ANALYSIS AND CONCRETIZATION OF FUZZINESS IN THE U-SPACE REGULATION

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Abstract

The U-space Regulation will come applicable on January 26, 2023, and it will allow EU Member States to designate U-space airspaces as well as to establish infrastructure. If UAS operators – private and commercial - wish to fly in a U-space airspace, they must use U-space services to maintain safety and an efficient airspace utilization. While the technical basis for the U-space services is included in the U-space Regulation, it omits some crucial details regarding the relationship between its key stakeholders like the U-space service provider and the UAS operator, imposing challenges on the technical implementation. Therefore, a plurality of legally abstract requirements and partially ambiguous provisions (henceforth referred to as fuzziness) need to be concretized in a first step. Subsequently, the derived legal interpretation needs to be tested for its technical practicability in order to practically realise an efficient drone traffic management in U-space. In doing so, this contribution addresses identified fuzziness of the UAS flight authorisation service according to Article 10 of the U-space Regulation and shows the concretization needs for this service in order to fulfil its extensive tasks, such as the authorisation and activation of UAS flights.

1. INTRODUCTION

Unmanned aircraft systems (UAS) carry a great social and economic potential, as they can not only be efficiently used in inspection, maintenance, and surveillance tasks, but also by enriching the multimodal mobility system by an additional transport mode [1]. At the same time, unlocking this potential requires ensuring safe and efficient airspace access for UAS, and thus a reliable regulatory framework and innovative technologies that provide the required level of safety and security in the course of UAS integration into the airspace, and existing airspace structures. The European Commission has recognized the need for a technical infrastructure and has adopted the Implementing Regulation (EU) 2021/664 on the legal framework of a U-space (U-space Regulation) [2] on April 22, 2021. U-space is understood to be a concept for UAS traffic management that realises airspace management in a defined geographical area, the U-space airspace.

Member States will be able to designate national U-space airspaces and establish a national U-space infrastructure from January 26, 2023, in accordance with the U-space Regulation. The so-called U-space services, which are intended to enable the safe and efficient integration of UAS into urban airspace, play a crucial role in this context. The Member States are faced with the challenge that the U-space Regulation does not contain any details on the technical implementation. Due to the legally abstract specifications or partly ambiguous provisions (fuzziness), these must first be concretized and the proposed solutions must be checked for their practicability in order to realise efficient drone traffic management in a national U-space.

In order to overcome this challenge, the UDVeo joint project funded by the Federal Ministry for Digital and Transport (BMDV) (cf. https://udveo.eu/) examined the inherent fuzziness of the regulation's article on the UAS flight authorisation service, which is the central element for the strategic planning phase of UAS flights. UDVeo then developed concretization solutions for the identified fuzziness to supplement the details missing in the U-space Regulation to enable the technical realisation. Figure 1 shows the paragraphs of Art. 10 from the U-space Regulation in which legal or technical fuzziness could be identified:

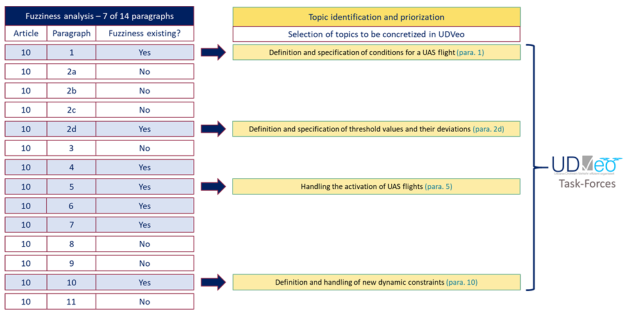

Figure 1: Fuzziness analysis and prioritized UDVeo topics

To achieve this goal and solve the problems at hand, task forces were established in UDVeo, consisting of interdisciplinary teams with legal and technical qualification. A selection of high-priority fuzziness with an urgent need for concretization for the realisation of a UTM, their scope for interpretation as well as the elaborated concretization solutions are presented in this contribution.

2. BACKGROUND

The problem of fuzziness is not a new topic and occurs in many other domains. Particularly in domains such as the manufacturing industry or software development, semantic fuzziness poses a great challenge. Misinterpretations of the underlying facts can lead to incorrect or inefficient results [3]. For this reason, it is important to address this problem already during the conception of a drone traffic management system.

The need for concrete and detailed regulations to enable UAS operations and the development of industry standards has already been elaborated in [4]. The formulation of specific legal regulations can also help to avoid room for interpretation as well as different technology developments. For this reason, the margin of interpretation in the current U-space Regulation should be reduced for the national implementation by the EU Member States.

The technical realisation of the U-space services requires the integration of the legal framework and specifications from the U-space Regulation. Due to the wide margin of interpretation of some issues in the U-space Regulation, a different understanding can lead to different actors of a U-space ecosystem operating with individual solutions in a U-space. Due to a lack of standards or common consensus, the different interpretations of the U-space Regulation may lead to different technical developments of the UAS flight authorisation service (U-FAS), these fuzziness from the U-space Regulation must first be identified and then concretized in order to realise a common development of a safe and efficient U-space and the U-space services provided within.

The fuzziness for U-FAS derives from Art. 10 of the U-space Regulation, shown in Figure 2 according to [2]:

Article	Paragraph	Minimum legal requirements according to U-Space regulation
10	1	The U-space service providers shall provide UAS operators with the UAS flight authorisation for each individual flight, setting the terms and conditions of that flight, through a UAS flight authorisation service.
	2	Where U-space service providers receive from the UAS operator an UAS flight authorisation request, they shall: a. check if the UAS flight authorisation request is complete and correct and submitted in accordance with Annex IV; b. accept the UAS flight authorisation request if the flight under the UAS flight authorisation is free of intersection in space and time with any other notified UAS flight authorisations within the same U-space airspace in accordance with the priority rules set out in paragraph 8; c. notify the UAS operator about the acceptance or rejection of the UAS flight authorisation request; d. when notifying the UAS operator about the acceptance of the UAS flight authorisation request, indicate the allowed UAS flight authorisation deviation thresholds.
	3	When issuing a UAS flight authorisation, the U-space service providers shall use, where applicable, weather information provided by the weather information service as referred to in Article 12.
	4	Where U-space service providers are unable to grant an UAS flight authorisation in accordance with the UAS operator's request, U-space service providers may propose an alternative UAS flight authorisation to the UAS operator.
	5	Upon receiving the request for an UAS flight authorisation activation referred to in Article 6(5), the U-space service providers shall confirm the activation of the UAS flight authorisation without unjustified delay
	6	U-space service providers shall establish proper arrangements to resolve conflicting UAS flight authorisation requests received from UAS operators by different U-space services providers.
	7	U-space service providers shall check the request for UAS flight authorisations against U-space airspace restrictions and temporary airspace limitations.
	8	When processing UAS flight authorisation requests, the U-space service providers shall give priority to UAS conducting special operations as referred to in Article 4 of Implementing Regulation (EU) No 923/2012.
	9	When two UAS flight authorisations requests have the same priority, they shall be processed on a first come first served basis.
	10	U-space service providers shall continuously check existing flight authorisations against new dynamic airspace restrictions and limitations, and information about manned aircraft traffic shared by relevant air traffic service units, in particular regarding manned aircraft known or believed to be in a state of emergency, including being subjected to unlawful interference, and update or withdraw authorisations as may be necessitated by the circumstances.
	11	U-space service providers shall issue a unique authorisation number for each UAS flight authorisation. This number shall enable the identification of the authorised flight, the UAS operator and the U-space service provider issuing the UAS flight authorisation.

Figure 2: Legal basis for the U-FAS from the U-space Regulation [2]

3. FUZZINESS AND ITS NEED FOR CONCRETIZATION

The UDVeo analysis of the legal requirements in the U-space Regulation has shown that some paragraphs allow for a margin of interpretation (cf. Figure 1). The interpretation has a direct influence on the efficiency and design of the U-space.

An example to illustrate the problem of fuzziness of the U-space Regulation from a technical point of view, can be shown by the process flow of the U-FAS. The U-FAS combines the processes of UAS flight authorisation and UAS flight activation. It should be noted that the two processes are sequential. First, a UAS flight authorisation request is processed in order to issue an authorisation for a UAS flight, so that subsequently a UAS activation request can be processed in order to issue a flight clearance.

The U-space Regulation describes both processes in their basic structures, but no detailed information or requirements are provided. A comparison of the two processes shows which forms of fuzziness exist in the U-space Regulation. While minimum information is available for the UAS flight authorisation process with its modifiable characteristics, no information can be derived regarding the UAS flight activation process from the U-space Regulation. This leads to two forms of fuzziness:

1. Semantic fuzziness: There is only limited information (facts and terms) available, allowing for interpretation, which thus can influence the technical realisation.

2. Procedural fuzziness: There are no information or indications about the process section available, so that the design of the technical realisation is completely open.

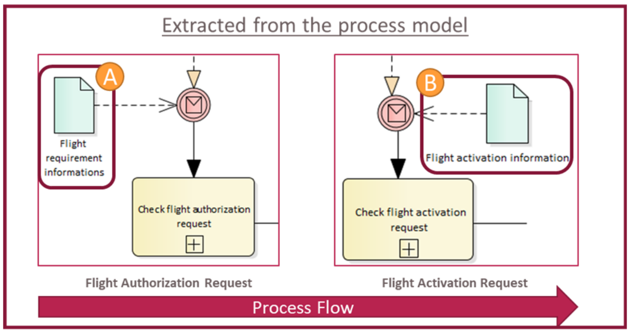

Figure 3: Process model of the UAS flight authorisation service according to [5]

The problem described above can be illustrated with Figure 3. While limited information requirements for the UAS flight authorisation request can be derived from Art. 10 and Annex IV of the U-space Regulation (A), there are no specifications of information for the flight activation request (B). Accordingly, there is room for interpretation regarding the realisation of the authorisation and activation process. The problem of processual fuzziness can be visualised with the idea of a time corridor for the activation of a UAS flight: If the activation time window available to the UAS operator after the activation is requested is considered, it can be seen that the range of this time window can have a large impact on the overall strategic planning of UAS flights in a U-space. If the activation time window is large, the UAS operator may deviate significantly from the actual planned and authorised flight launch time, such that other planned UAS flights might be affected, possibly resulting in the need to update the affected flight plans.

The conducted analysis of the fuzziness from Art. 10 of the U-space Regulation was evaluated, divided into topics to be worked on and prioritized in order to identify and concretize the fuzziness with the strongest influence on a U-space. This contribution comprises the analysis and concretization in four fuzziness areas:

I. Definition and specification of conditions for a UAS flight (derived from Art. 10 (1))

II. Definition and specification of threshold values and their deviation (derived from Art. 10 (2d))

III. Handling the activation of UAS flights (derived from Art. 10 (5))

IV. Definition and handling of new dynamic constraints (derived from Art. 10 (10))

In order to describe the effects of the above-mentioned fuzziness areas in a comprehensible way, this is done by means of a case study. For this purpose, the operational phases of a UAS can be used, which can be divided into a strategic, tactical and a post-flight phase. Looking at these phases in the context of a UAS flight, the fuzziness can be placed in a chronological order. If the UAS operator submits a flight authorisation request to a USSP, the conditions applicable to the requested UAS flight must first be specified (I.), and the thresholds applicable to the UAS flight must be defined (II.). The UAS flight authorisation process is followed by the UAS operator's request for the activation of an authorized flight (III.). The classification of dealing with new dynamic airspace restrictions (IV.) must be considered continuously, but will have different effects on the flight of the UAS operator depending on the phase of the flight. In order to show the need for concretisation of the identified fuzziness (I.-IV.), the following section explains each fuzziness further. Based on the explanations and the need to concretise a fuzziness in the following section, chapter 4 then shows the first concretisation solutions that were developed within the scope of UDVeo.

I. Definition and specification of conditions for a UAS flight

USSPs providing U-space services must specify the applicable conditions for the requested UAS flight for each UAS flight authorisation request sent to the U-FAS by a UAS operator. These conditions, which predate from Art. 10 (1), are not further specified in the U-space Regulation. Annex IV of the U-space Regulation also does not provide any further details with regard to the trajectory of a flight plan. The definition of the term “UAS flight” is not to be interpreted unambiguously and does not emerge from the legal framework. As a result, an understanding of the term “UAS flight” is needed to enable efficient drone management in a U-space. From a technical point of view, there is accordingly a semantic fuzziness, since the interpretation of the facts can influence the technical realisation and thus the functional process in U-space.

The form and characteristics that a flight can depend on the application. While a flight path with a start and end point can be defined for delivery missions, this is different for other use cases such as inspection or agricultural flights that might be characterized by an area-based use of UAS. In addition to these clear differences, there are also different approaches to defining a flight within a use case. When taking a closer look at the use case of delivery missions, it becomes obvious that the simple consideration of a flight route from point A to point B is usually not sufficient, so that the definition of a “UAS flight” may differ. Overall, there may be two different manifestations in connection with the submission of a UAS flight authorisation request:

1. the definition of UAS flight includes a UAS trajectory from point A to point B.

2. the definition UAS flight includes a UAS trajectory from point A to point B and back to point A again.

Comparing the two possible definitions and transferring them to the U-space operation, it becomes clear that the second definition of a UAS flight blocks the U-space longer than the first definition.

II. Definition and specification of threshold and their deviation

Among the conditions which must be defined for a UAS flight are the threshold values and their maximum permissible deviation. The design of the thresholds has a decisive influence on the efficiency and the capacity limit of a U-space. If large buffer zones are selected as protection zones for UAS flights, the available airspace in a U-space decreases significantly. In addition, the thresholds to be set also have a significant influence on conflict management. For example, if smaller buffer zones (so-called operational volumes) are chosen, the risk of UAS flight paths overlapping and enabling a conflict increases. The airspace designs developed in UDVeo also address this issue and provide an overview of the impact of defining thresholds for the airspace organization [6]. In addition, further criteria for the definition of thresholds of a UAS flight can be added which can also be differentiated into spatial and temporal extensions. Besides the necessary definition of thresholds, measures have to be considered how to deal with the violation of thresholds.

III. Handling the activation of UAS flights

The term activation has not yet been clearly defined in the U-space context, neither legally nor technically. As already described at the beginning of chapter 3, in comparison to the authorisation process, no details or indications are provided on the required information for submitting a UAS activation request. In this context, the question arises as to how the process is to be understood from a legal and technical perspective. In addition, the definition of relevant information in UAS flight authorisation activation must be carried out to realise a uniform procedure for the activation of UAS flight authorisations in the U-space.

For example, if a UAS operator is about to begin his mission the question arises how to design the activation process in connection within the U-FAS such that already authorized and activated UAS flight authorisations are not affected. As shown in the initial example of chapter 3, the available activation corridor as well as the design of the activation process can have a large effect on other UAS flights. It is even possible that cascading adjustments may need to be made to already authorized flights if a UAS operator activates a flight in an unanticipated time period. To prevent this, the activation process and its effects need to be further described and defined from a legal and technical perspective.

IV. Definition and handling of new dynamic constraints

If an USSP has issued a UAS flight authorisation, he is obliged to check the authorisation continuously in accordance with Art. 10 (10). However, which information gives rise to check already issued authorisation is not clearly defined by the U-space Regulation. The regulation thus leaves the task of interpretation to the currently several different USSPs operating in a U-space. Due to the scope for interpretation of these terms, it cannot be ruled out that one and the same event may have different consequences for the flight authorisations of the UAS. And for the UAS operator, it ultimately depends on which USSP he has chosen. Therefore, a concretisation for all USSPs (at least) in the same U-space is required prior to the establishment of U-space in order to ensure equal consequences for each UAS flight authorisation. This has been realised in UDVeo as part of the research work.

Notably, requests for UAS flight authorisations do not have to be submitted in a specific time window (e.g. a few weeks before the flight), so that both long-term and short-term planned UAS flights can be realised. Thus, UAS flight authorisations can "exist" even months before the flight actually takes place and thus fall under the review requirement of Art. 10 (10). However, since dynamic events are checked for collision with the existing UAS flight authorisations, Art. 10 (10) is of importance in actual terms on the UAS operator side, especially in the pre-tactical and tactical phases.

4. RESULTS OF THE UDVEO FUZZINESS TASK FORCES

Four specific proposed solutions to the identified fuzziness from chapter 3 are presented below. Both a legal and a technical assessment of the issues is made.

4.1. Definition and specification of conditions for a UAS flight

In the context of the UAS flight authorisation, Art. 6 (4) of the U-space Regulation mandates that “the UAS operator shall submit an UAS flight authorisation request to its U-space service provider [USSP], through the UAS flight authorisation service referred to in Article 10”. Furthermore, it is stated in Art. 2 (1) that the USSP “shall provide UAS operators with the UAS flight authorisation for each individual flight, setting the terms and conditions of that flight, in compliance with Annex IV”. According to common understanding, a single flight can be considered as a mission, that begins with the take-off and concludes with the touch-down of the operating vehicle, while several segments of climb, descent and horizontal flight can be conducted in between. In conventional aviation, there have been multiple EU regulation documents in which a contextual definition of the term “flight” is available. In Regulation (EC) No 1008/2008 for instance, it is described as *“a departure from a specified airport towards a specified destination airport”* [7], while in Commission Decision C (2009) 4293, a flight *“commences at a parking place of the aircraft and terminates at a parking place of the aircraft”* [8] In urban air traffic however, there can be multiple potential use cases, each one of them entailing individual boundary conditions that do not necessarily fit this conventional view. However, the U-space Regulation lacks a contextual definition of the term “flight”, arising the question how we should interpret the term in the context of our investigations. One major field of UAS application with a high potential is represented by surveillance and inspection flights, as described in [9,10].

In contrast to a conventional point to point mission as described before, a mission conducting an inspection can comprise a multitude of mission legs, each starting with a take-off and ending with a touch-down. Multiple mission legs can be required, for instance, if the operational time exceeds the maximum UAS energy capacity and a battery change is necessary, or if technical incidents occur during operation. Another promising field of UAS operations is represented by logistic applications. A logistics mission usually includes at least two separate mission legs, starting from the distribution center at location 1 to transport a payload to a destination location 2, where an intermediate landing is conducted. After the on-ground payload disposal is complete, at least one further mission leg follows, in which the UAS either returns to its original location 1, or to another location to conduct further deliveries.

A wide variety of research has been carried out on potential application fields of UAS in delivery operations [11-13]. Therefore require the capability of requesting complex UAS flight authorisations, containing a variety of mission legs with multiple points for take-off and touch-down regarding location and time for a single mission, where all mission legs are conditionally linked to each other and from an operational point of view, can hardly be requested and authorized independently from each other.

As presented in [6], UDVeo has developed an evolutionary U-space airspace allocation design where all four stages are based on a first come first served policy. With each stage, the concept provides a more sophisticated and efficient utilization of airspace, but also more complex technological challenges that are to be coped with for the operational realisation. In design 1 (cf. Figure 4, left column), which represents the technological capability level of the UDVeo prototype control station, a vehicle reserves the full extent of airspace along the segment between two points for the entire time of a mission, as marked by the blue area, reaching over all altitude levels. In the next design levels, the scope of these operational volumes is subsequently reduced. Design 2 allows for a clearance of airspace in the wake of a vehicle, once a position has been passed. In design 3, the extent of an operational volume is reduced regarding its altitude, enabling a vertical separation between vehicles. Finally in design 4, the allocated part of the airspace along the next trajectory segment is reduced regarding its time horizon, practically reducing the operational volume around the vehicle to a tube segment.

There are three different options (A-C) depicted in Figure 5, how a single flight might be defined, whereas all options start the flight with the activation process at location 1.

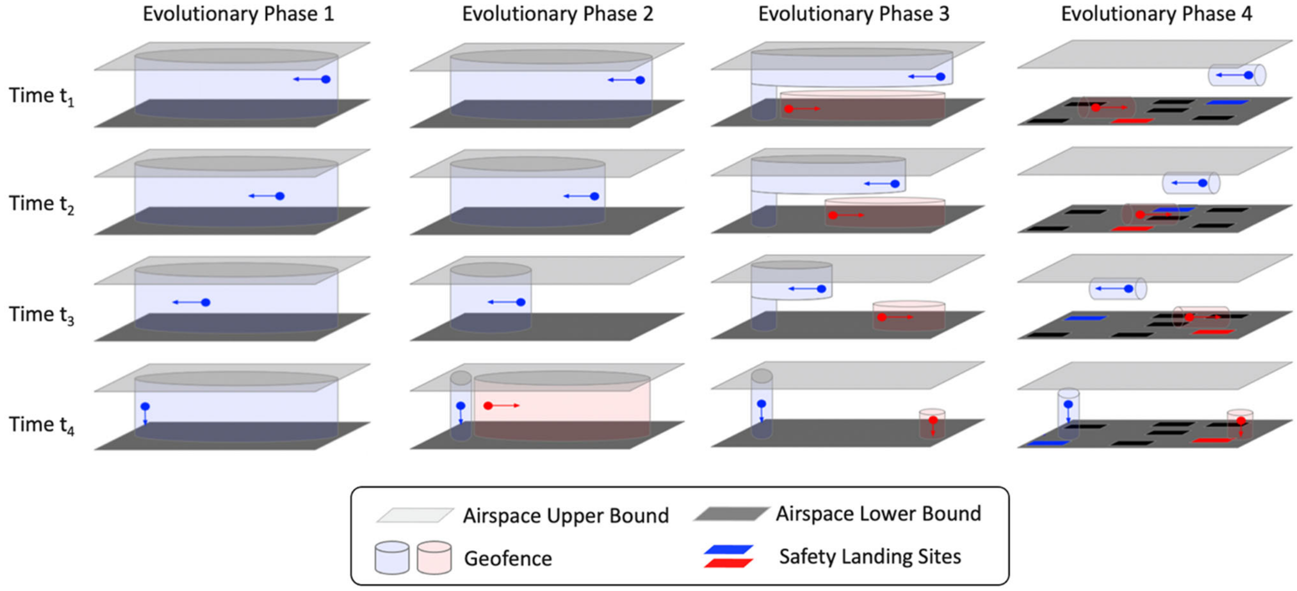

Figure 4: Evolutionary phases of airspace allocation design in UDVeo [6]

According to option A, only the starting and ending coordinates of an authorisation request can be set to an altitude of zero meters with regard to the local ground level, such that the touch-down at location 2 terminates the flight. In order to conduct a delivery mission, a logistics operator needs to submit two individual flight authorisation requests from location 1 to 2 and vice versa. Hence, each flight starts with its individual activation, followed by take-off, cruise flight, touch-down and finally a deactivation, which terminates the flight. The payload delivery could thus be conducted in between the two flights. Although a deactivation step is not intended by the U-space Regulation, it is considered to be a reasonable measure to reduce the risk of misunderstandings and to increase the safety level.

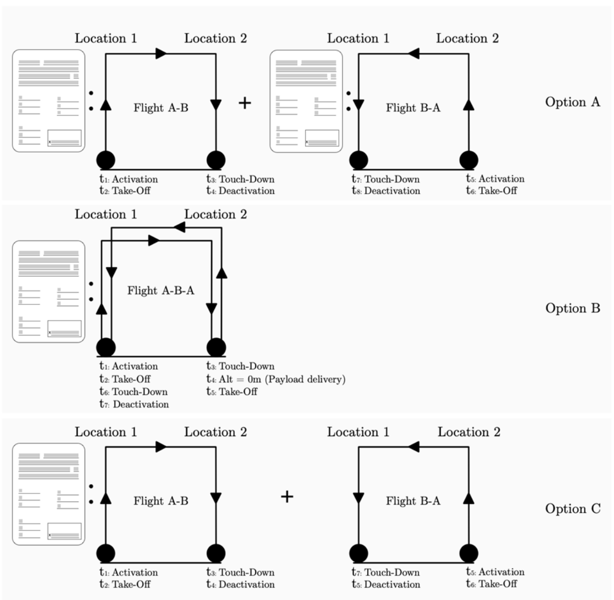

Figure 5: Interpretation of the term "flight" and three resulting options for authorisation request of an exemplary mission

However, from the perspective of a logistics operator, option A includes the possibility of receiving approval for only one of the two required UAS flight authorisations between locations 1 and 2, which effectively voids the feasibility of the complete mission. Particularly in the light of the high efforts, which logistics operators usually invest into efficient tour planning, this approach does not provide sufficient reliability in the planning process for en-route missions, especially for delivery tours with multiple stops. In addition, missions that are locally conducted, such as for infrastructure inspection, intermediate touch-downs might be necessary, for instance in order to exchange batteries. A further challenge might result from the implementation of a binding and reliable touch-down detection procedure.

According to option B, the definition of mission segments with altitude levels of zero meters are permitted, providing the capability of integrating planned intermediate landing segments, which might be used to conduct payload deliveries. Subsequently, the mission can be continued with at least one further take-off, cruise and landing segment. Since Annex IV states that a UAS flight authorisation request must include a 4D trajectory, but does not specify further boundary conditions on these points, the addition of further ground segments to a trajectory is not in conflict with the U-space Regulation. From a UAS logistics operator point of view, this option also solves the challenge of requesting UAS flight authorisation for multiple mission legs at the same time. However, a closer look at Figure 4 displays significant challenges to maintain an adequate airspace efficiency, if airspace allocation design 1 is used for delivery missions in combination with flight definition option B.

Furthermore, the compatibility of combinations between airspace allocation designs 1-4 and flight definitions A-C needs to be taken into account. While airspace allocation design 1 requires a complete reservation of airspace along all coordinates between activation of a flight and its termination, option B supports UAS flight authorisation requests with multiple intermediate stops and extended operational time. As a consequence, this exemplary combination (1-B) might result in single flights with potential to block a good portion of the U-space over a long period.

While the U-space Regulation demands that a UAS flight authorisation request shall be submitted to the USSP for each individual flight, with option C, all mission legs are referred to as one flight. Each flight has its own activation and deactivation process, such that a convenient request for complex mission authorisation with several intermediate stops can be facilitated. At the same time, airspace efficiency can be maintained on a high level, independent of the prevailing airspace allocation level.

As a result, UDVeo concludes that flight definition option A is rather restrictive, hardly facilitating convenient and reliable operations for UAS operators. Option B on the other hand provides a user-friendly authorisation process for UAS operators, but does not support a sufficiently high airspace efficiency for low levels regarding airspace allocation technology. Therefore, option C might represent an adequate, temporary solution for flight definition, until higher levels of airspace allocation design can be realised.

4.2. Definition and specification of thresholds and their deviation

The definition and specification of thresholds and the maximum deviations allowed is an elementary way to design a U-space safely and efficiently. Art. 10 (2d) of the U-space Regulation makes it mandatory for USSPs to inform the UAS operator of the permissible thresholds for the deviation from a UAS flight authorisation. These are therefore limits defined by the USSP for a UAS flight, which must be strictly adhered to by the UAS operator for reasons of air traffic safety. Thresholds are mentioned more often in the U-space Regulation, so that further criteria have to be considered when observing and defining deviation thresholds. Art. 6 (6) obliges the UAS operator to comply with the threshold defined by the USSP, only the USSP may update or adjust the threshold within the framework of the U-FAS if necessary. This measure is conceivable, for example, in emergency situations in the U-space. Furthermore, there are additional conditions for the concept of threshold values in Art. 6 (7), which must be observed by the UAS operator. Complementary to Art. 10 (2d), UAS operators must apply for a new UAS flight authorisation if they cannot comply with the deviation thresholds defined for the flight under consideration. Finally, the concept of deviation threshold values is mentioned in Art. 13 (1). The conformance monitoring service must ensure that a warning is sent to all affected UAS operators in the event of a violation of the deviation threshold.

When looking at the legal requirements of the U-space Regulation, it becomes clear that obligations of individual actors are defined by these thresholds and their maximum deviations. However, no details are given as to how these factors for determining thresholds might look. From a technical point of view, therefore, various questions arise which need to be implemented for realisation:

- What can be understood by a deviation threshold?
- Which characteristics or factors can be defined for a deviation threshold?
- How can maximum deviations of threshold be defined in relation to individual criteria?

In order to answer these questions, the procedural flow and the information required to apply for a UAS flight authorisation from a UAS operator in accordance with Annex IV of the U-space Regulation must be considered. While information such as the operating mode or serial number of a UAS does not reveal much potential for defining thresholds, information on the 4D trajectory is different. Here, concrete information is needed for the flight to be conducted. The information basis is basically divided into spatial and temporal information, which can be accompanied by further information such as speed or weight of the UAS. Thresholds for a UAS flight can therefore be an indicator for the maximum deviation from the 4D trajectory. The issue is closely related to the design of buffer zones.

With regard to the spatial definition of threshold, the elaboration of SORA provides a good basis [14]. A spatial definition of maximum deviations of a UAS flight can be illustrated by the following Figure 6:

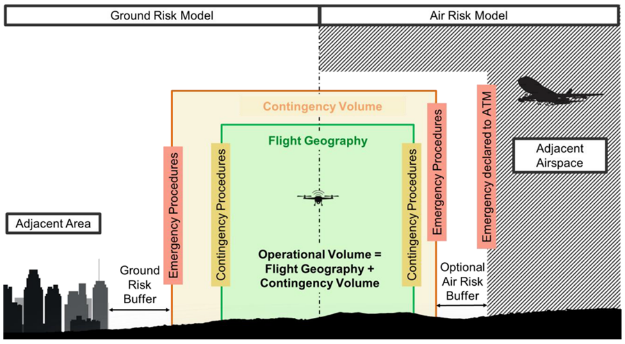

Figure 6: Specific Operations Risk Assesement (SORA) according to [14]

The Flight Geography Zone describes the space in which the UAS can fly freely and represents the 4D trajectory on which the UAS flight authorisation approval is based, including a buffer zone. The Contingency Volume describes the threshold to be defined, i.e. the extended buffer zone defined by the USSP for the UAS flight under consideration, in order to ensure the safety of all actors in the U-space. When determining the Flight Geography Zone and the Contingency Volume, important factors such as the capabilities of the UAS (manoeuvrability, GPS accuracy, ...) must be taken into account.

Especially when taking the proposed evolutionary phases of airspace allocation design for U-spaces (cf. Figure 4) into account, the precise definition and communication of thresholds and acceptable definitions gain importance. With denser use of the airspace in higher evolutionary phases, the spatial and temporal thresholds need to be tighter and the deviation monitoring needs to be stricter to allow for more efficient airspace use while still maintaining the same level of safety. There is a variety of technologies available for UAS manufacturers and integrators such as high precision Global Navigation Satellite System (GNSS) for improved spatial estimation or the rollout of 4G and 5G mobile data services with improved bandwidth and latency for time-synced communication. With the improvement of capabilities of commercially available UAS at the same time, UAS operators are able to meet stricter requirements regarding thresholds and allowed deviations.

In consequence, the fuzziness in thresholds require precise definition to ensure safe operations in the U-space. With evolution of the airspace allocation design and continuous technological innovations, these definitions need to be reviewed continuously. UDVeo has further pointed out that a clear communication of the technical capabilities may allow more capable UAS to operate in more confined airspaces, e.g. during times of intense use, while UAS with inferior technical capabilities are only able to operate with higher thresholds or may be temporarily excluded from U-space participation.

4.3. Handling the activation of UAS flights

If a UAS flight has been authorised by a USSP under its UAS flight authorisation service, the UAS operator must still have its authorisation activated prior to departure. This is stipulated in Art. 6 (5) U-space Regulation. According to Art. 10 (5) U-space Regulation the USSP is responsible for the activation: *"Upon receiving the request for an [...] activation referred to in Article 6 (5), the U-space service providers shall confirm the activation of the UAS flight authorisation without unjustified delay."* The regulation does not specify in more detail. From a USSP's perspective, questions arise when attempting a practical implementation.

First, why do UAS flight authorisations have to be activated by the UAS operator *"when ready to start the flight"* (Art. 5 (5) U-space Regulation) at all? UDVeo is convinced that this information is needed on the one hand, so that a USSP knows the exact start time of a flight. Without activation, a USSP would only know (as part of the UAS flight authorisation request) when the scheduled take-off of a flight is. Indeed, temporal deviation thresholds (cf. 4.2 above) result in flights that may not be launched at a specific time, but within a time corridor. On the other hand, the activation by the USSP provides the UAS operator with the certainty that the USSP has re-approved his flight planning and that there are still no obstacles (cf. 4.4. below) to his flight. Summarized, the activation has an important function for the USSP's internal operations ("Who is in the air?"), and for the safety of each individual flight ("May I take off or are there reasons to the contrary?").

The activation can only achieve these purposes identified if the activation is linked to certain preconditions. Since the prerequisites for activation are not specified in the U-space Regulation, there is a great scope of interpretation here for practical implementation. In our view, the activation should be preceded by a final check (Art. 10 (10) U-space Regulation) of the granted UAS flight authorisation. Thus, the prerequisite for an activation is that the already authorized flight is not opposed by any new dynamic airspace restrictions, limitations or information about manned aircraft traffic. If this is the case, for example because a dynamic airspace reconfiguration has taken place, the USSP must not only reject the activation, but also withdraw or update the UAS flight authorisation according to Art. 10 (10). In contrast, it is not necessary to check whether the flight is effectively ready for take-off. Even though Art. 5 (5) states that UAS operators should only request activation when their flight is ready for take-off, the USSP has no way to verify this circumstance. This is because communication between USSPs and UAS operators is purely digital. In manned aviation, there are also no general specifications that could be used to determine "when ready to start the flight". It is therefore practical, simple and reasonable to let the UAS operator decide when he is "ready to start". Only one limit arises: a flight shall only be activated when the temporal deviation thresholds for the take-off have been entered. Otherwise, UAS operators could launch their flight significantly earlier than their UAS flight authorisation allows them to.

In addition to the information that the UAS operator is "ready to start", two further pieces of information are required from the UAS operator for the efficient operation of U-space services: 1. Knowing the individual UAS flight authorisation number makes it possible to relate the activation request and the UAS flight authorisation that has already been issued. The examination of new obstacles (Art. 10 (10) U-space Regulation, cf. 4.4.) can begin. 2. With the activation request, the name of the pilot in command with the corresponding contact number should also be passed over to the USSP. The UAS flight authorisation request does not require the name of the pilot-in-command to be provided. In many cases, it will not be known who is piloting the UAS until the flight is activated. The information about the pilot-in-command is a major safety benefit. The USSP than has the possibility to reach the pilot directly via the contact number in case of an emergency - and not via the detour of the UAS operator. Especially in initial U-spaces, in which newly developed U-space systems are used that are interdependent, such (analogue) emergency procedures should be considered.

Finally, it is fuzzy how the activation is timed in the UAS flight authorisation service. Once a UAS flight authorisation has been issued by the USSP, only a few hours or weeks may pass before the activation request is received by the USSP. In this respect, the U-space Regulation does not specify a maximum lead time for requesting a UAS flight authorisation. This is not without problems, since the authorisation request that has priority over a conflicting request is the one that was submitted first (Art. 10 (9) U-space Regulation). However, this is a question preceding the activation, which must be answered in a different context. It is then not specifically determined - and this affects the activation process - in which period of time the activation must be applied before take-off. In this respect, "ready to start" can be interpreted in different ways. The same applies to "without unjustified delay". From a technical point of view, however, it does not seem necessary to assign fixed times to these terms. The outer limits are the temporal deviation thresholds. No activation can be requested before the threshold is reached. Once the threshold has passed, no activation can be allowed. Otherwise, there would be conflicts with other authorised UAS flights. This determines the amount of time the UAS operator has to start his flight after he received his activation. The UAS operator must launch before the temporal deviation threshold is exhausted. This leaves only little time for the USSP to check the activation. Accordingly, the activation should be as automated as possible.

Based on the previously outlined understanding of Art. 10 (10) U-space Regulation, we propose the following activation process: The UAS operator applies for activation of an already authorised flight at the USSP, if *he* thinks that his flight is "ready to start". For this purpose, he submits his UAS flight authorisation number as well as the name and contact number of the pilot in command. The USSP will deny the request if, according to the latest information, there are obstacles or if the temporal deviation thresholds of the flight authorisation have not yet begun. Otherwise, the USSP activates the UAS flight authorisation. The prerequisites are checked automatically. The UAS operator then starts his flight within the temporal deviation thresholds.

4.4. Definition and handling of new dynamic airspace constraints

Once a USSP has issued a UAS flight authorisation, he is responsible for keeping it under continuous review. This is also part of the U-FAS. According to Art. 10 (10), the USSP no longer has to check whether there are spatial or temporal overlaps with other UAS flights, but whether "*new dynamic airspace restrictions and limitations*, and *information about manned aircraft traffic"* conflict with already authorised flights. Art. 10 (10) conclusively regulates what the USSP must check after an authorisation has been granted. If the new information conflicts with the execution of an already authorised UAS flight, the USSP is obliged to update the granted UAS flight authorisation according to the circumstances or even to withdraw it completely. However, Art. 10 (10) leaves us with numerous fuzziness. In the following, three central fuzzy sections will be dealt with in more detail. The first two sections concern the scope of the obligation: In which interval do the USSPs *continuously* check issued flight authorisations? And even more important: Which situations fall under "*new dynamic airspace restrictions and limitations"* as well as "*information about manned air traffic"* and give rise to check UAS flight authorisations? Once answers have been found regarding the scope of the check, a look should be taken at the consequences for the affected UAS flights. The USSP has two options: update or withdrawal of the (affected) flight authorisations, "*as may be necessitated by the circumstances*." But it remains open for what reason USSPs should update and for what reason they should withdraw.

To answer the questions on the scope, it needs to be known that USSPs do not generate their own information. Their task specialises in offering the U-space services which include "only" an assessment of authorisations and in forwarding of information towards the UAS operator. The USSPs receive information required for their task from third parties through the Common Information Service (CIS), cf. Art. 5 U-space Regulation. According to this, the Member State and the Air Traffic Service Provider (ATSP), next to the USSPs themselves, shall forward Common Information (CI). New common information triggers the USSP's obligation to review existing UAS flight authorisations – which is already an answer to the first question raise, when does the USSP *continuously* fulfil its duty to review? The duty does not have to be understood as continuous in the literal sense, but on an occasion-related basis.

The second question raised concerns the scope of these triggering information. Let's start with the "*information about manned aircraft"* because it is most specified. First the U-space Regulation specifies its sender as Art. 10 (10) further states "*shared by the air traffic service units."* Secondly, we get an example what kind of information is involved: "*in particular regarding manned aircraft known or believed to be in a state of emergency, including being subjected to unlawful interference*." This means that all conceivable emergency scenarios can be a trigger, regardless of whether they are confirmed as an emergency or could only potentially be one. Thus, even in case of doubt as to whether an emergency exists at all, Art. 10 (10) shall lead to withdrawal or update. The independence of whether the emergency happens on purpose (terrorist attack, suicide attempt) or for reasons unrelated to people (force majeure, defective aircraft) also speaks in favour of a fundamentally broad interpretation.

To define *"new dynamic airspace restrictions and limitations*" on the other hand, is not that simple. Art. 10 (10) does not provide any indications as to who sends out this information as CI, nor any examples. The phrase *"new dynamic airspace restrictions"* is at least found used in a similar way in the U-space Regulation three times. Bringing these three passages together, we can figure out more about the definition. The quite similar term "*dynamic airspace restrictions*" (without "new") is first found in Art. 5 (1f) U-space Regulation. With Art. 5 (1f) firstly we can identify the sender as it states "*by the relevant authorities"*. The third one, recital (13) presents us reasons for so-called "*dynamic U-space (airspace) restrictions".* Recital 13 thus also interprets Art. 5 to concrete relevant authorities. In recital (13) the term "*dynamic U-space airspace restrictions"* is used for airspace restrictions imposed by military or state aircraft operations so that they can carry out their missions safely. State aircraft includes e.g. activities of the police, customs, air rescue, fire brigade and similar activities necessary to maintain general state security and order. Triggering events are: a police drone is being used to search a missing person; a rescue helicopter transports an emergency doctor to an accident; a ground-based event such as a fire or bomb discovery have hazardous effects on UAS flights. In particular, these are all events that can take place in a U-space, but unplanned and known at short notice and therefore require dynamic vehicle to restrict the airspace.

Lastly UDVeo investigated what should be understood by the term "*limitations"*. Rather a limitation, in linguistic terms, defines a change in the own boundaries of the U-space airspace. With this reading, one central piece of information in particular can be subsumed under limitation. We find the link in the Commission Implementing Regulation (EU) 2017/373 [15] to which Art. 5 U-space Regulation refers. Accordingly, the ATSP obliges trough the CIS to discharge the common information that becomes necessary *"in order to accommodate short-term changes in manned traffic demand [..] by adjusting the lateral and vertical limits of the U-space airspace"* [15]. In the end we are dealing with exceptional situations (short-term changes) affected by manned aviation in the U-space airspace here. This leads us to a conclusion, which is not important for Art. 10 (10), but for the entire U-space concept. Common information which are sent out through the ATSP are always triggered by exceptional cases. In reverse the normal state is characterised by the absence of manned air traffic. Preferably, therefore, U-space airspace with low horizontal U-space altitude is in focus, otherwise Art. 10 (10) would show large safety gaps by excluding "regular" manned air traffic from the consideration of Art. 10 (10). In order not to risk any safety gaps as a result, however, the scope of all information should always be understood broadly in case of doubt.

When the USSP starts the review process, he must check whether the new Cleads to the (partial) impossibility of an already authorised flight. For the most part, the technical verification capabilities that are already applied when issuing a UAS flight authorisation can be used here. Spatial and temporal correspondence between the new geographic information and the existing UAS flight authorisations must be checked. If the review shows that one or more flights can no longer be performed because the lateral and vertical limits of the U-space airspace have been limited (e.g. due to manned aviation) or parts of the U-space airspace have been closed (e.g. due to state aviation), the USSP must decide to update or withdraw the UAS flight authorisation. Withdrawal means that the UAS authorisation is no longer valid, partly or entirety. Comparing the alternatives, it becomes clear that a withdrawal entails a much harsher consequence for the UAS operator than a (mere) update of his authorisation. This is because authorisations that have already been granted give UAS operators confidence that they can fly as planned. They plan accordingly. For economic and proportionality reasons, the complete or partial withdrawal must therefore always be preceded by an attempt to update the granted authorisation.

However, in order to update the authorisation in the interest of the UAS operator and thus make a reasonable change, the USSP first needs information on what would be an acceptable new flight plan for the operator. He does not know the specifications of the UAS used and the purpose of the flight only very approximately due to the type of flight specified (cf. Annex IV U-space Regulation). If, for example, the USSP withdraws only a part of the flight route of an authorisation or updates the flight in the form of an alternative route, he does not know whether the flight is still suitable for the UAS operator. For transport missions, only the second option is likely to be appropriate and only as long as the destination (and maybe also arrival time) remains the same. For inspections, a partial flight could be sufficient for the UAS operator or, for example, a postponement of its authorisation. To make this clear: if the USSP wants to make adjustments according to the circumstances of the air situation and the needs of UAS operators affected by the restriction or limitation, this requires an intensive exchange of information between the UAS operator and his USSP. Procedures for this are not prescribed by the U-space Regulation. However, this offers opportunities for USSPs to differentiate themselves from their competitors and provide their customers (UAS operators) with appropriate tools. These adaptation tools and USSP competencies would be economical and efficient but could pose difficulties in technical implementation. The adjustment of flight authorisations should not be problematic within the framework of the flight conditions and the deviaton thresholds set (cf. 4.1. and 4.2. above). That means that a USSP can update a UAS flight authorisation solely within the already authorised operational (spatial and temporal) volume. All other adjustment measures, however, require further communication with all other USSPs that manage UAS flights in the same U-space. We give the following example for a better understanding: flight A and flight B are affected by a dynamic reconfiguration of the airspace in their flight paths according to Art. 10 (10). It would be possible for the operators of both flights to continue their mission by extending (temporally extending or spatially shifting) their operational volume. However, the extension of A's operational volume, as modified by USSP A, would overlap in space and time with the extension of B's operations volume, as modified by USSP B. Without communication between USSP A and USSP B both USSPs update their new flight authorisations with high risk of conflict. The conclusion is: communication between all appropriate USSPs is essential before updating any authorisations.

It would also be necessary to establish rules as to which flight has priority here. The communication of USSPs with regard to Art. 10 (10) is not legally prescribed. This is not the case for "a*rrangements [between USSPs] to resolve conflicting UAS flight authorisation requests*", cf. Art. 10 (6). Arrangements to resolve conflicting UAS flight authorisation updates are missing but would be recommended for efficient use of the U-space airspace. In the example mentioned, flight A or flight B could then take place. If there are no arrangements between the USSPs regarding the update, neither flight A nor flight B can take place or the UAS operators would have to take care of new applications themselves, cf. Art. 6 (7), which, however, are rarely successful, because then the U-FAS starts all over again. The operator(s) were at the bottom of the priority list due to the first come first serve rule, cf. Art. 10 (9). If the UAS operator has already made economic arrangements because of the planned flight, he already has costs. So far, there is no regulatory definition of who has to bear these costs. It is up to the USSP to deal with this in its terms and conditions. As a result, it must be noted that as long as there are no voluntary arrangements between the USSPs to extend the quality of adjustment according to Art. 10 (10), the USSPs have little room for manoeuvre. This shows us an overriding insight into the U-space Regulation: the USSP does not have the role of a tactical traffic manager and cannot contribute to the efficient use of airspace in tactical phase.

5. CONCLUSION AND FUTURE WORK

Once the U-space Regulation enters into force on January 26, 2023, the EU Member States will be able to designate U-space airspaces and set up their digital infrastructure. For this venture to be successful, the scope for interpretation of individual issues arising from the U-space Regulation must be further specified.

For this purpose, UDVeo has developed a legal-technical overall concept for safe and efficient drone traffic management. With the development of practical concepts and solutions for the integration of UAS in urban airspace, essential processes could be elaborated and implemented in the context of a prototypical control center application. The key findings on U-space Regulation have already been published as part of an interim report on February 08, 2022 [16].

In this context, this contribution addresses the process of the UAS flight authorisation service and shows the need for concretization of the technical realisation of this U-space service. For this purpose, a well-founded legal-technical analysis of Art. 10 of the U-space Regulation was carried out in UDVeo, the need for concretization was identified and first concretisations and solutions were shown for the fuzziness mentioned in chapter 3 and 4. The U-FAS is a central service which the USSPs must offer in order to enable the safe and efficient use of the U-space airspace. The technical design of this service can have a considerable influence on the efficiency and functionality of a U-space as well as the strategic planning phase of UAS flights. For this reason, the identified fuzziness in the U-space Regulation need to be addressed and further specified in the national implementation. In addition to the specification and resolution of the fuzziness, there is a need for further research within the U-FAS to realise a safe and efficient UAS flight authorisation and activation process, these include:

Representation of interdependencies between U-space services:
As outlined in previous publications, the U-space services are interdependent in their information requirements [17]. For example, the UAS flight authorisation service requires information from the geo-awareness service for the particular conflict check. Representing these interdependencies is a core task for translating the legal basis of the U-space services into a technical practice. The nature of the data exchanged must also be addressed. While the UAS flight authorisation service is an event-driven process, the provision of relevant information from other U-space services is continuous.

Timing of a UAS flight request:
Depending on when a UAS flight authorisation is requested, there is different underlying information that can be considered during review and processing. Provided the UAS flight authorisation request is submitted to the USSP well in advance of the planned take-off time, this flight may still be affected by dynamic effects between submission and activation.

Decentralized vs. centralized conflict detection and resolution (CD&R):
The location of the conflict management in the U-space has a major impact on the safe and efficient operation of UAS flights. A distinction is made between a centralised and a decentralised approach. The current U-space Regulation requires the respective USSP to check the submitted UAS flight authorisations for conflicts with other flight plans, among others, and thus prescribes a decentralised implementation. However, it may not be possible to take all information into account in this process, so that further work should also investigate the applicability of centralized conflict detection, such as with the single common information service provider (SCISP).

Data provision between the USSPs via SCISP:
In order to ensure safe and efficient operation in a U-space with several USSPs, the SCISP has the central task of passing on information between the individual USSPs. Suitable coordination procedures, which are still to be researched, are required for the individual UAS flight authorisations in order to comply with the first come first served regime stipulated in the U-space Regulation.

UAS flight activation process:
For the activation process, technical solutions need to be developed to identify a dedicated activation time so that a planned flight, in the event of delays, can select the optimal activation time without affecting preceding or subsequent strategically planned flights. This should avoid cascading adjustments in the strategic planning phase of UAS flights. In addition, as part of the activation process, the necessary information that a UAS operator submits to the USSP must be included and specified in the national implementation. In addition to the activation process, technical solutions for a deactivation process must also be worked out.

Despite the far-reaching orientation of UDVeo and other projects, many aspects of the U-space ecosystem remain to be explored. It is evident that further concretisation of the U-space Regulation is indispensable for the national implementation. These will be further advanced with the LUV project (cf. https://luv-projekt.de). The solution proposals presented here must then be comprehensively validated in field tests and adjusted if necessary.

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