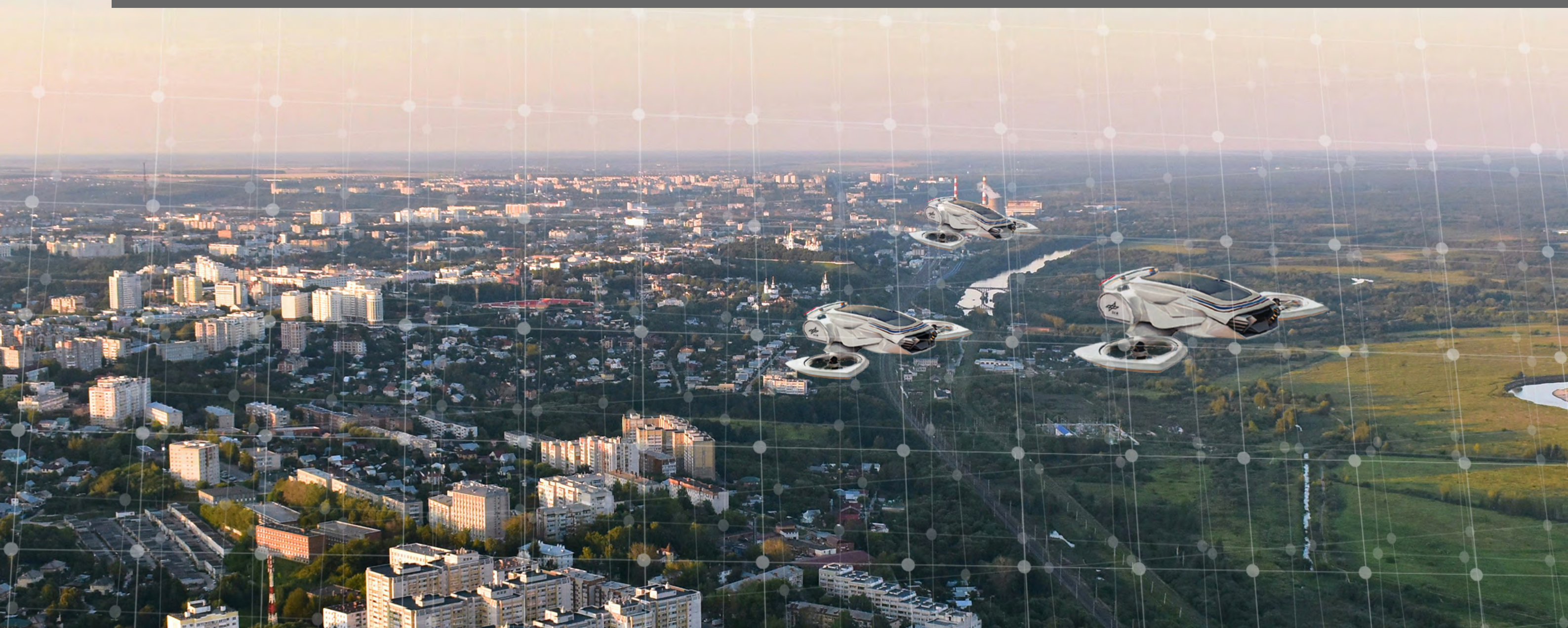
DLR Blueprint
Initial ConOps of U-Space Flight Rules (UFR)

Pioneering ATM to achieve highly automated airspace operations



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Contents

Document purpose

What is a Blueprint?
A Blueprint is the initial creation of a copy of plans or drawings, which is intended to provide an initial template for further designs. In a figurative sense, a Blueprint serves as a conceptual prototype on which further concepts can be built.

What is a ConOps?
A Concept of Operations (ConOps) describes the characteristics of a proposed system from the user's perspective based on different applications. This ConOps describes the principles of U-space Flight Rules (UFR) based on the U-space architecture from the perspective of crewed and uncrewed airspace users while harmonising with today's flight rules and Air Traffic Management (ATM) system.

Provision of feedback
This Blueprint can be seen as a "living document" that is intended to be updated regularly. The persons involved in this Blueprint will follow the ongoing regulations and progress in the research field of new flight rules for Uncrewed Aircraft Systems (UAS) integration and revise the Blueprint versions over time. Therefore, the DLR Institute of Flight Guidance (DLR-FL) invites all readers and UAS enthusiasts to provide feedback on this Blueprint and the concepts proposed therein. Comments and ideas can be sent to DLR-FL via the following e-mail address: UFR-FL@dlr.de

Executive summary

Uncrewed Aircraft Systems (UAS) have the potential to transform traditional aviation markets by introducing new airspace entrants, business models, and multimodal use cases. As a result, it is expected that the increasing diversity of UAS, together with new aircraft capabilities and varying performance characteristics, will have a significant impact on the current Air Traffic Management (ATM) system and crewed airspace users. Accordingly, the overarching goal is to enable airspace integration of UAS as seamless as possible and with minimal impact on current air traffic procedures. The Single European Sky ATM Research (SESAR) Joint Undertaking is therefore progressively improving the European airspace architecture towards a “Digital European Sky” by 2040. Building on increased utilisation of digital technologies, automation will enhance human-machine collaboration while seamlessly integrating European ATM and emerging airspace concepts over time.

Since early 2021, a European regulatory framework has been established to enable the integration of UAS together with crewed airspace users within one emerging airspace environment, called U-space. While traditional ATM is intended to enable safe and efficient airspace operations for crewed traffic, U-space will provide an operational framework for all airspace users. Based on four different U-space levels, sets of U-space services will be provided to enable the integration of a growing number of new airspace entrants. The U-space architecture is intended to allow for more automated and digitally connected air traffic procedures of all airspace users within U-space airspaces. However, it remains to be determined how UAS can satisfy the operational requirements of today’s air traffic while harmonising with the current ATM system.

In today’s ATM system, airspace operations of crewed traffic follow the principles of two main operating modes, Visual Flight Rules (VFR) and Instrument Flight Rules (IFR). However, the integration of increasingly automated, new airspace entrants together with crewed aircraft will inevitably lead to more automated air traffic procedures than today’s flight rules can provide. Accordingly, the need to introduce new flight rules to enable a safe and efficient integration of current and emerging airspace users within one airspace system has been discussed for over a decade. It is expected that new flight rules should be based on the requirements and capabilities of today’s flight rules to enable a seamless airspace integration of UAS together with crewed traffic.

The challenge of tomorrow’s flight rules largely depends on enabling common airspace access to all airspace users by collaborating safely and efficiently within one airspace environment. Therefore, it is likely that all airspace users will need to follow a harmonised and uniform framework of flight rules and air traffic procedures that enables the full integration of U-space and ATM. However, to date, no conceptual framework has been developed that provides a structured introduction of new flight rules for crewed and uncrewed airspace users within one airspace environment.

This Blueprint proposes an initial Concept of Operations (ConOps) of new flight rules for crewed and uncrewed airspace users in U-space airspaces, called U-space Flight Rules (UFR). Based on current European U-space architectures, UFR are intended to enable high-density UAS operations while harmonising with today’s flight rules and ATM system. This ConOps suggests that all airspace users in U-space airspaces follow a uniform framework of flight rules. The proposed UFR architecture is based on U-space levels, respective U-space services, and aircraft automation capabilities. UFR shall complement existing flight rules and leverage airspace access and flexibility of flight operations of all airspace users.

This ConOps proposes UFR to follow a stepwise implementation depending on the level of automation that each U-space will provide. Based on the advancements of the four different U-space levels, increased automation of aircraft capabilities as well as increased digital information exchange and connectivity of U-space services will lead to more automated procedures in ATM systems and U-spaces. In U-space airspaces, this ConOps suggests airspace users to fly under three different operational blocks X1 to X3. For each UFR operational block, a range of U-space services will be mandatory for airspace users to fulfil the technical and operational requirements of each U-space. Additionally, UFR operational block X0 is intended to apply exclusively for UAS operations that cannot

conform to VFR or IFR in airspace segments which have not been declared as U-space yet. This implies that all UAS operations will follow UFR principles, regardless of whether they operate in U-space airspace or not.

In summary, UFR are envisioned to apply to all airspace users within U-space airspaces and

- depend on U-space services and aircraft automation capabilities,
- complement existing flight rules,
- ensure fair and common airspace access,
- provide operational flexibility,
- increase safe and efficient air traffic procedures,
- enable increasingly automated air traffic procedures while providing
    - common flight information surveillance,
    - cooperative traffic interaction,
    - collaborative performance-based separation.

This Blueprint as a “living document” that is intended to be updated regularly after receiving feedback and further research is conducted. Further versions will expand on the current ConOps with more details on the role of UFR for crewed airspace users, transitions between UFR and today’s flight rules accompanied by their benefits for crewed operators. Further versions are likely to provide more detailed use cases of UFR for both crewed and uncrewed airspace users under different operational conditions in the four U-space levels.

1. Motivation for the introduction of new flight rules

Over the past decade, Uncrewed Aircraft Systems (UAS[1]) have become an increasingly central topic for aviation and transportation research in academia and industry. Particularly in recent years, there has been considerable progress in the field of UAS research worldwide. Rapid developments have taken place to enable technological and operational integration of UAS into the airspace system together with corresponding regulations. Accordingly, the Drones Outlook of the Single European Sky ATM Research (SESAR) Joint Undertaking predicts that by 2050, 20% of all aerial vehicles, namely UAS within the EASA "certified category"[2] [1], are likely to be controlled by remote pilots [2].

What started out with small private drones flying in visual line of sight (VLOS) is now experiencing a much more mature vision of large commercial UAS that transport cargo and passengers in complex urban airspaces, for example [3]. Building on these visions of high-density UAS airspace integration, UAS have the potential to disrupt the traditional aviation industry by introducing sustainable propulsion systems, innovative aircraft capabilities and novel business models. Future UAS operational concepts performed in European airspace systems are categorized by the term Innovative Air Mobility (IAM) that includes concepts and use cases referred to as Urban Air Mobility (UAM) and Regional Air Mobility (RAM) [4].

In view of the accelerating emergence of UAS operations in today's airspace systems, the European Organisation for the Safety of the Air Navigation (EUROCONTROL) already emphasised in 2018 that "the safe and efficient integration of UAS into Air Traffic Management (ATM) is one of the major challenges in aviation in the first half of the 21st century" [5]. In this context, it is indicated that UAS should be treated equally to crewed traffic and should not have a significant impact on today's crewed air traffic procedures. However, it remains to be clarified how UAS can satisfy the operational requirements of today's air traffic while harmonising with the current ATM system.

1.1. Introduction of ATM and U-space

Today, European airspace operations and air traffic, which is also part of airport operations on the ground, are managed within an integrated framework of facilities and services called "Air Traffic Management". The main objectives of ATM are to enable the safe flow of traffic through the provision of Air Traffic Services (ATS), to enable efficient traffic flow through Air Traffic Flow Management (ATFS) and to allocate airspace segments through Airspace Management (ASM) to enable efficient access to airspace by the users. In this context, ATM performs tasks such as coordinating flight plans and tracking airspace users, providing operators with separation and flight guidance services as well as dealing with contingency and emergency procedures. Additionally, support systems and services provide, for example, Communication, Navigation, and Surveillance (CNS) infrastructure services to support the ATM system by means of automation and digital technologies such as satellite-based navigation [6], [7].

In early 2021, the European Union Aviation Safety Agency (EASA) approved the first regulatory framework for UAS operations in the European Union (EU), the European uncrewed traffic management system called "U-space". The "Commission Implementing Regulation (EU) 2021/664" of April 22, 2021, establishes this regulatory framework and defines the technical and operational requirements together with Acceptable Means of Compliance (AMC) and Guidance Material (GM) to guide initial operations in U-space airspaces [8]. Within U-spaces, U-space services will be provided by U-space Service Provider (USSP). Furthermore, each EU Member States authority can assign a single Common Information Service Provider (CISP) [9]. The CISP will be responsible for the provision of common information regarding operations in the respective U-space airspace and for the data exchange of all stakeholders with USSP (see **Fig. 1**).

[1] In this Blueprint, the term UAS refers to all systems related to uncrewed aerial vehicles, including the terms drone and unmanned aerial system. UAS consist of an Uncrewed Aircraft (UA), a Remote Pilot Station (RPS) or Ground Control Station (GCS) and a Command-and-Control Link (C2 Link). UA have no pilots on board and can be used for various use cases, such as transporting passengers and/or cargo.

[2] UAS operations within the EASA "certified category" pose the highest level of risk (e.g., uncrewed urban air taxis or international UAS flights within controlled airspace) and can be considered a safety category equivalent to approaches used in crewed aviation [1].

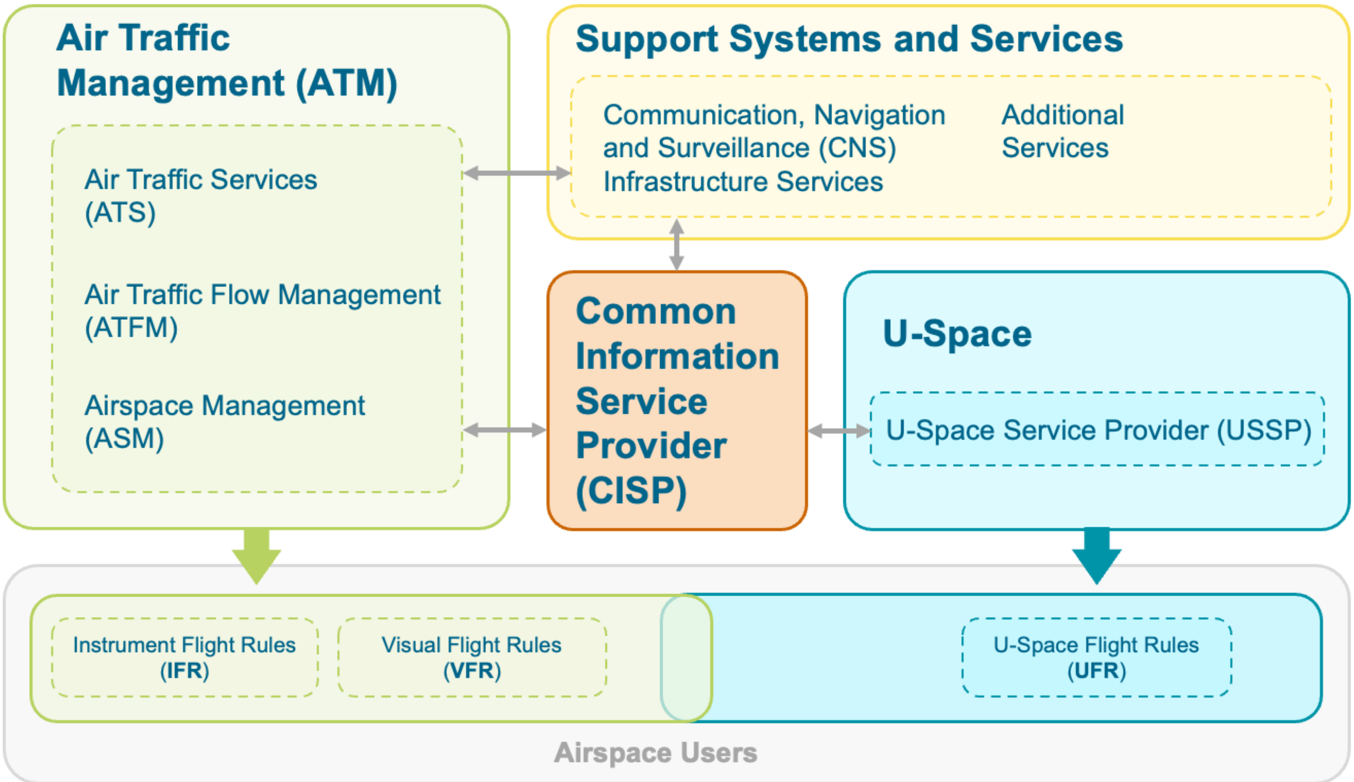


Fig. 1 Data exchange between different stakeholders and U-space via CISP

While traditional ATM is intended to enable safe and efficient airspace operations for crewed traffic, U-space will provide collaborative air traffic procedures for both crewed and uncrewed airspace users. It is expected that U-space will provide many similar functions and services compared to ATM. Based on a variety of U-space services, the U-space architecture is designed to seamlessly integrate UAS with today's crewed airspace users into the airspace while providing an operational framework for a growing number of new airspace entrants with different capabilities and performance characteristics. Therefore, it is anticipated that future airspace systems will be able to accommodate significantly larger numbers and more diverse airspace users than ever before [10]. Consequently, ATM and U-space, together with different support systems and services, need to be harmonised and interact effectively with each other to enable a seamless integration of all stakeholders in a future airspace system.

1.2. Description of current flight rules

Based on common international standards provided by the International Civil Aviation Organization (ICAO) in their Annex 2 [11], airspace operations of crewed traffic in today's ATM system follow the principles of two main operating modes, Visual Flight Rules (VFR) and Instrument Flight Rules (IFR). Under VFR, most of the in-flight navigation is carried out using visual references on the ground. This navigation technique can only be used in appropriate weather conditions, also known as Visual Meteorological Conditions (VMC). Flights under IFR are performed with the aid of onboard instrument navigation and Air Traffic Control (ATC) on the ground. This is typically the case in controlled airspace classes, where ATC services ensure an orderly flow of traffic by issuing clearances and flight instructions to maintain separation between flights. In contrast to VFR, flying under IFR enables aircraft operations under Instrument Meteorological Conditions (IMC) in cloudy or rainy weather, for example. Additionally, Special VFR (SVFR) allow for airport operations of VFR flights below VMC that have been cleared by ATC.

However, flights under IFR and VFR do not follow the same regulations in every country. Pilots must adhere to different regulations and standards regarding airspace classes and flight altitudes of the individual countries, which can vary from country to country in the case of an international flight. In Germany, for example, IFR flights in uncontrolled airspace are only permitted if a Radio Mandatory Zone (RMZ) is designated. These RMZs are generally set up for airport operations in uncontrolled airspace.

Initial UAS operations are likely to be carried out in uncontrolled airspace at very low level (VLL) below 500 ft above ground level (AGL) [9]. According to EASA regulations, that is below the permitted flight level for VFR operations (except 1,000 ft AGL above towns or for take-off or landing) [12]. Nevertheless, if authorised, many VFR flights tend to fly below 500 ft AGL. Therefore, initial UAS operations in VLL airspace will increasingly have to interact with VFR traffic, which is even more concentrated at higher altitudes in uncontrolled airspaces[3].

In short, pilots can visually separate their aircraft from other air traffic under VFR, and flights under IFR require ATC services that are generally not provided in uncontrolled airspace. How will UAS conform to today's flight rules, especially in uncontrolled airspaces, without having an onboard pilot to navigate and ensure operational safety?

1.3. The role of new flight rules

Today's standards and regulations for crewed airspace users are considered to provide the highest degree of safety. This is due to different factors, such as airworthiness certifications (for both manufacturing and maintenance processes) and the experience gained from decades of proven operational air traffic procedures, such as see-and-avoid (SAA) principles for crewed airspace users [5]. As UAS are unable to adhere to common SAA principles, new flight rules are becoming imperative for the safe and efficient airspace integration of UAS together with crewed traffic. The airspace integration of UAS is likely to be supported by advancements in flight automation and remote monitoring of the vehicle. It is anticipated that more advanced UAS will increasingly utilize automated onboard systems with detect-and-avoid (DAA) capabilities to detect and resolve in-flight conflicts. This provides an additional safety net to the flight rules that are designed to enable separation of air traffic in the first place.

New flight rules that enable the operation of UAS towards high-density airspace environments do not need to disrupt or drastically change the way current air traffic procedures work successfully. Needless to say, crewed air traffic is already operating at an extremely high level of safety and efficiency. Any fundamental change to the functionality of today's flight rules would likely affect the proven efficiency of the air transportation system. More likely, new flight rules that aim for a seamless airspace integration of UAS together with crewed air traffic will build on today's existing air traffic procedures and regulations. It can be expected that new flight rules will complement the standardised flight rules and enable airspace access to all airspace users in a designated environment. The overall objective should be to integrate all airspace users into a single airspace environment while increasing the level of interoperability and flexibility of all airspace operations. Therefore, new flight rules should not exclude some airspace users in order to integrate new airspace users. New flight rules should be available to all airspace users that meet the requirements of the respective airspace, as intended for operations in U-space environments.

[3] In Germany and France, for example, uncontrolled airspace goes up to 2,500 ft AGL and up to 1,000 ft AGL around airports.

2. Challenges in the high-density integration of UAS into ATM systems

A high-density integration of UAS into today's airspace system is not possible without corresponding regulations for interaction with crewed traffic. Initial establishments of regulatory frameworks will pave the way for safe and fair air traffic procedures as UAS participation increases. However, several challenges need to be resolved before UAS can safely and efficiently interact with crewed traffic within one airspace environment. On the one hand, the increasing variety of requirements and performances of new airspace participants along a growing number of airspace operations will lead to new operational challenges. On the other hand, interoperability and harmonisation of various technological advancements, for example in the area of CNS, will require a rethinking of current technological standards.

2.1. Operational challenges

Before corresponding regulations come into force and practical concepts are developed, efforts have been made in recent years to solve the airspace integration of UAS with theoretical models and flight simulations. Research has increasingly focused on questions of how UAS with different capabilities can operate in dense airspace environments such as in urban airspace [13]. In this context, UAM research has been highly relevant in the past with UAS use cases focusing on urban air taxi services. At the same time, start-ups and large companies are pushing into the market to develop innovative mobility concepts for urban airspaces with novel electric Vertical Take-off and Landing (eVTOL) vehicles. In the meantime, however, several other use cases for different airspace environments have been added. In addition to UAM and initial use cases of UAS, such as the medical transportation of goods using small transport drones, use cases are currently becoming increasingly complex. Academics and industry are focusing on regional aviation with larger fixed-wing UAS that transport passengers and cargo in regional aircraft over several hundred kilometres across national borders, for example [14].

The growing multitude of use cases with UAS of different sizes and therefore with diverse vehicle capabilities and performance characteristics makes it increasingly complex to develop harmonised operational solutions involving all airspace users. The growing traffic volumes of UAS in combination with the increasing variety of requirements and performances of new airspace entrants pose major operational challenges for the high-density integration of UAS into current air traffic and ATM.

Solutions to ensure operational safety and efficiency will most likely be developed as part of U-space concepts. It can be assumed that U-space will automate the traffic flow of tomorrow to an increasing extent. This concerns, for example, the dynamic allocation of airspace segments and performance-based traffic separation while at the same time collaborating with the current ATM system. In addition to challenges that affect operability at system level, there are more specific operational challenges that make the interaction of UAS and crewed traffic more complicated. In uncontrolled airspaces, UAS will increasingly face crewed airspace users flying under VFR and applying SAA procedures. At non-towered airfields in uncontrolled airspace, for example, UAS have to seamlessly integrate into traffic patterns without overly impacting crewed traffic that relies on SAA principles. Furthermore, terminal airspace environments in uncontrolled airspaces represent an increased uncertainty, as air traffic operations at non-towered airports today might be non-cooperative (e.g., not radio-equipped). Therefore, UAS require reliable operational integration procedures to minimise potential conflicts without causing restrictive constraints on today's crewed traffic operations.

Additionally, in view of the growing diversity and automation capabilities of UAS, there will be more variations in flight speed and separation minima, both in vertical and lateral movement, which will make right-of-way rules more challenging. To remain well clear of other traffic, airspace users must adapt their flight activities much more to other air traffic and UAS in their vicinity. Accordingly, harmonised standards need to be established for all airspace users within one framework of rules to ensure robust but flexible nominal and off-nominal air traffic procedures. U-space is expected to provide this regulatory framework to guide the safe and efficient integration of UAS together with crewed traffic in one airspace environment.

2.2. Technological challenges

Operations in U-space airspace will have to be electronically visible to the ground and to other airspace users, following the so called "e-conspicuity" standards (EU 2021/666 article 1) [15]. E-conspicuity standards will include certified ADS-B (Automatic Dependent Surveillance - Broadcast) Out systems and newly established ADS-L (Automatic Dependent Surveillance - Light) systems, the latter transmitting via SRD-860 (Short-Range Device 860 frequency band) or via mobile telecommunication networks. This is prescribed in EASA's Easy Access Rules for Standardised European Rules of the Air (SERA) 6005(c) "Requirements for communications, SSR [Secondary Surveillance Radar] transponder and electronic conspicuity in U-space airspace" [16]. However, the interoperability between different systems to enable a standardised communication between all stakeholders poses additional technological challenges. Harmonised standards for equipment requirements that enable seamless handover between different CNS systems and frequency bands as well as varying network coverage and connectivity remain to be clarified.

The effective use of harmonised CNS standards will also depend heavily on the availability of a wide and reliable C2 link availability to ensure safe UAS navigation. If an UA loses contact to its RP or GCS, it will move "blindly" in the airspace. This makes contingency procedures that deal with a lost C2 link (LC2L) even more important. It must be ensured that UAS, especially under beyond visual line of sight (BVLOS) and in uncontrolled airspace, always have safe and appropriate contingency procedures in place. In case of a LC2L, no remote pilot can track and navigate the vehicle. New flight rules that integrate UAS and crewed traffic within one airspace environment will have to ensure safe and reliable contingency procedures. This becomes increasingly important in airspaces with higher traffic densities or in terminal airspaces with relatively complex airport approach procedures.

Additionally, CNS latency is more and more being addressed in the UAS community. Based on harmonised CNS standards, it must be ensured that the latency of data transmission is as low as possible and that reliable contingency procedures are available at all times. This affects communication between an UA and its RP or GCS as well as communication between different entities such as USSP, ATC, and UAS. With a growing number of UAS in the airspace and a decreasing number of remote pilots, the risk of conflicts rises when data transmission latency increases or LC2L situations emerge. Therefore, regulations and flight rules are also responsible for creating a framework to ensure that technical challenges are overcome and that air traffic in U-space is as safe and efficient as possible.

3. U-space – an emerging operating environment for all airspace users

U-spaces are established in airspaces to enable the integration of uncrewed aviation into existing air traffic structures. They are foreseen to enable airspace access to BVLOS UAS operations while safely interacting with crewed aviation. U-spaces are airspace portions within a maximum vertical and lateral limit (i.e., UAS geographical zone) designated by the respective EU Member States authority with U-space services to provide safe, secure, and efficient UAS operations (EU 2019/947 article 15) [8]. USSP ensure the provision of corresponding U-space services required to fulfil the operational and technical requirements of each U-space that are defined by the EU Member States authority (EU 2021/664 article 7) [8].

For U-space airspaces established in uncontrolled airspace, crewed airspace users are obliged to make themselves e-conspicuous to the USSP [16]. In U-space airspaces that are set up in controlled airspace, ATC will delegate airspace segments to either UAS or crewed airspace users applying the method of Dynamic Airspace Reconfiguration (DAR) (EU 2021/664 article 4) [8].

The concept of U-space follows several key principles that shall provide and ensure [17]:

- Safety of airspace users and their environment
- Fair and secure airspace accessibility
- Responsive airspace systems based on scalable, flexible, and adaptable architectures
- High-density airspace operations
- Cost-effective business models
- Minimisation of operating costs by maximising interoperability with other systems
- Adoption of interoperable cross-sector technologies and standards

Since January 2023, the EU has put the legal framework for the common establishment of U-space airspaces into force. Initial U-space regulatory sandboxes, such as the AREA U-space project at the DLR site in Cochstedt, are demonstrating the required U-space infrastructures together with a variety of U-space services. AREA U-space is intended to establish a long-term U-space and to test the general integration of U-spaces, exemplified at Cochstedt Airport, into the existing ATM system. At the same time, AREA U-space develops a virtualisation environment, whereby U-spaces can be mapped realistically in other geographical regions [18].

The initial rollout of U-space airspaces is likely to occur in airspaces below 1,000 ft AGL, where limited crewed air traffic can be expected. However, the "SESAR U-space Blueprint" published in 2017 envisages U-space services to evolve over time across four different U-space levels U1 to U4 (see **Fig. 2**). U-space services are expected to advance with the increasing level of automation of UAS and the enhanced connectivity of crewed and uncrewed airspace operations enabled by digital information exchange [17].

U-space level U1 will provide foundational U-space services such as the electronic registration and identification of UAS operators and the definition of the geographical zone of the U-space. Accompanied by initial U-space services in U-space level U2, UAS are envisioned to operate in both controlled and uncontrolled airspaces. Accordingly, with continuing technological progress, UAS air traffic density is likely to increase. This will lead to advanced U-space services in U-space level 3, where UAS operations will be common, and U-spaces will typically expand over 1,000 ft AGL. The final U-space level U4 will provide full U-space services, with a significant share of airspace operations being performed by commercial UAS accompanied by autonomous onboard DAA systems to enable a highly automated and seamless airspace integration of UAS, such as applications for UAM [9].

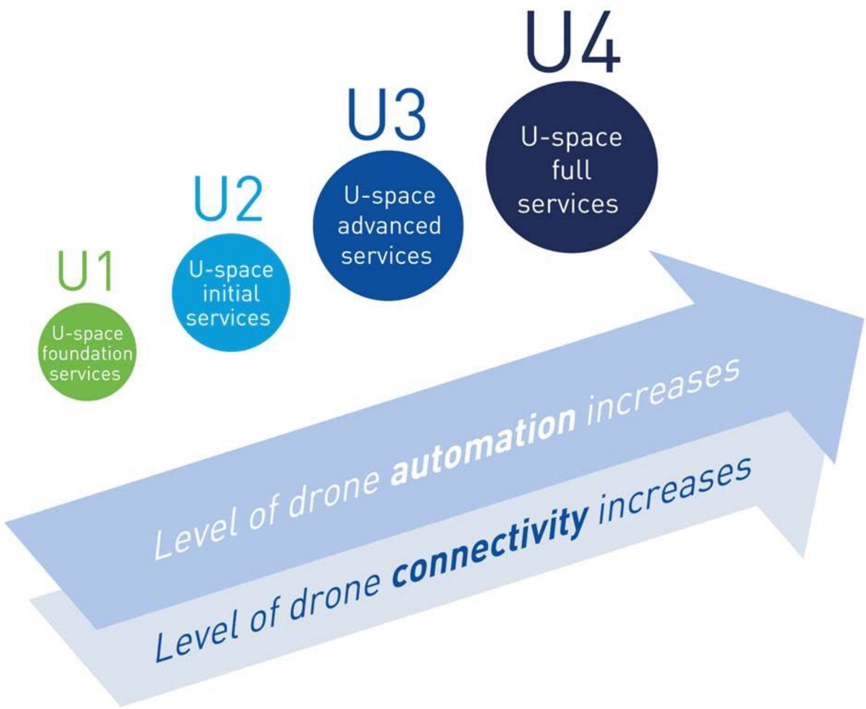


Fig. 2 Progressive development of the four different U-space levels [17]

Throughout the progression of the four U-space levels, U-space services will increasingly enable safe, secure, and efficient airspace operations by means of automation and digital information exchange. Starting with a handful of U-space services in U1, more complex services such as tactical conflict prediction and resolution services, together with technological advancements onboard and on the ground, will enable UAS to operate autonomously in the future [9], [17].

4. U-space flight rules to enable highly automated airspace operations

The need to introduce new flight rules to enable a safe and efficient integration of current and emerging airspace users within one airspace system has been discussed at least since 2011 [19]. Integrating UAS of different sizes with different capabilities together with crewed aircraft in a high-density airspace environment will inevitably lead to more automated procedures than today's flight rules can provide. The "Airbus Unmanned Traffic Management (UTM) Blueprint" published in 2018 was one of the first proposals to introduce a more detailed implementation of new flight rules named Basic Flight Rules (BFR) and Managed Flight Rules (MFR) [20]. These suggested new flight rules were intended to enable the integration of UAS in future airspace systems. BFR would allow UAS to operate independently following a free route principle (i.e., in uncontrolled airspace) with MFR to operate under the supervision of ATM services (i.e., in controlled airspace).

In September 2022, NASA proposed the concept of Digital Flight Rules (DFR), a complementary operating mode to IFR and VFR. DFR are intended to enable cooperative and self-separated airspace operations for all airspace users in all airspace classes by means of enhanced digital connectivity [21]. DFR are based on four equally addressed essential elements: digital information connectivity and services, shared traffic awareness, cooperative practices, and separation automation. An initial certification and approval of these flight rules is expected by 2045 [22]. DFR are expected to support the Federal Aviation Administration's (FAA) UAS Traffic Management (UTM) vision of a seamless UAS integration, which differs partially from the European concept of future airspace systems in terms of system requirements and service infrastructure. For a better understanding and comparative analysis of similarities and differences of UTM and U-space concepts, see Lieb & Volkert, 2020 [23].

In addition to NASA's proposal of new flight rules for emerging new airspace entrants, the FAA introduced the concept of Tailored Flight Rules (TaFR) in December 2022 [24]. TaFR are intended be applicable to airspace users that cannot conform to the existing flight rules. These new flight rules will follow the principles of a cooperative traffic management by means of data sharing, shared traffic awareness, deconfliction and monitoring services provided by Extensible Traffic Management (xTM) services through vehicle operators or third-party service suppliers with FAA oversight.

The most recent proposal of new flight rules was published in January 2024 by the Joint Authorities for Rulemaking of Unmanned Systems (JARUS). JARUS is an international organisation with experts from 63 countries that focuses on conceptual work related to UAS operations and UAS airspace integration [25]. The "Whitepaper on the Automation of the Airspace Environment" suggests Enhanced Flight Rules (EFR) to complement existing flight rules [26]. EFR are supposed to enable cooperative traffic separation under all-weather conditions in a shared airspace environment. For the future, the Whitepaper proposes that all airspace operations will be conducted under EFR, with certain obligations such as e-conspicuity standards and data exchange via UTM services.

Currently, the ICAO Advanced Air Mobility (AAM) Study Group is preparing a Whitepaper "Automation, Autonomy and New Flight Rules" with the objective to provide consolidated information and recommendations for the safe interaction of new traffic participants, new kinds of operations and business models, while ensuring continued safe and efficient operation of traditional air traffic [27].

In Europe, the Digital European Sky initiative by SESAR Joint Undertaking is intended to progressively improve the European airspace architecture by 2040. Building on increased utilisation of digital technologies, automation will enhance human-machine collaboration while seamlessly integrating European ATM and emerging U-space systems over time [10]. The success of the seamless integration of these systems depends largely on enabling common airspace access to all airspace users by collaborating safely and efficiently in one airspace environment. Ultimately, all airspace users, whether crewed or uncrewed, will have to follow a harmonised and uniform framework of flight rules and procedures that enables the full integration of U-space and ATM.

In November 2018, EUROCONTROL published a high-level proposal regarding new flight rules for UAS operations that are based on the accessibility to specific airspace volumes. The "UAS ATM Integration Operational Concept" distinguishes between Low-level Flight Rules (LFR) for UAS in VLL airspace and High-level Flight Rules (HFR) commonly above FL600 [5]. LFR were foreseen for small UAS operating below current VFR altitudes with the aim of being compatible with VFR. On the other side, HFR were intended to apply for both crewed and uncrewed airspace users at high altitudes and had to ensure compatibility with IFR.

The latest efforts on advancing the European airspace architecture resulted in the development of U-space concepts and related services that are likely to allow for a structured introduction of new flight rules. This new operating mode associated with a set of rules will be called U-space Flight Rules (UFR). The latest CORUS-XUAM "U-space ConOps and architecture (edition 4)" by SESAR Joint Undertaking from July 2023 introduces an initial definition of UFR "which is currently of low maturity" [9]. It builds on current U-space concepts to work as a new operating mode for airspace users operating in U-space airspaces receiving U-space services. Airspace users that operate in U-space under UFR are obliged to be e-conspicuous to the U-space environment, receive traffic information services, comply to instructions issued by ATS, and be in receipt of U-space separation services. The CORUS-XUAM vision of UFR starts with initial UFR operations in U-space level U2 with full UFR deployment for all U-space airspace users in level U4. It remains to be determined what kind of capabilities UFR will provide, who will operate under UFR and under what conditions, and how UFR will be deployed over time in different U-space levels with different requirements.

4.1. Definition of UFR operational blocks

This UFR ConOps envisions the introduction of UFR to follow a stepwise approach depending on the level of automation that each U-space will provide. Following the advancements of the four different U-space levels, increased levels of automation of UAS operations as well as increased digital information exchange and connectivity of U-space services will lead to more automated procedures in ATM systems and U-spaces. To seamlessly integrate mixed traffic (i.e., crewed and uncrewed airspace users) within one airspace system, UFR are intended to provide the baseline for advanced levels of automation, which shall enable efficient and safe airspace operations. This ConOps foresees operations under UFR to be dependent on various U-space services for both crewed and/or uncrewed airspace users. UFR will enable highly automated mixed airspace operations, integrating current air traffic and projected high-density UAS operations within one single airspace system.

This ConOps proposes the implementation of UFR within four operational blocks that guide the automation of future airspace operations: UFR operational blocks X1 to X3 enable increased automation of mixed airspace operations in U-space airspaces leading to conditional automation of operations in U-spaces under UFR X1, high automation under UFR X2, and full automation under UFR X3. UFR operational block X0 is intended to apply exclusively for UAS operations that cannot conform to VFR or IFR in airspace segments which have not been declared as U-space yet. This implies that all future airspace operations of UAS will follow UFR principles, regardless of whether they operate in U-space airspace or not.

UFR in U-space airspaces:

- **UFR X1** will enable **common flight information surveillance**
- **UFR X2** will enable **cooperative traffic interaction**
- **UFR X3** will enable **collaborative performance-based separation**

UFR in non-U-space airspaces:

- **UFR X0** will enable **rule-based UAS coexistence**

Building on the Digital European Sky vision, UFR will guide the transformation of partially interacting ATM and U-space systems towards one fully integrated system (see **Fig. 3**). This transformation will result in a fully scalable system that provides a safe and efficient integrated environment for mixed airspace operations. Thereby, harmonized information exchange and surveillance, enhanced human-machine collaboration, and connected ATM and U-space services are provided by an integrated digital ecosystem that will enable advanced levels of operational automation.

The stepwise deployment of UFR requires corresponding U-space services that will enable different levels of automation. The higher the UFR operational blocks X1 to X3, the higher the automation of U-space services and corresponding airspace operations in individual U-spaces. Accordingly, in the different levels of U-spaces, both crewed and uncrewed airspace users will operate under UFR while receiving sets of mandatory and optional U-space services. UFR X0 operations, however, are not relevant for the progressive development of UFR X1 to X3 and can be considered as a UAS-only operating mode that will contribute to the overall automation of airspace operations in non-U-space airspaces.

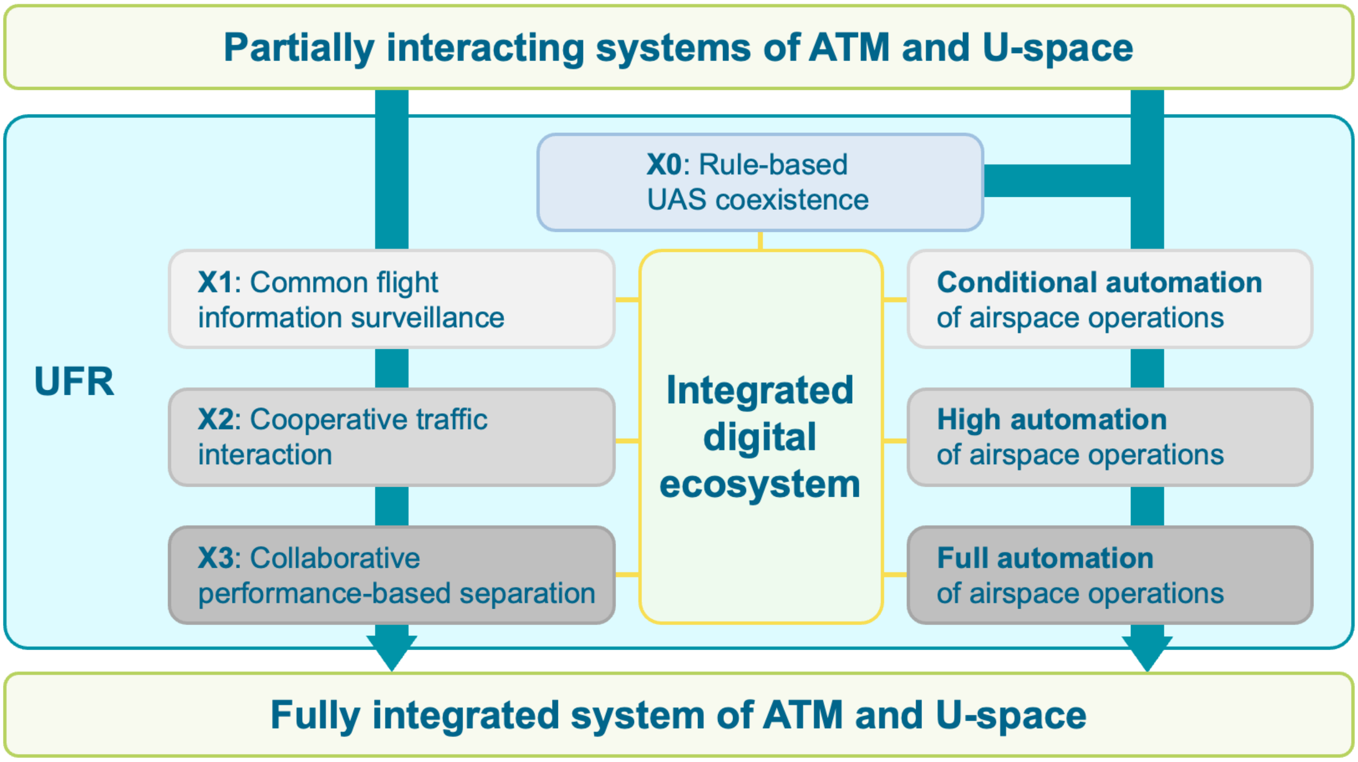


Fig. 3 UFR enabling operational automation within an integrated ATM and U-space system

Mixed airspace users intending to operate in U-space airspaces will have to fly under one of the UFR operational blocks X1 to X3, which are assigned to different U-space levels. Based on the automation of aircraft capabilities and the U-space level of the planned operation, each airspace user will be assigned a set of required U-space services. For each UFR operational block, a range of U-space services will be mandatory for airspace users to fulfil the technical and operational requirements of the respective U-space (see **Fig. 4**).

The increased automation and density of airspace operations is likely to be followed by a growing number of diverse airspace users with different aircraft capabilities. As a result, the overall complexity of airspace systems can be expected to increase significantly. Therefore, it can be expected that relatively low automated airspace users (e.g., VLOS operations) that cannot conform to the requirements of highly automated U-space airspaces (e.g., U-space levels U3 and U4) will have limited access to these respective U-space airspaces.

This ConOps differentiates between three categories of UAS operations that will fly under UFR in the future. First, UAS with no or low automation that will be operated by a remote pilot in VLOS. Second, UAS with basic automation capabilities (e.g., onboard DAA systems for obstacle avoidance) that will be operated under "basic BVLOS". Operations under basic BVLOS are likely to be conducted with one remote pilot controlling one UA out of sight. Third, fewer remote pilots (m) that will control more UA (N) simultaneously by the principles of m:N [28], called "advanced BVLOS" in this ConOps. Here, advanced BVLOS UAS are likely to have higher automation capabilities (e.g., autonomous onboard DAA systems) to perform tasks and make decisions with limited remote pilot intervention. These advanced BVLOS UAS are likely be the only uncrewed operations flying in highly automated U-space level U4 by the principles of UFR X3.

This ConOps proposes operations of crewed airspace users in U-space airspaces to be performed under UFR as well. As with UAS operations under UFR, crewed airspace users will be assigned U-space services depending on their aircraft's capabilities and the respective U-space level to fulfil the U-space requirements. However, it can be expected that crewed airspace users will be allowed to receive significantly fewer mandatory U-space services than UAS (due to the SAA capabilities of crewed traffic) and at higher U-space levels than UAS.

Following the current introduction of the first regulatory sandboxes of U-space airspaces, it is likely that UAS will operate in non-U-space airspaces over the next years before airspaces are declared as U-space. Especially for long-range BVLOS UAS operations in en-route airspace, it is likely that UAS will have to transition from U-space airspace into non-U-space airspace and vice versa. Therefore, this ConOps proposes UAS operations in non-U-space airspace to be conducted under UFR operational block X0. UFR X0 will be exclusive to UAS operations in non-U-space airspaces with UFR X0 U-space services[4] to provide safe and efficient segregation of UAS from crewed traffic (especially from VFR traffic in uncontrolled airspaces).

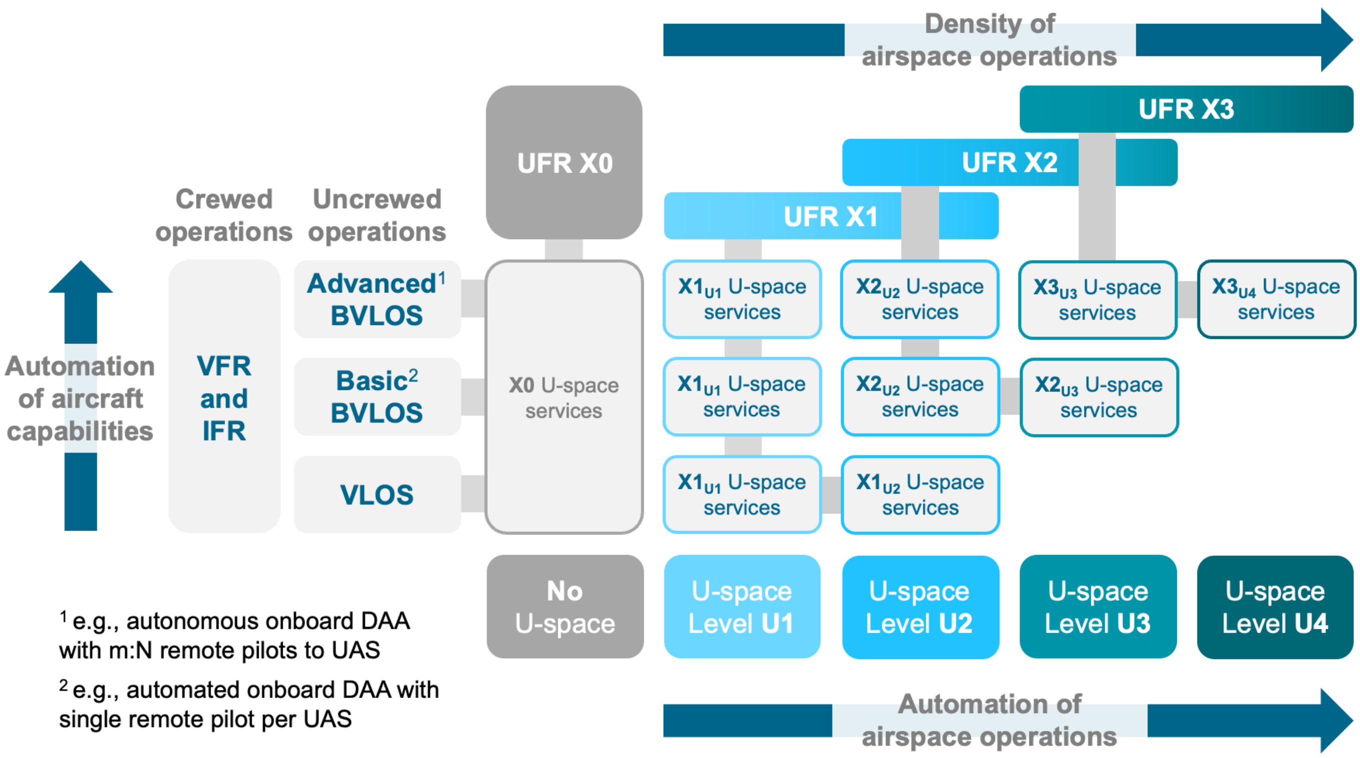


Fig. 4 Airspace operations under UFR in different U-space levels

In an exemplary U-space level U2, which could for illustration be located around a non-towered airfield in uncontrolled airspace, mixed airspace users will have to operate under UFR operational block X1 or X2 depending on the level of automation of their aircraft capabilities. VLOS UAS operations will fly under UFR X1 in U2 and receive corresponding $X1_{U2}$ U-space services, while more automated UAS (e.g., BVLOS) will operate following UFR X2 and additional U-space services (i.e., $X2_{U2}$). Airspace users operating under UFR will have to receive the U-space services assigned to their UFR operational block as well as those of the lower UFR operational blocks and U-space levels. This means that operations, for example, in U-space level U2 under UFR X2 (i.e., $X2_{U2}$) will receive UFR $X1_{U1}$ and UFR $X1_{U2}$ U-space services with additional U-space services offered for UFR $X2_{U2}$.

4 Concepts for the implementation of UFR X0 and UFR X0 U-space services will be part of future versions of the Blueprint.

Airspace operations under UFR $X1_{U3}$, $X1_{U4}$, $X2_{U1}$, $X2_{U4}$, $X3_{U1}$, and $X3_{U2}$ will not be conducted because aircraft capabilities, performance standards, and operating methods of airspace users will evolve over time, leading to a natural self-driven progress of automation. For example, airspace users with a comparatively low automation of aircraft capabilities flying under UFR X1 (e.g., VLOS) will be prohibited to operate in U-space level 4, which requires a range of comparatively highly automated U-space services. Nevertheless, highly automated UAS (e.g., advanced BVLOS) will be able to operate in low automated U-space levels (e.g., U1). Their advanced aircraft automation capabilities (e.g., autonomous onboard DAA) will enable safe and efficient separation from other airspace users without the help of advanced U-space services that are required in higher U-space levels with increased traffic density and operational automation.

The proposed architecture of the UFR operational blocks and their stepwise implementation within the different U-space levels will allow for modular designs of future U-spaces. According to the operational and technical requirements of each individual airspace environment, authorities can assign different UFR operational blocks to meet the requirements of the respective airspace. UFR are likely to enable a modular set up of different U-spaces from low-complexity U-spaces in regional airspaces (e.g., U1) with small numbers of different airspace users under UFR X1 to autonomously operating aerial vehicles within dense urban environments (e.g., U4) under UFR X3.

UFR X1: Common flight information surveillance

In this UFR ConOps, initial operations in U-space (e.g., in U-space level U1) will take place under UFR operational block X1 (see Fig. 5). UFR X1 sets the baseline for operations under UFR to progressively enhance automated airspace operations. This foundation is based on common flight information surveillance through sharing and tracking of flight data in U-spaces, called basic traffic information U-space service in this ConOps. Flight information sharing will be enabled by the principles of e-conspicuous standards. E-conspicuity will be mandatory starting in U-space level U1. Airspace users operating under UFR X1 must be electronically visible to the ground and among each other based on different harmonised technical standards. Transmitted flight data will be processed by USSP and displayed to UAS via traffic information systems, using mandatory e-conspicuity standards and other data sources such as ground-based primary radar and satellite-based systems.

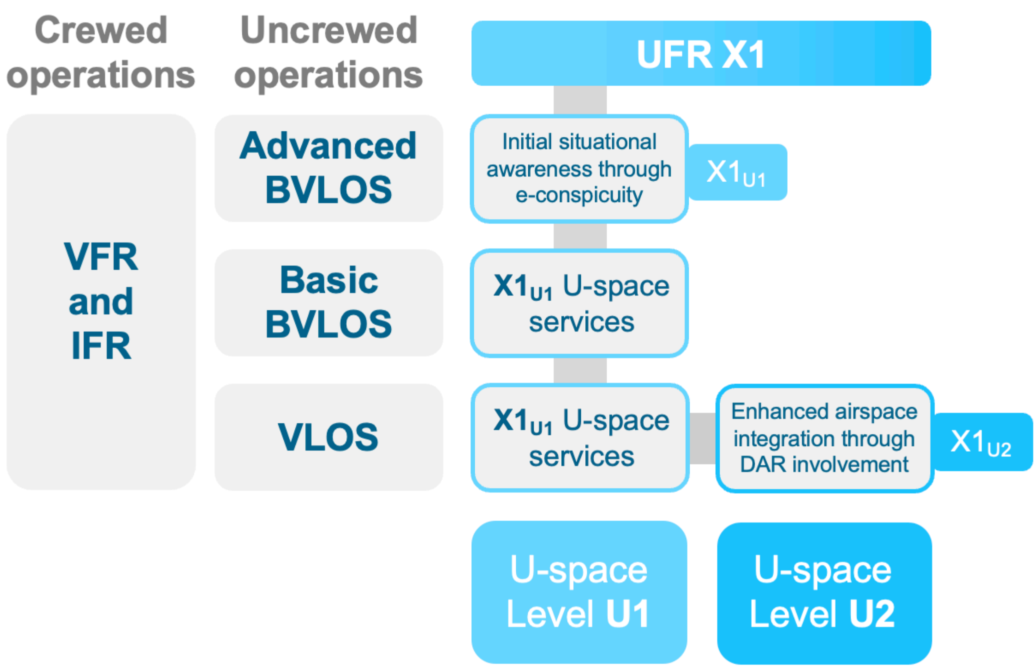


Fig. 5 Principles of UFR X1 – Common flight information surveillance

Under UFR X1, all airspace users will be obliged to transmit their vehicles position and motion to a USSP to provide initial situational awareness of all airspace users in real time. Additionally, UAS will be obliged to track e-conspicuous flight information by receiving the flight position and motion of other airspace users to enhance automated navigation in U-space (see **Fig. 6**). This will be provided by UFR $X1_{U1}$ U-space services.

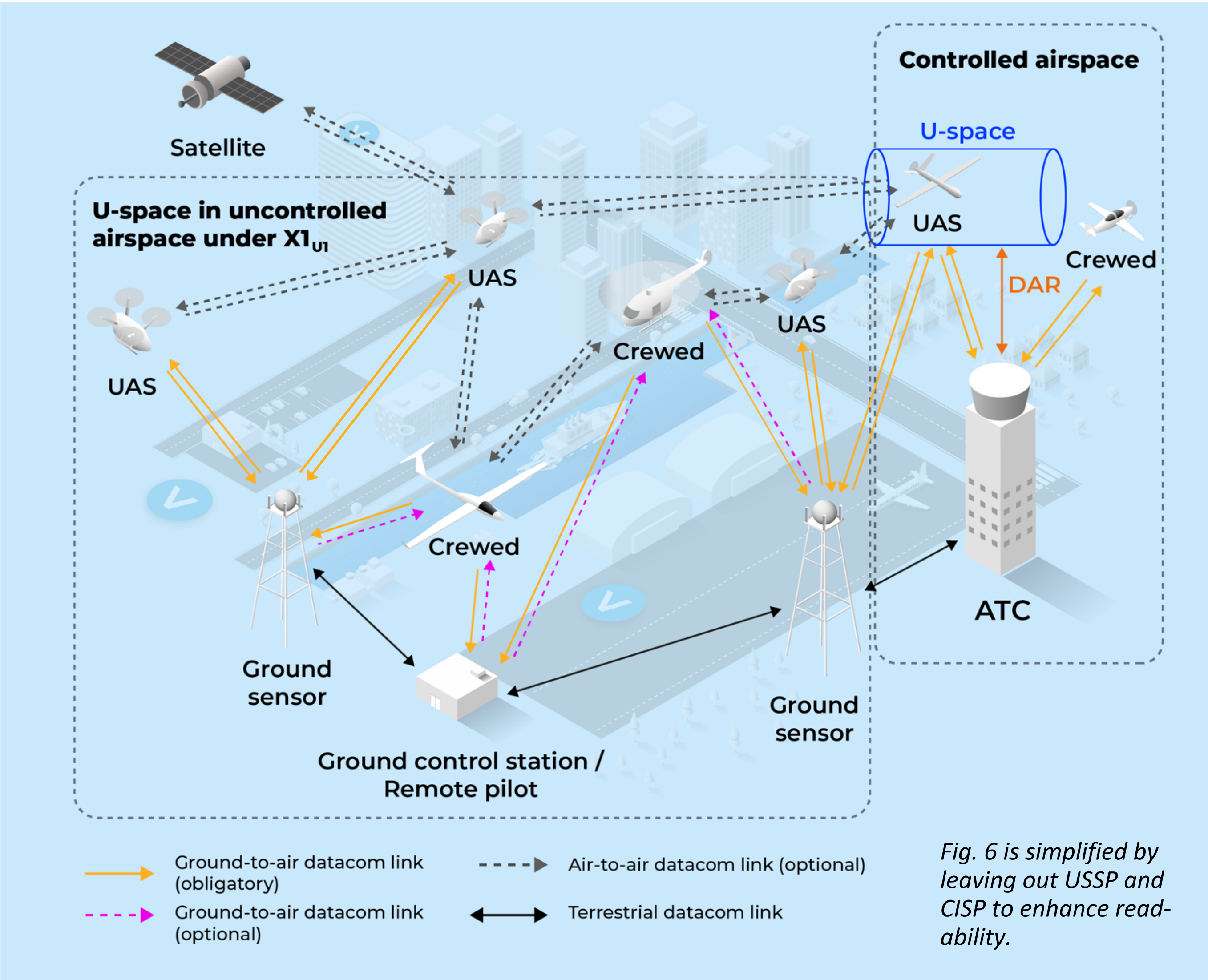


Fig. 6 Exemplary U-space operations under UFR X1 in U-space level U1

UFR X1 operations in U-space level U2 (i.e., UFR $X1_{U2}$) will utilize additional U-space services. This will enable airspace operations to enhance situational awareness. Flights under UFR $X1_{U2}$ are likely to receive U-space services providing enhanced geo-awareness, legal recording and reporting of airspace operations, digital logbook services, and an ATC procedural interface for transitions from U-spaces in uncontrolled airspaces to controlled airspaces.

Initial U-space airspaces for UFR X1 operations are likely to be smaller airspace volumes up to 20 km^2 horizontally and 1,000 ft AGL vertically in uncontrolled airspace, for example in low-density urban and regional areas or around less busy private regional airfields. Airspace volumes for UFR X1 operations will mainly accommodate VLOS operations and limited BVLOS flights. Airspace users will be, for example, smaller drones with less than 25 kg Maximum Take-Off Weight (MTOW) for initial UAS use cases such as delivery and inspection purposes. In these initial and less busy U-space airspaces, crewed operations under UFR X1 around smaller regional airfields, for example, are likely to be smaller vehicles such as helicopters and gliders. These crewed aircraft under UFR X1 will primarily rely on existing SAA principles, with some crewed operators also receiving traffic data on a voluntary basis, for example via mobile apps. Mixed traffic operations in U-spaces under UFR X1 will not need to be strategically and tactically deconflicted as the total number of overall operations will be limited, and initial U-spaces will be set up in less busy airspaces.

Generally, crewed traffic being e-conspicuous may only enter U-spaces in uncontrolled airspace. For mixed traffic operations in controlled airspace, ATC will ensure separation between UAS and crewed traffic by temporarily delegating controlled airspace segments to USSP responsible for managing the corresponding UAS operations. Controlled airspace segments for UAS operations are activated and deactivated by ATC using the DAR method [9].

UFR X2: Cooperative traffic interaction

The second UFR operational block X2 builds on the e-conspicuity capabilities of UFR X1. UFR X2 is intended to advance automation enabled by UFR X1 to achieve a state of cooperative traffic interaction (see Fig. 7). Starting in U-space level U2, UAS operations under UFR X2 are obliged to receive flight authorisation services and file a U-plan to enable the reception of initial strategic conflict management services (i.e., UFR $X2_{U2}$). Flight authorisation services will issue conflict alerts prior to the flight and may offer a resolution proposal. A U-plan is filed by an operator and will consist of a conflict-free 4D trajectory with overlapping 4D airspace volumes. Strategic conflict management services will detect an operator's conflicting trajectory pre-flight and will resolve it by providing a conflict-free alternative flight route. Additionally, UAS flying under UFR $X2_{U2}$ will receive initial tactical conflict detection and resolution services. These tactical conflict management services are likely to be implemented as ground-to-air systems rather than air-to-air systems, with the latter working as additional safety nets (e.g., onboard DAA systems).

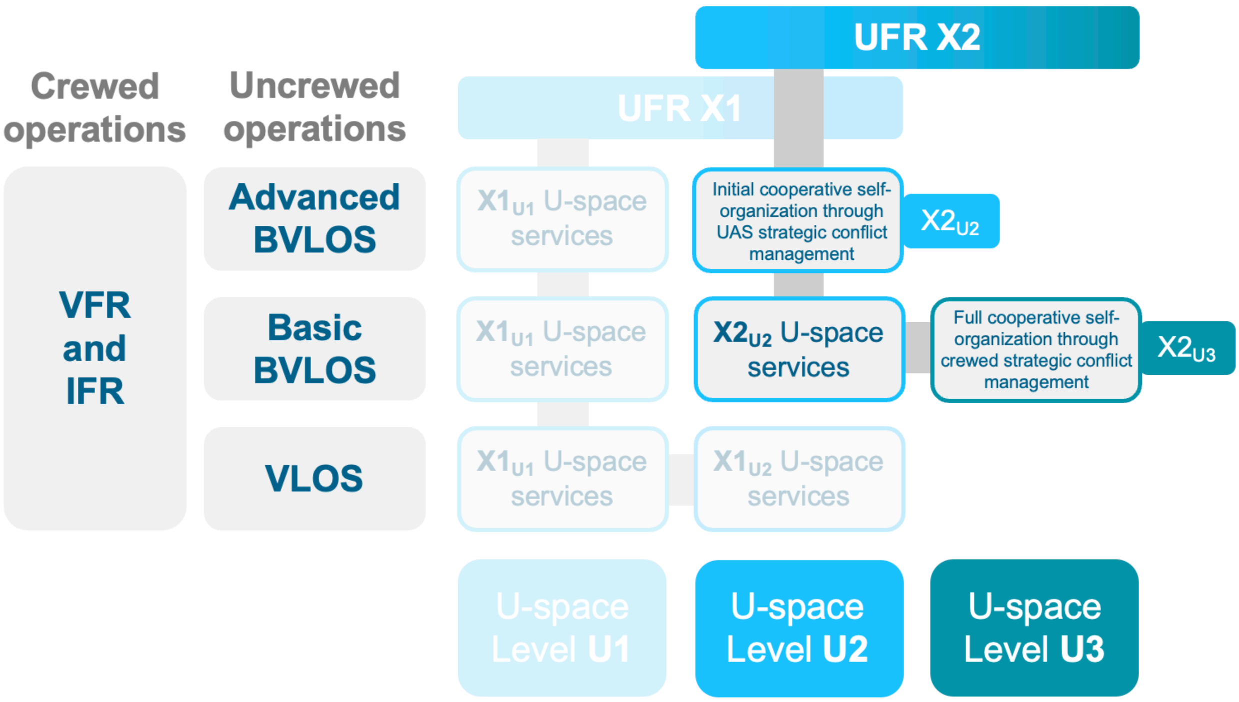


Fig. 7 Principles of UFR X2 – Cooperative traffic interaction

Additionally, UAS operating under UFR $X2_{U2}$ will receive enhanced traffic information U-space services of current and expected traffic densities and traffic information such as warnings and potential conflicts of airspace users in their vicinity. UAS operating under UFR $X2_{U2}$ are likely to utilize U-space services providing information and monitoring services of the airspace environment such as geographical information, vertical alert information, navigation infrastructure monitoring, and communication infrastructure monitoring information.

For airspace operations under UFR X2 in U-space level U3 (i.e., $X2_{U3}$) all airspace users will cooperatively avoid potential conflicts in-flight based on the principles of a self-organizing airspace. As a requirement, crewed airspace users are now obliged to receive processed traffic information of other airspace users in their vicinity by USSP. As described above, this service was already mandatory for UAS flying under UFR $X1_{U1}$, called basic traffic information U-space service.

For all airspace users under UFR $X2_{U3}$, flight authorisation, U-plan services, as well as strategic conflict detection and resolution services are mandatory. Operations under UFR $X2_{U3}$ will enable self-organized mixed traffic environments based on common flight principles. Here, this ConOps suggests that crewed operators will also provide a U-plan for their crewed operation. However, with UAS obliged to file predictable 4D trajectories as part of their U-plan, it is unlikely that crewed airspace users (e.g., private pilots performing leisure flights or training flights) will be able to submit an accurate flight path prior to their flight in a U-space airspace. Rather likely, this ConOps proposes that crewed airspace users will be required to digitally provide information about their flight purpose, approximate flight route based on geographical waypoints, and approximate flight timeframe as part of a U-plan for crewed operations. Based on these information, U-plan services and strategic conflict management services can predict flight intents of crewed airspace users with relative certainty, without overly restricting the freedom of flight of crewed airspace users. Accordingly, it can be envisioned that crewed airspace users will receive digital alerts (e.g., via mobile traffic display app) if their planned flight faces potential conflicts due to congested U-space airspace being used by UAS.

Crewed flights in uncontrolled airspace without e-conspicuity obligation often act as non-cooperative traffic (e.g., not radio-equipped) nowadays. When approaching a non-towered airfield, for example, they visually separate themselves following SAA principles. Future mixed airspace operations at a non-towered airfield surrounded by a U-space airspace are likely to be operated initially under UFR $X2_{U2}$. In this example, crewed aircraft under UFR $X2_{U2}$ will continue to rely largely on current SAA principles. However, UAS will be required to receive tactical conflict management services to ensure separation minima based on traffic information transmitted by crewed traffic (see **Fig. 8**). Under UFR $X2_{U2}$, crewed airspace users are not required to receive traffic information of other airspace users in their vicinity. For non-towered airfield operations in U-space levels with higher traffic densities (e.g., U3), crewed traffic will be required to receive traffic information of other U-space users (i.e., UFR $X2_{U3}$).

As mentioned above, this ConOps proposes that UAS under UFR $X2_{U2}$ are required to utilize tactical conflict management services offered by USSP to enable automated conflict detection and resolution procedures, especially in denser mixed traffic environments. It is likely that in U-spaces where tactical conflict management services are only mandatory for UAS operations (i.e., $X2_{U2}$), UAS will give right-of-way to crewed traffic. Initial tactical conflict management services for UAS are particularly important for operations in relatively complex terminal airspace environments with SAA principles and given airfield traffic patterns as the only separation procedures for crewed airspace users. Enhanced procedural automation through tactical conflict management services for UAS and e-conspicuity traffic displays for all airspace users are likely to ensure an efficient and safe interaction of mixed traffic operations within one airspace environment.

Tactical conflict management U-space services are expected to utilize performance-based information of different systems. Performance-based information refer to the characteristics of UAS, CNS, and DAA systems together with calculated aircraft positions of crewed aircraft [29]. By processing traffic information provided by e-conspicuity standards, dead reckoning navigation can be used by UAS and provided by U-space services to predict the flight intent of crewed airspace users. With dead reckoning navigation, UAS operations under UFR $X2_{U2}$ can be provided with different calculated future aircraft positions of crewed traffic in real time. U-space services will predict and suggest the most efficient and safest performance-based flight route for UAS with minimal conflict potential. In the future, it is likely that highly automated UAS will perform dead reckoning navigation onboard the vehicle.

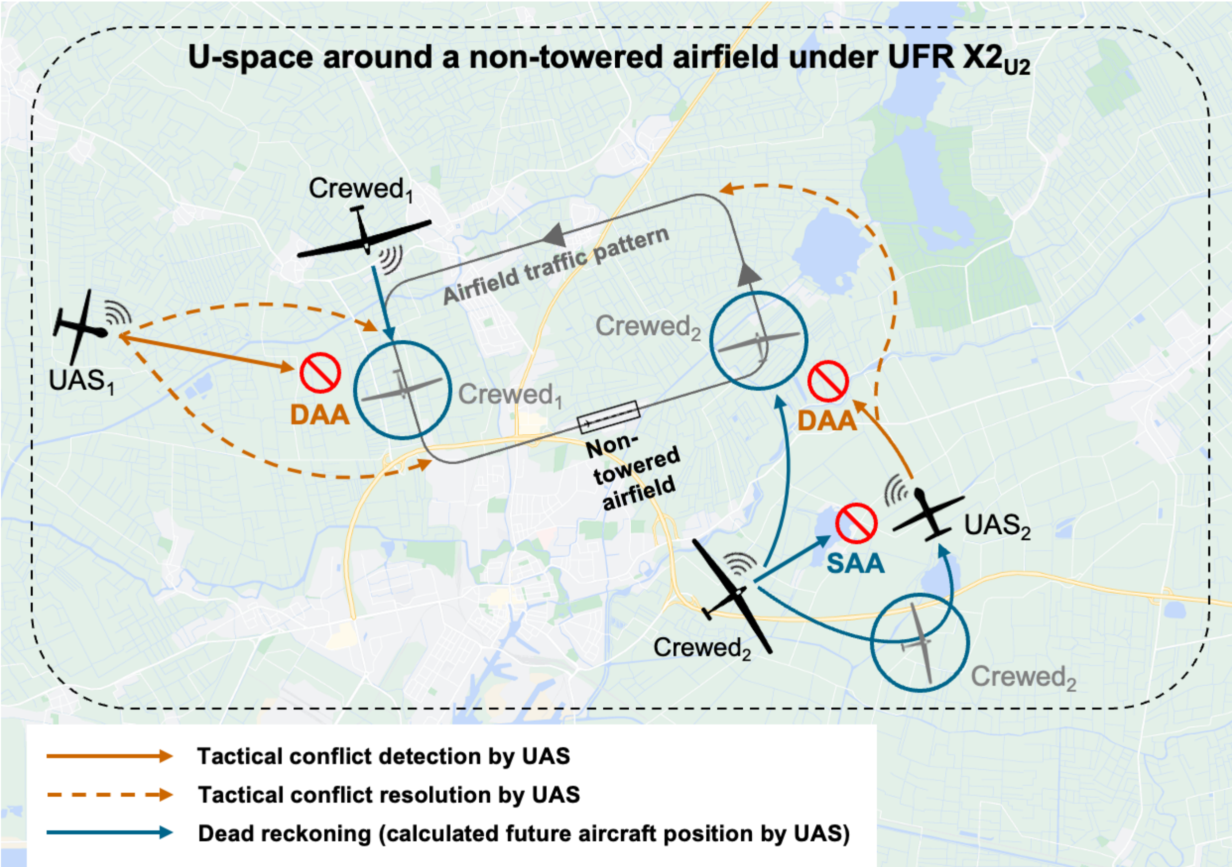


Fig. 8 Exemplary U-space operations under UFR X2 in U-space level U2

As discussed, U-space airspaces with higher traffic densities will require operations under UFR X2, which offers a broader range of U-space services than U-spaces with UFR X1 obligation. These U-space airspaces under UFR X2 are likely, for example, to extend up to 50 km^2 horizontally and up to 2,500 ft AGL vertically in denser urban and regional areas, around public regional airfields, and around small airports and newly established vertiports. Crewed traffic in U-space airspaces under UFR X2 is also likely to increase in performance and automated aircraft capabilities and will include turboprop, piston, and jet aircraft with less than 25 tonnes MTOW, helicopters, and gliders. For UAS operations in these U-space airspaces, UAS will increasingly operate under BVLOS with, for example, vehicles being regional fixed-wing aircraft and eVTOL vehicles for commercial transportation purposes of cargo and passengers. U-spaces with UFR X2 obligation will have increasing shares of UAS with different sizes and capabilities together with conventional crewed aircraft that need to be strategically and tactically deconflicted via U-space services offered by USSP.

Moreover, UAS under UFR X2 will increasingly use U-spaces in controlled airspace such as Controlled Traffic Regions (CTR), the terminal airspace around towered airports. Here, ATC will use DAR concepts to separate crewed and uncrewed airspace users, which requires collaborative interfaces between ATC, CISP, and USSP.

UFR X3: Collaborative performance-based separation

This ConOps envisions autonomous airspace operations with advanced onboard automation and DAA systems to operate under UFR operational block X3. Airspace operations and traffic density will increase substantially in the next decades, with significantly more airspace users than ever before. UAS are likely to outnumber crewed operations in highly automated U-space airspaces (i.e., U4) and air traffic will be characterized by a variety of different airspace users in terms of size, aircraft capabilities, and operational tasks [9]. UFR X3 will enable all these different airspace users to collaborate within one airspace environment by the principles of collaborative performance-based separation (see **Fig. 9**).

Advanced U-space services offered in U-space level U3 will enable highly automated traffic separation procedures with vanishingly smaller proportions of crewed airspace users under UFR $X3_{U3}$. U-space airspaces with UFR $X3_{U3}$ are likely to have high traffic densities requiring highly efficient performance-based traffic separation. Airspace users will have to collaboratively self-optimise their flights by receiving tactical dynamic capacity planning and trajectory re-planning services. Additionally, advanced air-to-air systems such as onboard DAA automation will increasingly support ground-to-air systems responsible for tactical conflict management services.

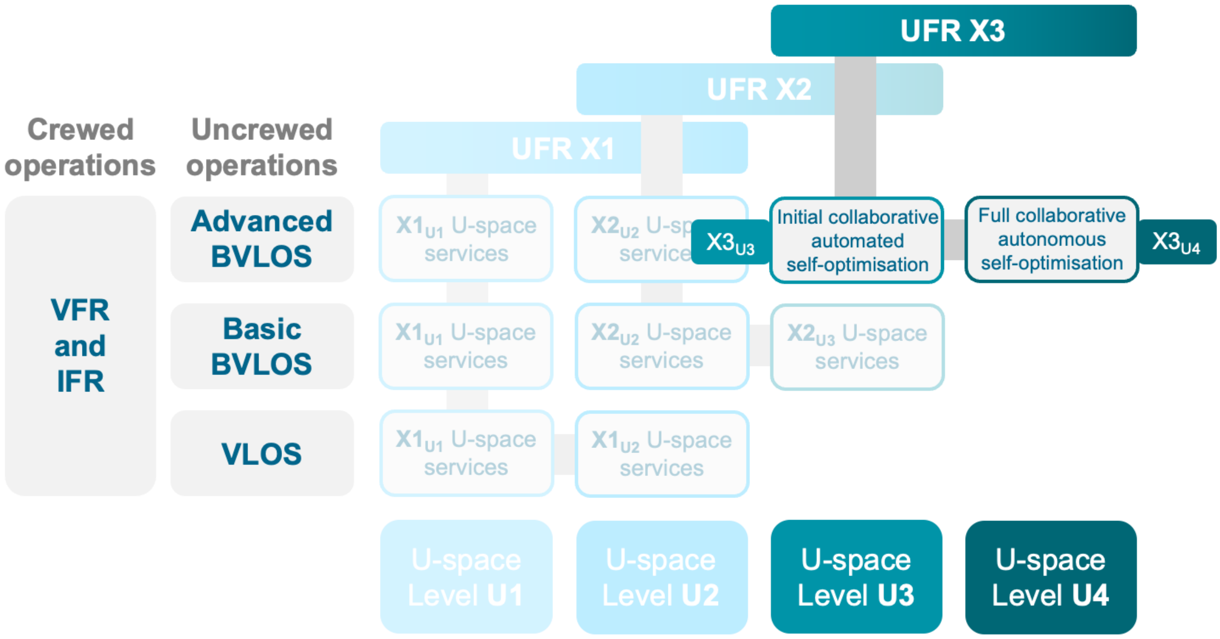


Fig. 9 Principles of UFR X3 – Collaborative performance-based separation

The availability of full U-space services in U4 is based on a fully connected digital information system. This will result in varying boundaries of human-machine interaction and enables flexible and adaptive self-optimised air traffic procedures. Operations under UFR $X3_{U4}$ will collaboratively operate in dynamic airspace environments. These airspaces will require flexible airspace capacity planning services to enable high traffic densities at vertiports, for example. Additional UFR $X3_{U4}$ services are likely to enable autonomous trajectory prediction and re-planning together with advanced multimodality interfaces. Airspace users operating in U-spaces with $X3_{U4}$ obligation are likely to autonomously separate themselves by communicating and collaborating with each other in-flight. UFR $X3_{U4}$ are likely to enable highly efficient contingency and emergency procedures by autonomously detecting and resolving off-nominal traffic situations, such as LC2L of airspace users.

UFR $X3_{U4}$ will enable autonomous free route airspace operations in dense traffic environments based on dynamic 4D trajectories under performance-based navigation. Collaborative decision-making among all airspace users will allow for an integrated optimisation of airspace operations and airspace configurations. It is unlikely that crewed airspace users will operate under UFR $X3_{U4}$, as 4D trajectories of numerous autonomous vehicles are tactically updated second by second, especially in high-density traffic situations, which makes non-autonomous flights and human-monitored air traffic displays impractical. Additionally, air transport services within U-spaces will be interconnected with various multimodal transport solutions that enable seamless and autonomous transportation of people and goods outside the airspace.

Future U-space airspaces with operations under UFR X3 are likely to expand over entire cities enabling autonomous UAS operations in dense urban airspaces. Within UAM and RAM, airspace users will be characterized by increasingly different aircraft capabilities and performance characteristics with UAS ranging from small urban delivery drones up to large fixed-wing and eVTOL UAS for commercial transportation of cargo and passengers. To enable real-time surveillance of all airspace users in both densely populated and remote areas, widely available and reliable advanced communication structures (e.g., satellite-based ADS-B) are likely to be required.

4.2. Implementation of UFR within U-space architectures

The implementation of UFR will be realized through different U-space services according to the technical and operational requirements of each U-space. For each UFR operational block in each U-space level, airspace users will receive sets of mandatory and optional U-space services managed by USSP. Accordingly, airspace users in higher U-space levels or UFR operational blocks will receive all U-space services offered in U-space levels or UFR operational blocks of lower levels.

The sets of U-space services will differ for UAS and crewed operations. It can be expected that more services will be mandatory for UAS, with UAS typically receiving these services at a lower U-space level or in a lower UFR operating block than crewed operations. The following section of this ConOps provides an overview of U-space services (already proposed in [8]/[9], adjusted based on [8]/[9], or new) that could be mandatory for UAS and/or crewed operations (if not indicated as "optional") in each UFR operational block and U-space level. For each U-space service, the two columns on the right-hand side of **Fig. 10** to **Fig. 12** indicate whether the service is mandatory/optional for UAS and/or crewed operations. Each of these U-space services is described in **Table 1** to **Table 3**. For a longlist and a more detailed description of most of these U-space services, see [9], the CORUS-XUAM "U-space ConOps and Architecture (Edition 4)". Note that the CORUS-XUAM U-space ConOps only proposes U-space services for UAS operations.

X1U1 U-space services and capabilities	Uncrewed	Crewed
Basic common information*	✓ (Mandatory)	✓ (Mandatory)
Registration of UAS operators	✓ (Mandatory)	— (Not relevant)
Drone aeronautical information management	✓ (Mandatory)	— (Not relevant)
Basic geo-awareness	✓ (Mandatory)	✓ (Optional)
Network identification (e-conspicuity)	✓ (Mandatory)	✓ (Mandatory)
Basic traffic information	✓ (Mandatory)	✓ (Mandatory in higher UFR operational blocks) X2U3
Vertical conversion	✓ (Mandatory)	✓ (Mandatory in higher UFR operational blocks) X2U3

X1U2 U-space services and capabilities	Uncrewed	Crewed
Enhanced geo-awareness	✓ (Mandatory)	✓ (Optional)
Legal recording and reporting	✓ (Mandatory)	✓ (Optional)
Digital logbook	✓ (Optional)	✓ (Optional)
ATC procedural interface	✓ (Mandatory)	✓ (Mandatory)
Dynamic airspace management (DAR)**	✓ (Mandatory)	✓ (Mandatory)

✓ Mandatory ✓ Optional ✓ Mandatory in higher UFR operational blocks — Not relevant

*Cannot be seen as a U-space service in a narrow sense, as the common information are provided by the CISP.

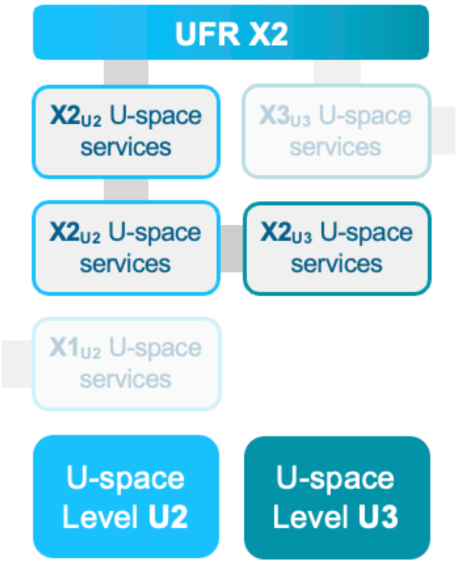
**No separate U-space service; provided to airspace users by utilizing "ATC procedural interface" or "ATC collaborative interface" services.

Fig. 10 Allocation of U-space services and capabilities to UFR X1

Table 1 Overview of U-space services and capabilities for UFR X1

U-space services and capabilities for UFR X1
Basic common information – Definition of U-space airspace horizontal and vertical limits and geographical zones and information regarding USSP according to EU 2021/664 article 5 *(Adjusted based on* [8]/[9]*)*
Registration of UAS operators – E-registration service providing a unique registration number according to EU 2019/947 article 14 *(Proposed in* [9]*)*
Drone aeronautical information management – Information on general technical and operational requirements of airspaces, airports, airfields, vertiports, and other information that are relevant for UAS operations; comparable to current aeronautical information publications *(Proposed in* [9]*)*
Basic geo-awareness – Provision of information on geographical zones for UAS (e.g., restricted access) according to EU 2019/947 article 18(f) and EU 2021/664 article 9 *(Adjusted based on* [8]/[9]*)*
Network identification (e-conspicuity) – Unified surveillance data sharing procedures enable the communication of the U-space users' geographical position, flight direction, flight level, status, and type of vehicle to a USSP following e-conspicuity standards according to EU 2021/664 article 8 and EU 2021/666 article 1 *(Proposed in* [8]/[9]/[15]*)*
Basic traffic information – Provision of U-space users surveillance data to airspace users in their vicinity to track the U-space users positions and motions according to EU 2021/664 article 11 *(Adjusted based on* [8]/[9]*)*
Vertical conversion – Altitude conversion of different reference systems to allow for unified data provision of flight altitudes *(Proposed in* [9]*)*
Enhanced geo-awareness – Provision of enhanced information on geographical zones for UAS regarding operational requirements *(Adjusted based on* [9]*)*
Legal recording and reporting – Recording and reporting of different incidents and accidents with UAS involvement *(Proposed in* [9]*)*
Digital logbook – Post-flight access of own historical and statistical flight information *(Proposed in* [9]*)*

ATC procedural interface
– Coordination of air traffic operations into controlled airspace with taking over control of flights
(Proposed in [9]*)*
Dynamic airspace management (DAR)
– Dynamic delegation of airspace segments in controlled airspace by ATC to either UAS or crewed airspace users according to EU 2021/664 article 4
(Proposed in [8]/[9]*)*



$X2_{U2}$ U-space services and capabilities	Uncrewed	Crewed
Enhanced traffic information	Mandatory	Mandatory in higher UFR operational blocks: $X2_{U3}$
Geographical information	Mandatory	Optional
Vertical alert and information	Mandatory	Optional
Navigation infrastructure monitoring	Mandatory	Optional
Communication infrastructure monitoring	Mandatory	Mandatory in higher UFR operational blocks: $X2_{U3}$
Weather information	Mandatory	Optional
Flight authorisation (U-plan)*	Mandatory	Mandatory in higher UFR operational blocks: $X2_{U3}$
Conformance monitoring	Mandatory	Not relevant
U-plan preparation	Optional	Optional
ATC collaborative interface	Mandatory	Mandatory
Emergency management	Mandatory	Mandatory in higher UFR operational blocks: $X2_{U3}$
Strategic conflict management	Mandatory	Mandatory in higher UFR operational blocks: $X2_{U3}$
Tactical conflict management	Mandatory	Mandatory in higher UFR operational blocks: $X3_{U3}$

$X2_{U3}$ U-space services and capabilities	Uncrewed	Crewed
Strategic dynamic capacity management	Mandatory	Mandatory
Aerodrome infrastructure management**	Mandatory	Mandatory
Aerodrome capacity management**	Mandatory	Mandatory

Mandatory   Optional   Mandatory in higher UFR operational blocks   Not relevant

*Even though flight authorisation services are required for all U-space operations (EU 2021/664), the obligation to file a U-plan for each flight will significantly increase operational complexity. Therefore, this ConOps introduces flight authorisation services for operations under UFR X2 and higher.

**These services are intended to enable high-density UAS operations at aerodromes. Initial UAS operations at aerodromes together with crewed aviation are likely to be carried out without these services.

Fig. 11 Allocation of U-space services and capabilities to UFR X2

Table 2 Overview of U-space services and capabilities for UFR X2

U-space services and capabilities for UFR X2
Enhanced common information – ATC traffic information and DAR procedures with corresponding U-space geographical boundaries in controlled airspace *(Adjusted based on* [9]*)*
Enhanced traffic information – Provision of U-space users processed surveillance data to display current and expected traffic densities and traffic information such as warnings and potential conflicts according to EU 2021/664 article 11 *(Adjusted based on* [8]/[9]*)*
Geographical information – Provision of ground obstacles and terrain information (e.g., 3D geospatial information) *(Proposed in* [9]*)*
Vertical alert and information – Provision of collision risks with ground obstacles *(Proposed in* [9]*)*
Navigation infrastructure monitoring – Ongoing monitoring of navigation infrastructure requirements to provide information in case of a loss of navigation accuracy *(Proposed in* [9]*)*
Communication infrastructure monitoring – Ongoing monitoring of communication infrastructure requirements and related infrastructure availability (e.g., warnings about potential LC2L due to a lack of available communication infrastructure) *(Proposed in* [9]*)*
Weather information – Provision of forecasted and live weather situations according to EU 2021/664 article 12 *(Proposed in* [8]/[9]*)*
Flight authorisation for UAS **(U-plan)** – Authorisation of flight plans with receiving and archiving U-plans that contain planned and conducted 4D flight trajectories of UAS operations according to EU 2021/664 article 10; initial strategic deconfliction tool for UAS operations *(Adjusted based on* [8]/[9]*)* **Optional U-plan preparation** – Population density map – Electromagnetic interference information – Navigation Coverage information – Communication Coverage information – Risk Analysis Assistance *(Proposed in* [9]*)*

Flight authorisation for crewed operations
(U-plan)

- Authorisation of flight plans with receiving and archiving U-plans that contain planned and conducted flight information of crewed operations; initial strategic deconfliction tool for crewed operations
- Digital provision of information about flight purpose, approximate flight route based on geographical waypoints, and approximate flight timeframe

(New)

Optional U-plan preparation (See above)

Conformance monitoring

- Monitoring of UAS in-flight information regarding deviations from flight authorisation and alerting in case of non-conformances according to EU 2021/664 article 13

(Proposed in [8]/[9]*)*

ATC collaborative interface

- Communication between ATC and USSP such as DAR procedures and UAS close to controlled airspaces

(Proposed in [9]*)*

Emergency management

- Supporting the airspace user that experiences an emergency with relevant information and informing other airspace users in the vicinity of the emergency

(Proposed in [9]*)*

Strategic conflict detection/prediction for UAS

- Pre-flight detection of conflicts within a U-plan to ensure conflict-free 4D trajectories, at least for UAS operations

(Adjusted based on [9]*)*

Strategic conflict resolution for UAS

- Pre-flight resolution of conflicts by assigning a conflict-free 4D trajectory to the operators U-plan; the U-plan with the highest priority or the earliest authorised will get accepted

(Adjusted based on [9]*)*

Strategic conflict detection/prediction for crewed operations

- Pre-flight detection of conflicts within a U-plan for crewed operators based on flight information such as approximate flight route based on geographical waypoints and flight timeframe

(New)

Strategic conflict resolution for crewed operations

- Pre-flight resolution of conflicts by notifying the crewed operators if their flight plan faces many potential conflicts due to an estimated congested U-space airspace used by UAS

(New)

Tactical conflict detection/prediction

- In-flight detection of conflicts based on violations of the tactical conflict threshold volume of airspace users

(Adjusted based on [9]*)*

Tactical conflict resolution

- In-flight resolution of conflicts by instructing the airspace user to resolve the conflict by adjusting the speed, flight level, and/or heading of the vehicle

(Adjusted based on [9]*)*

Strategic dynamic capacity management

- Pre-flight coordination of air traffic to regulate demand and capacity; pre-flight determination of capacity maxima and allocation of demands

(Adjusted based on [9]*)*

Aerodrome infrastructure management

- Coordination of aerodrome (i.e., airport, airfield, and vertiport) availabilities, vehicle requirements and infrastructure conditions for planned aerodrome operations, as well as aerodrome contingency procedures

(New)

Aerodrome capacity management

- Cooperative real-time planning and allocation of aerodrome capacities based on air traffic, vehicle performances, and flight priorities

(New)

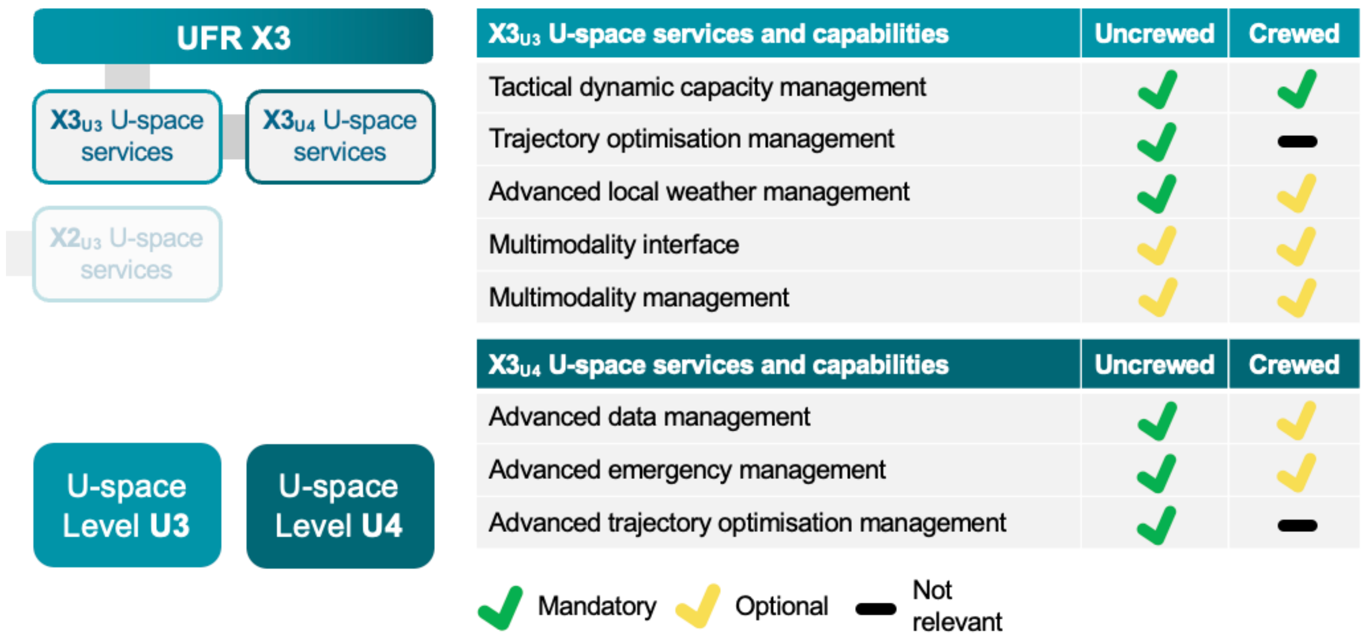


Fig. 12 Allocation of U-space services and capabilities to UFR X3

Table 3 Overview of U-space services and capabilities for UFR X3

U-space services and capabilities for UFR X3

Tactical dynamic capacity management

- In-flight coordination of air traffic to regulate demand and capacity
- In-flight determination of capacity maxima and allocation of demands

(Adjusted based on [9]*)*

Trajectory optimisation management – Automated and continuous planning and updating of UAS trajectories according to UAS performance characteristics to guarantee highly optimised flight routes dependant on airspace traffic density and external factors such as weather *(New)*
Advanced local weather management – Detailed forecasts and information about local weather and turbulences such as urban wind gusts (e.g., in skyscraper canyons or at urban vertiports) together with atmospheric weather influences on flight trajectories and vehicle performances *(New)*
Multimodality interface (optional) – Provision of an operator interface that enables the planning and selection of various multimodal transport solutions to take place pre-flight or post-flight (e.g., passenger transportation on the ground from the vertiport to the final destination) *(New)*
Multimodality management (optional) – Coordination and planning of various multimodal transport solutions (e.g., urban passenger transportation via public ground transportation or regional air cargo shipping via truck); multimodality interface service required *(New)*
Advanced data management – Continuous optimisation of airspace operations through comprehensive and standardized smart data processing and provision of lifecycle data such as of aerial vehicles, operated flight paths, environmental information (e.g., weather, urban infrastructure etc.) in accordance with data privacy requirements *(New)*
Advanced emergency management – Prediction of emergencies along with recommended actions to be executed autonomously if operators or third parties fail to interact in time to ensure the least impact caused by the emergency – Provision of emergency behaviours with autonomous intervention for respective airspace users in the vicinity of the emergency *(New)*
Advanced trajectory optimisation management – Autonomous adaption of UAS trajectories in real-time according to UAS performance characteristics to provide the highest degree of flexibility and safety of flight routes dependant on airspace traffic density and external factors such as weather *(New)*

This list of U-space services for the different UFR operational blocks is not exhaustive. It can be anticipated that further services, especially U-space services for U4, will be introduced in the future as soon as technological and regulatory advances substantiate the vision for U-space level U4.

5. Compatibility of UFR with existing operating modes and today's ATM

UFR are intended to enable safe and efficient airspace operations in airspaces declared as U-space airspace. With the recent establishment of the first U-space airspaces in Europe, U-spaces are projected to expand significantly in the next years to systematically enable the integration of UAS and crewed operations within one airspace environment. However, it is relevant to determine how today's airspace users operating under VFR or IFR will transition from these operating modes to UFR when entering a U-space airspace.

5.1. Transition from VFR/IFR operations to UFR operations

There are two general use cases for a transition from VFR or IFR flights to a UFR flight. The first describes a crewed airspace user flying in uncontrolled airspace (likely under VFR) entering a U-space in uncontrolled airspace. The second use case deals with a crewed airspace user flying in controlled airspace (likely under IFR) entering a U-space in uncontrolled airspace. Transitions to a U-space in controlled airspace follow the principles of DAR and are addressed separately.

The standard procedure for a transition from VFR or IFR to UFR is likely to be implemented digitally in an automated manner. For a crewed airspace user intending to operate in a U-space airspace, the pilot will most likely be informed of the entry into the U-space by the USSP, informing the pilot of the U-space extension, required U-space services and the technical and/or operational requirements of the U-space. The information about the entry will be provided shortly before the entry of the U-space airspace in order for the pilot to react in time if the requirements for a flight under UFR in a specific U-space airspace are not fulfilled.

For initial crewed airspace operations under UFR in low traffic density U-space airspaces (e.g., VFR to UFR $X1_{U1}$), the pilot's behaviour and duties are not affected by the automated transition to UFR compared to his/her initial operating mode. The only difference for the pilot is that he/she will be informed about the entry into U-space and the geographical boundaries of the U-space airspace (basic common information U-space service), information regarding USSP, and the obligation of the crewed aircraft to be e-conspicuous to the ground and other aerial vehicles (network identification U-space service). Therefore, for a crewed aircraft transitioning form VFR to UFR, the pilot will still be largely subject to the flight principles of VFR in low complexity U-space airspace. For crewed operations transitioning to UFR in highly automated U-spaces with higher traffic densities and increasing UAS operations, pilots will likely have to fulfil significantly more technical and operational requirements. This will include utilizing U-space conflict management services and carrying more automated onboard systems (e.g., for operations in highly automated U-spaces with UFR X3 obligation).

Generally, airspace users under IFR are less likely to enter uncontrolled airspaces compared to VFR traffic. According to EU commission implementing regulation 923/2012, IFR flights outside of controlled airspace require a continuous two-way radio communication link to maintain air-to-ground voice contact with ATS to receive flight information services [30]. In Germany, IFR flights are not even permitted in uncontrolled airspace (i.e., airspace class G). However, it can be assumed that IFR flights will usually avoid uncontrolled U-space airspaces, especially in low-level airspace environments.

One use case for IFR operations in uncontrolled airspace that requires the transition to UFR would be the approach to a non-towered airfield surrounded by a U-space airspace (see **Fig. 13**). Nowadays, the one-in one-out rule generally applies for IFR flights approaching to or departing from a non-towered airfield, whereby ATC allows one IFR aircraft at a time to arrive at or depart from the non-towered airfield. Compared to towered airfields, ATC does not clear the IFR aircraft to a specific runway, only to the airfield by clearing the terminal airspace of the non-towered airfield. If another IFR aircraft wants to operate at the non-towered airfield, it is common for the IFR aircraft to cancel IFR and proceed as a VFR aircraft.

However, it is likely, that for the case of an IFR aircraft to operate at a non-towered airfield surrounded by a U-space airspace, the IFR aircraft will still become a UFR aircraft. In this case, ATC would continue to provide the one-in one-out principles and USSP to provide an ATC collaborative interface and relevant traffic information. Comparable to the DAR method enabling UAS operations in controlled airspace, a similar approach could allow for IFR operations in an uncontrolled U-space airspace around non-towered airfields. IFR aircraft flying under UFR could be assigned a cleared flight corridor by ATC and USSP restricting the access for other airspace users to enable a temporary access for IFR aircraft flying under UFR in U-space.

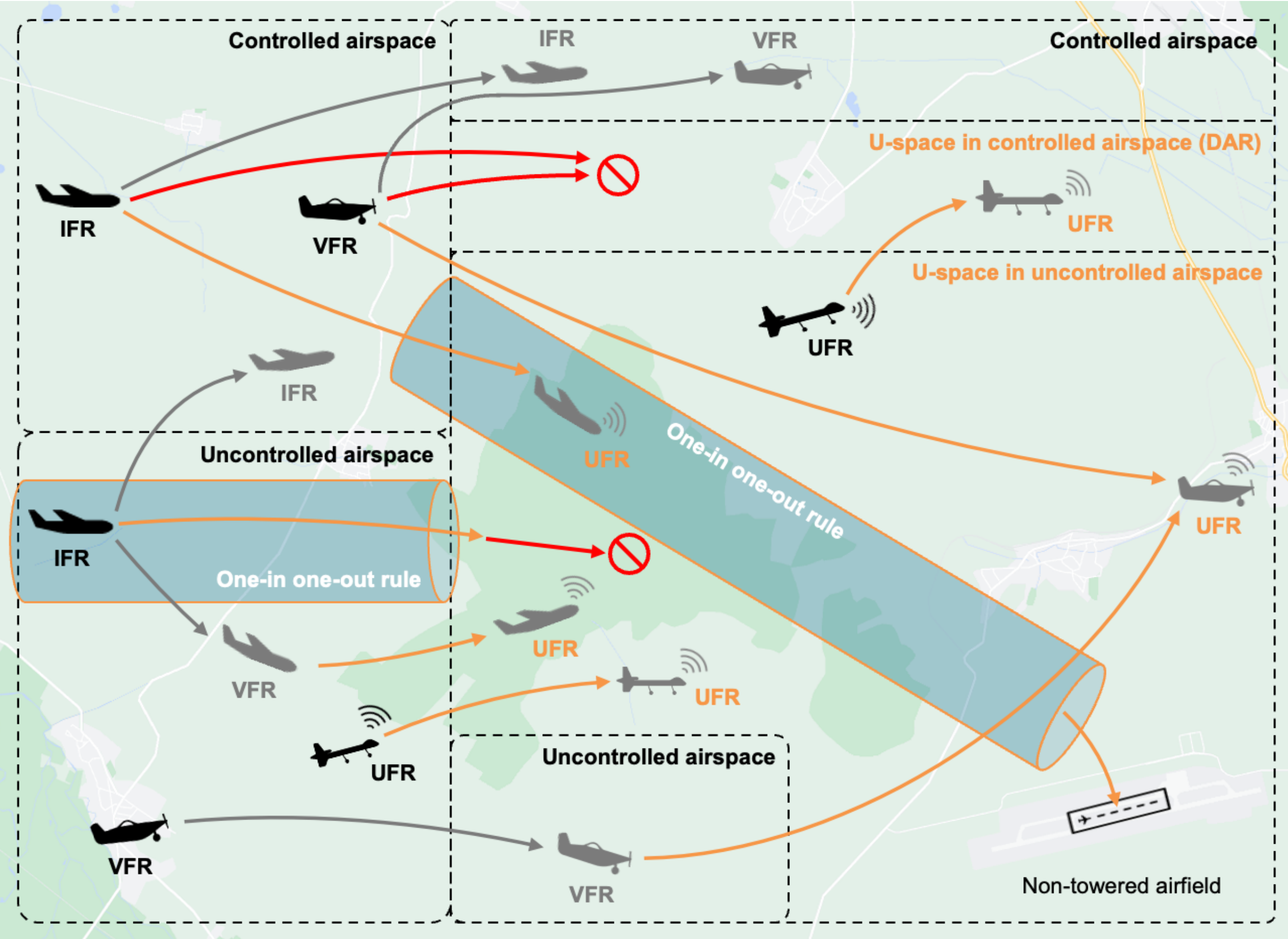


Fig. 13 Transition scheme between VFR/IFR and UFR in the respective airspaces

5.2. Transition between UFR operations in uncontrolled and controlled airspace

The DAR method has already been introduced earlier for the transition of UAS operations under UFR into designated U-space airspace segments in controlled airspace. For UAS operations entering controlled airspace supervised by ATC, controlled airspace segments are dynamically assigned to UAS operations under the responsibility of USSP. As a result, it can be assumed that the integration of UAS into controlled airspace will occur more seamless than into uncontrolled airspace, as ATC will continue to monitor these flights in controlled airspace. Moreover, initial UAS operations in controlled airspace (e.g., fixed-wing UAS operating in a Terminal Manoeuvring Area (TMA)) are likely be conducted according to IFR procedures anyway [31].

Given the example of an initial, single UAS operation with a regional flight distance of several hundred kilometres that largely operates in uncontrolled airspace, it is unlikely that a U-space will be established for this specific UAS operation. An exemplary use case would be a regional fixed-wing cargo UAS operation with the aircraft having less than 25 tonnes MTOW within a flight distance of less than 1,000 km [32]. For this case, this ConOps proposes UAS operations in non-U-space, uncontrolled airspaces to be carried out under UFR X0 (see section 4.1).

Another option could be the establishment of temporary U-space airspaces to enable a safe airspace integration of UAS. Given an exemplary cargo fixed-wing UAS departing from a non-towered airfield, that normally does not serve any UAS operations, the airfield could be assigned a temporary U-space until the flight reaches controlled en-route airspace initiating DAR. This would allow the UAS to operate in a relatively safe, temporary U-space environment before a permanent U-space will be established around that non-towered airfield to enable regular UAS operations (e.g., daily or for regular time slots). VFR aircraft approaching this airfield will be informed of the temporary U-space airspace and will receive notification that their flight must transition from VFR to UFR (to ensure e-conspicuity obligation). Likewise, for fast transitions with relatively short flight distances from a U-space airspace to controlled airspace through a non-U-space, uncontrolled airspace, temporary U-space airspaces segments could be declared to ensure safe airspace integration of UAS.

An alternative would be the introduction of additional or the extension of existing Transponder Mandatory Zones (TMZ) to guarantee e-conspicuity in the respective non-U-space airspace. VFR could continue to be operated under VFR, while UAS would operate under UFR X0. This would allow UAS to become aware of other air traffic in non-U-space airspace before reaching controlled airspace or U-space airspace again.

6. Key takeaways and outlook

New flight rules that safely and efficiently integrate current and emerging airspace users within one airspace system have been under discussion for over a decade. However, the initial conceptual work on new flight rules only briefly addresses the potential of these flight rules. Although initial cooperative practices that the introduction of new flight rules must entail are derived, the capabilities of new flight rules for the integration and interaction of crewed and uncrewed airspace users are scarcely addressed. In addition, specific regulations apply to the European airspace, which must be considered when developing and introducing new flight rules. For the European airspace, it remains to be determined who will operate under these new flight rules and under what conditions, and how new flight rules will be deployed over time in different U-space levels with different requirements. There is the need for a conceptual framework that provides a structured introduction of new flight rules for both crewed and uncrewed airspace users operating within a single European airspace environment.

This Blueprint proposes an initial ConOps of new flight rules for crewed and uncrewed airspace users in U-space airspaces, called U-space Flight Rules – UFR. Based on current European U-space architectures, UFR are intended to enable high-density UAS operations while harmonising with today's flight rules and ATM system. This ConOps suggests that all airspace users in U-space airspaces follow a uniform framework of flight rules. The proposed UFR architecture is based on U-space levels, respective U-space services, and aircraft automation capabilities. UFR shall complement existing flight rules and leverage airspace access and flexibility of flight operations of all airspace users.

This ConOps proposes UFR to follow a stepwise implementation depending on the level of automation that each U-space will provide. Based on the advancements of the four different U-space levels, increased automation of aircraft capabilities as well as increased digital information exchange and connectivity of U-space services will lead to more automated procedures in ATM systems and U-spaces. In U-space airspaces, this ConOps suggests airspace users to fly under three different operational blocks X1 to X3. For each UFR operational block, a range of U-space services will be mandatory for airspace users to fulfil the technical and operational requirements of each U-space. Additionally, UFR operational block X0 is intended to apply exclusively for UAS operations that cannot conform to VFR or IFR in airspace segments which have not been declared as U-space yet. This implies that all UAS operations will follow UFR principles, regardless of whether they operate in U-space airspace or not.

In summary, UFR are envisioned to apply to all airspace users within U-space airspaces and

- depend on U-space services and aircraft automation capabilities,
- complement existing flight rules,
- ensure fair and common airspace access,
- provide operational flexibility,
- increase safe and efficient air traffic procedures,
- enable increasingly automated air traffic procedures while providing
  - common flight information surveillance,
  - cooperative traffic interaction,
  - collaborative performance-based separation.

This Blueprint as a "living document" that is intended to be updated regularly after receiving feedback and further research is conducted. Further versions will expand on the current ConOps with more details on the role of UFR for crewed airspace users, transitions between UFR and today's flight rules accompanied by their benefits for crewed operators. Further versions are likely to provide more detailed use cases of UFR for both crewed and uncrewed airspace users under different operational conditions in the four U-space levels.

Figure index

Table index

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List of abbreviations

A

AAM	Advanced Air Mobility
ADS-B	Automatic Dependent Surveillance - Broadcast
ADS-L	Automatic Dependent Surveillance - Light
AGL	Above Ground Level
AMC	Acceptable Means of Compliance
AREA	Air Space Research Area
ASM	Airspace Management
ATC	Air Traffic Control
ATM	Air Traffic Management
ATFS	Air Traffic Flow Management
ATS	Air Traffic Services

B

BFR	Basic Flight Rules
BVLOS	Beyond Visual Line Of Sight

C

CISP	Common Information Service Provider
CNS	Communication, Navigation, and Surveillance
CTR	Controlled Traffic Region
ConOps	Concept of Operations
C2 Link	Command-and-Control Link

D

DAA	Detect-And-Avoid
DAR	Dynamic Airspace Reconfiguration
DFR	Digital Flight Rules
DLR	German Aerospace Center

E

EASA	European Union Aviation Safety Agency
EFR	Enhanced Flight Rules
EUROCONTROL	European Organisation for the Safety of the Air Navigation
eVTOL	Electric Vertical Take Off and Landing
EU	European Union

F

FAA	Federal Aviation Administration
FL	Flight Level

G

GCS	Ground Control Station
GM	Guidance Material

H

HFR	High-level Flight Rules

I

IAM	Innovative Air Mobility
ICAO	International Civil Aviation Organization

IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
J	
JARUS	Joint Authorities for Rulemaking of Unmanned Systems
L	
LC2L	Lost Command and Control Link
LFR	Low-level Flight Rules
M	
MFR	Managed Flight Rules
MTOW	Maximum Take-Off Weight
N	
NASA	National Aeronautics and Space Administration
R	
RAM	Regional Air Mobility
RMZ	Radio Mandatory Zone
RPS	Remote Pilot Station
S	
SAA	See-And-Avoid
SERA	Standardised European Rules of the Air
SESAR	Single European Sky ATM Research
SRD	Short-Range Device
SSR	Secondary Surveillance Radar
SVFR	Special Visual Flight Rules
T	
TaFR	Tailored Flight Rules
TMA	Terminal Manoeuvring Area
TMZ	Transponder Mandatory Zone
U	
UA	Uncrewed Aircraft
UAM	Urban Air Mobility
UAS	Uncrewed Aircraft System
UFR	U-space Flight Rules
USSP	U-space Service Provider
UTM	Unmanned / Uncrewed / UAS Traffic Management
V	
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
VLL	Very Low Level
VLOS	Visual Line Of Sight
X	
xTM	Extensible Traffic Management

DLR at a glance

DLR is the Federal Republic of Germany's research centre for aeronautics and space. We conduct research and development activities in the fields of aeronautics, space, energy, transport, security and digitalisation. The German Space Agency at DLR plans and implements the national space programme on behalf of the federal government. Two DLR project management agencies oversee funding programmes and support knowledge transfer.

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