Preliminary Characterization of Unmanned Air Cargo Routes Using Current Cargo Operations Survey

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The introduction of regional cargo unmanned aircraft systems into the National Airspace System is anticipated within the coming years. Because they are remotely piloted, these aircraft are expected to utilize increasing aircraft automation and autonomy, require special infrastructure accommodations for navigation, communication, command and control and potentially need special treatment from air traffic control. In order to assess the accessibility and impacts of these operations across the national airspace, this preliminary study investigates current and estimated future demand for air cargo operations in the continental United States. Air cargo demand is broken down by aircraft type and airport categories to produce a rough nation-wide classification of cargo operations. Then, the state of Texas is investigated as a focus region, where the impacts of regional cargo unmanned aircraft systems on the airspace are investigated in further detail. The potential technologies that can assist in regional cargo unmanned aircraft system accessibility are defined at airports across the focus region. A single airport, Fort Worth Alliance, is highlighted to discuss airport-level statistics. Finally, a qualitative classification of airports by the type of cargo operations is suggested.

I. Introduction

Air cargo operations without a pilot on board, referred to as cargo Unmanned Aircraft Systems (UAS), are anticipated to enter the National Airspace System (NAS) within the coming years. The introduction of these cargo UAS is expected to allow for a more flexible flight schedule, lower fuel consumption, and reduce personnel requirements (and thus the personnel and operational costs) [1]. Cargo UAS operations also may enable more point-to-point operations to a greater number of airports, which in turn alleviates growing demands at capacity-constrained hub airports as well as reducing the number of cargo trucks on national highways.

The goal of the present paper is to assist development of concepts and associated requirements for large, type-certified§ UAS operations in the NAS, with cargo UAS being an initial use case. The cargo UAS use case will help to pave the way for aircraft with increasing levels of autonomy to operate in an integrated manner within the NAS. Increasing aircraft automation capabilities, such as auto-taxi, auto-take-off, and auto-land (auto-TTL), are assumed to be necessary enablers of cargo UAS operations. The use and integration of such automation technologies within the NAS must maintain the safe, orderly, expeditious and secure flow of air traffic that exists today.

The research described in this paper aims to assess the demand of, and inform the accessibility assumptions for, cargo UAS operations by quantifying air cargo demand and accessibility at airports across the Continental United States (CONUS). Current cargo aircraft traffic, when combined with estimated future truck traffic across the CONUS, suggests where cargo demand is today and where it may be in the future. While overall air and truck cargo

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§ See 14 CFR Part 21.

demand will be investigated, the focus of this paper will be on regional air cargo UAS operations. A 2021 market study determined that a regional cargo UAS use case is the most promising use case for the advancement of aircraft automation technologies [2]. This regional use case incorporates aircraft with payloads of 1-10 tons, typically turboprop aircraft, with a range of 75-1,000 nautical miles. Such regional air cargo is operational in present day. FedEx's contracted Feeder fleet, for example, operates Cessna 208B Super Cargomaster, ATR-42, ATR-72, and ATR-72 600F turboprop aircraft in regional operations [3]. Numerous other airlines operate turboprop aircraft on a contract basis for the regional operations of other major cargo carriers, such as United Parcel Service (UPS) and DHL. Air cargo demand in this work will be differentiated by aircraft type to investigate these regional operations.

Another motivation behind this work is that a remote pilot (RP) may need to operate the unmanned aircraft (UA) via a command and control (C2) link system which requires additional ground infrastructure. Cargo UAS are expected to be operated in a m:N architecture, where m RPs operate N UAs at the same time. Among other factors, geographic limitations in the availability of the C2 link system will have a significant impact on the m:N architecture. For example, RPs may need to be geographically distributed based on where adequate (with respect to latency and reliability) C2 links (using radio, cellular, High Altitude Relay System (HARS), or satellite technologies) are available. These C2 links are either radio line-of-sight (RLOS) or beyond radio line-of-sight (BRLOS). The RLOS C2 link has minimal latency but limited range, whereas the BRLOS C2 link has larger, potentially unacceptable latency for time-critical functions but a vast range. For cargo UAS operations occurring in an integrated environment with other aircraft (i.e., in the NAS), it is possible that, especially in the terminal environment, the RP will need to operate the UA over RLOS to minimize latency. Given the limited range and cost of implementing RLOS receivers, it is desirable to know where cargo UAS might be operating.

An in-depth study of an initial focus region, the state of Texas, will investigate the existing accessibility for cargo UAS operations, as well as provide further information about the impact cargo UAS operations will have on the airspace and what a possible C2 RLOS coverage map might look like. The findings will then be generalized to estimate future demand and accessibility across the CONUS.

This paper will review the study methodology and data sources in Section II. The current demand across the CONUS for cargo jet and propeller/turboprop flights, as well as estimated demand for cargo truck traffic, will be investigated in Section III. Section IV will discuss the focus region, the state of Texas, and the existing accessibility technologies present at the airports therein. Section IV will also discuss airport-level information to discern what type of operations are occurring at airports to which the cargo UAS may fly. General classifications of airports at which air cargo operations are occurring will be presented in Section V. Finally, concluding remarks and future work will be presented in Section VI.

II. Methodology

Flight summary data from the NASA Ames Sherlock Data Warehouse [4] was obtained for a period of nearly seven months (July 20, 2021, to February 17, 2022). Air Route Traffic Control Centers (ARTCC) flight data was obtained for every control center within the CONUS, which contains information such as the origin and destination of the flight, the airline (or general aviation), and the aircraft type. To obtain the cargo flights, the flight data was sorted by airline and by origin airport. If the airline was one of the target cargo airlines and the flight originated from an airport within the CONUS, then the flight was classified as a cargo flight. The target cargo airlines include major cargo airlines--such as FedEx Express and UPS--and contractor airlines--such as Polar Air Cargo, Empire Airlines, and Ameriflight, that operate for larger companies, such as FedEx, UPS, Amazon, and DHL (see Appendix Table 1 for the list of airlines). There are two caveats to this dataset, as there is not a way to distinguish between passenger and cargo flights given that both use the same airline code: 1) Some of the contractor airlines do operate passenger services which were counted with the cargo flights, but the total number of passenger flights is small enough to be negligible. 2) Cargo flights operated by major passenger transport airlines, such as American Airlines or Delta Air Lines cargo flights, are not included in the dataset. To avoid overestimation, these passenger transport airlines have been excluded. In the remainder of this paper, the term *cargo* is used to refer to the flights as defined above. Finally, the flight summary files indicate whether the aircraft flown is a propeller, turboprop, or jet. This data point is used to differentiate regional (propeller and turboprop, hereafter referred to simply as *prop*) and national (jet) operations.

Airport and runway data were obtained from the FAA NAS Resource (NASR) database [5], which includes data such as airport operations by type (e.g., commercial, air taxi, general aviation), runway lengths, available precision landing systems, and presence or absence of an air traffic control tower (ATCT). Further airport data, including usage classification, was obtained from the FAA National Plan of Integrated Airport Systems (NPIAS) [6]. The percentage of visual flight rules (VFR) flights at an airport was found via the FAA Operations Network (OPSNET) [7]. From this data, the number of instrument flight rules (IFR) itinerant, VFR itinerant, and local flights for a specified airport were found. Local flights are typically VFR, so were counted as VFR itinerant. Then, the percentage of VFR flights at an airport was calculated. The airspace class of each airport was identified by looking up a list of Class B and Class C airports. If the airport was not in that list and had an ATCT, the airport was classified as a Class D. Otherwise, the airport was classified as Class E or G. Finally, the percentage of cargo flights was calculated. This flight data was also broken down by type of aircraft (propeller, turboprop, and jet) for cargo flights and for all flights. To facilitate display and analysis of the CONUS- and airport-level data, Jupyter Notebooks were created.

III. Demand

A. Estimated future demand

Air cargo, especially domestic air cargo, has increased rapidly in recent years. From 2018 to 2021, the amount of domestic revenue tons enplaned has increased roughly 26% [8]. Overall revenue tons enplaned, including Atlantic, Pacific, Latin America, and international air cargo, despite taking a step back in 2019 and 2020, rose over 12% from 2018 to 2021. With the rise of same-day and next-day shipping, air cargo traffic is only expected to increase [2]. At the same time, the number of capacity constrained or cautioned airports in the NAS are expected to grow by 22% and 500%, respectively, by 2030 [6] (see Fig. 1). As capacity constraints at airports grow alongside demand for air cargo, alternative solutions to using these major airports need to be found.

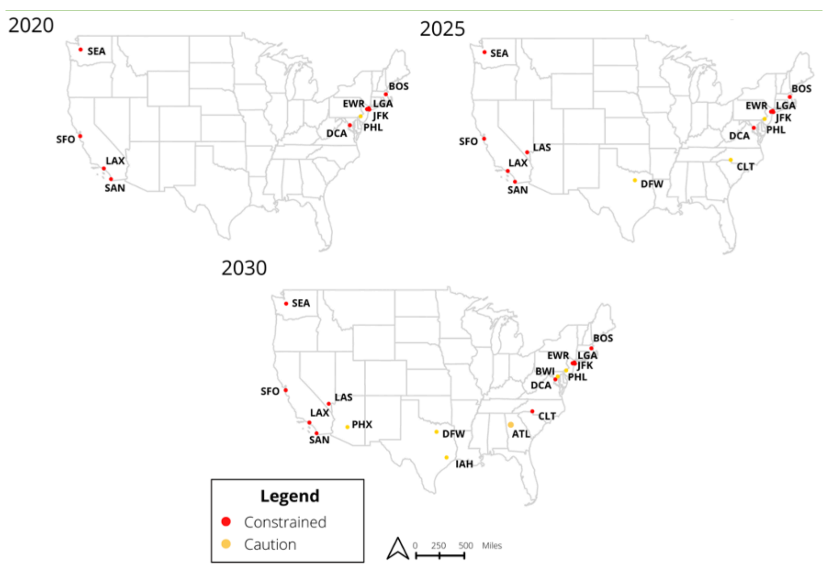

Fig. 1 Capacity constrained and cautioned airports – 2020, 2025, and 2030.

Regional air cargo operations, especially those operated in an m:N manner, present the opportunity to help alleviate some of the airport and highway capacity constraints by potentially shifting freight and truck traffic from major airports to more regional airports. These types of operations can also help to service under-utilized airports and under-serviced communities, especially those outside of major metropolitan areas. Regional operations also show the most promise for the advancement of automation technology [2].

Airports are not the only infrastructure overwhelmed by increase of cargo demand. According to Ref [9], the estimated average annual daily cargo truck traffic (AADT) in 2012 indicated cargo truck traffic levels greater than 213,400 trucks per day in many downtown areas across the United States (see Fig. 2a). By 2045, the Bureau of Transportation Statistics estimate that these 2012 downtown levels of cargo truck traffic will be seen on highways across the United States, including rural areas (see Fig. 2b). This significant increase of cargo truck traffic will further increase congestion on highways. One of the potential use cases for cargo UAS, is to supplement or even replace some cargo truck traffic.

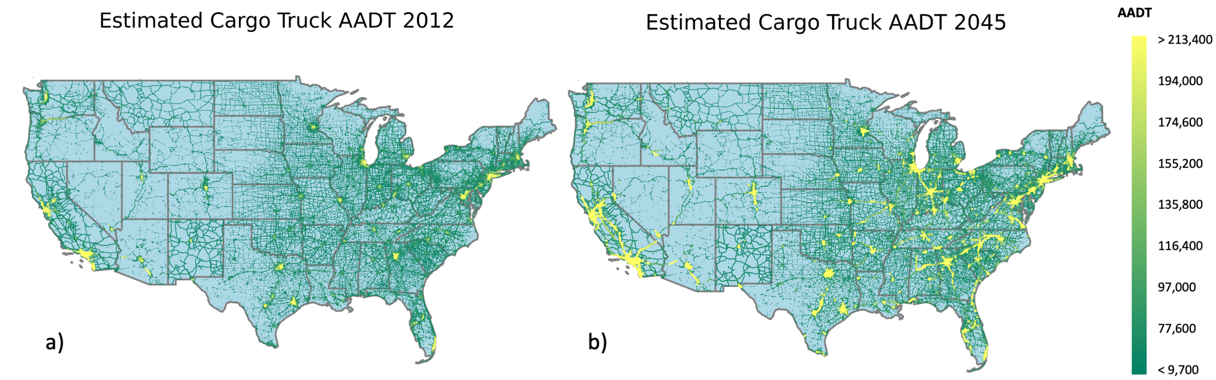

Fig. 2 Estimated average annual daily cargo truck traffic. The levels of estimated AADT seen in major cities in a) 2012 (>213,400 AADT) are estimated to be present on highways across the country by b) 2045 [9].

B. Current air cargo demand

To get an estimate of current demand for air cargo and the locations to which air cargo is flying, cargo flights within the NAS are shown in Fig. 3. The data from July 20, 2021, to February 17, 2022, were used for the analysis. The size of the circle indicates the number of flights arriving at the airport, with a radius of $x^{0.6}$, where x is the number of flights. The blue circles indicate the arriving aircraft is classified as jet aircraft, whereas red as prop. In Fig. 3a, significant jet traffic occurs at the FedEx World Super Hub in Memphis (KMEM) and the UPS Worldport in Louisville (KSDF), as well as other major cargo hubs (e.g., Indianapolis: KIND, Ontario: KONT, Cincinnati-Northern Kentucky: KCVG, Oakland: KOAK, Chicago-Rockford: KRFD, and Newark: KEWR). As expected, the highest levels of overall cargo flights, including the props, occur at these airport hubs. Like major passenger transport airlines, cargo carriers typically operate in a hub-and-spoke model, which means that the hubs have the most traffic. For a list of the top twenty airports by total cargo departures, see Appendix Table 2. In Fig. 3b, prop cargo flights occur at many more airports across the NAS, though the number of total prop flights is less than the number of total jet flights. Many Class C airports, such as Milwaukee (KMKE) and Lansing (KLAN), see significant levels of prop cargo flights. For a list of the top twenty airports by number of prop cargo flights, see Appendix Table 3.

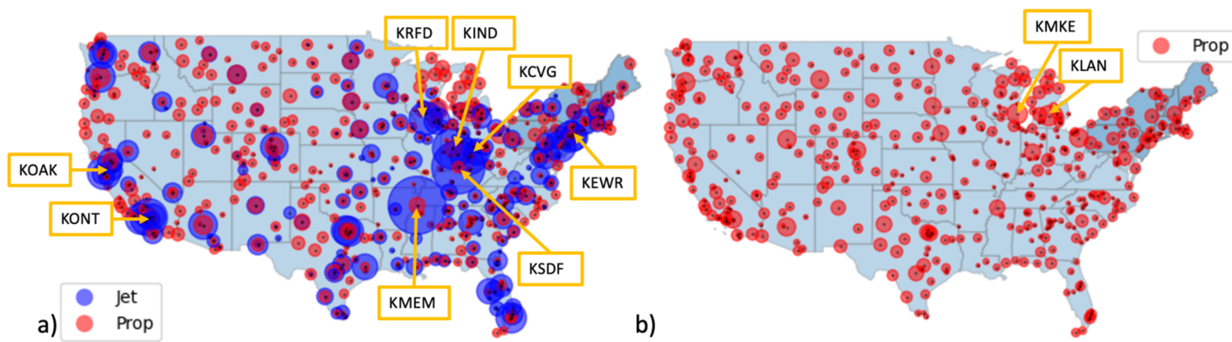

Fig. 3 Cargo flights for July 20, 2021, to February 17, 2022, for a) combined jet and prop traffic and b) prop traffic only. The size of the circle represents the number of flights departing that airport and is plotted with $x^{0.6}$ as radius, where x is the number of flights.

The ratio of cargo flights to all flights at an airport is a measure of how "cargo-focused" an airport is. Appendix Table 4 lists the top airports by cargo flight percentage. Known cargo carrier hubs, such as Fort Worth Alliance (KAFW), are easy to identify as "cargo-focused." While an airport like KIAB (McConnell Air Force Base near Wichita, Kansas) does indicate a very high percentage of cargo flights (65.4% of departures) over the seven-month date range studied, only 101 departures occurred in that same date range. Therefore, the airport has too few operations to provide sufficient information to justify classification as "cargo-focused." An airport like KAFW, on the other hand, a FedEx and Amazon hub, had 28,177 departures over the seven-month date range studied, of which 46.3% were cargo, or roughly 280 times the number of cargo departures as KIAB.

C. Demand by airport type

Several statistics can be calculated to quantify cargo demand in the NAS by airport type. In Fig. 4a, the percentage of CONUS-wide cargo departures by class of airspace is shown. With 38.2% of total cargo departures, Class C airports have the greatest number of operations of any class of airspace. Additionally, Class D airports also have a large percentage of the total cargo operations, with 29.8% of total cargo. Thus, these two classes of airspace are likely to be most impacted by the introduction of cargo UAS. For airports that operate as a Class D airport when the tower is operating, the impact could be even greater when the tower is not operating, as there would be less ATC support for the cargo UAS.

In Fig. 4b, the percentage of CONUS-wide cargo departures by NPIAS type are shown. Roughly half of flights occur at airports that are classified as a Small Hub or Non-Hub. These airports, classified more generally in the NPIAS as *primary commercial service* airports, offer commercial passenger services and receive 0.05 to 0.25 percent of the annual U.S. commercial enplanements (Small Hub) or less than 0.05 percent of the annual U.S. commercial enplanements but more than 10,000 annual commercial enplanements (Non-Hub). The median percentages (median number of operations divided by the total number of operations) of cargo departures within each NPIAS type are shown in Appendix Table 5. An airport's median cargo percentage substantively exceeding the median percentage of its NPIAS type suggests that the airport is may be characterized as an airport with high levels of cargo operations. See Appendix Table 4 and Section V for more information and discussion.

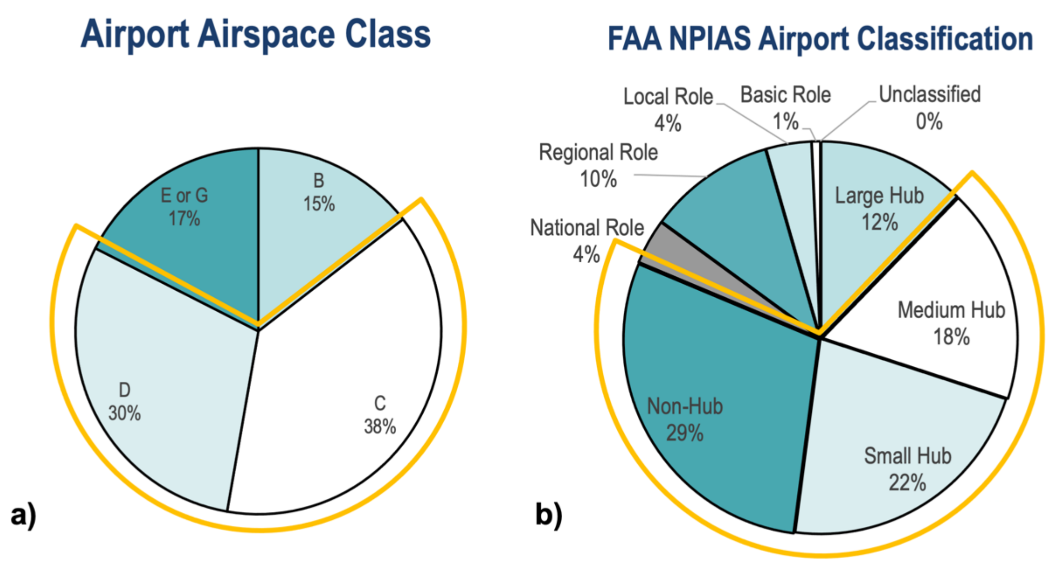

Fig. 4 Percentage of cargo departures at airports by a) class of airspace and b) NPIAS classification.

In Fig. 5a, the total number of cargo departures for each airport in the cargo dataset is plotted against the total number of departures at the airport (including general aviation and commercial passenger flights). For the primary commercial NPIAS types (Large, Medium, and Small Hub, and Non-Hub), there is generally strong horizontal grouping, which is to be expected given those classifications are assigned from the number of annual enplanements. The general trend of increasing number of cargo operations with increasing number of total operations is visible. However, there are a few notable outliers: 1) The "cargo-focused" airports with high levels of cargo traffic relative to the total traffic in addition to high levels of total traffic, see Fig. 5b. Many of these airports are major hubs for cargo companies (e.g., KMEM, KSDF, KRFD, KAFW). 2) The heavily trafficked airports with low levels of cargo operations, such as Chicago-Midway (KMDW, Large Hub) and Dallas Love Field and Houston Hobby (KDAL, KHOU, both Medium Hubs). These airports are all located in major metropolitan areas near another Large Hub airport (KORD, KDFW, and KIAH, respectively). The nearby Large Hubs, as well as other "cargo-focused" airports

(KRFD - a Non-Hub airport for KMDW, and KAFW - a nonprimary, National airport for KDAL) may satisfy existing cargo demand for the metropolitan area these airports serve.

Additionally, most airports within the cargo dataset (430 of 648, or 66.4%) receive low levels of cargo operations (<5% of total operations). This data point indicates that current cargo operations are heavily concentrated at cargo hubs. If cargo UAS operated in a m:N manner can reduce the cost of operations sufficiently, it may be beneficial to sort packages locally, which could help balance the cargo demand across more airports. Further investigation is required to provide quantitative statements about these airports and will be the focus of a follow-up study.

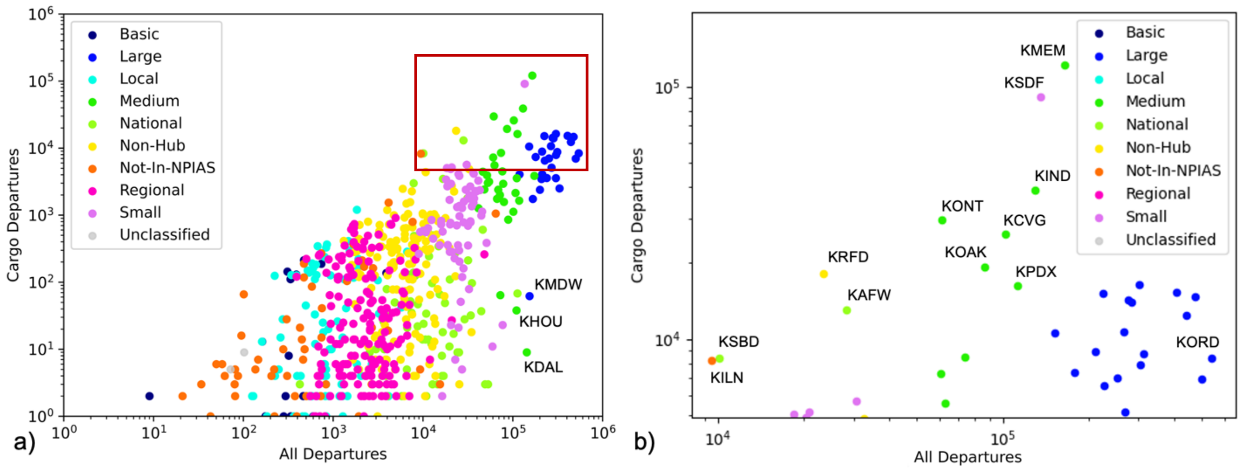

Fig. 5 Total number of cargo departures versus total number of departures for a) every airport in the cargo dataset by NPIAS type and b) enlarged plot of the marked area in a).

IV. Focus Regions and Access

To narrow the scope of investigation and to delve more deeply into the airports themselves, four focus regions have been identified (see Fig. 6). These focus regions will provide a variety of environments for research purposes, including trade studies, Human-In-The-Loop simulation evaluations, and flight tests. The first focus region, and the one that will be exhibited further in this paper, is the state of Texas. Texas was selected as the state has several major metropolitan areas spaced far enough apart to make flight between the metro areas viable, vast rural areas, eight of the Top 75 cargo airports [10], and highways (especially I-35) that are expected to have heavy levels of cargo truck traffic in the future (see Fig. 2b). The next three focus regions (California, Ohio/Great Lakes, and the Upper West) will be studied in future work and are discussed in Section VI.

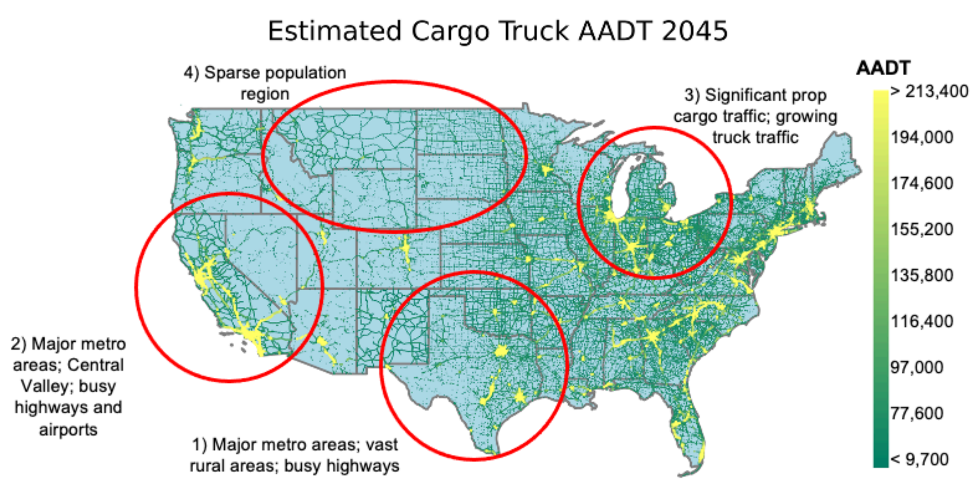

Fig. 6 Potential focus regions: 1) Texas, 2) California, 3) Ohio/Great Lakes, and 4) Upper West.

A. Airspace Impact

One of the goals of the present paper is to assess the impact that the introduction of cargo UAS will have on the airspace. To that end, the airspace of Texas is shown in Fig. 7. Class B airspace is located around the four busiest airports: Dallas-Fort Worth (KDFW) and Dallas Love Field (KDAL) in Dallas-Fort Worth and George Bush Intercontinental (KIAH) and Houston Hobby (KHOU) in Houston. Several Class C airports are servicing the larger cities, e.g., Austin (KAUS), San Antonio (KSAT), and El Paso (KELP). Many of the Class D airports also receive cargo flights, though generally in far fewer numbers than larger airports. Two notable examples are San Angelo (KSJT) and Laredo (KLRD). Fort Worth Alliance (KAFW) is unique among Texas airports in that it is a Class D airport underneath the Class B shelf and, unlike similar airports, receives a significant amount of cargo traffic. Finally, there are a small number of airports without an operating control tower that receive cargo flights, such as Del Rio (KDRT).

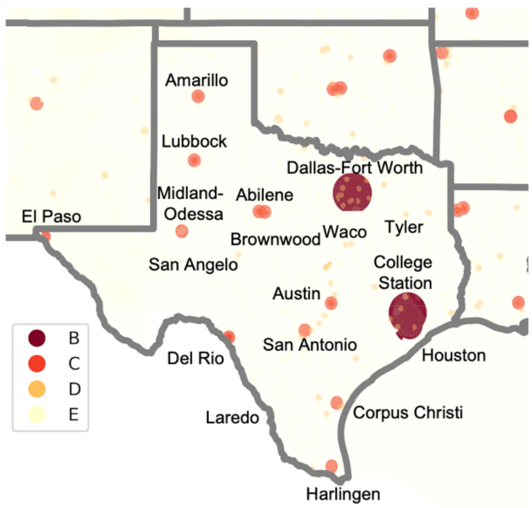

Fig. 7 Texas airspace structure.

B. Current Air Cargo Demand in Texas

The current cargo flight demand within Texas can be seen in Fig. 8. Like in Fig. 3a, the number of total cargo arrivals is higher at larger airports in or near Class B airspace (e.g., KDFW, KAFW, KIAH). At these airports, jet traffic is more dominant than prop traffic. At many Class C airports, however, there is a much more balanced mix of jet and prop traffic, e.g., Austin (KAUS) and San Antonio (KSAT). Class C airports in smaller cities, e.g., Abilene (KABI) and Midland-Odessa (KMAF) receive almost exclusively prop cargo traffic. KLRD, despite being in a Class D airport, has a significant proportion of cargo jet traffic. A likely explanation for this deviation from the norm is that Laredo has, by far, the busiest inbound truck traffic crossing in the country border [11]. Some of the cargo from these trucks then is loaded onto cargo aircraft at KLRD and flown across the country. In particular, flights from Laredo to the Detroit area carry cargo from automotive manufacturing plants just south of the Texas-Mexico border to the epicenter of the American automotive industry.

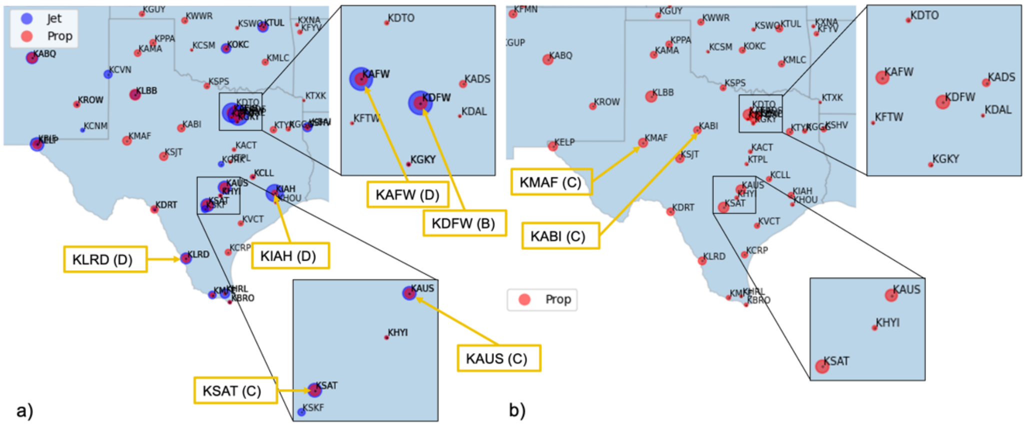

Fig. 8 Cargo flight departures by airport in Texas for a) jet and prop aircraft and b) prop aircraft. Select airports are highlighted and their class of airspace is given in parentheses. The size of the circle represents the number of flights departing that airport and is plotted with $x^{0.6}$ as radius, where x is the number of flights.

C. Operating Environment and Accessibility

The type of operations a cargo UAS will need to interact with is an important consideration when determining how the integration of the UAS into the NAS will occur. Particularly, an expectation of visual flight behavior around the airport present difficulties for the UAS, due to the lack of see-and-avoid capability for the RP[**]. Knowledge of the percentage of VFR aircraft is an indicator of the degree of dependency on visual flight capabilities. In Fig. 9a, the percentage of VFR operations relative to the number of total operations is shown. Larger airports, such as KDFW and KIAH, have a very low percentage of VFR operations (though may still have a large total number of VFR operations). Smaller airports, such as many of the Class D airports, have VFR operation percentages greater than 60%.

Another consideration for cargo UAS is the availability of enabling procedures or technologies, such as instrument approach procedures and landing systems. While specific technological requirements for procedures such as auto-TTL are yet to be determined, it is helpful to examine what current procedures and technologies are present at airports. In Fig. 9b, the airports in Texas are classified by the availability of Instrument Approach Procedures (IAP). Our research team's SME ranked the IAP by the likelihood of their use in future auto-landing operations as shown in Fig. 9b. Then, airports are plotted by their highest-ranked IAP available, even if the IAP is not available for all runways at an airport. Note that airports with higher-ranked IAPs also have lower-ranked IAPs.

The most likely IAP to be used is the GLS. The GLS utilizes ground-based systems to provide accuracy corrections to Global Positioning System (GPS) signals with less operational impact than the Instrument Landing System (ILS) [12]. While only Category (CAT) I approaches using GLS are operational at present, requirements for CAT II and III approaches have been identified [13]. The only existing GLS in Texas is located at KIAH. The next type of landing system that may increase access for cargo UAS is the ILS. Three categories of approach are existing for ILS, with CAT III having the most stringent requirements. In addition to KIAH, four airports have a CAT III ILS approach: KHOU, KDFW, KAFW, and KAUS. In addition to airports previously mentioned, two more airports have CAT II ILS: KDAL and KSAT. Numerous airports in Texas have CAT I ILS, including several Class D airports. Many more airports in Texas have at least an RNAV GPS IAP published.

[**] A possible mitigation to this lack of capability is the advancement of detect-and-avoid systems, though the current detect-and-avoid standards do not address all challenges related to visual flight behaviors.

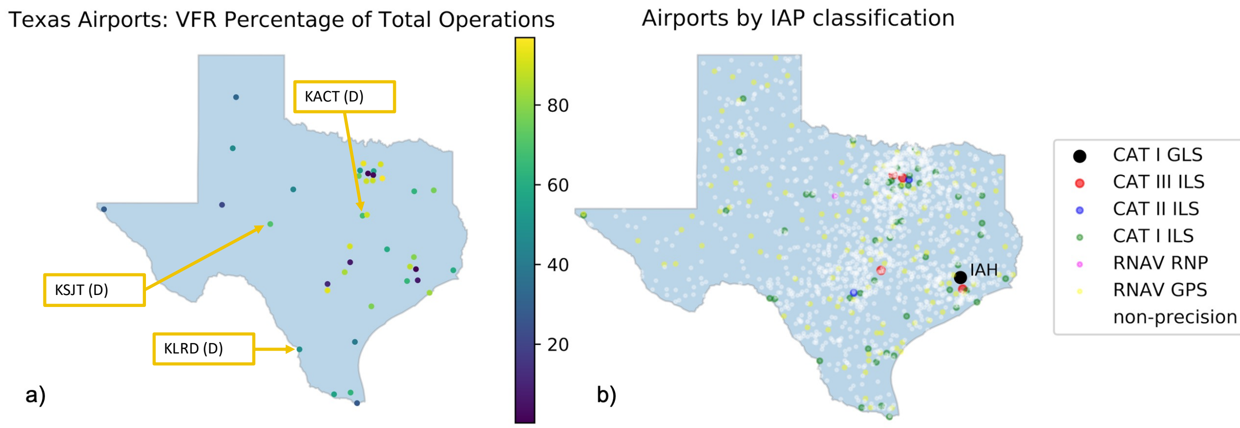

Fig. 9 a) Percentage of VFR operations at Texas airports. b) Texas airports classified by Instrument Approach Procedure.

D. C2 Link System Coverage

The integration of cargo UAS will also be impacted by the type of C2 link system the RP will need to use, especially in the TTL phases of flight. As previously mentioned, the availability and coverage area of the C2 link system depends on the type of link. BRLOS C2 link systems have very broad coverage, but also introduce latency into command, control, and potentially communication that may exceed acceptable limits, especially in the terminal area. Alternatively, RLOS C2 link systems have minimal latency but limited range. To illustrate, current expected latency of the RLOS link system is estimated at up to 0.2256 seconds one-way, whereas the BRLOS link system (specifically, satellite C2 link system) is estimated to have a one-way latency of up to 0.7200 seconds [14]. If necessary for TTL operations, the RLOS receivers would need to be in place at or near airports at which cargo UAS operations are occurring. While still an area of ongoing research, a proposed map of RLOS C2 link system coverage can be seen in Fig. 10. The RLOS C2 receiver location representation in Fig. 10 is similar to a proposed FAA-compliant network map from a third party. SMEs have indicated that the radius of coverage for each receiver is roughly estimated to be 100 km, or 54 nautical miles. This example coverage map indicates that several airports currently receiving prop cargo operations would be unable to receive cargo UAS operations that require RLOS C2 link.

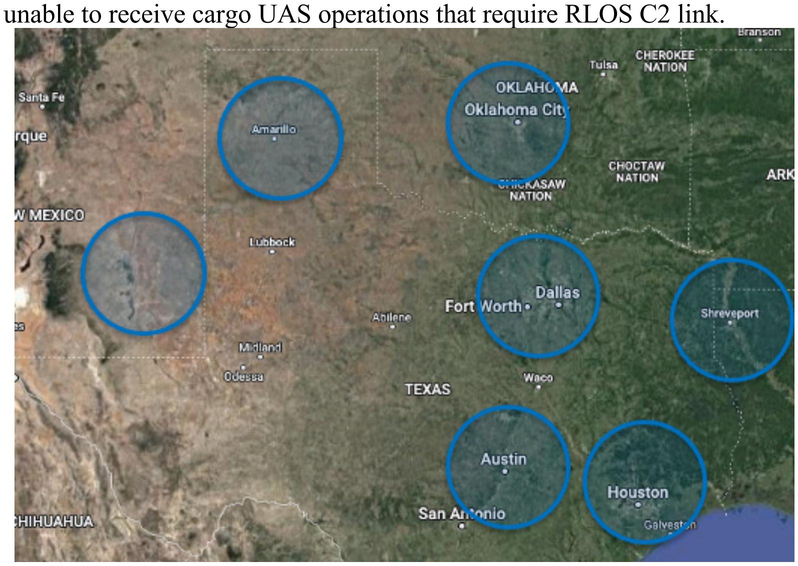

Fig. 10 Estimated RLOS C2 coverage map. Background map data © 2022 Google.

E. Example Airport

Narrowing the scope to a single airport, the type of information relevant to future cargo UAS operations can be seen. The example airport presented here, Fort Worth Alliance (KAFW), is a cargo-focused (46.3% cargo) Class D airport located underneath the Class B of Dallas-Fort Worth International (KDFW) and Dallas Love Field (KDAL). The airport is a hub for both FedEx Express and Amazon Air. The airport has many features which may increase accessibility to the airport for future cargo UAS: 1) The airport has a continuously operating control tower. 2) The airport has two 11,000 ft runways (16R/L and 34R/L). 3) Runways 16L and 34R have ILS approaches, including a CAT II/III approach on 16L.

KAFW is classified as an NPIAS National airport, meaning that it has "very high levels of aviation activity with many jets and multiengine propeller aircraft" [6]. Statistics from the date range studied (July 20, 2021, to February 17, 2022) support this designation; of all flights at KAFW, 11.1% were propeller aircraft, 8.9% were turboprop aircraft, and 80.0% were jet aircraft. For cargo flights, the numbers are similar (0.0%, 10.5%, and 89.5%, respectively), though no propeller aircraft were used for cargo flights. The airport, despite its cargo focus, still operates a significant number of general aviation flights. For the year preceding May 31, 2017[††], KAFW operations were distributed as follows: 7.0% commercial, 4.8% air taxi, 39.1% local general aviation, 36.4% itinerant general aviation, and 12.7% military, according to FAA NASR data. With high percentages of general aviation (75.5% from May 31, 2016, to May 31, 2017), it is understandable that, for the date range studied, the percentage of VFR flights at KAFW was similarly high (53.1%). The information helps to inform the operating environment at the airport and identify what may have an impact on cargo UAS operations. For example, because the tower at KAFW is operating continuously, the RP will be expected to communicate with the air traffic controller (ATCo), which introduces workload to the RP. Nonetheless, the ATCo can assist the RP in maintaining separation from other traffic, in turn helping to mitigate RP workload and mitigate safety concerns under a loss of the C2 link. For more information on how the operating environment will impact cargo UAS operations, the reader is referred to [15].

Additionally, Fig. 11 shows the airports to which cargo flights – distinguished by type of aircraft – flew from the user-defined airport (here KAFW) for the date range studied. Jet flights are predominant (89.5%), departing primarily for large airports such as KORD, KTPA, and KOAK. The counts of the regional operations, flown by turboprop aircraft, are shown in the table in Fig. 11. These regional flights fly to medium and small commercial airports within a few hundred miles. For KAFW specifically, these regional flights are FedEx Feeder operations (i.e., contractor airlines flying scheduled cargo flights for FedEx) and typically are Cessna 208B or ATR-72 aircraft.

Destination	Prop Count
KAUS	572
KICT	377
KLBB	192
KMAF	93
KSHV	89

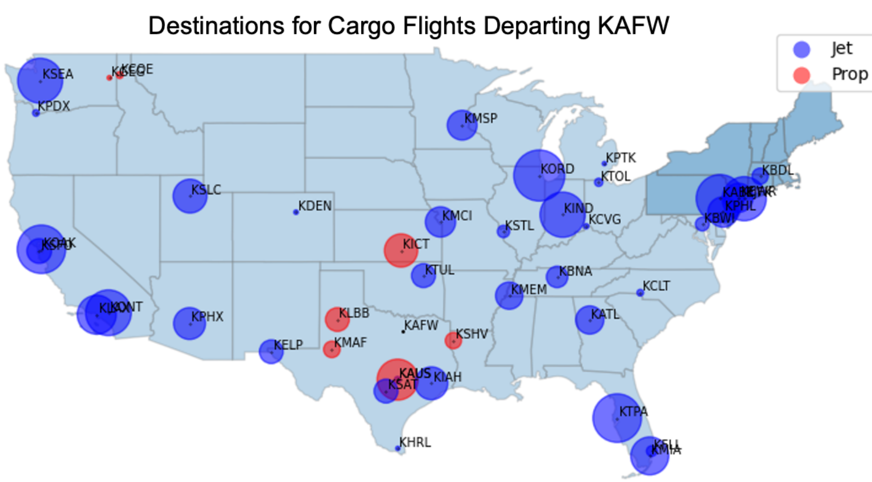

Fig. 11 Cargo flight destinations for flights departing KAFW from July 20, 2021, to February 17, 2022. The top five turboprop aircraft destinations and flight counts are shown in the table. The size of the circle represents the number of flights departing that airport and is plotted with x^1 as radius, where x is the number of flights.

V. Preliminary Qualitative Airport Classifications

Qualitative classification of cargo airports by level of cargo demand and accessibility for cargo UAS are presented in this paper. These classifications are preliminary because exact, quantitative criteria will be developed in future work. These initial groupings are based on example airports that stand out as having high levels of cargo operations.

[††] While slightly outdated, the data presented here is the latest data in the FAA NASR database.

The five classes, as shown in Table 1, are as follows: 1) Major cargo hub, 2) other cargo hubs, 3) medium/small commercial airport with larger percentage of cargo, and 4) regional airport with larger percentage of cargo. The classification highlights the different types of airports at which cargo operations are occurring and guides future studies.

Table 1 Preliminary qualitative classification of cargo airports.

Airport Classification	Aircraft Type	Airspace Class	ILS CAT II-III?[‡‡]	Operating Environment	Example Airports
1. Major Cargo Hub	Heavy Jet	B, C	Yes	Low VFR %	KMEM, KSDF, KCVG, KIND, KEWR
2. Other Cargo Hub	Heavy Jet, Prop	C, D	Some	Mixed VFR %	KAFW, KONT, KLCK
3. Medium/Small Commercial	Mixed Jet, Prop	B, C	Some	Medium VFR %	KCAK, KSAT, KLBB, KPVD
4. Regional	Light Jet, Prop	D, E, G	No	High VFR %	KSJT, KROW, KBFL, KVIS

Major cargo hubs, such as KMEM, KSDF, and KCVG, have heavy jet traffic, are located within Class B or C airspace, typically have CAT II or III ILS, and have very high levels of cargo demand (i.e., high percentage and number of cargo operations). Many other larger airports, like KIND or KEWR, also fall into this category. These major cargo hubs generally have a very low percentage of VFR operations. Other cargo hubs are those airports that, while smaller than the major cargo hubs, have a very high percentage of cargo demand. These other cargo hubs (e.g., KAFW, KONT, and KLCK) typically have a mix of heavy jet and prop traffic, are located within Class C or D airspace, and may have CAT II or III ILS. The percentage of VFR operations is highly-variable across this classification. Medium/small commercial airports with larger percentage of cargo are primary commercial airports (e.g., NPIAS Medium or Small Hub), often located in Class B or C airspace, that offer commercial passenger services, but also receive cargo demand at a percentage higher than the median for the appropriate NPIAS type (usually ~6-20% cargo). Hence, these airports typically see a mix of jet traffic (heavy and light jets) and prop traffic. Examples of this classification are KCAK, KSAT, KLBB, and KPVD. Some of these airports have ILS CAT II or III, though not all and typically have a medium overall percentage of VFGR traffic. The final classification of airports is regional airports that have a higher percentage of cargo. These airports generally do not have significant levels of commercial passenger operations. These smaller airports may have some light jet traffic, but the majority is prop traffic. These airports may have an operating control tower (if the airport is in Class D airspace and the tower is operating), but the many do not. None of the airports in the classification have ILS CAT II or III and all of the airports have a high overall percentage of VFR traffic. Examples of these airports are KSJT, KROW, KBFL and KVIS.

VI. Concluding Remarks and Future Work

This study investigated the present demand of cargo operations within the CONUS, both air cargo and truck cargo. The present demand for cargo flight operations across the CONUS was quantified and visualized. Based on this analysis, the demand for propeller and turboprop cargo UAS operations is expected to be greatest at NPIAS Medium and Small Hubs and Non-Hubs located in Class C or D airspace. Cargo truck traffic demand in 2012 and 2045 was also investigated and regions of significant estimated traffic demand growth were highlighted. Then, Texas, the first of four focus regions, was chosen for in-depth investigation. The percentage of VFR aircraft at Texas airports was quantified and the airports in Texas were classified by IAP type. An example hypothetical RLOS C2 coverage map for Texas was presented and the impact on future cargo UAS operations was discussed. Finally, a qualitative classification of airports by cargo demand and accessibility was presented.

Future work will investigate the remaining three focus regions: California, Ohio/Great Lakes, and the Upper West. California was selected as the state has two major metropolitan areas separated by the large Central Valley. The state also has nine of the Top 75 cargo airports [10], three capacity constrained airports (see Fig. 1), and the highways that are estimated to have among the greatest demand for cargo truck traffic in 2045. Ohio and the Great Lakes region at

[‡‡] Does at least one runway at the airport have an ILS CAT II-III approach?

large contains four airports that are in the Top 11 airports by number of prop cargo departures (KMKE, KLAN, KCAK, and KIND). The region is also estimated to see some of the greatest percentage increase in cargo truck traffic by 2045. Finally, the Upper West region containing Montana, Wyoming, and the Dakotas was selected as a counter to the other three regions; the region is very sparsely populated and is not estimated to see cargo truck traffic anywhere near the levels of the other regions. Nonetheless, the region has three of the Top 18 airports by prop cargo departures (KBIL, KFSD, and KFAR) and provides an example of low complexity regional operations. By investigating other regions, we hope to gain additional insight on the findings from Texas presented in this work. Further, a quantitative airport classification of demand and accessibility will be created and vetted by SMEs. The work presented in this paper, as well as future quantitative analysis will be used to assist in the selection of airports for future UAS cargo operation studies, including trade studies, Human-In-The-Loop simulation evaluations, and flight tests.

Appendix

Tables with relevant data are presented here in the appendix.

Table 1 Cargo airlines included in the cargo dataset analyses.

ICAO Code	Airline
ATN	Air Transport International
ABX	Airborne Express
AIP	Alpine Air Express
AMF	Ameriflight
GTI	Atlas Air
BVN	Baron Aviation Services
CJT	Cargojet Airways
CSJ	Castle Aviation
CPT	Corporate Air
IRO, CSA	CSA Air, Inc.
CFS	Empire Airlines
FDX	FedEx Express
FRG	Freight Runners Express
TSU	Gulf & Caribbean Cargo / Contract Air Cargo
IFL	IFL Group
LYM	Key Lime Air
MRA	Martinaire
MEI	Merlin Airways
MAL	Morningstar Air Express
MTN	Mountain Air Cargo
MBI	Mountain Bird
PAC	Polar Air Cargo
UPS	United Parcel Service
PCM	Westair Industries
WIG	Wiggins Airways

Table 2 Airports ranked by total number of cargo departures from July 20, 2021, to February 17, 2022.

ICAO ID	Total Cargo Departures	Total Departures	% Cargo	Class of Airspace	Airport Name	NPIAS Type
KMEM	121,188	164,494	76.67	B	MEMPHIS INTL	Medium
KSDF	91,112	135,476	67.25	C	LOUISVILLE MUHAMMAD ALI INTL	Small
KIND	38,998	129,676	30.07	C	INDIANAPOLIS INTL	Medium
KONT	29,704	61,205	48.53	C	ONTARIO INTL	Medium
KCVG	25,915	102,534	25.27	B	CINCINNATI/ NORTHERN KENTUCKY INTL	Medium
KOAK	19,326	86,133	22.44	C	METRO OAKLAND INTL	Medium
KRFD	18,165	23,340	77.83	D	CHICAGO/ROCKFOR D INTL	Non-Hub

KEWR	16,345	301,574	5.42	B	NEWARK LIBERTY INTL	Large
KPDX	16,256	112,423	14.46	C	PORTLAND INTL	Medium
KLAX	15,294	406,289	3.76	B	LOS ANGELES INTL	Large
KPHL	15,158	224,251	6.76	B	PHILADELPHIA INTL	Large
KDFW	14,734	474,252	3.11	B	DALLAS-FORT WORTH INTL	Large
KMIA	14,287	276,740	5.16	B	MIAMI INTL	Large
KPHX	14,010	283,518	4.94	B	PHOENIX SKY HARBOR INTL	Large
KAFW	13,047	28,177	46.30	D	FORT WORTH ALLIANCE	National
KDEN	12,348	443,006	2.79	B	DENVER INTL	Large
KSEA	10,716	265,669	4.03	B	SEATTLE-TACOMA INTL	Large
KBWI	10,556	151,893	6.95	B	BALTIMORE/ WASHINGTON INTL THURGOOD MARSHALL	Large
KSLC	8,876	211,560	4.20	B	SALT LAKE CITY INTL	Large
KJFK	8,765	312,259	2.81	B	JOHN F KENNEDY INTL	Large

Table 3 Airports ranked by total number of prop cargo arrivals from July 20, 2021, to February 17, 2022.

ICAO ID	Prop Cargo Departures	Total Cargo Departures	Total Departures	Prop Cargo %	Total Cargo %	Class of Airspace	Airport Name	NPIAS Type
KMKE	3,893	5,548	62,535	70.17	8.87	C	GENERAL MITCHELL INTL	Medium
KLAN	3,821	4,389	10,655	87.06	41.19	C	CAPITAL REGION INTL	Non-Hub
KPDX	3,109	16,256	112,346	19.13	14.47	C	PORTLAND INTL	Medium
KCAK	2,740	2,747	20,772	99.75	13.22	C	AKRON-CANTON RGNL	Non-Hub
KPHX	2,650	14,010	283,450	18.92	4.94	B	PHOENIX SKY HARBOR INTL	Large
KSLC	2,599	8,876	211,505	29.28	4.20	B	SALT LAKE CITY INTL	Large
KDEN	2,500	12,348	442,990	20.25	2.79	B	DENVER INTL	Large
KBIL	2,475	5,052	18,447	48.99	27.39	C	BILLINGS LOGAN INTL	Small
KONT	2,255	29,704	61,204	7.59	48.53	C	ONTARIO INTL	Medium
KFSD	2,056	3,861	25,351	53.25	15.23	D	JOE FOSS FLD	Small
KIND	1,824	38,998	129,669	4.68	30.08	C	INDIANAPOLIS INTL	Medium
KEWR	1,791	16,345	301,569	10.96	5.42	B	NEWARK LIBERTY INTL	Large
KLBB	1,630	2,697	18,534	60.44	14.55	C	LUBBOCK PRESTON SMITH INTL	Small
KOMA	1,628	3,934	51,602	41.38	7.62	C	EPPLEY AIRFIELD	Medium
KGEG	1,576	5,660	30,604	27.84	18.49	C	SPOKANE INTL	Small
KDFW	1,570	14,734	474,224	10.66	3.11	B	DALLAS-FORT WORTH INTL	Large
KMEM	1,544	121,188	164,486	1.27	73.68	B	MEMPHIS INTL	Medium
KFAR	1,541	3,404	18,045	45.27	18.86	D	HECTOR INTL	Small
KSMF	1,490	8,505	73,791	17.52	11.53	C	SACRAMENTO INTL	Medium

KAFW	1,373	13,047	28,152	10.52	46.34	D	FORT WORTH ALLIANCE	National

Table 4 Airports ranked by percentage of cargo departures relative to total departures from July 20, 2021, to February 17, 2022.

ICAO ID	Total Cargo Departures	Total Departures	% Cargo	Class of Airspace	Airport Name	NPIAS Type
KILN	8,243	9,463	87.11	D	WILMINGTON AIR PARK	N/A
KSBD	8,361	10,081	82.94	D	SAN BERNARDINO INTL	National
KRFD	18,165	23,340	77.83	D	CHICAGO/ROCKFORD INTL	Non-Hub
KMEM	121,188	164,494	73.67	B	MEMPHIS INTL	Medium
KSDF	91,112	135,476	67.25	C	LOUISVILLE MUHAMMAD ALI INTL	Small
KTVF	1,204	1,837	65.54	E	THIEF RIVER FALLS RGNL	Local
KIAB	66	101	65.35	D	MCCONNELL AFB	N/A
KCTB	125	223	56.05	E	CUT BANK INTL	Local
KAIA	345	672	51.34	E	ALLIANCE MUNI	Local
KONT	29,704	61,205	48.53	C	ONTARIO INTL	Medium
KPUC	144	309	46.60	E	CARBON COUNTY RGNL/BUCK DAVIS FLD	Basic
KAFW	13,047	28,177	46.30	D	FORT WORTH ALLIANCE	National
KIYK	213	472	45.13	E	INYOKERN	Basic
KMLC	223	502	44.42	E	MC ALESTER RGNL	Regional
KLDM	366	851	43.01	E	MASON COUNTY	Local
KATY	738	1,719	42.93	E	WATERTOWN RGNL	Regional
KESC	695	1,659	41.89	E	DELTA COUNTY	Regional
KSCK	2,474	5,948	41.59	D	STOCKTON METRO	Non-Hub
KLAN	4,391	10,696	41.05	C	CAPITAL REGION INTL	Non-Hub
KSUU	189	472	40.04	D	TRAVIS AFB	N/A

Table 5 Median values by NPIAS classification.

NPIAS Type	Airports	Cargo Departures	All Departures	% Cargo: Departures
Large Hub	27	7,387.00	265,669.00	2.79
Medium Hub	30	3,094.00	77,282.50	4.40
Small Hub	70	798.00	25,337.00	4.05
Non-Hub	141	239.00	6,541.00	3.92
National	64	25.00	11,167.00	0.28
Regional	167	18.00	2,217.00	0.78
Local	178	12.50	812.50	1.36
Basic	17	8.00	337.00	2.50

Unclassified	2	7.00	87.00	7.88

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