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Potential of United States and European Regional Air Cargo Operations for Uncrewed Aircraft Systems

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***Abstract*— Regional air cargo is a promising initial use case for Uncrewed Aircraft Systems (UAS) to address scalability challenges such as pilot shortage. This paper investigates current air cargo flight movements to assess the potential of using UAS for regional air cargo operations in the United States (US) and in Europe. Air cargo data from 2021 were analyzed to provide a baseline of where and how these operations occur today and hence for how the introduction of UAS may evolve and impact the airspace in the two regions. For example, the US operates significantly more air cargo flight movements than Europe, both in general and in regional markets. Cargo flight movements in the US tended to be shorter and conducted by smaller aircraft than those in Europe, which may provide an environment in the former that is more ready for one-to-one replacement of regional air cargo flight movements by cargo UAS. With the premise that regional cargo UAS will initially operate at smaller, under-utilized airports, many US states, such as Alaska and California, appear to be well-suited for this type of operation due to the prevalence of these small, under-utilized airports. Only a few European countries, notably Germany, have a significant number of small commercial airports.**

Keywords-Uncrewed aircraft systems; regional air mobility; regional aircraft; air cargo; comparative analysis.

I. INTRODUCTION

Highly automated flight operations without a pilot on board, termed Uncrewed Aircraft System (UAS), could have a substantial impact on current Air Traffic Management (ATM) systems due to their projected higher number and density of operations compared to conventional air traffic [1]. UAS are expected to be part of newly developing aviation markets for both passenger and cargo transport, which NASA refers to as Advanced Air Mobility (AAM) [2]. Within AAM, Urban Air Mobility (UAM) is envisioned to mainly operate with small, electric vertical takeoff and landing (eVTOL) aircraft around metropolitan areas using new infrastructure, such as vertiports [3]. Regional Air Mobility (RAM), another subset of AAM, covers flight missions under 1,000 kilometers using primarily fixed-wing aircraft and existing infrastructure, such as runways [4].

Air cargo operations, especially those in the RAM realm, typically do not have passengers on board and thus present a promising initial use case for the development of advanced aircraft and supporting ground automation leading to the use of UAS for regional air cargo, as the presence of passengers on board introduce additional certification requirements [5]. Although regional air cargo may be less known, it is a crucial part of the overall air cargo system. Regional cargo aircraft, which typically fly routes less than 1,000 kilometers in length, are equipped with piston or turboprop engines, can carry payloads of less than 9 tonnes (<10 tons), and have a maximum take-off weight (MTOW) of less than 25 tonnes (<27.56 tons) – example aircraft include the Cessna 208 Caravan, the ATR 42, and ATR 72 [5, 6]. Current regional air cargo fleets are aging out over the next decade, necessitating technological retrofit of existing fleets or the introduction of innovative aircraft with electric and hydrogen propulsion technologies, for example [4, 5].

The introduction of cargo UAS is expected to enable increased flexibility in operations, more point-to-point operations, and reduced personnel requirements and associated costs [7]. These benefits will mitigate the ongoing regional air cargo pilot shortage and enable greater use of small, under-utilized airports in the United States and Europe, connecting more communities via air cargo.

This paper investigates current air cargo operations to assess the potential of using UAS for regional air cargo operations in the United States and Europe. Air cargo data from 2021 were analyzed to provide a baseline of where and how these operations occur today and hence for how the introduction of UAS may evolve and impact the airspace differently in the two regions. The paper will review the background on emerging regional air cargo operations in Section II followed by the methodology applied in Section III before the analysis of current regional air cargo operations in Section IV. Section V presents an assessment of the airspace and airport impacts of using UAS for international, domestic, and intra-state regional air cargo operations. Finally, concluding remarks and future work are presented in Section VI.

II. BACKGROUND

The European Commission's "Flightpath 2050" calls for 90% of travelers within the European Union to reach their

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destination in less than four hours – RAM and UAM are important components for achieving this goal [8]. While passenger operations are not the focus of this work, "Flightpath 2050" points to a renewed interest in regional flight. RAM and UAM share many similarities while having some differences. Sustainable propulsion technologies, autonomy, and increased utilization will significantly reduce operating costs of both UAM and RAM aircraft. RAM could offer a nearer-term opportunity to advance autonomy because it can use existing, under-utilized infrastructure in more remote areas. In addition, leveraging small regional airports using fixed-wing aircraft with greater payload capabilities and greater vehicle ranges could result in lower operating costs compared to UAM operations [4]. Meanwhile, UAM must rely on new infrastructure such as vertiports, along with new eVTOL aircraft in densely populated urban areas [3].

The RAM sector has been in decline since 1998, as large, low-cost carriers have outperformed regional carriers. Aiming at cutting costs, airlines have added larger, more efficient aircraft to their fleet, focusing their operations at major airports, which has led to higher demand at those airports [9]. However, established players as well as start-ups are increasingly working on new technologies and business models to revitalize the RAM sector and to leverage the regional airport infrastructure. Some Scandinavian countries in northern Europe are already reconnecting small regional airports to their mobility network. Finland, for example, plans to advance its regional airport system in peripheral Lapland with the usage of electric aircraft. Initially, regional routes will be flown by ATR 72 turboprop aircraft powered by renewable aviation fuel. At the same time, regional airports in the neighboring countries of Norway and Sweden will be more closely integrated into Finland's regional air transportation network [10]. In the United States, several companies are actively working on increasingly autonomous aircraft for the regional air cargo market. Efforts from companies such as Xwing and Reliable Robotics are focused on converting Cessna 208 Caravan aircraft from crewed vehicles to remotely piloted and/or automated UAS, with plans to expand to larger aircraft in the future [11, 12]. Other companies, such as Sabrewing, are building new aircraft – specifically designed to be cargo UAS – that can take off and land either conventionally or vertically [13].

In aviation research, the focus is often on the passenger transportation segment, with far less research focused on the cargo segment [14]. Although air cargo account for a small percentage of the total freight tonnage transported in the United States in 2019 (0.069%) and in the freight-intensive European country of Germany in 2021 (0.115%) [15, 16] and trucks account for the majority of cargo tonnage transported [17], air cargo is a crucial part of the cargo infrastructure. Air cargo enables the delivery of time-sensitive goods like medicine and high value/low weight goods like electronics and mail. Regional aircraft represent a long-standing and integral part of the air cargo industry, especially when the ground transportation alternative is not an option [4].

Due to the increasing relevance and public attention to emerging innovative and sustainable regional air transportation, there is an increasing demand for cargo UAS. However, research into air cargo operations is fairly limited (see [6] for a preliminary overview of air cargo in the United States and [7] for a value analysis study). This study expands upon [6] and assesses current regional air cargo operations in US and European airspace and its potential for emerging applications such as UAS.

III. Methodology of the Analysis of Current Air Cargo Operations

In this section, the data sources and metrics used in this study are described while defining regional air cargo operations.

A. Data sources

Data were gathered for one year's worth of cargo flight movements in both Europe and the United States. The year 2021 was selected because it was the most recent complete year. Although the COVID-19 pandemic certainly had a detrimental impact on aircraft operations worldwide, air cargo tonne-kilometres (CTKs) had largely recovered to 2019 levels by January 2021 and, in December 2021, exceeded December 2019 values by 8.9% [18].

European statistics were primarily sourced from Eurostat, the Statistical Office of the European Union [19]. The Air Transport Measurement category data are broken down by various metrics such as passenger, cargo, and mail operations. This is followed by subcategories such as: geopolitical entity (referring to the 35 reporting European countries); unit of measurement (flight movements and tonnes); traffic and transport measurement (freight and mail commercial air flights as well as freight and mail on board both as the sum of arrivals and departures); transport coverage (national operations referring to domestic operations as well as international operations referring to intra- and extra-European flight movements between European countries and between a European country and a non-European country). Furthermore, data are sorted by airports, airport pairs, and aircraft types whereby not every (sub)category can be combined with every other.

Statistics for the United States[1] were primarily sourced from the Bureau of Transportation Statistics T-100 Segment data (BTS T-100) [20]. These data combine domestic and international non-stop segment data by aircraft type and service class for transported passengers, freight, and mail. The number of departures performed between airport pairs, the distance between these airport pairs, and the flight time are also included. Flights movements with both origin and destination outside the United States are excluded from this dataset. Additional airport information for both the United States and Europe, such as airport latitude and longitude, is gathered from the FAA's National Airspace System Resource (NASR) [21]. While the T-100 Segment data does distinguish between freight and mail tonnage, they will be grouped together as "cargo" for this

[1] Unless otherwise specified, data for the United States includes Puerto Rico and other US territories. A flight from Miami, Florida to San Juan, Puerto Rico, for example, would be counted as domestic.

analysis to get a better estimate of the tonnage that could be carried using cargo UAS.

B. Metrics

The primary metric that will be analyzed in this paper is air cargo flight movements, which include solely cargo-only flight movements. That is, flights with any passengers were excluded. An air cargo flight movement is the sum of the arrival and departure of an aircraft at an airport. The number of air cargo movements is expected to be the most relevant metric for investigating the impact of the introduction of cargo UAS on the airspace. Furthermore, transported air cargo in tonnage is investigated to understand the ratio of air cargo to aircraft types. Transported air cargo tonnage is counted differently in Europe and the United States. In European data, the amount of cargo transported between airport pairs is not distinguished by aircraft configuration. Therefore, the total tonnage includes cargo transported during cargo-only flight movements, as well as cargo transported during combi freight flight movements, where the main cabin of the aircraft is split between passenger seats and cargo area. However, it is assumed that cargo UAS will operate without passengers. Total tonnage transported in the US data is counted for only cargo-only flight movements to better estimate the tonnage that could be transferred to cargo UAS. Flight movement and tonnage data are listed for 408 commercial airports across 35 European countries and for 1,408 commercial airports in the United States. However, data were not available for every European airport listed.

C. Regional air cargo definition

The term "regional" can be somewhat ambiguous. NASA's definition of RAM encompasses flight missions of 50-500 nautical miles (93-926 kilometers) [2]. In their automated air cargo use case analysis, LMI defined regional aircraft as those having a mission range of 75-1,000 nautical miles (139-1,852 kilometers), a payload of 1-10 tons (0.907-9.07 tonnes), and a speed of 150-300 knots (278-556 km/h) [5]. Although some jet aircraft are used for this cargo use case, the vast majority are turboprop aircraft.

1) Flight distance of regional air cargo: Discussions with air cargo industry subject matter experts have resulted in some clarification of the above definitions for the regional air cargo use case. The priority in regional air cargo is delivering the cargo to the appropriate place on time, especially when the cargo needs to be transferred to the next flight connecting to a major sorting hub. Typically, the timeline does not allow for a slower aircraft like the Cessna 208 to fly long distances (and correspondingly for a long duration), even if it is capable of flying such distances. Therefore, we have defined the regional flight range as less than 1,000 kilometers (540 nmi) for this analysis. Within the United States, 43% of all cargo flight movements and 52% of all domestic cargo flight movements are under 1,000 kilometers. 95% of all flight movements performed by a regional aircraft and 97% of domestic flight movements performed by a regional aircraft are under 1,000 kilometers in distance. For Europe, 48% of cargo-only flight movements and 94% of the investigated domestic cargo-only flight movements are under 1,000 kilometers. Because specific flight movements by regional aircraft between city pairs in Europe are not available, based on the US data, it is assumed that a similar percentage of regional aircraft movements in Europe as in the United States (i.e., >90%) is under 1,000 kilometers. This assumption allows for an estimate of total regional cargo flight movements that could be converted to cargo UAS.

2) Aircraft payload of regional air cargo: Regional air cargo aircraft have a wide spread of payload tonnage values. This is because, according to one regional-cargo industry expert, aircraft frequently "volume out before weighing out", meaning the interior of the aircraft is volumetrically filled up before the MTOW of the aircraft is exceeded. Due to this phenomenon, aircraft such as the Cessna 208 will frequently carry less than 0.9 tonnes worth of cargo. As such, the definition of regional air cargo used in this work will include those aircraft with less than 9 tonnes of cargo. Aircraft with these tonnage capabilities typically have a MTOW of <25 tonnes. A MTOW of 25 tonnes also exists as a rough upper bound of MTOW for smaller aircraft used in cargo operations [22].

Regional turboprop aircraft (those with <9 tonnes of payload and <25 tonnes MTOW) are utilized in both regions in 2021. Nine such aircraft types were used in European operations, whereas over 20 such aircraft types were used in the United States.

IV. Characteristics of Regional Air Cargo Operations

In this section the regional air cargo operations are analyzed in terms of location, frequency, quantity, and aircraft type.

A. Geographical concentration of regional cargo flights

To get a general overview of where cargo aircraft are flying, maps of cargo-only flight movements between airport pairs across the United States and Europe were created. To showcase routes that could, theoretically, be flown by regional turboprop aircraft, the distance cutoff of 1,000 kilometers was applied. Note that these maps show flight movements that have at least one airport of the airport pair in the United States or the included European countries[2]. Thus, flight movements to and from Mexico, Canada, and other countries are also shown if they are cargo-only flight movements under 1,000 kilometers in distance. To simplify the maps, only airport pair routes with over 50 flight movements between the two airports in 2021 were included. The thickness of the lines in Figs. 1-3 correspond to the number of flight movements between the airport pair. The scale of the lines is the same for all maps.

[2] For 2021, data from the United Kingdom was not available in Eurostat, as they had withdrawn from the European Union. Data for airport pairs within Turkey, Montenegro, and Czechia were also unavailable. Data from several countries, including Albania, Russia, Belarus, and Ukraine, are completely unavailable in Eurostat.

In Fig. 1, the major European cargo hubs of Leipzig/Halle (EDDP)[3] and Cologne/Bonn (EDDK)[4] airports in Germany, Brussels (EBBR) and Liège (EBLG)[5] airports in Belgium, Paris-Charles de Gaulle (LFPG)[6] airport in France, and Milano Malpensa (LIMC) airport in Italy can clearly be seen. Regions further from these central hubs, such as Southeast Europe and the Baltic States, have relatively few flight movements. This lack of flight movements under 1,000 kilometers could be due to the distance from the central hubs, the relatively low population in these regions relative to the central hub regions, or inconsistencies in flight data. Note that although flight movements that have one airport of the airport pair within the United Kingdom (UK) are shown, flight movement data for the UK are unavailable from Eurostat as from February 2020, therefore intra-UK flights are not shown.

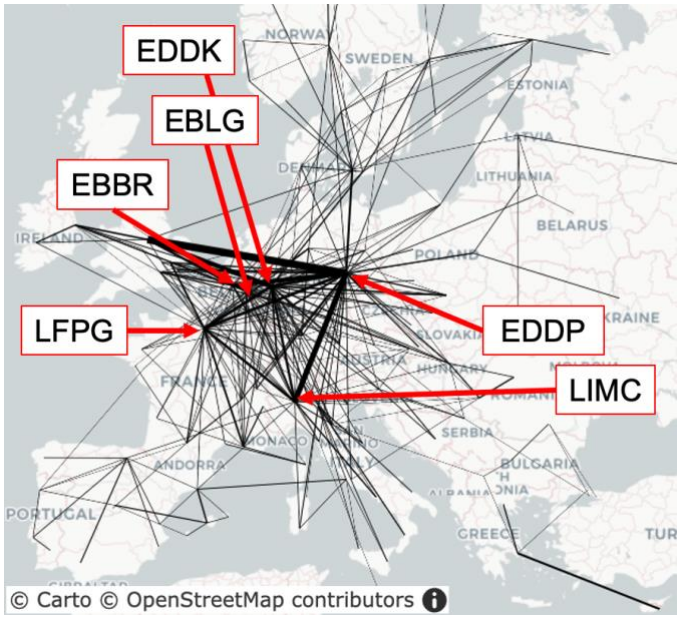

Figure 1. Cargo-only flight movements <1,000 kilometers in Europe[7]

When looking at cargo flight movements in the United States in Fig. 2, a similar picture can be seen. Flight movements under 1,000 kilometers in distance are predominant at the major cargo hubs: Memphis (KMEM) airport in Tennessee[8], Louisville (KSDF) airport in Kentucky[9], and Cincinnati/Northern Kentucky (KCVG) airport in Kentucky[10]. Other airports with significant activity are the regional hubs for major air cargo companies: Indianapolis (KIND), Philadelphia (KPHL), Newark (KEWR), Oakland (KOAK), Ontario (KONT), Fort Worth Alliance (KAFW), and Miami (KMIA).

Outside of the conterminous United States (CONUS), are two states (Alaska and Hawaii) and several territories (Puerto Rico, the US Virgin Islands, and others in the Pacific). Flight movements in these regions differ significantly from those in the CONUS. First, in Alaska (Fig. 3), Anchorage (PANC) is an important international hub for flight movements between Asia and North America. Anchorage is also the largest city in Alaska by a significant margin. Whereas Alaska is the most sparsely populated state in the US, its size, remoteness, and rough terrain have necessitated the use of aircraft as a major means of transportation and accessibility between populated areas.

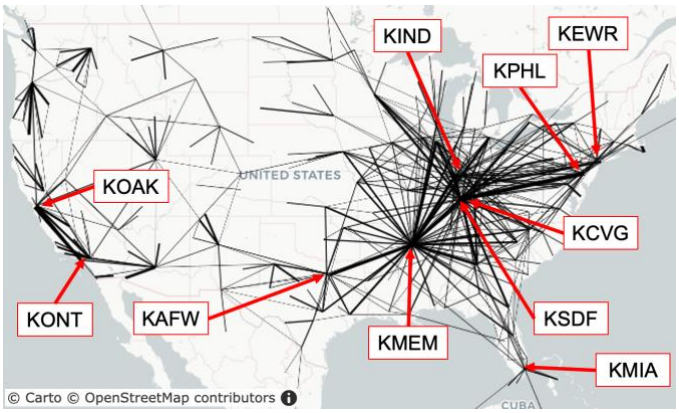

Figure 2. Cargo-only flight movements <1,000 kilometers in the CONUS[11]

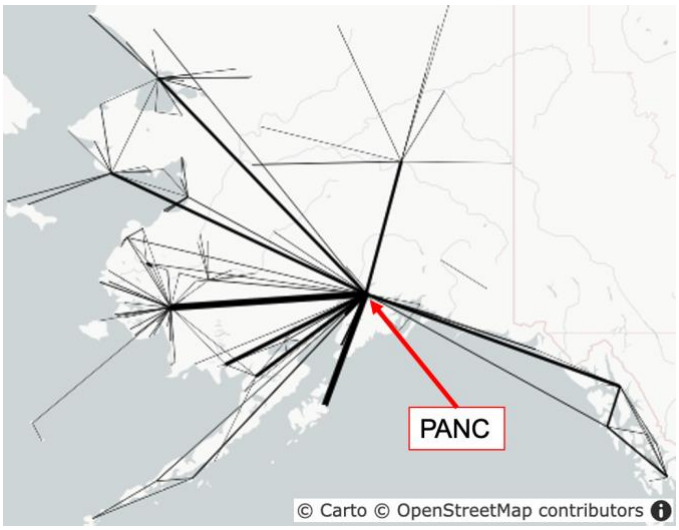

Figure 3. Cargo-only flight movements <1,000 kilometers in Alaska[12]

Hawaii, Puerto Rico, the US Virgin Islands, and the US territories in the Pacific Ocean are all islands. This unique geography gives rise to a significant use of aircraft for cargo transportation.

B. Air cargo flown by regional aircraft type

Although the map in Fig. 1 is useful for distinguishing where cargo aircraft operate, Eurostat unfortunately does not distinguish flight movements between airport pairs by type of aircraft. This lack of granularity also means that flight movements by regional aircraft type cannot be restricted to those less than 1,000 kilometers. However, flight movements at

[3] The DHL Aviation European hub and an AeroLogic GmbH hub.
[4] The UPS Airlines European hub and a FedEx Express hub.
[5] The ASL Airlines Belgium global hub.
[6] The FedEx Express European hub.
[7] Base map © Carto © OpenStreetMap contributors.
[8] The FedEx Express World Super Hub.
[9] The UPS Airlines Worldport.
[10] The Global hub for DHL Aviation, Amazon Air, and other cargo airlines.
[11] Base map © Carto © OpenStreetMap contributors.
[12] Base map © Carto © OpenStreetMap contributors.

individual airports are distinguished by type of aircraft, allowing for a different level of clarity in the number of flight movements flown by regional aircraft and non-regional aircraft. Note here that the term "domestic" means within a single country (e.g., within Germany or within the United States). See Table I for more information.

TABLE I. AIR CARGO FLIGHT MOVEMENTS BY ALL DISTANCES

All distances	Europe	United States	Combined
Total	582,660	917,465	1,500,125
Total by regional aircraft	60,422	186,076	220,601
Domestic	89,976	887,898	977,874
Domestic by regional aircraft	25,299	171,194	184,654

In Europe, 10.4% of all cargo flight movements are flown by regional aircraft compared to 20.3% that are flown by regional aircraft in the United States. Compared to Europe, the United States has 1.6 times more total cargo flight movements and 3.1 times more total cargo flight movements flown by regional aircraft.

In Europe, the percentage of cargo flight movements flown by regional aircraft is nearly triple at 28.1% of domestic flight movements, which is expected since international flights tend to be longer in distance. A relatively small percentage, 15.4%, of all European cargo flight movements are domestic. However, 41.9% of cargo flight movements by a regional aircraft are domestic flight movements.

Cargo flight movements in the United States exhibit different characteristics than in Europe, in part due to the significantly larger size of the United States compared to individual European countries. 96.8% of all cargo flight movements in the United States are domestic. Additionally, nearly all, 92.0%, of cargo flight movements flown by regional aircraft in the United States are domestic flight movements. Also, the percentage of domestic cargo flight movements flown by regional aircraft, 18.7%, is close to the percentage of total cargo flight movements flown by regional aircraft, 20.3%.

C. *Type of regional cargo aircraft*

Regional turboprop aircraft have been identified as the most likely candidates for replacement by cargo UAS in the future [5]. To better understand the characteristics of regional air cargo operations in the United States and Europe, it is helpful to differentiate the number of flight movements by type of regional aircraft. The top aircraft in each region can be seen in Fig. 4.

A few types of regional aircraft are predominant in their respective regions. In the United States, the Cessna 208 Caravan is the most prevalent, accounting for more than 83% of all domestic US cargo flight movements. It is a single-engine turboprop with a MTOW of about 4 tonnes in its Grand Caravan cargo configuration [23]. Despite this popularity, it does not appear at all in the European data. In Europe, the Aerospatiale ATR 42 and ATR 72 and the Embraer EMB-120 Brasilia account for more than 94% of domestic European cargo flight movements using regional aircraft. One of the largest regional turboprop aircraft, the twin-engine ATR 72 (AT72), with a MTOW of 23 tonnes [24], is the most commonly used regional aircraft in Europe.

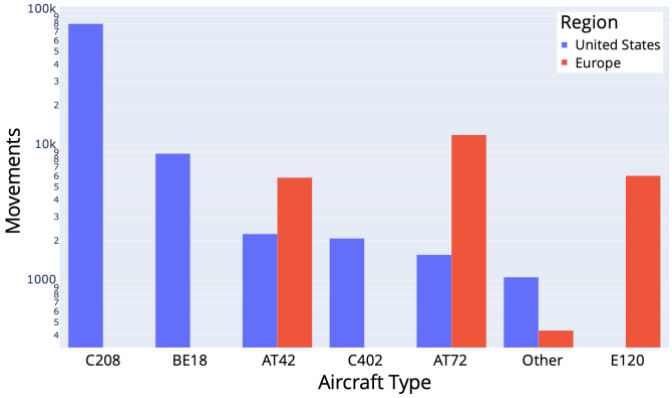

Figure 4. Domestic cargo flight movements by regional aircraft type[13]

The graph in Fig. 4 indicates that the introduction of cargo UAS into the airspace may look different in the United States and Europe. The companies aiming to replace regional cargo aircraft with UAS are taking varied approaches to the problem. At least two companies intend to retrofit Cessna 208s with additional avionics to enable remotely piloted UAS operations. Other entrants are designing cargo specific UAS, designed to not have a pilot on board. The Cessna 208 is typically operated with only one pilot on board, whereas the larger ATRs are typically operated with two.

D. *Distance and network coverange of regional air cargo operations*

Examining regional air cargo routes with a distance less than 1,000 kilometers, there is a large difference between the number of flight routes in the United States and Europe. A flight route describes the connection of two airports, where for instance the European flight route from Frankfurt Airport (EDDF) to Paris-Charles de Gaulle Airport (LFPG) and vice versa is considered as two airport pairs. In Europe there are 677 main-to-main airport pairs[14], whereas within the United States there are 2,608 main-to-main airport[15] pairs for commercial air cargo operations (8,028 total US airport pairs with airport pairs between main, other, and small airports). It should be noted that the European

[13] A caveat to the data presented here: FedEx Express has a waiver to report all its small aircraft to the Bureau of Transportation Statistics as the Beechcraft Beech 18 C-185 (BE18), regardless of the actual aircraft type. Numerous regional air cargo carriers operate on a contract basis for FedEx, flying their own aircraft, such as the Beechcraft 1900, which all get counted as the Beechcraft Beech 18 C-185.

[14] In Eurostat, the European data per airport include more reported flight data than the data per airport pair because European countries only report traffic between their main airports and their main partner airports for the data per airport pair. This results, for example, in the number of cargo-only flight movements by airport pairs (total 552,368 and domestic 84,214) being lower than by airports (total 582,660 and domestic 89,976).

[15] In Eurostat, a "main" airport is defined as an airport with ≥150,000 passenger units per year where one passenger unit corresponds to either one passenger or 100 kilograms of cargo. An "other" airport has <150,000 and ≥15,000 annual passenger units and a "small" airport has <15,000 annual passenger units [19].

data for airport pairs are primarily data from main commercial airports with more than 150,000 yearly passenger units, whereas significantly more other and small airports were included in the US data analysis. Flight movements within this distance cutoff are shown in Table II.

TABLE II. AIR CARGO FLIGHT MOVEMENTS BY REGIONAL DISTANCES

Regional distances <1,000 kilometers	Europe	United States	Combined
Total	266,461	390,444	656,905
Total by regional aircraft	n/a	176,303	n/a
Domestic	78,745	372,301	451,046
Domestic by regional aircraft	n/a	165,459	n/a

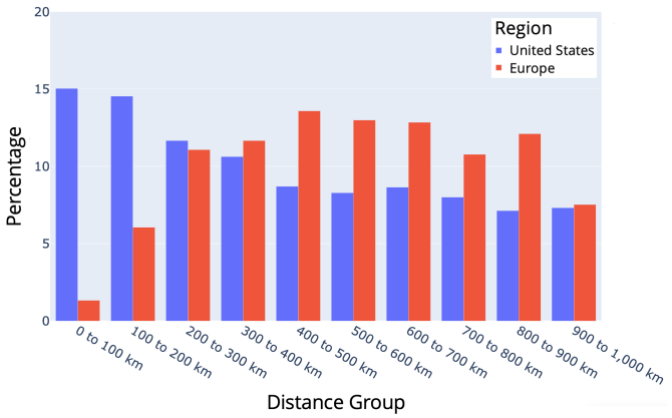

Figure 5. Percentage of airport pairs with <1,000 kilometers distance by distance group

The percentage of airport pairs by distance group is illustrated in Fig. 5. The United States has a higher percentage of airport pairs within a short distance (<300 km) of each other. This distribution of airport pair distances could indicate that more frequent flights by smaller aircraft is a possible path forward. Whereas, in Europe, airport pairs are further apart, indicating that fewer flights by larger (and faster) aircraft may be more desirable. In fact, these observations align with current regional air cargo operational paradigms, as can be seen in Figs. 6 and 7.

An analysis of the distribution of air cargo operations by distance flown <1,000 kilometers shows that only 12.8% of all European air cargo flight movements occur between 0- and 300-kilometers flight distance, see Fig. 6. The majority, 59.8%, of all European air cargo flight movements <1,000 kilometers, operate between 300- and 700-kilometers flight distance. In comparison, the share of air cargo operations between 0– and 300-kilometers flight distance in the United States is 33.7%, significantly higher than for cargo flight movements in Europe. However, for longer flight distances between 300 and 700 kilometers, the US share is 42.7%, which is lower than the European share. The relatively higher share of shorter cargo aircraft movements in the United States compared to Europe can be explained by the predominant use of smaller aircraft in the United States, such as the Cessna 208 Caravan, with shorter ranges than the cargo aircraft types commonly used in Europe, such as the ATR 72.

Interestingly, whereas the number of flight movements <1,000 kilometers is higher in the United States than in Europe (390,444 versus 266,461 cargo flight movements), the amount of cargo carried <1,000 kilometers is marginally higher in Europe than in the United States (3.9 versus 3.7 million tonnes). This data also confirms the observation that fewer larger aircraft are used to transport more cargo over flight distances <1,000 kilometers in Europe, whereas more smaller aircraft transport less cargo in the United States.

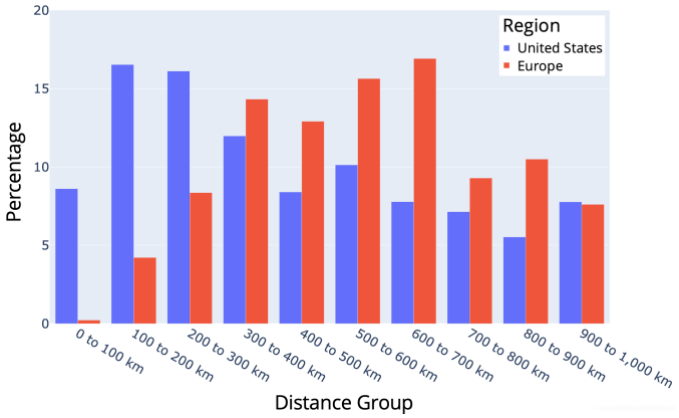

Figure 6. Percentage of cargo flight movements with <1,000 kilometers distance by distance group

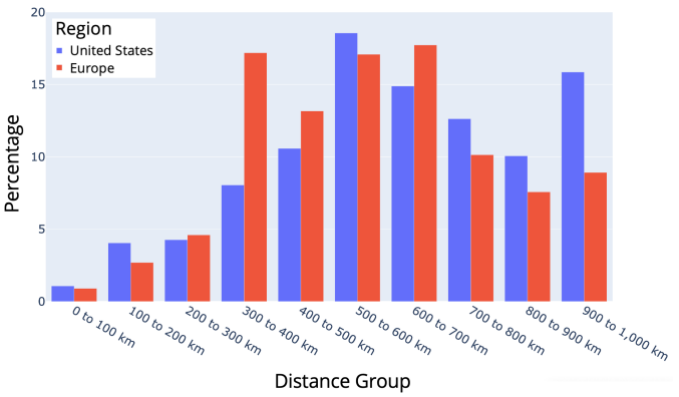

Figure 7. Percentage of air cargo tonnage flown with <1,000 kilometers distance by distance group

V. ASSESSING THE POTENTIAL OF CARGO UAS

In this section we assess the impacts of introducing UAS operations first on the airspace associated with different countries or states and then on airports.

A. Potential of cargo UAS operations: overall airspace

Cargo UAS may behave differently from the conventional regional aircraft they are replacing or need different handling. When considering the impact that the introduction of cargo UAS operations might have, it is important to have an estimate of the potential number of cargo UAS that could be flying in the airspace. Estimates in the United States and Europe will be of slightly different quality because of data availability. Ideally, an estimate would be a count of all flight movements less than

1,000 kilometers that were flown by regional aircraft, according to the criteria laid out in Section III.

In the United States, it is possible to generate this estimate from the available data: 176,303 cargo flight movements <1,000 kilometers in distance were performed in 2021 by regional aircraft, of which 165,459, or 96.7%, of these flight movements were domestic. Thus, the introduction of cargo UAS could have a significant impact on the air cargo market for flight movements <1,000 kilometers.

In Europe, this same estimate is more difficult to obtain because the data for cargo-only flight movements are unfortunately not differentiated by aircraft type. Although it is possible to obtain percentages of cargo flight movements operated by regional aircraft from airport data, that data is on an airport-by-airport basis and does not include any flight distance values. Summing up data across airports, it is possible to determine that there were 60,422 total European cargo flight movements by regional aircraft in 2021. In the United States, 94.8% of all cargo flight movements by regional aircraft were <1,000 kilometers in distance. Recalling that regional cargo flight movement counts by distance are unavailable for Europe, we can apply the US percentage to the European data to estimate that 57,249 cargo flight movements were flown by regional aircraft on flight movements <1,000 kilometers in distance. This estimate would account for about 21% of cargo flight movements <1,000 kilometers in distance performed by all aircraft (266,461).

Thus, based on current operations, it appears that the introduction of cargo UAS would have a greater impact, both in number and percentage of operations, in the United States than in Europe. However, these estimates of the impact rely solely on historical data. Cargo UAS have the potential to enable different route structures and crew and resources utilization [5]. For example, an operational paradigm known as m:N, whereby m remote pilots (pilots located off-board the UAS) concurrently control N UAS, is highly desired in industry [25, 26]. The impact that potential m:N cargo UAS operations may have on the airspace is beyond the scope of this work.

B. Potential of cargo UAS operations: state level

In this section, we take a closer look at the use of regional cargo by European countries and US states to see if the overall trends carry to individual states. The United States and Europe are both vast regions, with numerous differences between the respective states. Given the range limitations of potential cargo UAS, it is helpful to look at the data in a more granular manner: at the state level, where in this paper the term "state" refers to individual US states or territories as well as individual European countries. To do that, the metrics of percentage of total cargo flight movements that are intra-state (which, in European countries, are also domestic) and the percentage of total cargo flight movements that are intra-state and by regional aircraft are calculated. Table III contains a percentage comparison of total cargo flight movements for all distances. The table includes the mean (μ), median, and standard deviation (σ) for N European countries or US states/territories, respectively.

TABLE III. PERCENTAGE COMPARISON OF CARGO FLIGHT MOVEMENTS OF EUROPEAN COUNTRIES AND US STATES

	%[a] by regional aircraft	**%[a] that are intra-state**	**%[a] that are intra-state and by regional aircraft**
European μ	15.55	16.62	10.73
US States μ	21.12	29.43	17.40
European Median	10.03	15.51	4.23
US States Median	12.60	18.89	9.36
European σ	17.05	12.47	12.35
US States σ	22.80	25.39	21.69
European N	21	32	13
US States N	53	53	53

a. Percentage of total cargo flight movements.

The average percentage of total cargo flight movements (regardless of distance) flown by regional aircraft over 21 European countries is 15.6%. Over the 53 individual US states and territories, this percentage is nearly six points higher, at 21.1%. US states and territories with higher percentages of regional aircraft flight movements are likely to be either islands (such as the US Virgin Islands, with 99.2% of flight movements by regional aircraft, the highest percentage of any state) or sparsely populated (such as North Dakota, with 70.5% of flight movements by regional aircraft). The European country with the highest percentage of flight movements by regional aircraft is Romania, which at 36.3% would rank 21st behind 20 US states and territories. It is also important to note that the median value for the percentage of flight movements by regional aircraft is much lower than the average value, especially in the United States. Given that the median is more resistant to outliers than the mean, this discrepancy suggests that a few outlier states exist that have especially high percentages of flight movements by regional aircraft. Indeed, nine states have percentages that are greater than 1.5 standard deviations (σ) from the mean (μ).

A high percentage of intra-state flight movements typically correlates to the presence of one hub airport in the state, through which most inter-state cargo flows, with subsequent distribution to other intra-state airports. Some examples are PHNL in Honolulu, Hawaii, ENGM in Oslo, Norway, and KPDX in Portland, Oregon. All three states have percentages of total cargo flight movements that are intra-state in excess of 50% and 1.5 σ from the μ.

Finally, whereas the percentage of total cargo flight movements that are intra-state and flown by regional aircraft is lower than the previous two types of percentages discussed, there are six US states that have percentages over 50% and >1.75 σ from the μ. These states (North Dakota, South Dakota, Oregon, Montana, Nebraska, and Maine) have low population densities. The region with the highest percentage of total cargo flight movements that are intra-state and flown by regional aircraft is the US territories in the Pacific.

TABLE IV. PERCENTAGE COMPARISON OF CARGO FLIGHT MOVEMENTS OF SPECIFIC EUROPEAN COUNTRIES AND US STATES

Country / State	%[a] by regional aircraft	Z-Score[b] for %[a] by regional aircraft	%[a] that are intra-state	Z-Score[b] for %[a] that are Intra-State	%[a] that are intra-state and by regional aircraft	Z-Score[b] for %[a] that are intra-state and by regional aircraft
European countries						
Germany	6.26	-0.83	10.03	-0.32	0.25	-0.85
Spain	22.33	0.46	37.02	1.26	17.11	0.52
France	8.23	-0.67	31.01	0.91	3.25	-0.61
Norway	28.78	0.98	52.54	2.17	20.63	0.80
Romania	36.31	1.58	27.71	0.71	12.10	0.11
US states						
Alaska	50.56	0.83	65.55	1.95	50.56	1.53
California	15.87	-0.53	24.89	0.17	15.63	-0.08
Texas	18.95	-0.41	25.45	0.19	15.33	-0.10
Tennessee	2.61	-1.06	3.36	-0.78	0.25	-0.79
Maryland	26.93	-0.10	19.47	-0.07	19.21	0.08

a. Percentage of total cargo flight movements.

b. Z-score is equal to the number of standard deviations away from the mean. The mean for the respective region (United States or Europe) was used for the state's calculation. The larger the absolute value of the Z-score, the further away from the mean that value is. A negative Z-score indicates that the value is below the mean; a positive Z-score indicates a value above the mean.

C. Investigation into specific states

Ten specific states, five in Europe and five in the United States, were chosen for further investigation and are presented in Table IV. Germany, the busiest air cargo country in Europe in terms of total cargo flight movements (and third-busiest overall, after Alaska and California) has 2.64 times more total cargo flight movements than the next busiest European country, Belgium. Being centrally located and having a high number of long-haul international flight movements, Germany has a relatively low percentage of cargo flight movements by regional aircraft (6.26%, Z=-0.83), despite having the second-highest number of cargo flight movements by regional aircraft in Europe: 9,870. By comparison, two other countries of similar size, Spain, and France, with the fifth- and fourth-busiest countries in Europe by total air cargo movements, respectively, have similar percentages of total cargo flight movements that are intra-state (37.02%, Z=1.26 and 31.01%, Z=0.91, respectively). However, the percentages of total flight movements performed by regional aircraft in these two countries are significantly different. In Spain, the country with the highest number of cargo flight movements by regional aircraft in Europe (10,117), 22.33% of total cargo flight movements are performed by regional aircraft (Z=0.46), whereas in France, only 8.23% (4,540 flights, fourth overall in Europe, Z=-0.67) are. A similar difference is observed in the percentage of total cargo flight movements that are intra-state and performed by regional aircraft. Norway, a country on the periphery of Europe with an elongated geography, has a high percentage of both regional and intra-state flights. In fact, Norway has the highest Z-score for intra-state flights, 2.17, of any European country. This high deviation from the mean is likely due to the fact that there are several areas of Norway, especially in northern Norway, that are a day's travel from Oslo by road or train, yet only a few hours away by air. In Norway, there were 12,993 total cargo flight movements. 3,740 were by regional aircraft, 6,826 were intra-state, and 2,680 were intra-state and by regional aircraft. Over half of all cargo flights in Norway were intra-state. Finally, Romania is presented as an "average" European country with respect to the percentage of total cargo flight movements that are intra-state and performed by regional aircraft (853).

Alaska, the largest and least-densely populated state, is the busiest air cargo state, with over 210,000 total flight movements. It also has the highest number of total flight movements by regional aircraft (106,574 Alaska has geography such that air cargo is often the only practical way to connect some of the more isolated villages. The next busiest state is the most populous state and third largest by area: California. Whereas the state has a lower-than-average (Z=-0.53) percentage of total flight movements by regional aircraft (possibly due to the presence of West Coast hubs for FedEx and UPS in California), it represents an "average" state in terms of the percentage of total cargo flight movements that are intra-state and performed by regional aircraft (Z=-0.08). California has, however, a high number of cargo flight movements by regional aircraft (28,370), almost all of which are also intra-state (27,952). California also has a high number of intra-state flight movements (44,504). Another large, populous state with major regional hubs, Texas, has similar percentages to California, albeit with fewer total cargo flight movements by regional aircraft (18,575), intra-state cargo flight movements (24,946), and intra-state cargo flight movements by regional aircraft (15,026). Nonetheless, both California and Texas are still among the busiest states in terms of cargo flights. Tennessee, like Germany, is the location of a major international cargo hub (FedEx's World Super Hub). Like Germany, Tennessee has a relatively low percentage of intra-state and regional flight movements. Intra-state cargo flight movements by regional aircraft are minimal in both Germany (392 movements) and Tennessee (388 movements). Finally, Maryland is included as an "average" US state across all three percentages (14,287 total cargo flight movements, 3,848 by regional aircraft, 2,782 intra-state, and 2,744 intra-state by regional aircraft).

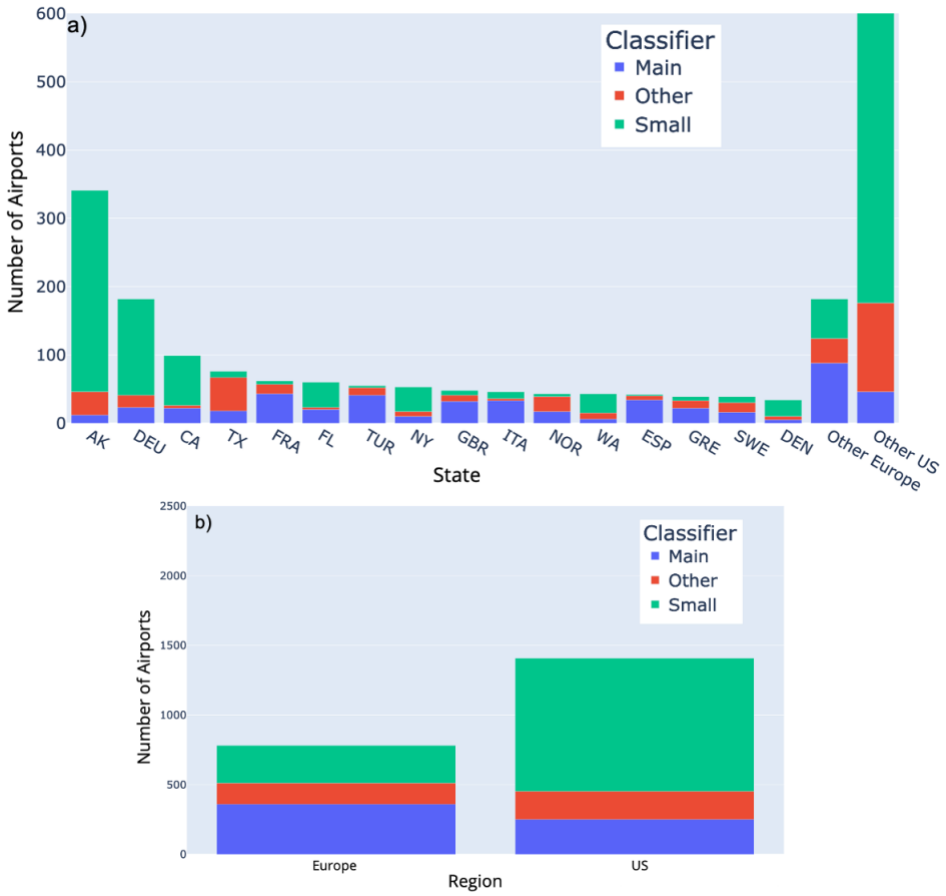

Figure 8. a) Number of airports by classifier by US states/European countries and b) Number of airports by classifier by the United States/Europe

D. Potential of cargo UAS operations: airport level

Looking at the proportion of commercial airports of various sizes in Fig. 8 that are publicly accessible, it is apparent that the United States has many more commercial airports in operation than Europe (1,408 versus 781). Since the potential introduction of commercial cargo UAS operations is believed to occur first at commercial airports, priority is given to the analysis of airports that are currently commercially viable. The usability of non-commercial airports for cargo UAS operations is of course not excluded in the future.

In Fig. 8b, about one fifth (250) of US airports are, using Eurostat definitions, main airports, one seventh (202) are other airports, and two thirds (956) are small airports [19]. Looking at the European countries and US states with the most commercial airports in Fig. 8a, Germany (DEU) stands out as the country with the most commercial airports in operation. According to Eurostat, Germany has 182 commercial airports in operation, of which 141 are small commercial airports, representing over half of all small commercial airports in Europe with public access and scheduled traffic. Furthermore, Alaska (AK) with 341 commercial airports (295 small airports), Germany, California (CA) with 99 commercial airports (73 small airports), Texas (TX) with 76 commercial airports (9 small airports), France (FRA) with 62 commercial airports (5 small airports) and Florida (FL) with 60 commercial airports (37 small airports) are the six US states and European countries with the highest number of airports[16].

In the case of France, it can be added that the relatively central European country located west of Germany has several hundred small airports. However, these airports are not commercially operated and are therefore not open to the public without permission. Since Eurostat does not fully cover smaller airports in its regulatory data collection, it must be noted that, according to the Union des Aéroports Français, France has over 30 small commercial airports according to the airport size definition by Eurostat. However, many of these small commercial airports have less than 100 annual commercial passenger units [27].

On the other hand, according to Eurostat, Italy (ITA) (46 total and 10 small airports) and Denmark (DEN) (34 total and 24 small airports) have a relatively high number of small commercial airports. Note that whereas California and Texas have similar percentage values in Table IV and have a similar number of total airports, the former has a higher percentage of small airports. This could imply that, even between two

[16] It should be noted that the number of small commercial airports might not be fully available, as this information depends on data provided by each European country to Eurostat ("smaller airports are not covered by the regulatory data collection") [19].

similar states in the same country, the introduction of cargo UAS could vary.

There are two potential forms for the introduction of cargo UAS into an airspace: 1) replacing existing flight movements or 2) expanding flight movements including into new areas. States that have a high percentage of total cargo flight movements operated by regional aircraft could be more likely to see introduction of cargo UAS via replacement. On the other hand, states that have a low overall percentage of total cargo flight movements operated by regional aircraft could be more likely to see introduction via expansion. Determination of specific routes for expansion would involve various factors, such as market size and growth potential of the target area and is outside of the scope of this work. Similarly, the environmental transformation in aviation towards, for example, sustainable propulsion technologies and thus the introduction of newly developed aircraft, different (cargo) business models, and emerging and shifting markets are not considered in this paper.

Several major airports, especially in Europe, are capacity constrained and operate using International Air Transport Association Worldwide Airport Slot Guidelines (WASG). During the summer of 2023, 107 airports in Europe (including the United Kingdom) are expected to be at WASG Level 3 (i.e., severely capacity constrained), with a further 91 airports expected to be at WASG Level 2 (i.e., moderately capacity constrained). Although the issue is not as acute in the United States, with only one Level 3 airport and six Level 2 airports, it is nonetheless of concern, with several US airports operating at capacity without usage of Slot Guidelines [28]. As such, the introduction of cargo UAS into these capacity-constrained airports could prove difficult. An easier path forward may be to utilize smaller airports that are not as busy. Likewise, providing connectivity through small airports for regional cargo UAS missions over low-population density areas holds significant potential for gaining both public and regulatory confidence in the automation of aircraft [5]. In addition to the large international airports serving within a hub-and-spoke network for large passenger or cargo volumes, there are numerous small regional airports that serve feeder traffic to hubs or point-to-point connections but are often not used by scheduled commercial air traffic [29, 30].

The presence of small, under-utilized airports could be another positive factor for the introduction of cargo UAS. It is assumed that, at least initially, cargo UAS will operate out of these less-busy airports. Examining the selection of prime locations for regional cargo UAS operations based on the number of small commercial and often under-utilized airports, both Alaska and California could be prime locations within the United States. Germany would clearly be the preferred country with the required regional airport infrastructure for initial cargo UAS operations in the European region. In the 1990s, large investments were made in German regional airports to accommodate the rapidly growing aviation industry. However, the majority of these small and regional airports experience annual financial losses and rely on subsidies [31]. Criticism has been voiced that regional airports are increasingly focusing on passenger transport while underestimating and overlooking the advantages of the air cargo market, even though the latter has high revenue margins [32]. Similarly, criticism has also been voiced that scientific research in the past has also paid too little attention to the role of air cargo and the needs and operational requirements of small and regional airports [33, 14].

VI. Conclusion and Future Work

Using data from the year 2021, air cargo operations were compared between the United States and Europe as well as between their individual states and countries, respectively. Operations by regional, mostly small turboprop, aircraft were of particular interest, because they are considered the first candidates for replacement by cargo UAS in the future. It was observed that the United States has significantly more cargo flight movements overall, as well as more cargo flight movements by regional aircraft. However, the percentage of air cargo tonnage by distance group is similar between the two regions, implying that a fewer number of large aircraft are used in Europe whereas a greater number of small aircraft are used in the United States.

Given that cargo UAS are anticipated to begin initial operations at smaller, under-utilized airports, many US states with higher numbers of these airports, including Alaska and California, appear to be well suited for these operations. A small number of European countries, primarily Germany, have a high number of small commercial airports, that are publicly accessible. This research indicates that, although it currently has a low percentage of regional air cargo flight movements, Germany could be a prime location for the introduction of regional cargo UAS in Europe.

Future work includes quantitative classification of regional airports suitable for cargo UAS operations as well as definition of cargo UAS use cases and reference missions for different regions in Europe and the United States. Mixed (crewed and UAS) traffic simulations will be performed to assess the impact of UAS on crewed traffic at small, regional airports.

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