Noise Exposure Maps of Urban Air Mobility

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A noise exposure map is "a scaled geographic depiction of an airport, its noise exposure contours, noise-sensitive facilities, and land uses in the airport surrounding area" developed in accordance with the FAA's 14 Code of Federal Regulation Part 150. This paper is the first to explore the applicability of airport noise exposure maps to Urban Air Mobility (UAM). The FAA's airport noise compatibility planning program is first described. Then the applicability of the noise exposure map to Urban Air Mobility (UAM) is explored. Finally, new airspace infrastructure, including vertiport locations and UAM routes from NASA's UAM engineering simulations, and local noise-sensitive facility locations and land use information were collected and processed to develop the noise exposure maps of UAM near the Dallas-Fort Worth area. The DNL noise contours resulting from a six-passenger electric quadrotor prototype vehicle are predicted using NASA's AIRNOISEUAM software. The noise exposure maps of UAM are generated automatically using Python's data analysis and visualization libraries. The results have applications for UAM's noise compatibility planning, noise-reducing route planning, and vertiport location selection.

1. Introduction

Recent studies by NASA and Airbus have found that public perception of Urban Air Mobility (UAM) is primarily influenced by vehicle safety and noise [1-3]. Today aircraft noise is mainly limited to the airport and heliport's vicinity. The community noise level resulting from aircraft operations is regulated under the provision of the FAA's 14 Code of Federal Regulations Part 150, titled "Airport noise compatibility planning" [4]. Part 150 requires airport operators to submit the Noise Exposure Map (NEM) and Noise Compatibility Program (NCP) to the FAA for noise compliance review and approval or disapproval whenever there are substantial noise changes at the airport.

The UAM noise management is a brand-new research topic. It is among the most important topics because it is directly related to local municipal and community acceptance of UAM operations. The white paper from the UAM noise working group [5] has identified barriers and gaps associated with UAM noise into four categories that may hamper UAM vehicle entry into service. Each category and their recommendation are summarized as follows:

(1) Tools and technologies – develop new vehicle noise model, noise prediction tools, and noise mitigation strategies
(2) Ground and flight testing – perform vehicle noise lab test and field measurement
(3) Human response and metrics – define new metrics to measure human perception of noisiness
(4) Regulation and policy – define manufacturer's vehicle noise certification process to the FAA, and community engagement for UAM operation acceptance

This paper addresses the gap in the regulation and policy category and is the first to explore the applicability of current practices of the FAA's airport noise compatibility program to UAM. In this paper, the current practice of the FAA's airport noise exposure map and noise compatibility program is described in Section 2. Then the applicability of noise exposure maps to UAM will be explored in Section 3. Section 4 overviews the AIRNOSIEUAM tool, a newly developed tool, modeled after the FAA Aviation Environmental Design Tool (AEDT) software [6] for fleet noise assessment at the airport, with the capability to predict noise levels generated by UAM vehicles, such as electric Vertical Take-Off and Landing (eVTOL) [7]. New airspace infrastructure data is discussed in Section 5, including vertiport locations and UAM routes from the UAM engineering simulations [8], and local noise-sensitive facilities

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and land-use data acquired from various public sources such as USGS, local state and municipal websites, and Google Map API. These data have been collected and processed to develop noise exposure maps of UAM at the Dallas Fort-Worth area. The noise exposure map is presented in the standard format similar to airport noise exposure maps in accordance with Part 150. An interactive web-based noise exposure map is also created using Python's Bokeh visualization library. Section 6 presents preliminary analysis results of UAM operations to the local communities using Python's data analysis library. Section 7 is the conclusion and future work.

2.   Noise Exposure Map and Noise Compatibility Program

A noise exposure map is "a scaled geographic depiction of an airport, its noise exposure contours, and surrounding area" per Part 150 [4]. The noise exposure contours are measured by Day-Night average sound Level (DNL) in decibel (dB). The DNL is the average Sound Exposure Level (SEL) caused by estimated annual flight operations at the airport. The FAA required airport operators to use Aviation Environmental Design Tool (AEDT) software for noise prediction at the airport.

The map also includes noise-sensitive facilities such as hospitals, schools, place of worship, and land use in the airport surrounding area. Land uses in airport neighbors are categorized as compatible land use and noncompatible land use. Compatible land use means land use is compatible with the outdoor noise environment, i.e., noise exposure DNL is no more than the threshold defined in Part 150 at the location. In contrast, noncompatible land use means land use is not compatible with the outdoor environment, i.e., noise exposure DNL is above the location's threshold. The Noise Compatibility Program (NCP) describes options and programs applicable to reduce noise exposure for noncompatible land uses. Sixty-five decibels are broadly used as the threshold for land use combability. However, it varies slightly by the facility, as summarized in Table 1. Here, partially compatible land use means noise level reduction from outdoor to indoor is required to be categorized as compatible land use. However, it will not eliminate outdoor noise problems.

Table 1. Required DNL threshold for compatible land use defined in the FAA's 14 CFR Part 150

Land use	DNL below 65dB	65-75dB	Over 75dB
Residential	Compatible	Noncompatible	Noncompatible
Schools	Compatible	Noncompatible	Noncompatible
Churches	Compatible	Partially Compatible	Noncompatible
Parking	Compatible	Compatible	Compatible up to 85dB
Hospitals	Compatible	Partially Compatible	Noncompatible
Parks	Compatible	Compatible	Noncompatible

In summary, the FAA requires the subject matter experts to create the noise exposure maps and develop the noise compatibility program with community engagement at the airport. The whole process may take six months or even longer starting from collecting the data, predicting noise exposure, creating the noise exposure maps, developing a noise compliance program, holding multiple public hearings, and responding to public comments. The final noise exposure maps and their noise compatibility program may be published at local airport websites or can be requested to the local airport noise management office.

3.   Noise Exposure Map of Urban Air Mobility

In this paper, the initial noise exposure map of UAM is designed to strictly follow Part 150 with similar elements as the airport noise exposure map. Specifically, it models vertiports similar to airports, and UAM routes similar to instrument procedures. It also includes predicted DNL contours, local municipal boundaries, noise-sensitive facilities (school, hospital, and place of worship), and land uses (residential area and water area) surrounding the vertiports.

Figure 1 depicts the process of creating noise exposure map of urban air mobility. New tools and algorithms were developed to automate data processing and map generation processes. In contrast, the airport noise exposure maps are created by the subject matter experts. As a result, it can reduce the initial map development time from days or weeks to minutes. The map will provide a good baseline that will be refined by the subject matter experts for operational use. Raw data in different formats are first pre-processed and saved into a single shapefile format. Next, the noise exposure map of UAM is built using Python's Bokeh interactive visualization library. Bokeh displays different data in layers, so it is convenient to add new layers of data such as UAM-authorized airspace and UAM route corridors specific to UAM in the future. The output is in the standard HTML-language format viewable on any web browser. The USS

(UAS Service Supplier) is a critical component of NASA and FAA's proposed UTM (Unmanned Aircraft System Traffic Management) architecture [9]. The USS can utilize the digital noise exposure map as a supplement data service.
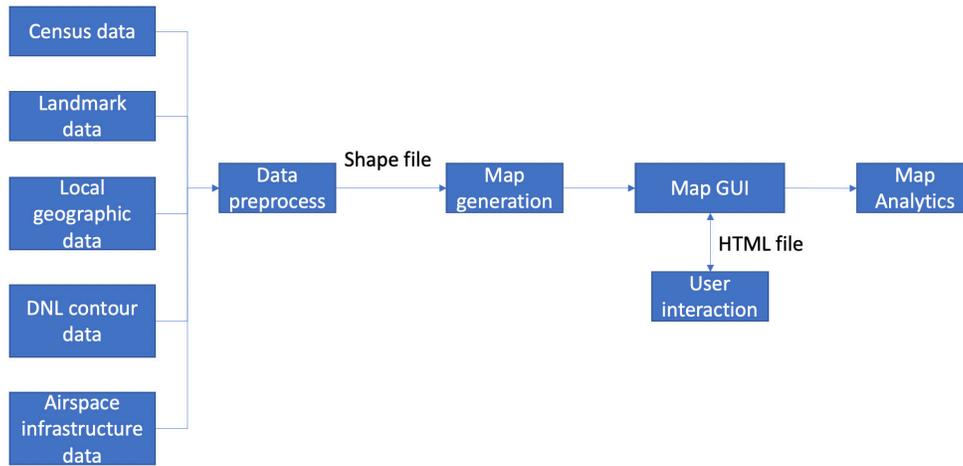

Figure 1. Process for creating noise exposure map of urban air mobility

4. UAM Vehicle Noise Prediction Tool

The FAA requires Aviation Environmental Design Tool (AEDT) software for airport fleet noise prediction. As mentioned in Section 2, a NASA-led UAM noise working group identified gaps in the application of AEDT for the assessment of UAM community noise impact. It is recommended that research be conducted to more fully explore limitations, and that a software development plan be generated to address these limitations [5]. A tool called AIRNOISE was developed for fast-time aircraft noise exposure assessment and noise-abatement trajectory design [10, 11]. Recently a new tool called AIRNOISEUAM has been developed for UAM vehicle noise prediction [7]. The AIRNOISEUAM applies similar noise computation methods as AEDT and AIRNOISE software. Moreover, it integrated with new UAM vehicle acoustic and performance data generated by Revolutionary Vertical Lift Technology (RVLT) project [12]. The predicted sound exposure level results from individual flight segments and integrated scenarios have been verified with AEDT.

Figure 2 depicts the notional system diagram of the AIRNOISEUAM tool. Each block's primary functions are described as follows:

a. **airnoiseUAM:** The C language program computes sound exposure using the SAE method given input of flight profile data. The flight profile data should include vehicle type, flight profile (latitude, longitude, and altitude), speed, and operating state. This module also includes various Python scripts for validation and plotting.

b. **Gen-1.2 NPD data**: The NPD data contain eVTOLs' A-weighted sound exposure levels and the maximum A-weighted sound pressure levels at a set of vehicle operating states and distances to the receptor at a standard atmospheric condition.

c. **airnoiseProfile**: Methods are developed to convert flight data from various sources into the fixed-point flight profile input data required by airnoiseUAM.

d. **airnoiseMap**: It visualizes vertiport, airspace infrastructure, and local noise-sensitive land uses, overlaying with noise exposure contours by following the FAA's airport noise compatibility program rules using Python's interactive visualization library.

e. **airnoiseAnalytics**: Various algorithms were developed to evaluate noise impact on local communities using Python's data analysis libraries.
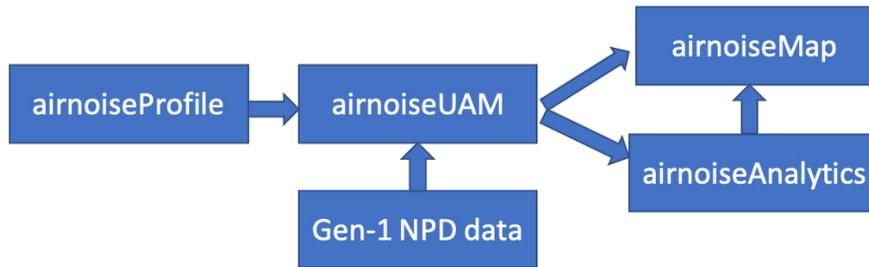
Fig. 2 System block diagram of AIRNOISEUAM

This paper mainly discusses the airnoiseMap module and, to a much lesser extent, the airnoiseAnalytics module in Figure 2. Please refer to [9] on developing airnoiseUAM and refer to [10] on developing Gen-1.2 NPD data. The airnoiseProfile module is under development to accurately and efficiently convert flight plans into flight profiles in preparation for the large-scale UAM noise assessment.

5.   Experiments

The UAM engineering simulation data contain 16 UAM routes between 15 vertiports near the Dallas Fort-Worth (DFW) region, as shown in Figure 3. Local noise-related geographic information defined in Part 150 was collected from various public sources. Specifically, the number of households and population are extracted from USGS's Census TIGER database. Noise-sensitive facility (schools, hospitals, and places of worship) locations are queried using Google map API. Information such as municipal boundary, water body, and highway are collected from local city and state websites. The household number determines the residential area. For example, a census tract, the smallest territorial entity, can be defined as residential if the household number is equal to or greater than 100.
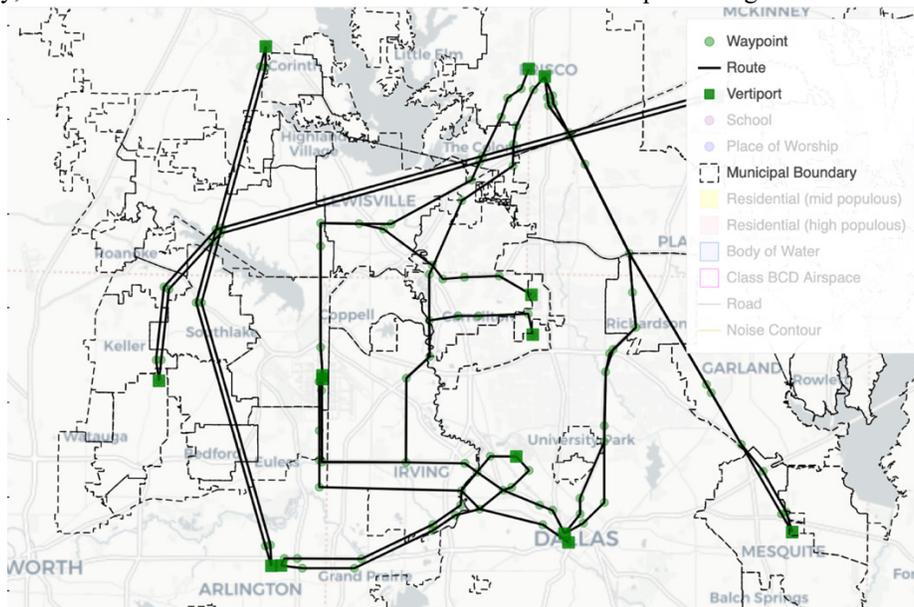

Fig. 3 Vertiports and UAM routes from NASA's UAM Engineering Simulations (grayed legends represent map layers that are disabled)

Figures 4 show the noise exposure map of urban air mobility near the Dallas Fort-Worth area. The map is similar to the airport noise exposure map. The map displays vertiport locations, UAM routes, municipal boundaries, noise-sensitive facilities, residential land use, water body, and overlaying with 55dB, 60dB, and 65dB DNL contours caused by a six-passenger quadrotor with 600 daytime operations per each route. The quadrotor's DNL contours were predicted using the AIRNOISEUAM tool. Note that the UAM operation demand of 600 daytime operations each route is not the actual estimated demand by UAM engineering team but rather a gross estimation for illustration.
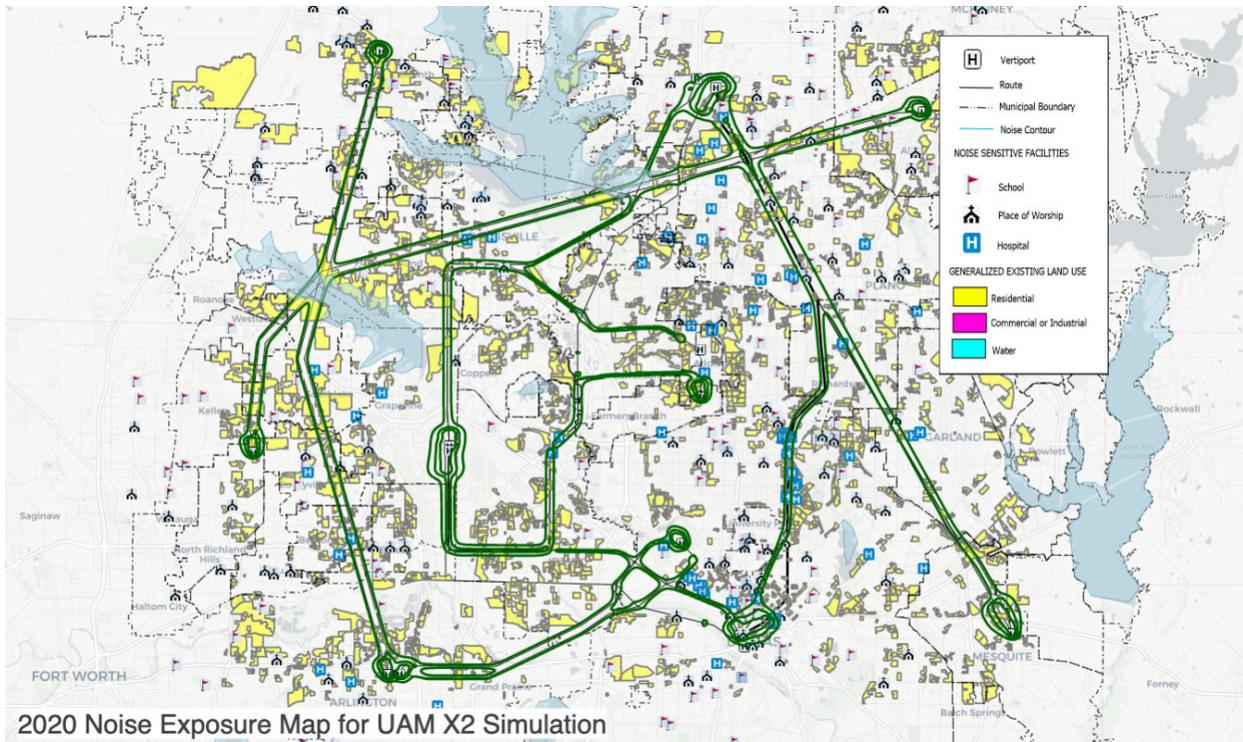
**Fig. 4 Noise exposure map of urban air mobility near Dallas Fort-Worth region similar**

Figure 5 show local noise impact at a number of selected locations. The digital map can be zoomed in and out to show the noise exposure near any local community location and point of interest.
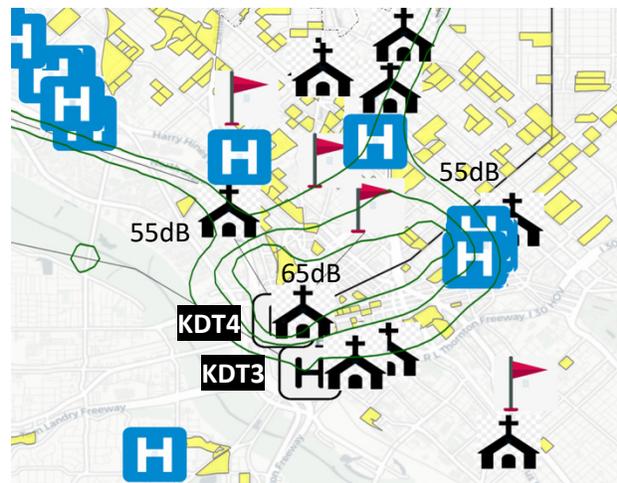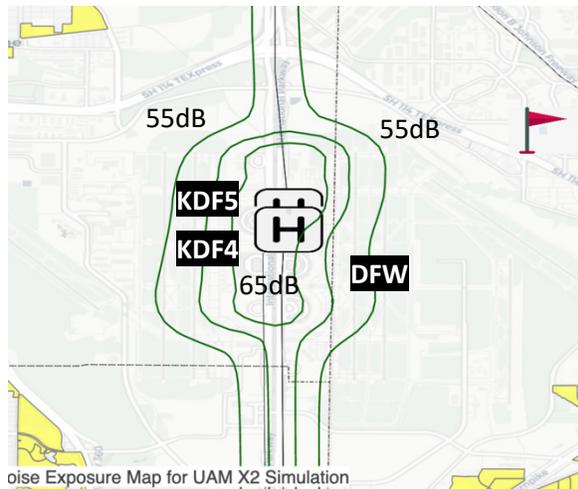
Fig. 5 DNL contours at selected locations: (upper left) vertiports KDF4 and KDF5 near DFW airport, (upper right) vertiports KDT3 and KDT4, (bottom left) vertiports KFR1 and KCAT, and (bottom right) vertiport KAD4

Furthermore, the data underlying the map contain detailed information on all displayed noise contours, vertiports, landmark, and etc. objects, as illustrated in Figure 6. Those data become inputs to the noise impact analysis.
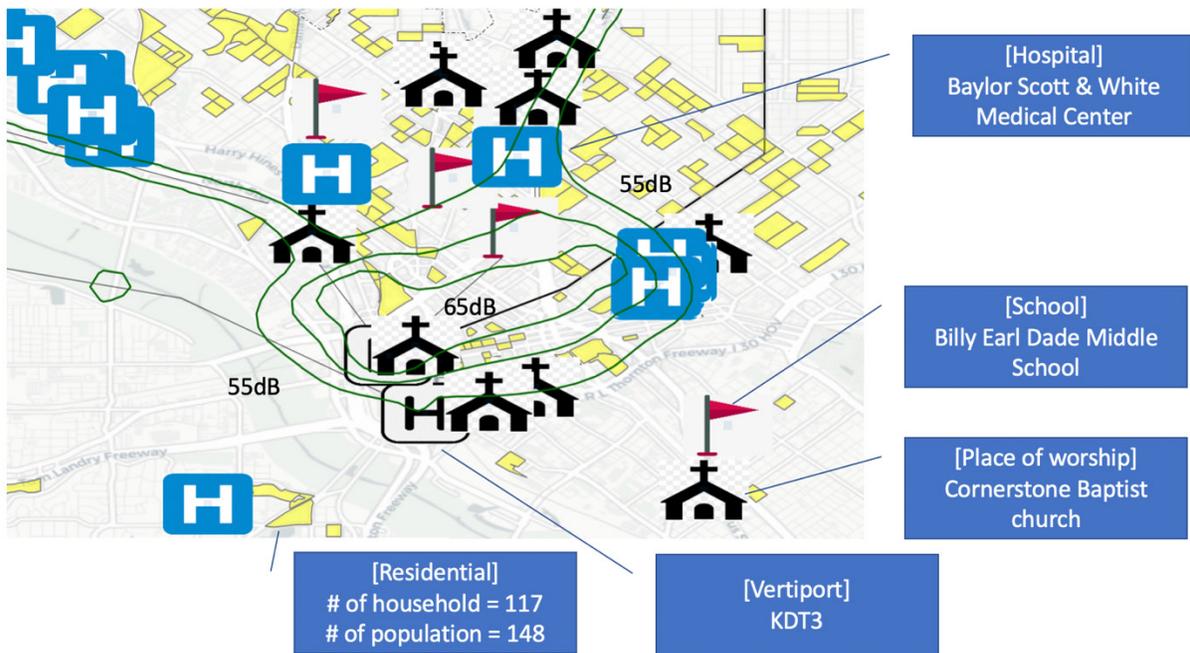
Fig. 6 Noise exposure map with object information near vertiports KDT3 and KDT4

6. Preliminary UAM Noise Local Community Impact Analysis

This section presents some preliminary analysis of UAM noise impact on the local communities. First, Table 2 lists the number of affected residences and noise-sensitive facilities along the flight route and near departure and arrival vertiports. Here potentially affected households and facilities are defined as those within one-mile distance along the flight route and vertiports. The one-mile distance is chosen arbitrarily for simplicity. In the future, the DNL contours created by AIRNOISEUAM will be used for the noise impact study.

Table 2. Analysis of UAM noise to local community

route name	# of affected household	# of affected individuals	# of affected school	# of affected place of worship	# of city pass through
U-UAM150	48840	115256	10	4	8
U-UAM200	49642	115027	3	3	5
U-UAM250	37539	103583	0	5	4
U-UAM300	37552	99822	4	2	4
N-UAM100	61348	164175	7	1	11
N-UAM150	62590	166868	7	2	11
N-UAM200	132795	277388	6	13	3
N-UAM217	89570	224622	4	6	6
N-UAM251	43626	106278	2	5	4
N-UAM268	58068	134935	0	0	8
N-UAM285	63867	154225	1	0	11
N-UAM302	21160	57018	1	2	2
N-UAM352	136887	275864	10	16	5
N-UAM402	87441	220280	5	7	7
N-UAM452	22861	58514	1	0	2

Table 3 lists those ATC-controlled airspace that each UAM route crosses through. Such information can be helpful for the initial UAM route planning.

Table 3. ATC-Controlled Airspace crossing through by each route

route name	ATC-Controlled Airspace Crossing Through
U-UAM150	['DALLAS CLASS B', 'DALLAS-FT WORTH CLASS E5']
U-UAM200	['DALLAS CLASS B', 'DALLAS-FT WORTH CLASS E5', 'DALLAS ADDISON AIRPORT CLASS D']
U-UAM250	['DALLAS CLASS B', 'DALLAS-FT WORTH CLASS E5']
U-UAM300	['DALLAS CLASS B', 'DALLAS-FT WORTH CLASS E5']
N-UAM100	['DALLAS-FT WORTH CLASS E5']
N-UAM150	['DALLAS-FT WORTH CLASS E5']
N-UAM200	['DALLAS CLASS B', 'DALLAS-FT WORTH CLASS E5']
N-UAM217	['DALLAS-FT WORTH CLASS E5']
N-UAM251	['DALLAS CLASS B', 'DALLAS-FT WORTH CLASS E5']
N-UAM268	['DALLAS CLASS B', 'DALLAS-FT WORTH CLASS E5', 'DALLAS ADDISON AIRPORT CLASS D']
N-UAM285	['DALLAS CLASS B', 'DALLAS-FT WORTH CLASS E5']
N-UAM302	['DALLAS CLASS B', 'DALLAS-FT WORTH CLASS E5']
N-UAM352	['DALLAS CLASS B', 'DALLAS-FT WORTH CLASS E5']
N-UAM402	['DALLAS-FT WORTH CLASS E5']
N-UAM452	['DALLAS CLASS B', 'DALLAS-FT WORTH CLASS E5']

7. Conclusion and Future Work

This paper is the first to explore the applicability of the FAA's airport noise exposure map and noise compatibility program to urban air mobility following the FAA's 14 Code of Federal Regulation Part 150. In this paper, digital noise exposure maps are generated automatically in just minutes with NASA's UAM engineering simulation data at the Dallas Fort-Worth area. Analyses were then conducted to quantify UAM operations' noise impact on the local communities.

The noise exposure map of urban air mobility can be used as a baseline that is refined by the subject matter experts for the FAA's UAM noise compatibility planning use. In addition, the interactive map can be presented at the local

community engagement meetings. Visualization and analysis results will provide insight into vertiport selection and route planning.

Currently, we are integrating the noise exposure map with the AIRNOISEUAM tool so that DNL contours calculated by AIRNOISEUAM can be used for local noise impact analysis. We are also developing web-based user-interactive noise exposure maps using Python's Bokeh library. Moreover, we are developing new algorithms to quantify UAM operations' noise impact on the local communities using Python's data analysis and machine learning libraries. We plan to conduct large-scale noise impact analyses for NASA's serial UAM engineering simulations.

Acknowledgments

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