layer) is managed by ATC and how IFR and VFR flights are handled by ATC in this context. The following table and description provide overall definition of different type of airspaces. The deployment strategy varies among different regions (e.g., the US and Europe) and especially in the lower altitudes also partially among European countries. Some details concerning low altitude airspace classes relevant to the FACT project scope are discussed in Annex.

ATS airspaces shall be classified and designated in accordance with the following:

Class A. IFR flights only are permitted, all flights are provided with air traffic control service and are separated from each other.

Class B. IFR and VFR flights are permitted, all flights are provided with air traffic control service and are separated from each other.

Class C. IFR and VFR flights are permitted, all flights are provided with air traffic control service and IFR flights are separated from other IFR flights and from VFR flights. VFR flights are separated from IFR flights and receive traffic information in respect of other VFR flights.

Class D. IFR and VFR flights are permitted and all flights are provided with air traffic control service, IFR flights are separated from other IFR flights and receive traffic information in respect of VFR flights, VFR flights receive traffic information in respect of all other flights.

Class E. IFR and VFR flights are permitted, IFR flights are provided with air traffic control service and are separated from other IFR flights. All flights receive traffic information as far as is practical. Class E shall not be used for control zones.

Class F. IFR and VFR flights are permitted, all participating IFR flights receive an air traffic advisory service and all flights receive flight information service if requested.

Class G. IFR and VFR flights are permitted and receive flight information service if requested.

Class	*Type of flight*	*Separation provided*	*Service provided*	*Speed limitation**	*Radio communication requirement*	*Subject to an ATC clearance*
A	IFR only	All aircraft	Air traffic control service	Not applicable	Continuous two-way	Yes
B	IFR	All aircraft	Air traffic control service	Not applicable	Continuous two-way	Yes
	VFR	All aircraft	Air traffic control service	Not applicable	Continuous two-way	Yes
C	IFR	IFR from IFR IFR from VFR	Air traffic control service	Not applicable	Continuous two-way	Yes
	VFR	VFR from IFR	1) Air traffic control service for separation from IFR; 2) VFR/VFR traffic information (and traffic avoidance advice on request)	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	Yes
D	IFR	IFR from IFR	Air traffic control service, traffic information about VFR flights (and traffic avoidance advice on request)	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	Yes
	VFR	Nil	IFR/VFR and VFR/VFR traffic information (and traffic avoidance advice on request)	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	Yes
E	IFR	IFR from IFR	Air traffic control service and, as far as practical, traffic information about VFR flights	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	Yes
	VFR	Nil	Traffic information as far as practical	250 kt IAS below 3 050 m (10 000 ft) AMSL	No	No
F	IFR	IFR from IFR as far as practical	Air traffic advisory service; flight information service	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	No
	VFR	Nil	Flight information service	250 kt IAS below 3 050 m (10 000 ft) AMSL	No	No
G	IFR	Nil	Flight information service	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	No
	VFR	Nil	Flight information service	250 kt IAS below 3 050 m (10 000 ft) AMSL	No	No

* When the height of the transition altitude is lower than 3 050 m (10 000 ft) AMSL, FL 100 should be used in lieu of 10 000 ft.

Table 2: Airspace classification. Source: [3]

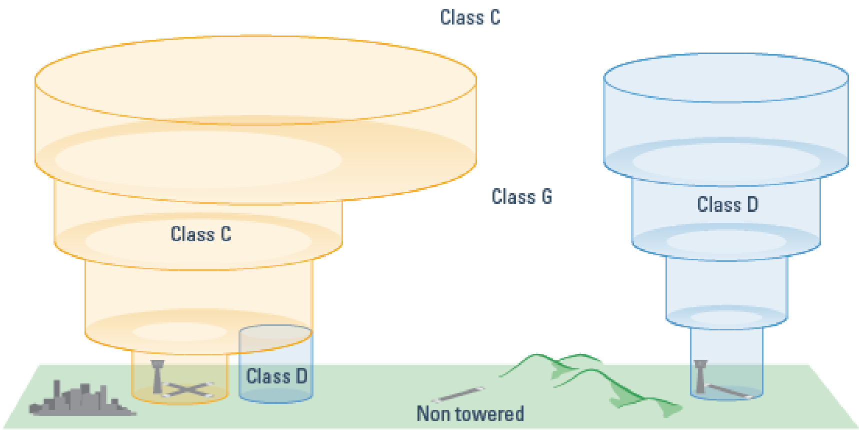

Figure 10: Example of airspace deployment [4]

4.2 U-space Classification of Airspace

CORUS ConOps also classifies the airspaces according to available conflict management services. Namely, it proposes the following types:

- Airspace X where no conflict resolution is offered
- Airspace Y where only pre-flight conflict resolution is offered
- Airspace Z where both pre-flight conflict resolution and in-flight separation are offered

The following operations are possible in these airspaces:

	Operation	X	Y	Z
Drone	VLOS	Yes	Yes	Yes
Drone	Follow-me	Yes	Only be undertaken with reasonable assessment of the risk involved.	Only be undertaken with reasonable assessment of the risk involved.
Drone	Open	Yes	Yes, provided access requirements are met	Yes, provided access requirements are met
Drone	Specific	Yes. However, the risk of unknown drone operations must be considered, evaluated and mitigated appropriately.	Yes	Yes
Drone	Certified		Yes	Yes
Drone	BVLOS		Yes	Yes
Drone	Automated		As for X	Yes in Zu
Crewed	VFR		Yes, but the use of U-space services by VFR flights is strongly recommended	Yes. However, type Za is controlled airspace. Crewed flights in Za will need to behave as such.
Crewed	IFR	No	No	

Figure 11: Airspace operations [5]

According the EASA regulatory framework, the Member States have full authority on the designation of the U-space airspace, and therefore have the power to decide how their airspace is designed, accessed, restricted, etc. U-space airspace can be established in either controlled or uncontrolled airspace.

The EASA Implementing Regulation 2021/664 provides in its Appendix this summary of the U-space services provided in U-space part of specific ATS airspaces.

Class	Type of flight	Allowed in U-space airspace	Services in U-space airspace by USSPs
A	IFR only	Not without dynamic airspace reconfiguration	
	UAS (1)	Yes	UAS flight authorisation Traffic information about UAS
B, C and D	IFR and VFR	Not without dynamic airspace reconfiguration	
	UAS (1)	Yes	UAS flight authorisation Traffic information about UAS
E	IFR	Not without dynamic airspace reconfiguration	
	VFR	Yes, subject to sharing position with USSPs	Nil
	UAS (1)	Yes	UAS flight authorisation Traffic information about UAS and VFR
F	IFR	Yes, subject to sharing position with USSPs	Nil
	VFR	Yes, subject to sharing position with USSPs	Nil
	UAS (1)	Yes	UAS flight authorisation Traffic information about UAS, IFR and VFR
G	IFR	Yes, subject to sharing position with USSPs	Nil
	VFR	Yes, subject to sharing position with USSPs	Nil
	UAS (1)	Yes	UAS flight authorisation Traffic information about UAS, IFR and VFR

(1) Except UAS flying according to Instrument Flight Rules.

4.3 Operational Environment Targeted by the FACT project

Within the FACT project, the operational demo is planned in Turkey (see Chapter 5 for detailed description) where the above classifications of the airspace is not used. Nevertheless, taking into account the logic of the both ATM and U-space classifications it can be stated that the project targets two types of the airspace:

1. Uncontrolled ATM airspace (corresponding to airspace G) with U-space declared in lower part of this airspace.
2. Controlled ATM airspace at the airport (corresponding to airspace D) again with U space declared in a part of it.

EASA framework specifies the following rules for these types of environments:

"The principle is that ANSPs provide air navigation services (ANS) to manned aircraft while USSPs provide U-space services to UAS operators. Both ANSPs and USSPs are certified to provide their respective services in a safe, secure and continuous manner."

"Within controlled airspace, U-space airspace is designated by the Member States and is dynamically managed by the ANSP. The safety of operations is guaranteed by the fact that manned and unmanned traffic will not mix with each other as they are dynamically segregated and ANS and U-space services are not provided at the same time in the same volume of airspace."

"In uncontrolled airspace, the airspace remains uncontrolled for manned aircraft. But when the Member States designate a volume of airspace as U-space airspace, there is a restriction (therefore it could be established as a restricted area): for UAS operators, to use U-space services to fly in that airspace; and for manned aircraft operators, to make available their position at regular intervals to the USSPs. The latter can provide manned traffic information to unmanned aircraft or can geo-fence the unmanned traffic around the manned traffic. The manned aircraft operator will also be informed about the U-space airspace and the unmanned traffic either by the FIS provider or by the USSP, depending on the specific implementation."

4.3.1 ATM Services Considered for CNS Performance Requirements

Detailed use cases are described in Chapter 6, however for assessment and analysis of CNS technologies performance the following ATM services are considered[3]:

- FIS/TIS and supporting services
- Ground surveillance using position reports provided by aircraft
- Pre-flight strategic deconfliction using flight plan[4]
- Strategic deconfliction using 3D/4D trajectory[5]
- Ground conformance monitoring
- ATC separation management

[3] Not all of them will be included in the final operational demo.

[4] Success of strategic de-confliction imposes requirement on on-board navigation function – capability to follow reliably the agreed flight plan.

[5] Similarly, as for the previous item, the performance requirements on onboard navigation and guidance functions are key prerequisites for successful trajectory-based deconfliction.

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4.3.2 U-space Services Considered for CNS Performance Requirements

As stated above, there are not a definitive list of U space services, however the following services are considered for evaluation of CNS technologies:

- Network identification service (position and state reporting)
- Geo-awareness and traffic information service (similar to FIS/TIS for ATM)
- Tracking & conformance monitoring
- Strategic De-confliction using flight authorization (pre-flight), and using 3D/4D trajectories[6]
- Tactical De-confliction

4.3.3 Information Sharing Architecture(s)

EASA regulation [20] is considered as a basis for high level information sharing architecture showed Figure 12.

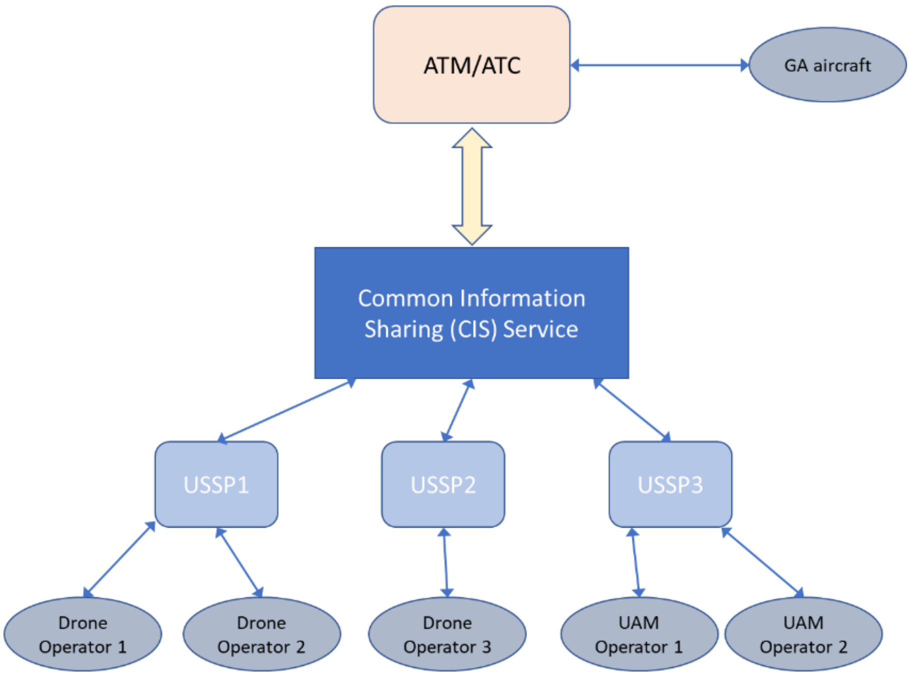

Figure 12: High level information sharing overview.

[6] Strategic deconfliction based on trajectory or flight plan brings operational benefits only if on-board navigation (and guidance) function meets some minimum performance requirements and aircraft is able to follow the agreed/planned trajectory with sufficient reliability.

In addition, on ATM side the architecture proposed by SESAR 14.2.5 project in the context of FIS/TIS services provided to GA over cellular network is considered.

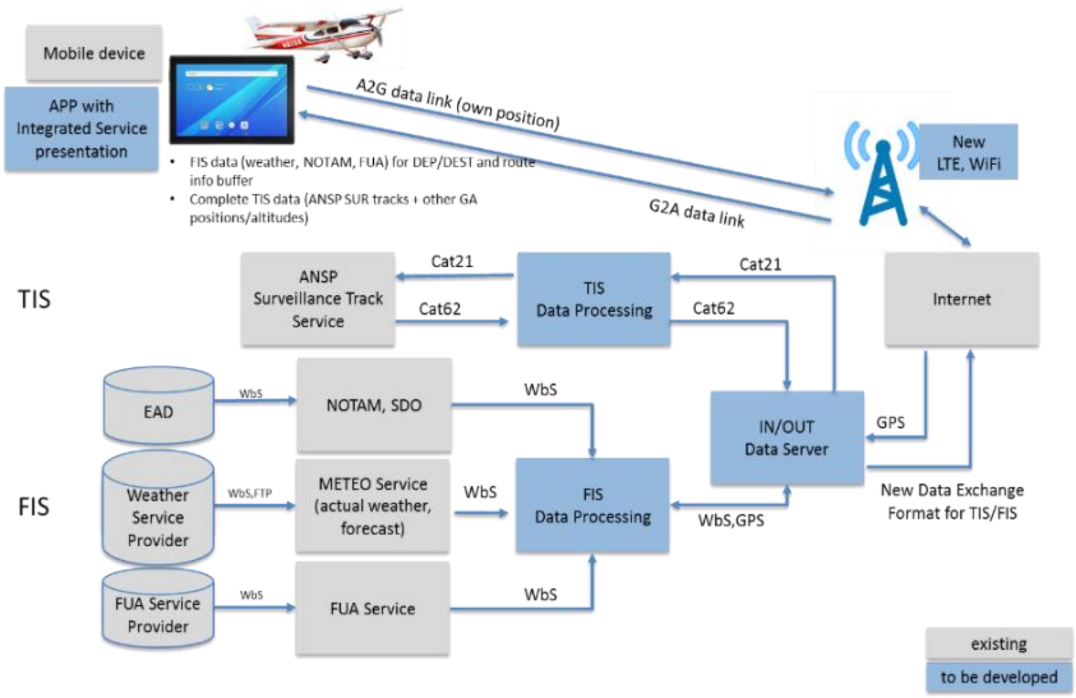

Figure 13: FIS/TIS functional architecture defined by SESAR 14.2.5 project.

These architectures were used as basis for functional architecture tasks and described in deliverables D2.2 (initial version) and D2.4 (final – to be delivered after this document).

5 Operational Environment for Project Demo

The FACT objectives will help the ICAO Global plans and applications to support general aviation safety and efficiency by better monitoring and management of the air traffic including unmanned systems in different categories and cost-efficient integrated solutions. FACT methodology and technological solutions will be developed and tested in ESTU aerodrome control simulation environment and transferred to the real air traffic environment of Hasan Polatkan International Airport (LTBY). ESTU LTBY is a single runway airport with medium sized general and commercial air traffic density and has conventional CNS technologies. The airport and the campus together give a suitable opportunity to realize and test FACT objectives to serve ICAO's plans by focusing on general aviation and unmanned aerial traffic integrated with the other air traffic entities. Besides the airport and airspace potential ESTU will be contributing to the project with educational and research knowledge on aviation and experience by human and technological infrastructure such as aerodrome simulator and its flight training fleet.

5.1 Introduction of the Faculty of Aeronautics and Astronautics

Eskisehir Technical University-ESTU (formerly Anadolu University before May 2018) has all scientific disciplines including unique facilities such as the Faculty of Aeronautics and Astronautics and International Airport together. The Faculty of Aeronautics and Astronautics of ESTU is the leading institution in supplying qualified human resources to rapidly growing Turkish Aviation Industry. Since its establishment in 1986, the faculty has been providing academic education and professional training in the various disciplines of aviation:

- Air Traffic Management,
- Aviation Management,
- Pilot Training,
- Airframe and powerplant maintenance,
- Aircraft electricity and electronics.

The faculty offers an intensive combination of theoretical and practical classes complying with ICAO standards in well-designed and equipped laboratories, workshops and state of the art simulators.

Besides the training facilities, the faculty operates its own international airport (LTBY-Hasan Polatkan Airport) serving for domestic and international flights and tower control facility providing air traffic services to the commercial and training flight operations.

ESTU has its own international airport and flight operations are performed by the personnel of airport together with the academics that are the permanent employees of ESTU. ESTU performs its own fleet management and aircraft maintenance operations compatible with ICAO and EASA. The aerodrome control service is performed by the DHMI by providing controllers only in the ESTU facilities.

Also, the academics of Air Traffic Management and Air Transportation Management Departments provide scientific (theoretical) support, which will be combined by practices at the airport.

5.2 Virtual ATM Research and Training Facilities

The faculty extended its capabilities in Airport and ATM research by the installation of the new radar and 3D and 360 degrees aerodrome simulator systems (6 different simulation environments including the busiest Turkish airports). The system provides creating very effective airport and air traffic scenarios as well as testing even emergency and dangerous situations in the air and on the ground.

Figure 14: ESTU Aerodrome Simulation

ESTU aerodrome simulation general features can be listed as:

- Realistic aerodrome image with 360 and 3D view,
- Realistic aircraft and operational performances,
- All weather conditions,
- Emergency conditions,
- 6 different airport layouts including validation airport and airspace for the FACT,
- Airport layout design tool FAB,
- 4 operational positions and 1 supervisor with 2 pseudo pilot positions,
- Pseudo pilot positions can be extended with radar pilot positions,

The aerodrome simulation will play an important role to create and mature FACT validation scenarios during the project studies. With the support of advanced features of the simulator and experts' collaboration, FACT validation scenarios will be developed and tested virtually to manage project objectives better considering safety and efficiency issues. System is capable of operating unmanned aerial systems with general and commercial air traffics together.

5.3 Flight Training Aircraft Fleet and Maintenance

ESTU performs flight training operations from basic PPL through ATPL-Frozen licensing requirements at international standards. ESTU operates its own fleet consisting of 3 Cessna 172 Skyhawk for adaptation phase, 5 Socata TB-20 Trinidad for maturation phase and 2 KingAir C-90 GTI for the multi engine phase, images of which can be seen below. The fleet will play role during the FACT validation testing phases.

(5) Cessna 172 Skyhawk Aircraft for AdaptationPhase

(5) Socata TB-20 Trinidad Aircraft for Maturation Phase

(2) King Air C90 GTi Aircraft for Multiple Engine Phase

Figure 15: Aircraft Fleet Available for Project Demo

The aircraft fleet is operated by ESTU flight instructor pilots and flight training students depending on the training phases. ESTU has its own aircraft maintenance hangar and qualified aircraft maintenance technicians who perform planned and unplanned maintenance operations with university resources.

5.4 Description of Airfield and Airspace

ESTU educational campus is unique in including an international airport where all educational and operational facilities create aviation culture with the support of engineering faculties in addition to the faculty of Aeronautics and Astronautics.

The real environment for FACT validation testing studies will be performed in the ESTU Hasan Polatkan International Airport and its airspace including campus area for the drone testing. The ICAO code of airport is LYBY and IATA code is AOE. The airport is used for the training and general aviation mainly and commercial flights from mostly for Brussels, Lion and Mecca pilgrim travel flights operated by Turkish Airlines, Pegasus, TUIFly, Tailwing and Correndon Airlines on charter bases. Campus and airport areas can be seen at aerial photo below.

Figure 16: Hasan Polatkan Airport

ESTU airport has single runway which is 09-27 (3000x45 meters) with parallel taxiway which can be used as an emergency runway. Runway and taxiways are lighted for the night and low visibility operations. It has two aprons; one is located in front of the control tower and other is located in front of the RFF facilities. The runway 09 only has ILS CATI for the low visibility operations. Airfield has VOR/DME and NDB facilities operated by the ESTU ATSEP personnel. The operational details of airfield can be seen at the AIP chart of Hasan Polatkan Airport below.

ESTU aerodrome control zone is limited by the south of the airfield due to military airbase approach and departure zones. LTBY and its Anadolu airspace is operable for the other ways with the vertically limited with 1000 ft AMSL. The terminal manoeuvring areas is operated by the neighbour military airbase RAPCON air traffic controllers with a high level of communication and coordination. In other words, air traffic responsibility belongs to Military RAPCON above 1000 ft AMSL around the LTBY. The aerodrome circuit is operated for the northern side of the field for runways 09/27. Flight training areas are mainly designated and used as the west side of the field which is 20 NM away from the aerodrome and its details can be seen below parted from Turkish AIP.

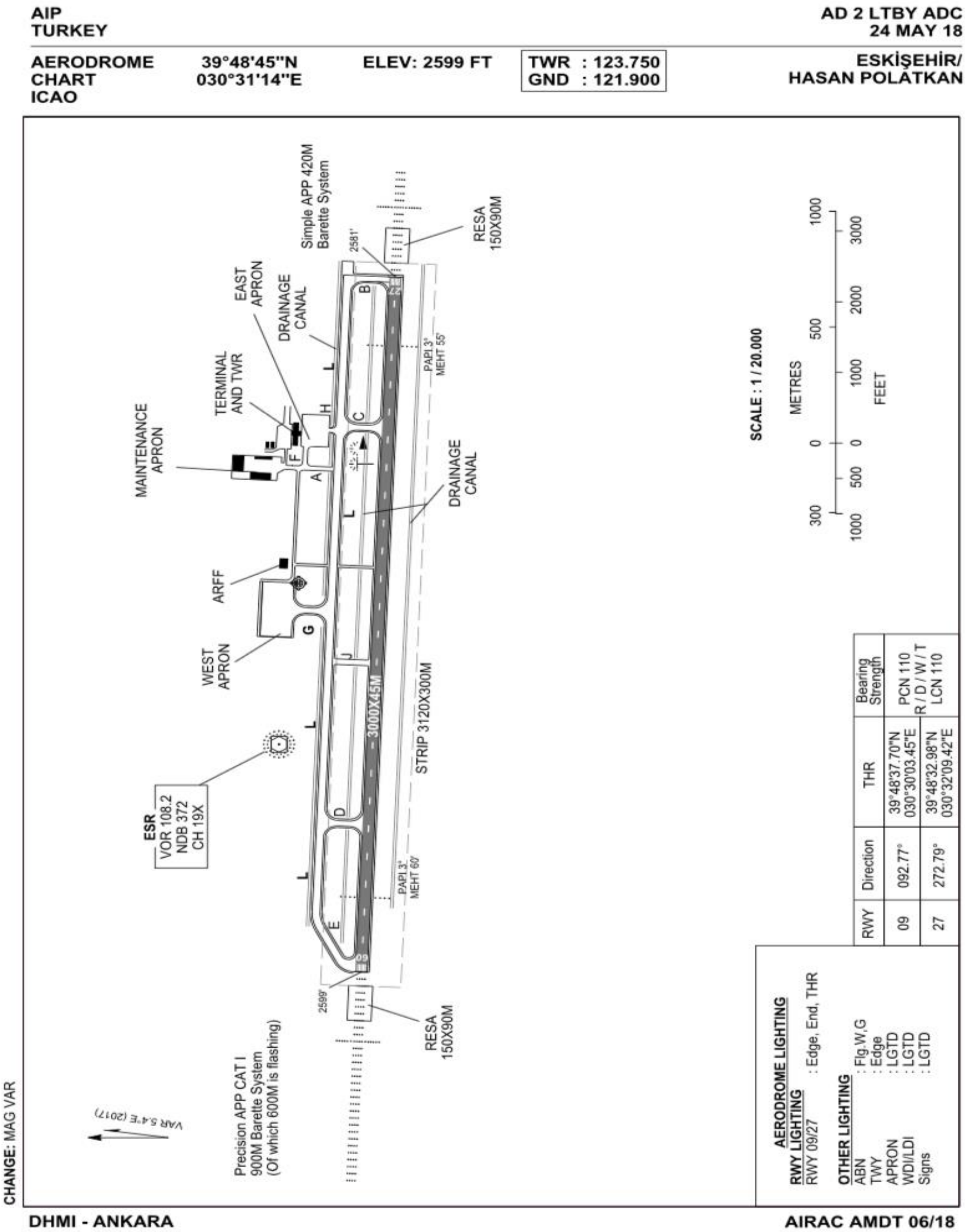

Figure 17: Hasan Polatkan Airport Aerodrome Chart

6 Use Cases and Operational Scenarios

Within this section main use cases addressed by the project are defined. For each of the use cases a set of operational scenarios targeted in the operational demo is defined. The scenarios are also used for analysis/definition of performance requirements and interpretation of technical validations results. All the use cases address the following project's objectives.

- Improve resilience of CNS functions
- Enable advanced services for airspace users
- Rationalization and optimization of frequency spectrum usage

In addition, the specific objectives for individual use cases are mentioned in the following.

6.1 Stakeholders Roles and Responsibilities

There are five main stakeholders directly involved in the targeted use cases: two representing typical ATM environment (GA as an airspace user, and ATS/ATC as services provider), two representing new U-space environment (drones as airspace users, and USSP as services provider), and one representing key common point enabling smooth interaction among them (Common Information Service).

Common Information Service is entity enabling real time sharing of information between ATM and U-space and among individual services providers. According EASA regulatory framework it will be certified and unambiguously assigned by an authority defining the specific U-space (typically Member State). It consolidates actual traffic data and other airspace related information (such as geofencing zone, restricted airspace, etc.) from all USSPs and ATC / AFIS, and provides access to this information to the relevant stakeholders.

Air Traffic Services addressed within the project are focused on information sharing and support of separation management.

- In uncontrolled airspace, the services will consist of providing Flight and Traffic Information Service including AFIS (Aerodrome Flight Information Service). Extension beyond the current situation will consist in providing also data about drone's operating in area which ATS obtain through the Common Information Service. In the opposite direction, ATS is responsible for feeding information about manned traffic and airspace restrictions to the CIS. Communication with GA pilot is realized by standard communication means as voice over VHF.
- In controlled airspace, beyond information sharing services as in uncontrolled airspace, ATC is responsible for deconfliction (separation management) of manned aviation. Extension beyond the current situation will be the ATC responsibility of dynamic airspace allocation for drones operations and of providing this information into CIS.

U-Space Service Provider has similarly responsibility for information sharing and deconfliction of drones operating in U-space. It manages flight missions including their approvals, performs real time tracking of drones under its responsibility (there may be multiple USSPs) and provides relevant data to the CIS.

- In uncontrolled airspace (from ATM perspective) with defined U-Space, the USSP is responsible for conflict management among drones and for separation of drones from manned traffic. Data from CIS (obtained through AFIS and other USSP) will be used for this purpose. It also provides relevant traffic and airspace information with drone/operator.

- In controlled airspace, beyond the responsibilities mentioned above, USSP is responsible to maintain drones under its responsibility within segregated airspace dynamically defined by ATC or follow the rules/separation criteria applicable for given airspace (agreed with ATC and authorities). Separation from manned traffic can be realized by providing geofencing are within the segregated airspace or by conformance monitoring of assigned 3D trajectory (more advanced solution). Both ways are intended to be evaluated.

General Aviation aircraft should operate in the same way as today. Extension beyond the today's situation will be that it needs to support ground traffic surveillance in order that USSPs have access to its position (as they are responsible for keeping drones away). EASA in the proposed Acceptable Means of Compliance (AMC) [23] requires that GA aircraft flying in U-space needs to be electronically conspicuous in one of the three options:

1. Emitting ADS-B messages through certified ADS-B Out capability on 1090 MHz frequency

2. Systems transmitting position information on SRD 860 frequency band (technical specification expected to be available from EASA mid 2022).

3. Systems transmitting position information through standardized mobile telecommunication network services.

Project FACT ConOps is therefore fully compliant with this regulation and focuses on the third option. GA pilot can communicate with ATC/FIS and is required to maintain visual separation from traffic as today. However, GA pilot will benefit from increased situation awareness through on-board traffic application profiting from additional information provided both about manned and unmanned traffic. Within all operational scenarios it is assumed that GA aircraft is in coverage of USSP services.

Drone and operator [7] is entity responsible for providing the mission plan to USSP for flight approval. Then it is required to execute the approved mission according the USSP instructions. Electronic Identification and trajectory data have to be provided to USSP. Information from on-board sensors and traffic information service (provided by USSP) are used for situational awareness of remote pilot.

6.2 Use Case 1: GA and Drone(s) Operating in Uncontrolled Airspace

The first use case is focused to uncontrolled airspace (Class G) with defined U-space in a part of it. Generally, it can be said that General Aviation aircraft operating in uncontrolled airspace are often very limitedly equipped in terms of surveillance and conflict management. GA pilot could highly benefit from obtaining traffic data and next flight relevant information (such as approved mission plans)

[7] They are considered together because splitting functionalities between drone and operator highly depends on technical maturity of drone (level of autonomy).

through reliable link. Drones are expected to operate under U-Space Service Providers control which handle conflict among them and also separation from other traffic.

USSP realizes primarily strategic conflict management by deconfliction of drone's mission plans, providing geofenced areas, and performing conformance monitoring, but it is potentially able to resolve conflicts also in tactical manner.

The precondition for successful USSP-driven deconfliction of GA and drones and conflict management between drones is the reliable surveillance and information sharing. The CIS collects traffic data from both manned aviation and unmanned vehicles and mediates it for traffic management systems.

Proposal of high-level information flow is depicted below in the Figure 18. Note, that although the project is technically focused on selected CNS elements such as efficient air-ground datalink communication, for the assessment of feasibility/usefulness of targeted application it is essential to consider overall latency of the whole end-to-end communication path including ground segments and information sharing related delays[8]. For instance, considering TIS application the whole communication chain: position reporting → USSP1 → CIS → USSP2 (TIS) → other aircraft, needs to be taken into account.

Direct vehicle-to-vehicle link is not assumed in a baseline configuration as there is not a common technology standardized for all involved airspace users. Nevertheless, the use of ADS-B In capability may be included when available. Ground-to-ground communication is expected to be realized as internet (IP) connection to cloud-based CIS service.

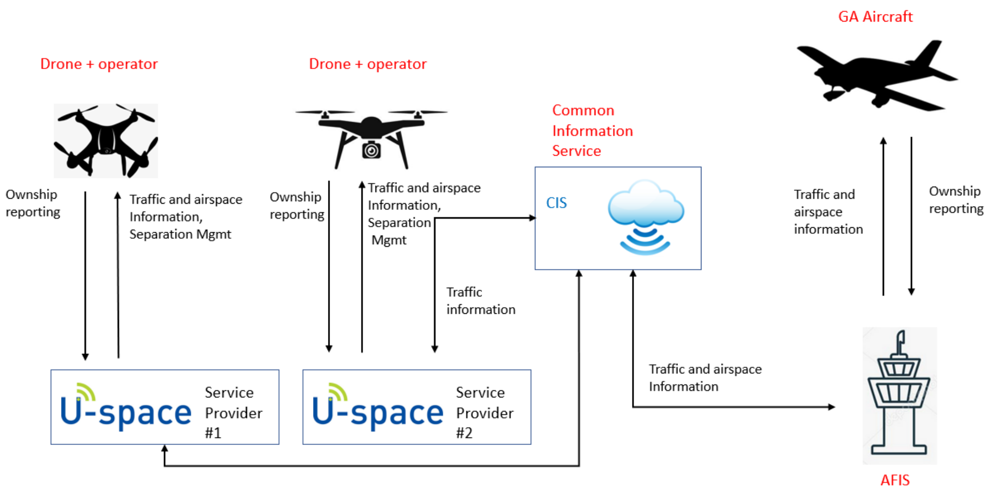

Figure 18: Use Case 1 Information Flow

[8] Implementation/modeling of these ground segments and services will be done only at fit-for-purpose level and/or performance figures will be adopted from other R&D development projects/standardization activities.

6.2.1 Operational Scenario 1: Unplanned GA flight through U-space

The purpose of this scenario is to demonstrate the procedure allowing to manage safely the situation when a GA aircraft needs to cross urgently the U-space and this situation was not known during strategic deconfliction phase.

Participants

- Drone
- GA aircraft (Cessna 172)

No active role of ATC is planned in this scenario.

Pre-requisites

- Airspace organization (namely parts of airspace allocated to drones and GA) defined and agreed with ATC, information available through FIS/Airspace Info to all stakeholders.
- GA aircraft is in coverage of U-space services.

Procedural Flow

1. GA and drone fly in their allocated area
2. GA is entering drone area intentionally and GA pilot is aware of entering that airspace through its Situational Awareness application.
3. Exp. CNS of GA aircraft sends alert message to USSP.
4. USSP issues geofence zone (=restricted area for drone in its area) around aircraft flight intent (flight intent is estimated based on current speed vector) and provides it to drone(s) and to GCS.
5. Drone operator via GCS changes flight plan to avoid geofence and provides it to USSP.
6. USSP approves flight plan.
7. If drone operator does not react in predefined time, drone is forced to land by USSP.

The overall flow of the operational scenario is graphically shown in the following diagram.

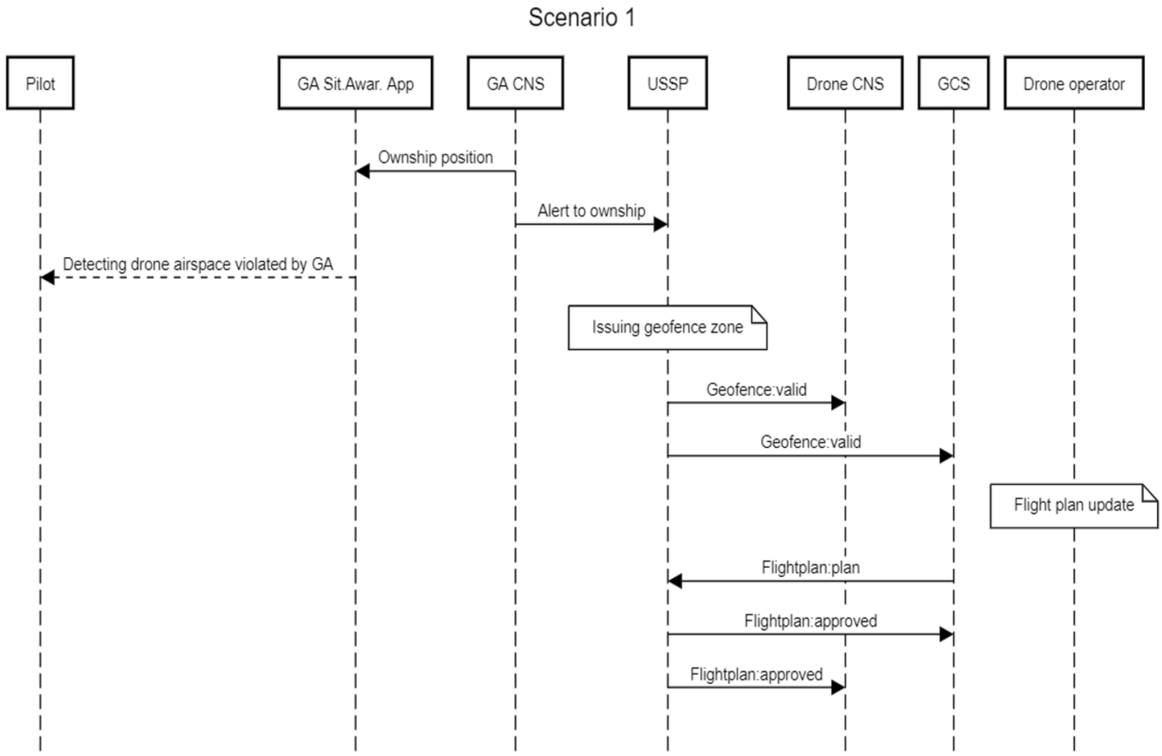

Figure 19: Scenario 1 interaction diagram.

Figure 20: Scenario 1 airspace configuration (black = GA flight, yellow = drones' allocated area, green = planned geocage area).

6.2.2 Operational Scenario 2: Drone leaving unintentionally allocated airspace

This scenario addresses the situation when a drone unintentionally leaves the allocated airspace and represents a potential threat for GA traffic.

Participants

- Drone
- GA aircraft (Cessna 172)

No active role of ATC is planned in this scenario.

Pre-requisites

- Airspace organization (namely parts of airspace allocated to drones and GA) defined and agreed with ATC, information available through FIS/Airspace Info to all stakeholders.
- Drone area boundaries described by USSP's geocage message. The GCS shall ask for free flight permission from USSP in this constrained air space and waits for it. Drone can take-off after this permission.
- GA aircraft is in coverage of U-space services.

Procedural Flow

1. GA and drone fly in their allocated area
2. Drone appears in GA area accidentally (reason – e.g., navigation or autopilot fault)
3. Violation is detected by USSP's conformance monitoring.
4. USSP issues alert to GA aircraft, to drone operator and drone
5. GA pilot can see violating drone position on Situational Awareness Application and he is aware by receiving alert message. He can change his trajectory to safely avoid the drone if needed.
6. USSP produces message forcing drone to land through drone CNS device.
7. Drone is forced to land.

The overall flow of the operational scenario is graphically shown in the following diagram.

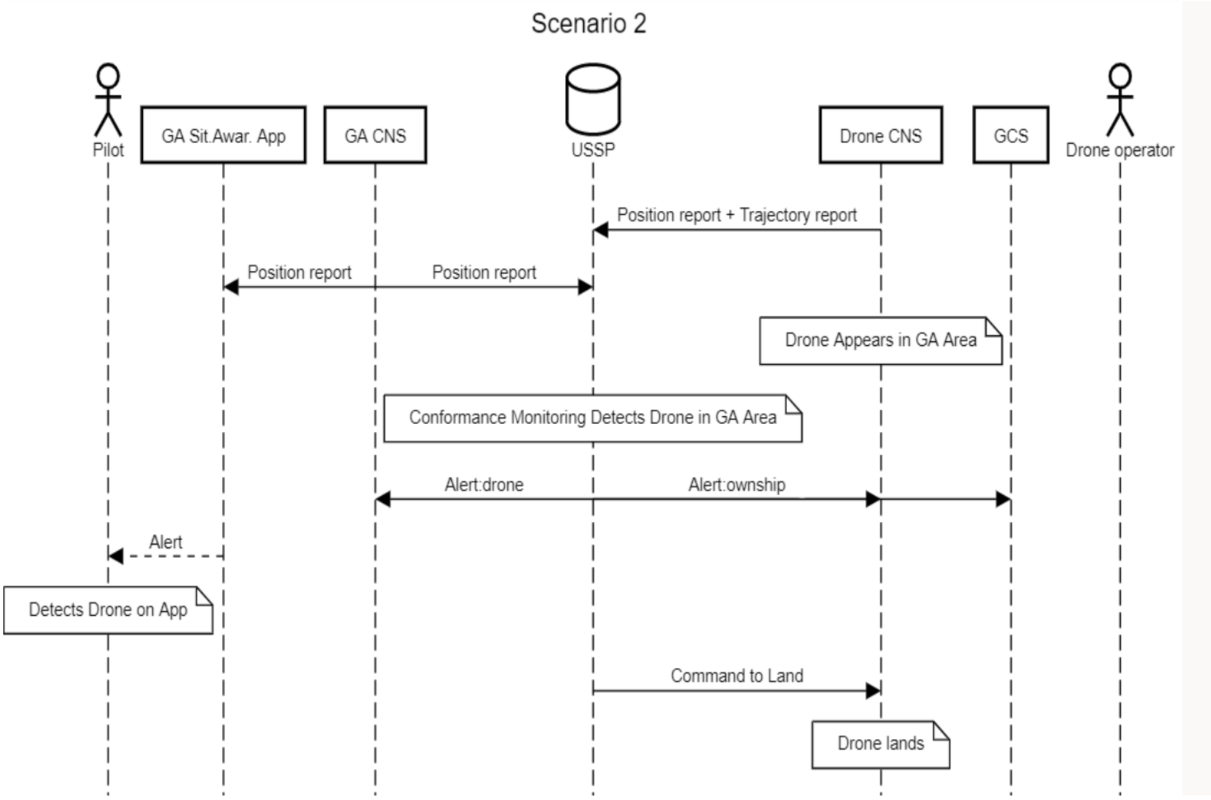

Figure 21: Scenario 2 interaction diagram.

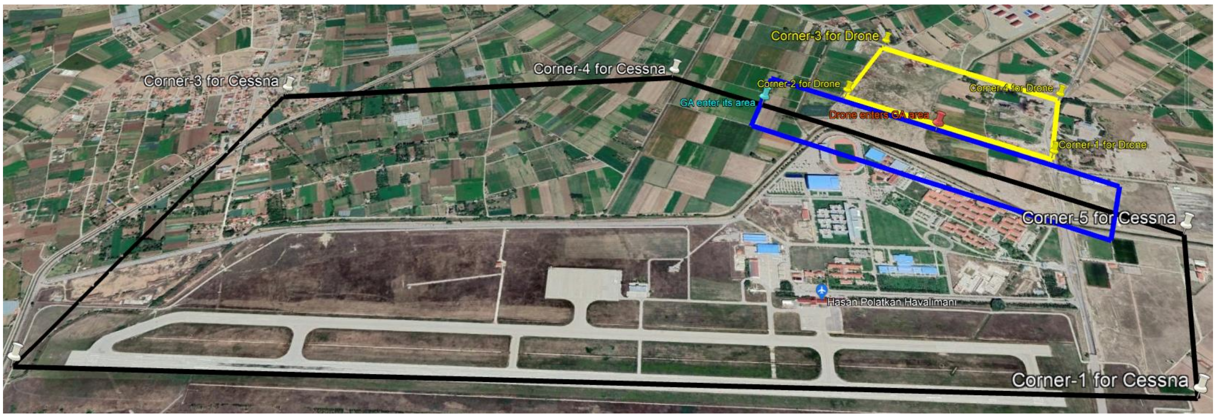

Figure 22: Scenario 2 airspace configuration (black = GA flight, yellow = drones' allocated area, blue = area violated by drone).

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6.2.3 Operational Scenario 3: Drone deviating from the corridor (trajectory based strategic deconfliction)

In this scenario the trajectory-based approach is used for strategic deconfliction of drones within U-space rather than airspace segregation. Drones are expected to follow approved trajectories with the operational boundary defined in terms of a corridor. In the scenario, a non-nominal event is created when one drone starts to deviate from the approved trajectory and leaves the corridor.

Participants

- Two drones

No role of ATC is planned in this scenario.

Pre-requisites

- Predefined trajectories for drones + acceptable deviation (corridor) checked and approved by USSP (and its strategic-deconfliction service).
- Airspace segregation (drones below a given altitude that can't be crossed) from other traffic.
- Approved trajectories for drones visible in SA applications.

Procedural Flow

1. Drones fly the approved trajectories within designated corridors
2. Drone A starts to deviate from corridor (e.g., due to wind or technical difficulties); USSP's conformance monitoring service detects it.
3. USSP issues an alert to GCS and drones.
4. USSP issues temporary geofence zone around deviating drone A. The geofence requires flight plan update of drone B (geofence zone extends to its corridor).
5. GCS of drone A provides new flight plan to USSP which won't be affected by the original difficulties.
6. GCS of drone B provides new flight plan to USSP.
7. USSP approves new trajectories by providing for both drones and cancels geofence.

The overall flow of the operational scenario is graphically shown in the following diagram.

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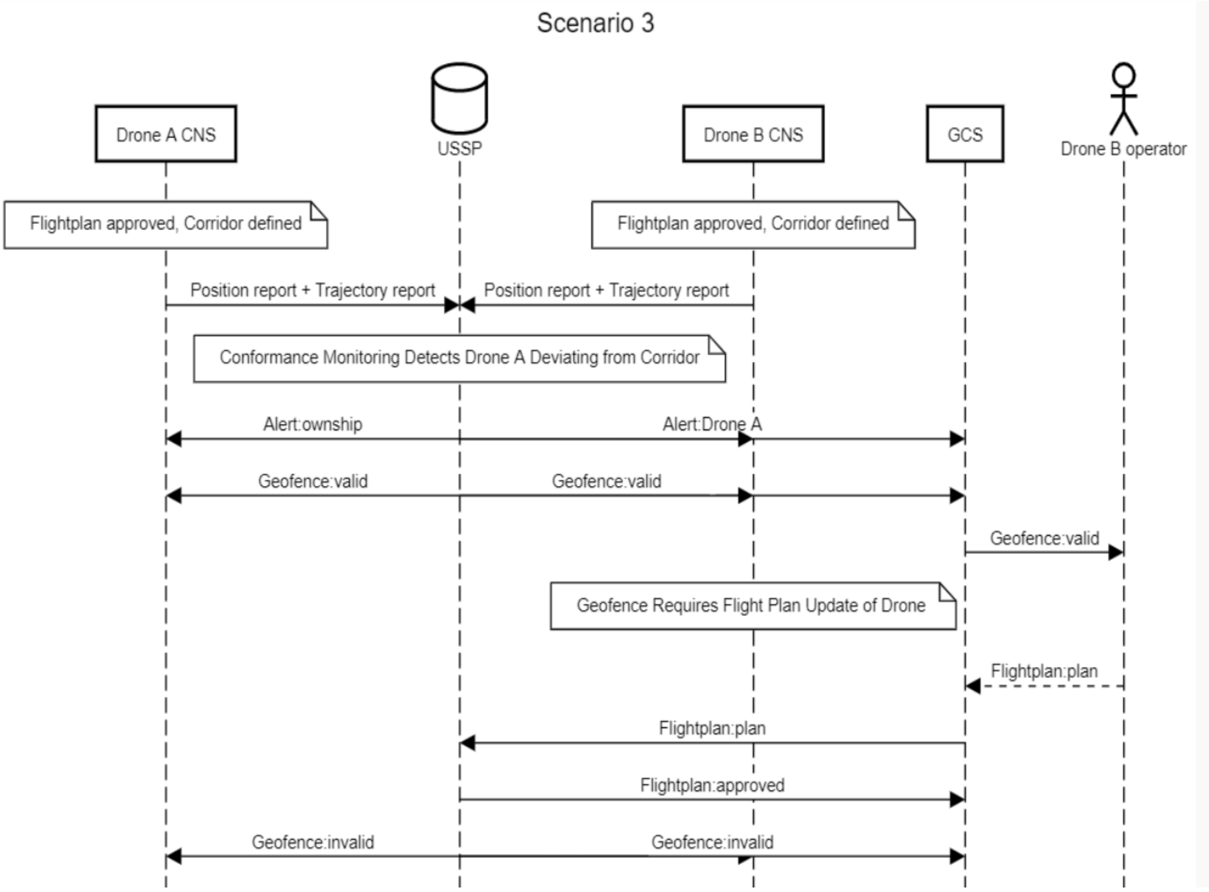

Figure 23: Scenario 3 interaction diagram.

6.3 Use Case 2: GA and Drone(s) Operating in Controlled U-space (Airport)

Environment of second use case is controlled airport terminal area with access of both manned and unmanned traffic (U-Space is defined in a part of that airspace). Air Traffic Control will be responsible for segregation of the traffic through dynamic allocation of the airspace for drones' operations as requested by EASA regulation. Ability ATC to directly communicate with drone operator is considered highly beneficial as a potential safety backup. Communication with GA pilot is assumed by standard communication means like voice over VHF radio. This communication is marked by red lines in the Figure 24. Ground-to-ground communication is expected to be realized as internet (IP) connection to cloud-based CIS service, and through VoIP technology over cellular network for emergency interaction between ATC and remote pilot.

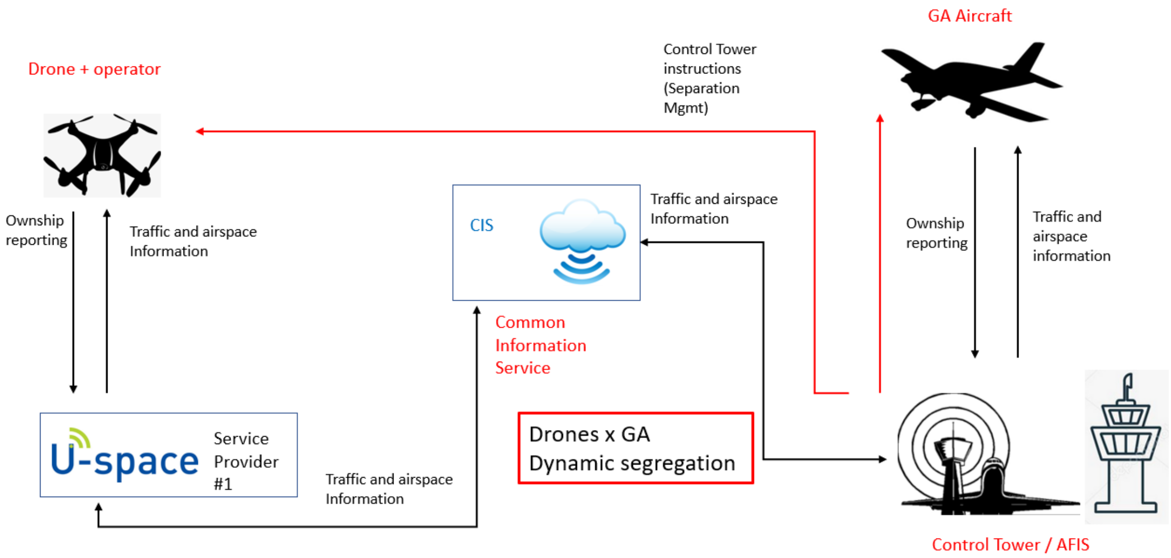

Figure 24: Use Case 2 Information Flow.

Information sharing is working as for previous use case (FIS/TIS for GA, U-space Traffic information service for drones). Possible enhancement is use of U-space traffic data from CIS by ATC for separation provision in non-nominal situations. There is also possibility of potential de-confliction based on 3D/4D trajectory data rather than through segregated airspace which should improve operational capacity. Overall system latency will be crucial in that case.

6.3.1 Operational Scenario 4: Accidental GA flight through U-space

The purpose of this scenario is to demonstrate the procedure allowing to manage safely the situation when a GA aircraft flying in a controlled airspace accidentally enters the U-space.

Participants

- Two drones
- Rotorcraft (Sikorsky)
- ATC.

Pre-requisites

- Airspace organization (namely parts of airspace allocated to drones and GA) defined and agreed with ATC, information available through FIS/Airspace Info to all stakeholders.
- Boundary of allocated drones' area defined by USSP's geocage.
- The GCS shall ask for free flight permission from USSP in this constrained air space and waits for it. Drone can take-off after this permission.
- GA aircraft is in coverage of U-space services.

Procedural Flow

1. GA and drone fly in allocated airspace.
2. GA appears in drone area accidentally (lack of attention).
3. ATC detects the GA by SA app for ATC
4. ATC gives instructions to GA pilot how to leave the drone area through VHF voice
5. ATC provides message to USSP requiring geofence around GA flight intent
6. USSP transfers this information to GCS and drone(s) together with alert
7. ATC informs drone operator by VoIP voice if necessary (one drone is too close, no time for reacting to geofence – emergency situation)
8. If drone operator does not react in predefined time, drone is forced to land by ATC (ATC send request to USSP, USSP send instruction to drone CNS dev.)

The overall flow of the operational scenario is graphically shown in the following diagram.

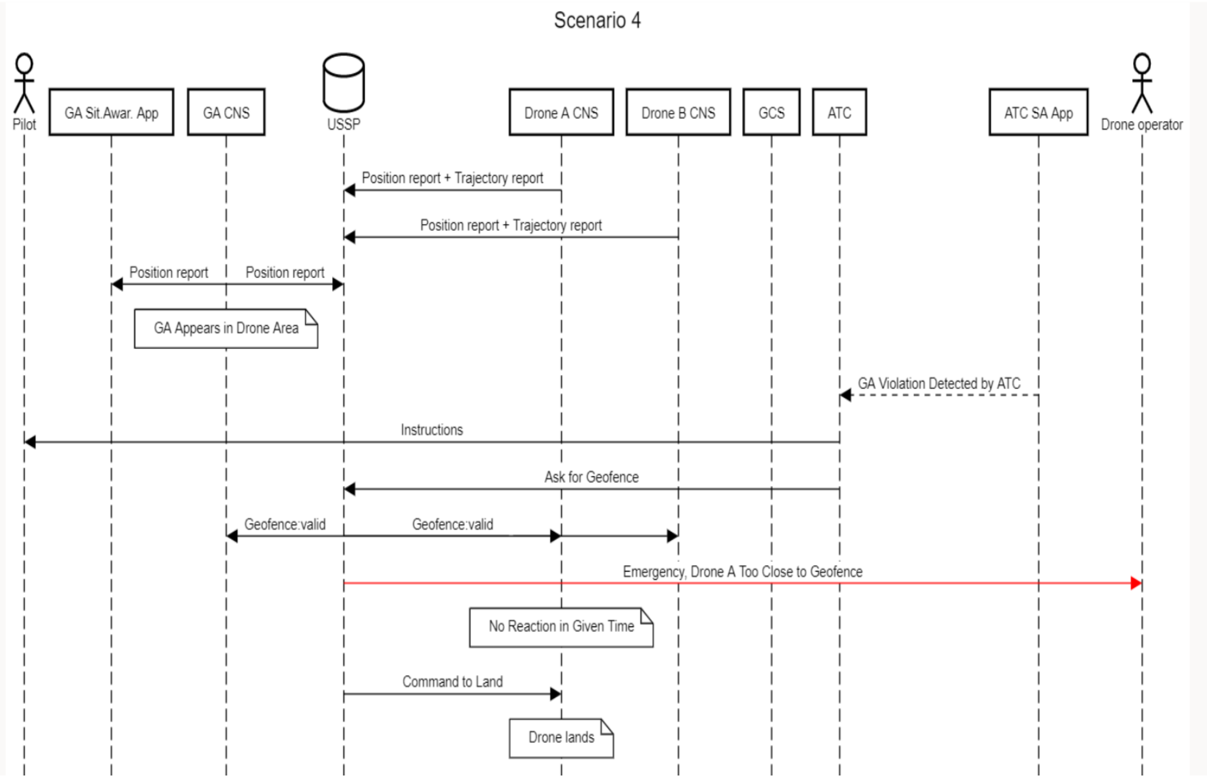

Figure 25: Scenario 4 interaction diagram.

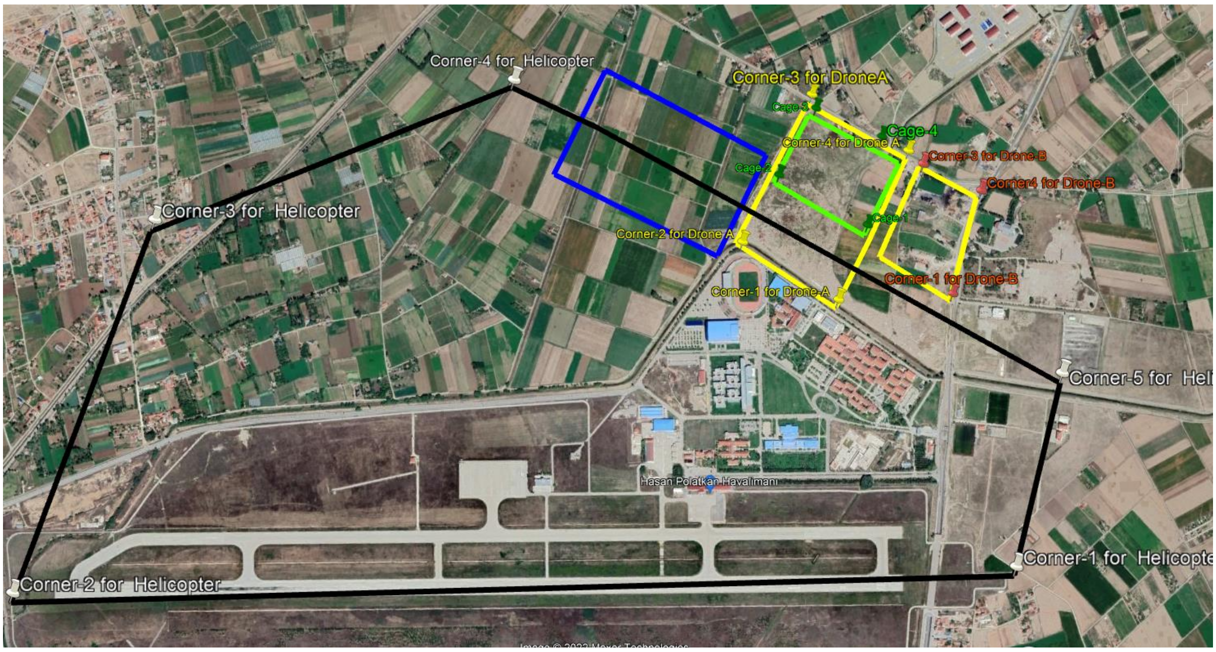

Figure 26: Scenario 4 airspace configuration (black = helicopter flight, yellow = drones' allocated areas, green = planned geocage area).

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6.3.2 Operational Scenario 5: Drone accidentally leaving U-space

The purpose of this scenario is to demonstrate the procedure allowing to manage safely the situation when a GA aircraft flying in a controlled airspace accidentally enters the U-space.

Participants

- Drone
- Rotorcraft (Sikorsky)
- ATC.

Pre-requisites

- Airspace organization (namely parts of airspace allocated to drones and GA) defined and agreed with ATC, information available through FIS/Airspace Info to all stakeholders.
- Boundary of allocated drones’ area defined by USSP's geocage.
- The GCS shall ask for free flight permission from USSP in this constrained air space and waits for it. Drone can take-off after this permission.
- GA aircraft is in coverage of U-space services.

Procedural Flow

1. GA and drone fly in allocated airspace.
2. Drone appears in GA area accidentally (e.g., due to strong wind, problems with flight control system, remote pilot mistake, etc.)
3. Violation is detected by conformance monitoring. GA pilot and ATC can see violating drone position through their Situational Awareness Applications.
4. USSP issues alert to ATC, to GA aircraft, drone, GCS.
5. ATC alerts and instructs (if required) GA through VHF voice, GA reacts per ATC instructions.
6. In parallel: GCS controls the drone to return back to its airspace
7. GA pilot and ATC can monitor violating drone position on Situational Awareness Application

The overall flow of the operational scenario is graphically shown in the following diagram.

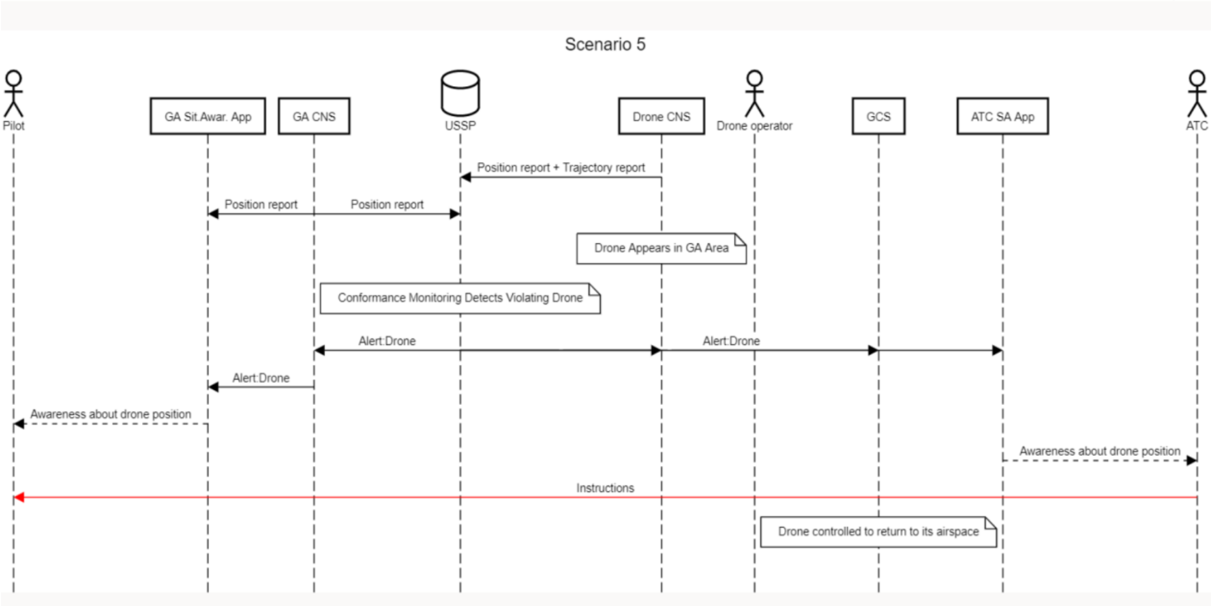

Figure 27: Scenario 5 interaction diagram.

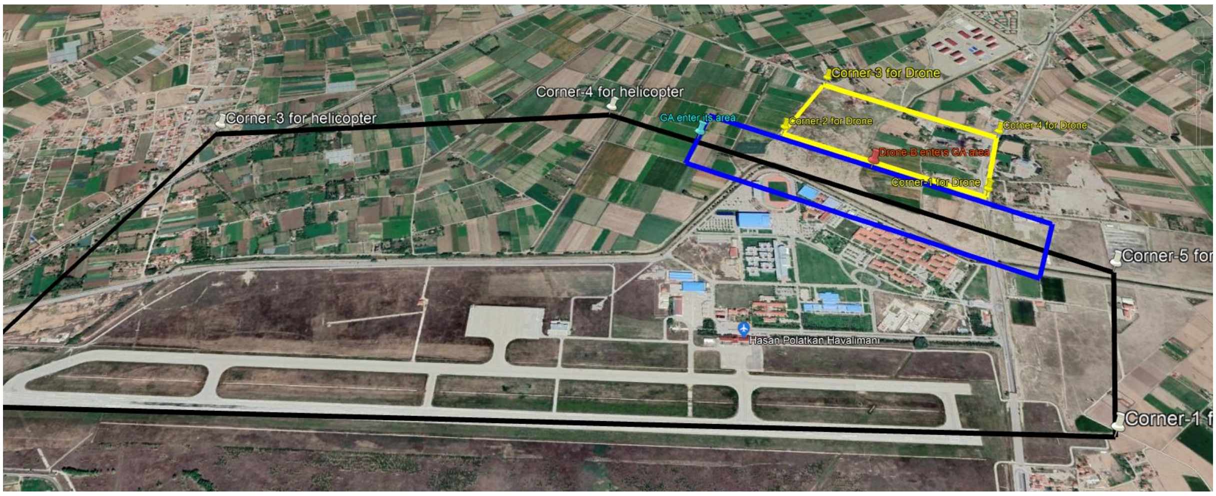

Figure 28: Scenario 5 airspace configuration (black = helicopter flight, yellow = drones' allocated area, blue = area violated by drone).

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Appendix A CNS Equipment Today

A.1 Commercial Aviation

A.1.1 Current CNS Equipment: Communication

This section is focused primarily on safety critical communication.

Communication is divided into voice and data. Voice communication is realized through VHF radios providing the primary communication mean with ATC. For commercial transport, the VHF radio is an item on the minimum equipment list (MEL). For transport category, at least two operational units are required.

Dedicated frequency range for VHF communication is 118-113.975 MHz. Range limitation represents radio horizon, but in reality, the size of ATC sectors is smaller. The VHF band consists of channels 25 kHz separated, in Europe 8.33 kHz separated.

Modern airborne radio is based on A/D converter converting analog signal of voice input into digital representation and digital signal processor combining this representation with RF carrier [6].

High frequencies in range 2.850 – 23.350 MHz are used for communication with ATC in remote areas (oceanic). HF voice provides greater range due to reflecting such signals from bottom parts of ionosphere. Since this project is not focused to oceanic airspace, the HF voice won't be discussed in deeper detail.

Data communication is significantly broader topic. Currently, there are two technological standards for networks in place: ACARS (Aircraft Communication and Reporting System) and ATN (Aeronautical Telecommunication Network). ATN is newer technology based on the Open Systems Interconnection (OSI) model. Internet Protocol Suite (IPS) is upcoming network infrastructure based on Internet Protocol. IPS would enable to use Commercial-Off-The-Shelf (COTS) components for air to ground safety communications. COTS infrastructure would be used for both Air Traffic Services (ATS) and Aeronautical Operational Communications (AOC) safety service applications to provide the robust network supporting emerging and growing data link applications [7].

Datalink can be realized by different radio links: VHF (historically very little modified voice radios were used), satellite (Inmarsat and Iridium), HF datalink and VDL Mode 2.

Introduction of satellite-based data link services for en route ATM, both for CPDLC and for surveillance, has allowed suitably equipped ANSPs to trial reduced oceanic procedural separation standards. However, inconsistent data link performance mainly attributed to a combination of satellite outages, and poor Ground Earth Station (GES) availability and data link capacity issues, have temporarily reduced confidence in some early applications [8]. First satellite constellation used for datalink was Inmarsat. Iridium constellations came after the Inmarsat.

VDL Mode 2 is datalink technology using very high frequencies. Use of 25 kHz wide channel with D8PSK (Differential 8-Phase-Shift-Keying) modulation significantly reduces the channel congestion, but there is still awaited reaching a capacity limit in given point in the future.

HF datalink uses high frequency channels. Different propagation characteristics enable global coverage with only around fifteen ground stations. Negative is a need of large HF antenna, low performance and susceptibility to "space weather".

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Controller Pilot Data Link Communications (CPDLC) represent a mean of communication between air traffic controller and a pilot. It is an application providing ATC messages (clearance, request, confirmations) corresponding to voice phrases. Substitution of voice communication by text messages decrease the working load of both pilot and controller, brings possibility to handling more requests simultaneously and decrease probability of failure due to misunderstanding. Pilots manage CPDLC messages through the DCDU (Datalink control and display unit) or MCDU (Multi-function control and display unit).

Commercial aviation communication equipment thus typically consists of VHF radio, HF radio, Communications Management Unit (CMU) or Air Traffic Services Unit (ATSU) and Flight Management System (FMS).

A.1.2 Current CNS Equipment: Navigation

Navigational equipment is usually the GNSS receiver unit, Inertial Reference System (IRS) and radio for ground navigational aids. GNSS measurement of position and velocity is fused with IRS outputs due to their complementary characteristics. The integrated navigation solution provides benefits of both methods (IRS accuracy drifts with time, GNSS is susceptible to short time outcomes).

Important advantage of inertial navigation is autonomy - inertial navigation systems do not need any external equipment except sensors (accelerometers and gyroscopes sensing the accelerations and angular rates) and navigation processor providing navigation solution. Thus, they are independent of external electromagnetic signals. Next advantages of IRS are high short-term accuracy and short period output rate. The continuous operation provides not just velocity and position, but also attitude, angular rates and accelerations. Disadvantages include rapid increase of error with time due to integration in the calculation. Outputs from accelerometers and gyroscopes are corrupted by noises and biases and without corrections result in unbounded errors.

Low cost of user equipment and high long-term accuracy belong among the advantages of GNSS. On the contrary this system is characterized by long period of output rate and possible unavailability because GPS is vulnerable to interference. Also high bandwidth noise is characteristic for GNSS. Next potential drawback is a high short-term noise. A complete navigation system fusing IRS and GNSS results in high performance and robustness due to complementary attributes of IRS and GNSS. A typical integration architecture means that measurements from GNSS used by an estimation algorithm to apply corrections to the navigation solution of IRS.

Conventional radio navigational aids are the most legacy technology among currently used navigation methods. Systems which are mostly in use by commercial air transport are ground-based radio beacons as VHF omnidirectional range (VOR), Instrument Landing Systems (ILS) and Distance Measuring Equipment (DME).

VOR is omnidirectional radio beacon enabling aircraft to establish a direction to the beacon. VOR is often installed together with DME. This type of ground navigational aid then provides both azimuth and distance to the beacon. These methods of radio navigation have less and less significance for commercial aviation with expanding concept of Area Navigation (RNAV).

Although ILS is used for approach and landing for more than 50 years, this system is still attractive for use due to economy of operations, accuracy and worldwide spread. It consists from the localizer providing horizontal guidance and the glide slope providing vertical guidance. Modernised ILS have performance enabling operations according to ICAO CAT I, II and III.

Area navigation (RNAV) means capability of aircraft to fly from any given point to another (without dependency on ground nav aids waypoints) . Performance based navigation (PBN) is a concept enabled by RNAV. It represents a shift from sensor-specific procedures and routes to definition of required navigational performance (RNP) for proposed operation or airspace. Typical RPNs are RNP 4 for remote and oceanic operations, RNP 2 for en-route continental, RNP 1 for arrival and initial, intermediate and missed approach as well as departure navigation applications. Each RNP value is defined by requirements in term of accuracy, integrity, continuity and availability.

Commercial aviation navigation system is realized by the Flight Management System (FMS) together with other functions (Flight Management Computer, Automatic Flight Control, Electronic Flight Instrument System).

A.1.3 Current CNS Equipment: Surveillance

Commercial aviation is obliged to carry a transponder for purpose of cooperative surveillance. Precise conditions differ in particular states, but generally it is possible to say that Enhanced Surveillance transponder equipage is required for all fixed-wing transport aircraft with maximal take-off weight MTOW above 5 700 kg or with maximum true airspeed greater than 250 knots flying under Instrument Flight Rules (IFR) for European Union Aviation Safety Agency (EASA) registered aircraft.

Transponder is a device generating radio signal as a reply to interrogation. The interrogating counterparts are Airborne Collision Avoidance Systems (ACAS) and Secondary Surveillance Radars (SSR). SSR regularly interrogating aircraft in its range is a pillar for Air Traffic Control. Responses are encoded messages with requested data. Transmitted data depend on mode of communication. The mode is recognized by spacing between two transmitter pulses. Legacy modes are Mode A and Mode C, the newest is Mode S enabling selective interrogations and providing more transmitted parameters (Elementary Surveillance and even more parameters through Enhanced Surveillance). SSR uses 1030 MHz frequency band for interrogating and 1090 MHz for receiving the replies.

Mandate to equip with the Automatic dependent surveillance broadcast (ADS-B Out) functionality is coming in December 2020. ADS-B Out is the surveillance technology based on aircraft itself reporting its position and other quantities. 1090 MHz Extended Squitter is used in Europe. This is the reason why this functionality is tied with the transponder unit into one product.

A.2 General Aviation

AOPA’s expertise is based on knowledge and experience of its members, mostly active pilots, and close cooperation with partner pilot’s and aircrafts operator’s associations not only in Europe but also worldwide.

Official statistics on GA aircraft and GA flights do not exist. Data shown below are taken from a survey by the General Aviation Manufacturers Association (GAMA) and AOPA collected 2018/19, may give an impression of the order of magnitude.

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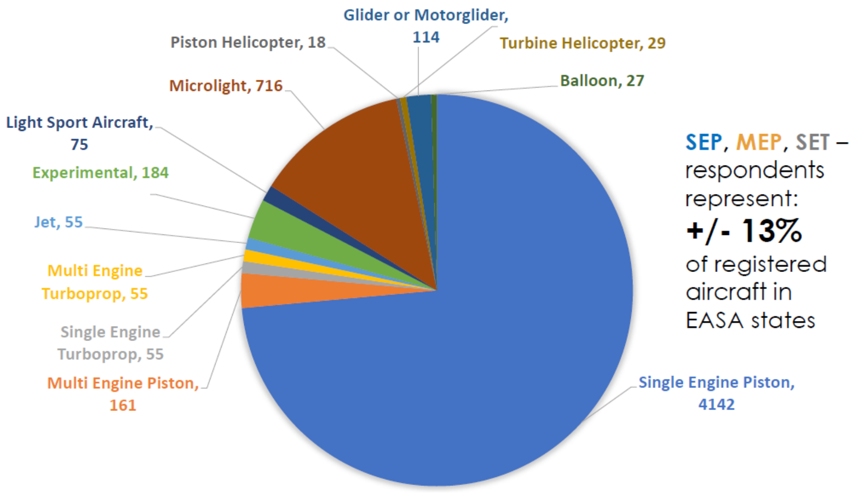

Figure 29: Aircraft types and number of respondents to the survey [GAMA, AOPA]

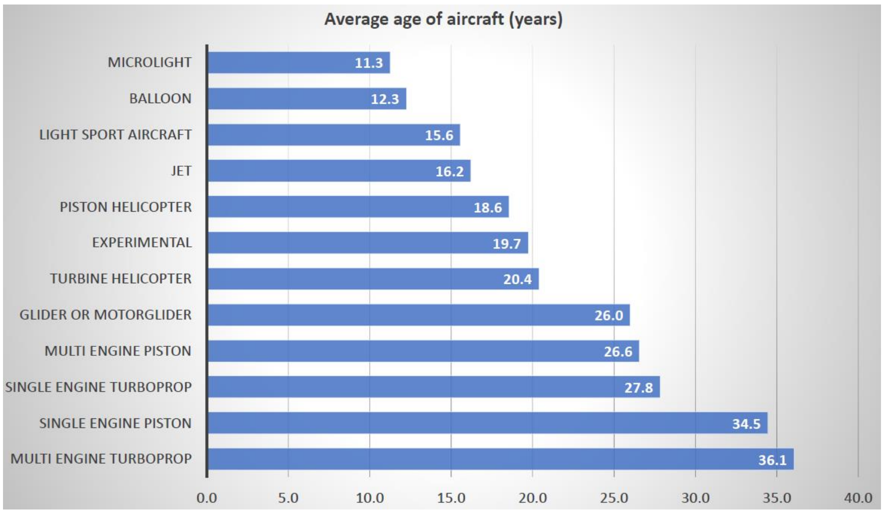

Figure 30: Average age of aircraft per type [GAMA, AOPA]

The numbers above are based on 2688 responses, representing 6085 aircraft, which were registered at all 28 EU member states plus 4 others, thereby 363 in the USA.

A.2.1 Current CNS Equipment: Communications

Voice Communications Equipment in Aircraft

The legal requirement for voice communications requirement for GA aircraft is one analogue 2-way VHF transceiver, for IFR operations two are required. Outside central Europe and in lower altitudes 25 kHz channel spacing still is acceptable, in Central Europe 8,33 kHz channel spacing is required. Data communications on the analogue VHF band (ACARS / VDL2, VDL3, CPDLC) are used by GA aircraft in exceptional cases only but is not un-common in business aviation. Some ATC units have their INMARSAT phone numbers published to be used for ATC communications. HF radios have to be installed on a temporary basis for flights across remote regions, e.g. Atlantic crossings, where this is still legally required.

Digital Communications Equipment in Aircraft – Voice and Data

Digital communications using GSM smart phones (public networks 3G and higher) and SATCOM networks are used for new services not provided by FIS or ATC, and as a backup in case of a failure of the analogue VHF radios. Tablet computers or mobile phones are used in aircraft on the ground shortly before take-off for flight plan modifications or updates of MET reports using public GSM networks. Moreover, similar services are provided through SATCOM providers and can be used in flight.

Emergency Locator Transmitters (ELT) are installed in most aircraft. They transmit automatically an aircraft ID and if possible, its position in case of an emergency to a SAR network.

Reports indicate that GSM phones work at low altitudes. The service quality varies strongly between locations, and it will always be a point-to-point connection. The telephone numbers to reach the appropriate ATC units or aerodromes are not published regularly.

Communications Equipment for ATM on the Ground.

Surface communications networks exist to connect remote transmitter/receiver stations which ensure reliable communications at long distances from the ground station or at low altitudes.

A.2.2 Current CNS Equipment: Navigation

Traditionally in use by GA aircraft are at minimum ADF and VOR, DME. ILS, and RNAV exist in addition in more than 50 % of all GA aircraft. ADF receiver and indicators, however, are threatened by extinction. New aircraft are routinely delivered without them during the last 10 years. GNSS position data, however, is used by nearly all VFR flights, based often on non-certified receivers in mobile phones or tablet computers with varying quality of the indicators and of the aeronautical databases installed.

For IFR flights, since it became impossible to navigate to 100s of waypoints within the required RNP 1.0 by VOR and ILS only approx. 25 years ago, certified GNSS receivers are standard. Typical devices are the Garmin 430/430W/530W and plug compatible devices such as Avidyne's IFD series and others.

These can legally be used for en-route navigation and most GNSS approaches, SIDs and STARs. For some PBN procedures, however, a modern autopilot may be required in addition to ensure the required precision.

Last not least: VDF (VHF Direction Finder) still exist at some aerodromes. Their purpose is to assist an aircraft without any NAV equipment – except for a magnetic compass -, but with working voice communications, to find its way to the receiver station.

A.2.3 Current CNS Equipment: Surveillance

ATM Services

Positive control of flights, surveillance and flight conformance monitoring are provided as ATM services. Information on aircraft IDs, their current positions and altitudes available to ATC is provided by voice position reports from pilots, by primary or secondary radar or by ADS-B. Today modern transponders broadcast very accurate GNSS position, altitude and aircraft ID to the ground and to all other aircraft (ADS-B-out). In some airspaces this is already mandatory for flights of aircraft above a certain weight or a certain number of seats. Such transponders are on the market for GA aircraft, but they are still not installed in great numbers yet.

All versions of transponders have in common a continuous electric power consumption of 40...70 W. This poses no problem for engine driven aircraft. Aircraft without engine have a need to save electrical power as much as possible. Nowadays modern LiFePO4 accumulators weighting 1,6 kg with 12 Ah at 12 V DC would be good for about 3 hours of flight time with operative ATC transponder, which appears to be sufficient for most use cases of glider flights. For parachutes, hang gliders and light drones this would be not feasible. Moreover, the usage of transponders for air sports, as long it is operating mostly at low altitudes, is not even desirable because it may cause an overload of this frequency band at times of high traffic volume.

Traffic avoidance advices under VFR – sometimes referred to as “flight following” - are a voluntarily offered by FIS on a “time available” basis. With increased traffic volumes, e.g. on sunshine weekends, FIS becomes overloaded, and the service is terminated when it is needed most.

Airborne automatic independent traffic information and avoidance systems exist since many decades, and are mandatory for a part of the fleet: ACAS (i.e. TCAS II). For GA aircraft this never had been an option because its high cost for the equipment which can be close to the value of the entire aircraft.

Non-ATM Services

Gliders fly frequently close to each other, and therefore have a particular need for automated warnings if a colleague, invisible in a steep turn, comes too close. For them the “island solution” FLARM (“Flight-Alarm”) had been developed, based on the use of automated GNSS position broadcasts on the unprotected frequencies 868,2 and 868,4 MHz, while an onboard unit evaluates the transmissions and displays the relative positions of the other aircraft locally, i.e. within a range of < 10km. Resolution advisories are not given. FLARM is mainly used by operators in Central Europe.

A similar, but incompatible, system named PilotAware**,** transmitting on 869,525 MHz, exists in the UK, with more functionality, greater range, and a supporting ground network. PilotAware is recommended by the UK CAA, and financial support of 50 % for aircraft operators installing it is provided by the by the UK Department of Transport [9] for UK operators only. Technical details can be found here: https://www.pilotaware.com/knowledge-base

Both, FLARM and PilotAware, operate under a manufacturer’s license but without certification by any aviation authority. Their usage is recommended but not mandatory, and consequently, traffic information always remains incomplete. FLARM transmitters, when fixed installed in aircraft, are controlled under their respective maintenance program and receive firmware updates on a yearly basis. Ground networks exist *(OGN and GRID/ATOM*) for both systems and provide traffic information services like ADS-B-in, but without a defined service level for resilience, coverage, response times, etc.

For both systems low power / low cost / display on mobile phone versions with varying reception range and functionality to be used operators of parachutes, hang gliders and others can be purchased. Both use standard interfaces for data export to popular Flight Management Apps on Tablet Computers such as AirNavPro, SkyDaemon, and many others. Again, as mentioned above, their usage is not mandatory, and therefore the traffic information displayed is always incomplete.

As these systems are on the route to specify a pseudo standard, an increasing number of rotorcraft operate with FLARM / PilotAware transceivers to avoid collisions with air sports aircraft. As an example even helicopters operated by police and medical emergency services, which routinely have to land off aerodromes, have installed and are using them.

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A.3 Urban Air Mobility (UAM)

Urban air mobility (UAM) in principle covers mobility services in an urban environment using air vehicles. This can potentially include many different types of vehicles such as helicopters, various types of drones or flying taxis. Nevertheless, the term is the most often used having in mind exclusively flying taxis with alternative (electrical) propulsion (typically so-called eVTOL aircraft) operating at low and very low altitudes of suburban and urban areas.

A.3.1 Envisioned CNS Equipment for initial deployment

CNS equipment for Urban Air Mobility (UAM) early deployment must take into account some specifics of these vehicles and its operation. First specific means that UAM will very probably be all electric vehicles. This means that avionics will be based on batteries and this fact strongly affect the Size, Weight and Power Consumption (SWaP) requirements on equipment. Weight of the vehicle will be a very important factor for performance in terms of range and payload. The higher weight then means the bigger and heavier batteries – and probably very limited space in the vehicle for avionics with its batteries. Use of ground infrastructure to the maximum extent possible seems to be sensible in minimalizing amount of onboard equipment.

Navigation task has also some specifics in case of UAM operation. Per NASA study [10] it is assumed that majority of UAM traffic will be above cities in altitudes between 500 and 5000 feet. Lower altitudes in city environment brings higher risk of GNSS degradation (for example, landing at rooftop of building in other very high buildings surrounding). This means even higher need of alternate positioning source for backup navigation data or for data fusion. Required navigation performance for these operations will must be defined and it will drive the navigational equipment of UAM.

Communication requirements for UAM operation have to be discussed and specified for both air-to-ground (vehicle to UTM service provider) and air-to-air (vehicle to vehicle). Datalink for safety critical information will must contain backup solution. Datalink can be based both on commercial and preserved aviation spectrum.

Conventional surveillance means can be used for UAM operation with consideration to low altitude and city environment specific. Low altitudes can represent issue for detection by secondary radar. ADS-B Out equipment seems reasonable, but risk of 1090 MHz saturation must be considered. There is assumption to use ground surveillance infrastructure as much as possible. At the same time, interoperability with standard ATM systems is necessary due to preserving approach to airports.

A.4 Drones

Modern drones are equipped with critical light-weight, high-performance devices accommodating the CNS requirements. For the ease of operation and cost and weight efficiencies, small drones use GNSS, redundant strapdown inertial sensors and magnetometers for each axis in 3D, digital barometers and sensor fusion algorithms in order to have the navigation solution. UHF, L, S, C band radios mostly using ISM frequencies and also X and Ku band radios are utilized in telemetry, command and control units. The valuable data gathered on the drone such as its position, attitude, velocity estimations, or the payload data like video stream is downloaded to the ground station through these units. For VLOS operations, drones have separate RC links in general, although the telemetry and command links can be utilized for the remote pilot connection. Networked drones establish their internet connection through available mobile networks. Currently, 3G/4G equipment is preferred for BVLOS operations, if

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both the drone and its ground control station stay in the network coverage. Electronic conspicuity devices in U-space with the primary aim of enabling Surveillance such as ADS-B In, P3i and enabling collaborative Detect-and-Avoid such as FLARM are currently available with very low weights and power consumption with enough range for avoidance. For leisure activities, a limited set of above mentioned CNS technology is enabled on a drone. On the other hand, flights in densely-populated and urban areas, and flights near protected sites for surveillance or cargo purposes require more as they have more probability to share the airspace with other vehicles both manned and unmanned.

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Appendix B Low Altitude Operational Environment

B.1 CTR of Airports (airspace D)

B.1.1 ATM and U-Space Services Available/Expected

A control zone (CTR or controlled traffic region) in aviation is a volume of controlled airspace, normally around an airport, which extends from the surface to a specified upper limit, established to protect air traffic operating to and from that airport. Because CTRs are, by definition, controlled airspace, aircraft can only fly in it after receiving a specific clearance from air traffic control. This means that air traffic control at the airport know exactly which aircraft are in that airspace, and can take steps to ensure aircraft are aware of each other, either using separation or by passing traffic information.

In the USA the term control zone is no longer used and has been replaced by airspace class D. Typically it extends 5 miles in diameter with a height of 2500 ft AGL (above ground level) around small commercial airports. Aircraft are required to establish radio contact with the control tower before entering and to maintain in contact while in class D airspace. This implies that an aircraft must be equipped with at least a portable radio to fly in Class D airspace.

In the UK, control zones are normally class D airspace and usually extend from the surface to 2000 ft AGL. They can be observed to be usually rectangular, extending along the axis of the main runway, although irregular shapes may be used where more complex airspace dictates this (see Liverpool and East Midlands). A control area (CTA) is often placed between a CTR and nearby airways to give uninterrupted controlled airspace to airways arrivals and departures.

In Germany, control zones are a special type of class D airspace, called *D (CTR)*. The main difference to the regular German class D airspace is, that within a CTR there is a minimum required cloud ceiling of 1500 ft AGL.

Generally, available ATM services are: Approach control service, Aerodrome control service, Advisory service, Flight Information service and the Alerting service.

B.1.2 Operational Needs Driving CNS Requirements

To address performance requirements in the CTR of airports (airspace Class D), evaluation of the Air Traffic Control needs is crucial because ATC is responsible for traffic separation in this controlled airspace. Performance of ATC systems could serve as clue for definition of required integrated CNS performance.

ATC main source of aircraft position is Secondary Surveillance Radar (SSR). SSR range resolution is about 200 meters for the conventional ones, but the modernized monopulse secondary radars offer resolution up to 13 meters. Other source represents ADS-B. ADS-B performance depend on quality of navigational information onboard the aircraft and on quality of communication (it can be said that ADS-B is already kind of example of integrated CNS functionalities).

Required navigation performance for approach is 0.1, 0.3 or 1. For example, "A performance value of RNP 0.3 assures that the aircraft has the capability of remaining within 0.3 of a nautical mile to the right or left side of the centerline 95 percent of the time." [11]. Required navigational performance in CTR of airport mean ability to follow RNAV STAR.

Performance based approach for integrated CNS then can look as follows:

- Overall iCNS performance should conform to overall performance when addressing CNS functionalities separately
- Required navigational performance can be lowered in case of use of other than onboard position source (for example position information from 5G cellular network). If this information is used, it consists of navigational part (position determining) and communication part (transmitting the information to the aircraft and/or to the ATC)
- Required communication performance can be lowered in case of use of other communication mean (for example 5G datalink)

Shift from conventional approach to CNS to performance based iCNS is illustrated in the figure below:

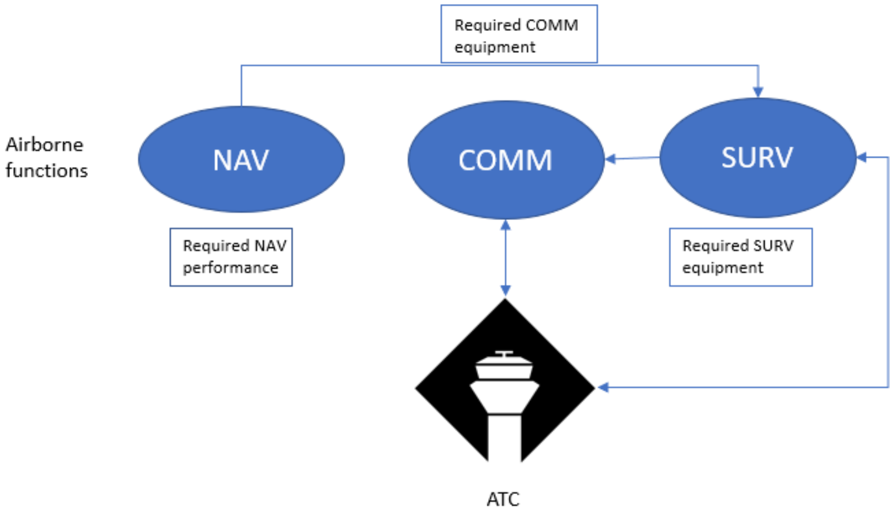

Figure 31: Conventional Approach to CNS.

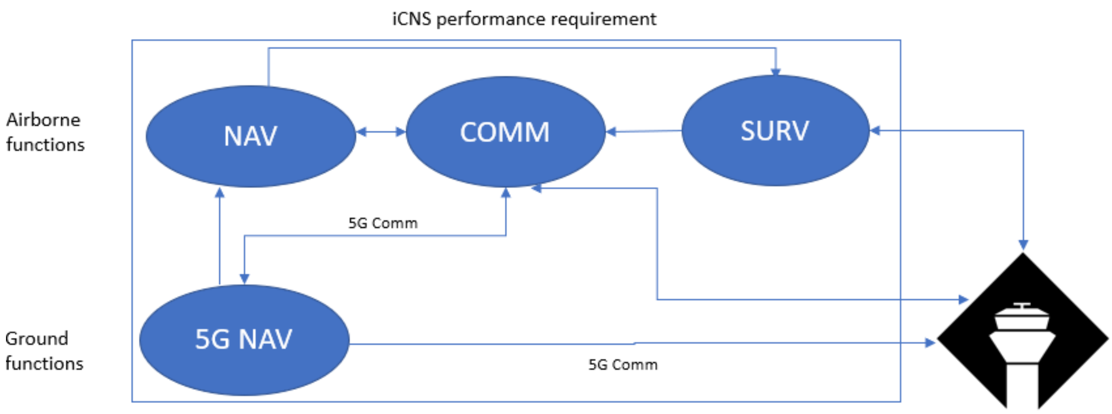

Figure 32: Performance based approach to iCNS.

B.2 Low Level airspace (< 1 500 ft) in urban area (Class G, Class E)

B.2.1 ATM and U-space Services Available/Expected

Altitudes up to 1500 ft belong to airspace Class G (uncontrolled) or Class E. In case of Class G, no ATM services are provided (low altitudes around the airport are excluded from this section). In case of Class E, separation is provided only for IFR flights where possible. But practically, the IFR traffic is not usual in such low altitudes.

U-space services are expected in this airspace. FAA expect providing supporting framework for unmanned operations at altitudes under 400 ft. Not dramatically different values could be supposed for European U-space. Description of U-space services is in the Section U-space Services.

B.2.2 Operational Needs driving CNS requirements

Probable very low level urban airspace users are small UAS, UAM and rotorcraft, where the latter two ones do not use such a low altitudes for cruise, but probably only for take-off and landing. Small UAS will have to follow U-space practises while preserving interoperability with manned aviation.

Very low altitudes represent uncontrolled airspace. Current common approach is based on visual observing of possible threats. Drone operators are required to operate drone at visual line of sight (VLOS), BVLOS operations are approved by Civil Aviation Authorities after careful evaluation of risks and means for their mitigation. On the other side, rotorcraft belonging to Part 29 (Transport Category) are the most equipped from the all lowest airspace users and some of them undergo requirements to carry Traffic Collision Avoidance System.

It is impractical to require equipage with transponder from each very low altitude vehicle. The key for interoperable surveillance solution could be:

- equipage of drones with systems like ADS-B In enabling timely avoidance of manned aircraft
- U-space information available for pilots of manned aircraft

Navigation in very low heights in urban environment brings next challenges. Many high buildings result in much higher probability of GNSS signal multipath. Aiding by additional position source to usually used GNSS+INS combination (manned aircraft) or GNSS + low cost inertial sensors could be very useful. Since there is an assumption of 5G deployment in cities, 5G network seems to be good candidate for integrated NAV+COMM solution.

Integrated CNS performance for drone have to be set to the level enabling:

- drone’s capability to stay in given geofenced area
- drone’s capability to communication - C2 link for ground pilots and for U-space traffic control
- drone’s capability to avoid other vehicles

Integrated CNS performance for rotorcraft have to be se to the level enabling:

- communication capability for both the U-space and the ATM
- capability to enable specific operations in bad visual conditions in GPS denied environment

- capability to detect all potential air threats (can be reached by sufficient communication performable enabling receiving reliable data from ground surveillance)

Urban environment in altitudes between 500 and 1500 ft is typical airspace for future UAM traffic. Next, rotorcraft and partly lower classes of general aviation[9] are users of the environment. Regarding the UAS, ne European legislative valid from January 2020 restrict maximal altitude for majority of drones to 120 meters (previously valid rules per ICAO Annex 2 permits operation in Class G airspace). Thus, only UAS categories as *Certified* or *Specific* (professional work) will operate above that altitude. This airspace generally belongs to the Class G or E.

UAS for professional work will probably be operated BVLOS. Thus, Detect-and-Avoid system will be required.

The difference from previous very low environment is then in absence of small UAS traffic and significantly larger ratio of manned traffic. Majority of general aviation (including rotorcraft) rely on visual scanning of surroundings. This method of traffic avoidance would become very difficult in case of UAS presence.

Performance based approach for this environment have consider following:

- communication capability for both the U-space and the ATM
- navigation capability for respecting geofence area
- surveillance capability to detect all surrounding traffic including UAS (can be reached by sufficient communication performable enabling receiving reliable data from ground surveillance).

B.3 Low Level (VLL) airspace (< 1 500 ft) in rural area (Class G, Class E)

B.3.1 ATM and U-space Services Available/Expected

Regarding the ATM services, the situation is the same as in the previous section.

EASA regulations, and most European countries' national regulations, highlight the necessity to fly under 120m (~400ft), or to fly far from manned aviation activity. Despite this an encounter with a manned aircraft is already relatively common.

[9] Over the congested areas of cities, towns or settlements or over an open-air assembly of persons, VFR flight is permitted to be conducted with at least 1000 ft height distance above the highest obstacle within a radius of 600 m from the aircraft (except when necessary for take-off or landing or except by permission from the competent authority, ICAO Annex 2)

The remote pilot must ensure that he or she keeps the unmanned aircraft (UA) at a distance less than 120 m (400 ft) from the terrain, and the picture below shows how the maximum height that the UA may reach changes according to the topography of the terrain [12]

In addition, when the Member State (MS) has defined a geographical zone with a lower maximum height, the remote pilot must ensure that the UA always complies with the requirements of the geographical zone. When flying an unmanned aircraft within a horizontal distance of 50 metres from an artificial obstacle taller than 105 metres, the maximum height of the UAS operation may be increased up to 15 metres above the height of the obstacle at the request of the entity responsible for the obstacle [12].

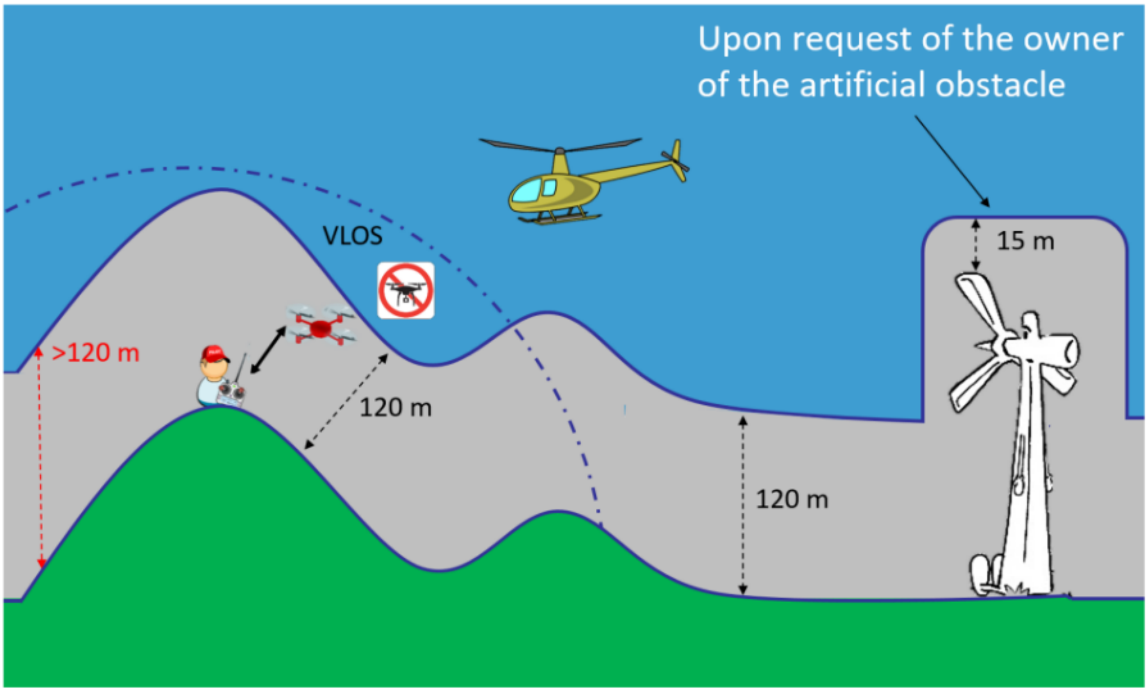

Figure 33: UAS Operations In The 'Open' And 'Specific' Categories [12].

B.3.2 Operational Needs driving CNS requirements

Very low level airspace above rural country differs from the same altitudes in cities on following aspects:

- UAM operation is not probable
- Infrastructure as 5G network may not be available
- General aviation traffic can be present (agricultural purpose)

Rural area will be probably significantly less utilised than the city area. Small general aviation aircraft used for agricultural purposes are being replaced by drones capable to perform the same tasks at lower operational costs.

Integrated CNS performance for UAS should consider following:

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- drone's capability to stay in given geofenced area
- drone's capability – C2 link for ground pilots and for U-space traffic control
- drone's capability to avoid other vehicles

B.4 Upper controlled airspace (class A-C)

Upper airspace is a controlled airspace which is used mainly by jets in the cruise flight phase.

In Europe, the Upper Information Region (UIR) is defined as airspace above a division level (generally FL195). It may vary in different countries. Maastricht Upper Area Control Centre (MUAC) covers airspace above FL245 in Belgium, the Netherlands, Luxembourg and NW Germany. In the USA, UIRs are not used, but high altitude en-route sectors typically begin at FL240. Upper airspace is controlled through area control centers (ACC) in Europe or ATC centers (ATCC) in the USA. Categorization varies, e.g. Class C in most of ECAC; Class B in the UK until 2006; and Class A in the USA [13] .

B.4.1 ATM Services Available

Upper controlled airspace represents the airspace with the largest number of ATM services. Air traffic service (Area Control service), Advisory service, Flight Information service and the Alerting service are available.

B.4.2 Operational Needs driving CNS requirements

Upper controlled airspace means the highest and the most precisely defined requirements to CNS equipment. Airspace users are especially commercial air transport, higher classes of general aviation and potentially the large UAS capable of IFR flight.

Performance based approach will reflect following:

- Capability to satisfy Required Navigational Performance 2 (en-route continental navigational applications)
- Surveillance capability corresponding at least to current performance level achieved with PSR, SSR, and ADS-B.

Appendix C General Operational Safety Requirements

SERA.5005 "Visual flight rules" defines the minimum and maximum altitudes that may be flown by a VFR flight as follows:

(a) Unless authorized by the competent authority in accordance with Regulation (EC) No 730/2006, VFR flights shall not be operated:

> *(1) above FL 195;*

(b) Authorization for VFR flights to operate above FL 285 shall not be granted where a vertical separation minimum of 300 m (1 000 ft) is applied above FL 290.

(c) Except when necessary for take-off or landing, or except by permission from the competent authority, a VFR flight shall not be flown:

> *(1) over the congested areas of cities, towns or settlements or over an open-air assembly of persons at a height less than 300 m (1 000 ft) above the highest obstacle within a radius of 600 m from the aircraft;*
>
> *(2) elsewhere than as specified in (1), at a height less than 150 m (500 ft) above the ground or water, or 150 m (500 ft) above the highest obstacle within a radius of 150 m (500 ft) from the aircraft.*

Altitude limits for IFR are generally defined for the applicability of these rules by the state in which the aircraft is being flown, but the rules define such altitudes for cases where the state in question has not defined them. SERA.5015 IFR altitude limits are less important to the question of UAS ATM integration but are given here for completeness.

(a) Minimum levels ...

> *(1) over high terrain or in mountainous areas, at a level which is at least 600m (2,000ft) above the highest obstacle located within 8km of the estimated position of the aircraft;*
>
> *(2) elsewhere than as specified in (1), at a level which is at least 300m (1,000ft) above the highest obstacle located within 8km of the estimated position of the aircraft.*

C.1 The Requirement for Additional Flight Rules

As described above, VFR flights must generally fly no lower than 1,000ft/300m over the congested areas of cities etc. or 500ft/150m elsewhere. With the introduction of UAS into the airspace, it becomes obvious that many of these will be flown (VLOS and BVLOS) below these limits. This airspace is referred to as Very Low-Level (VLL) airspace. It must be remembered, however, that these "lower limits" for VFR are not a barrier. There are many manned flights allowed below this level - police, fire and ambulance helicopters, hang-gliders, ultralights - and these must be allowed to carry out their activities without hindrance from UAS.

Similarly, certain organizations propose flying UAS at very high levels (VHL) above FL600 which is currently the maximum altitude flown by civilian aircraft.

There are currently no specific rules governing UAS other than those that govern all aircraft, as described above. Two more sets of flight rules are needed, therefore, which sit on top of the General Flight Rules.

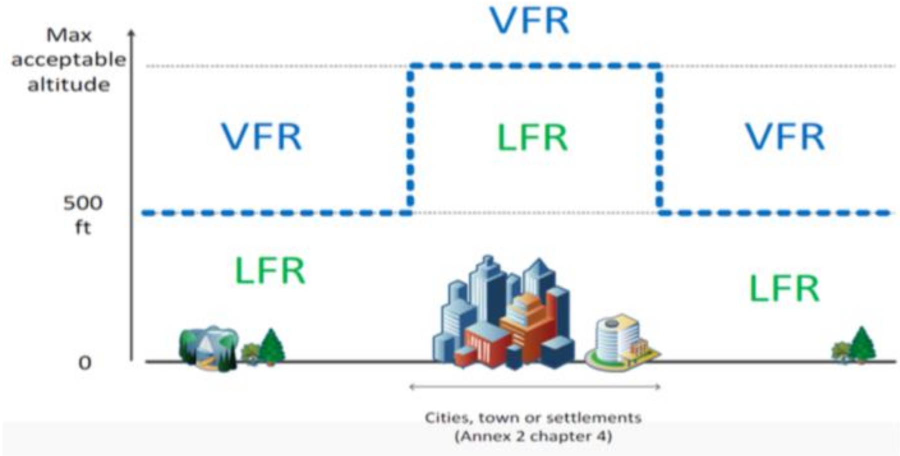

Figure 34: VFR/LFR boundary [14].

SERA.5005(f)(2) states that 'except when necessary for take-off or landing, or except by permission from the competent authority, a VFR flight shall not be flown ... at a height less than 150m (500ft) above the ground or water ...". But this does not mean that 150m is a barrier for all VFR traffic. In practice, most states give permanent permission to certain categories of airspace user to fly below 150m for their specific needs - for example balloons, or gliders when they need to land on the countryside. In reality, it is possible to land/take-off everywhere - not just at an airport - with special authority, and although it might not happen very often, there could be traffic anywhere below 150m.

There is certainly a need now for flight rules addressing the interaction between drones and manned aircraft. Different rules may, however, be required later to address separation between drones. These rules should take the different certification standards for GA, microlights, etc. into account, and the rules for rotorcraft, parachutists, balloons, and model aircraft also need to be updated. For example, rotorcraft have specific paths they have to follow in some (e.g. urban) areas but not in others; could this apply to UAs.

EASA Opinion 01-2018 [EASA, 2018] covers model aircraft and has proposed three solutions: an authorization for clubs and associations recognizing their good service experience; zones in which alleviations can be acceptable; and the use of sub category A3. This has raised and continues to raise some concern. Paragliders are not covered by EASA rules and in some states are not treated as aviation but as a sport.

With the numbers of drones that will be flying in the future, there is a case for considering the airspace below 150m to be "drone airspace" with all other traffic having to adjust. In the Netherlands today, there are roads designated for bicycles where cars are allowed as "guests". In a similar fashion, rather than trying to make drones follow the rules for manned aviation, which can be very difficult, in this "drone airspace" manned aviation would comply with some rules for drones.

For drones and manned aircraft to be able to cooperate in the same airspace, however, rules need to be conceived in terms of a common altitude reference system. Such a system could enable a strategic vertical separation to be applied to drone transit at low level, similar to the rules applicable to flight levels at higher altitudes. The common altitude reference system is the subject of a different set of guidelines.

Doole and etc [15] conducts a survey on the needs of drone operators and users and manned aviation pilots and officials in relation to current and future drone operations. The purpose of this survey was to support the following activities of this study:

- Identification of stakeholder needs;
- Identification of target scenarios for the study;
- Recognition of key information to unlock future Beyond Visual Line of Sight (BVLOS) operations and information that would enhance drone flight operations;
- Assess the minimum dataset for drone information required to operationalize U-Space.

Survey results collected from drone operator and user (cohort 1) and manned airplane pilots and authorizations (cohort 2) are shown in Table 4 and Table 5 [15].

Survey intent	Cohort 1	Cohort 2
Typical drone applications	Aerial image capture, inspections, agricultural use	Aerial image capture
Typical operational altitude	300 to 400ft	0 to 200ft
Urban environment flights	Occasional flights	High-density
Flight operations data	Obstacle data, hyperlocal weather, detailed 3D elevation, Geofenced areas, Real-time traffic position data, Population density of overflown areas, bird warning, Separation rules	Geofenced areas, obstacle data, real-time traffic position data, separation rules, hyperlocal weather
Flight operational risks	Presence of obstacles, presence of birds, poor GPS/GNSS signal, loss of video datalink, sudden wind gusts, loss of communication and control, flying over urban areas, presence of other traffic	Presence of obstacles, presence of other traffic, loss of communication and control, poor GPS/GNSS signal, flying over urban areas
Time demanding pre-flight phase activities	Flight permission, mission planning, mission verification, gathering hyperlocal data, gathering obstacle data	Flight permission, mission planning, securing area for flight, gathering obstacle data, gathering hyperlocal data
Real-time data for BVLOS flights	Real-time traffic position data, location of birds (uncontrolled traffic), temporary geofenced areas, active NOTAMs (Notice to Airmen), hyperlocal weather, detailed 3D elevation map, population density of overflown areas	Temporary geofenced areas, active NOTAMs Real-time traffic position data, hyperlocal weather, location of birds, population density of overflown areas
Mandatory BVLOS flight planning data	De-conflicting flight plans, active NOTAMs, GNSS availability, hyperlocal weather, obstacle data, temporary geofenced areas	Active NOTAMs, de-conflicting flight plans, temporary geofenced areas, hyperlocal airspace data, obstacle data

Table 4: Drone information service gaps for U-space [15]

Information categories	Information service gap
Flow management	Urban airspace capacity management High-density traffic management De-confliction management Congestion management Urban airspace intrinsic and strategic conflict risk management First/last $50ft$ operations guidance Hyperlocal airspace data Dynamic geofencing
Meteorological	Past, present, future hyperlocal weather data Sudden atmospheric warning: hyperlocal wind gusts
Environment	Permanent obstacle data Non-permanent obstacle data Geometrical (height and dimensions of obstacles) data Population density of overflown areas Advisory of uncontrolled traffic
Flight	Flight planning assistance Flight risk analysis Optimal altitude allocation Vertical separation guidance Horizontal separation guidance Real-time telemetry Contingency management Emergency management
Communication	Hyperlocal GNSS and 4G/5G coverage map ATC-Drone operator/user communication datalink U-Space instant message service High-quality video datalink Authorities datalink
Surveillance	Real-time unmanned traffic data Digital NOTAM management Drone incident support Traffic monitoring (state and intent information)
Drone	Vehicle performance characteristics Vehicle specifications Vehicle serial number

Table 5: Drone Information Service Gaps [15].

Doole and etc described the identified information gaps in Table 4 for achieving safe drone operations in VLL urban airspace. This was done by comparing existing information services from manned aviation and UTM service providers against the requirements derived from drone operators and users and the standard U-Space services [15].

C.2 Current Operations

Current flight rules specify that aircraft can fly below 150m for take-off and landing. This is obviously necessary for every operation. They can also do so whenever authorised by the competent authority, without need for this authority to notify ICAO or ask EASA for an exemption.

It is currently the responsibility of ANSPs to provide separation between aircraft, but in areas with the high numbers of drones or in an emergency, an ANSP could have great difficulty tactically separating manned aircraft from unmanned. In fact, it will probably be necessary to separate analysis between several densities of traffic, with high-density traffic requiring flow control first to enable self-separation and anti-collision. A system of fixed routes could also facilitate things, even if it doesn't fill all operational needs.

If there is no strategic or tactical separation, flight rules must determine the responsibility for deciding how multiple aircraft/UAS should avoid each other. For example, under current rules, aircraft on final may proceed and others have to avoid them. This could mean that a UAS landing has priority over manned aircraft. Perhaps the biggest real risk comes from low-flying helicopters, however.

Nevertheless, rules cannot distinguish between whether an aircraft is manned or unmanned, VLOS or B-VLOS, since this state is not visible to the other users. The variety of aircraft and UAS dynamics could also present problems.

C.3 Navigation and Surveillance

Mandatory ADS-B equipage in VLL for both manned and unmanned aircraft would reduce the technical challenge to DAA radars or cameras, which could then be just a final safety net, useful for obstacle detection (cranes etc.).

Manned aviation safety could be undermined, however, by drones' using the 1090MHz frequency that Mode-S ADS-B transponders operate with. EUROCONTROL investigation into ADS-B/1090MHz shows that this frequency band is already close to its maximum capacity. However, this is mainly in high-altitude airspace due to over-interrogation by SSR radars (both civil and military), and its use in VLL might be acceptable. Low-power ADS-B may partly solve the issue of 1090MHz congestion, although the cost could be high. Simulations of an airport could show what the impact of equipping drones with a miniature ADS-B transmitter or transceiver would be on tracking capability and how they would interact.

4G/5G could be a better surveillance technology in terms of scalability and reliability. Providing UAS pilots with information of flights below 150m in the surrounding area via 4G or 5G would resolve the issue of their not being aware of what is flying near them. If this method were applied to manned aviation below 150m (a small proportion of the actual flights today) and combined with special rules or restrictions to manned aviation at these altitudes, manned and unmanned would be aware of each other in the same airspace.

If the separation management will be managed by on-board systems, the latency requirements will become even more critical and possible use of V2V communication will become more suitable.

The key question is whether 4G/5G would allow drone-to-drone or drone-to-manned aircraft communications. If they do, then DAA and conflict resolution could be done on-board and there would be no latency issues. There is also the possibility of using them to create self-organising networks, where each drone/aircraft acts as a node in a larger system. This would be a very interesting concept if applied to UTM and would also help improve the availability of C2 Links.

The PODIUM project will look at the use of 1090MHz, cellular networks (via Orange) and UNB/L-band. It aims to demonstrate and provide clear conclusions on maturity and recommendations for improvements.

Defining technology requirements for LFR (ADS-B, 4G/5G, etc.) that may go beyond current VFR requirements could mean that GA would have to be upgraded to be able enter an LFR-only area. It will also be necessary to install additional equipment on manned aircraft to protect the lives of occupants since, given the nature and size of small UAS, and their kinds of operation, it is almost impossible for manned aviation users to detect and avoid them. To be acceptable to the GA community, the rules of the air for UAS should not mandate equipment for GA aircraft unless such equipment is cheap, light and provides some operational benefits.

The idea behind LFR or HFR is to avoid creating any new rules in VFR and IFR, but to have something in place for operations below 500 ft. UAS not flying LFR (VLOS or BVOLS) or HFR must comply with VFR or IFR. In any case, rules will have to be updated and integrated from both a VLOS and a BVLOS perspective.

An important aspect to be considered is the link to ATS/ATC criteria; for instance the services provided to UAS in relation to services provided to other traffic. Certain services are provided for VFR traffic only; for VFR and IFR traffic; or for separation between VFR and IFR traffic. These relations need to be defined for UAS and new sets of flight rules established to enable differentiation between them.

The only concern here is with flight rules from the perspective of a UAS flight. However, there are many ATC issues involved with applying VFR and IFR rules to drones since these rules are specifically designed to manned VFR and IFR traffic and do not concern other types of flight operation linked to UAS. New rules must therefore be established for UAS and included in the flight rules procedures for ANSPs to ensure that all players know what to do to ensure separation. This applies anywhere above 150m, not just to the CTR [14].

C.4 Flight restrictions around aerodromes

Flights of unmanned aircraft around airfields or airports that are designated as ‘protected aerodromes’ are tightly restricted. Unmanned aircraft of any size must not be flown within the Flight Restriction Zone (FRZ) of a protected aerodrome, without appropriate permission (UK sample).

The Flight Restriction Zone consists of the following three elements:

- **The Aerodrome Traffic Zone**: A 2 or 2.5 nautical mile radius ‘cylinder’ around the aerodrome, extending 2000 ft above ground level, centred on the longest runway.

- **Runway Protection Zones**: A rectangle extending 5Km from the threshold of the runway away from the aerodrome, along the extended runway centreline, and 500m either side- also to a height of 2000 ft above ground level.

- **Additional Zones**: In the case where the 1Km boundary of an aerodrome extends beyond the Aerodrome traffic zone, and so would not be protected by it, the flight restriction zone will include a ‘bump’ (the airfield boundary + 1KM) to protect this part of the aerodrome.

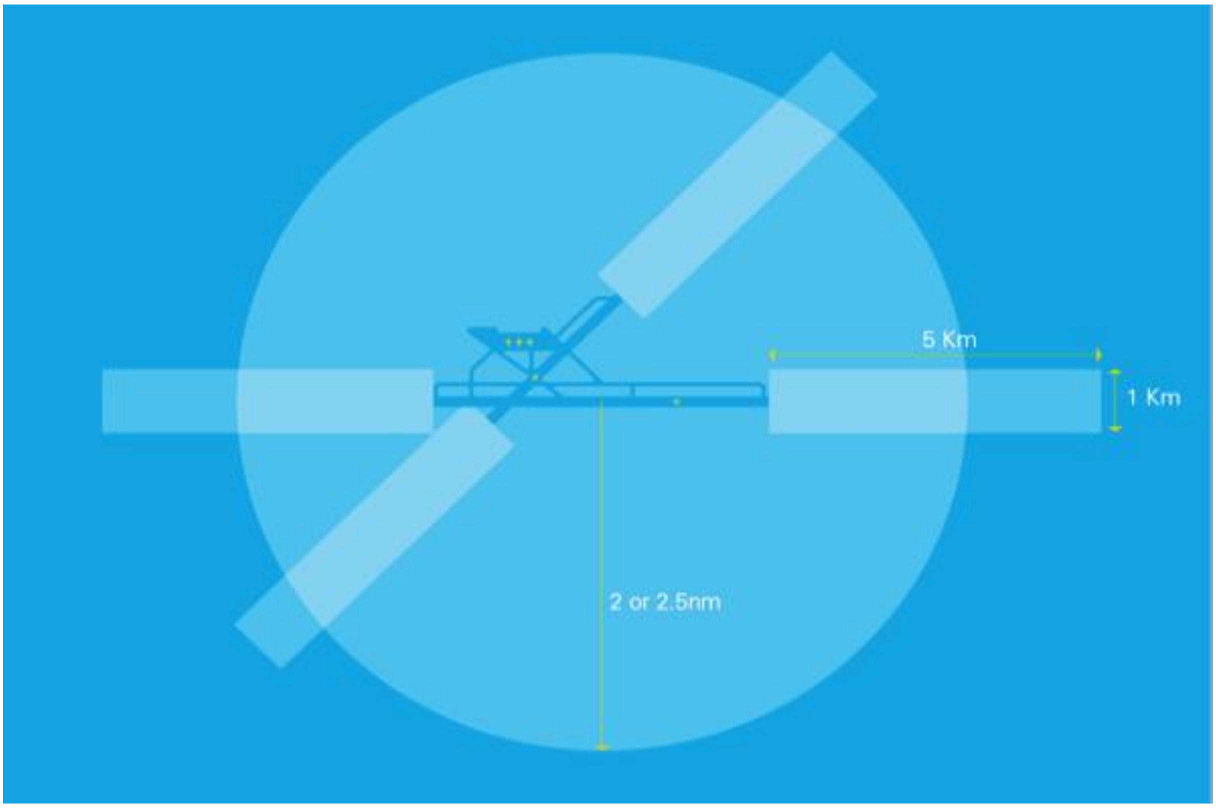

Figure 35: Flight restrictions around aerodromes [16].

Controlled Airspace and Aerodrome Traffic Zones (ATZ)

There are no separate regulations in place regarding the flight of small unmanned aircraft in controlled airspace below 400 ft (Class A, B, C, D, E). Restrictions involving the flight of UAS within Aerodrome Traffic Zones are described in Flight restrictions around aerodromes. UAS pilots are reminded of all other responsibilities, including the Air Navigation Order requirements, that any person in charge of a small UAS:

- may only fly the aircraft if reasonably satisfied that the flight can safely be made and;
- must maintain direct, unaided visual contact with the aircraft …for the purpose of avoiding collisions.

If operating above 400 ft within controlled airspace, the permission to do so granted by the CAA will state that appropriate permission from the relevant Air Traffic Service Unit (ATSU) must also be obtained.

C.5 UK Royal helicopter flight airspace

When royal flights in helicopters take place airspace known as a Royal Low-Level Corridor (RLLC) is established between the departure and arrival sites; the details of the flights, including the route and timings, are published by NOTAM and so will also be depicted on airspace mapping apps.

A RLLC encompasses the airspace five nautical miles either side of the intended track of the Royal helicopter, a five nautical mile 'circle' around the departure and arrival sites, and extends from the surface up to 1,000ft above the royal helicopter's highest planned transit altitude. RLLCs are also divided into 20 minute 'sectors', with checkpoint locations nominated at the start and end of each sector.

The key requirements for operators of small unmanned aircraft are to be aware of the flight, keep a good look out and maintain adequate separation from the royal helicopter; however, small unmanned aircraft operators are strongly advised to keep their aircraft at least one nautical mile horizontally clear of the departure and arrival sites during the published active periods (15 minutes before until 30 minutes after the planned departure/arrival time detailed in the NOTAM).

C.6 The role of statutory bodies

Any operator of a camera equipped small unmanned aircraft who does not have an additional permission from the UK CAA, is restricted to remaining at least 150 meters from congested areas or any organized, open-air assembly of more than 1,000 people. Operators must not fly camera fitted unmanned aircraft within a distance of 50 meters of any person, vessel, vehicle or structure that is not under the control of the Remote Pilot (during take-off and landing the distance from uninvolved people may be reduced to 30 meters). This means that a 'bubble' exists around the UAS, with a radius of 50m within which there should be no uninvolved members of the public. This is difficult to achieve in a busy urban environment and will likely involve the operator making formal arrangements with the relevant authority to temporarily restrict pedestrian and vehicular access or to restrict access to shops, dwellings and other property. Whilst the UAS may be flown over people at a distance greater than 50m, operators must only do so when satisfied that it is safe to do so, and any failure of the UAS will not endanger any uninvolved people [16].

C.7 Airspace Assessment and Specific Operational Risk Assessment (SORA)

The Joint Authorities on Rulemaking for Unmanned Systems (JARUS) has developed guidelines on performing a Specific Operational Risk Assessment (SORA) [JARUS, 2017]. EASA intends to adopt the final version of the SORA, as an Acceptable Means of Compliance for the risk assessment required from operators in the Specific category.

UAS can pose a serious safety and security threat. There is a real need to ensure that they only fly in areas of airspace and in certain conditions in a way that will ensure the safety, security, privacy of people, property and state apparatus to the greatest extent possible. The environmental impact should also be minimized.

A SORA provides a method for minimizing this: especially those aspects that concern the safety of people or of property through assessments of ground risks and air risks.

A SORA looks at these risks from the operator's perspective. It proposes a means of evaluating risks and mitigations to enable an authority to authorize a given operation. It analyses whether the operator has ensured all that is required to conduct a safe flight, i.e. it deals with the pilot, the aircraft, the airspace, and people and infrastructure on the ground.

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he perceived level of air risk – the risk of a mid-air collision - is incorporated though an Airspace Encounter Category (AEC) for a given region of airspace. The SORA method assigns an Air- Risk Class (ARC) ranging from 1 (low risk) to 4 (high risk) to these AECs – see Table 1 – based on three factors: the rate of proximity, dependent on the number of aircraft assumed to be in the airspace; the geometry of the aircraft, use of specific routes etc., in the airspace; dynamics, or how fast aircraft travel in the airspace. Measures can be proposed to reduce these impacts.

Height/Altitude/FL	Airspace Class/Type	AEC	ARC
Above FL600 (VHL)	VHL	11	2
Between 150m/500ft and FL600 (Integrated Airspace)	Class A, B, C, D, or E	1	4
	In an Airport Environment	2	4
	Class G with Mode C Veil/TMZ	3	4
	Class G over urban environment	4	3
	Class G over rural environment	5	3
Below 150m/500ft (Very Low-Level Airspace)	Class A, B, C, D, or E	6	3
	In an Airport Environment	7	4
	Class G with Mode C Veil/TMZ	8	3
	Class G over urban environment	9	3
	Class G over rural environment	10	2
Any	Atypical Airspace	12	1

Table 6: Airspace Encounter Categories and Air-Risk Classes [14].

Once the ground and air risks and their mitigations have been determined, the mitigation of, or barriers to, the various threats that could cause the loss of control can be analyzed. Finally, the safety or otherwise of the operation can be confirmed.

It is clear that an airspace assessment is necessary for evaluation both air and ground risks – which regions are above large populations, which are in proximity of vital infrastructure etc. Such an assessment will also provide the operator with additional barriers to the impacts that they need for the flight to be authorised by enabling a flight to be planned to avoid areas of high impact where possible.

These airspace assessments can also be a major factor in reducing the threats of an out-of-control flight by an operator to keep the UA clear of areas of electromagnetic interference etc.

When preparing an airspace assessment it is important to take all the factors that come into play during this analysis into account. These include:

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- Ground risks
    - obstacles, buildings, etc.
- Air risks
    - uncontrolled airports, paragliders, gliders, known areas for GA • Critical aviation-related areas and volumes
    - Airports arrival and departure routes (SIDs and STARs), sensitive areas
    - Helipads
- Critical non-aviation-related areas and volumes
- Critical industry
- Military facilities (airbases, shooting ranges, etc.)
- Protected VIP zones
- CNS

C.8 Areas where CNS can be impacted

These are each handled separately in the following subsections. In looking at these factors, it is important to take every possible use of drones into account. For example, whilst it is considered important that drones not fly over nuclear power plants, military based or inside airports, the operators of these facilities may wish to contract drones for inspection and other legitimate purposes. Even areas of natural beauty may require drones for forest surveillance at some times. No zones can therefore be truly considered drone-free zones.

Aviation related areas and volumes

In general, an airport vicinity is defined by the CTR around it and most authorities forbid the use of drones in this zone. It is clear, however, that there are parts of this CTR where operators would want to fly drones for specific applications such as runway inspections, bird control, and weather measurement. It would appear logical, therefore, to redefine the CTR to include areas that are defined as a “No-Fly Zone” and areas where UAs could be operated with ATC coordination. Even the no-fly zones could be opened up to drone flight if the runway is closed to normal traffic, for example.

Since operations in these zones would be carried out in tight coordination with the ATC provider at the airport in question, it is evident that there is no need to respect a general limitation to 150m (500ft); the operational envelope should be agreed between the relevant parties as should the services that ATC will provide to the drone operator, the separation standards to be applied etc.

When assessing airspace around an airport, it is important to consider whether it just has an ILS approach or whether VOR or NDB approaches should be included. The missed approach segment also needs to be considered. If there is also VFR traffic at the airport, VFR routes should be assessed in a similar way.

Non-Aviation Related Areas and Volumes

Drone activity may pose a threat to military installations; nuclear facilities; critical infrastructure such as bridges, dams, telecommunication centres; areas of natural beauty; schools, hospitals, and other public buildings. They must also be kept clear of cities and towns, and crowds.

The protection of VIPs (both physical safety and private life) has to be taken into account in the airspace assessment. Some states are very concerned about privacy because of the specific population they host.

CNS

Radio frequency is a very important aspect of modern life and especially of drone operations. Communication, navigation and surveillance all rely heavily on the ability of radio waves to travel unimpeded between the drone, its ground control station/pilot, satellites, and navigation beacons etc. Should interference be encountered, this can cause: loss of the drone's command and control (C2) link leading to contingency procedures being undertaken; loss of GNSS data leading to the drone's losing height and position information; loss of ADS-B coverage meaning that air-traffic management loses awareness of the drone's position with respect to other traffic; and other problems.

It is important, therefore, that areas that could be responsible for a loss of radio cover, whether from high-power transmission nearby or owing to ground features or buildings that might interrupt the signal, be taken into account when assessing the suitability of airspace for drone use (Eurocontrol (2018). UAS-ATM flight rules v1.2).

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