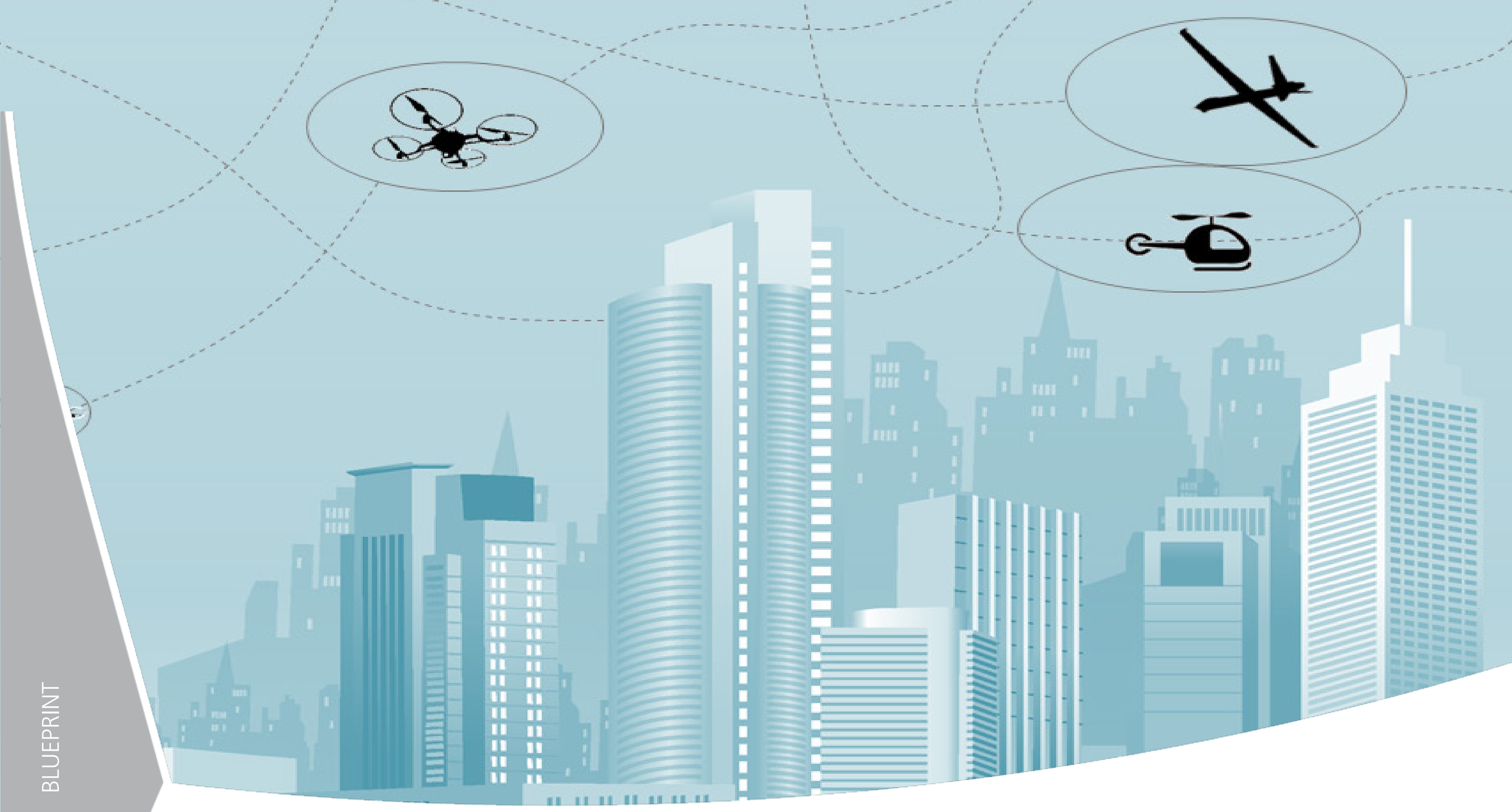

BLUEPRINT

DLR Blueprint

Concept for Urban Airspace Integration

December 2017

Integrating UAS into the future aviation system

A flexible approach enabling large-scale UAS operations

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Summary

A future airspace management system for Unmanned Traffic Management (UTM) or U-space will need to address a variety of constraints to ensure secure and efficient integration of Unmanned Aircraft Systems (UAS) with other airspace users. These may be very diverse and, in addition to VFR air traffic, also include other participants such as parachutists, weather balloons or prioritized aviation such as rescue helicopters. In addition to the various UAS design, performance and capability aspects, further requirements regarding protected flight areas (geofencing) or favored risk-minimized routes (possibly resulting from area characteristics or SORA CONOPS) must also be taken into account in any future U-space concept. One possible consequence of these new airspace users and their expected similar mission profiles could be the emergence of natural nodes on favorable mission routes. Based on this assumption, the DLR is working on a density-based airspace management concept for Very Low level (VLL) airspace. This future U-space airspace management and traffic management needs to be flexible enough to be applied in all kinds of airspace – not only the currently discussed VLL airspace below 500ft and the Urban airspace. Equally important when attempting to develop a long-term approach is the applicability of any new airspace management **throughout all airspace** where manned and unmanned aircraft will be operating together.

In this Blueprint paper the DLR proposes a density-based airspace management system for future U-space. The concept focusses on the integration of new airspace users (e.g., UAS and Urban Air Taxis) into uncontrolled airspace (here airspace G). The advantage of the proposed concept is that it **opens up the airspace equally for UAS with low technical equipment levels as well as with high**. The concept gives **incentives for UAS manufacturers and operators** to invest in performance relevant technology, but doesn’t exclude minimally equipped and less performant airspace users from entering the U-space airspace. The concept behind this approach relies on efficient airspace segmentation and UAS performance modelling. Based on airspace characteristics (e.g. ground class, geofences, U-space service availability, occurrence of VFR-traffic or other non-cooperative airspace users) the airspace is segmented into cells of similar requirements on airspace usage. Generally, each airspace user is modelled by an ellipsoid defining its individual performance parameters with regard to navigation, communication and the capability of being detected and of detecting other airspace users (cooperatively and uncooperatively). The lower the overall performance, the larger the resulting safety ellipsoid will be for the aircraft. As a result, an airspace cell might be used solely by few aircraft with a large ellipsoid – therefore quickly reaching the cell's capacity– or by more aircraft with smaller ellipsoids. This results in an airspace management which allows a **lot of freedom at low density, but little freedom at high density**. This concept provides a means to safely and efficiently organize the U-space airspace and strategically plan conflict-free routings and missions, even in dense airspace scenarios.

1. Introduction

Any future airspace management system for Unmanned Traffic Management (UTM) or U-space will need to address a variety of constraints to ensure secure and efficient integration of Unmanned Aircraft Systems (UAS) with other airspace users. These can be very diverse and, in addition to VFR air traffic, also include other participants such as parachutists, weather balloons or prioritized aviation such as rescue helicopters. In addition to the various UAS design, performance and capability aspects, additional requirements regarding protected flight areas (geofencing) or favored risk-minimized routes (possibly resulting from area characteristics or SORA CONOPS) must also be taken into account in any future U-space concept. One possible consequence of these new airspace users and their expected similar mission profiles could be the emergence of natural nodes on favorable mission routes. Based on this assumption, DLR is working on a density-based airspace management concept for VLL airspace. DLR’s concept is based on on-going studies of expected UAS/Air Taxi mission profiles, UAS/ Air Taxi outreach and factors of social acceptance, and has been developed to facilitate airspace management by defining flight rules, separation requirements and performance based profiles in a future joint airspace.

This future U-space airspace management and traffic management needs to be flexible enough to be applied in all kinds of airspace – not only the currently discussed Very Low level (VLL) airspace below 500ft and the Urban airspace. Equally important when attempting to develop a long-term approach is the applicability of any new airspace management throughout all airspace where manned and unmanned aircraft will be operating together.

The proposed DLR-U-space concept divides the airspace into individual segments of similar characteristics (e.g. technical and operational flight requirements, geofences) and develops a strategic management system that dynamically, based on current traffic and forecasted demand, either approves mission requests within an airspace segment or reschedules them in the event of reaching maximum capacity. The airspace segments are dependent in their capacity on the separation requirements of the airspace users operating therein. Depending on their specific equipment and capability, these may differ in their separation requirements and thus also dynamically influence the capacity of an airspace segment. This results in an airspace management which allows a lot of freedom at low density, but little freedom at high density. Conflict-free aircraft operations will be ensured on a strategic level by the U-space system. In the proposed U-space system, control of air traffic would, in principle, be decentralized. The U-space system would handle information provision (including traffic data and proximity warnings), airspace management and traffic flow control. A density-based airspace and traffic management system assures the optimal mission management of UAS/Air Taxi operations within a pre-defined time interval. Aircraft positions and mission data (4D trajectories) would be reported back to a central system after reviewing all airspace conditions. Higher priority missions (esp. rescue helicopters) would be reported to the system and any necessary dynamic adjustments to the affected airspace segments would be initiated. Affected missions in the area would be identified and reported to the responsible airspace user. Separation, mission optimization and replanning remains the responsibility of the airspace user. This requires certain technical (esp. performance-related constraints on CNS and Detect & Avoid) and operational requirements on UAS allowed to operate in these areas. These are determined and defined within the scope of the U-space concept developed here.

1.1. Document structure

This blueprint document describes the DLR's concept for U-space management. The document is structured as followed:

- Concept of density based airspace management
    - Airspace segmentation
    - Performance based operations
    - Dynamic Geofencing
- U-space airspace and traffic management
    - Strategical level
    - Tactical level
- Risk assessment and mitigation strategies

1.2. Motivation

The importance of Unmanned Aircraft Systems (UAS) is growing in all aspects of aviation. Platforms range from small, user-friendly, off-the-shelf drones ("micro UAS") to large transportation aircraft. Possible applications range from goods delivery, infrastructure monitoring and search & rescue, to agricultural surveillance. However, the airspace integration of such novel systems is still a major challenge. There is currently no legal framework or established traffic management infrastructure to enable and securely manage the widespread use of general airspace for UAS and Air Taxi operations, regardless of the nature of the aircraft.

With regard to different mission requirements and applications, today's UAS systems vary significantly in their capabilities as a result of:

- different mission requirements (from quadcopters, VTOL systems up to MALE (Medium Altitude Long Endurance)/ HALE (High Altitude Long Endurance) systems),
- varying performance (including maneuverability and avoidance capability) and
- specific technical equipment (including sensor technology, degree of autonomy and transponders).

Therefore, the challenge is to manage and monitor UAS with such diverse characteristics safely together with other airspace users (e.g., helicopters, gliders, and paragliders) in a future joint airspace.

The DLR would like to make a significant contribution to these current issues following the objective **"all aircraft in all airspaces".** With this central objective, the proposed concept is not limited to implementations in VLL airspace, which is conventionally defined as the airspace below 500ft[1], but aims to achieve long-term compatibility with all categories of airspace, in which manned and unmanned aircraft operate together.

The concept presented in this Blueprint is designed to meet the requirements in uncontrolled airspace – with special emphasis on urban airspaces.

1.3. Relation to other UTM/U-space initiatives

A variety of national and international organizations (e.g., ICAO, EASA), bodies (e.g., JARUS, EUROCAE) and initiatives (e.g., NASA UTM, NASA UAM, Global UTM Association) have been formed in recent years. The objectives range from the provision of legal framework conditions for a future UTM and possible CONOPS for the use of UAS, to technical and operational requirements for the architecture of a future UTM system. At the beginning of 2017, SESAR continued to develop a blueprint for the U-space. The U-space includes an operational framework in which UAS can safely operate in all areas (regardless of the density of populations), in all fields of application and with all types of UAS. In particular, the concept envisages higher levels of UAS automation in combination with a linked information infrastructure. Based on these initiatives and on work already conducted, the DLR has developed a concept detailing the airspace and traffic management component of a possible future U-space system.

SESAR’s recent study on the growth in the number of drones predicts a European fleet of over 7 million by 2050. Of these, over 400,000 drones will be for commercial applications [1]. Most likely, businesses such as parcel services and online retailers will be the major players establishing their own drone fleets. Given the typical volumes of such businesses it is likely that this will pose huge demands on the urban airspace in terms of capacity and conflict resolution. The aforementioned UTM concepts – NASA UTM and U-space – provide infrastructure and some concepts for operating the airspace free of conflicts.

[1] ICAO (International Civil Aviation Organization) “Annex 2: Rules of the Air” specifies that VFR flights shall not be flown at a height less than 1000ft above the highest obstacle over cities and congested areas; and 500ft elsewhere. Therefore, in U-space the maximum altitude for flights in rural areas is conventionally set to 500ft and in urban areas to 1000ft above the highest obstacle.

A range of different national and international projects have been launched to provide technical capabilities, prototypical U-space/UTM infrastructures and related services to integrate UAS into the VLL airspace. The German Air Navigation Service Provider (ANSP), Deutsche Flugsicherung (DFS), has recently started a project, together with Deutsche Telekom, called U:CON [2]. The project has the objective of developing and investigating a LTE-based communication network for UAS and to provide a tracking, monitoring and surveillance system able to fuse multiple sensor data (e.g. radar, FLARM) in order to enhance situational awareness for air traffic control in a future U-space.

The project “Skyways”, which is led by the National University of Singapore (NUS) in cooperation with Airbus Helicopters, is aimed at deploying UAS to deliver parcels across Singapore. The concept foresees the implementation of specific aerial corridors in which small UAS would be able to fly within a predefined aerial network [3]. In a first step only a small number of UAS will be deployed, ensuring safe separation between the flights.

First flights within a pilot U-space have already been demonstrated in Switzerland by their national ANSP, Skyguide. The demonstration proved that different, simultaneously operated UAS missions within a predefined airspace area can be planned, approved and monitored safely. Even dynamic requests to terminate the UAS flights, in the event of a rescue helicopter passing through the airspace area, could be initiated immediately.

Various other projects and initiatives exist and demonstrate important aspects and functionalities of a future U-space or Urban Air Mobility (UAM). Current concepts propose means to automatically detect and solve conflicts on a smaller scale. However, the question of to what degree it may be possible to operate hundreds or thousands of drones occupying the same airspace without conflict remains unanswered. This is especially important when considering urban airspaces. The DLR’s Blueprint proposes a concept to enable conflict-free routings of UAS together with other aircraft in high traffic scenarios, while meeting complex (urban) airspace requirements.

2. Density based airspace management

Classical Air Traffic Management (ATM) consists of three different core activities: Air Space Management (ASM), Air Traffic Flow Management (ATFM) and Air Traffic Services (ATS). These should be reflected when defining the core functionalities of a future U-space airspace and traffic management system. The overall objective of U-space is to enable safe and efficient UAS operations - in the medium term in VLL airspace and, in the long term, also in controlled airspace - by providing services such as:

- airspace provision and dynamic configuration of airspaces
- dynamic geofencing
- weather and wind restrictions
- dynamic capacity control
- terrain and obstacle maps
- route planning and route changes
- contingency management
- separation management, conflict and emergency management.

This Blueprint describes a U-space management system enabling dynamic airspace configuration and traffic management. The central services listed above can be realized applying the described concept effectively.

The airspace considered corresponds with the envisioned SESAR U-space (comprising all categories of airspace), while giving special emphasis to defining a concept for uncontrolled and urban airspaces.

2.1. Airspace configuration and density management

The airspace management system relies on the assumption that all future airspace users should be granted access to the airspace irrespective of their specific technical capabilities and performance. The concept focusses on the integration of new airspace users (e.g. UAS and Urban Air Taxis) into uncontrolled airspace (here airspace G), but is also applicable to other airspace categories. The advantage of the proposed concept is that it opens up the airspace equally for airspace users with both low and high levels of technical equipment. The concept gives incentives for (unmanned) aircraft manufacturers and operators to invest in performance relevant technology, but doesn’t exclude airspace users with low levels of equipment from entering the U-space airspace. The concept behind this approach relies on efficient airspace segmentation and UAS performance modelling. Based on airspace characteristics (e.g. ground classes, population density, geofences, U-space service availability, occurrence of VFR-traffic or other non-cooperative airspace users) the airspace is segmented into cells of similar requirements. This segmentation, with its specific requirements, is valid for a predefined time interval and can be dynamically adapted to new requirements. UAS mission approval in this future U-space is then based on the strategic allocation of airspace users (taking into account their mission requirements) to the segments of the airspace that meet the mission objectives and the specific airspace segments' requirements. This allocation is based on a performance based modelling of UAS.

Generally, each airspace user is modelled by an ellipsoid defining its individual performance parameters with regard to navigation, communication and the capability to detect other airspace users (cooperatively and uncooperatively). The lower the overall performance, the larger the resulting safety ellipsoid will be for the aircraft. As a result, an airspace cell might either be used by only a few aircraft with a large ellipsoid – reaching the cell's capacity – or by more aircraft with smaller ellipsoids. ***This results in an airspace management system which allows a lot of freedom at low density, but little freedom at high density.***

2.1.1. Airspace segmentation and dynamic adaptation

In a future airspace management system enabling joint unmanned and manned aviation, a complex set of constraints must be considered to ensure safe traffic operations. The airspace management system needs to consider:

- terrain and ground obstacles
- static no-fly zones (including critical infrastructure) and static restricted zones
- dynamically arising restricted and prohibited zones (rescue and security forces missions)
- a combination of traffic users with different capabilities, performances and priorities
- and the current and forecasted demand of airspace use for strategic airspace and traffic management.

The modelling of this kind of complexity requires a multi-dimensional representation. Therefore, the DLR's concept foresees that the airspace is segmented into a virtual multi-dimensional map. Each segment or group of segments can be described by its

- 3D coordinates (x, y, z)
- time of validity
- specific segment characteristics (e.g., weather, geofences, obstacles, validity)
- specific segment requirements (performance requirements)

Based on the aircraft's specific flight approval, technical capabilities and performance parameters a traffic user is allowed to operate in those parts of the airspace in which his specific characteristics meet those required in that specific area. The U-space system monitors the airspace requirements and the current planned UAS missions and updates the segments accordingly over time.

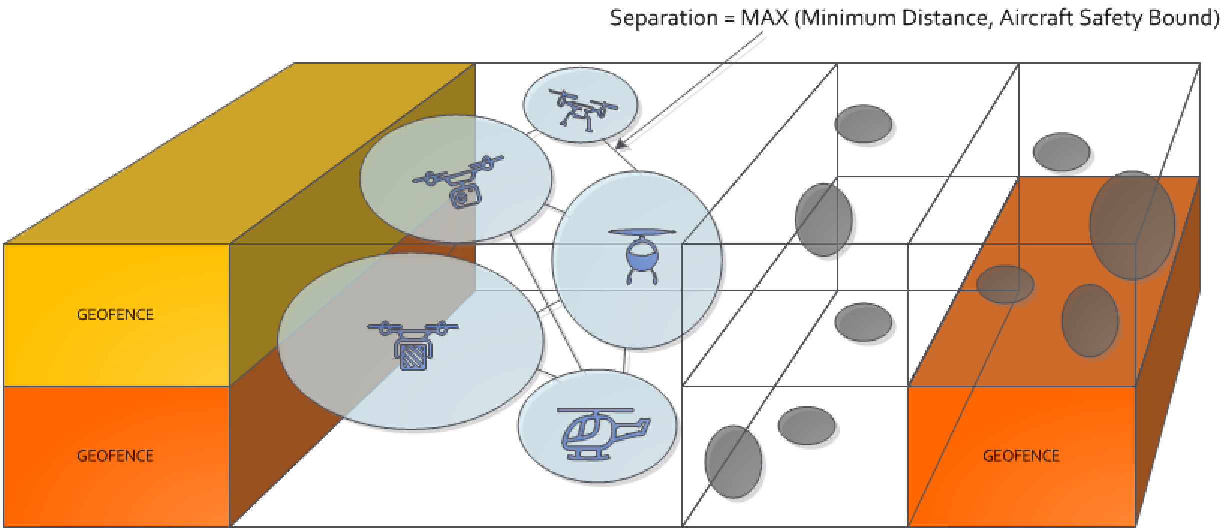

Figure 1: Dynamic airspace segmentation

One important element in this airspace management system is the modelling and management of geofences. Different kinds of airspace segments can be defined to prohibit or restrict access by the airspace users to this part of the airspace. Ground based obstacles, e.g. critical infrastructures (airports, railways or hospitals), endangered or protected areas (recreational areas, nature reserves) and static ground obstacles (high voltage pylons, buildings or broadcasting towers) can be defined as static 3-dimensional geofences covering a group of segments in the airspace. Further safety can be provided to ground-based static geofences by implementing a cooperative transponder at the location of the infrastructure concerned, sending the 3D coordinates defining its boundaries. Manned aircraft as well as unmanned or autonomous aircraft - if capable - could use this broadcast position for relative navigation and thus improve their navigational accuracy and the infrastructure's safety.

Besides static geofences, which in most cases are already known before a planned flight, dynamic geofences might need to be inserted into the airspace system in order to avoid unforeseen danger to the airspace users or people on the ground. One popular example is the creation of a temporary no-fly zone implemented by rescue forces or the police in the event of accident, crisis or crime. In these cases all airspace users are prohibited from entering the relevant airspace above the incident in order to ensure uninterrupted police and rescue force missions. These kinds of geofences arise dynamically and have expiring time validity. In the proposed airspace management system, these geofences are modelled as a 4-dimensional group of segments (x, y, z, t) with a 5th dimension defining this area as a no-fly zone. Another example of dynamic geofences is severe weather (wind, rain or visibility) within the airspace concerned. The movement and severity of weather cells can be modelled by defining multiple dimensions in the proposed airspace concept. Different kinds of weather influences and their respective severity might result in different levels of flight approvals dependent on the kind of aircraft used. The resulting airspace segment characteristics defining the geofence's requirements for entering/passing the segment can be modelled in a further dimension of the segment.

Geofences are protected by dividing the relevant airspace segment into three different protection layers, providing a safety net for UAS:

a. Alert and Awareness Boundary
b. Advisory Boundary
c. Intervention Boundary

When an airspace user enters the alert area, the airspace management system sends an alert to the aircraft and/or operator to ensure his/her awareness of entering a prohibited or restricted area. After passing the next protection layer, an alert is sent to the aircraft and/or operator giving precise instructions to leave the geofence area. Different measures may be taken if the airspace user doesn't follow the given instructions and passes the innermost protection area. The airspace and traffic management system may try to take over control of the aircraft (precondition here is the availability of a control link) to terminate or re-route the flight. If this isn't possible, additional measures to terminate the flight (including defense actions) may be required.

The 3-layered concept of geofence management has already been introduced by NASA Langley Research Center under the name "SafeGuard" [4]. EUROCAE WG 105 FA UTM has defined a geofencing concept that includes different performance classes enabling UAS flights based on the aircraft's specific localization, navigation and communication performance [5]. Both concepts cohere with the airspace and traffic management system proposed in this Blueprint and are adopted in the definition of the management system.

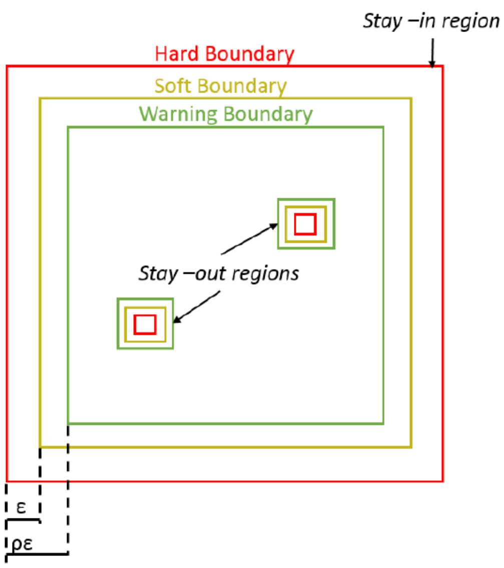

Figure 2: Geofencing Boundaries as introduced by Nasa SAFEGUARD [4]

Updates on geofences are provided by the information management system underlying the airspace and traffic management system.

2.1.2. Aircraft Safety Bound

In the proposed airspace and traffic management system, flight approvals are dependent on the densities and characteristics of the airspace segments which the required flight path will traverse. The basic approach of multi-dimensional airspace segmentation was described in section 2.1.1. Each of these segments or groups of segment has the capacity to enable multiple traffic operations at a time. The amount of traffic movement at any one time is strongly dependent on the kind of aircraft, their capabilities and respective performances. Highly performant aircraft with, e.g., highly accurate navigation capabilities (e.g. aerial mapping or inspection UAS) or a very reliable Detect & Avoid system (e.g. UAS operating with manned aviation) require smaller separation distances, because they can either detect and avoid approaching aircraft effectively or are navigating so accurately that all surrounding airspace users and the traffic management system can locate and initiate avoidance at any time. In comparison, a poorly equipped UAS (e.g. a simple cargo UAS for short-haul transportation) may require larger separation to other airspace users due to possibly limited maneuverability or Detect & Avoid equipment with a comparatively smaller detection range. As a result, the proposed concept defines individual Aircraft Safety Bounds for each traffic user based on its specific characteristics. The respective volume of the Aircraft Safety Bounds currently planned for an airspace segment implies the density of the segment and enables or prohibits additional aircraft movements.

Results from different research projects in the relevant field, e.g. EDA TRAWA, EDA MIDCAS, DLR internal projects WW-ATM[2], ALAADy[3] and City-ATM, reveal that UAS separation needs to be based on several aspects, not only the wake vortex classes as applied in manned aviation. New airspace users such as UAS (e.g., multicopter, helicopters, gyrocopters, fixed wing drones) and Urban Air Taxis (mostly Vertical-Take-Off-and-Landing (VTOL) or hybrid systems) differ significantly in their technical capabilities, size, maneuverability and performance and thus require new means of modelling the safety distances required to enable safe traffic operations in a joint airspace respecting these individual airspace user characteristics.

The concept within this Blueprint enabling density-based airspace and traffic management is based on the definition of Aircraft Safety Bounds, describing an ellipsoid shaped area of safety protection surrounding each individual airspace user. The shape of an ellipsoid has been chosen for reasons of simplicity and exemplification - in order to be able to visualize the idea of modelling multi-dimensional performance parameters. In reality, the resulting shape might be a

[2] WW-ATM (World Wide Air Traffic Management): http://www.dlr.de/fl/en/desktopdefault.aspx/tabid-1149/1737_read-47227/
[3] ALAADy (Automated Low Altitude Air DeliverY): http://www.dlr.de/fl/en/desktopdefault.aspx/tabid-1149/1737_read-47166/

more complex polygon when considering multiple effects on an aircraft’s performance, e.g. its specific affectability by wind or its behavior when initiating a parachute landing. For the scope of this paper, the actual shape doesn’t influence the proposed method of airspace organization and traffic management. Therefore, an ellipsoid is used to describe the different parameters influencing an aircraft’s specific performance in horizontal and vertical direction over time.

Each airspace user – manned or unmanned – has different technological capabilities and aircraft characteristics meeting its individual purpose of application. These varieties result in significant differences with regard to the performance of existing communication, navigation and Detect & Avoid systems.

The EDA project TRAWA (Standardisation of Remotely Piloted Aircraft System (RPAS) Detect and Avoid) is working on the specification of ‘well clear’ boundaries in exact terms so that specifications for DAA technical systems can be derived. The basis for the definition of these ‘well clear’ boundaries is the analysis of minimal sensor detection ranges in scenarios comprising different kinds of UAS. These values can be used as one parameter defining the performance of the airspace user with regard to its Detect & Avoid capability.

Besides the Detect & Avoid capabilities, the vertical and horizontal performance of a specific UAS is also dependent on navigation and communication performance parameters. The navigation performance can be determined by defining the aircraft’s lateral and horizontal flight technical errors (here especially navigation system error). These can be determined by applying methods already established in manned aviation for Performance Based Navigation, e.g. ICAO (Procedures for Air Navigation Services – Aircraft Operations) [6] and EASA AMC 20-27A [7].

Another important influencing factor when describing an UAS (or general aircraft’s) performance is its specifics on communication. Parameters such as datalink latency, robustness, integrity and availability influence its overall ability to respond to new requirements.

These three main influencing factors on overall performance can be used to define specific parameters describing an ellipsoidal shaped bound for each aircraft. It is evident that additional parameters might be applicable which modify the resulting ellipsoid shaped bound over time. Based on this assumption, scaling parameters can be applied to adapt the resulting ellipsoid for higher speeds, remaining battery charge or in case the UAS carries passengers. The ellipsoid’s shape is therefore defined as variable over time.

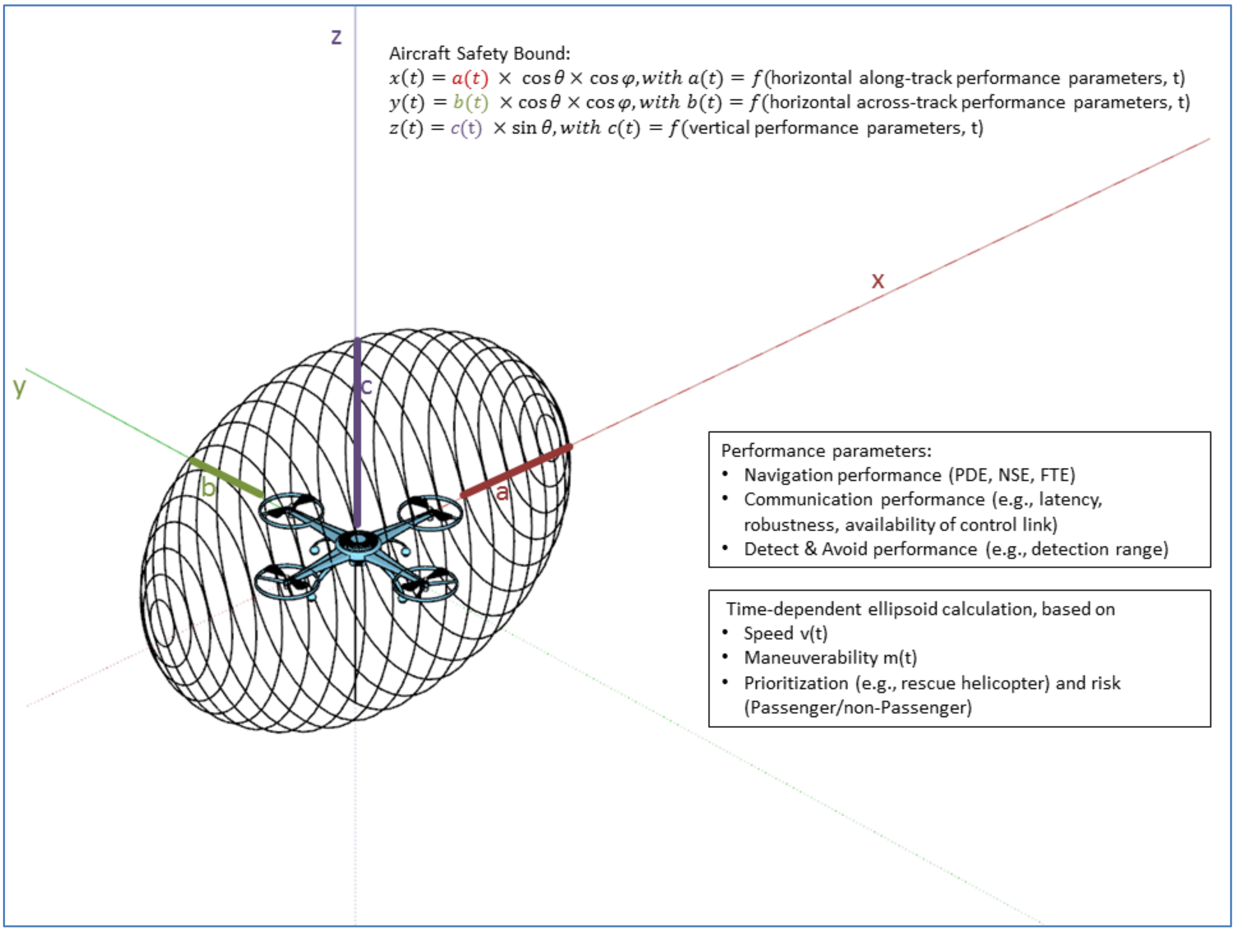

Figure 3: Aircraft Safety Bound

In this concept, prioritized traffic (e.g. rescue helicopters) is modelled by defining relatively large Aircraft Safety Bounds, which as a result blocks the relevant airspace segments and so empties the route for these kinds of traffic operations. In future work this prioritization could be further detailed to provide different levels of priority, e.g. rescue helicopters, passenger/non-passenger UAS, medical transport or hobbyist applications.

The concept of Aircraft Safety Bounds is a simple means of providing individual models of performance for each aircraft. Representation by an ellipsoid is feasible and enables strategic planning, approval and monitoring of multiple different aircraft within a future airspace system that must already consider multiple dimensions of requirements (e.g., geofences, obstacles). A parameter representation of an ellipsoid to define the Aircraft Safety Bound ASB can be derived from the parameters explained in the previous paragraphs.

$$\boldsymbol{ASB\begin{pmatrix} x \\ y \\ z \end{pmatrix} = p \times \begin{pmatrix} a(t) \times \cos\theta \times \cos\varphi \\ b(t) \times \cos\theta \times \sin\varphi \\ c(t) \times \sin\theta \end{pmatrix}}, \textbf{ for} \qquad \textbf{(2.1)}$$

$$a(t) = f(along - track\ performance\ parameters, t) \quad (2.2)$$

$$b(t) = f(across - track\ performance\ parameters, t) \quad (2.3)$$

$$c(t) = f(vertical\ performance\ parameters, t) \quad (2.4)$$

$$Priority\ p = \{1,2,3 \dots n\}$$

The time-dependent functions $a(t)$, $b(t)$ and $c(t)$ define the scaling of the ellipsoid along the axes. With $c(t) > a(t)$, the ellipsoid will be extended along the z-axis (representing a decreased vertical performance). In case of $c(t) < a(t)$ the ellipsoid will be flattened, representing a comparatively good vertical performance in relation to horizontal performance (see Figure 4).

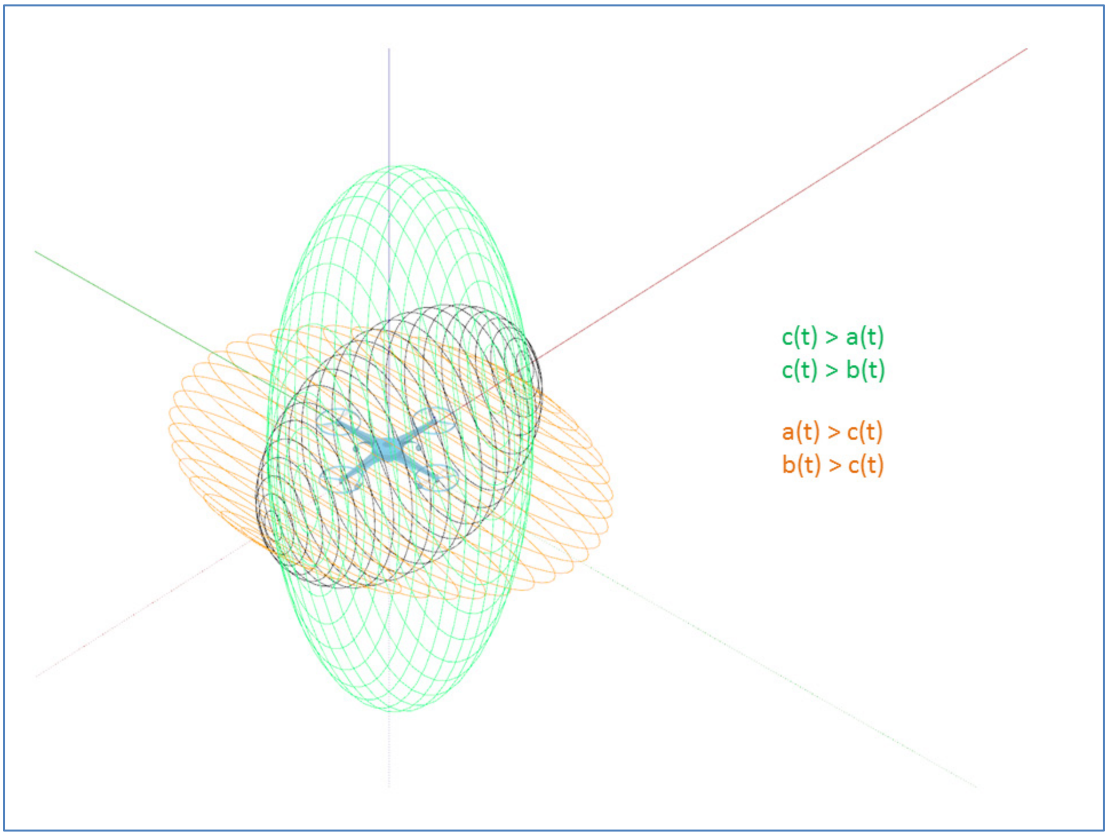

Figure 4: Scaling the Aircraft Safety Bound

In addition, a safety oriented traffic management system must consider the effects of wake vortices and weight classes between two aircraft operating within one segment. A possible example could be a large helicopter cargo UAS flying above or in front of a quadcopter. The maneuverability of the quadcopter might be disrupted when flying below a safety distance. This is addressed in the presented model by defining minimum separations between two types of aircraft (see Figure 5).

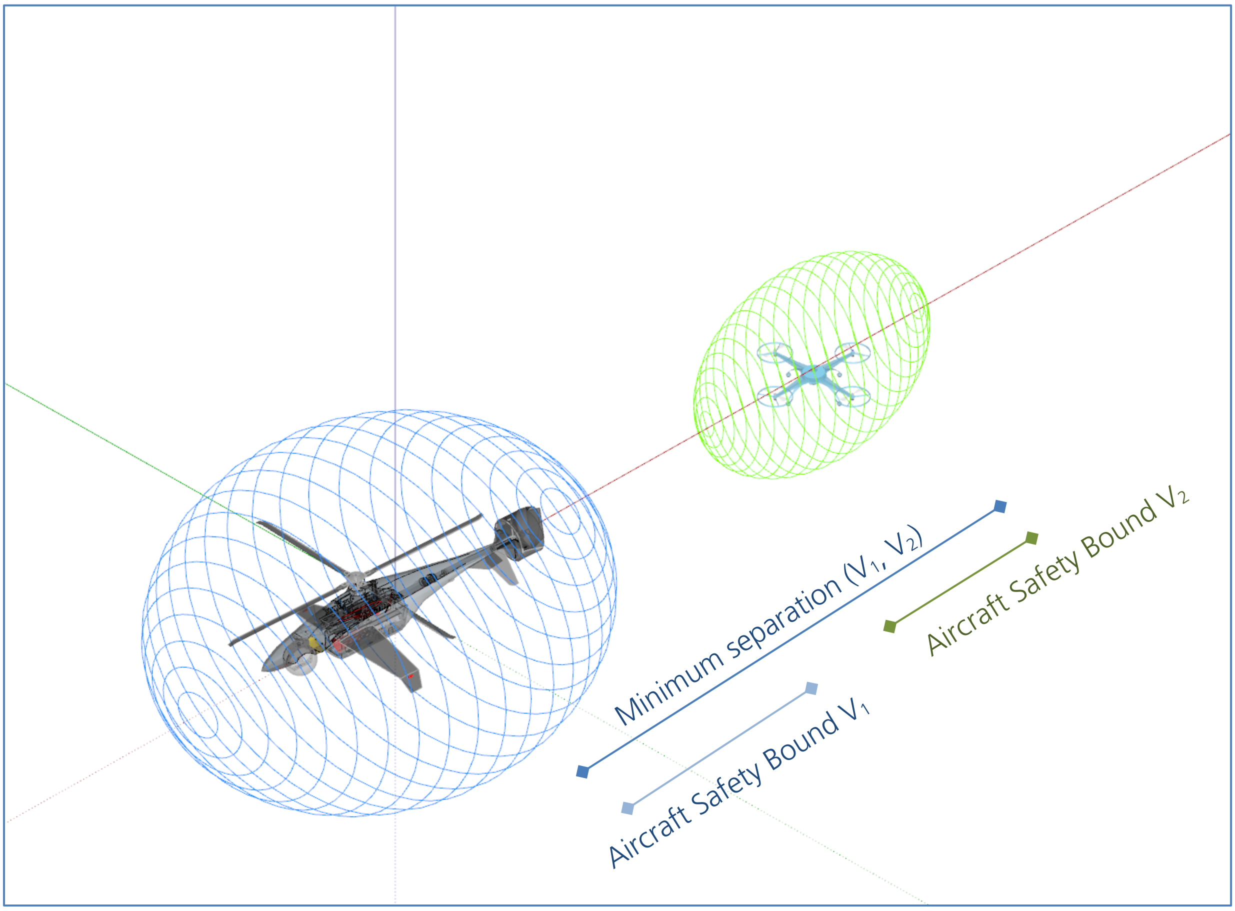

Figure 5: Relative separation distances considering different aircraft types

The actual required separation between two aircraft in a segment then results in

$$SEP\ (x,y,z) = MAX(Aircraft\ Safety\ Bound\ (x,y,z,t), SEP(x_{v1,v2}, y_{v1,v2}, z_{v1,v2}) \qquad (2.5)$$

The segments’ requirements with regard to the performance of an aircraft entering this specific segment are not only a result of the current and planned traffic status, but also result from the airspace conditions in the area under consideration. One possible example could be flights in areas of limited surveillance. This could be the case when implementing, for example, LTE (Long Term Evolution) as a communication network for UAS monitoring, control and surveillance, because LTE coverage is restricted in height and doesn’t provide complete coverage yet. The same holds true for EAN (European Aviation Network), which is intended to offer a communication network for altitudes above 2000ft. Based on coverage maps the airspace could be further detailed and the requirements for flights in areas of bad coverage could be refined to meet aircraft performance minimum requirements. Aircraft with relatively low navigation performance would be prohibited from flying within these areas. Exceptions could be defined if there were no further missions planned during the considered time interval, so that conflicts with other airspace users could be precluded.

Some segments might allow compensation between different performance relevant factors (communication, navigation, DAA, size, speed). Relatively low performant aircraft with regard to navigation could be allowed to enter some airspace segments when fulfilling higher requirements on DAA so that other airspace users and obstacles could still be detected and avoided without the traffic management system being able to precisely locate the aircraft at all times. But this argument doesn't always hold true in airspace segments including non-object related geofences (e.g. police missions). Therefore, the performance requirements need to be defined with care when modelling an airspace and traffic management system.

2.1.3. Flight rules, separation and performance requirements

In uncontrolled airspace, where VFR, IFR traffic and other airspace users (such as hot air balloons, parachutists) have equal access, there is a need to develop appropriate technologies and procedures to enable conflict detection and resolution. The integration of UAS and Air Taxis poses a great challenge here, because conflict detection and resolution together with uncooperative airspace users needs to be ensured. At present, UAS differ significantly in their ability to Detect & Avoid. The reason is that these aircraft are built for a variety of applications requiring different technological capabilities. Requesting a minimum level of Detect & Avoid performance for all UAS entering the airspace isn't feasible, not only because this would lead to higher UAS costs, possibly hampering the business case for smaller operations, but also because it isn't necessary when applying an appropriate airspace management approach that reflects different levels of performance by the airspace users.

In addition to Detect & Avoid, another key issue that should be considered when interacting with UAS is the need to adapt existing flight rules. If airspaces with VFR traffic are to be approved for UAS, secure and at the same time practicable requirements for separation and performance must be determined and defined. The separation size must be adapted to the size and equipment of the UAS. Solid, established values are difficult to derive and should be determined in the context of studies and simulations and processed in a robust way. One possible research question here is, in general, whether additional requirements should be made only to UAS or also to manned aviation (for example transponder requirements).

Initial work on adapting flight rules is already being carried out in the EDA project TRAWA. The concepts developed here for well-clear rules for UAS form a basis for further research in the area of separation and performance-based operations (PBO) for UAS. The concept of the PBO not only includes aircraft performance (minimal lateral and vertical deviations from the planned flight path according to performance-based navigation (PBN) [6] of manned aviation), but also includes the performance of a CNS (e.g., accuracy of position detection, data transmission latencies) and the performance of a Detect & Avoid system.

2.2. U-space Management System Services

The U-space Management System is responsible for (a) the provision of all necessary data to enable safe traffic operations (information management), (b) the seamless and collaborative airspace management required for optimum use of airspace (airspace management) and (c) the monitoring of the airspace operations on a strategic and tactical level (traffic management). On a strategic level the U-space enables optimal planning of UAS movements so that each mission can be conducted safely and the airspace is utilized most efficiently. Therefore, each mission needs to be verified and approved taking into account its specific characteristics and requirements.

The proposed process of UAS mission planning and approval is as follows:

a. UAS operator or pilot defines a flight plan (4D trajectory) for his mission taking into to his individual mission requirements (e.g. based on SORA CONOPS)
b. UAS operator or pilot transmits all the information regarding his mission and technical performance data of his aircraft required for the calculation of the Aircraft Safety Bound[4] to the U-space system
c. U-space system receives flight plan for a predefined future time slot[5] (e.g. no later than one hour before initiation of the flight)
d. U-space system analyses and verifies all available flight plans with regard to airspace requirements and optimizes the trajectories so that they are conflict-free
e. U-space system either approves a mission or sends additional modification requirements to the UAS operator or pilot
f. Each approval for a specific mission’s 4D-trajectory is preliminary
g. Dynamic changes within the airspace (weather, police missions) and prioritized flights triggers another verification of all relevant flights and may therefore result in modification requests to the UAS operator or pilot

The complete process described in this document can be easily automated. The DLR is already running a prototype and is working on improving the systems’ functionalities and services. Further into the development process, the airspace and traffic management system described will be adapted and the details refined to meet the requirements for urban airspaces (with more complex segmentation requirements and possibly higher densities of traffic). This will be demonstrated in one of the DLR’s largest internal projects, entitled “City-ATM”, involving all major institutes participating in UAS related research.

[4] It might be more feasible to require UAS manufacturers to provide a specific Aircraft Safety Bound for their products

[5] There may be a business case for charging higher service fees for short-notice mission requests

2.3. Strategic airspace management

The U-space system is responsible for managing the airspace and traffic movements on a strategic and tactical level. On a strategic level the airspace management system is responsible for planning and segmenting available airspace with the aim of making the best possible use thereof. Efficient airspace management requires the avoidance of permanent segregation between different airspace users, which can be achieved by a dynamic allocation of airspace meeting respective airspace and performance requirements. Further, there is a need to optimize the planned traffic in order to utilize the available airspace efficiently. This is most important when trying to ensure safe UAS operations even in dense traffic scenarios. The DLR's concept and implemented management systems are based on long-standing research in the area of (unmanned) traffic management (e.g. [8], [9]). One of the DLR's recent patents (in particular patent no. US 20120158278 A1) [10] is enabling the presented concept of planning conflict-free trajectories in scenarios of multi-dimensional optimization criteria and high traffic densities[6].

In the proposed management system, new mission requests are gathered for a predefined time slot. All airspace users (when cooperating with the U-space system) will be obliged to provide their aircraft and mission characteristics needed for the definition of their individual Aircraft Safety Bound. The planned trajectories of the aircraft requesting operation in this time slot will then be verified. Each cell in the multi-dimensional map representing an airspace segment can hold a maximal number of aircraft at any one time (dependent on the segment's characteristics and the aircraft performances defined by their "Aircraft Safety Bounds"). Possible strategies for allocating aircraft to airspace segments while considering their respective mission constraints (e.g. defined by SORA) are "First-come-first-serve", which approves missions based on previously approved trajectories, or possible optimization methods enabling a more efficient traffic flow. An example of optimization criteria could be to calculate the smallest route deviations for all currently planned trajectories. An aircraft operator or pilot is then obliged to follow the verified and approved trajectory as precisely as possible.

2.4. Tactical airspace management

The traffic management system in a future U-space is responsible for monitoring and surveilling the airspace. The underlying information management system collects all available traffic data (position, heading, speed) in order to provide situational awareness and to be able to give traffic or geofencing alerts to the airspace users when necessary. The information management system should consider different sources of traffic data (including standards and technology already used in manned aviation). Therefore, LTE or EAN based position data could be fused with data provided by FLARM, ADS-B or VHF-VDL to improve situational awareness. Updates regarding situational awareness (e.g. traffic data, geofences, weather) can be provided to the UAS over a

[6] Peinecke, N., Kuenz, A.: "Method for determining a potential conflict situation" (US 20120158278 A1)

communication network, based for example on LTE [11], UMTS (Universal Mobile Telecommunications System) [12] in lower airspaces including urban areas or EAN [13] in altitudes above 2000ft. In addition, information updates to manned aviation can be provided by using services based on FLARM [14] or VHF-VDL [15]. One possible communication and surveillance infrastructure is displayed in Figure 6.

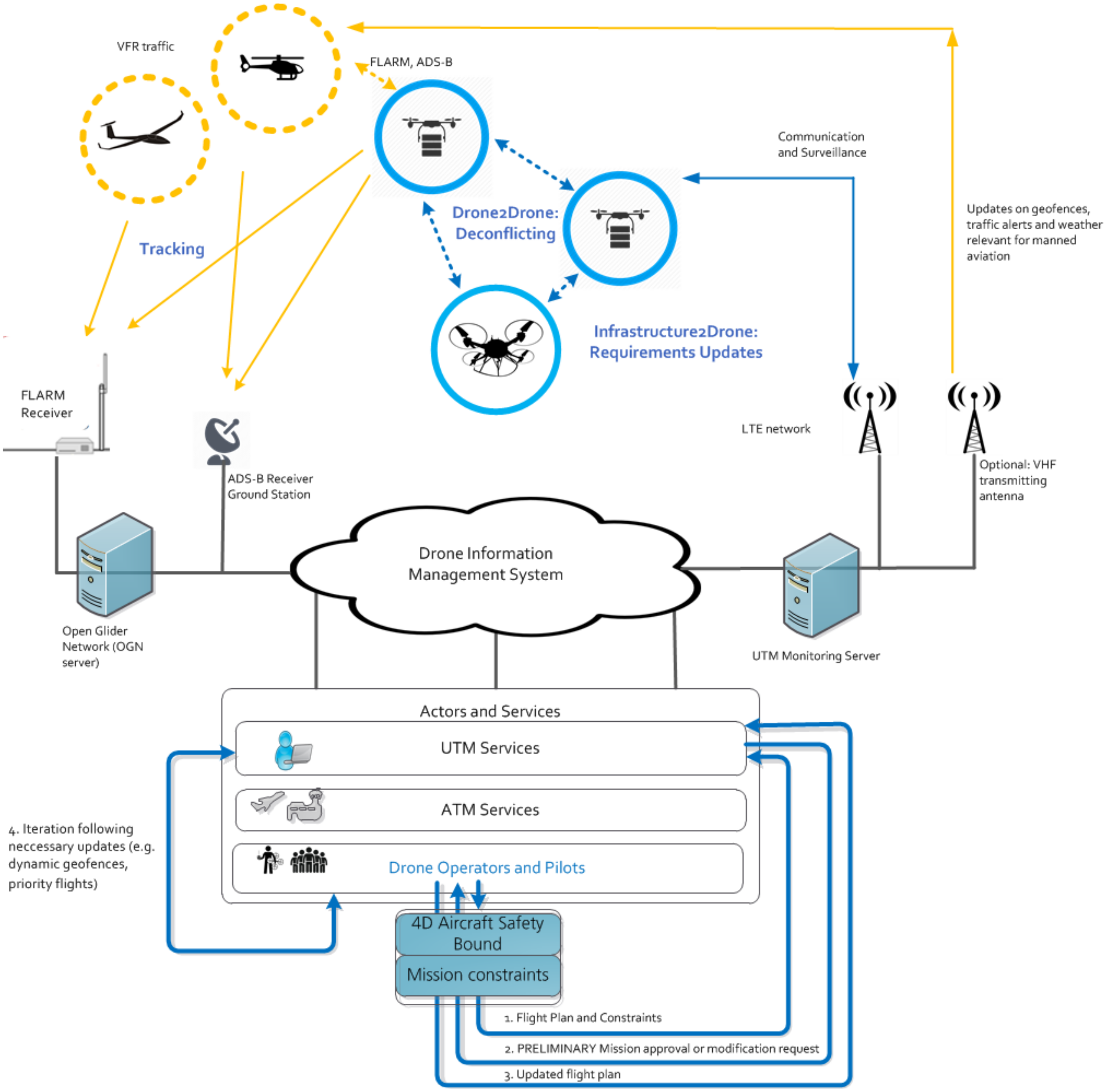

Figure 6: Concept for Communication and Surveillance

U-space foresees permitting higher levels of autonomy of UAS and also supports advanced UAS-to-UAS and UAS-to-infrastructure communication. Additional benefits could result from enabling higher levels of multimodal communication and cooperation, e.g. when integrating U-space with available urban infrastructure for intelligent mobility and automated ground vehicles (such as car-to-car technology [16] and associated mobility services).

This approach is incorporated in the presented concept, in which conflict detection and resolution is the responsibility of the UAS operator or pilot. Based on this assumption, the U-space system monitors the traffic movements and sends traffic alerts to the airspace user via multiple communication channels, but avoidance initiation remains with the UAS operator or pilot. Especially when flying in airspace segments in which uncooperative aviation could occur, the aircraft either needs the technical capability to receive traffic updates from the U-space system or needs a highly performant DAA system.

Three different integration levels exist in a future airspace system enabling VFR traffic (and possibly un-cooperative traffic):

a. Level 1: VFR-traffic provides no information of any kind
b. Level 2: VFR-traffic is required to provide a flight plan
c. Level 3: VFR-traffic has an onboard transponder

Level 1 is the situation any near-term U-space solution will have to face and comply with. As a result, all airspace areas in which VFR traffic might occur must be defined as geofences allowing only UAS flights that meet high DAA performance requirements. In Level 3 the VFR-traffic is equipped with cooperative transponders. Position data can then be transmitted via FLARM[7] or ADS-B to a central information management system and incorporated into the traffic management and monitoring system. Nevertheless, VFR-traffic will possibly comply with different integration levels within the next few years – the timeframe in which U-space will be launched.

A central contingency management system monitors all traffic movements and verifies deviations from approved trajectories. Therefore, limits for deviations are determined for each trajectory and monitored over time. If an aircraft deviates from its trajectory, regardless of the cause of the deviation (e.g. low navigation performance, weather influences or human error), the U-space system informs the UAS operator and gives suggestions on a trajectory update. If the UAS operator or remote pilot doesn’t respond to the trajectory update request, a range of alternative actions can be initiated (e.g. further alerts, contacting the pilot, terminating flight).

[7] FLARM can also be used as a back channel - like VHF and LTE - to provide tactically relevant information to the airspace users

Identified risks and mitigation strategies with regard to airspace and traffic management:

a. **Airspace areas providing low monitoring and surveillance coverage**
   In areas where the communication infrastructure can't provide complete or real-time traffic data, the precise position of the aircraft therein isn't known by the U-space system and can't be provided to all other airspace users. In this case the traffic management system isn't capable of providing traffic or geofence alerts. A solution could be to define specific flight requirements, e.g.
   i. Only UAS with high performance DAA
   ii. UAS with low performance navigation systems are only allowed in these areas when no other airspace user is present
   iii. UAS operator must expect to be contacted by phone to initiate immediate termination of the flight if necessary

b. **Airspace area with non-object related geofences**
   In the case of geofences not bound to a specific object (e.g. no-fly zone dynamically defined to secure police missions) a good DAA system isn't providing the level of safety required to fly in these areas, because the secured area can't be detected. In these kinds of airspace areas a possible solution could be to establish an external determination of the aircraft's position by the CNS-infrastructure (e.g. multilateration) when approving flights with low navigation performance. In these cases the U-space system sends correction data for updating the trajectory. Flight approval can then only be issued for areas of low risk. This approach gives high incentives for investing in systems with high performance, but doesn't exclude poorly equipped aircraft from the airspace.

List of figures

List of abbreviations

ATM	Air Traffic Management
CNS	Communication, Navigation, Surveillance
CONOPS	Concept of Operations
DAA	Detect & Avoid
EAN	European Aviation Network
FDD	Functional Driven Design
HALE	High Altitude Long Endurance
HRC	High Reliability Configuration
LTE	Long-Term Evolution
MALE	Medium Altitude Long Endurance
MRC	Minimum Risk Configuration
PAV	Personal Air Vehicle
PBO	Performance Based Operations
PBN	Performance Based Navigation
RPAS	Remotely Piloted Aircraft System
SORA	Specific Operations Risk Assessment
UAS	Unmanned Aircraft System
VFR	Visual Flight Rules
UAM	Urban Air Mobility
UTM	Unmanned Traffic Management
VLL	Very Low Level
VTOL	Vertical Take-Off and Landing

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