Deutscher Luft- und Raumfahrtkongress 2021
DocumentID: 550082

TECHNICAL AND LEGAL BOUNDARY CONDITIONS FOR THE EXTENSION OF THE AIR CARGO LOGISTICS CHAIN BY UAVS INTO THE CITY CENTRE

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Abstract

The share of the retail market transported via air cargo logistics has constantly risen in the past years, especially due to an extension of e-commerce. However, air cargo logistics chains are currently ending at cargo airports and are continued by ground transportation units. Since traffic and environmental pollution are increasing due to the growing number of delivery trucks, this paper proposes an alternative logistics chain from cargo airports to city centres with the help of Unmanned Aircraft Systems (UAS). Concepts for transportation units, distribution centres, and three different autonomous, CO_2-neutral unmanned aerial vehicles (UAVs) that provide links between cargo airports, regional airfields, and city hubs in urban centres are presented. Furthermore, the technical and legal requirements for this scenario are evaluated and insufficiencies in the legal framework are outlined. In addition, the legal boundary conditions are applied to the UAVs and the safety framework of UAS is evaluated, using the Specific Operations Risk Assessment (SORA) approach. Furthermore, the security issues concerning cyber-attacking of autonomous vehicles are discussed. The study provides an overview on the legal and technical feasibility of an extension of air cargo logistics chains to city centres and to provide solution approaches to tackle the existing barriers for UAV assisted delivery services.

Keywords

Delivery UAS, urban airspace, UTM, UAV regulations, EASA, air cargo logistics chain

1. INTRODUCTION AND OBJECTIVES

In the past decade, the relevance of urban cargo transportation has consistently grown. Firstly, due to an increasing percentage of population living in urban areas: In 1950, 51.7 percent of the European population were living in urban areas, while in 2018, it was already 74.5 percent. In 2030, it will be approximately 77.5 percent [1]. Secondly, a recent driver of market needs for urban cargo transportation is the rising market share of e-commerce. In Germany, 18 percent of enterprises' turnovers were gained through e-commerce in 2020. In Ireland it was even 44 percent [2]. The increasing urban cargo transportation with street vehicles leads to increasing traffic and, thus, pollution load, especially in urban regions [3, 4]. The rising amount of delivery trucks on the streets leads to more frequent traffic jams [5, 6]. Air cargo companies profit especially from the rising cross-border e-commerce due to short shipping times [7]. However, air cargo logistics chains are currently only connecting big airports. The gap between airport and the final destination of packages still requires the use of ground transportation units [8]. Simultaneously, Urban Air Mobility (UAM) has gained increased attention [9], enabling the possibility of extending the air cargo logistics chain to the end customer via flying units. The European Union Aviation Safety Agency (EASA) is working consistently on the framework for implementing Unmanned Air Vehicles (UAV) [10] especially for Vertical Take-Off and Landing (VTOL) aircrafts [11–13]. A rising number of drone registrations can already be observed, and the number of produced civil UAVs will approximately rise from around 3.4 Million in 2020 to 6.4 Million in 2029 [14]. In order to reduce road congestion and traffic obstruction, a shift of transportation from street vehicles to air vehicles presents a promising approach. Still, for the aim of scalability of UAM, there are some constraints that need to be overcome for a broad applicability of urban and regional air freight. One major constraint is the availability of ground infrastructure [15]. In Germany, around 86.3 percent of the population is living within a 20 km range to an airfield [16]. Since airports and airfields offer the possibility of relieving road traffic with a corresponding airfreight logistics chain, this approach will be examined in more detail in this paper. The paper is intended as a concept for upscaling of air cargo logistics systems to a broad usage all over Germany and other countries with similar conditions. It gives an overview about the requirements and recommendations for the implementation of UAV systems both on a technical and legal level. Therefore, it serves as a guide for research and industry projects that aim to realize implementation strategies for urban and regional air freight systems.

At first, the theoretical background of the air transportation market is presented and recent trends and their benefits are evaluated. Then, the logistic concept is portrayed, and its technical boundary conditions are

doi: 10.25967/550082

examined. This includes a presentation of the relevant required types of UAVs and distribution points. Lastly, the present study analyses the legal situation of UAV systems in the European Union (EU) and transfers it to the presented model to point out critical insufficiencies of the legal framework. To this end, certification bases and safety frameworks are taken into account.

2. THEORETICAL BACKGROUND

UAVs were introduced to the logistics sector with various concepts regarding their design, mission and requirements. Generally, three different use cases can be identified. Firstly, intercity transport connects airports and airfields within approximately a 250 to 500 km range. For this use case, the most suitable aerial vehicle concept is the fixed-wing configuration [17]. This type of cargo transportation corresponds to small aircrafts that enable fast connections and high payload. An efficient flight is reached through the aerodynamic lift generated by the wings [18]. Respective concepts are e.g. NLR UCA [19], Nuuva Pipistrel V300 [20] and Cessna Sky Courier [21].

Secondly, intra-city transport connects airfields and logistics hubs in the centre or on the outskirts of cities within a radius of approximately 25 to 30 km. Respective aerial vehicles that operate in this urban environment must have the capability to vertically Taking-Off and Landing (VTOL), as runways or other large ground spaces for aircraft operations are unavailable in urban areas. As the intra-city use case is typically characterized by low-medium distances, the Multicopter configuration (with numerous layouts such as quadcopters, hexacopters, coaxial rotors, tandem set, etc.) is the most diffused layout today as it is the most compact, efficient in hover and reliable for the operations in the urban environment [22]. In this use case, heavy-lift vehicles need the capability to transport a payload of approximately 100 to 150 kg. Concepts that can be considered in this context are, for example, DLR Alaady [23], VoloDrone [24], VA-X2 [25], Sabrewing Rhaegal [26] and additional concepts developed by Boeing [22].

The third use case is also intended for intra- or intercity transport, but unlike the case described before, it connects distribution centres directly with one final end customer for urgent deliveries to their front door, parking lot, or similar. A lower payload of about 2.5 to 5 kg is required along with the VTOL configuration. Examples of this type are the Amazon Prime Air [27] and the DHL Paketcopter[1] [28]. Additionally, a fast flight capability is essential for the delivery of time-critical goods or documents. However, a configuration that covers both a VTOL and high-speed capability is underrepresented in existing concepts so far.

In this case, cruise efficiency is necessary in addition to the hover condition benefits. Indeed, hybrid layouts are fixed-wing configurations (for conventional forward flight) with the VTOL capability through fixed rotors (Lift and Cruise) or tilting mechanisms (Tiltwing/Tiltrotor) [22].

Existing research and development is currently only focused on one of the mentioned use cases or is exclusively focused on the application in passenger transportation. The present work is therefore intended to contribute to how all of the three mentioned concepts can be linked together in a meaningful and efficient way for a future air cargo transportation logistics chain.

Following the targets of Flightpath 2050 [29], the latest UAV concepts are limited to configurations with emission-free powertrains such as battery-electric architectures and hydrogen-powered fuel cells [30], as traditional concepts are incompatible with the European Green Deal [31]. Nowadays, the dominant emission-free architecture is the all-electric, battery-powered powertrain [30, 32]. This technology is constantly growing and improving efficiency and reliability along with the strong advantage of silent operation. However, battery capacity and weight are limiting the use of battery-architectures to intra-city use cases only. Hybrid architectures with hydrogen-powered fuel cells are preferable for inter-city transport due to the increased required range [33, 34].

While the market of such new-generation aerial vehicle concepts is accelerating, the regulatory framework might become a bottleneck limiting the market adoption of the advanced air mobility, including urban and regional air mobility [35]. To obtain the authorization to fly, UAVs must be accordingly certified by the aviation authorities. Evidence of fulfilment that a satisfactory state of flight safety is met need to be accurately presented. However, European UAVs regulations are partially finalized and a documented delineation of the unmanned traffic management (UTM) is currently under investigation by SESAR JU for the U-Space [36]. U-Space is a set of services for the implementation of UAVs into a safe and efficient environment, supported by the European Union and EUROCONTROL [37]. Moreover, the UAV-related rules are still lacking sustainable UAM-based aspects such as the pilotless and autonomous flight, beyond visual line of sight (BVLOS) mode, flight over urban or densely populated areas or an emission-free powertrain. Overall, a lack of regulations specifically upon delivery services with high-automated aerial vehicles

[1] The project was discontinued in August 2021, among other reasons, due to the strict guidelines and requirements for unmanned flight operations over populated areas in Germany

regardless of their size, weight, powertrain architectures, operations, etc. still hinders the allocation of such an air cargo logistics chain into an operational and safe context.
Therefore, a further contribution of the present paper is to enable technical progress in research and development on the described concepts by systematically investigating the legal and technical framework conditions and prerequisites. The applied methodology is described in more detail below.

3. METHODOLOGY

A comprehensive research synthesis upon the contemporary European UAV regulations is performed following the approach proposed by STÖCKER ET AL. (2017) [38]. The available material is thoroughly considered including required data and techniques to pursue a safe UAV design and operations evaluation criteria.
The main technical aspects of the UAVs (briefly introduced in section 2 and described in detail in section 4.3) were established in preceding activities. On the one hand, small cargo aircraft's specifications were derived from the hybrid-electric taxi version proposed by SCHUH, ET AL. (2019, 2021) [39, 40] and adapted for freight transportation with hydrogen-powered fuel-cell powertrains. On the other hand, the specifications of the VTOL-UAVs were derived by implementing a conceptual design methodology tailored for VTOL-UAVs as proposed by BABETTO AND STUMPF (2021) [22].
Considering that the majority of UAVs requires the authorities' approval to fly [41], a deep analysis of the standard airworthiness requirements was especially carried out, addressing the UAVs technical and legal aspects (i.e. the compliance with flight safety).
To verify the airworthiness, an exploratory literature review of the European aviation laws is conducted. Thus, European Certification Specifications (CS) for small aircraft (CS-23) and light rotorcraft (CS-27) have been considered (see section 5).
Although these CS deal with manned vehicles, they provide specification standards while leaving flexibility to certify various design concepts. This way, it is possible to verify that the UAVs *technically* conform to their design type with respect to the aviation standard.
On an UAV legal basis, currently available UAV operating guidelines are partial and thus, still inadequate to handle various UAV-peculiar aspects, such as a high-level of autonomy and a *safe* flight in the urban environment, in order to protect uninvolved people and infrastructures. However, this examination permits the identification of design constraints that engineers still need to address to achieve the UAV approval to safely and legally fly. Hence, the authors have iteratively adjusted the UAV design, where possible, to conform to temporary UAV regulations and currently requested levels of safety (see e.g. section 5.1.2). It is envisioned that, by using this approach at the beginning of the UAV design process, extensive adjustments will not be required on the UAV design to be compliant with future guidelines.

4. TECHNICAL BOUNDARY CONDITIONS

The logistics chain presented in this paper involves the use of three emissions-free UAVs to deliver packages from an international cargo airport to the end-customers within the city centre. Diverse configurations, size, and propulsion technologies characterize the three UAVs on account of their different design requirements. In fact, each one of the involved UAVs covers a distinct spatial segment of the proposed air cargo logistics chain. Spatial segments correspond to specific ranges and, thus, transport purposes (e.g. inter-city, intra-city, time-critical delivery, etc.), which entail different design requirements (see section 2).

4.1. Overview of the Logistics Chain

The logistics chain consists of various steps that are presented and described in this section (Figure 1).

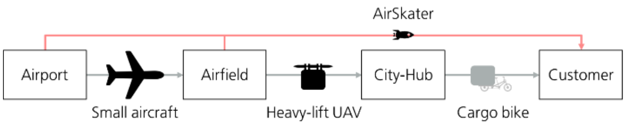

Figure 1: Airfreight logistics chain from the airport to the end customer

The starting point is an international cargo airport, where a cargo aircraft lands and packages are systematically unloaded. The packages are sorted and loaded in standard containers (see section 4.2) with respect to their destination (same-day delivery supply chain, in grey in Figure 1).
The increasing volume of parcels, increasing variety in size and shape of the parcels and peak times that occur every day lead to an intensification of physical work and increased capacity and time pressure during processing [42]. These challenges can be addressed through fully - or partially - automated sorting processes that are already state-of-the-art at parcel logistics centres and at cargo airports. After sorting packages into different containers, these are loaded into a small aircraft that covers the spatial segment from the international airport to the local airfield. At the airfield, the packages are handed over to an all-electric cargo heavy-lift drone, which heads to the appropriate city hubs located in the city-centre, suburbs, or industrial areas within a radius of 25 km from the airfield. The city-hubs can be multi-stores, car parks, rooftops, or other unused areas that are suitable for

the safe operations of a VTOL-UAV and are accessible from the outside. At the city-hub, the container is transferred from the heavy-lift UAV to an electric-bike for the last mile delivery to the end customer. Additionally, a small VTOL-UAV, a so-called AirSkater, is also envisaged for time-critical deliveries of individual packages directly to the final customer such as urgent medical supplies. The high-urgency delivery chain is identified with red colour in Figure 1. For all vehicles except the AirSkater, a container solution is used for efficient handling of packages for different destinations, bundling packages according to their end-site. This solution is described in the following section.

4.2. Container Concept

Tailored standard containers are used to enable efficient and safe transfer of cargo among the different transport vehicles. The packages loading/unloading, sorting and conveying process for containers at airfields and city-hubs are supposed to be highly automated to support a fast and smooth transfer. The containers allow the transportation of a wide variety of goods, a decrease of the handling time, extra protection to the parcels, reduction in losses and spoilage and more security. The Unit Load Device (ULD) M-1 [43] is the basis for the design of the standard container tailored to this logistics chain. Its size occupies around 1.5 m^3, and 90 percent of its internal volume can be used for packages. The container structure has a weight of less than 30 kg to avoid unnecessary transport weight in the small aircraft and in the heavy-lift UAV.

4.3. Air Vehicles

In the following, the technical framework of the different air vehicles is presented based on their mission profiles.

4.3.1 Small Aircraft

A small CO2-neutral aircraft carries out *inter-city* transport by covering the distance between the international cargo airports and regional airfields. It is characterized by a speed of approximately 300 km/h and a high range. The desirable range to address nationwide use is 500 km to perform the roundtrip between the international airports in Germany and any regional airfield. A hydrogen-powered fuel-cell powertrain has emerged as a potential solution for a CO_2-neutral operation of the aircraft [33, 34].
Nowadays, a roundtrip of 500 km is still challenging for hydrogen-powered fuel-cell powertrains. Firstly, liquid hydrogen has a comparably low volumetric energy density (8.64 MJ/l), so up to five times bigger fuel tanks are required in comparison to jet fuel [44]. Furthermore, liquid hydrogen tanks are subjected to strict safety requirements due to boil-off and leakage risks [45]. An initial solution for the nationwide applicability states in assuming refuelling processes at the stopover airfields, although hydrogen storage infrastructures are still not developed at a proper level yet. The aircraft is designed for short take-off and landing (STOL) capability with a target runway length fewer than 600 meters. With very few exceptions, all German airports and airfields provide runways that permit STOL operations [16, 46].
The volume of the cargo bay of the small aircraft is approximately 5 m^3. Thus, based on the available volume, the small aircraft has a payload capacity of three standard containers along with the possibility to place extra items in the vacant space of the cargo bay. The payload requirement is 500 kg while still reaching a maximum take-off mass (MTOM) of less than 2,000 kg [47].

4.3.2 Heavy-Lift Cargo UAV

A heavy-lift UAV transfers individual containers from the regional airfield to the city-hubs (*intra-city* transport). It is characterized by a low to medium range, low speed (approx. 90km/h), and medium payload capacity. The VTOL capability along with a compact size is necessary to operate in the urban environment, as no runways are available.
The required range to allow for the connection between an airfield and city-hubs is assumed to be 25 km plus reserves as regional airports or local airfields in Germany are located usually within a 15 to 20 km of a radius of a medium-sized city (number of inhabitants greater than 250,000) [48].
A multicopter layout is selected for the heavy-lift UAV, as it is the most energy-efficient configuration for this range and payload [22]. The multicopter is also more suitable for operations in the urban environment as it is characterized by a high thrust-to-volume ratio and thus, a more compact size compared to a fixed-wing configuration with similar capabilities. Moreover, a configuration with six coaxial rotors assures abundant redundancies that are necessary to operate safely in residential areas. This all-electric vehicle is powered via a Lithium Polymer (Li-Po) battery that can be charged with a 22 kW power supply[2] at airfields or the city-hubs[3]. The payload requirement is 100 kg and a MTOM below 300 kg is reached [25]. The cargo bay of the heavy-lift UAV can carry a fully-loaded single container (section 4.2).

[2] The 22 kW power supply is already available in public charging stations for e-cars, e-scooters, e-vans, etc.
[3] The assumption is to charge the heavy-lift UAV at the airfield only. However, key city-hubs, for instance, the amplest one, are equipped with a charging station to tackle any emergency. The city-hubs must provide a charging station when the city is located at a distance higher than 15 km from the regional airport/airfield.

4.3.3 AirSkater

The so-called AirSkater deals with time-critical delivery of cargo directly to the customer's site (*inter*- and *intra-city transport*). It is characterized by high speed, medium range, but low payload capability. The VTOL capability is essential to carry the parcel directly to the end customer located in a radius of 50 km from any starting point (either the international cargo airport or the regional airfield). This avoids waiting times caused by stopovers, loading, dispatching, etc.
To meet the requirements of high range and high speed, "Lift and Cruise" is the configuration chosen for the AirSkater[4]. It can reach a speed of 130 km/h to guarantee the time benefits in comparison to conventional ground-based transports [49] and thus, it can reach any destination within its operational range in less than 2 hours.
Table 1 provides an overview of the technical characteristics of all three presented UAVs.

Table 1: UAVs characteristics

	Small Aircraft	**heavy-lift UAV**	**AirSkater**
Payload	*500 kg*	*100 kg*	*2.5 kg*
MTOM	*< 2000 kg*	*< 300 kg*	*< 25 kg*
Range	*500 km*	*25 km*	*100 km*
Speed	*300 km/h*	*90 km/h*	*130 km/h*
Max dimension	*10 m (wingspan)*	*3 m (length)*	*2.5 m (wingspan)*
Powertrain	*Hydrogen-powered fuel cell electric*	*Battery electric*	*Battery electric*
TOL Strategy	*STOL*	*VTOL*	*VTOL*

4.4. Future Aerial Logistics Chain

An advanced logistics chain, including several well-synchronized logistics segments and a high level of digitalization, is essential to make the operation of the presented airfreight logistics concept possible.

4.4.1 Segmentation

The proposed logistics chain is composed of various air transportation segments and distribution centres. Each air transportation segment represents the flight path and the designated vehicle covering it (see section 4.3). These segments operate faster than comparable ground-based segments because they are not impeded by road traffic. UAVs are more efficient means of transportation in terms of faster delivery time per the distance to be covered [49, 50].

Any distribution centre along the transportation segments must provide ground surfaces (i.e. vertipads) to permit the VTOL capability and infrastructures to refuel and/or charge the vehicles. By using automated and autonomous equipment, the process becomes smoother and less expensive, and human error is kept to a minimum. Since containers for urban and regional air freight are already loaded with packages at the cargo airport according to the final destinations, the highest level of automation (targeting the full automation) is required there. Assuming that each vehicle is fully charged and ready to fly, the sorting process at the airport and the subsequent loading of the small aircraft (section 4.1) takes approximately one hour. After approximately 20 minutes to 2 hours of flight, the transfer of the single containers from the small aircraft to the heavy-lift UAV is executed. The reloading at the airfield approximately lasts 20 minutes with margins. After another approx. 10 to 20 minutes of flight, a similar duration is expected for the reloading at the city-hub, where the single container is directly moved upon an electrical cargo bike. The last-mile delivery is covered by e-bikes, which are part of the logistics chain as a ground transportation segment[5] and a delivery time of one hour can be assumed. This way an overall delivery time of three to six hours from the airport to the customer can be expected (see Figure 2).

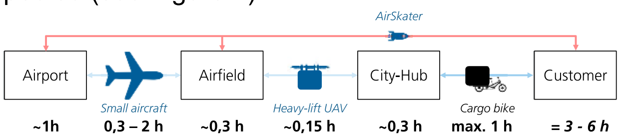

Figure 2: Delivery and reloading times along the logistics chain

4.4.2 Digitalization

The presented concept aims to provide a competitive and fast delivery service targeting a same-day delivery and an effective, customer-based and high-quality business. Therefore, the whole logistics chain must evolve towards a digital system. On the one hand, UAVs are pushing forward the level of autonomy. On the other hand, the use of human-assisted and highly automated machines on-ground also drives digitalisation. Authorized autonomous machines can take care of the loading/unloading, sorting and moving of packages and/or the containers to the respective vehicle. Big Data, analytics and cloud computing, combined with digital systems (tailored apps and QR codes), are key elements that enable the realization of a smart and highly efficient logistics chain [51]. The result is a logistics chain "network" that is monitored in real-time by a centralized node, the Ground Control

[4] The Lift & Cruise is a hybrid layout between an aircraft and a rotorcraft, where a fixed propeller is installed to provide thrust in forward flight and rotors make the VTOL possible.

[5] The ground transportation segment is not the focus of this work.

Station (GCS). The GCS works via a data-driven decision-making process. This way, it guarantees a responsive, agile, and transparent workflow segment by segment [52]. The digital structure empowers exchange and communication among the logistics chain segments, facilitates access to relevant information for operators and vehicles, and enhances a communication with customers by sharing the status of operations (tracing the containers/packages, planning the deliveries, offering customer support, etc.). Data-driven analytics also strengthens the system protection from security and cyber-security attacks. By identifying anomalies from usual processes, outlined from the comparison of current with past collected data (see section 6.2), a digital logistics chain network is safer against threats [53].

In the following, a corresponding legal framework for the presented air logistics chain is discussed in terms of physical characteristics of UAVs, flight altitude, autonomous flight control, and means of intercommunication.

5. LEGAL BOUNDARY CONDITIONS

In this work, an airworthiness analysis is carried out in order to verify, as far as consistent, that the UAV design meets European Certification Standards CS-23 [54] (for Normal, Utility, Acrobatic, and Commuter) and CS-27 [55] (for Small Rotorcraft) along with the Means of Compliance for VTOL (MOC-VTOL) [12].
Although the CS-23 and the CS-27 are not proportionate to UAVs [41], they are appropriately used as guidelines to assure that the UAVs type design is compliant with its technical certification.
The current available UAV regulatory is described in EASA 945/947 [41] and the Special Condition (SC) for Light Unmanned Aircraft Systems (UAS) [56]. These EASA directives comprise limitations upon flight altitude, weight, and overall size of the UAVs along with operational restrictions concerning the autonomous flight over populated areas and the flight in BVLOS mode. The UAV-framework is divided into the three categories, “Open”, “Specific” and “Certified” respectively, based on the UAV performance and operational scenario [41]. The “Open” category does not comply with the usability of the presented UAVs as the attention is on small UAVs (max. 25 kg) for personal use and flying in VLOS of a remote pilot. The “Specific” category generically addresses UAVs heavier than 25 kg. Since the weight upper limit is not expressed, it is challenging to accurately evaluate the airworthiness and guide the integration into airspace in a safe manner [41]. For this reason, UAVs within the “Specific” category are further classified based on their level of risk. This level of risk is preliminarily rated as *Low*, *Medium* or *High*. EASA and the Joint Authorities for Rulemaking of Unmanned Systems (JARUS) propose a predefined risk assessment approach to derive the level of risk within the “Specific” category. This qualitative approach, so-called Specific Operation Risk Assessment (SORA) [41], and its application to this specific case are presented in section 6.1. In the SORA (Art. 11 [41]) approach it is determined whether the UAV and the related operational scenario shows an acceptable level of safety[6].
The establishment of a preliminary risk level of a UAV is a requirement in the upcoming UAV-regulatory. For instance, EASA has published the SC for Light UAS [56] as the first certification basis proposal for UAVs. Here, the applicability is already limited to UAVs that exhibit a *Medium* risk level.
The BVLOS mode is partially taken into account in the “Specific” category guidelines (including SORA) (section 6) [41], whereas fully autonomous and pilotless vehicles[7] are still under investigation and thus, are not legally formalized yet[8].
Currently, the “Specific” category and the SC for Light UAS [56] are the only available documents sufficiently detailed to delineate further safety objectives and therefore, they are selected temporarily as a reference to carry out this work.

5.1. Certification bases

This section deals with the analysis of the technical aspects that address the UAV design and may affect the airworthiness.
The certification basis for the small aircraft is established on the CS-23 [54], while the certification basis for the heavy-lift UAV and the AirSkater is prescribed on the CS-27 [55] and the MOC-VTOL [56]. All UAVs must fulfil the CS in all its parts such as configuration, performance, materials, fabrication, equipment, etc. The UAVs directives are more restrictive than CSs, as CSs address vehicles already able to fly in a regulated Air Traffic Management (ATM). For this reason, the compliance with the CSs and the MOC is assumed already accomplished and is not further discussed here [41]. UAV-based aspects such as remote control, high-level of autonomy, BVLOS mode and flight in urban environment are still evolving concepts if they are applied to larger UAVs and in a broad scale. Technical and operational limitations to these aspects are derived from the examination of the

[6] Any UAV operator *must* present the risk assessment to the aviation authorities according to the European UAV regulatory. The aviation authorities verify the submitted risk assessment and determine the accordance with flight safety. If the safety status is satisfactory, the UAV receives operational authorization.

[7] A pilot might assist the GCS and control many UAVs at the same time throughout the initial rolling-out phase.
[8] The delivery services via UAVs are assumed part of the “Certified” category [10]; however, any further detail about the “Certified” category is still unpublished at the time of this manuscript.

guidelines corresponding to the “Specific” category. A preliminary Concept of Operations (ConOps) analysis to delineate the operational framework is performed [41]. The result is summarized in Table 2 together with top-level specifications of UAVs.

5.1.1 Size and Weight

Currently, the UAV main dimensions (height, width, length) are restricted to 3 m, with the exception of military drones and individual cases [41]. Moreover, although no explicit upper limit on the MTOM is outlined within the “Specific” category, the limit on the MTOM for this study is set to 600 kg as delineated in the EASA publication “Special Condition for Light Unmanned Aircraft Systems - Medium Risk” [56]. From a size perspective, this concludes that the heavy-lift UAV and the AirSkater meet this requirement, whereas the small aircraft might be more critical due to its greater MTOM and larger size. It is worth noting that so far, the proposed small aircraft cannot be operative, but as soon as policies for an Unmanned Traffic Management (UTM/U-Space) are consolidated, a safe operation can be realistic.

5.1.2 Flight Altitude

UAVs will share airspace with manned aircraft, which requires the establishment of a UTM. An appropriate integration of potential routes of UAVs into the manned airspace is under investigation.
The authors have undertaken a study to allocate the flight of the UAVs to pose no further risk on the ground and air safety. The minimum flight altitude for private aircraft is 500 ft (~152.4 m) over rural areas and 1,000 ft (~ 304.8 m) over cities [41, 57]. Current UAVs directives limit the UAV flight altitude to max. 120 m from the ground for small UAVs remotely controlled by a private pilot and always in VLOS (“Open” category [58]). Besides, the EASA Implementing Rules 2019/945-947 state that UAVs within the “Specific” category must not interfere with commercial aviation or smaller UAVs for personal use [41]. Hence, the 120 m is considered as the *minimum lower* limit and the 300 m as the *maximum upper* limit. Within this flight corridor, a flight altitude of 150 m is selected for the heavy-lift UAV and the AirSkater to maintain an additional 30 m of distance downwards from any highest obstacle and sufficient buffer margin upwards from any manned aircraft. The small aircraft is expected to fly at 3000 m according to its size and weight analogous to a conventional manned small aircraft.
The particular attention dedicated to the analysis of the size and the flight altitude arises from the Regulations and the SORA [41]. The MTOM and the flight altitude are necessary to calculate the kinetic energy generated by the vehicle in case of failure and thus, fall from the cruise altitude via the evaluation of the terminal velocity. The assessment of the potential risk on the ground is derived from the calculation of the expected kinetic energy (see section 6.1.1).

5.1.3 Flight BVLOS mode

For a realistic and economic implementation of delivery service within cities, a *remote pilot cannot* control the UAVs from the ground due to the latency and cost of human labour [59]. Furthermore, a high level of autonomy and automation cannot be accomplished with a remote pilot. For this reason, control management via autonomous Ground Control Stations (GCSs) in substitution of remote pilots is envisaged in a future application.
Currently, the maximum allowable range to fly in BVLOS mode[9] is limited to 1 to 2 km for UAVs [41]. This is insufficient to meet the requests of the UAVs to perform their missions, since BVLOS mode shall be permitted for a range at least equal to the distance

Table 2: UAV characteristics

	AirSkater	Heavy-lift UAV	Small A/C
Airspace	Class G	Class G	Class G
Qualitative likelihood to encounter manned aircraft	Low traffic at the airfield (VTOL), dedicated platform, Medium/High traffic at CGN (VTOL), dedicated platform	Low traffic at the airfield during VTOL, dedicated platform	Low traffic at the airfield (STOL), need of runway, High traffic at CGN (STOL), partially-dedicated platform
VLOS/BVLOS	BVLOS	BVLOS	BVLOS
Operational environment (straight flight point to point)	20-30% cities 80-70% suburbs, towns	20% cities 80% suburbs, towns	10% cities 90% suburbs
Main Dimension	Max. 3 m	Max. 3 m	Max. 12 m
MTOM	25 kg	265 kg	1,650 kg
Kinetic Energy	42 kJ	480 kJ	>>2000 kJ

[9] It is worth noticing that BVLOS is still referred to as a remote pilot on the ground.

between regional airfields and their closest international cargo airport. To *preliminary* tackle this barrier, the authors propose to allocate the main GCS as a "centralized headquarter" of the whole logistics chain and various supporting and local GCSs along the route. This way, coverage with at least one GCS per 10 km^2 should be guaranteed. GCSs (headquarter and local entities) should be linked through the terrestrial network to exchange information with each other. This strategy is accepted as sufficiently safe and reliable, as it facilitates the real-time monitoring of the whole logistics chain. Furthermore, a consolidated rulemaking of an autonomous and fully automated operating scenario, which is the assumption behind the automated/autonomous GCSs, is still the key challenge of the upcoming five years [60].

5.1.4 Preliminary communication allocation

A robust communication system is essential to reach the desired level of autonomy and guarantee a sufficient degree of safety. The only way to communicate successfully within the UTM is by merging heterogeneous technologies to create a stable and secure communication network [61]. Any link must be sufficiently reliable to guarantee that neither failures nor loss of communication affects the control of UAVs. In addition, advanced algorithms assist the UAVs as an extra-safe control approach in the remote case of e.g. complete loss of any communications and/or GPS navigation.

The GCS communicates with the UAVs for control and telemetry, e.g. via conventional radio-link (900 MHz). GPS navigation, weather information and autonomous flight in BVLOS can be afforded via the satellite link. In addition, GCS is assumed synchronized in real-time with the ATC and the UTM/U-Space Service Provider/Conformance Monitoring Service for geo-awareness, geo-caging, and tracking. This guarantees compliance with the mission authorised by the authorities such as the local municipality or third parties [41]. The UAVs are connected in real-time for Detection and Avoidance (DAA) through the ADS-B VHF radio link.

The extension of the communication in the UTM to the cellular network such as using LTE or WiFi frequency can extend the coverage range as each UAV can work as an additional node/access network point. These various communication technologies correspond to different devices, radio frequencies, ranges, data flows, etc. Given that, the reliance on the cellular network adds an extra redundancy in terms of communication technologies in comparison to the aircraft field [62, 63].

In this chapter, the UAV certification bases and the condition of the legal framework were presented. Insufficiencies of the regulations for the extension of the usage of UAVs for commercial use as the restrictions of size and autonomy of the drones were pointed out. Regarding these regulations, in the upcoming section, the safety risk of the presented UAVs is assessed and an applicable safety framework is proposed.

6. SAFETY FRAMEWORK

In this section, the technical aspects introduced in section 4 and section 5 are discussed by applying the SORA approach to evaluate the risk level of each UAV. This risk assessment concerns the UAV operating area to derive the risk upon people on the ground and mid-air collision. By specifying the barriers against the use of UAVs, mitigation measures can be put in place to minimize the arising risk and ensure safe operating scenarios.

6.1. SORA Approach

The qualitative Specific Operations Risk Assessment (SORA) [41] approach aims at the allocation of a risk level to each UAV and the related operations. The technical aspects presented in section 4 (see Table 1) are the input data for the SORA to evaluate an *initial* risk level.

The *final* risk level is derived from the initial risk level and is adjusted over mitigation measures (see Table 3).The SORA approach formally starts with the Concept of Operations (ConOps). In the ConOps, the operation framework like operation contents, safety culture and needed communication with navigation service providers is described.

Although the ConOps description should be as detailed as possible[10], the considerations in Table 2 are sufficient to carry out the main steps of SORA in this work.

The so-called Ground Risk Class (GRC) and the Air Risk Class (ARC) can be determined through these considerations. The GRC is the level of dangerous consequences that a UAV and the related operation, merged in the Unmanned Aircraft System (UAS), might cause to uninvolved people and infrastructures on the ground in case of failure. The ARC is the level of risk that might affect other flying (manned) systems.

[10] This risk assessment together with the ConOps is ideally an iterative process; for this reason, at each iteration of the SORA, additional details are provided for the ConOps, culminating in an accurate description of the planned operations.

6.1.1 GRC Calculation

The GRC can be extrapolated from the predefined Table 4 by matching the size/kinetic energy (Table 4, columns) with the operation type (Table 4, rows) [41]. These results are deemed conservative but are accepted as *initial* GRC values:

- AirSkater: *GRC = 6*. The expected kinetic energy exceeds the limit. This deviation is considered acceptable, as a major class is excessively conservative for the AirSkater;
- Heavy-lift UAV: *GRC = 8.* The high kinetic energy drives the selection of a medium-high class;
- Small aircraft: *GRC = 10*.

These *initial* values can be reduced up to four points through mitigation considerations (M) (Table 3). These considerations involve the decrease of the number of people at risk (M1), the reduction of the energy absorbed by people in case of impact (M2) and a comprehensive definition of an Emergency Response Plan (ERP) and/or the installation of a Flight Terminator System (FTS) (M3) [41].
The subtractable points are reported in Table 3.
It is worth noticing that by optimizing the path planning in a pre-flight process, the share of flight over sparsely populated areas can be reduced. Such consideration is assumed as a mitigation measure of type M1 (Table 3).

Table 3 Mitigation criteria.

	Robustness		
Mitigation for ground risk	**Low/ None**	**Medium**	**High**
M1- Strategic mitigations for ground risk	0: None, -1: Low	-2	-4
M2- Effects on ground impact are reduced	0	-1	-2
M3- (ERP) is in place, operator validated and effective	1	0	-1

The appropriable mitigation measures selected for the small aircraft are summarized here:
M1: *Medium* robustness derived from the limited existence of areas with low population density around its flight position for an emergency landing,
M2: *Low* robustness because of the lack of appropriate devices and operating modes to reduce the impact energy on the ground (e.g. parachute and/or autorotation state),
M3: *High* robustness to assure the highest level of safety, as the ERP is strictly requested by all the UTM/U-Space providers and it ensures a strong benefit in receiving a successful authorization to fly.
Thus, a value of "-3" points is assessed. An appropriate compromise is a final GRC equal to 7.
A similar logic is applied to the heavy-lift UAV and the Airskater. By strategically selecting the locations of city-hubs in industrial rather than in residential areas in such a way that the city centre is still easily reachable for the last-mile segment, the population density of the area is assumed lower. Figure 3 shows the potential locations of city hubs using the city of Aachen as an example.

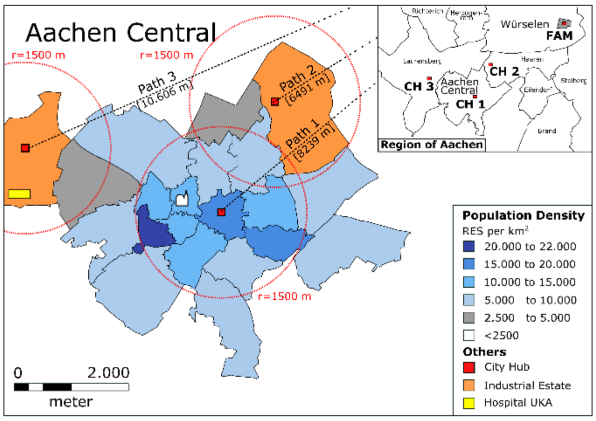

Figure 3: City-hubs location in Aachen.

Table 4: GRC reference table. [41]

	Intrinsic UAS ground risk class			
Max UAS characteristics dimension	1 m/ approx. 3 ft	3 m/ approx. 10 ft	8 m/ approx. 25 ft	>8m / approx. 25 ft.
Typical kinetic energy expected	< 700 J (approx. 529 ft lb)	< 34 kJ (approx. 25,000 ft lb)	< 1804 kJ (approx. 80,0000 ft lb)	> 1804 kJ (approx. 800,000 ft lb)
Operational Scenarios				
VLOS/BVLOS over controlled ground area	1	2	3	4
VLOS over sparsely populated area	2	3	4	5
BVLOS over sparsely populated area	3	4	5	6
VLOS over populated area	4	5	6	8
BVLOS over populated area	5	6	8	10
VLOS over assembly of people	7			
BVLOS over an assembly of people	8			

M1 with Low robustness might be initially selected for the heavy-lift UAV in the best-case scenario (city-hub *CH2*), but M1 equivalent to “None” is considered more adequate to include all the potential scenarios.
M2 with Medium robustness is temporally considered. The impact energy on the ground in crashes or uncontrollable landings can be reduced, as the heavy-lift UAV is a high-reliable system (section 4.3.2) and is able to identify emergency landing sites in real-time (i.e. industry rooftops, gardens or car parks). M3 with High robustness is chosen in line with the small aircraft. The final GRC for the heavy-lift UAV is 6.
Although the AirSkater is small and light, it operates in the city-centre to directly reach the end customer. Because of this, M1 has no impact on the GRC. Other emergency procedures in line with M2 (e.g. autorotation) might be considered with Low Robustness, which implies no effects on the reduction of the GRC. M3 with High robustness leads to a 1 point-reduction of the GRC. However, a conservative final GRC equivalent to 6 for the AirSkater is selected because of its operations particularly close to uninvolved people such as landing in public parking spaces, on balconies, or gardens and parks.

6.1.2 ARC Calculation

The ARC is defined as the chance of encountering manned aircraft throughout the flight. It concerns the flight altitude, the airspace class (controlled or uncontrolled), the operation type (e.g. near airports/heliports, within segregated areas, etc.), the environment (rural or urban), the number of aircraft assumed flying in the same airspace, the rate of proximity to manned aircraft, etc. [9]. The ARC classification is divided into four main qualitative categories: ARC-a, ARC-b, ARC-c and ARC-d. ARC-a assumes operation in atypical areas - none or low chance of encountering manned aircraft - while ARC-d implies that unmanned vehicles fly in Class B, C or D and thus, the encountering chance is high [9]. ARC-b and ARC-c both indicate a medium chance of encountering manned aircraft within operations in rural areas (ARC-b) and operations in urban areas (ARC-c) [9]. All presented UAVs fly over *populated* areas[11]. This leads to a conservative *initial* ARC-d.
The concession to fly is currently quite strict and limited to UAVs in the “Open” category and no concrete UTM-based directive is available so far (see section 5). Thus, the UAVs are preliminarily allocated in the uncontrolled airspace, Class G, as their operations are still improperly classified because of insufficient information. This allocation within Class G minimizes the likelihood to encounter manned vehicles throughout the flight since manned aircraft operates within the ATC.

[11] A populated area is currently defined as a residential, recreational and commercial area with a population density higher than 150 residents/km^2.

6.1.3 Specific Assurance and Integrity Level Calculation

The GRC and the ARC (rows and columns in Table 5) are necessary to evaluate the Specific Assurance and Integrity Level (SAIL), which determines the risk level.

Table 5: SAIL Evaluation [41]

SAIL Determination

	Residual ARC			
Final GRC	a	b	c	d
≤ 2	I	II	IV	VI
3	II	II	IV	VI
4	III	III	IV	VI
5	IV	IV	IV	VI
6	V	V	V	VI
7	VI	VI	VI	VI
>7	Category C operation			

SAIL I and II indicate a Low-risk level, SAIL III and IV are a Medium-risk level and SAIL V and VI result in a High-risk level [5, 41].
In this study, the small aircraft is labelled with SAIL VI, whereas the heavy-lift UAV and the AirSkater with SAIL V. This implies that all the vehicles are identified with *High* risk. This is mostly due to the BVLOS mode and the required high level of autonomy, the flight over populated areas and in the urban environment, the risk that they can cause to people on the ground and other aerial vehicles while flying.
Mitigation measures are also discussed in sections 6.1.1 and 6.1.2 to diminish this high-risk level and to guarantee operation as safe as possible in compliance with the aviation law. However, the UAVs cannot still get the approval to fly because no finalized UTM directive suits them.
For this reason, the delineation of the legal framework for the presented concept is not completed and it progresses together with the EASA publishing further documents.

6.2. Cyber-security framework

The autonomous and automated flight in the urban environment and over populated areas is the main obstacle to the consolidation of the UTM. The increase in autonomy and automation is accompanied by a massive use of Artificial Intelligence/Machine Learning (AI/ML) algorithms [53]. On the one hand, the assistance of advanced algorithms is necessary to cope with the expected large number of UAVs operating in the U-Space. On the other hand, an extensive amount of data has to be handled in real-time by the Flight and Mission Management Computer.

These data come from *(i)* the on-board sensors and instruments (such as gyroscopes, accelerometers, various cameras, Lidars, etc.), *(ii)* the wireless communication intra-vehicles, with the GCS/network and satellites, and *(iii)* the database generated by previous flights. They must be properly guarded in sensing/transferring and at rest to avoid any security flaw or cyber-assault. Encryption and cryptography are becoming obsolete protocols. The promising solution to ensure the IT-security of the systems is via advanced AI/ML algorithms[12] only [53].

However, this arises in turns weaknesses consenting hacker attacks. Vulnerabilities lie behind the massive application of AI as the hackers improve their capabilities of circumventing conventional attack-detection models because of the rule-based implemented algorithms[13] [53]. Hackers can thus hijack the UAVs and jam/spoof the communication of the UAVs with third parties e.g. the GPS signal or the radio-link with the GCS [62]. This leads to access to sensitive data, manipulation and information theft, modifications of the UAV routes and, in the worst case, malfunctions and accidents as crash/landing on-demand. This conveys privacy and liability issues. The threat of cyber-attacks is even higher for sensitive targets as this digitalised logistics chain concept (section 4.4). For this reason, the development of AI countermeasures rather than the conventional rule-based approach for detection must be preferred in order to protect the logistics chain. Data-driven[14] and Model-driven[15] approaches are valuable candidates. These approaches usually can be applied over short time intervals and might let only collateral damages occur [62]. These approaches support the detection of anomalies (comparing actual data with what is expected to be by seeking correlations and/or unusual evolutions) and autonomously provide the patch for threats. Thus, the advantage of AI-based countermeasures elaborated with Data- or Model-driven approaches is that they can prevent any vulnerability rather than detecting already-occurred attacks as traditional systems do, since this would be already detrimental.

This literature review on cyber-security calls for the adoption of the presented advanced models to assure the security of the proposed logistics concept. Future dedicated works will involve the study of these threats by modelling and simulating them more accurately.

7. CONCLUSION AND OUTLOOK

This work presents an overview of the UAV current technical and regulatory requirements along with the analysis and discussion of deficiencies that still affect the UAV rulemaking domain. The analysis of the described logistics chain as a case study drives the identification of today's main barriers against the adoption of UAVs for logistics. On a technical basis, the majority of the UAVs regardless of configuration, size, weight, and propulsion-plant can be smoothly certified according to their type design. However, from a legal perspective UAVs for assisting delivery service purposes cannot fly nowadays. The identified key operational limitation is the lack of regulations for UAV-peculiar aspects such as the high level of autonomy and the flight over an urban environment. These operations are still perceived as high-risk concerns to people and to third parties as well as to other aircraft. Therefore, upcoming work should investigate mitigations to minimize the air and ground harms risk. Potential approaches could be a high-reliable and advanced safety-based aircraft design that allows for UAV operations in coexistence with manned air traffic through the aid of AI/ML algorithms. Furthermore, future research should investigate, based on a life cycle assessment, to what extent the presented airfreight logistics chain contributes to CO2 savings compared to road-based parcel logistics. Finally, the development of a market entry strategy and an economically viable operating model for the presented concept could be worked on.

8. ACKNOWLEDGEMENTS

The presented study has been financed by the project Urban and Regional Air Freight (URAF), funded by the European Regional Development Fund (EFRE-0801696).

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[13] The rule-based approach is already used in aviation.

[14] Systems trained by a data-driven approach can make a decision and choose what to do based on a large amount of previously collected data from simulations/tests.

[15] Model-driven approaches consist in enabling the system to derive decisions from the physical modeling of the system.

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